GNF
Global Nuclear Fuel
A Joint Venture of GE, Toshiba, & Hitachi

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January 29, 2001

Mr. E. William Brach, Director
Spent Fuel Project Office, M/S O-13D13
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

Dear Mr. Brach:

Subject: Non-Proprietary Application for the New Powder Container (NPC) Package and Withdrawal Request for Protection of Proprietary Information

References:
(1) Docket 71-9294
(2) Letter, CM Vaughan to E. William Brach, "Certificate of Compliance Application for the Model NPC (New Powder Container) Package", Dated 5/16/00
(3) Letter, NL Osgood to CM Vaughan, NRC's Request for Additional Information, Dated 8/28/00
(4) Public Meetings of 10/5/00 and 10/17/00
(5) 10/26/00 Telecon, CM Vaughan to NL Osgood Regarding Schedule
(6) Letter, CM Vaughan to E. William Brach, "Request Delay in Response to RAIs for the New Powder Container (NPC)", Dated 10/27/00
(7) Letter, CM Vaughan to E. William Brach, "Certificate of Compliance Application for the Model NPC (New Powder Container) Package", Dated 11/10/00

Global Nuclear Fuel – Americas, L.L.C.'s (GNF-A) facility in Wilmington, North Carolina, hereby notifies the NRC that we no longer claim as proprietary the information contained in our prior submittals associated with the NPC. The NPC was issued Patent 6,166,391 dated 12/26/00. A consolidated non-proprietary application is included in this transmittal.

In addition, this transmittal includes clarifying and corrective changes to the application.

To facilitate the review process, changes identified in the Revision 1 application (dated 11/10/00) and this Revision 2 submittal (dated 1/29/01) are being submitted together as explained in Attachment 2 below.

Attachment 1 is the Explanation of Changes by page and section submitted to facilitate the NRC's review.

NMSS01 Public

Attachment 2 is a complete submittal of Revisions 1 and 2 as non-proprietary, in a three-ring binder. To facilitate the processing of the application, this binder has been organized as follows:

1. The outside of the binder identifies that this submittal contains both Revision 1 dated 11/2000 and Revision 2 dated 1/2001.
2. All references to proprietary information have been removed.
3. Revision 1 changes remain identified with a single vertical line (|) in the right hand column and remain dated 11/2000.
4. Revision 2 changes are identified with a double vertical line (**||**) in the right hand column and are dated 1/2001.
5. Where Revision 2 changes appear on a page where there are also Revision 1 changes, that page is identified as Revision 2 dated 1/2001.
6. Revision 2 changes affect the Table of Contents, Chapters 1.0 (including the drawings), 2.0 and 7.0.

Six (6) three-ring binders of this submittal are being provided for your use.

Please contact me on (910) 675-5656 if you have any questions or would like to discuss this matter further.

Sincerely,

Global Nuclear Fuel – Americas, LLC

Charles M. Vaughan, Manager
Facility Licensing

/zb
Enclosure

cc: CMV-01-008

Attachment 1

Explanation of Changes

Page	Section	Explanation
i	Table of Contents	Page numbers changed due to adding information in Section 2.5.2.
ii	Table of Contents	Page numbers changed due to adding information in Section 2.5.2.
iv	Table of Contents	In Section 7.2 inserted a new 7.2.1 "Unloading the Transport Vehicle" and incremented the previous 7.2.1 and 7.2.2 to 7.2.2 and 7.2.3 respectively, causing the page numbers to change.
1-1	1.0	Changed the wording "(Patent Pending)" to "Patent #6,166,391".
1-2	Figure 1.1-1	Changed the wording "(Patent Pending)" to "Patent #6,166,391".
1-2	Figure 1.1-2	Changed the wording "(Patent Pending)" to "Patent #6,166,391".
1-3	Figure 1.1-3	Changed the wording "(Patent Pending)" to "Patent#6,166,391".
1-4	1.2	Changed the wording "(Patent Pending)" to "Patent #6,166,391".
1-8	1.3.1	Removed the word "(proprietary)" from the second line, changed "NPC" to "New Powder Container" and added "Revision 2" after the drawing numbers.
1-8	1.3.1	Removed the last three lines that contain reference to the non-proprietary drawings 0060D0001 – 0060D0008. This set of drawings is no longer needed since all information is non-proprietary.

Attachment 1

Explanation of Changes

Page	Section	Explanation
Drawings 0019D0001 through 0019D0008, Rev. 2		Removed "(Proprietary)" from the title of all the drawings. Removed box containing "Global Nuclear Fuel Proprietary Information Exempt from Disclosure 10 CFR 2.790 Information" from all the drawings. Replaced the box that read "Patent Pending" with "Patent #6,166,391" on all the drawings.
Drawing 0019D0001	List of Material Item 40	Changed the Duro reading from "60" to "45 $\pm$5".
	Item 41	Changed to "Gasket, 1/8" Thk Silicone Rubber, Duro 60-70". These changes were due to an administrative error. The 60 Duro should have been on Item 41 and the 45 Duro should have been on Item 40. These materials were used on the containers that were tested. We have also added the tolerances based on the manufacturer's supplied data.
Drawing 0019D0001	List of Material Item 49	Added the regulatory requirement callout of 10 CFR 71.85.
Drawing 0019D0001	Note 23	Clarified the installation of the ceramic fiber board in the lid.
Drawing 0019D0001	Note 33	Provided additional clarification of the packaging and package weights.
Drawing 0019D0001	Note 38	Clarified that welds may be on either side of the surface.
Drawing 0019D0002	B9 and D11	Added reference to Note 38 in these two locations on the drawing.
Drawing 0019D0004	G9	Added a weld callout.
Drawing 0019D0008	A1	Identified in the title block that this name plate is a sample.

Attachment 1

Explanation of Changes

Page	Section	Explanation
2-2	Figure 2.1-1	Changed the wording "(Patent Pending)" to "Patent #6,166,391".
2-6 through 2-7	2.5.2	Clarified the blocking and bracing for securing the package within the transport vehicle.
7-1	7.1	Removed the last sentence, because there is no longer a distinction between proprietary and non-proprietary drawings.
7-2	7.1.2, 3.	Clarified the loading procedure.
7-2	7.1.2, 4.	Added a new 4. to clarify the loading procedure.
7-2	7.1.2, 5. Through 9.	As a result of adding a new 4., the previous items 4. through 8. became 5. through 9.
7-2	7.1.2, 8.	Clarified wording.
7-3	7.1.3, 6.	Clarified the package preparation instructions and assured that they are consistent with Section 2.5.2.
7-3	7.1.3, 7.	Clarified the package preparation instructions and assured that they are consistent with Section 2.5.2.
7-3	7.1.3, 8.	Clarified the package preparation instructions and assured that they are consistent with Section 2.5.2.
7-3	7.2	Replaced "This section delineates the procedures for unloading a payload out of the NPC packaging. Reference to specific NPC packaging components may be found in Appendix 1.3.1, *Packaging General Arrangement Drawings*." with "This section delineates procedures for unloading the NPC."
7-3	7.2.1	Changed the title from "Removal of the Payload from the NPC Package" to Unloading the Transport Vehicle".
7-3	7.2.1, 1.	Clarified the unloading instructions.

Attachment 1

Explanation of Changes

Page	Section	Explanation
7-3	7.2.1, 2.	Clarified the unloading instructions.
7-3	7.2.1, 3.	Clarified the unloading instructions.
7-3	7.2.2	Was 7.2.1 in Revision 1.
7-4	7.2.3	Was 7.2.2 in Revision 1.

Attachment 2

Complete Submittal of Revision 1 dated 11/2000 and Revision 2 dated 1/2001 in a three-ring binder

Revision 1 changes remain identified with a single vertical line (|) in the right hand column and remain dated 11/2000.

Revision 2 changes are identified with a double vertical line (**||**) in the right hand column and are dated 1/2001.

Chapter 1.0 includes *GNF New Powder Container Packaging (NPC)*, Drawing Numbers 0019D0001-0019D0008, Revision 2.

TABLE OF CONTENTS

1.0 GENERAL INFORMATION

This chapter of the Global Nuclear Fuel (GNF) New Powder Container, Model No. NPC (Patent #6,166,391), Safety Analysis Report presents a general introduction and description of the NPC. The major components comprising the NPC are presented in Figures 1.1-1, 1.1-2, and 1.1-3. Figure 1.1-1 presents an exploded view of all major NPC packaging components. Figure 1.1-2 illustrates details of the outer closure region. Figure 1.1-3 presents a detailed view of the inner containment canister and its closure seal region. A detailed description of the major packaging and payload components is presented in the following sections. Detailed drawings are presented in Appendix 1.3.1, *Packaging General Arrangement Drawings*.

1.1 Introduction

The GNF NPC is a transportation system designed to transport homogeneous oxide forms of non-irradiated uranium powder that is enriched up to 5 weight percent (w/o). The packaging consists of a stainless steel sheet metal Outer Confinement Assembly (OCA) body and lid that encases ceramic fiber insulation and rigid polyurethane foam, and nine equally spaced, individually sealed stainless steel Inner Containment Canister Assemblies (ICCAs). The closure of each canister is provided by a closure lid with a silicone rubber gasket and a standard stainless steel bolted band clamp assembly.

The package is a Type A-fissile package. To provide criticality control, the outer cylindrical surface of each canister is wrapped with a minimum 20-mil cadmium sheet, a 15-mil High Density Polyethylene (HDPE) sheet wrapped to achieve a minimum hydrogen areal density of 0.199 gm/cm^2, and a stainless steel wrapper. Criticality control is also provided by the neutron moderating polyurethane insulating foam distribution within the OCA body and lid. The uranium oxide powder is contained in the individual ICCAs. A stainless steel closure strip covers the OCA lid/body joint for additional protection.

Authorization is sought for shipment of 1,190 pounds (540 kg) of enriched uranium oxide powder (per package including powder plus powder packaging) as a Type A(F)-85, fissile material package per the definitions delineated in 10 CFR §71.4[1]. The transport index (TI) for the package, determined in accordance with the definitions of 10 CFR §71.4, is determined for each shipment. The TI is based on the number of packages for criticality control purposes (method for the transport index is defined in Chapter 6.0, *Criticality Safety Evaluation*).

[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-98 Edition.

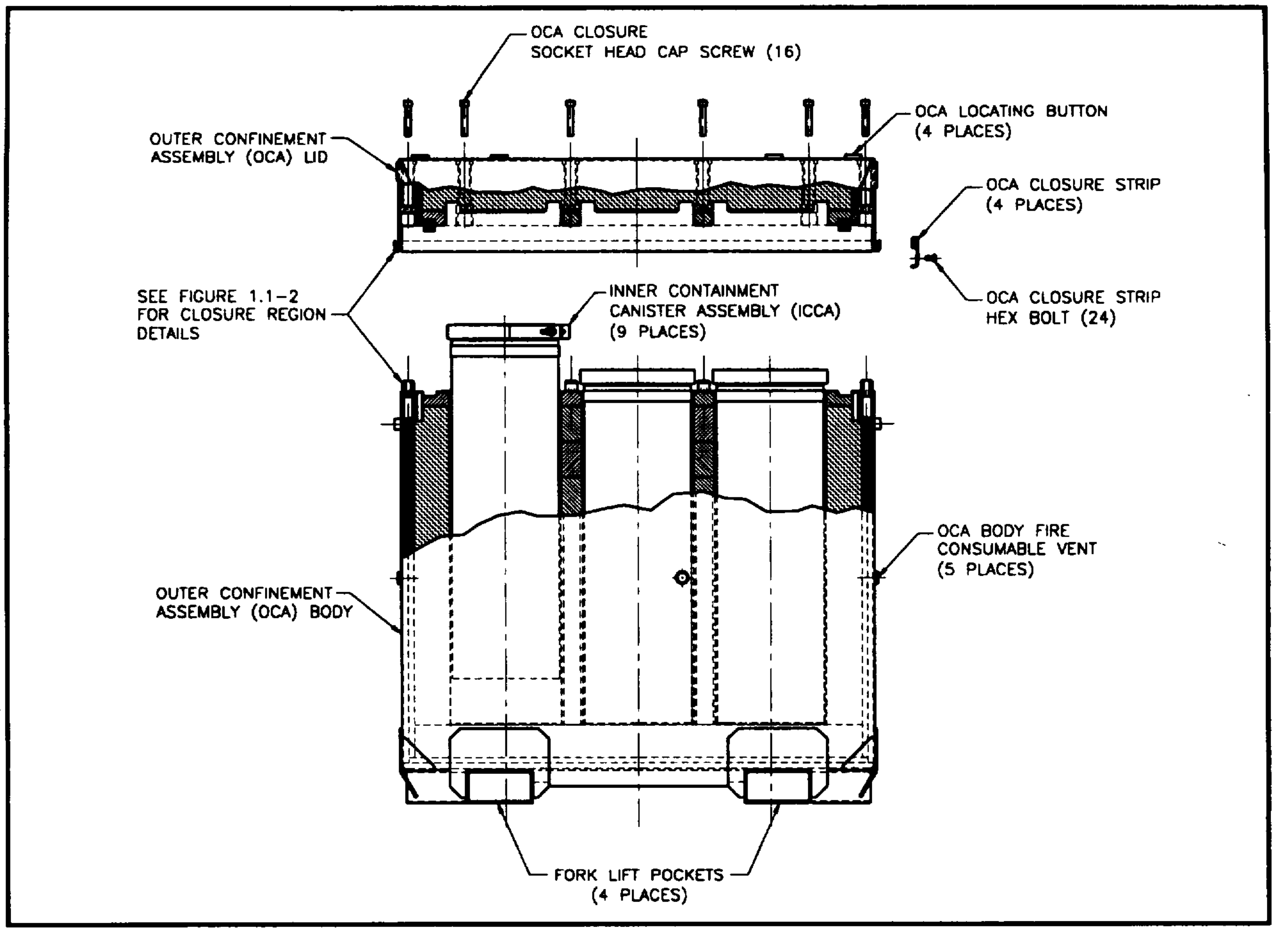

Figure 1.1-1 - GNF NPC Package Assembly (Patent #6,166,391)

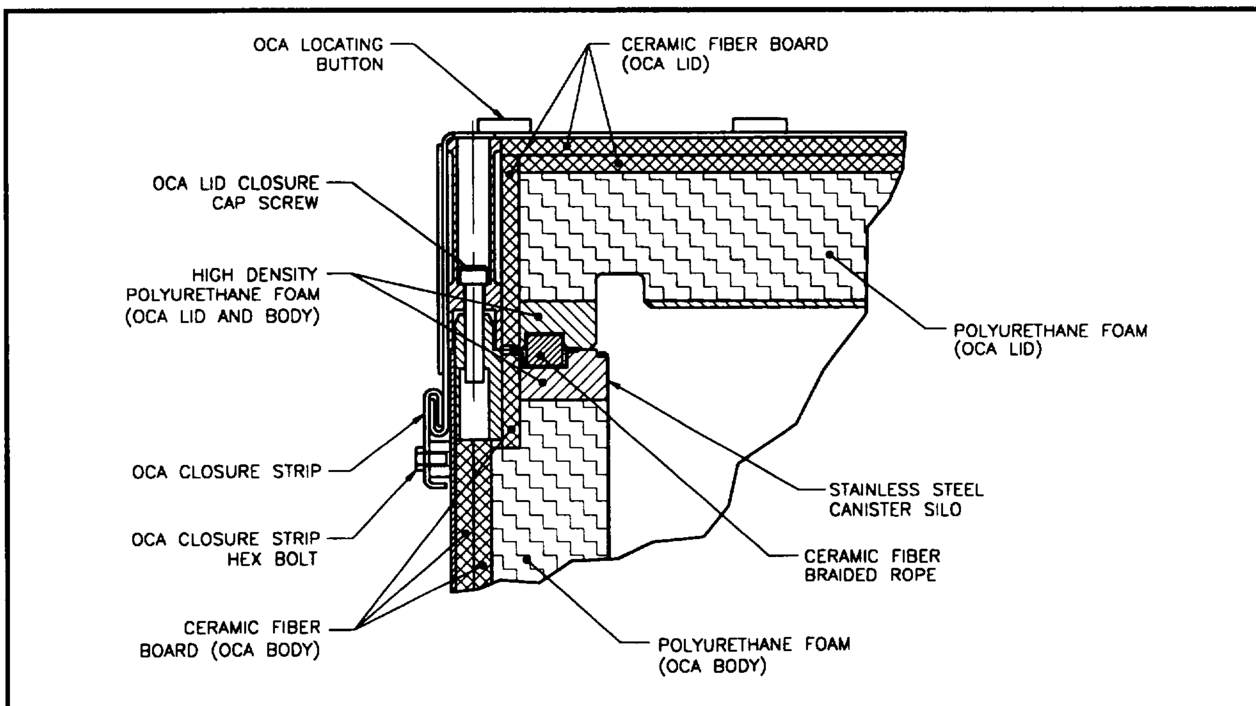

Figure 1.1-2 - GNF NPC Package Closure Region Details (Patent #6,166,391)

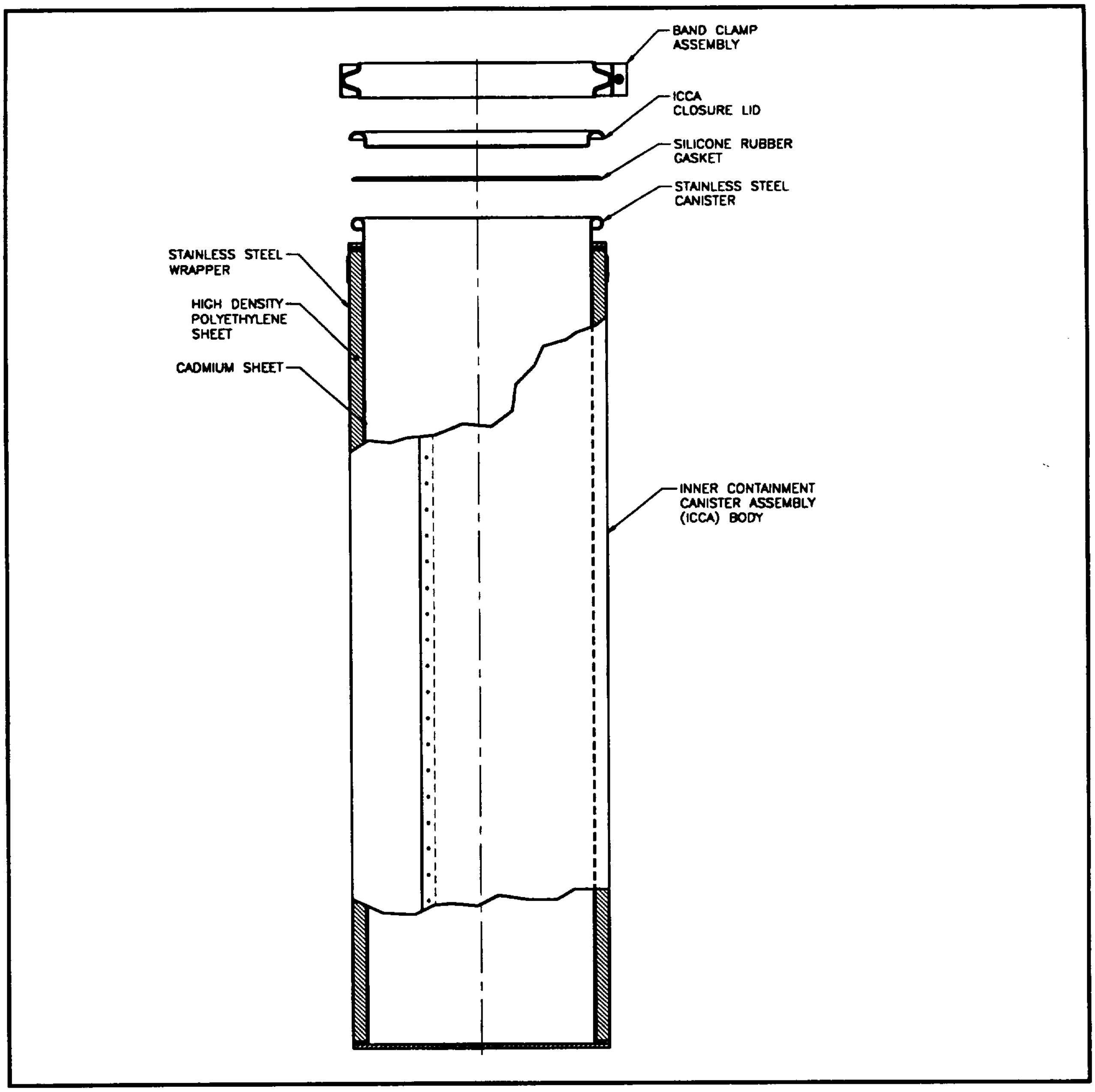

Figure 1.1-3 - GNF NPC Packaging Inner Containment Canister (Patent #6,166,391)

1.2 Package Description

This section presents a basic description of the GNF NPC package. General arrangement drawings of the NPC package (Patent #6,166,391) are presented in Appendix 1.3.1, *Packaging General Arrangement Drawings*.

1.2.1 Packaging

1.2.1.1 Packaging Description

The NPC packaging is a Type A(F) package designed for transportation of uranium oxide powder that is enriched up to 5% U235. The maximum gross weight of the package is 2,870 pounds (1,302 kg) and its primary components of construction are identified in Figure 1.1-1. The payload is uranium oxide powder enriched to a maximum of 5 w/o of U235, and is described in Section 1.2.3, *Contents of Packaging*. Detailed drawings of the NPC packaging are provided in Appendix 1.3.1, *Packaging General Arrangement Drawings*.

The NPC packaging is comprised of two primary components: 1) an outer confinement assembly, and 2) nine inner containment canister assemblies. These two components are fully described in the following sections.

1.2.1.1.1 Outer Confinement Assembly

The Outer Confinement Assembly (OCA) consists of an OCA lid and OCA body, each primarily comprised of an outer stainless steel sheet structure, a layer of ceramic fiber board, and a layer of rigid polyurethane foam. The polyurethane foam provides thermal insulation, energy absorption for the normal and hypothetical accident conditions of transport and neutronic isolation. Nine sealed individual canister assemblies, which provide containment of the uranium oxide powder, are located within the interior of the OCA. The canisters are positioned such that their center-to-center spacing is fixed.

The OCA lid has nominal external dimensions of 43 1/4-inches wide × 43 1/4-inches deep × 8 7/8- inches high. The OCA body has nominal external dimensions of 44-inches wide × 44-inches deep × 38 5/8-inches high. In its assembled configuration, the OCA has approximate nominal external dimensions of 44 7/8-inches wide × 44 7/8-inches deep × 44 3/16-inches high.

The OCA lid is secured to the OCA body with (16) 1/2-13UNC socket head cap screws, with four bolts installed on each edge of the OCA lid. At the joint between the OCA lid and OCA body, a stainless steel closure strip is attached between the OCA lid and OCA body. The closure strip is secured with (24) 7/16-14UNC hex head bolts that are screwed into a 5/8-inch thick stainless steel bar, which is welded to the OCA body. The purpose of the closure strip is to provide additional structural strength to the OCA closure.

The outer skin of the OCA is fabricated using a 10-gauge (0.135 inch) thick Type 304L austenitic stainless steel sheet. Behind the outer skin, two layers of 1/2-inch thick ceramic fiber board are positioned around the sides, bottom, and top of the OCA. Polyurethane foam is then installed between the ceramic fiber board and the containment canisters. A 1-inch × 1-inch ceramic fiber braided rope is installed in the polyurethane foam around the circumference of the OCA body to provide additional thermal protection of the OCA lid/body joint. Nine individual canister silos, fabricated of 22-gauge (0.029 inch) thick Type 304L austenitic stainless steel sheet, are located within the OCA body interior. These canister silos provide the receptacle for the Inner Containment Canister Assemblies (ICCAs). A 1/16-inch thick × 9-inch diameter, silicon rubber pad is placed in the bottom of each canister silo to provide cushioning of ICCA during transport.

1.2.1.1.2 Inner Containment Canister Assembly

The Inner Containment Canister Assembly (ICCA) consists of a closure lid and body, which are fabricated with Type 304L austenitic stainless steel sheet. The closure lid and body are fabricated using 16-gauge (0.0595 inch) and 18-gauge (0.048 inch) material respectively. An austenitic stainless steel band clamp assembly, which uses a 5/16-inch T-bolt, is utilized to secure the canister closure lid to the cylindrical canister body. The band clamp assembly includes a silicone rubber gasket between the canister closure lid and canister body. To provide criticality control, the outer cylindrical surface of each canister is wrapped with a minimum 20-mil cadmium sheet, and then a 15-mil High Density Polyethylene (HDPE) sheet wrapped to a thickness of 1/2-inch minimum. A 24-gauge (0.0235 inch) austenitic stainless steel sheet is wrapped around the cadmium/HDPE materials to secure these materials to the canister body.

The ICCA has a nominal external diameter of 9 3/4-inches and a nominal overall length of 32 1/8-inches. The band clamp assembly has a nominal external diameter of 10 1/4-inches. The payload contents in an ICCA is limited to a maximum of 132.2 pounds (60 kg) which is to include the weight of packing material in the ICCA (powder receptacles, etc.).

1.2.1.2 Gross Weight

The gross shipping weight of a NPC package is 2,870 pounds (1,302 kg). A further discussion of the gross weight is presented in Section 2.2, *Weights and Center of Gravity*.

1.2.1.3 Neutron Moderation and Absorption

Due to the fissile nature of the uranium oxide powder payload, neutron moderation and absorption design features are specifically incorporated into the NPC package. The fissile content of the package is limited to 1,190 pounds (540 kg) of uranium oxide powder (powder plus powder packaging). To provide the criticality safety for this payload, cadmium and HDPE sheeting are wrapped around the length of each payload canister. A stainless steel sheet is then fastened around the cadmium/polyethylene sheets to secure the material around each canister. Secondary neutron moderation and absorption are provided by the rigid polyurethane foam that surrounds the canisters. Further discussion of the neutron moderation and absorption is provided in Chapter 6.0, *Criticality Safety Evaluation.*

1.2.1.4 Receptacles, Valves, Testing, and Sampling Ports

There are no receptacles, valves, or sampling ports utilized within the NPC package.

1.2.1.5 Heat Dissipation

The uranium oxide powder payload results in essentially a negligible thermal heat load. Therefore, no special devices or features are needed or utilized in the NPC package to dissipate heat. A more detailed discussion of the package thermal characteristics is provided in Chapter 3.0, *Thermal*.

1.2.1.6 Coolants

Due to the passive design of the NPC package with regard to heat transfer, there are no coolants utilized within the NPC package.

1.2.1.7 Protrusions

The only significant protrusions on the NPC package exterior are the locating buttons utilized for stacking and the half-couplings utilized for the fire-consumable vents. The locating buttons extend approximately 3/8-inches above the top surface of the lid. The half-couplings extend approximately 0.30 inches above the surface of the body. Neither of these protrusions is significant.

1.2.1.8 Lifting and Tie-Down Devices

The NPC package is lifted utilizing only a standard forklift that lifts the package underneath the bottom of the package. Therefore, there are no lifting devices utilized in the NPC packaging.

The NPC package is transported within an overseas shipping container. A structural frame that acts as the tie-down system is positioned between the NPC packages and the inner walls of the container to secure the packages. There are no tie-down devices that are structural part of the NPC package. For alignment of stacked packages, four locating "buttons" are provided on the top surface of the NPC closure lid assembly. These buttons, which are attached by a minimal fillet weld to the outer stainless steel sheet, interface with a hole in each foot of the upper package. A detailed discussion of this interface and its behavior is provided in Section 2.5, *Lifting and Tie-down Devices for All Packages*.

1.2.1.9 Pressure Relief System

There are no pressure relief systems included in the NPC package design to relieve pressure from within the sealed canisters. Fire-consumable vents in the form of PVC plastic pipe plugs are employed on the exterior surface of the body. These vents are included to release any gases generated by charring polyurethane foam in the Hypothetical Accident Condition (HAC) thermal event (fire). During the HAC fire, the plastic pipe plugs melt, thus allowing the release of gasses generated by the foam as it flashes to a char. Five vents are used on the outer body, located at approximately the center of each side and bottom.

1.2.1.10 Shielding

Due to the nature of the uranium oxide powder payload, no biological shielding is necessary or provided by the NPC packaging.

1.2.2 Operational Features

There are no operationally complex features of the NPC packaging. All operational features are readily apparent from an inspection of the drawings provided in Appendix 1.3.1, *Packaging General Arrangement Drawings*. Operational procedures and instructions for loading, unloading, and preparing an empty NPC packaging for transport are provided in Chapter 7.0, *Operating Procedures*.

1.2.3 Contents of Packaging

The NPC packaging is designed to transport a maximum of 1,190 pounds (540 $kgUO_2$/476.1kgU) of uranium powder in oxide form (e.g., UO_2, U_3O_8, or $UO_{x,\,x>2}$), including powder receptacles and packing material in the ICCA, enriched with a maximum fissile content of 5 weight percent (w/o) of U235. The radionuclide content is uranium from natural sources which is commercially enriched.

The payload may be distributed in any ratio within the nine Inner Containment Canister Assemblies (ICCAs), provided that the content of any one ICCA never exceeds 132.2 pounds (60 kg). Within an ICCA, the powder is enclosed in plastic or metal powder receptacles (e.g. bags, bottles, cans).

1.3 Appendix

1.3.1 Packaging General Arrangement Drawings

This section presents the GNF NPC packaging general arrangement drawing[2], consisting of eight sheets entitled, *GNF New Powder Container (NPC) Packaging, Drawing Numbers 0019D0001-0019D0008, Revision 2.*

[2] The NPC packaging general arrangement drawings utilize the uniform standard practice of ASME Y14.5M, *Dimensioning and Tolerancing* American National Standards Institute, Inc. (ANSI).

NOTES, UNLESS OTHERWISE SPECIFIED:

1. INTERPRET DRAWING PER ANSI Y14.5.
   INTERPRET WELDS PER ANSI/AWS A2.4.
2. THREADS PER ANSI B1.1.
3. IDENTIFICATION: PACKAGE SHALL BE IDENTIFIED IN ACCORDANCE WITH THE REQUIREMENTS OF 10 CFR 71.85(c) ON THE OUTER SHELL OF THE PACKAGE BODY WITH A STAINLESS STEEL NAMEPLATE.
4. MATERIAL: ASTM A240, TYPE 304L STAINLESS STEEL PLATE AND SHEET OR ASTM A276 FLATS AND BAR.
5. PRIOR TO ASSEMBLY, ALL COMPONENTS SHALL BE CLEANED OF CUTTING OIL, MARKING DYES, WELD FLUX, SPATTER, SCALE, GRIME AND ALL OTHER FOREIGN MATERIAL. FINISHED ASSEMBLY AND ALL INTERIOR SURFACES SHALL BE CLEANED, AND VISUALLY OR WIPE TEST INSPECTED IN ACCORDANCE WITH ASTM-A380.
6. ALL WELDING PROCEDURES AND PERSONNEL SHALL BE QUALIFIED IN ACCORDANCE WITH ASME CODE, SECTION IX OR ALTERNATE DESIGN ENGINEERING QUALIFICATION. WELD PROCEDURE AND WELDER QUALIFICATIONS SHALL BE AVAILABLE FOR AUDIT OR REVIEW.
7. ALL WELDS SHALL BE VISUALLY EXAMINED IN ACCORDANCE WITH AWS D1.6.
8. INNER CONTAINMENT CANISTER ASSEMBLY SHALL BE SUBJECTED TO AN INTERNAL PRESSURE TEST AS SPECFIED IN SECTION 8.1.2.2 OF THE NPC SAFETY ANALYSIS REPORT.
9. COAT THREADS WITH A LUBRICANT PRIOR TO ASSEMBLY.
10. TAMPER INDICATING SEALS SHALL BE INSTALLED AT TWO (2) OPPOSITE SIDES.
11. TORQUE TO 50 ±5 LB-FT.
12. TORQUE TO 40 ±5 LB-FT.
13. STENCIL 1" WIDE X 4" LONG STRIPE AND 1/2" HIGH LETTERS AS SHOWN USING BLACK ENAMEL PAINT (ONE SIDE ONLY).
14. FIT CADMIUM SHEET TIGHTLY AROUND INNER SHELL OF CANISTER. BUTT ENDS TOGETHER WITH .000-.100" CLEARANCE. SECURE TO INNER SHELL OF CANISTER WITH DOUBLE SIDED TAPE.
15. WRAP HDPE SHEET CONTINUOUSLY AROUND THE CADMIUM SHEET TO OBTAIN A MINIMUM HYDROGEN AREAL DENSITY OF .199 GRAMS/CM^2. THIS DENSITY WILL BE BASED UPON THE MINIMUM POLYETHYLENE THICKNESS OF .57" AND WIDTH OF 30.3", THE MEASURED POLYETHYLENE ID, A POLYETHYLENE DENSITY OF .92 GRAMS/CC, AND A MINIMUM POLYETHYLENE HYDROGEN CONTENT OF 14.0%. SECURE ENDS WITH DOUBLE-SIDED TAPE.
16. FILL CAVITY WITH HOT GLUE, HYSOL 7804 OR EQUIVALENT, AT EACH END.
17. OPTION: SEAL CREVICE WITH BELZONA 1111 SERIES OR EQUIVALENT SEALANT.
18. COAT EXPOSED SURFACES OF FOAM SLAB WITH ONE THIN COAT OF POLYURETHANE COATING. AFTER INSTALLING SEAL CHANNEL, APPLY A SECOND COAT TO EXPOSED SURFACES OF FOAM SLAB.
19. FILL 1/8 DEEP SPACE OVER EDGES OF CERAMIC FIBER BOARD WITH 3M DP-605 OR EQUIVALENT URETHANE SEALANT.
20. BOLT HOLE PATTERN OF LID SHALL BE COORDINATED WITH THAT OF BODY LOCATING PINS TO ENSURE ALIGNMENT OF BOLTS AND NON-BINDING ASSEMBLY OF LID TO BODY.
21. INSTALL CERAMIC FIBER BOARD PANELS WITH MINIMUM JOINTS. ALL JOINTS, INCLUDING CORNERS, SHALL BE COVERED BY ADJACENT LAYER (STAGGERED). ADHERE PANELS TO BODY AND TO EACH OTHER WITH 3M SUPER 74 SPRAY ADHESIVE, OR EQUIVALENT ADHESIVE.
22. INSTALL PINS BY PIERCING THRU CERAMIC FIBER BOARD AND WELDING TO LID USING COMMERCIAL STUD WELD GUN.
23. INSTALL CERAMIC FIBER BOARD PANELS WITH MINIMUM JOINTS. ALL JOINTS, INCLUDING CORNERS, SHALL BE COVERED BY ADJACENT LAYER (STAGGERED). ADHERE PANELS TO INNER SURFACE OF LID AND TO EACH OTHER WITH 3M SUPER 74 SPRAY ADHESIVE, OR EQUIVALENT ADHESIVE. AT THE CORNERS, ADHERE PANELS TO ITEM 28 ONLY.
24. STENCIL CANISTER BAND CLAMP ORIENTATION ZONES (9 PLACES) USING BLACK ENAMEL PAINT.
25. POLYURETHANE FOAM INSTALLATION TECHNIQUES, ACCEPTANCE TESTS, AND ACCEPTABLE DEVIATIONS IN PROPERTIES ARE SUMMARIZED IN SECTION 8.1.4.1 OF THE NPC SAFETY ANALYSIS REPORT.
26. AN ADDITIONAL STRIP OF 24 GA. (.024") X 2" WIDE X 30.6" LONG STAINLESS STEEL MAY BE ADDED UNDER THE WELD JOINT NEAR THE OVERLAP TO FACILITATE SPOT WELDING.
27. THE CADMIUM SHEET MAY BE INSTALLED IN UP TO THREE SECTIONS WITH A MAXIMUM 0.1" GAP BETWEEN ANY MATING SURFACES.
28. EXTERNAL SURFACES OF NPC MAY BE LOCALLY DENTED OR BULGED UP TO A MAXIMUM DEPTH OF 1/2 INCH.
29. EXTERNAL SURFACES OF ICCA MAY BY LOCALLY DENTED UP TO A MAXIMUM DEPTH OF 1/4 INCH.
30. STENCIL "LID LIFT ONLY" APPROX AS SHOWN (4 PLACES) USING BLACK ENAMEL PAINT.
31. TORQUE TO 35-50 LB-IN.
32. CERAMIC FIBER BOARD AND BRAIDED ROPE ACCEPTANCE TESTS AND ACCEPTABLE DEVIATIONS IN PROPERTIES ARE SUMMARIZED IN SECTION 8.1.4.2 OF THE NPC SAFETY ANALYSIS REPORT.
33. MAXIMUM/MINIMUM WEIGHT OF PACKAGING: 1,680/1,580 LBS.
    MAXIMUM ALLOWABLE WEIGHT OF CONTENTS: 1,190 LBS.
    MAXIMUM ALLOWABLE WEIGHT OF CONTENTS IN ANY ICCA: 132.2 LBS.
    MAXIMUM WEIGHT OF PACKAGE 2,870 LBS.
34. FOAM SLABS MAY BE BONDED TOGETHER WITH EPOXY ADHESIVE.
35. MARKING IS PER 49 CFR 172.310(C).
36. CADMIUM SHEET ACCEPTANCE TESTS AND ACCEPTABLE DEVIATIONS IN PROPERTIES ARE SUMMARIZED IN SECTION 8.1.4.3 OF NPC SAFETY ANALYSIS REPORT.
37. HDPE POLYETHYLENE ACCEPTANCE TESTS AND ACCEPTABLE DEVIATIONS IN PROPERTIES ARE SUMMARIZED IN SECTION 8.1.4.4 OF NPC SAFETY ANALYSIS REPORT.
38. WELDS MAY BE MADE ON EITHER SIDE OF THE SURFACE.

A5	A4	A3	A2	A1	ITEM	PART NO.	DESCRIPTION	
						ASSEMBLY & QUANTITY	LIST OF MATERIAL	
					40		BAND, .06 X 1" SILICONE RUBBER, DURO 45 ±5	
	AR				39		WRAPPER, 24 GA (.024)	ASTM A240, TYPE 304L
	AR				38		SHEET, HDPE POLYETHYLENE, .015" NOM. THK X 30.3" MIN.	
	AR				37		SHEET, CADMIUM, .020" MIN. THK. X 30.3" MIN.	
	AR				36		RING, 7 GA (.187)	ASTM A240, TYPE 304L
	1				35		LID CANISTER, 16 GA (.059)	ASTM A240, TYPE 304L
	1				34		BASE CANISTER, 7 GA (.187)	ASTM A240, TYPE 304L
	1				33		BODY CANISTER, 18 GA (.048)	ASTM A240, TYPE 304L
			4		32		SCREW, MACHINE, 5/16-18 TRUSS HEAD	
		4			31		THREADED INSERT, 5/16-18, INTERNAL THD	
		1			30		ROPE, BRAIDED, CERAMIC FIBER, 1" X 1" X AR	
		AR			29		FOAM, 15 LBS/FT^3	POLYURETHANE
		8			28		LINER, 16 GA (.059) X 3.7 X 5.6	ASTM A240, TYPE 304L
		16			27		BOLT SUPPORT, 1.5 X 1.5 X 6	ASTM A276, TYPE 304L
		4			26		LIFT PAD, 3/8" THK X ø1.5	ASTM A276 OR A240, TYPE 304L
		4			25		CORNER REINFORCEMENT, 10 GA (.135)	ASTM A240, TYPE 304L
		4			24		ANGLE, 1 X 1 X 1/8	ASTM A276, TYPE 304L
		4			23		LID CORNER REINFORCEMENT, 10 GA (.135)	ASTM A240, TYPE 304L
		1			22		LID, 10 GA (.135)	ASTM A240, TYPE 304L
			9		21		PAD, ICCA, 1/16 THK X ø9.0	SILICONE RUBBER
			5		20		PIPE PLUG, 1/2 NPT, PLASTIC	
		12	16		19		CUPPED PIN, INSULATION	
		AR	AR		18		SEAL TROUGH, 24 GA (.0235)	ASTM A240, TYPE 304L
			AR		17		FOAM, 11 LBS/FT^3	
			5		16		HALF COUPLING, 1/2-14NPT	
		1	1		15		FOAM SLAB, 1 3/8" THK, 40 LBS/FT^3	POLYURETHANE
			9		14		FOAM SLAB, 3 1/4" THK, 7 LBS/FT^3	POLYURETHANE
			1		13		FOAM SLAB, 3" THK, 11 LBS/FT^3	POLYURETHANE
		AR	AR		12		CERAMIC FIBER BOARD, 1/2" THK	
1					11		LINER BASE, 22 GA (.029)	ASTM A240, TYPE 304L
1					10		LINER, 22 GA (.029)	ASTM A240, TYPE 304L
			8		9		GUARD, 7 GA (.187) X 6.3 X 9.0	ASTM A240, TYPE 304L
			16		8		LOCATING PIN, 1.3 X 1.5 X 3.5	ASTM A276, TYPE 304L
			4		7		BAR, 5/8 X 1	ASTM A276, TYPE 304L
			4		6		LIFT CHANNEL, 7 GA (.187) X 6.0 X 1.5 X 19.6	ASTM A240, TYPE 304L
			8		5		LIFT TUBE, 6 X 3 X 3/16 WALL	ASTM A240, TYPE 304L
			4		4		BODY CORNER GUSSET, 14 GA (.075)	ASTM A240, TYPE 304L
			1		3		DOUBLER, 16 GA (.060) X 18 3/8 SQ	ASTM A240, TYPE 304L
			1		2		BOTTOM PLATE, 10 GA (.135) X 27 13/16 SQ	ASTM A240, TYPE 304L
			4		1		BODY, 10 GA (.135)	ASTM A240, TYPE 304L
X				9	A5		SILO WELDMENT	
	X			9	A4		INNER CONTAINMENT CANISTER ASSEMBLY (ICCA)	
					A3		OCA LID ASSEMBLY	
					A2		OCA BODY ASSEMBLY	
				X	A1		OUTER CONFINEMENT ASSEMBLY (OCA)	
A5	A4	A3	A2	A1	ITEM	PART NO.	DESCRIPTION	
						ASSEMBLY & QUANTITY	LIST OF MATERIAL	

A5	A4	A3	A2	A1	ITEM	PART NO.	DESCRIPTION	
				8	52		WASHER, FLAT, 1/4-20 NOM	
				8	51		SCREW, MACHINE, 1/4-20UNC PAN HEAD	
				8	50		COVER, 16 GA (.060) X 3 X 6	ASTM A240, TYPE 304L
				1	49		NAMEPLATE, COMPLIES WITH 10CFR71.85	
				16	48		PLUG, WEATHER, ø1"	RUBBER & PLASTIC
				24	47		BOLT, HEX HD, 7/16-14UNC X 3/4	CAD PLATED GR 5
				16	46		SOC HD, CAP SCREW, 1/2-13UNC X 2	18-8 SS
				16	45		THREADED INSERT, 1/2-13UNC INTERNAL THD	
				24	44		THREADED INSERT, 7/16-14UNC INTERNAL THD	
				4	43		STRIP, CLOSURE, 10 GA (.135)	ASTM A240, TYPE 304L
	1				42		BAND CLAMP ASSY #NH1009394-10	AEROQUIP OR EQUIVALENT
	1				41		GASKET, 1/8" THK SILICONE RUBBER, DURO 60-70	
A5	A4	A3	A2	A1	ITEM	PART NO.	DESCRIPTION	
						ASSEMBLY & QUANTITY	LIST OF MATERIAL	

PATENT #6,166,391

TOLERANCES, UNLESS OTHERWISE SPECIFIED:

LINEAL DIMENSION RANGE	DECIMAL 3 PLACE	DECIMAL 2 PLACE	DECIMAL 1 PLACE	FRACTIONAL	ANGULAR
0-6"	±0.020	±0.05	±0.2	±3/16	±2°
6"-24"	±0.030	±0.10	±0.3	±5/16	
> 24"	±0.050	±0.20	±0.5	±1/2	

REV	DESCRIPTION	BY	DCR#	APPROVAL	DATE
2	FIRST ISSUE		9172	H. KNIGHT	1/26/01

REVISIONS

SIGNATURES	DAY	MO	YR
DRAWN RI VAN LE	21	1	00
CHECKED			
ENGR			
ENGR			

SCALE N/A

ALL SURF ✓

UNLESS OTHERWISE SPECIFIED
TOLERANCES ON :
2 PLACE DECIMALS ± FRACTIONS ±
3 PLACE DECIMALS ± ANGLES ±

GNF Global Nuclear Fuel

GNF NEW POWDER CONTAINER (NPC) PACKAGING

FMF

DWG NO. 0019D0001 REV 2

FILE NAME 990105AR011.DWG SH NO. 1 CONT ON 8

FIGURE WITHHELD UNDER 10 CFR 2.390

REV	DESCRIPTION	BY	DCR#	APPROVAL	DATE
2	FIRST ISSUE			H. KNIGHT	1/26/01

REVISIONS

SIGNATURES	DAY	MO	YR
RI VAN LE	21	1	00

Global Nuclear Fuel

GNF NEW POWDER CONTAINER (NPC) PACKAGING

SCALE 1/4

ALL SURF ✓

UNLESS OTHERWISE SPECIFIED
TOLERANCES ON :
2 PLACE DECIMALS ± FRACTIONS ±
3 PLACE DECIMALS ± ANGLES ±

FMF

0019D0002

2

SH NO. 2 CONT ON 8

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE WITHHELD UNDER 10 CFR 2.390

REV	DESCRIPTION	BY	DCR#	APPROVAL	DATE
2	FIRST ISSUE			H. KNIGHT	1/26/01

REVISIONS

SIGNATURES	DAY	MO	YR
RI VAN LE	20	1	00

Global Nuclear Fuel

GNF NEW POWDER CONTAINER (NPC) PACKAGING

SCALE 1/4

ALL SURF ✓

UNLESS OTHERWISE SPECIFIED
TOLERANCES ON :
2 PLACE DECIMALS ±   FRACTIONS ±
3 PLACE DECIMALS ±   ANGLES ±

FMF

0019D0004

2

4

8

FIGURE WITHHELD UNDER 10 CFR 2.390

REV	DESCRIPTION	BY	DCR#	APPROVAL	DATE
2	FIRST ISSUE			H. KNIGHT	1/26/01

REVISIONS

SIGNATURES	DAY	MO	YR
R VAN LE	20	1	00

Global Nuclear Fuel

GNF NEW POWDER CONTAINER (NPC) PACKAGING

SCALE 1/4

UNLESS OTHERWISE SPECIFIED
TOLERANCES ON :
2 PLACE DECIMALS ± FRACTIONS ±
3 PLACE DECIMALS ± ANGLES ±

FMF

0019D0005 | 2

SH 5 OF 8

FIGURE WITHHELD UNDER 10 CFR 2.390

REV	DESCRIPTION	BY	DCR#	APPROVAL	DATE
2	FIRST ISSUE		[illegible]	H. KNIGHT	1/26/01

REVISIONS

SIGNATURES		DAY	MO	YR
RI VAN LE	1/20/00			

SCALE 1/2

ALL SURF ✓

UNLESS OTHERWISE SPECIFIED
TOLERANCES ON :
2 PLACE DECIMALS ± FRACTIONS ±
3 PLACE DECIMALS ± ANGLES ±

GNF

Global Nuclear Fuel

GNF NEW POWDER CONTAINER (NPC) PACKAGING

FMF

DWG NO. 0019D0006

REV 2

SH 6 OF 8

FIGURE WITHHELD UNDER 10 CFR 2.390

REV	DESCRIPTION	BY	DCR#	APPROVAL	DATE
2	FIRST ISSUE			H. KNIGHT	1/26/01

REVISIONS

SIGNATURES	DAY	MO	YR
RI VAN LE	1	20	00

GNF Global Nuclear Fuel

GNF NEW POWDER CONTAINER (NPC) PACKAGING

SCALE 1/4

UNLESS OTHERWISE SPECIFIED
TOLERANCES ON :
2 PLACE DECIMALS ± FRACTIONS ±
3 PLACE DECIMALS ± ANGLES ±

FMF

0019D0007 — 2

SH NO. 7 — CONT ON 8

MODEL NO.: NPC

TYPE A

OWNER: GLOBAL NUCLEAR FUEL–AMERICAS

MANUFACTURE DATE:

SERIAL NO.:

PACKAGE IDENTIFICATION NUMBER: USA/9294/A(F)–85

GROSS WEIGHT: 2870 LBS (1302 KG)

DETAIL ITEM (49)

MATERIAL: STAINLESS STEEL (ANY GRADE)
LETTERING: 1/2" HIGH MINIMUM, ENGRAVED, BLACK PAINT FILLED

PATENT #6,166,391

TOLERANCES, UNLESS OTHERWISE SPECIFIED:

LINEAL DIMENSION RANGE	DECIMAL			FRACTIONAL	ANGULAR
	3 PLACE	2 PLACE	1 PLACE		
0–6"	±0.020	±0.06	±0.2	±3/16	±2°
6"–24"	±0.030	±0.10	±0.3	±5/16	
> 24"	±0.050	±0.20	±0.5	±1/2	

REV	DESCRIPTION	BY	DCR#	APPROVAL	DATE
2	FIRST ISSUE	RES	[signature]	H. KNIGHT	1/28/01

REVISIONS

SIGNATURES	DAY	MO	YR
RI VAN LE	1	21	00

SCALE N/A ALL SURF ✓

UNLESS OTHERWISE SPECIFIED
TOLERANCES ON :
2 PLACE DECIMALS ± FRACTIONS ±
3 PLACE DECIMALS ± ANGLES ±

GNF Global Nuclear Fuel

GNF NEW POWDER CONTAINER (NPC)
PACKAGING
SAMPLE NAMEPLATE

FMF

0019D0008 2

2.0 STRUCTURAL EVALUATION

This chapter presents the structural design criteria, weights, mechanical properties of material, and structural evaluations which demonstrate that the NPC package meets all applicable structural critēria for transportation as defined in 10 CFR 71[1].

2.1 Structural Design

The primary structural evaluation of the NPC is performed with various tests. The results of the tests are provided in the following sections. Supporting analyses and analyses of non-tested structural aspects are also provided.

The NPC consists of two major fabricated components: 1) an Outer Confinement Assembly (OCA), and 2) nine stainless steel Inner Containment Canister Assemblies (ICCAs). The OCA consists of a stainless steel outer shell for structural strength, a layer of ceramic fiber board insulation for thermal protection, and a layer of rigid polyurethane foam for thermal and impact protection. The ICCAs provide structural strength as well as containment of the uranium oxide powder payload. Polyethylene and cadmium sheeting around the body of the ICCAs assist in maintaining the nuclear reactivity at acceptable levels.

2.1.1 Discussion

A comprehensive discussion on the NPC package design and configuration is provided in Section 1.2, *Package Description*. As noted previously, the major components of the NPC packaging are the OCA, which provides confinement, and the ICCAs, which provide containment of the payload. Closure of the OCA is provided by (16) 1/2-13UNC socket head cap screws. The closure is further secured by the OCA closure strips and (24) 7/16-14UNC hex head bolts. The closure of the ICCAs is provided by a stainless steel band clamp assembly that utilizes a 5/16-24UNF T-bolt. The NPC packaging is illustrated in Figure 2.1-1. Full details of the NPC packaging design are provided on the drawings in Appendix 1.3.1, *Packaging General Arrangement Drawings*.

Standard fabrication methods are utilized to fabricate the NPC packaging. Visual weld examinations are performed on all welds of the NPC packaging in accordance with AWS D1.6[2].

[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-98 Edition.

[2] ANSI/AWS D1.1, *Structural Welding Code – Stainless Steel*, American Welding Society (AWS).

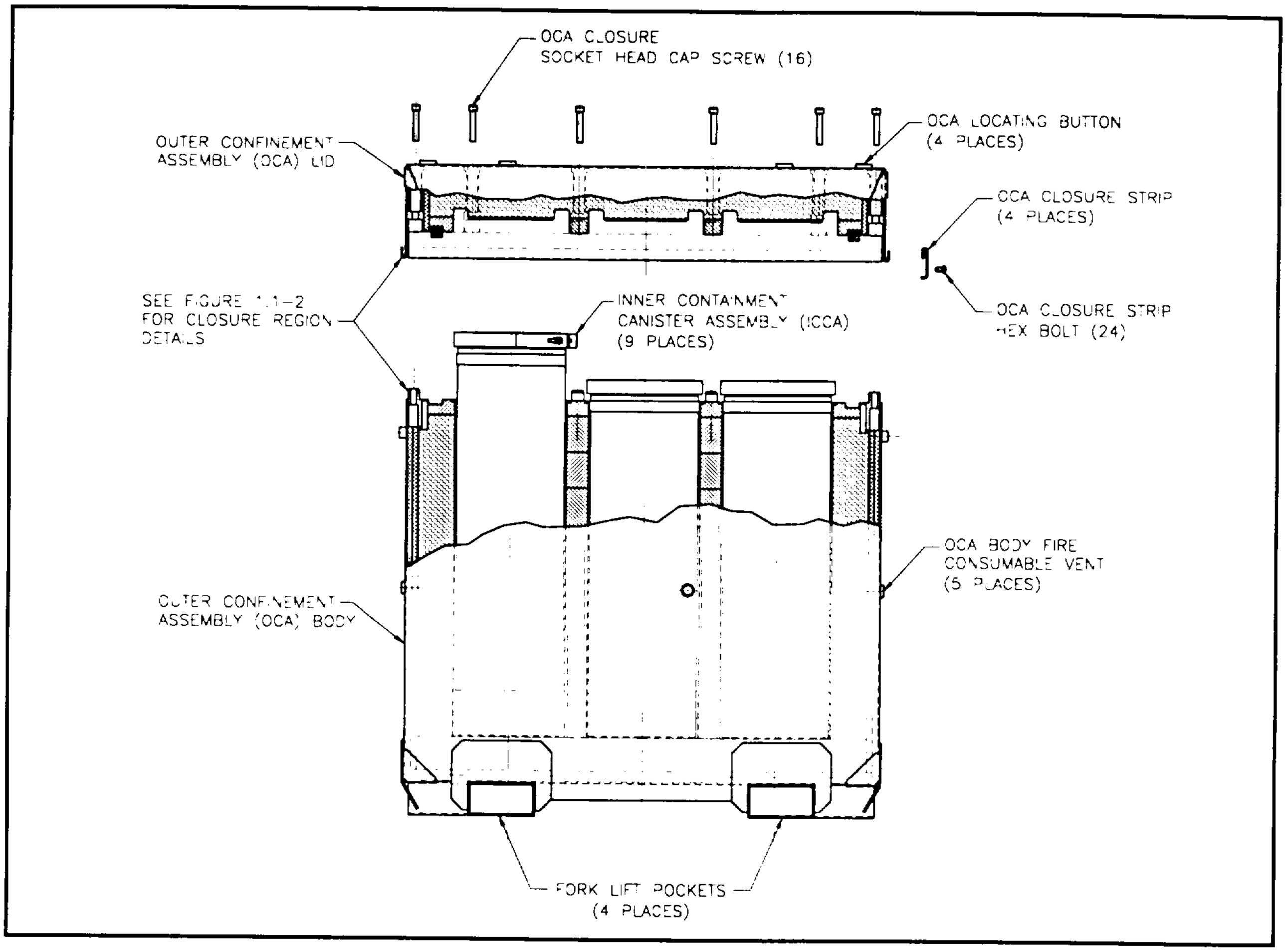

Figure 2.1-1 - Sectional View of the GNF NPC Packaging (Patent #6,166,391)

2.1.2 Design Criteria

2.1.2.1 Basic Design Criteria

Evidence of performance for the NPC package is achieved primarily by empirical evaluations using full-scale packages. The acceptance criterion for these evaluations is a demonstration that the ICCAs remain essentially undamaged throughout Normal Conditions of Transport (NCT) and Hypothetical Accident Condition (HAC) certification testing. Additionally, package deformation obtained from certification testing must be such that the deformed geometry assumptions utilized in subsequent criticality safety evaluations are validated.

2.1.2.2 Miscellaneous Structural Failure Modes

2.1.2.2.1 Brittle Fracture

The primary structural material of the NPC packaging is austenitic stainless steel. This material does not undergo a ductile-to-brittle transition in the temperature range of interest [i.e., down to -40 °F (-40 °C)], and thus does not require evaluation for brittle fracture.

2.1.2.2.2 Fatigue

Because the ICCAs of the NPC package are constructed of ductile stainless steel and are essentially a rigid body within the polyurethane foam, no structural failures of the containment boundary due to fatigue will occur.

2.1.2.2.3 Buckling

The NPC package provides both a confinement (OCA) and a containment boundary (ICCAs). For normal condition and hypothetical accident conditions, the containment boundary will not buckle due to free or puncture drops. This behavior has been demonstrated via full-scale testing of the NPC package.

2.2 Weights and Center of Gravity

The maximum gross weight of the NPC package, including a maximum payload weight of 1,190 pounds (540 kg), is 2,870 pounds (1,302 kg). The center of gravity is approximately at the geometric center of the OCA, i.e., approximately 23-inches above the base of the package.

2.3 Mechanical Properties of Materials

Mechanical properties for the materials used for the structural components of the NPC packaging are provided in this section. Temperature-dependent material properties for structural components are obtained from Section II, Part D, of the ASME Boiler and Pressure Vessel (B&PV) Code[3]. Since the evaluation of the NPC is primarily via test, only the material properties that are used in the analysis portion of the evaluation are given. Table 2.3-1 presents the properties of the structural material used in the packaging.

[3] American Society of Engineers (ASME) Boiler and Pressure Vessel Code, Section II, *Materials, Part A – Ferrous Material Specifications*, and *Materials, Part D – Properties*, 1995 edition, 1997 Addenda.

Table 2.3-1 - Type 304L Stainless Steel Material Properties

Material Specification	Temperature, °F	① Yield Strength (S_y), psi	② Ultimate Strength (S_u), psi	③ Design Stress Intensity (S_m), psi	④ Elastic Modulus, (x10⁶, psi)	⑤ Coefficient of Thermal Expansion, α (x10⁻⁶, in/in/°F)
Type 304L Stainless Steel	-40	**25,000**	**70,000**	**16,700**	**28.8**	**8.21**
	-20	25,000	70,000	16,700	**28.8**	**8.26**
	70	25,000	70,000	16,700	28.3	Not Available
	100	25,000	70,000	16,700	**28.1**	8.55
	200	21,400	66,200	16,700	27.6	8.79
	300	19,200	60,900	16,700	27.0	9.00

Notes:

① ASME B&PV Code, Section II, Part D, Table Y-1

② ASME B&PV Code, Section II, Part D, Table U

③ ASME B&PV Code, Section II, Part D, Table 2A

④ ASME B&PV Code, Section II, Part D, Table TM-1, Material Group G

⑤ ASME B&PV Code, Section II, Part D, Table TE-1, 18Cr-8Ni, Coefficient B

⑥ When necessary, values are linearly interpolated or extrapolated and given in **bold** text.

⑦ The weight density and Poisson's ratio for Type 304L stainless steel are 0.290 lb/in^3 and 0.29, respectively

2.4 General Standards for All Packages

The NPC packaging is evaluated, with respect to the general standards for all packaging specified in 10 CFR §71.43[3]. Results of the evaluations are discussed in the following sections.

2.4.1 Minimum Package Size

The smallest overall dimension of the NPC package is 44.17-inches (112 cm). This dimension is greater than the minimum dimension of 4-inches specified in 10 CFR §71.43(a). Therefore, the requirements of 10 CFR §71.43(a) are satisfied by the NPC package.

2.4.2 Tamper Indicating Device

Two tamper indicating seals (wire/lead security seal) are attached between the OCA closure lid and the OCA body (refer to Figure 2.1-1), which provide visual evidence that the closure was not tampered. Thus, the requirements of 10 CFR §71.43(b) are satisfied.

2.4.3 Positive Closure

The NPC package cannot be opened inadvertently. Positive closure of the NPC package is provided by (16) 1/2-inch socket head cap screws and (24) 7/16-inch hex head bolts. Thus, the requirements of 10 CFR §71.43(c) are satisfied.

2.4.4 Chemical and Galvanic Reactions

The NPC packaging is fabricated from Type 304L stainless steel, ceramic fiber board insulation, polyurethane foam, and cadmium/polyethylene sheeting. The stainless steel shell and canisters do not have significant chemical or galvanic reactions with the interfacing components, air, or water. Therefore, the requirements of 10 CFR §71.43(d) are met.

2.4.5 Valves

Because the NPC packaging is a confinement/containment system and designed to transport only enriched uranium oxide powder radioactive material, there are no valves or other pressure retaining devices on the package. Therefore, the requirements of 10 CFR §71.43(e) are satisfied.

2.4.6 Package Design

As shown in Chapter 2.0, *Structural Evaluation*, Chapter 3.0, *Thermal*, and Chapter 6.0, *Criticality Safety Evaluation*, the structural, thermal and criticality requirements, respectively, of 10 CFR §71.43(f) are satisfied for the NPC package.

2.4.7 External Temperatures

The NPC package is designed for non-exclusive use shipment. As presented in Section 3.4, *Thermal Evaluation for Normal Conditions of Transport*, the maximum accessible surface temperature with the negligible internal heat and no insolation is 100 °F. Since no surface temperature exceeds 122 °F (50 °C), the requirements of 10 CFR §71.43(g) are satisfied.

2.4.8 Venting

The NPC package does not incorporate any feature that would permit continuous venting during transport. Thus, the requirements of 10 CFR §71.43(h) are satisfied.

2.5 Lifting and Tie-down Devices for All Packages

For analysis of the lifting and tie-down devices of the NPC packaging, material properties from Section 2.3, *Mechanical Properties of Materials*, are taken at a bounding temperature of 200 °F, which is greater than the values presented in Section 2.6.1.1, *Summary of Pressures and Temperatures*. The primary structural material is Type 304L stainless steel used in the construction of the OCA.

A loaded NPC package is only lifted by forklift pockets, located on the underside of the OCA body. Mechanical properties of Type 304L stainless steel at 200 °F are summarized below:

Material Property	Value	Reference
Elastic Modulus, E	27.6×10^6 psi	Table 2.3-1
Yield Strength, S_y	21,400 psi	
Shear Stress, equal to (0.6) S_y	12,840 psi	

2.5.1 Lifting Devices

This section demonstrates that the forklift pockets, the only attachments designed to lift the NPC package, are designed with a minimum safety factor of three against yielding, per the requirements of 10 CFR §71.45(a). The lifting devices on the OCA lid (buttons) are restricted to only lifting the OCA lid.

The NPC package is lifted only by using forklift pockets underneath the package body. When lifting the entire package, the applied lift force without yielding is simply three times the gross package weight of 2,850 pounds, as specified in Section 2.2, *Weights and Center of Gravity.*

$$F_L = (3)(2{,}850) = 8{,}550 \text{ pounds}$$

The lifting load is considered to be concentrated at the forklift pocket interfaces and act parallel to the direction of foam rise. For the purposes of this analysis, the minimum assumed fork width is 5-inches and the minimum assumed engagement length of 36-inches. The total bearing area for two forks is:

$$A = (2)(5)(36) = 360 \text{ inches}$$

Assuming the entire lifted load is carried directly by the lower stainless steel structure, the compressive stress is:

$$\sigma_c = \frac{F_L}{A} = \frac{8{,}550}{360} = 24 \text{ psi}$$

The allowable yield stress for the Type 304L material is 21,400 psi. Therefore, the margin of safety (MS) is:

$$MS = \frac{21{,}400}{24} - 1.0 = +\text{Large}$$

2.5.2 Tie-Down Devices

The NPC package is secured for transport within a sea-land container or other enclosed transport vehicle. The NPC package is secured utilizing blocking and/or bracing horizontal restraints on each side and on the top of the package. For a single side or single top restraint configuration, the restraint must be located at or above the center of gravity height or location (respectively), which is approximately 23 inches above the base as noted in Section 2.2, *Weights and Center of Gravity*. Both lifting features of the NPC package (the eight forklift pockets and the four stainless steel locating "buttons" on the OCA lid) are disabled for transport. Therefore, the requirements of §10 CFR 71.45(b)(2) are satisfied.

To ensure that the interface pressure between the NPC package and the blocking/bracing restraints is limited to the compressive strength of the polyurethane foam, i.e., the weakest material in the load path. The minimum contact surface area is based on the compressive strength of the 11 lbs/ft^3 polyurethane foam, which is immediately adjacent to the outer sheet metal. For this foam density, the minimum acceptable compressive foam stress is taken at 10% strain for the perpendicular-to-foam rise orientation. Per Table 8-1.3, Section 8.1.4.1.2.2.3, *Perpendicular-to-Rise Compressive Stress*, this strength is 307 psi. Conservatively using the 10g requirement of §10 CFR 71.45(b)(1) for all directions, the minimum contact surface area (SA) is determined as follows:

$$SA_{10g} = \left[\frac{(10g)(2{,}870\,\text{lbs})}{307}\right] = 91.53\,\text{in}^2$$

The minimum length of any exterior flat surface on the NPC package is 42.0 inches. Therefore, the minimum width of any blocking/bracing restraint is:

$$\text{Width}_{min} = \frac{91.53}{42.0} = 2.18\,\text{inches}$$

Therefore, any structure member used as a tie-down restraint having a width of 2.18 inches will not result in a compressive stress within the NPC package in excess of 307 psi. Therefore, the requirements of §10 CFR 71.45 are satisfied.

2.6 Normal Conditions of Transport

2.6.1 Heat

The NCT thermal analyses presented in Section 3.4, *Thermal Evaluation for Normal Conditions of Transport*, consists of exposing the NPC package to direct sunlight and 100 °F still air per the requirements of 10 CFR §71.71(b).

2.6.1.1 Summary of Pressures and Temperatures

The Maximum Normal Operating Pressure (MNOP) for the ICCA is 6.1 psig, as determined in Section 3.4.1, *Maximum Internal Pressure*. Combining the MNOP with the reduced external pressure, per 10 CFR §71.71(c)(3), of 3.5 psia (11.2 psig), results in a maximum internal pressure in an ICCA of 17.3 psig.

The NCT heat input results in modest temperatures and temperature gradients throughout the NPC package. Maximum temperatures for the major packaging components are summarized in Table 3.4-3 from Section 3.4, *Thermal Evaluation for Normal Conditions of Transport*. As shown in Table 3.4-3, the maximum steady state temperature of any component in an ambient environment of 100 °F (38 °C) and full insolation is 174 °F (79 °C).

2.6.1.2 Differential Thermal Evaluation

Thermal conditioning of three, full scale test specimens to a steady state temperature of 132 °F (56 °C) indicate that the effects associated with differential thermal expansion of the various packaging components are negligible.

2.6.1.3 Stress Calculations

Successful testing of three, full scale NPC packages indicate that the stresses associated with differential thermal expansion of the various packaging components are negligible.

2.6.1.4 Comparison with Allowable Stresses

As discussed in Section 2.6.1.3, *Stress Calculations*, further evaluation of stresses associated with differential thermal expansion for the various NPC package components is not required.

2.6.2 Cold

The NCT cold condition consists of exposing the NPC packaging to a steady-state temperature of -40 °F (-40 °C). Insolation is assumed to be zero. A NPC package was chilled to a steady-state temperature of –40 °F (-40 °C). There was no evidence of any negative effects on the NPC package.

2.6.3 Reduced External Pressure

A sealed ICCA was subjected to a reduced external pressure of 3.5 lbs/in^2 absolute (psia) without experiencing any detrimental effects. Therefore, the requirements of 10 CFR §71.71(c)(3) are satisfied.

2.6.4 Increased External Pressure

A NPC package was immersed in water to a depth of 50 feet (15 m), which subjected the package to an external pressure of 21.7 lbs/in^2 gauge (psig) without experiencing any detrimental effects. Therefore, the requirements of 10 CFR §71.71(c)(4) are satisfied.

2.6.5 Vibration

A NPC package was tested in accordance with Section I-3.3 of Department of Defense (DOD) Military Standard 810E[4] for 4 hours in each axis (total of 12 hours), which is equivalent to an over-the-road truck transport of 4,000 miles. No indications or detrimental conditions existed with the NPC package following this vibratory exposure. Therefore, the requirements of 10 CFR §71.71(c)(5) are satisfied.

2.6.6 Water Spray

The materials of construction utilized for the NPC packaging are such that the water spray test identified in 10 CFR §71.71(c)(6) will have a negligible effect on the package.

2.6.7 Free Drop

Since the gross weight of the NPC package is less than 11,000 pounds (5,000 kg), a four-foot free drop is required per 10 CFR §71.71(c)(7). As discussed in Appendix 2.10.1, *Certification Tests*, NCT, four-foot drops were performed on NPC Certification Test Units (CTUs) as an initial condition for subsequent Hypothetical Accident Condition (HAC) tests. An examination following certification testing demonstrated the ability of the NPC packaging to maintain its structural and criticality control integrity. Therefore, the requirements of 10 CFR §71.71(c)(7) are satisfied.

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[4] U. S. Department of Defense, *Military Standard, Environmental Test Methods and Engineering Guidelines*, MIL-STD-810E, dated July 14, 1989.

2.6.8 Corner Drop

The corner drop test does not apply, since the gross weight of the package exceeds 100 pounds (50 kg), as delineated in 10 CFR §71.71(c)(8). However, to assure compliance with IAEA regulations, a one-foot corner drop was performed in the same drop orientation and prior to the four-foot corner drop for CTUs 1 and 3. The damage was inconsequential.

2.6.9 Compression

A 14,200-pound (6,441-kg) weight, which is greater than five times the minimum gross package weight of 2,770 pounds (1,256 kg), was applied to the top surface of the NPC package while sitting in its normal upright position. No observable deformation and damage was detected. The additional compressive load of 150 pounds (68 kg) required for the maximum gross weight of 2,870 pounds (1,302 kg) represents only a 1.06% increase above the applied load. Based on the condition of the test unit, no observable deformation or damage would be expected due to this small compressive load increase. Therefore, the requirements of 10 CFR §71.71(c)(9) are satisfied.

2.6.10 Penetration

The 40-inch (one meter) drop of a 1 1/4-inch diameter, 13-pound (6 kg), hemispherical end steel rod, as delineated in 10 CFR §71.71(c)(10), is of negligible consequence to the NPC packaging. This conclusion is due to the fact that the NPC package is designed to minimized the consequences associated with the much more limiting case of a 40-inch (one meter) drop of the entire package onto a puncture bar, as discussed in Section 2.7.3, *Puncture*. The 10-gauge minimum thickness of the outer shell of the OCA is not damaged by the penetration event.

2.7 Hypothetical Accident Conditions

When subjected to the hypothetical accident conditions as specified in 10 CFR §71.73, the NPC meets the performance requirements specified in Subpart E of 10 CFR 71. This conclusion is demonstrated in the following subsections, where each accident condition is addressed and the package is shown to meet the applicable design criteria. The method of demonstration is primarily by test. The loads specified in 10 CFR §71.73 are applied sequentially, per Regulatory Guide 7.8.

Test results are summarized in Section 2.7.7, *Summary of Damage*, with details provided in Appendix 2.10.1, *Certification Tests*.

2.7.1 Free Drop

Subpart F of 10 CFR 71 requires that a 30-foot (9-meter) free drop to be considered for the NPC package. The free drop is to occur onto a flat, essentially unyielding, horizontal surface, and the package is to strike the surface in an orientation for which the maximum damage is expected. The free drop is addressed by test, in which several orientations are used. The free drop precedes both the puncture and fire tests. The ability of the NPC package to adequately withstand this specified drop condition is demonstrated via testing of four full-scale, NPC Certification Test Units (CTUs). Except for the OCA lid reinforcement that was added as a design upgrade to CTU-1 prior to drop testing, all CTUs were identical to the NPC packaging design depicted in Appendix 1.3.1, *Packaging General Arrangement Drawings*.

2.7.1.1 Technical Basis for the Free Drop Tests

To properly select a worst case package orientation for the 30 foot (9 meter) free drop event, the foremost item that could potentially compromise the criticality control integrity of the NPC package must be clearly identified.

The criticality control integrity may be compromised by four methods: 1) excessive movement of the ICCAs such that their center-to-center distance results in an non-subcritical geometry, 2) damage/destruction of cadmium and polyethylene sheeting, 3) as a result of thermal degradation of the cadmium/polyethylene sheeting and the polyurethane foam in a subsequent fire event and/or 4) other structural damage that could affect the nuclear reactivity of an array of packages.

For the above reasons, testing must include orientations that affect the OCA lid and the interface between the OCA lid and OCA body. Therefore, orientations that place the Center-of-Gravity (CG) over the OCA lid/body interface were included in the test sequences.

2.7.1.2 Test Sequence for the Selected Tests

Based on the above discussions, the NPC was tested for four specific, HAC 30 foot (9 meter) free drop conditions: 1) CG over the OCA lid corner, 2) CG over the OCA lid/side edge, 3) shallow angle side drop and 4) bottom down drop. Although only a single "worst case" 30 foot drop is required by 10 CFR §71.73(c)(1), multiple tests were performed on a single CTU to ensure that the most vulnerable package features were subjected to "worst case" loads and deformations. The specific conditions selected for the NPC CTUs are summarized in Table 2.7-1.

2.7.1.3 Summary of Results from the Free Drop Tests

Successful HAC free drop testing of the CTUs indicates that the various NPC packaging design features are adequately designed to withstand the HAC 30 foot (9 meter) free drop event. The most important result of the testing program was the demonstrated ability of the NPC package to maintain its criticality safety integrity.

Following the fire test and disassembly of CTU-3, it was determined that the CG-over-lid corner drop resulted in excessive deformation of the closure lid of the ICCA immediately adjacent to the impact point. This deformation contributed to water in-leakage but did not result in loss of content. To rectify this condition, the corner of the OCA lid for the remaining NPC packaging (CTU-1) was reinforced with a 10-gauge (0.135 inch) thick stainless steel doubler plate, which is reflected in the drawings in Appendix 1.3.1, *Packaging General Arrangement Drawings*. This modified CTU was then subjected to the same free drop tests as CTU-3. Significant results of all of the free drop testing, including the CTU-1 tests, are as follows:

- There was no evidence of significant change in the center-to-center spacing between the ICCAs.
- There was no breach of the outer OCA stainless steel shell.
- The OCA lid remained attached to the OCA body.

Further details of the free drop test results are provided in Appendix 2.10.1, *Certification Tests*.

2.7.2 Crush

The crush test specified in 10 CFR §71.73(c)(2) is required only when the specimen has mass not greater than 1,100 pounds (500 kg), an overall density not greater than 62.4 lb/ft^3 (1,000 kg/m^3), and radioactive contents greater than 1,000 A_2, not as special form. The gross weight of the NPC package is greater than 1,100 pounds (500 kg). In addition, the A_2 limit for the enriched uranium oxide payload is unlimited. Therefore, the dynamic crush test of 10 CFR §71.73(c)(2) is not applicable to the NPC package.

2.7.3 Puncture

Subpart F of 10 CFR 71 requires performing a puncture test in accordance with the requirements of 10 CFR §71.71(c)(3). The puncture test involves a 40-inch (one meter) drop onto the upper end of a solid, vertical, cylindrical, mild steel bar mounting on an essentially unyielding, horizontal surface. The bar must be six inches (15 cm) in diameter, with the top surface horizontal and its edge rounded to a radius of not more than 1/4-inch (6 mm). The minimum length of the bar is to be eight inches (20 cm). The ability of the NPC package to adequately withstand this specified drop condition is demonstrated via testing of four full-scale, NPC CTUs.

2.7.3.1 Technical Basis for the Puncture Drop Tests

To properly select a worst case package orientation for the puncture drop event, items that could potentially compromise criticality control integrity of the NPC package must be clearly identified. For the NPC package design, the foremost item to be addressed is the integrity of the nine canisters and their neutron moderation and absorption materials (i.e., cadmium, polyethylene, and polyurethane foam).

The integrity of the canisters and the criticality control features may be compromised by two methods: 1) breach of the ICCA containment boundary, and/or 2) as a result of thermal degradation of the neutron moderation/control materials.

For the above reasons, testing must include orientations that attacks the OCA lid/body closure assembly, which may result in an excessive opening into the interior for a subsequent fire event, and/or the ICCAs, which contain the uranium oxide powder. Therefore, orientations that place the CG over and/or near the OCA closure were included in the test sequence. These orientations were also utilized for the HAC 30 foot (9 meter) free drops and hence, would expect to produce the worst case cumulative damage to the package. Orientations that directly attempted to attack the ICCAs (i.e., side and top), and to separate the OCA lid from the OCA body were also included in the test sequence.

2.7.3.2 Test Sequence for the Selected Tests

Based on the above general discussion, the CTUs were specifically tested for five HAC puncture drop conditions as part of the certification test program. Although only a single "worst case" puncture drop is required by 10 CFR §71.73(c)(3), multiple tests were performed to ensure that the most vulnerable package features were subjected to "worst case" loads and deformations. The specific conditions selected for the NPC Certification Test Units (CTUs) are summarized in Table 2.7-1.

2.7.3.3 Summary of Results from the Puncture Drop Tests

Successful HAC puncture drop testing of the CTUs indicates that the various NPC packaging design features are adequately designed to withstand the HAC puncture drop event. The most important result of the testing program was the demonstrated ability of the NPC to maintain its structural integrity. Significant results of the puncture drop testing are as follows:

- No evidence of movement occurred that would have significantly displaced the sealed ICCAs from their desired positions. For the modified OCA corner (CTU-1), there was no damage to the ICCA closure lid and gasket.
- There was no evidence of loss of contents from the ICCAs due to the puncture drop events.
- There was minimal evidence of deterioration of the polyethylene sheeting in a subsequent fire event.
- There was no evidence of deterioration of the cadmium sheeting in a subsequent fire event.

Further details of the free drop test results are provided in Appendix 2.10.1, *Certification Tests*.

2.7.4 Thermal

Subpart F of 10 CFR 71 requires performing a thermal test in accordance with the requirements of 10 CFR §71.71(c)(4). To demonstrate the performance capabilities of the NPC packaging when subjected to the HAC thermal test specified in 10 CFR §71.71(c)(4), three, full-scale CTUs were burned in three, separate, fully engulfing pool fires. Each test unit was subjected to a variety of 4-foot (1.2 meter) and 30-foot (9 meter) free drops and puncture tests prior to being burned, as discussed in Section 2.71, *Free Drop*, and Section 2.7.3, *Puncture*.

Type K thermocouples were installed on the exterior surface of the packaging (each side, top, and bottom) to monitor the package's temperature during the test. In addition, passive, non-reversible temperature indicating labels were installed on each ICCA closure lid, and on the inner surface of the outer stainless steel wrap.

Three CTUs (CTU-1, CTU-2 and CTU-3) were separately exposed to a minimum 1,475 °F (800 °C), 30-minute pool fire. As discussed in Appendix 2.10.1, *Certification Tests*, the packagings were orientated such that the most damaged area of the OCA was at the highest point of the package. This orientation would result in the possible formation of a chimney and thus, possibly result in maximum combustion of the interior foam and some degradation of the polyethylene sheeting.

Following the 30-minute fire, each CTU was allowed to cool naturally in air, without any active cooling systems.

2.7.4.1 Summary of Pressures and Temperatures

Since the OCA acts only as a confinement boundary, the ICCA is the only component that pressure build-up may occur. Therefore, the maximum internal pressure for the ICCAs is conservatively determined by assuming the air temperature with the ICCA is at the maximum average temperature of the simulated payload. The bulk average temperature of the simulated payload is determined by exposing the ICCA to a 30-minute transient analysis with the peak temperatures from the temperature indicating strips. From the fire testing, the peak temperatures for any of the ICCAs tested were 340 °F (171 °C) (lid), 330 °F (166 °C) (top of the outer stainless steel wrapper), and 340 °F (171 °C) (bottom of the outer stainless steel wrapper). These peak temperatures were located on CTU-2, ICCA No. II-3. These peak temperatures result in a maximum average payload temperature of 250 °F (121 °C). The ICCA pressure increase, ΔP_{ICCA}, using an initial temperature of -40 °F (-40 °C), is determined using ideal gas relationships:

Table 2.7-1 - Summary of NPC Certification Test Unit (CTU) Tests

Test No.	Test Description (Certification Test Unit No.)	Preconditioning Temperature (°F)	Test Unit Angular Orientation			Remarks
			X-Axis (0° = horizontal)	Vertical Axis (0° = upright)	Z-Axis (0° = horizontal)	
1	4 foot, CG over Lid Corner (CTU-1, CTU-3)	132	127°	45°	45°	NCT impact on most vulnerable location.
2	30 foot, CG over Lid Corner (CTU-1, CTU-3)	132	127°	45°	45°	Drop orientation on region to cause maximum deformation of most vulnerable location.
3	4 foot, CG over Lid/Side Edge (CTU-2)	132	135°	0°	0°	NCT impact on OCA closure lid/body interface.
4	30 foot, CG over Lid/Side Edge (CTU-2)	132	135°	0°	0°	Drop orientation on OCA closure lid/body interface.
5	4 foot, Shallow Angle Side Drop (CTU-4)	-40	97°	0°	0°	NCT impact to produce maximum secondary impact (slapdown).
6	30 foot, Shallow Angle Side Drop (CTU-4)	-40	97°	0°	0°	Drop orientation to produce maximum secondary impact (slapdown).
7	4 foot Bottom Drop (CTU-4)	-40	0°	0°	0°	NCT impact to produce maximum inertia loading.
8	30 foot Bottom Drop (CTU-4)	-40	0°	0°	0°	Drop orientation to produce maximum inertia loading.
9	Puncture drop, CG adjacent to Lid/Side Edge (CTU-2)	132	109°	0°	0°	Attempt to increase damage resulting from Test No. 4 free drop.
10	Puncture drop near Lid Reinforcement (CTU-1)	132	78°	45°	45°	Attempt to produce maximum damage to thermal protection design features of OCA lid.
11	Puncture drop below Lid/Body Interface (CTU-3)	-40	132°	0°	0°	Attempt to increase damage resulting from Test No. 2 free drop.
12	Puncture drop, CG over Side (CTU-4)	-40	90°	0°	0°	Attempt to produce maximum damage to thermal protection design features of OCA body.
13	Puncture drop, CG over Lid/Body Interface (CTU-4)	-40	107°	45°	45°	Attempt to produce maximum damage to thermal Protection design features of OCA lid/body interface.
14	Puncture, Oblique CG drop thru Lid (CTU-4)	-40	156°	0°	0°	Attempt to produce maximum damage to thermal Protection design features of OCA lid.
15	HAC Fire Test (CTU-1, CTU-2, CTU-3, or CTU-4)	132	90°	0°	0°	Most damaged CTU(s) to be selected.

$$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Rightarrow \frac{P_{-40^\circ F}}{T_{-40^\circ F}} = \frac{P_{250^\circ F}}{T_{250^\circ F}} \Rightarrow P_{250^\circ F} = P_{-40^\circ F}\left[\frac{T_{250^\circ F}}{T_{-40^\circ F}}\right]$$

$$P_{250^\circ F} = 14.7\left[\frac{250+460}{-40+460}\right] = 24.9 \text{ psia } (10.2 \text{ psig})$$

$$\Delta P_{ICCA} = 24.9 - 14.7 = 10.2 \text{ psig}$$

The partial pressure due to water vapor is based on the minimum payload cavity temperature, which is 202.7 °F (94.8 °F). At this temperature, the partial pressure of water vapor is equal to the saturation pressure at this temperature, or 12.2 psia. Thus, the maximum internal pressure increase for an ICCA due to HAC is:

$$\Delta P_{ICCA} = 24.9 + 12.2 = 37.1 \text{ psia } (22.4 \text{ psig})$$

2.7.4.2 Differential Thermal Expansion

Fire testing of three, full scale NPC packages indicate that the effects associated with differential thermal expansion of the various packaging components are negligible.

2.7.4.3 Stress Calculations

Successful fire testing of three, full scale NPC packages indicate that the stresses associated with differential thermal expansion of the various packaging components are negligible.

2.7.4.4 Comparison with Allowable Stresses

As discussed in Section 2.7.4.3, *Stress Calculations*, further evaluation of stresses associated with differential thermal expansion for the various NPC package components is not required.

Successful HAC thermal testing of the CTUs indicates that the various NPC packaging design features are adequately designed to withstand the HAC thermal test event. The most significant result of the testing program was the demonstrated ability of the NPC packaging to maintain its criticality control integrity, as demonstrated by post-test inspection of the moderator and poison materials, the remaining polyurethane foam, and the position of the ICCAs.

Further details of the thermal test results are provided in Appendix 2.10.1, *Certification Tests*.

2.7.5 Immersion – Fissile

Subpart F of 10 CFR 71 requires performing an immersion test for fissile material packages in accordance with the requirements of 10 CFR §71.73(c)(5). Although the criticality safety analysis in Chapter 6.0, *Criticality Safety Evaluation*, assumes optimum hydrogenous moderation of the contents, the CTU that was exposed to the thermal test was subjected to a water immersion test equal to a 3 foot (0.9 m) head of water for eight hours. Results are discussed in Sections 2.10.1.7.1.6 (CTU-1), 2.10.1.7.2.6 (CTU-2) and 2.10.1.7.3.6 (CTU-3). The NPC package satisfies the requirements of 10 §71.73(c)(5).

2.7.6 Immersion – All Packages

Subpart F of 10 CFR 71 requires performing an immersion test of an undamaged specimen in accordance with the requirements of 10 CFR §71.73(c)(6). Nine undamaged ICCAs were subjected to a water immersion test equal to a 50 foot (15 m) head of water eight hours. No in-leakage of water into the ICCAs was observed. Therefore, the NPC package satisfies the requirements of 10 §71.73(c)(6).

2.7.7 Summary of Damage

As discussed in the previous sections, the cumulative damaging effects of free drop, puncture drop, and thermal tests were satisfactorily withstood by the NPC packaging certification testing. Subsequent destructive examinations of the CTUs confirmed that integrity of the criticality control components was maintained throughout the test series. In addition, the center-to-center distance between ICCAs remained essentially unchanged from the pretest condition. Therefore, the requirements of 10 CFR §71.73 have been adequately satisfied.

2.8 Special Form Certification

The contents of the NPC package do not classify as special form material.

2.9 Fuel Rods

This section does not apply, since fuel rods are not shipped in the NPC package.

2.10 Appendix

2.10.1 Certification Tests

Presented herein are the results of Normal Conditions of Transport (NCT) and Hypothetical Accident Condition (HAC) tests that address free drop, puncture, and thermal test performance requirements of 10 CFR 71[1].

2.10.1.1 Introduction

The NPC packaging, when subjected to the sequence of HAC tests specified in 10 CFR §71.73, subsequent to the NCT tests specified in 10 CFR §71.71, is shown to meet the performance requirements specified in Subpart E of 10 CFR 71. As indicated in the introduction to Chapter 2.0, *Structural Evaluation*, the primary proof of performance for the HAC tests is via the use of full-scale testing. In particular, free drop, puncture, and thermal testing of NPC CTUs confirm that the packaging will retain its integrity following a worst case HAC sequence.

2.10.1.2 Summary

As seen in the figures presented in Section 2.10.1.7, *Test Results*, successful testing of the CTUs indicates that the various NPC packaging design features are adequately designed to withstand the HAC tests specified in 10 CFR §71.73. The most important result of the testing program was the demonstrated ability of the NPC packaging to maintain its criticality control safety integrity.

Significant results of the free drop tests are as follows:

- No evidence of structural failure of the OCA structure.
- No evidence of loss of any contents from the ICCAs.
- No evidence of significant change in the center-to-center spacing of the ICCAs from their pretest position.

Significant results of the puncture drop testing are as follows:

- No evidence of structural failure of the OCA structure.
- No evidence of loss of any contents from the ICCAs.
- No evidence of significant change in the center-to-center spacing of the ICCAs from their pretest position.

Significant results of the thermal testing are as follows:

- No evidence of damage to the cadmium sheet that would affect the neutronics of the package.
- No evidence of significant damage to the polyethylene sheeting that would affect the neutronics of the package.
- Gases formed by thermal degradation of the polyurethane foam were safely vented out of the OCA.

[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71) *Packaging and Transportation of Radioactive Material*, 1-1-98 Edition.

- The polyurethane foam was not completely consumed in the test, however, the remaining foam was treated conservatively in the criticality analysis.
- None of the components that are important to safety (i.e., cadmium and polyethylene sheeting, ICCAs) sustained any degradation due to excessive temperatures, which significantly affected the neutronic characteristics of the package.

Significant results regarding hydrogen stability in the foam:

- Polyurethane Foam: The average measured hydrogen content of the foam regions used to fabricate the test units was 6.48%. The average of 12 replicate samples taken from residual foam in the certification test units resulted in measured hydrogen content of 6.40% with the lowest observed value at 6.07% hydrogen. The 6.07% hydrogen value corresponded to a sample taken from what appeared to be one of the hottest areas observed. This criticality safety demonstration assumes a conservative 6% hydrogen content in the foam material.

Significant results regarding hydrogen stability in the polyethylene:

- Polyethylene: The average measured value of the hydrogen content in the polyethylene material use to fabricate the certification test units was 14.23%. The average measured value from four post-test replicate samples strategically withdrawn from what was believed to be the hottest regions observed was 14.09% with the lowest observed value of 14.01%. The average of 8 eight additional replicate samples taken from various locations showing some indications of heating in the moderator averaged 14.20% with the lowest observed value of 14.09%. The measured values show little change in the hydrogen content in the polyethylene region before and after the test even in the hottest regions. This criticality safety demonstration assumes a conservative 14.00% hydrogen content in the polyethylene wrap region surrounding each ICCA.

Significant results regarding the top and bottom polyethylene wrap gaps

- The cumulative gap at the top plus bottom of the polyethylene wrap was measured for all ICCAs in CTU-1 and CTU-2. The maximum observed total gap was 0.69" (0.40" +0.29" = 0.69").

2.10.1.3 Test Facilities

Drop testing of the NPC CTU packages was performed at Southwest Research Institute's (SwRI) San Antonio, TX facility. The drop testing was performed using a horizontal reinforced concrete slab, which is approximately 10-feet × 10 feet × 6 feet. A 1-inch × 96-inch × 96-inch steel plate is attached to the concrete slab utilizing J-bolts that are embedded into the concrete. The estimated mass of the drop pad is 95,000 lbs_m, which is more than 33 times the mass of the NPC package. Based on these characteristics, the drop pad satisfies the requirement of 10 CFR §71.71 and 10 CFR §71.73 for an essentially unyielding, horizontal surface.

Two puncture bars for the puncture tests were utilized: a 6-inch diameter × 17-inch long solid bar and a 6-inch diameter × 50-inch long. Both bars were orthogonally socket welded through a 2-inch × 18-inch × 18-inch steel plate. The top circumferential edge of the bar has a 1/4-inch radius. The free length of the bars are 15-inches and 48-inches (i.e., length minus the 2-inch thick plate), thus ensuring an adequate length to potentially cause maximum damage to the CTU as required by 10 CFR §71.73(c)(3). Following the 30 foot free drop tests, the 2-inch thick plate of the puncture bar assembly is then bolted (using 8 bolts) to the 1-inch thick plate on the drop pad. This attachment ensures that the puncture bar is restrained for the puncture drop tests.

Fire testing of the NPC CTU packages was performed at Southwest Research Institute's (SwRI) D'Hanis, TX facility. The open pool fire facility is a fixed sized pool, measuring nominally 25 feet by 25 feet. During fire testing, thermocouples are strategically placed to measure and record fire temperatures as well as the surface temperature of the package being tested. For the fire testing of CTU-1, added thermocouples and calorimeters were added to the test setup to measure and record fire temperatures and the heat flux respectively. No wind screens are utilized at the D'Hanis, TX facility. Agricultural diesel fuel was utilized as the fuel source for fire testing CTU-2 and CTU-3. For the CTU-1 fire testing, Jet-A fuel was utilized. The SwRI fire pit is capable of temperatures up to 2,300 °F (1,260 °C).

2.10.1.4 Certification Test Unit Description

The NPC packaging consists of a stainless steel Outer Confinement Assembly (OCA) lid and body, each primarily comprised of an outer stainless steel sheet structure, a layer of ceramic fiber board, and a layer of rigid polyurethane foam. The polyurethane foam provides thermal insulation as well as energy absorption for the normal and hypothetical accident conditions of transport. Nine sealed, individual Inner Containment Canister Assemblies (ICCAs), which provide containment of the uranium oxide powder, are located within the interior of the OCA. The ICCAs are positioned such that their center-to-center spacing is fixed.

Prior to free drop, puncture, and thermal testing, the nine ICCAs of each CTU were loaded with lose sand and bagged lead shot to simulate the 132 pounds (60 kg) of uranium oxide powder. The actual gross weights of the CTUs were: 2,788 pounds (CTU-1), 2,758 pounds (CTU-2), 2,752 pounds (CTU-3), and 2,754 pounds (CTU-4). CTU-1 represents the final design. Except for the OCA lid corner reinforcement , all other CTUs were identical to the package design depicted in Appendix 1.3.1, *Packaging General Arrangement Drawings*.

The actual mechanical and thermal properties of the polyurethane foam of the CTUs satisfied the requirements of §8.1.4.1, *Polyurethane Foam*. The primary polyurethane foam physical property of interest for the HAC drop and puncture tests is its compressive strength. For the HAC thermal event, the primary polyurethane foam physical properties of interest are its thermal conductivity and specific heat.

The compressive strength of the foam utilized in the CTUs is shown relative to the specified maximum and minimum compressive strengths for the 11 lbs/ft^3 and 15 lbs/ft^3 foam in Figure 2.10.1-1 through Figure 2.10.1-4. These two foam densities act as the primary impact absorbing foam for the NPC package. As shown by these two figures, the as-poured polyurethane foam compressive strengths of the CTUs were closer to the minimum specified compressive strength over the compressive strain range of interest. Since the survival of ICCAs to withstand the HAC thermal event is highly dependent on the OCA structure, deformation of this structure is more critical to the NPC package. Therefore, the minimum foam compressive strength bounds the maximum compressive polyurethane foam condition.

The actual, minimum, and maximum thermal conductivities and specific heat of the polyurethane foam used in the CTUs are tabulated in Table 2.10.1-1. As illustrated by these values, the thermal conductivities of the polyurethane foam were closer to the nominal or minimum values. However, the actual specific heat was equal to the nominal value.

Table 2.10.1-1 - CTU Polyurethane Foam Thermal Conductivities and Specific Heat

Foam Density (lbs/ft³)	Thermal Conductivity [(BTU-in)/hr-ft²- °F)]		Specific Heat (BTU/Lb$_m$-°F)	
	Specified Range	Actual	Specified Range	Actual
7	0.200 – 0.300	0.201	0.38 – 0.56	0.468
11	0.231 – 0.347	0.249		
15	0.262 – 0.392	0.298		
40	0.448 – 0.672	0.603		

The actual thermal properties of the ceramic fiber board of the CTUs satisfied the requirements of §8.1.4.2, *Ceramic Fiber Board and Ceramic Fiber Braided Rope*. The actual density and thermal conductivity of the material used in the CTUs are tabulated in Table 2.10.1-2.

Table 2.10.1-2 - CTU Ceramic Fiber Board/Braided Rope Densities & Thermal Conductivity

Property	Ceramic Fiber Board	
	Specification (Range)	Actual (Min – Avg – Max)
Density (lbs/ft³)	14.0 – 21.0	17.0 – 17.2 – 17.6
Thermal Conductivity [(BTU-in/hr-ft²) - °F]		
@ 600 °F	0.50 – 0.74	0.546 – 0.55 – 0.555
@ 1000 °F	0.68 – 1.02	0.795 – 0.831 – 0.858

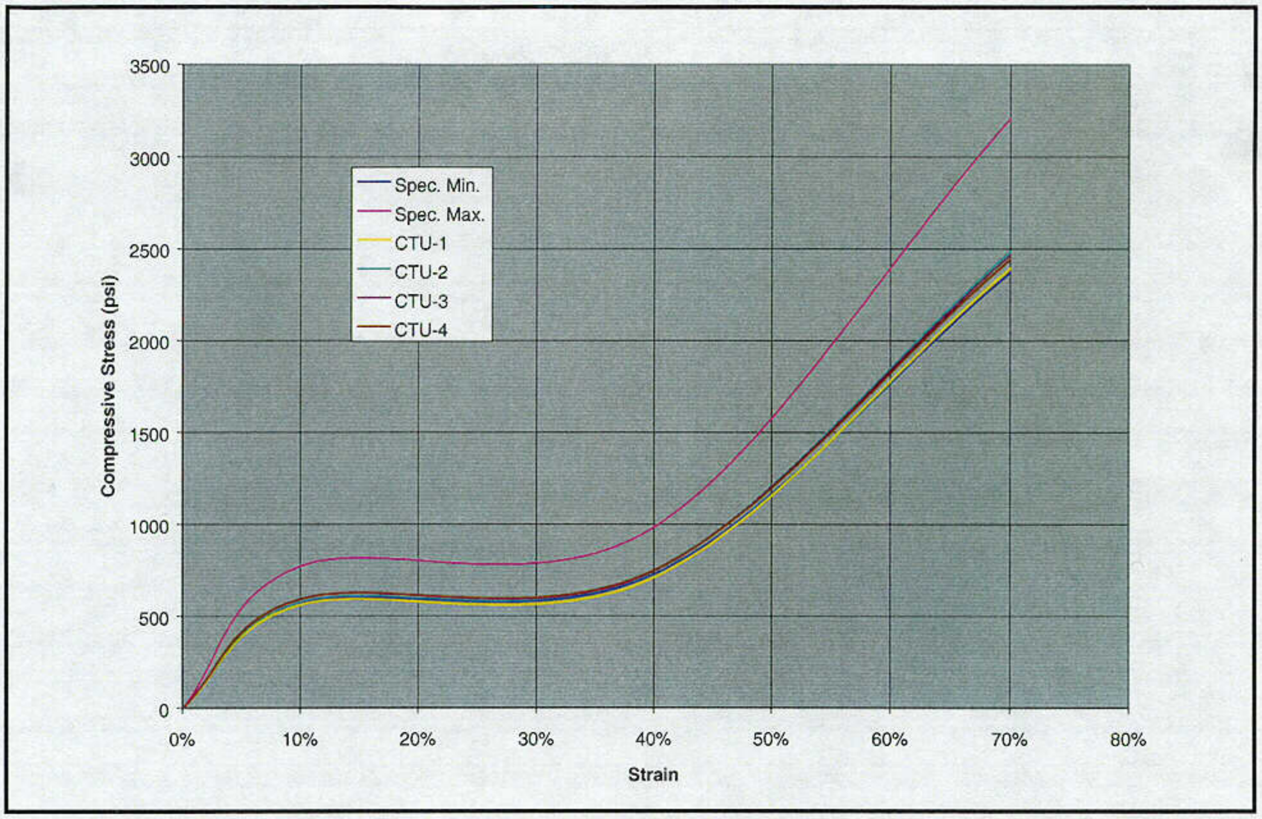


Figure 2.10.1-1 - OCA Lid Perpendicular-to-Foam Rise (15 Lbs./Ft^3)

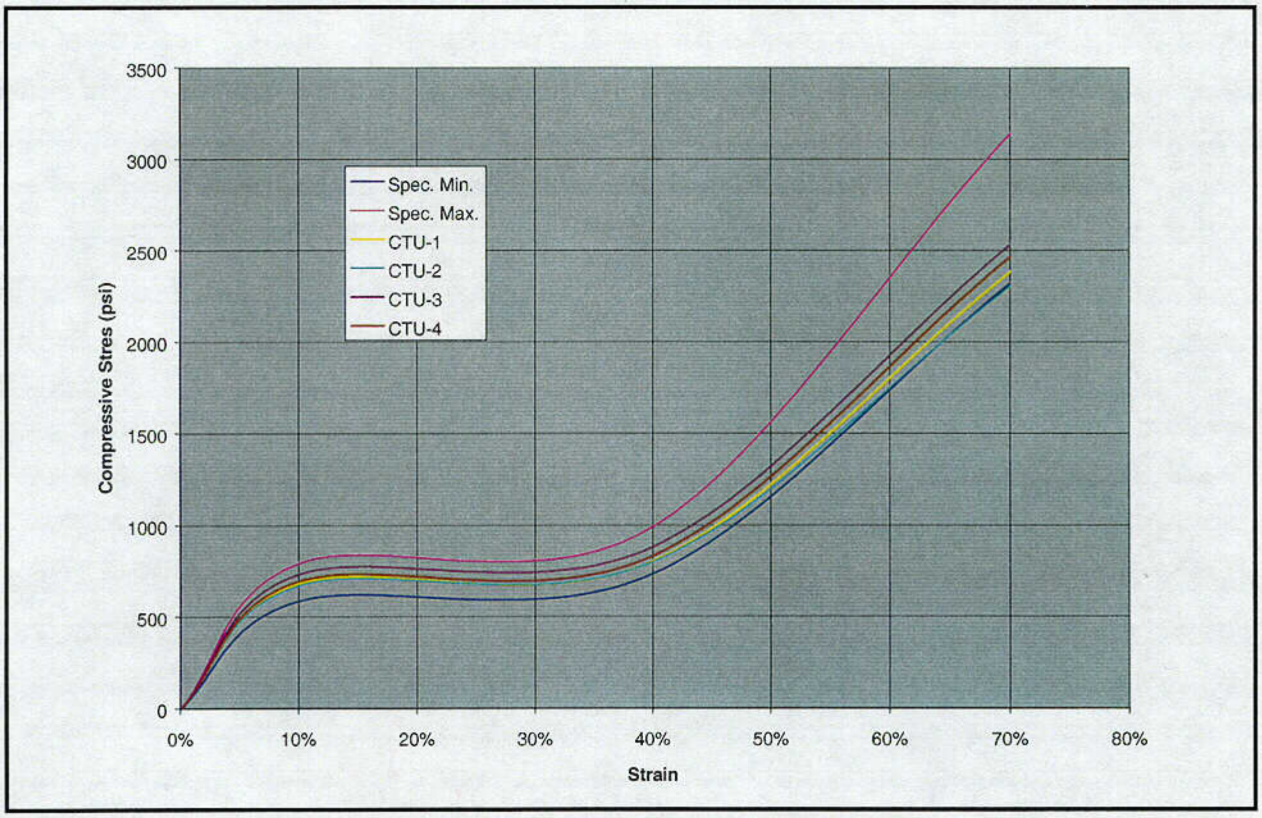


Figure 2.10.1-2 - OCA Lid Parallel-to-Foam Rise (15 Lbs./Ft^3)

C01

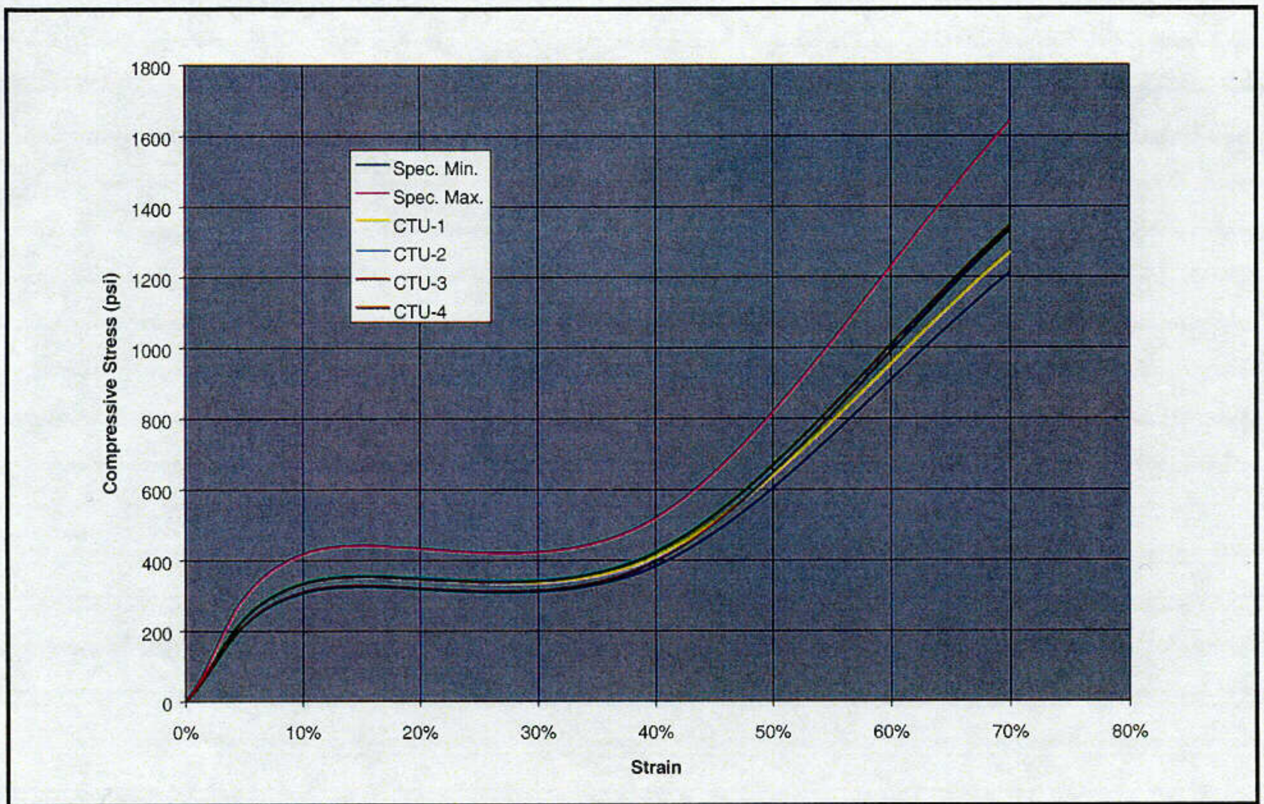


Figure 2.10.1-3 - OCA Body Perpendicular-to-Foam Rise (11 Lbs./Ft^3)

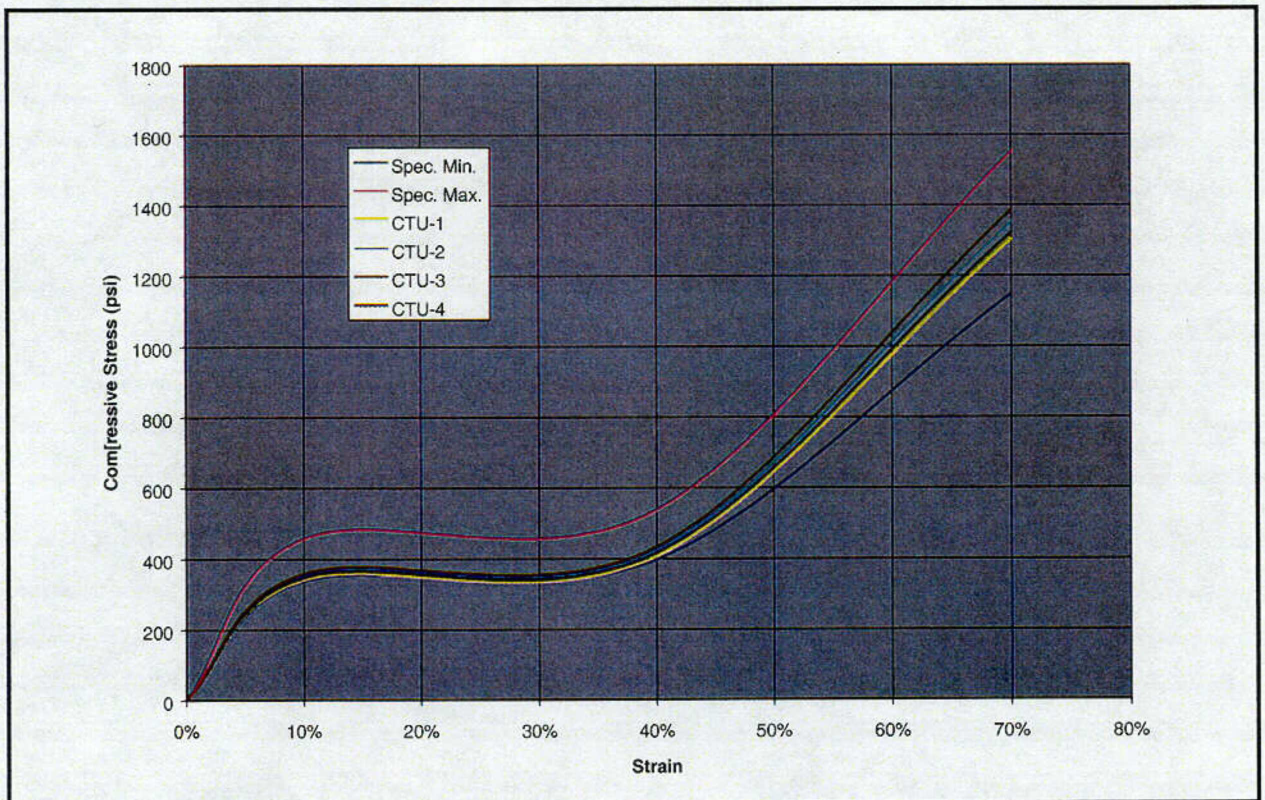


Figure 2.10.1-4 - OCA Body Parallel-to-Foam Rise (11 Lbs./Ft^3)

2.10.1.5 Technical Basis for Tests

For the NPC package design to fail, the integrity of the nine canisters and their neutron moderation and absorption materials (i.e., cadmium, polyethylene, and polyurethane foam) would need to sustain significant damage so the neutronic characteristics of the package were no longer functional. The integrity of the canisters and the criticality control features may be compromised by two methods:

1. Breach of the ICCA containment boundary.
2. Thermal degradation of the neutron moderation/control materials.

For either of these potential conditions to occur, the NPC package would need to sustain significant damage due to the normal and hypothetical accident condition free drops, and then sustain further damage due to the 1-meter (40-inch) drop onto a 6-inch diameter vertical steel bar. Therefore, the primary objective of the 4 foot (1.2-meter) normal condition and 30 foot (9-meter) Hypothetical Accident Condition (HAC) free drops is to severely damage the OCA or cause significant changes in the center-to-center spacing of the ICCAs.

For the above reasons, testing included orientations that attacked the OCA lid/body closure assembly, which were postulated to result in an excessive opening into the interior for a subsequent fire event, and/or the ICCAs, which contain the uranium oxide powder. Therefore, orientations that place the CG over and/or near the OCA closure were included in the test sequence. These orientations were also utilized for the HAC 30 foot (9 meter) free drops and hence, would expect to produce the worst case cumulative damage to the package. Orientations that directly attempted to attack the ICCAs (i.e., side and top), and to separate the OCA lid from the OCA body were also included in the test sequence.

The following sections provide the technical basis for the chosen test orientations and sequences for the NPC CTUs as presented in Appendix 2.10.1.6, *Test Sequence for Selected Free Drop, Puncture Drop, and Thermal Tests.*

2.10.1.5.1 Temperature

Both elevated and sub-zero temperature preconditioning of the CTUs were utilized for NPC certification testing. The results of the NPC package testing demonstrated that extreme temperatures had no effect on the shielding integrity of the NPC packaging. In addition, the austenitic stainless steel material is not susceptible to brittle fracture, as delineated in Section 2.1.2.2.1, *Brittle Fracture.*

2.10.1.5.2 Free Drop Tests

The NPC package is qualified primarily by full scale testing, with acceptance criterion being the ability to demonstrate criticality control integrity. Per 10 CFR §71.73(c)(1), the package is required to "strike an essentially unyielding surface *in a position for which maximum damage is expected.*" Therefore, for determining the drop orientations that satisfy the regulatory "maximum damage" requirement, attention is focused on the issue of criticality control integrity since the NPC is a type A fissile materials package.

To maximize the damage to the NPC package and potentially opening the OCA with subsequent exposure of the ICCAs to the subsequent hypothetical accident condition thermal event, four orientations were selected for free drop testing. Excessive exposure of the ICCAs to the hypothetical accident condition thermal event has been shown to be a possible failure of the criticality control components (i.e., polyethylene sheeting, polyurethane foam).

1. CG-Over-OCA Lid Corner: This orientation targets the joint between the OCA lid and OCA body. Should this impact be sufficiently severe, the OCA lid and body may potentially separate and expose the ICCAs to the subsequent hypothetical accident condition thermal event.
2. Lid/Side Edge: This orientation again targets the OCA closure as well as the spacing of the ICCAs. Should this impact be sufficiently severe, the OCA lid and body may potentially separate and expose the ICCAs to the subsequent hypothetical accident condition thermal event. In addition, the impact may be sufficiently severe to potentially affect the center-to-center spacing of the ICCAs. Excessive movement of the ICCAs has been shown to be an unsafe condition for the function of the criticality control components.
3. Shallow Angle Side: This orientation again targets the OCA closure, but at a shallow angle. The intent of this orientation is to attempt to apply the maximum shearing force on the OCA closure bolts. Should this impact be sufficiently severe, the joint between the OCA lid and body may potentially separate and expose the ICCAs to the subsequent hypothetical accident condition thermal event.
4. Bottom: This orientation will result in maximum impact loads to the OCA structure. Should this impact be sufficiently severe, the OCA structural may potentially fail and exposed the ICCAs to the subsequent hypothetical accident condition thermal event.

2.10.1.5.3 Puncture Drop Tests

10 CFR §71.73(c)(3) requires a free drop of the specimen through a distance of 40-inches (1 meter) onto a puncture bar "in a position for which maximum damage is expected." As in Section 2.10.1.5.2, *Free Drop Tests*, the "maximum damage" criterion is evaluated primarily in terms of loss of criticality control integrity. Loss of criticality control integrity could occur indirectly by damage to the OCA structural that would result in exposure of the ICCAs to the subsequent hypothetical accident condition thermal event. Excessive exposure of the ICCAs to the hypothetical accident condition thermal event has been shown to be a possible failure of the criticality control components.

The selected puncture orientations were primarily based on accumulating the damage from the free drop tests, as described in Section 2.10.1.5.2, *Free Drop Tests*. Additional orientations were added to ensure a "worst case" puncture test.

To maximize the damage to the NPC package and potentially opening the OCA with subsequent exposure of the ICCAs to the subsequent hypothetical accident condition thermal event, five orientations were selected for puncture drop testing. Excessive exposure of the ICCAs to the hypothetical accident condition thermal event has been shown to be a possible failure of the thermally sensitive criticality control components (i.e., polyethylene sheeting, polyurethane foam).

1. CG Adjacent to OCA Lid/Side Edge: This orientation targets the joint between the OCA lid and OCA body. Should this impact be sufficiently severe, increased separation between the OCA lid/body may potentially result and expose the ICCAs to the subsequent hypothetical accident condition thermal event.

2. Puncture Below the OCA Lid/Body: This orientation targets the OCA lid. Should this impact be sufficiently severe, increased separation between the OCA lid/body may potentially result and expose the ICCAs to the subsequent hypothetical accident condition thermal event.
3. CG-Over-OCA Side: This orientation targets the wall of the OCA side. Should this impact result in penetration of the OCA shell, excessive exposure of the polyurethane foam to the subsequent hypothetical accident condition thermal event would occur. Excessive loss of the polyurethane foam would result in severe thermal degradation of the thermally sensitive criticality control components (i.e., polyethylene sheeting, polyurethane foam).
4. CG-Over-OCA Lid/Body Interface: This orientation again targets the joint between the OCA lid and OCA body. Should this impact be sufficiently severe, increased separation between the OCA lid/body may potentially result and expose the ICCAs to the subsequent hypothetical accident condition thermal event.
5. CG Through the OCA Lid: This oblique orientation targets the wall of the OCA lid. Should this impact result in penetration of the shell of the OCA lid, excessive exposure of the polyurethane foam to the subsequent hypothetical accident condition thermal event would occur. Penetration of the OCA lid shell may also result in excessive exposure of the ICCA closure lid to the subsequent hypothetical accident condition thermal event.

Should a condition surface during the certification testing that results in unanticipated damage, then a new evaluation and assessment to determine most-damaging orientation(s) for the puncture drop test will be performed.

2.10.1.5.4 Fire Test

At the conclusion of the free and puncture drop testing, the NPC packaging will be subjected to a fully engulfing pool fire in accordance with 10 CFR §71.73(c)(4). The packages will be oriented in the flames such that the worst case will be utilized for the test. In particular, the test orientation will ensure that the possible formation of chimneys will be maximized. The packages will be minimally supported during the fire test to not impede heat flow into the test article.

Because several of the NPC CTUs experienced moderate damage during the free drop testing, thermal tests of CTU-1, CTU-2, and CTU-3 were performed at the thermal test facility described in Section 2.10.1.3, *Test Facilities*.

2.10.1.6 Test Sequence for Selected Free Drop, Puncture Drop and Thermal Tests

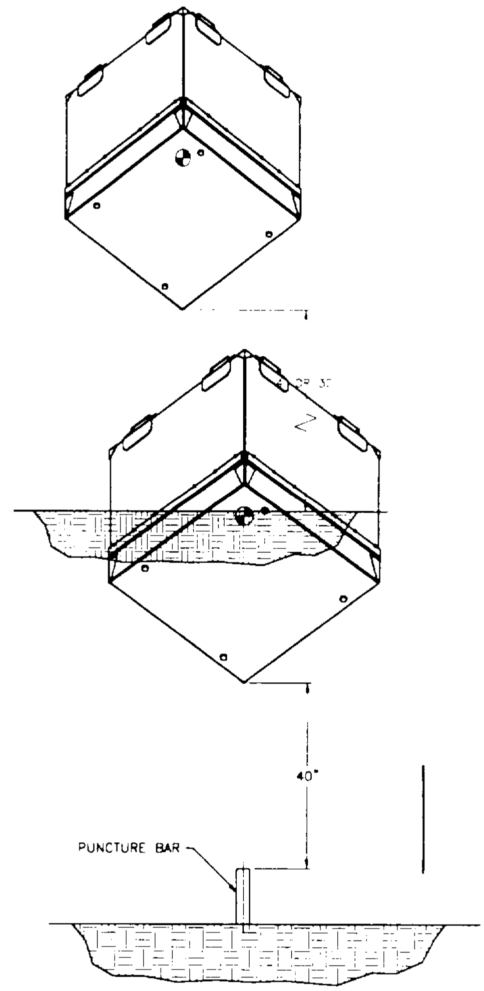
The following sections establish the selected free drop, puncture drop, and thermal test sequence for the NPC CTUs based on the discussions provided in Section 2.10.1.5, *Technical Basis for Tests*. The test sequences are summarized in Table 2.10.1-6 and illustrated in Figures 2.10.1-5, 2.10.1-6, 2.10.1-7, and 2.10.1-8.

2.10.1.6.1 Certification Test Unit No. 1 (CTU-1)

In the test on CTU-3, excessive deformation on the corner was determined to be a problem. To alleviate the excessive deformation problem, the corner of the CTU-1 OCA lid was reinforced with a 10-gauge (0.135 inch) doubler plate. CTU-1 was a re-test of the CTU-3 test sequence (CTU-3 test results were not used because it does not represent the final design configuration). The reason for the re-test was that the CG-over-Lid Corner orientation resulted in excessive deformation of the closure lid of the ICCA located adjacent to the impact point.

Free Drop No. 1 is a NCT free drop from a height of four feet, impacting the corner of the OCA lid. The four foot drop height is based on the requirements of 10 CFR §71.71(c)(7) for a package weight not exceeding 11,000 pounds. The purpose of this test was to cause maximum damage to the most vulnerable feature (OCA Lid/Body Interface) of the packaging.

Free Drop No. 2 is a HAC free drop from a height of 30 feet, impacting the corner of the OCA lid, which is the same impact point as the NCT Free Drop No. 1. In this way, NCT and HAC free drop damage is cumulative. The 30 foot drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test is to cause maximum damage to the most vulnerable feature (OCA Lid/Body interface) of the packaging.

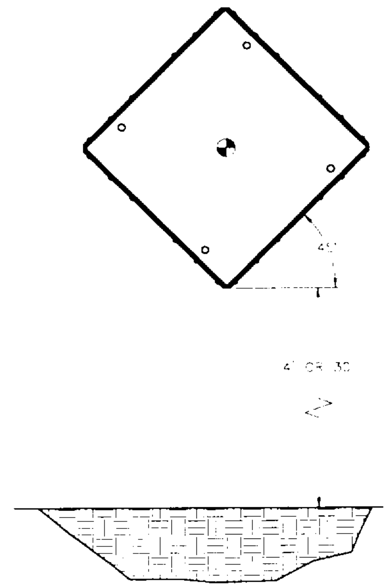


Puncture Drop No. 10 impacts adjacent to the damage created by Free Drop Tests 1 and 2, on the corner of the OCA lid. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 10 is to cause maximum damage to the most vulnerable feature (OCA Lid/Body interface) of the packaging.

Fire Test No. 15 is performed by orientating the cumulative damage from Free Drop Tests 1 and 2, and Puncture Drop Test 10. Jet A fuel was utilized for the pool fire test. Orientation of the packaging is based on the observed damaged.

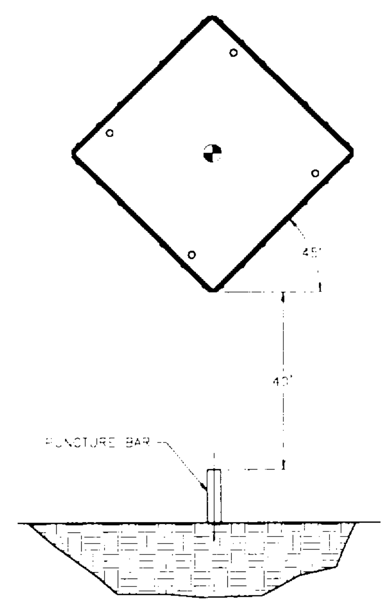
2.10.1.6.2 Certification Test Unit No. 2 (CTU-2)

Free Drop No. 3 is a NCT free drop from a height of four feet, impacting the side edge of the OCA. The four foot drop height is based on the requirements of 10 CFR §71.71(c)(7) for a package weight not exceeding 11,000 pounds. The purpose of this test was to cause maximum damage to the OCA Lid/Body.



Free Drop No. 4 is a HAC free drop from a height of 30 feet, impacting the side edge of the OCA, which is the same impact point as the NCT Free Drop No. 3. In this way, NCT and HAC free drop damage is cumulative. The 30 foot drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test is to cause maximum damage to the OCA Lid/Body.

Puncture Drop No. 9 impacts the damage created by Free Drop Tests 3 and 4, near the OCA Lid/Body interface. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 9 is to cause maximum damage to the most vulnerable feature (OCA Lid/Body interface) of the packaging.

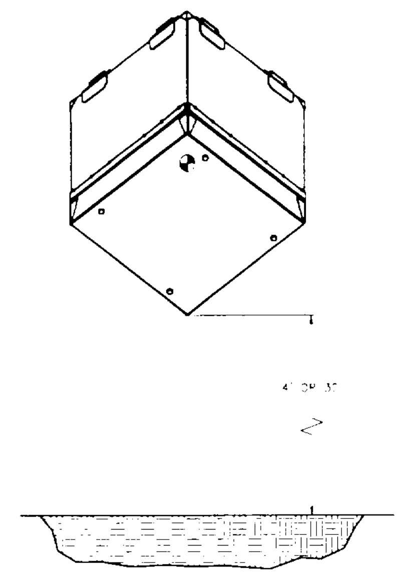


Fire Test No. 15 is performed by orientating the cumulative damage from Free Drop Tests 3 and 4, and Puncture Drop Test 9. Agricultural diesel fuel was utilized for the pool fire test. Orientation of the packaging is based on the observed damaged.

2.10.1.6.3 Certification Test Unit No. 3 (CTU-3)

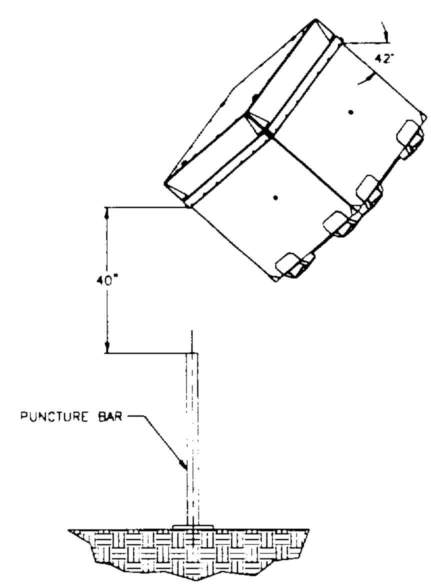
NOTE: The results from the tests on CTU-3 were not used because the lid corner damage produced unacceptable results. CTU-1 was modified to the final design configuration and tested to the same conditions as CTU-3. CTU-1 test results were used as the basis to demonstrate compliance to 10 CFR 71 requirements. for certification.

Free Drop No. 1 is a NCT free drop from a height of four feet, impacting the corner of the OCA lid. The four foot drop height is based on the requirements of 10 CFR §71.71(c)(7) for a package weight not exceeding 11,000 pounds. The purpose of this test was to cause maximum damage to the most vulnerable feature (OCA Lid/Body Interface) of the packaging.



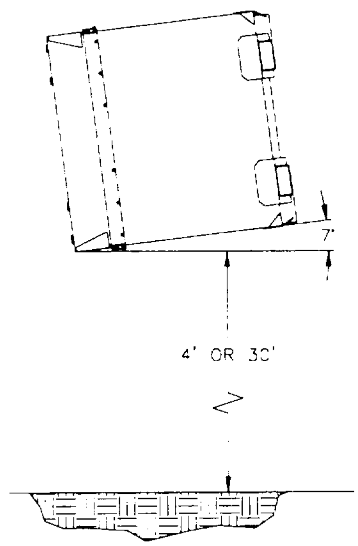
Free Drop No. 2 is a HAC free drop from a height of 30 feet, impacting the corner of the OCA lid, which is the same impact point as the NCT Free Drop No. 1. In this way, NCT and HAC free drop damage is cumulative. The 30 foot drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test is to cause maximum damage to the most vulnerable feature (OCA Lid/Body interface) of the packaging.

Puncture Drop No. 11 impacts adjacent to the damage created by Free Drop Tests 1 and 2, on the corner of the OCA. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 11 is to cause maximum damage to the most vulnerable feature (OCA Lid/Body interface) of the packaging.



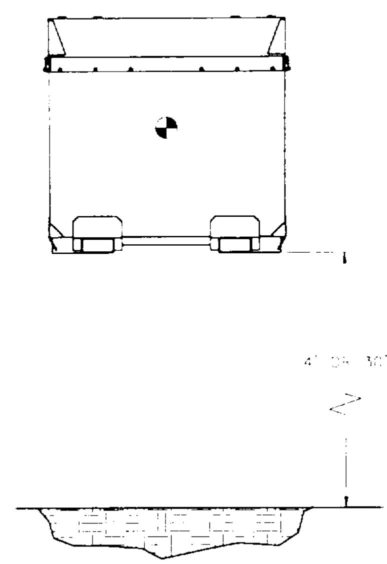
Fire Test No. 15 is performed by orientating the cumulative damage from Free Drop Tests 1 and 2, and Puncture Drop Test 11. Agricultural diesel fuel was utilized for the pool fire test. Orientation of the packaging is based on the observed damaged.

2.10.1.6.4 Certification Test Unit No. 4 (CTU-4)



Free Drop No. 5 is a NCT free drop from a height of four feet, first impacting the corner of the OCA lid, followed by a slapdown of the OCA body. The four foot drop height is based on the requirements of 10 CFR §71.71(c)(7) for a package weight not exceeding 11,000 pounds. The purpose of this test was to cause maximum damage to the most vulnerable feature (OCA Lid/Body Interface) of the packaging.

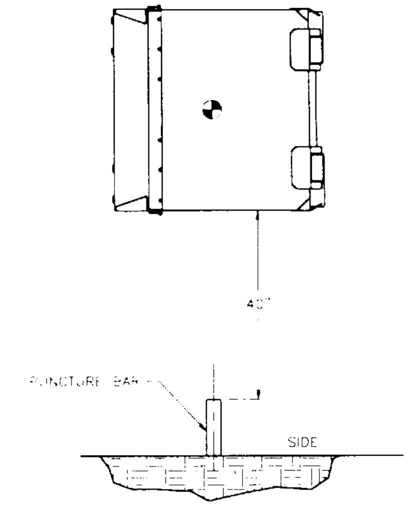
Free Drop No. 6 is a HAC free drop from a height of 30 feet, first impacting the corner of the OCA lid, followed by a slapdown of the OCA body. This test is the same impact point as the NCT Free Drop No. 5. In this way, NCT and HAC free drop damage is cumulative. The 30 foot drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test is to cause maximum damage to the most vulnerable feature (OCA Lid/Body interface) of the packaging.



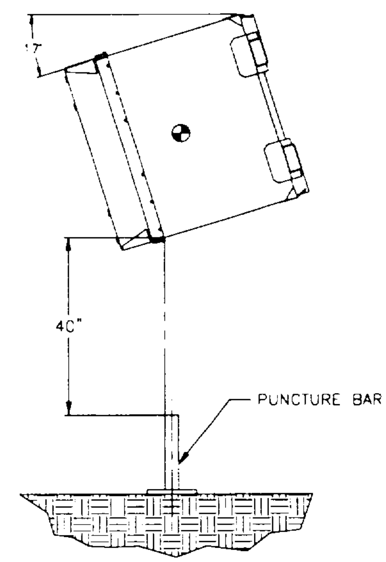
Free Drop No. 7 is a NCT free drop from a height of four feet, impacting the bottom of the OCA. The four foot drop height is based on the requirements of 10 CFR §71.71(c)(7) for a package weight not exceeding 11,000 pounds. The purpose of this test is to produce the maximum inertia loading on the packaging.

Free Drop No. 8 is a HAC free drop from a height of 30 feet, impacting the bottom of the OCA. The test is the same impact point as NCT Free Drop No. 7. In this way, NCT and HAC free drop damage is cumulative. The 30 foot drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose of this test is to cause the maximum inertia loading on the packaging.

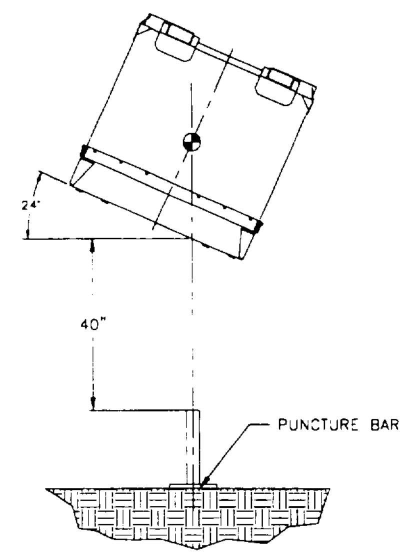
Puncture Drop No. 12 directly impacts the side of the OCA. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 12 is to cause maximum damage to the thermal protection design features of the OCA body.



Puncture Drop No. 13 directly impacts the area adjacent to the OCA Lid/Body interface. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 13 is to cause maximum damage to the most vulnerable feature (OCA Lid/Body interface) of the packaging.



Puncture Drop No. 14 is an oblique drop that directly impacts the OCA lid. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 14 is to cause maximum damage to the thermal protection design features of the OCA Lid.



2.10.1.7 Test Results

The following sections report the results of free drop, puncture drop, and thermal tests following the sequence provided in Section 2.10.1.6, *Test Sequence for Selected Free Drop, Puncture Drop and Thermal Tests*. Results are summarized in Table 2.10.1-7 (refer also to Figure 2.10.1-5, Figure 2.10.1-6, Figure 2.10.1-7, and Figure 2.10.1-8). All figures depict the final design configuration represented by CTU-1.

Figure 2.10.1-9 through Figure 2.10.1-98 sequentially photo-document the certification testing process for the NPC CTUs.

2.10.1.7.1 Certification Test Unit No. 1 (CTU-1)

2.10.1.7.1.1 CTU-1 Free Drop Test No. 1

Free Drop No. 1 is a NCT free drop from a height of four feet, impacting the corner of the OCA lid. As shown in Figure 2.10.1-9, the CTU was oriented such that the CG was located over the OCA lid corner (x-axis angle 127°, vertical axis angle 45°, and z-axis angle 45°). The following list summarizes the test parameters:

- verified x-axis angle as 127° ±1°
- verified vertical axis angle as 45° ±1°
- verified z-axis angle as 45° ±1°
- verified drop height as 4 feet, +3/-0 inches (actual drop height 4 feet)
- measured ambient temperature as 73 °F
- conducted test at 9:35 a.m. on Wednesday, 3/1/00

The packaging rebounded upon impact. The deformation of the upper corner of the side of the OCA lid was approximately 1-inch, with a flat width of approximately 2 1/2-inches . The impact damage is shown in Figure 2.10.1-10.

2.10.1.7.1.2 CTU-1 Free Drop Test No. 2

Free Drop No. 2 is a HAC free drop from a height of 30 feet, impacting the upper corner of the OCA closure lid. The impact point is the same as Free Drop Test No. 1. As shown in Figure 2.10.1-11, the CTU was oriented such that the CG was located over the OCA lid corner (x-axis angle 127°, vertical axis angle 45°, and z-axis angle 45°). The following list summarizes the test parameters:

- verified x-axis angle as 127° ±1°
- verified vertical axis angle as 45° ±1°
- verified z-axis angle as 45° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient temperature as 70 °F
- conducted test at 9:50 a.m. on Wednesday, 3/1/00

The packaging rebounded upon impact. The impact resulted in severe buckling and folding of the OCA lid corner. The area of the deformation was primarily limited to the lid reinforcement area, with a resultant width and depth of approximately 19-inches and 6-inches respectively. The stainless steel sheet of the OCA lid beyond the lid reinforcement was deformed approximately 3-inches above the reinforcement. The two OCA closure strips near the impact point were bent inward approximately 3-inches. A small tear of the OCA lid was noted adjacent to one of the reinforcements for OCA closure socket head cap screws. There was no failure of any OCA fastener. The impact damage is shown in Figures 2.10.1-12, 2.10.1-13, 2.10.1-14 and 2.10.1-15.

2.10.1.7.1.3 CTU-1 Puncture Drop Test No. 10

Due to the observed deformations, the orientation for Puncture Drop No. 10 was revised so that the bar impacted near the damaged created by Free Drop Tests 1 and 2, near the transition between the reinforced and non-reinforced section of the OCA lid corner. The CTU was oriented so that the impact point of the puncture bar would occur near the transition (x-axis angle 78°, vertical axis angle 45°, and z-axis angle 45°). This orientation was attempting to potentially tear the OCA lid, which would provide direct access of the fire onto the ICCAs . The following list summarizes the test parameters:

- verified x-axis angle as 78° ±1°
- verified vertical axis angle as 45° ±1°
- verified z-axis angle as 45° ±1°
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 75 °F
- conducted test at 11:14 a.m. on Wednesday, 3/1/00

The packaging rotated off the puncture bar and struck the opposite corner of the OCA lid. The impact point was onto the non-reinforced "bulge" on the OCA lid that resulted from Free Drop Tests 1 and 2. The impact resulted in a crescent shaped indentation into the OCA lid, but no thru-wall perforation occurred. The impact damage is shown in Figure 2.10.1-16.

2.10.1.7.1.4 CTU-1 Fire Test

Since the maximum damage for the NPC CTU-3 previous test resulted in maximum damage to the corner ICCA, Fire Test No. 15 was performed on NPC CTU-1 to demonstrate compliance with 10 CFR 71, and followed the guidelines set forth in IAEA Safety Series No. 37. The following list summarizes the test parameters:

- NPC CTU-1 was orientated on its side (x-axis angle 90°, vertical axis angle 0°, and z-axis angle 0°), with the damaged corner located at the top. The CTU was oriented to provide as much surface area of the package as possible for heat transfer during the test (refer to Figure 2.10.1-17).
- Consistent with Paragraph A-628.4 of IAEA Safety Series No. 37, NPC CTU-1 was installed onto an insulated test stand at an elevation to place the lowest part of the package one meter above the fuel surface.
- Consistent with 10 CFR §71.73(c)(4) and Paragraph A-628.4 of IAEA Safety Series No. 37, requiring the test pool to extend 1 to 3 meters beyond the package edges, the test pool size extended approximately 3 meters beyond each side of the CTU.

- Consistent with Paragraph A-628.5 of IAEA Safety Series No. 37, requiring wind speeds not to exceed 2.5 m/s (4.5 mph), the average wind speed during the fire test duration was 1.8 m/s (4.0 mph).
- Consistent with Paragraph A-628.6 and A-628.8 of IAEA Safety Series No. 37, JP4 fuel was used for the fire test, and the amount of fuel was controlled to ensure the fire duration exceeded 30 minutes. The fuel was floated on a pool of water to ensure even distribution during burning. The fire test was approximately 32 minutes, and burning continued after the end of the fire.
- Consistent with Paragraph A-628.7 and A-628.9 of IAEA Safety Series No. 37, the test pool was instrumented to measure fire temperatures at various locations around the CTU. Temperatures were monitored before, during, and following the fire test until magnitudes were stabilized. The average measured flame temperature was 1,809 °F (987 °C).
- Commenced fire testing at 5:20 p.m. on Thursday, 3/2/00. The ambient temperature was 80 °F at the start of the fire.

Active instrumentation was utilized before, during, and after the fire test. Type K thermocouples were attached to each exterior surface (sides, top and bottom) of NPC CTU. These thermocouples measured the surface temperature of the test unit. In addition, passive, non-reversible temperature indicating labels were installed at several locations on the ICCAs: two orthogonal directions on the ICCA closure lid, and near the top and bottom of the stainless steel wrapper. These labels were used to record the temperatures of the criticality control materials of the ICCAs. Each set of temperature indicating labels recorded temperatures in 30 steps from 190 °F to 500 °F.

As stated in Section 3.4, *Thermal Evaluation for Normal Conditions of Transport*, the initial condition temperatures for the HAC fire test are presented in Table 3.4-3. Accordingly, the CTU was placed into an oven overnight and reheated to a uniform temperature of 132 °F prior to being placed on the fire test stand in the fire pit. The CTU was removed from the oven on the morning of the fire test, wrapped with blankets, and transported to the fire test site. The NPC CTU-1 fire test is illustrated in Figure 2.10.1-18 through Figure 2.10.1-21.

2.10.1.7.1.5 CTU-1 Immersion Test

Following the fire test and cool-down to ambient temperature, NPC CTU-1 was submerged in water to a depth of 3 feet (0.9 m) for a period of eight hours. Since it is assumed for the criticality safety evaluation that in-leakage occurs, this test is not required by 10 CFR §71.73(c)(5). However, the test was performed to demonstrate the ability of the NPC package to remain watertight following the HAC tests. The following list summarizes the test parameters:

- The NPC CTU-1 was positioned in its normal, upright position (x-axis angle 0°, vertical axis angle 0°, and z-axis angle 0°).
- The NPC CTU-1 was lowered into a tank so that a minimum water depth of 3 feet (0.9 m) was above the OCA lid.
- Commenced immersion test at 6:30 p.m. on Friday, 3/3/00
- Completed immersion test at 2:30 a.m. on Saturday, 3/4/00

2.10.1.7.1.6 CTU-1 Post-Test Disassembly

Post-test disassembly of CTU-1 was performed on Monday, 3/6/00 (refer to Figure 2.10.1-22 and Figure 2.10.1-23). Prior to cutting open the test article, the OCA closure strip hex bolts and the OCA closure cap screws were checked for tightness, using a value equal to one-half of the original installation torque. In spite of experiencing a number of drop tests and a fire test, all of the fasteners were found to have retained some of their initial tightness. There were no fasteners that were not fully engaged and functional at the end of the tests. An abrasive cutting wheel was then utilized to cut the two deformed closure strips and allow removal. The remaining OCA lid fasteners and OCA closure strips were removed in their normal method.

Upon removal of the OCA lid, the polyurethane foam of the OCA lid and OCA body was slightly charred (refer to Figure 2.10.1-24 and Figure 2.10.1-25). Following removal of the foam char and the remaining foam from the OCA lid, the top plane of the ICCA/foam block structures was visibly tilted towards one side, as shown in Figure 2.10.1-26. This condition was the result of an uneven foam burn on the bottom that was in the vertical orientation during the fire test. Prior to removing the ICCAs, the center-to-center dimensions between ICCAs were measured and recorded. Measurements were also taken on the relative position between each of the cavities once all of the ICCAs were removed. From these measurements, it was determined that the position of the ICCAs remained essentially unchanged from their pre-test condition.

In addition, a black light examination of the area around each ICCA closure was performed to detect the presence of any fluorescine, which was placed into the upper surface of each ICCA simulated payload. No fluorescine was detected, indicating no water leakage into the ICAA.

Each ICCA closure lid was then removed to check the simulated payload (i.e., loose sand with lead shot in bags). With the exception of a single ICCA, the simulated payload of all the ICCAs was found to be dry and with no evidence of water in-leakage from the immersion test. The single ICCA that was found to have evidence of water intrusion was located next to the ICCA that was nearest to the impact point. Following inspection, it was determined that the cause of the water intrusion was due to sand particles migrating between the ICCA closure lid/seal and the body. This condition was attributed to the elastic "burping" of the closure lid during drop testing, thus allowing some of the loose sand particles to get onto the sealing surface.

To confirm that this test phenomenon was the cause of the water in-leakage, the seal surfaces (ICCA closure lid and body lip) were wiped clean. The loose sand was replaced with 125 pounds (57 kg) of bagged lead shot for ballast. The ICCA closure lid was re-installed, and the band clamp tightened to the specified tightening torque of 35 lbs-in. The ICCA was then subjected to an immersion test at a depth of 50 feet (15 m) for eight hours. Following the test and removal of the ICCA closure lid, no water was found in the interior cavity.

Based on the above observations and the powder loading method, which requires separate, sealed containers within the ICCAs, water in-leakage will be prevented.

Once all of the ICCAs were removed from the OCA body and after the re-immersion test of the single ICCA, the stainless steel wrapper was removed so that the passive, non-reversible temperature indicating labels could be accessed. Unfortunately, each of these temperature indicating labels was damaged by water exposure in the immersion test and were unreadable. For the inner surface of the ICCA closure lids, the maximum temperature of any the temperature indicating labels was 300 - 310 °F (149 - 154 °C).

As expected, the most damaged ICCA was the unit located closest to the impacted corner. The ICCA body was deformed, approximately 0.33 inches deep, where it contacted the edge of the

ICCA cavity in the OCA body. In addition, the polyethylene sheeting was pushed upward against the upper stainless steel ring. The hot glue that was installed at the top and bottom of the polyethylene sheeting was melted. Some of the polyethylene sheeting was determined to have melted near this upper stainless steel ring. The amount of polyethylene sheeting loss was estimated to be approximately 5 grams. This small amount of polyethylene represents less than 0.1% of the total polyethylene sheeting on an ICCA. No other damage was detected in either the cadmium or polyethylene sheeting on any other ICCA.

Since the polyurethane foam provides some moderation of neutrons emitting from the uranium oxide payload, the amount of the residual foam was an important parameter to be determined. With the ICCAs removed, the remaining foam block with the cavities for the ICCAs was removed from the OCA body (refer to Figure 2.10.1-27). Near the impacted corner, the remaining foam was cracked from the bottom to the top of the foam block (7 lbs/ft^3 density), as shown in Figure 2.10.1-28 and Figure 2.10.1-29. Remaining foam thickness was measured and recorded at various locations around the foam block, as well as the remaining foam section from the bottom (refer to Figure 2.10.1-30). The minimum, average, and maximum foam thicknesses of the residual polyurethane foam (11 lbs/ft^3 and 15 lbs/ft^3 densities) at provided in Table 2.10.1-3.

Table 2.10.1-3 - Minimum/**Average**/Maximum Residual Foam Thicknesses, NPC CTU-1

Position	Top or Front Face	Bottom or Rear Face	Left Face	Right Face
Lid	2.36/**3.09**/4.36	NA	NA	NA
Body	1.35/**2.19**/2.86	0.25/**0.89**/1.30	2.41/**1.71**/1.14	0.04/**1.01**/1.53
Bottom	NA	0.07/**0.23**/0.43	NA	NA

The closure lid and gasket from the ICCA that was closest to the impact point (ICCA No. AA-1) are shown in Figure 2.10.1-31 and Figure 2.10.1-32. As illustrated by these photographs, the ICCA gasket was undamaged and fully functional at the conclusion of the tests.

The effects of the HAC on the hydrogen of the polyurethane foam and the polyethylene sheeting were evaluated collectively for the test units. The results are summarized in Section 2.10.1.2.

The polyethylene gap at the top and bottom of the wrap was measured for all 9 ICCAs. The maximum total gap observed was 0.43" (0.15" + 0.28" = 0.43").

Based on the post-test structural condition of the ICCAs, it was concluded that the NPC CTU-1 successfully demonstrated its ability to retain its criticality control integrity.

2.10.1.7.2 Certification Test Unit No. 2 (CTU-2)

2.10.1.7.2.1 CTU-2 Free Drop Test No. 3

Free Drop No. 3 is a NCT free drop from a height of 4 feet, impacting the upper edge of the OCA closure lid/body interface. As shown in Figure 2.10.1-33, the CTU was oriented 45° with respect to the horizontal impact surface (x-axis angle 135°, vertical axis angle 0°, and z-axis angle 0°). The following list summarizes the test parameters:

- verified x-axis angle as 135° ±1°

- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 4 feet, +3/-0 inches (actual drop height 4 feet)
- measured ambient temperature as 52 °F
- conducted test at 2:07 p.m. on Monday, 1/31/00

The packaging rebounded upon impact. The OCA body was deformed slightly (3/4-inches or less) on each side. No failure of any structure occurred as a result of the impact. The impact damage is shown in Figure 2.10.1-34.

2.10.1.7.2.2 CTU-2 Free Drop Test No. 4

Free Drop No. 4 is a HAC free drop from a height of 30 feet, impacting the upper edge of the OCA closure lid/body interface. The impact point is the same as Free Drop Test No. 3. As shown in Figure 2.10.1-35, the CTU was oriented 45° with respect to the horizontal impact surface (x-axis angle 135°, vertical axis angle 0°, and z-axis angle 0°). The following list summarizes the test parameters:

- verified x-axis angle as 135° ±1°
- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient temperature as 53 °F
- conducted test at 2:29 p.m. on Monday, 1/31/00

The packaging rebounded upon impact. The OCA body was deformed approximately 11-inches on each impacted side, with the flat measuring approximately 9-inches. Two of the OCA closure strip hex bolts were sheared due to the impact. The impact damage is shown in Figure 2.10.1-36 and Figures 2.10.1-37.

2.10.1.7.2.3 CTU-2 Puncture Drop Test No. 9

Puncture Drop No. 9 impacted directly onto the damage created by Free Drop Tests 3 and 4, directly impacting the upper edge of the OCA closure lid/body interface. As shown in Figure 2.10.1-38, the CTU was oriented 19° with respect to the horizontal impact surface (x-axis angle 109°, vertical axis angle 0°, and z-axis angle 0°). The following list summarizes the test parameters:

- verified x-axis angle as 109° ±1°
- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 59 °F
- conducted test at 3:20 p.m. on Monday, 1/31/00

The packaging rebounded upon impact. The point of impact was approximately 4-inches below the targeted area. The impact resulted in a concave indentation in the OCA body, measuring approximately 10½-inches across the previous deformed area from Free Drop Tests 3 and 4. A small tear, approximately 1/16-inches wide × 5/8-inches long, of the OCA stainless steel skin was also noted. The impact event and damage are shown in Figure 2.10.1-39 and Figure 2.10.1-40 respectively. Since the actual impact point missed the targeted impact point, the puncture drop test was again performed on CTU-2. The following list summarizes the test parameters:

- verified x-axis angle as 109° ±1°
- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 62 °F
- conducted test at 4:10 p.m. on Monday, 1/31/00

The packaging rebounded upon impact. The point of impact was approximately 1/2-inch below the OCA closure strip. The second bar impact continued and increased the damage resulting from the first puncture drop. The urethane sealant used in the OCA body closure area was visible on each side of the impact area. The impact damage is shown in Figure 2.10.1-41 and Figure 2.10.1-42.

2.10.1.7.2.4 CTU-2 Fire Test

Fire Test No. 15 was performed on NPC CTU-2 to demonstrate compliance with 10 CFR 71, and followed the guidelines set forth in IAEA Safety Series No. 37. The following list summarizes the test parameters:

- NPC CTU-2 was orientated on its side (x-axis angle 90°, vertical axis angle 0°, and z-axis angle 0°), with the damaged corner located at the top. The CTU was oriented to provide as much surface area of the package as possible for heat transfer during the test (refer to Figure 2.10.1-43).
- Consistent with 10 CFR §71.73(c)(4) and Paragraph A-628.4 of IAEA Safety Series No. 37, NPC CTU-2 was installed onto an insulated test stand at an elevation to place the lowest part of the package one meter above the fuel surface.
- Consistent with 10 CFR §71.73(c)(4) and Paragraph A-628.4 of IAEA Safety Series No. 37, requiring the test pool to extend 1 to 3 meters beyond the package edges, the test pool size extended approximately 3 meters beyond each side of the CTU.
- Consistent with Paragraph A-628.5 of IAEA Safety Series No. 37, requiring wind speeds not to exceed 2.5 m/s (4.5 mph), the average wind speed during the fire test duration was 0.5 m/s (1.1 mph).
- Consistent with Paragraph A-628.6 and A-628.8 of IAEA Safety Series No. 37, diesel fuel was used for the fire test, and the amount of fuel that was used was adequate to ensure a minimum fire duration for 30 minutes. The fuel was floated on a pool of water to ensure even distribution during burning. The fire test duration was approximately 35 minutes, and burning continued after the end of the fire.

- Consistent with Paragraph A-628.7 and A-628.9 of IAEA Safety Series No. 37, the test pool was instrumented to measure fire temperatures at various locations around the CTU. Temperatures were monitored before, during, and following the fire test until magnitudes were stabilized. The average measured flame temperature was 1,972 °F (1,078 °C).
- Commenced fire testing at 7:41 p.m. on Thursday, 2/3/00. The ambient temperature was 58 °F at the start of the fire.

Active instrumentation was utilized before, during, and after the fire test. Type K thermocouples were attached to each exterior surface (sides, top and bottom) of NPC CTU. These thermocouples measured the surface temperature of the test unit. In addition, passive, non-reversible temperature indicating labels were installed at several locations on the ICCAs: two orthogonal directions on the ICCA closure lid, and near the top and bottom of the stainless steel wrapper. These labels were used to record the temperatures of the criticality control materials of the ICCAs. Each set of temperature indicating labels recorded temperatures in 30 steps from 190 °F to 500 °F.

As stated in Section 3.4, *Thermal Evaluation for Normal Conditions of Transport*, the initial condition temperatures for the HAC fire test are presented in Table 3.4-3. Accordingly, the CTU was placed into an oven overnight and reheated to a uniform temperature of 132 °F prior to being placed on the fire test stand in the fire pit. The CTU was removed from the oven on the morning of the fire test, wrapped with blankets, and transported to the fire test site. The NPC CTU-2 fire test is illustrated in Figure 2.10.1-44 through Figure 2.10.1-46.

2.10.1.7.2.5 CTU-2 Immersion Test

Following the fire test and the cool-down to ambient temperature, NPC CTU-2 was submerged in water to a depth of 3 feet (0.9 m) for a period of eight hours. Since it is assumed for the criticality safety evaluation that in-leakage occurs, this test is not required by 10 CFR §71.73(c)(5). However, the test was performed to demonstrate the ability of the NPC package to remain watertight following the HAC tests. The following list summarizes the test parameters:

- The NPC CTU-2 was positioned in its normal, upright position (x-axis angle 0°, vertical axis angle 0°, and z-axis angle 0°).
- The NPC CTU-2 was lowered into a tank so that a minimum water depth of 3 feet (0.9 m) was above the OCA lid.
- Commenced immersion test at 10:55 a.m. on Saturday, 2/5/00
- Completed immersion test at 6:55 p.m. on Saturday, 2/5/00

2.10.1.7.2.6 CTU-2 Post-Test Disassembly

Post-test disassembly of NPC CTU-2 was performed on Monday, 2/7/00 and Tuesday, 2/8/00 (refer to Figure 2.10.1-47). Prior to cutting open the test article, the OCA closure strip hex bolts and the OCA closure cap screws were checked for tightness, using a value equal to one-half of the original installation torque. In spite of experiencing a number of drop tests and a fire test, thirteen out of a total of sixteen of the OCA cap screws were found to have retained some of their initial tightness. However, a majority of the OCA closure strip hex bolts were found to be loose, i.e., less than one-half of the original installation torque. There were no fasteners that were not fully engaged and functional at the end of the tests. An abrasive cutting wheel was then utilized to cut the two deformed closure strips and allow removal. The remaining OCA lid fasteners and OCA closure strips were removed in their normal method.

Upon removal of the OCA lid, the polyurethane foam of the OCA lid and OCA body was significantly charred (refer to Figure 2.10.1-48). Following removal of the foam char (refer to Figure 2.10.1-49) and the remaining foam from the OCA lid, the ICCA/residual foam block structure was visibly tilted towards one side, as shown in Figure 2.10.1-50. This condition was the result of increased foam burning on the bottom and upper side that were in the vertical and upper orientations respectively during the fire test. Prior to removing the ICCAs, the center-to-center dimensions between ICCAs were measured and recorded. Measurements were also taken on the relative position between each of the cavities once all of the ICCAs were removed. From these measurements, it was determined that the position of the ICCAs remained essentially unchanged from their pre-test condition.

In addition, a black light examination of the area around each ICCA closure was performed to detect the presence of any fluorescine, which was placed into the upper surface of each ICCA simulated payload. No fluorescine was detected, indicating no water leakage into the ICAA.

Each ICCA closure lid was then removed to check the simulated payload (i.e., loose sand with lead shot in bags). The simulated payload in all of the ICCAs was determined to be dry, with no evidence of water in-leakage from the immersion test.

Once all of the ICCAs were removed from the OCA body, the stainless steel wrapper was removed so that the passive, non-reversible temperature indicating labels could be accessed and read. The maximum indicated temperature of any of the temperature indicating labels on the stainless steel wrappers was 330 - 340 °F (166 - 171 °C). For the inner surface of the ICCA closure lids, the maximum temperature of any the temperature indicating labels was 310 - 320 °F (154 - 160 °C).

As expected, the most damaged ICCA was the unit located closest to the impacted side edge. The ICCA body was deformed due to the puncture bar drop, as shown in Figure 2.10.1-51. In addition, the polyethylene sheeting was pushed upward against the upper stainless steel ring. The hot glue that was installed at the top and bottom of the polyethylene sheeting was melted. Some of the polyethylene sheeting was determined to have melted near this upper stainless steel ring. Based on pre- and post-test weights, the amount of polyethylene sheeting loss was estimated to be approximately 38 grams. This small amount of polyethylene represents less than 0.6% of the total polyethylene sheeting on an ICCA (refer to Figure 2.10.1-52). No other damage was detected in either the cadmium or polyethylene sheeting on any other ICCA.

The closure lid and gasket from the ICCA that was closest to the impact point are shown in Figure 2.10.1-53 and Figure 2.10.1-54. As illustrated by these photographs, the ICCA gasket was undamaged and fully functional at the conclusion of the tests.

Since the polyurethane foam provides some moderation of neutrons emitting from the uranium oxide payload, the amount of the residual foam was an important parameter to be determined. With the ICCAs removed, the remaining foam block (7 lbs/ft^3 density), with the cavities for the ICCAs, was removed from the OCA body (refer to Figure 2.10.1-55). Near the impacted edge, the polyurethane foam was nearly burned completed away, as shown in Figure 2.10.1-56. Remaining foam thickness was measured and recorded at various locations around the foam block. No residual foam remained in the bottom, below the ICCAs. The minimum, average, and maximum foam thickness of the residual polyurethane foam (11 lbs/ft^3 and 15 lbs/ft^3 densities) at provided in Table 2.10.1-4.

Table 2.10.1-4 - Minimum/**Average**/Maximum Residual Foam Thicknesses, NPC CTU-2

Location	Top or Front Face	Bottom or Rear Face	Left Face	Right Face
Lid	3.0 (estimated)	NA	NA	NA
Body	0.0/**0.58**/1.60	0.0/**0.23**/0.54	0.0/**0.26**/0.80	0.0/**1.41**/2.43
Bottom	NA	**0.0**	NA	NA

The effects of the HAC on the hydrogen of the polyurethane foam and the polyethylene sheeting were evaluated collectively for the test units. The results are summarized in Section 2.10.1.2.

The polyethylene gap at the top and bottom of the wrap was measured for all 9 ICCAs. The maximum total gap observed was 0.69" (0.40" + 0.29" = 0.69").

Based on the post-test structural condition of the ICCAs, it was concluded that NPC CTU-2 successfully demonstrated its ability to retain its criticality control integrity.

2.10.1.7.3 Certification Test Unit No. 3 (CTU-3)

<u>Note:</u> Reported for information only. CTU-1 test results are used to demonstrate compliance to 10 CFR 71 requirements. See Sections 2.1.6.1 and 2.1.1.6.3.

2.10.1.7.3.1 CTU-3 Free Drop Test No. 1

Free Drop No. 5 is a NCT free drop from a height of 4 feet, the upper corner of the OCA lid/body. As shown in Figure 2.10.1-57, the CTU was oriented such that the CG was located over the OCA lid corner (x-axis angle 127°, vertical axis angle 45°, and z-axis angle 45°). The following list summarizes the test parameters:

- verified x-axis angle as 127° ±1°
- verified vertical axis angle as 45° ±1°
- verified z-axis angle as 45° ±1°
- verified drop height as 4 feet, +3/-0 inches (actual drop height 4 feet)
- measured ambient temperature as 50 °F
- conducted test at 11:30 a.m. on Tuesday, 2/1/00

The packaging rebounded upon impact. The OCA lid corner was deformed into a triangular flat, with a flat width of approximately 5-inches. The impact damage is shown in Figure 2.10.1-58.

2.10.1.7.3.2 CTU-3 Free Drop Test No. 2

Free Drop No. 2 is a HAC free drop from a height of 30 feet, impacting the upper corner of the OCA closure lid/body. The impact point is the same as Free Drop Test No. 1. The CTU was oriented such that the CG was located over the OCA lid corner (x-axis angle 127°, vertical axis angle 45°, and z-axis angle 45°). The following list summarizes the test parameters:

- verified x-axis angle as 127° ±1°

- verified vertical axis angle as 45° ±1°
- verified z-axis angle as 45° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient temperature as 51 °F
- conducted test at 11:50 a.m. on Tuesday, 2/1/00

The packaging rebounded upon impact (refer to Figure 2.10.1-59). The impact resulted in severe buckling and folding of the OCA lid corner. The primary area of the deformation was limited to the OCA lid, with a resultant width and depth of approximately 18-inches and 6-inches respectively. The two OCA closure strips near the impact point were bent inward approximately 3-inches. A small tear of the OCA body was noted adjacent to the stainless steel bar for the OCA closure strips. There was no failure of any OCA fastener. The impact damage is shown in Figure 2.10.1-60.

2.10.1.7.3.3 CTU-3 Puncture Drop Test No. 11

Puncture Drop No. 11 impacted near the damage created by Free Drop Tests 1 and 2, directly impacting the interface between the OCA body and OCA lid. As shown in Figure 2.10.1-61, the CTU was oriented at an angle 42° with respect to the horizontal impact surface (x-axis angle 132°, vertical axis angle 0°, and z-axis angle 0°). The following list summarizes the test parameters:

- verified x-axis angle as 132° ±1°
- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 60 °F
- conducted test at 3:05 p.m. on Wednesday, 2/2/00

The packaging rotated upon impact, and then glanced off the puncture bar. No visible damage beyond the damage from Free Drop No. 1 and Free Drop No. 2. The impact damage is shown in Figure 2.10.1-62.

2.10.1.7.3.4 CTU-3 Fire Test

Fire Test No. 15 was performed on NPC CTU-3 . The following list summarizes the test parameters:

- NPC CTU-3 was orientated on its side (x-axis angle 90°, vertical axis angle 0°, and z-axis angle 0°), with the damaged corner located at the top. The CTU was oriented to provide as much surface area of the package as possible for heat transfer during the test (refer to Figure 2.10.1-63).
- Consistent with 10 CFR §71.73(c)(4) and Paragraph A-628.4 of IAEA Safety Series No. 37, NPC CTU-3 was installed onto an insulated test stand at an elevation to place the lowest part of the package one meter above the fuel surface.
- Consistent with 10 CFR §71.73(c)(4) and Paragraph A-628.4 of IAEA Safety Series No. 37, requiring the test pool to extend 1 to 3 meters beyond the package edges, the test pool size extended approximately 3 meters beyond each side of the CTU.

- Consistent with Paragraph A-628.5 of IAEA Safety Series No. 37, requiring wind speeds not to exceed 2.5 m/s (4.5 mph), the average wind speed during the fire test duration was 2.3 m/s (4.1 mph).
- Consistent with Paragraph A-628.6 and A-628.8 of IAEA Safety Series No. 37, diesel fuel was used for the fire test, and the amount of fuel that was used was adequate to ensure a minimum fire duration for 30 minutes. The fuel was floated on a pool of water to ensure even distribution during burning. The fire test duration was approximately 30 minutes, and burning continued after the end of the fire.
- Consistent with Paragraph A-628.7 and A-628.9 of IAEA Safety Series No. 37, the test pool was instrumented to measure fire temperatures at various locations around the CTU. Temperatures were monitored before, during, and following the fire test until magnitudes were stabilized. The average measured flame temperature was 2,025 °F (1,107 °C).
- Commenced fire testing at 6:28 p.m. on Friday, 2/4/00. The ambient temperature was 58 °F at the start of the fire.

Active instrumentation was utilized before, during, and after the fire test. Type K thermocouples were attached to each exterior surface (sides, top and bottom) of NPC CTU. These thermocouples measured the surface temperature of the test unit. In addition, passive, non-reversible temperature indicating labels were installed at several locations on the ICCAs: two orthogonal directions on the ICCA closure lid, and near the top and bottom of the stainless steel wrapper. These labels were used to record the temperatures of the criticality control materials of the ICCAs. Each set of temperature indicating labels recorded temperatures in 30 steps from 190 °F to 500 °F.

As stated in Section 3.4, *Thermal Evaluation for Normal Conditions of Transport*, the initial condition temperatures for the HAC fire test are presented in Table 3.4-3. Accordingly, the CTU was placed into an oven and preheated to a uniform temperature of 132 °F prior to being moved to the fire test site. The NPC CTU-3 fire test is illustrated in Figure 2.10.1-64 through Figure 2.10.1-67.

2.10.1.7.3.5 CTU-3 Immersion Test

Following the fire test and the cool-down to ambient temperature, NPC CTU-3 was submerged in water to a depth of 3 feet (0.9 m) for a period of eight hours. Since it is assumed for the criticality safety evaluation that in-leakage occurs, this test is not required by 10 CFR §71.73(c)(5). However, the test was performed to demonstrate the ability of the NPC package to remain watertight following the HAC tests. The following list summarizes the test parameters:

- The NPC CTU-3 was positioned in its normal, upright position (x-axis angle 0°, vertical axis angle 0°, and z-axis angle 0°).
- The NPC CTU-3 was lowered into a tank so that a minimum water depth of 3 feet (0.9 m) was above the OCA lid.
- Commenced immersion test at 10:55 a.m. on Saturday, 2/5/00
- Completed immersion test at 6:55 p.m. on Saturday, 2/5/00

2.10.1.7.3.6 CTU-3 Post-Test Disassembly

Post-test disassembly of NPC CTU-3 was performed on Monday, 2/7/00 and Tuesday, 2/8/00 (refer to Figure 2.10.1-68 and Figure 2.10.1-69). Several small, burn-through holes were visible on the outer OCA stainless steel skin. These burn-through holes occurred at the locations of insulation pins, which were spot welded to the inner surface of the OCA stainless steel skin (refer to Figure 2.10.1-70).

Prior to cutting open the test article, the OCA closure strip hex bolts and the OCA closure cap screws were checked for tightness, using a value equal to one-half of the original installation torque. In spite of experiencing a number of drop tests and a fire test, all but one of the OCA cap screws were found to have retained some of their initial tightness. All of the OCA closure strip hex bolts were determined to be loose, i.e., less than one-half of the original installation torque. There were no fasteners that were not fully engaged and functional at the end of the tests. An abrasive cutting wheel was then utilized to cut the two deformed closure strips and allow removal. The remaining OCA lid fasteners and OCA closure strips were removed in their normal method.

Upon removal of the OCA lid, the polyurethane foam of the OCA lid and OCA body was charred (refer to Figure 2.10.1-71 and Figure 2.10.1-72). Following removal of the foam char and the remaining foam from the OCA lid, the top plane of the ICCA/foam block structure was visible (refer to Figure 2.10.1-73). As expected, the most damaged ICCA (ICCA #1) was the unit located closest to the impacted corner. The ICCA closure lid was severely damaged, as shown in Figure 2.10.1-74.

Prior to removing the ICCAs, the center-to-center dimensions between ICCAs were measured and recorded. Measurements were also taken on the relative position between each of the cavities once all of the ICCAs were removed. From these measurements, it was determined that the position of the ICCAs remained essentially unchanged from the pre-test condition.

In addition, a black light examination of the area around each ICCA closure was performed to detect the presence of any fluorescine, which was placed into the upper surface of each ICCA simulated payload. Of the nine ICCAs, fluorescine was detected around the closure lid of the ICCA nearest to the impact corner (ICCA #1). The presence of the fluorescine provided evidence that ICCA #1 did not remain watertight during the immersion test. This condition was attributed to the excessive deformation of the ICCA closure lid on this cylinder, as shown by Figure 2.10.1-74.

Each ICCA closure lid was then removed to check the simulated payload (i.e., loose sand with lead shot in bags). With the exception of ICCA #1, the simulated payload in the remaining eight ICCAs were found to be dry, with no evidence of water in-leakage from the immersion test. As noted previously, ICCA #1 that experienced water intrusion was located nearest to the impact point.

Once all of the ICCAs were removed from the OCA body, the stainless steel wrapper was removed so that the passive, non-reversible temperature indicating labels could be accessed. The maximum indicated temperature of any of the temperature indicating labels on the stainless steel wrappers was 360 - 370 °F (182 - 188 °C). For the inner surface of the ICCA closure lids, the maximum temperature of any the temperature indicating labels was 450 - 465 °F (232 - 241 °C).

On each ICCA, the polyethylene sheeting was pushed upward against the upper stainless steel ring. The hot glue that was installed at the top and bottom of the polyethylene sheeting was melted. Some of the polyethylene sheeting was determined to have melted near this upper stainless steel ring. Based on pre- and post-test weights, the amount of polyethylene sheeting loss was estimated to be approximately 71 grams. This small amount of polyethylene represents 1.0% of the total polyethylene sheeting on an ICCA (refer to Figure 2.10.1-75). No other damage was detected in either the cadmium or polyethylene sheeting on any other ICCA.

Since the polyurethane foam provides some moderation of neutrons emitting from the uranium oxide payload, the amount of the residual foam was an important parameter to be determined. With the ICCAs removed, the remaining foam block (7 lbs/ft^3 density), with the cavities for the ICCAs, was removed from the OCA body (refer to Figure 2.10.1-76). The remaining foam thickness was measured and recorded at various locations around the foam block, as well as the remaining foam section from the bottom (refer to Figure 2.10.1-77). The minimum, average, and maximum foam thickness of the residual polyurethane foam is provided in Table 2.10.1-5.

Table 2.10.1-5 - Minimum/**Average**/Maximum Residual Foam Thicknesses, NPC CTU-3

Location	Top or Front Face	Bottom or Rear Face	Left Face	Right Face
Lid	3.0 (estimated)	NA	NA	NA
Body	0.0/**1.99**/2.54	0.32/**0.74**/1.00	1.35/**1.86**/2.71	0.0/**0.78**/1.37
Bottom	NA	1.02/**1.30**/1.68	NA	NA

While it can be concluded from the post test structural condition of the ICCAs that the criticality control requirements were met for the package, the overall performance did not meet the design expectations due to the higher than desirable damage to the lid corner and the corner ICCA. Results from CTU-3 were not used to demonstrate compliance to 10 CFR 71 requirements. A design modification was performed on CTU-1 and CTU-1 was re-tested fully successfully to the same NCT-HAC as CTU-3. CTU-1 represents the design basis for the package.

2.10.1.7.4 Certification Test Unit No. 4 (CTU-4)

2.10.1.7.4.1 CTU-4 Free Drop Test No. 5

Free Drop No. 5 is a NCT free drop from a height of 4 feet, impacting 7° from horizontal with primary impact on the lower edge of the OCA lid and secondary impact on the lower edge of the OCA body. As shown in Figure 2.10.1-78, the CTU was oriented at angle 7° with respect to the horizontal impact surface (x-axis angle 97°, vertical axis angle 0°, and z-axis angle 0°). The following list summarizes the test parameters:

- verified x-axis angle as 97° ±1°
- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 4 feet, +3/-0 inches (actual drop height 4 feet)
- conducted test on at 2:20 p.m. on Tuesday, 2/1/00

The packaging rebounded upon impact. The OCA closure strip on the impacted edge was deformed inward approximately 3/16-inches. No other damage to the CTU was visible.

2.10.1.7.4.2 CTU-4 Free Drop Test No. 6

Free Drop No. 6 is a HAC free drop from a height of 30 feet, impacting 7° from horizontal with primary impact on the lower edge of the OCA lid and secondary impact on the lower edge of the OCA body. The impact point is the same as Free Drop Test No. 5. The CTU was oriented 7° with respect to the horizontal impact surface (x-axis angle 97°, vertical axis angle 0°, and z-axis angle 0°). The following list summarizes the test parameters:

- verified x-axis angle as 97° ±1°
- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- conducted test 2:32 p.m. on Tuesday, 2/1/00

The packaging rebounded upon impact. The OCA closure strip on the impacted edge was further deformed inward (concave), with a total deformation of approximately 1/2-inch. The three non-impacted sides were deformed outward (convex) approximately the same amount, i.e., 1/2-inch. The OCA lid was also deformed outward (convex) approximately 7/8 to 1-inch. The impact damage is shown in Figure 2.10.1-79 and Figure 2.10.1-80.

2.10.1.7.4.3 CTU-4 Free Drop Test No. 7

Free Drop No. 7 is a NCT free drop from a height of 4 feet, impacting the bottom of the OCA body. As shown in Figure 2.10.1-81, the CTU was oriented in its normal upright position with respect to the horizontal impact surface (x-axis angle 0°, vertical axis angle 0°, and z-axis angle 0°). The following list summarizes the test parameters:

- verified x-axis angle as 0° ±1°
- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 4 feet, +3/-0 inches (actual drop height 4 feet)
- measured ambient temperature as 49 °F
- conducted test at 8:20 a.m. on Thursday, 2/3/00

The packaging rebounded upon impact. Minor damage to the bottom OCA body structure was noted. The OCA lid was deformed down approximately 3/4-inch. The three of OCA body sides were deformed outward while the remaining side was deformed inward, approximately 1/2-inch. No other damage to the CTU was visible. The impact event is shown in Figure 2.10.1-82.

2.10.1.7.4.4 CTU-4 Free Drop Test No. 8

Free Drop No. 8 is a HAC free drop from a height of 30 feet, impacting the bottom of the OCA body. The impact point is the same as Free Drop Test No. 7. As shown in Figure 2.10.1-83, the CTU was oriented in its normal upright position with respect to the horizontal impact surface (x-axis angle 0°, vertical axis angle 0°, and z-axis angle 0°). The following list summarizes the test parameters:

- verified x-axis angle as 0° ±1°
- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient temperature as 49 °F
- conducted test at 8:43 a.m. on Thursday, 2/3/00

The packaging rebounded upon impact. All forklift structures on the OCA body were buckled and deformed approximately 1/2-inch to 2-inches. The center area of the OCA body was bulged approximately 1-inch. In addition, three sides of the OCA body were deformed outward (convex) an average of 3/4-inch. The other OCA body side was deformed inward (concave) approximately 5/8-inch. The impact damage is shown in Figure 2.10.1-84, through Figure 2.10.1-86.

2.10.1.7.4.5 CTU-4 Puncture Drop Test No. 12

Puncture Drop No. 12 impacted directly onto the side of the OCA body. As shown in Figure 2.10.1-87, the CTU was oriented 90° with respect to the horizontal impact surface (x-axis angle 90°, vertical axis angle 0°, and z-axis angle 0°). The following list summarizes the test parameters:

- verified x-axis angle as 90° ±1°
- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 48 °F
- conducted test at 9:20 a.m. on Thursday, 2/3/00

The packaging rebounded upon impact and rotated off the puncture bar. A circular indentation, approximately 15 to 17-inches in diameter and 1 1/2-inches deep, was created in the side of the OCA. The outer OCA stainless steel skin was not punctured nor was any other damage noted. The impact damage is shown in Figure 2.10.1-88.

2.10.1.7.4.6 CTU-4 Puncture Drop Test No. 13

Puncture Drop No. 13 impacted obliquely onto the side of OCA body, striking the same surface as Puncture Drop No. 12. As shown in Figure 2.10.1-89, the CTU was oriented 17° with respect to the horizontal impact surface (x-axis angle 107°, vertical axis angle 0°, and z-axis angle 0°). The following list summarizes the test parameters:

- verified x-axis angle as 107° ±1°
- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 59 °F
- conducted test at 10:18 a.m. on Thursday, 2/3/00

The packaging rebounded upon impact and rotated off the puncture bar. A crescent-shaped indentation, measuring 1 3/4-inches deep × 10-inches long × 12-inches wide, was formed in the OCA body, approximately 2-inches from the OCA closure strip. The outer OCA stainless steel skin was not punctured nor was any other damage noted. The impact damage is shown in Figure 2.10.1-90 and Figure 2.10.1-91.

2.10.1.7.4.7 CTU-4 Puncture Drop Test No. 14

Puncture Drop No. 14 impacted obliquely onto the OCA lid. As shown in Figure 2.10.1-92, the CTU was oriented 66° with respect to the horizontal impact surface (x-axis angle 156°, vertical axis angle 0°, and z-axis angle 0°). The following list summarizes the test parameters:

- verified x-axis angle as 156° ±1°
- verified vertical axis angle as 0° ±1°
- verified z-axis angle as 0° ±1°
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 61 °F
- conducted test at 10:55 a.m. on Thursday, 2/3/00

The packaging rebounded upon impact and rotated off the puncture bar. A dished-shaped indentation, measuring 2 1/2-inches deep, was formed in the OCA lid. The outer OCA stainless steel skin was not punctured nor was any other damage noted. The impact damage is shown in Figure 2.10.1-93.

2.10.1.7.4.8 CTU-4 Post-Test Disassembly

Post-test disassembly of NPC CTU-3 was performed on Friday, 2/4/2000. Prior to opening the test article, the OCA closure strip hex bolts and the OCA closure cap screws were checked for tightness, using a value equal to one-half of the original installation torque. In spite of experiencing a number of drop tests, all but four of the accessible OCA cap screws were found to have retained some of their initial tightness (one cap screw was damaged). All but five of the OCA closure strip hex bolts were determined to be loose, i.e., less than one-half of the original installation torque. There were no fasteners that were not fully engaged and functional at the end of the tests. The OCA lid fasteners and OCA closure strips then were removed in their normal method.

Once the OCA lid was removed, the ICCAs and OCA body were visible. Small pieces of the high density polyurethane foam had broken away from the OCA lid and were lying on top of the OCA body/ICCAs, as shown in Figure 2.10.1-94 and Figure 2.10.1-95. In addition, the vertical position of the ICCAs were noticeably different from their pretest position (refer to Figure 2.10.1-96). With the polyurethane foam debris removed, the high density polyurethane foam in the OCA body was found to have several fractures, as shown in Figure 2.10.1-97.

Prior to removing the ICCAs, the center-to-center dimensions between ICCAs were measured and recorded. Measurements were also taken on the relative position between each of the cavities once all of the ICCAs were removed. From these measurements, it was determined that the position of the ICCAs remained essentially unchanged from their pre-test condition.

In addition, a black light examination of the area around each ICCA closure was performed to detect the presence of any fluorescine, which was placed into the upper surface of each ICCA simulated payload. No fluorescine was detected.

Each ICCA was then removed from the OCA body for further examination. The only ICCA exhibiting any damage was the ICCA adjacent to Puncture Drop Test No. 13. The side of the ICCA was found to be deformed due to the puncture bar (refer to Figure 2.10.1-98). No other damage was found on this or the other ICCAs.

In conclusion, the NPC packaging design has been demonstrated to satisfy the requirements of Subpart F of 10 CFR 71 for the transportation of fissile radioactive material.

Table 2.10.1-6 - Summary of NPC Certification Tests*

Test No.	Test Description (Certification Test Unit No.)	Preconditioning Temperature (°F)	Test Unit Angular Orientation			Remarks
			X-Axis (0° = horizontal)	Vertical Axis (0° = upright)	Z-Axis (0° = horizontal)	
1	4 foot, CG over Lid Corner (CTU-1, CTU-3)	132	127°	45°	45°	NCT impact on most vulnerable location.
2	30 foot, CG over Lid Corner (CTU-1, CTU-3)	132	127°	45°	45°	Drop orientation on region to cause maximum deformation of most vulnerable location.
3	4 foot, CG over Lid/Side Edge (CTU-2)	132	135°	45°	0°	NCT impact on OCA closure lid/body interface.
4	30 foot, CG over Lid/Side Edge (CTU-2)	132	135°	45°	0°	Drop orientation on OCA closure lid/body interface.
5	4 foot, Shallow Angle Side Drop (CTU-4)	-40	97°	0°	0°	NCT impact to produce maximum secondary impact (slapdown).
6	30 foot, Shallow Angle Side Drop (CTU-4)	-40	97°	0°	0°	Drop orientation to produce maximum secondary impact (slapdown).
7	4 foot Bottom Drop (CTU-4)	-40	NA	0°	NA	NCT impact to produce maximum inertia loading.
8	30 foot Bottom Drop (CTU-4)	-40	NA	0°	NA	Drop orientation to produce maximum inertia loading.
9	Puncture drop, CG adjacent to Lid/Side Edge (CTU-2)	132	109°	0°	0°	Attempt to increase damage resulting from Test No. 4 free drop.
10	Puncture drop near Lid Reinforcement (CTU-1)	132	78°	45°	45°	Attempt to produce maximum damage to thermal protection design features of OCA lid.
11	Puncture drop below Lid/Body Interface (CTU-3)	-40	132°	0°	0°	Attempt to increase damage resulting from Test No. 2 free drop.
12	Puncture drop on Side (CTU-4)	-40	90°	0°	0°	Attempt to produce maximum damage to thermal protection design features of OCA body.
13	Puncture drop, CG over Lid/Body Interface (CTU-4)	-40	107°	45°	45°	Attempt to produce maximum damage to thermal Protection design features of OCA lid/body interface.
14	Puncture, Oblique CG drop thru Lid (CTU-4)	-40	156°	0°	0°	Attempt to produce maximum damage to thermal Protection design features of OCA lid.
15	HAC Fire Test (CTU-1, CTU-2, CTU-3)	132	90°	0°	0°	Most damaged CTU(s) to be selected.

* Tested 1/3100 thru 2/4/00, and 3/1/00 thru 3/3/00.

Table 2.10.1-7 - Summary of NPC Certification Test Results*

Test No.	Test Description (Certification Test Unit No.)	Preconditioning Temperature (°F)	Test Unit Angular Orientation			Results
			X-Axis (0° = horizontal)	Vertical Axis (0° = upright)	Z-Axis (0° = horizontal)	
1	4 foot, CG over Lid Corner (CTU-1, CTU-3)	132	127°	45°	45°	CTU-1: ~2½" wide flat, ~1" deep CTU-3: ~5" wide flat
2	30 foot, CG over Lid Corner (CTU-1, CTU-3)	132	127°	45°	45°	CTU-1: ~19" wide flat, ~6" deep CTU-3: ~18" wide flat, ~6" deep
3	4 foot, CG over Lid/Side Edge (CTU-2)	132	135°	45°	0°	~3/4" × ~3/4" on each OCA lid side edge
4	30 foot, CG over Lid/Side Edge (CTU-2)	132	135°	45°	0°	~11" × ~11", ~9" wide flat on OCA lid side edge
5	4 foot, Shallow Angle Side Drop (CTU-4)	-40	97°	0°	0°	~3/16" dent on OCA lid edge
6	30 foot, Shallow Angle Side Drop (CTU-4)	-40	97°	0°	0°	~1/2" dent on OCA lid edge
7	4 foot Bottom Drop (CTU-4)	-40	0°	0°	0°	~3/4" deformation of forklift pockets
8	30 foot Bottom Drop (CTU-4)	-40	0°	0°	0°	~1/2" to 2" deformation of forklift pockets
9	Puncture drop, CG adjacent to Lid/Side Edge (CTU-2)	132	109°	0°	0°	1st test: ~10½" wide dent 2nd test: increased damage due to 1st test
10	Puncture drop near Lid Reinforcement (CTU-1)	132	78°	45°	45°	Crescent-shaped dent in OCA lid.
11	Puncture drop below Lid/Body Interface (CTU-3)	-40	132°	0°	0°	Minor damage to OCA.
12	Puncture drop on Side (CTU-4)	-40	90°	0°	0°	~1½" deep × ~16" wide dent
13	Puncture drop, CG over Lid/Body Interface (CTU-4)	-40	107°	45°	45°	~1¼ " deep × ~10" wide × ~12" long dent
14	Puncture, Oblique CG drop thru Lid (CTU-4)	-40	156°	0°	0°	~2½" deep dent in OCA lid
15	HAC Fire Test (CTU-1, CTU-2, CTU-3)	132	90°	0°	0°	CTU-1: ~1,809 °F temperature, ~32 minutes CTU-2: ~1,972 °F temperature, ~36 minutes CTU-3: ~2,025 °F temperature, ~30 minutes

* Tested 1/3100 thru 2/4/00, and 3/1/00 thru 3/3/00.

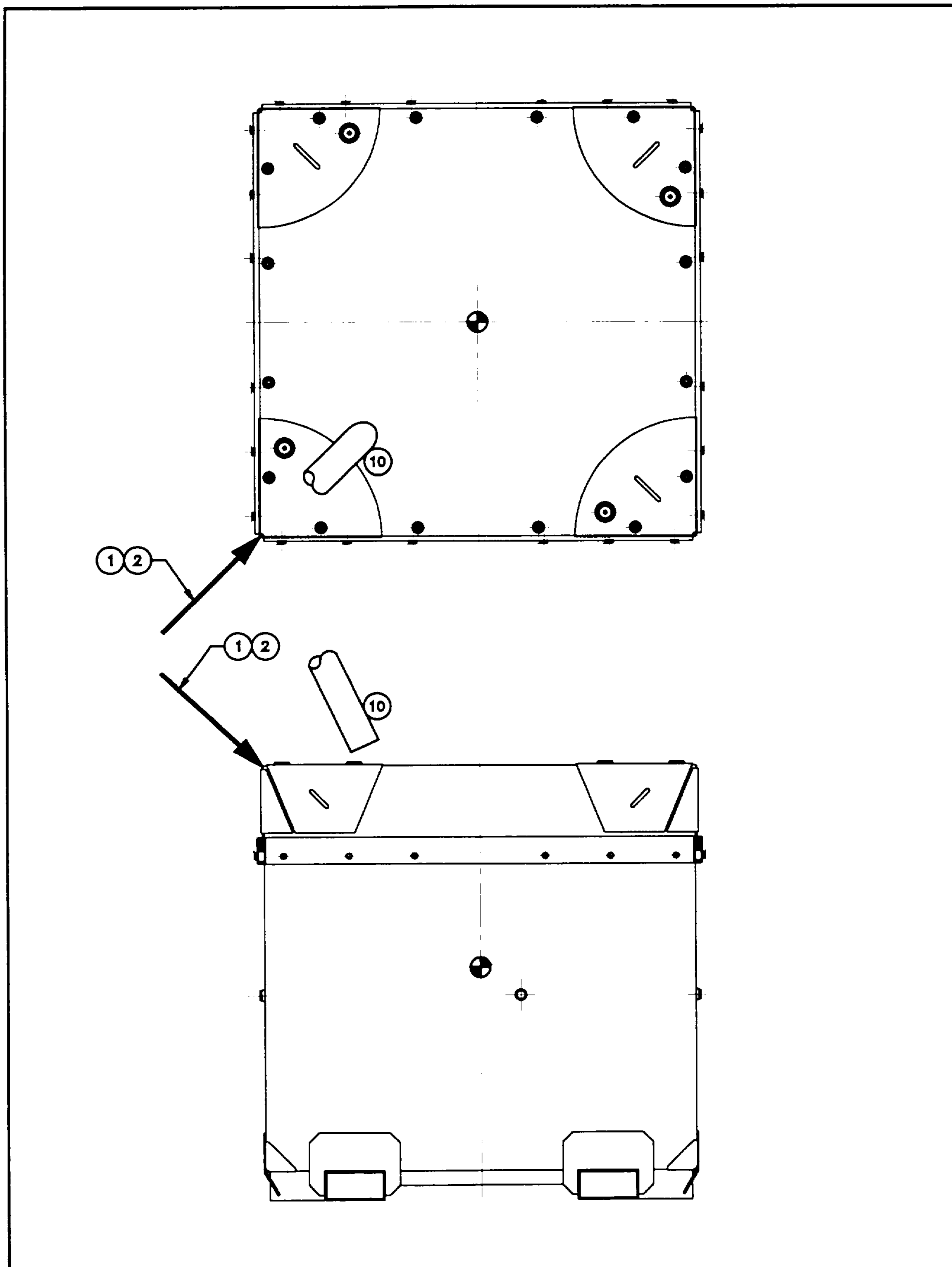


Figure 2.10.1-5 - Schematic Summary of CTU-1 Testing

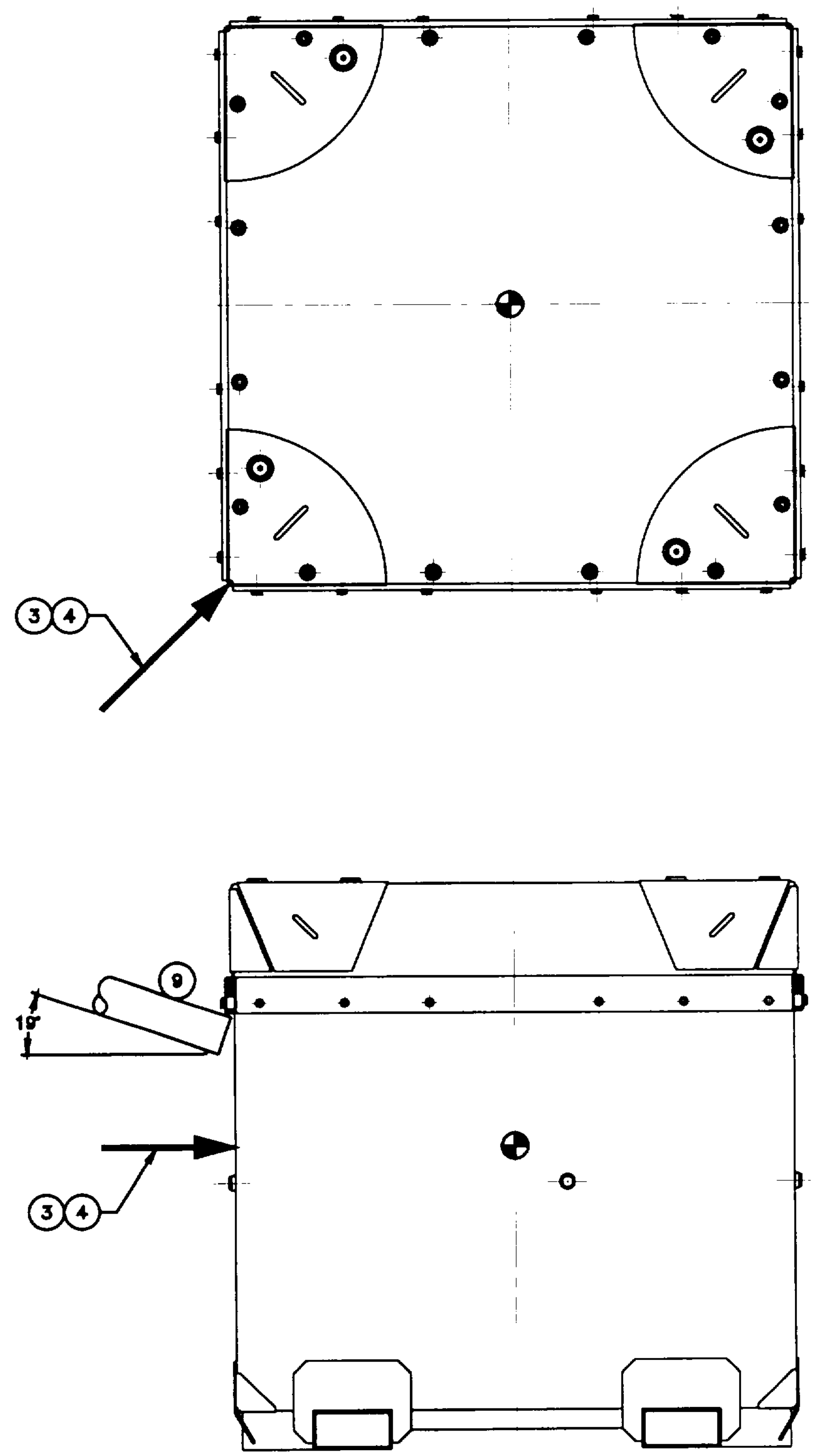


Figure 2.10.1-6 - Schematic Summary of CTU-2 Testing

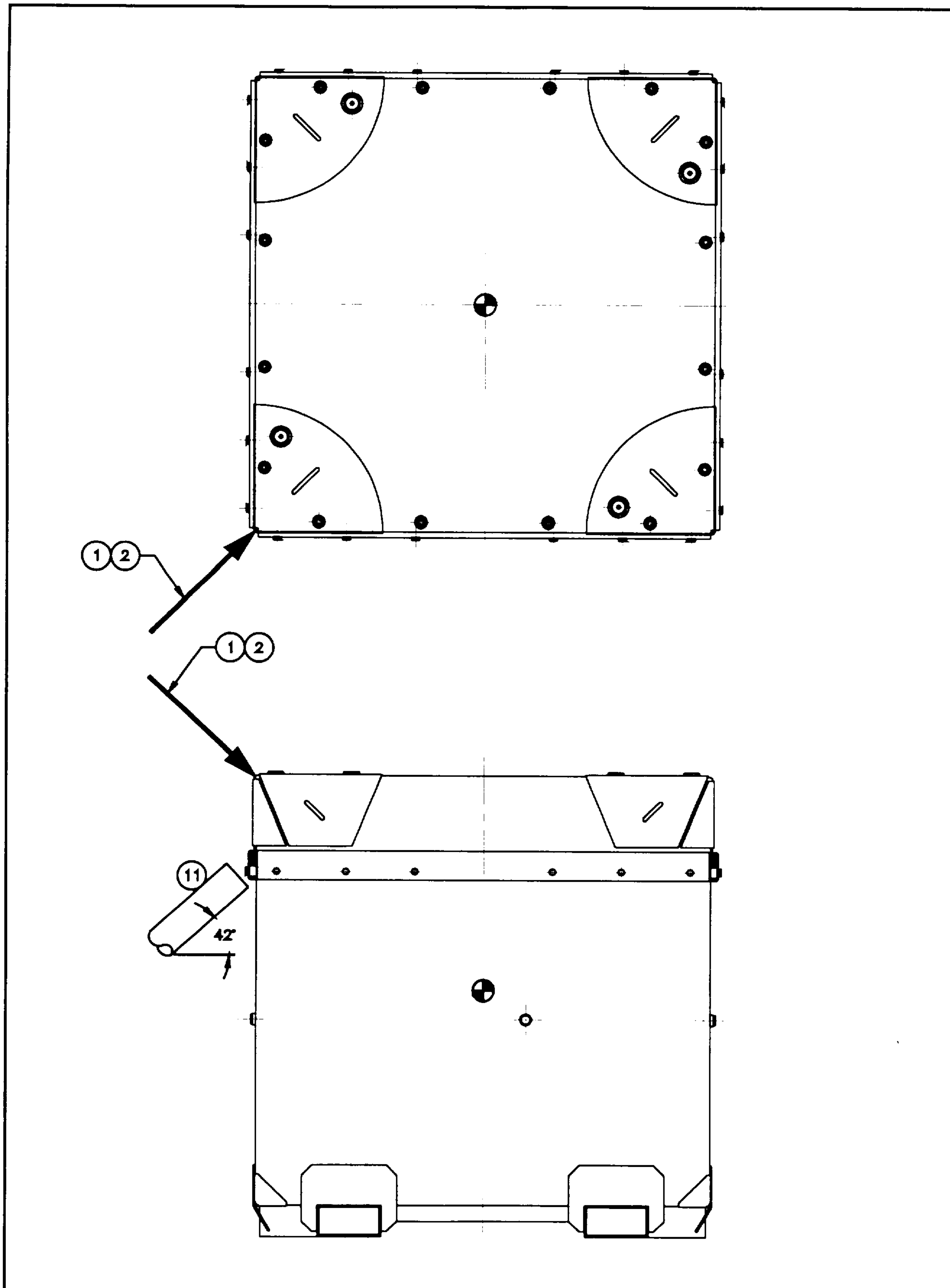


Figure 2.10.1-7 – Schematic Summary of CTU-3 Testing

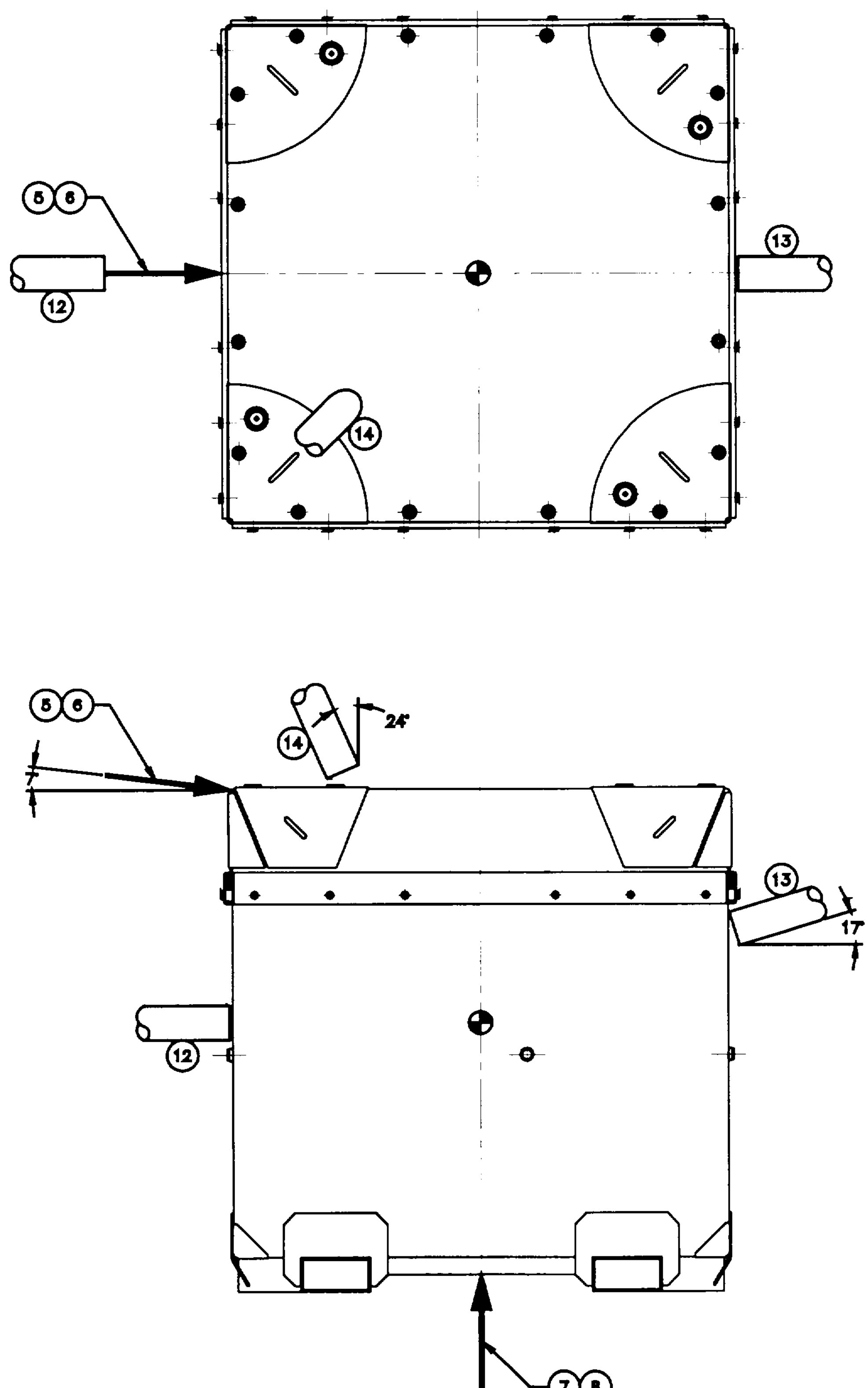


Figure 2.10.1-8 – Schematic Summary of CTU-4 Testing

Figure 2.10.1-9 - CTU-1 Free Drop Test No. 1; NCT Drop onto OCA Lid Corner

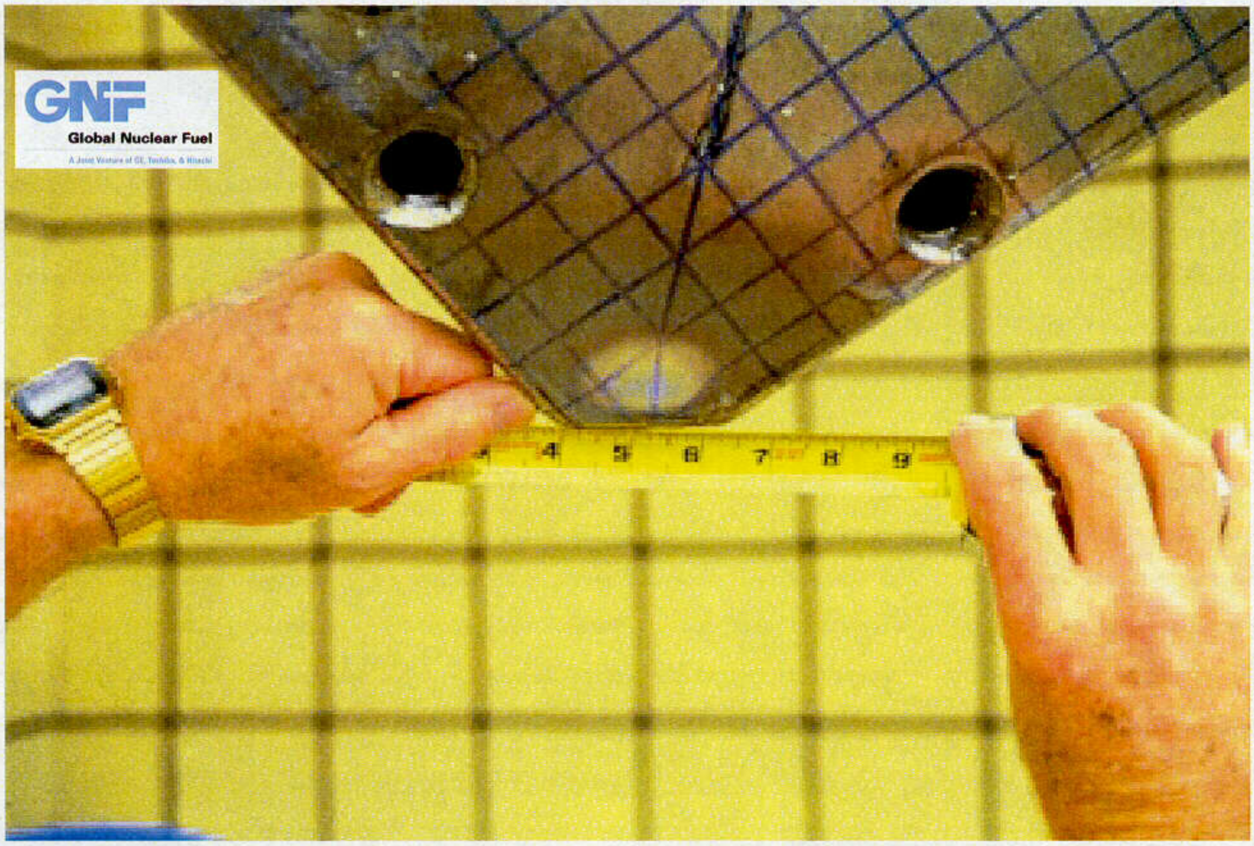


Figure 2.10.1-10 - CTU-1 Free Drop Test No. 1; OCA Lid Corner Damage; ~2½" Wide

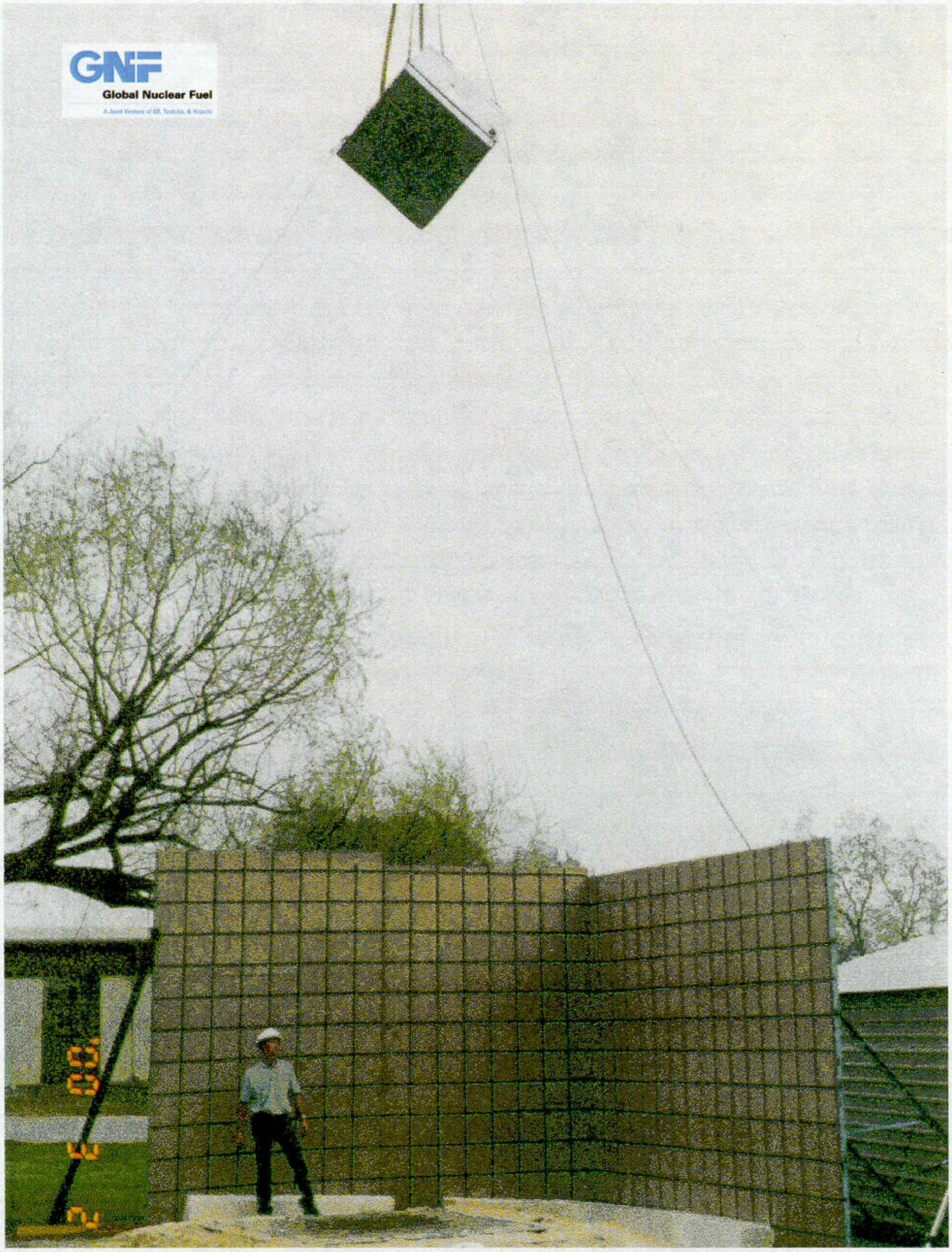


Figure 2.10.1-11 - CTU-1 Free Drop Test No. 2; HAC Drop onto OCA Lid Corner

C04

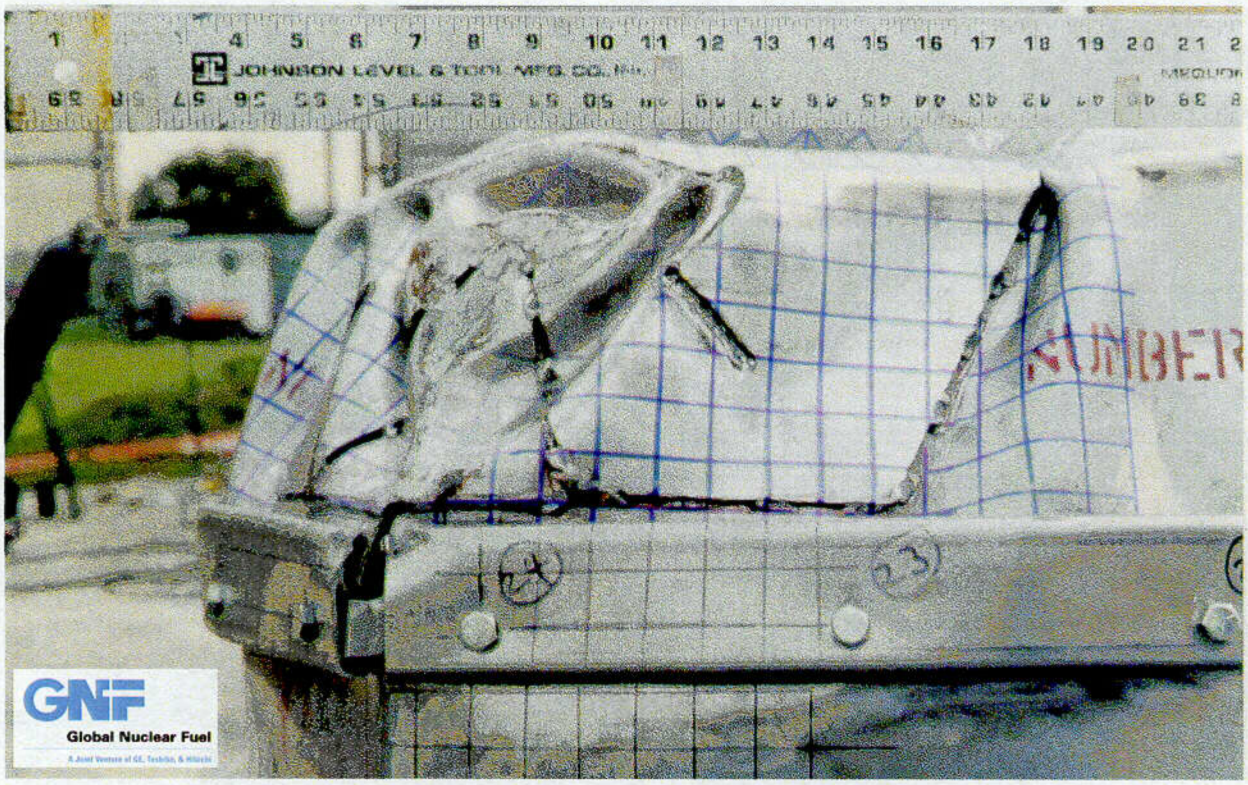


Figure 2.10.1-12 - CTU-1 Free Drop Test No. 2; Close-up View of Damage

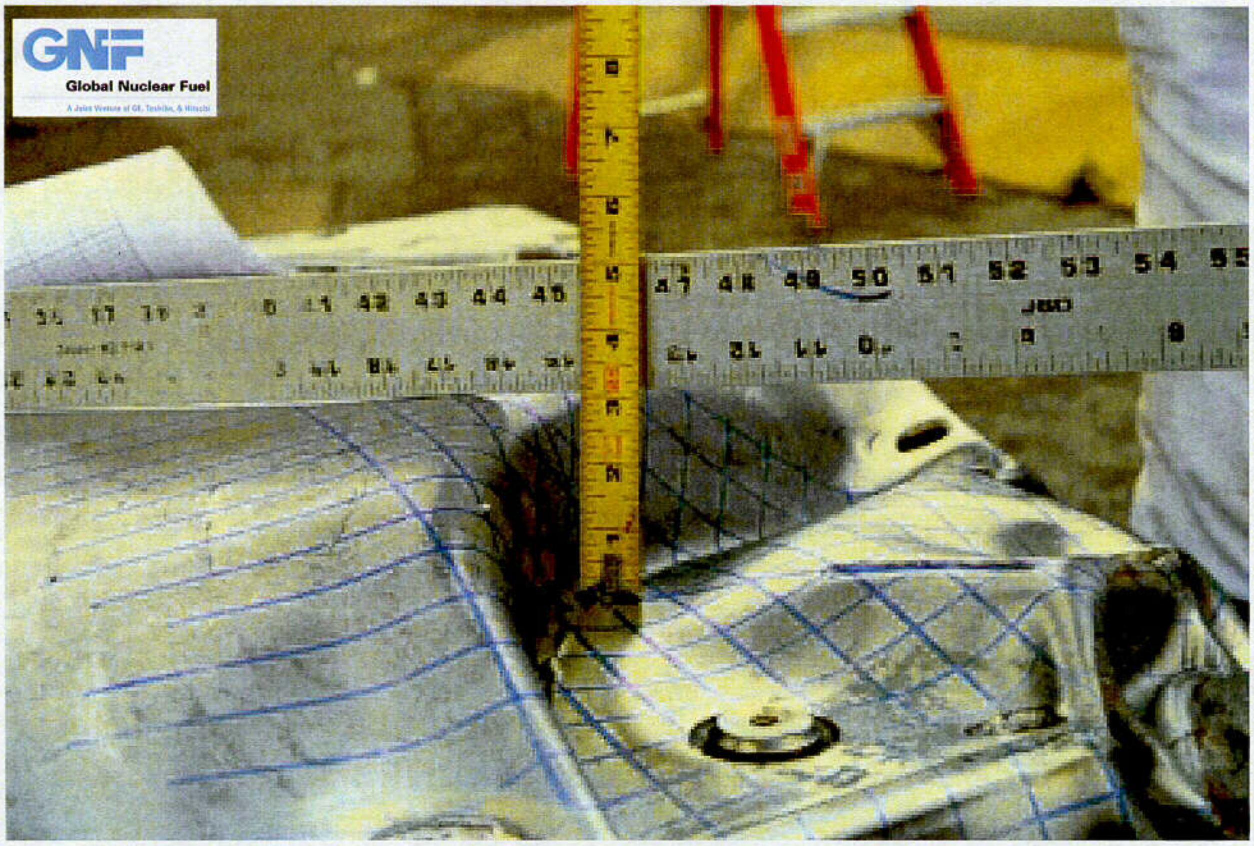


Figure 2.10.1-13 – CTU-1 Free Drop Test No. 2; Height of Buckle of OCA Lid Corner

C05

Figure 2.10.1-14 - CTU-1 Free Drop Test No. 2; Overall Vertical Deformation of OCA Lid Corner

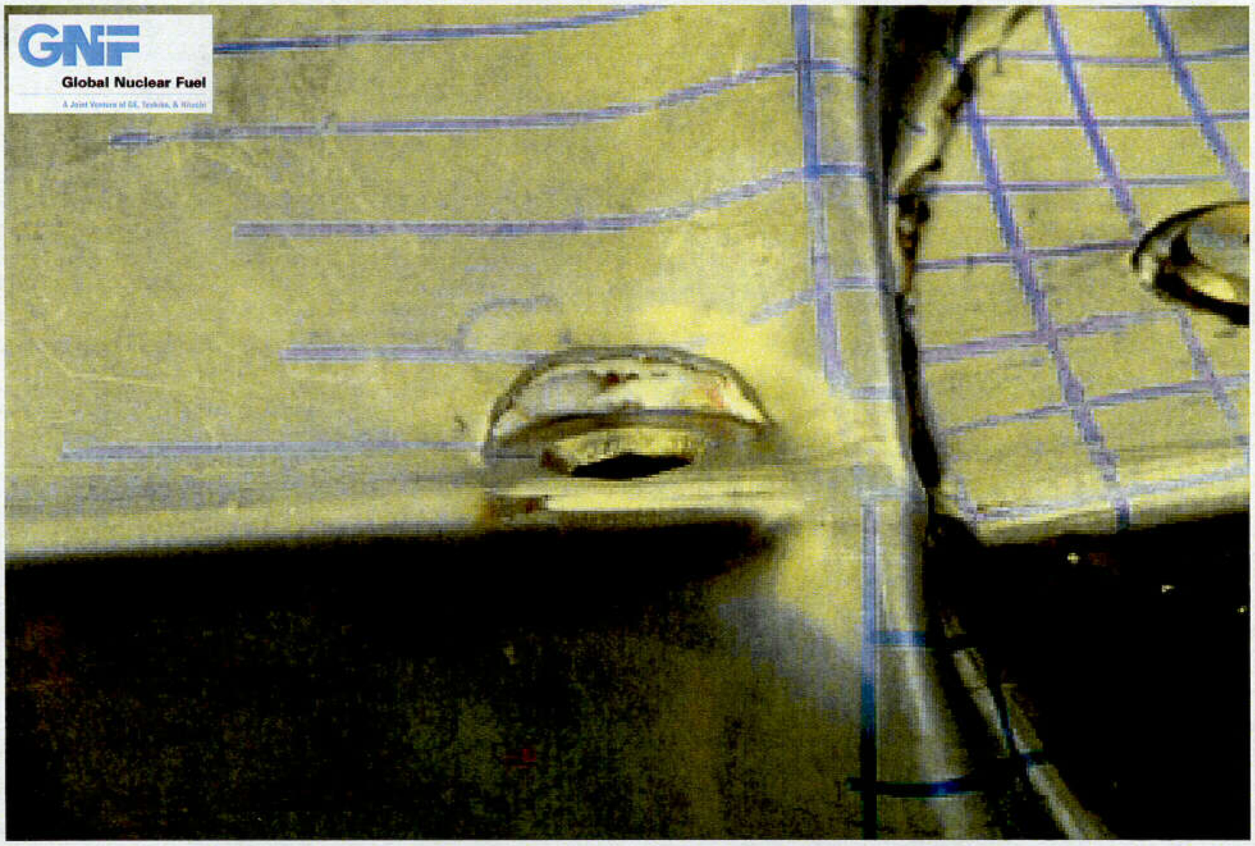


Figure 2.10.1-15 – CTU-1 Free Drop Test No. 2; Tear of OCA Lid Around Closure Bolt

C06

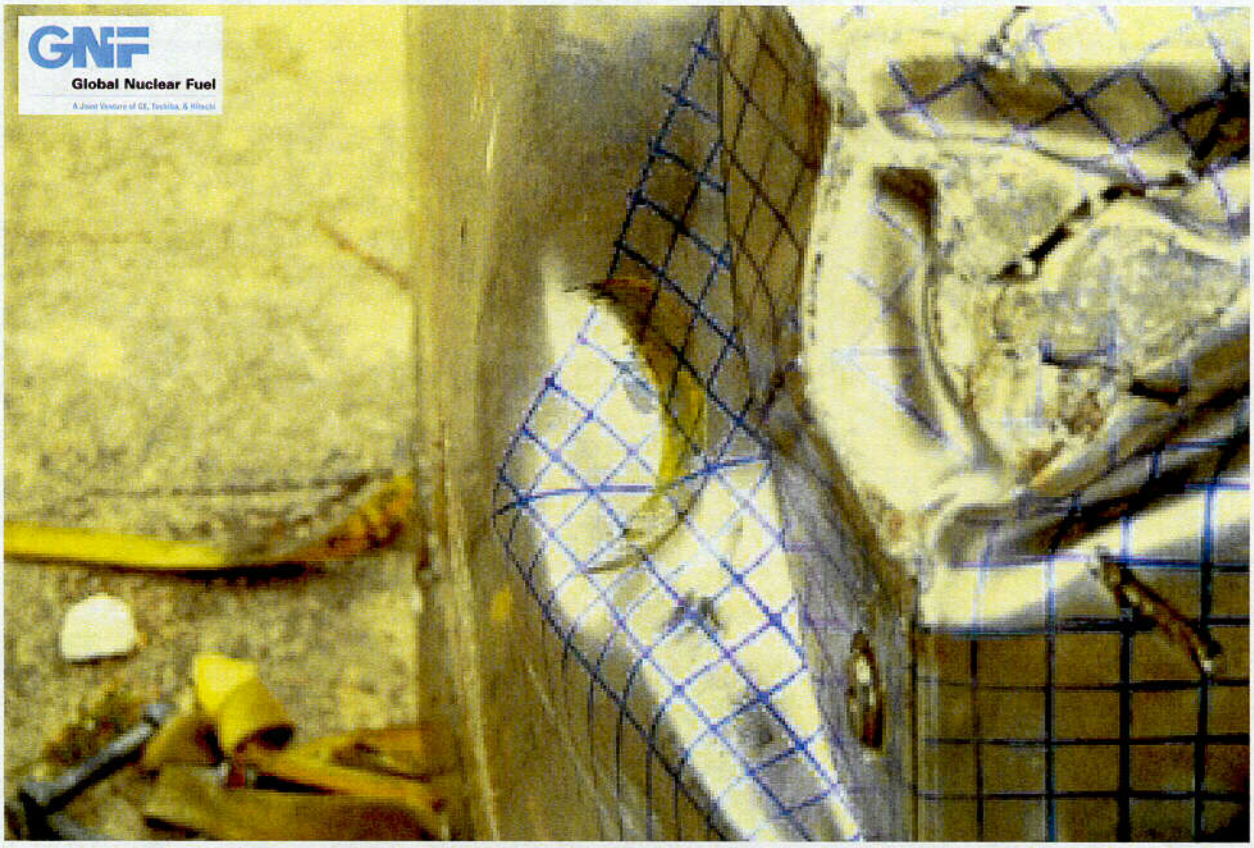


Figure 2.10.1-16 - CTU-1 Puncture Drop Test No. 10; Close-up of Damage

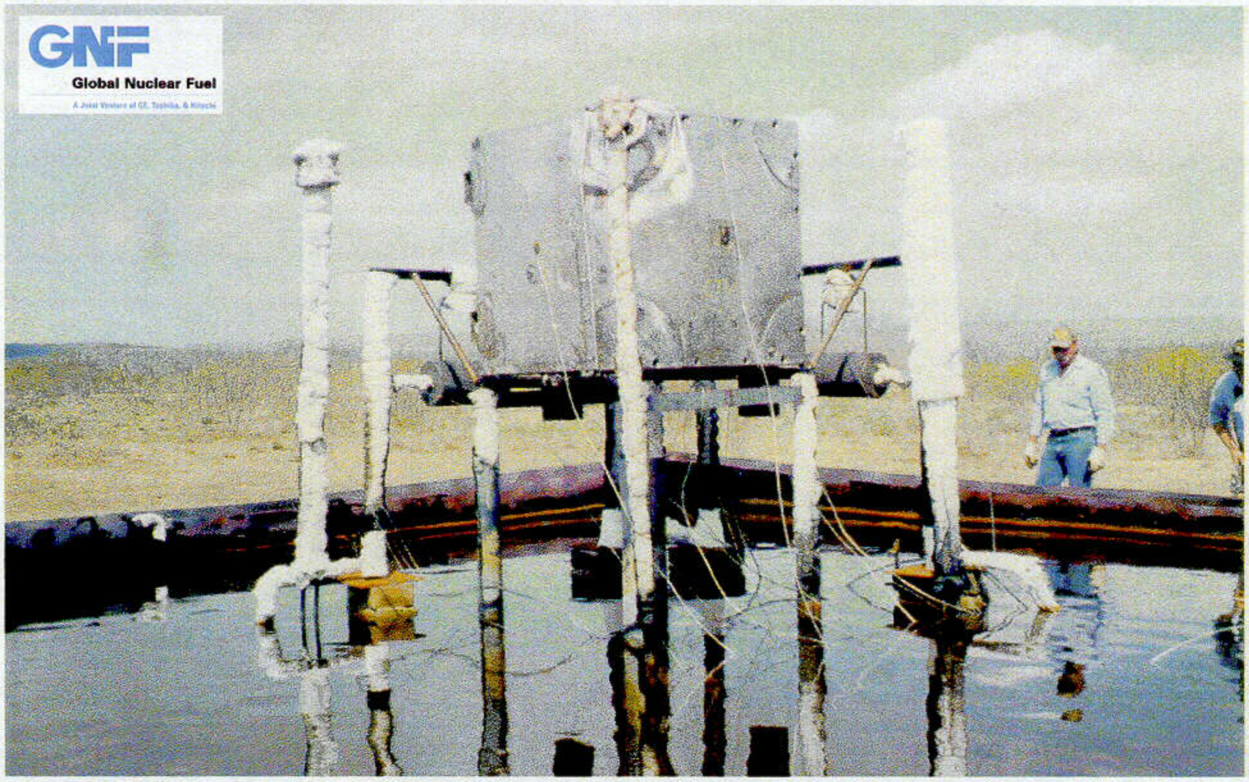


Figure 2.10.1-17 – CTU-1 Fire Test No. 15; View Before Fire Showing Tests 1, 2 & 8 Damage

C07

Figure 2.10.1-18 – CTU-1 Fire Test No. 15; Overall View ~3 Minutes after Start

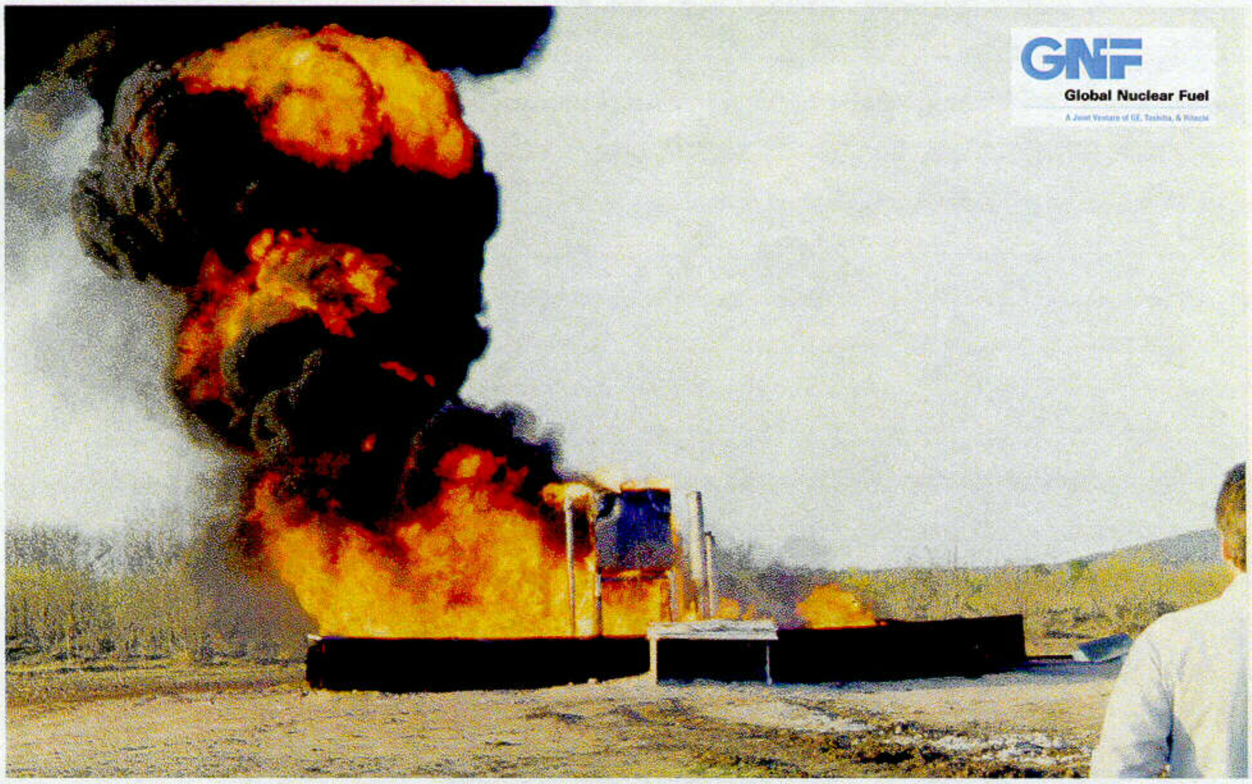


Figure 2.10.1-19 - CTU-1 Fire Test No. 15; Overall View ~32 Minutes after Start

C08

Figure 2.10.1-20 - CTU-1 Fire Test No. 15; View ~35 Minutes after Start

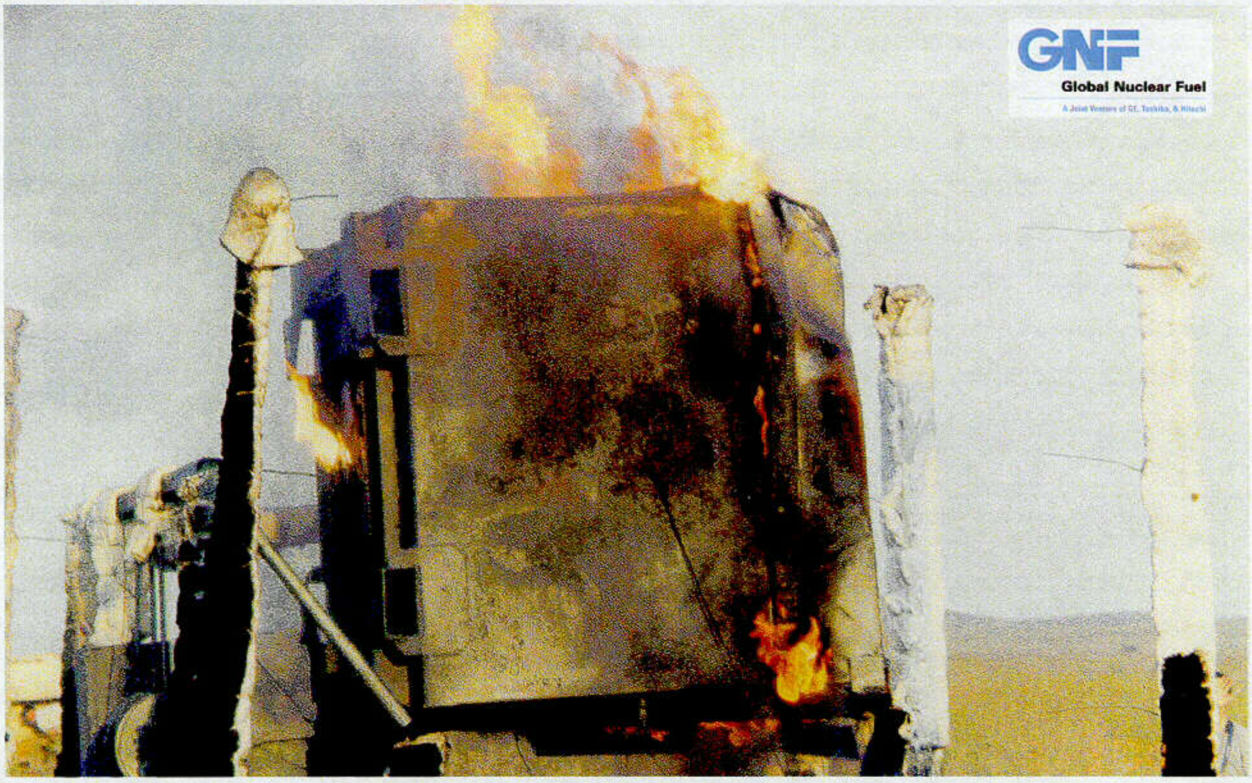


Figure 2.10.1-21 - CTU-1 Fire Test No. 15; View ~37 Minutes after Start (Note Flares at Vents)

C09

Figure 2.10.1-22 – CTU-1 Post-Test Disassembly; Overall View of Test Unit

Figure 2.10.1-23 – CTU-1 Post-Test Disassembly; Close-up View of Damage

Figure 2.10.1-24 – CTU-1 Post-Test Disassembly; View of OCA Body with OCA Lid Removed

Figure 2.10.1-25 – CTU-1 Post-Test Disassembly; View of Residual Foam w/ Foam Char Removed

Figure 2.10.1-26 – CTU-1 Post-Test Disassembly; View of ICCAs/Foam Block Structure

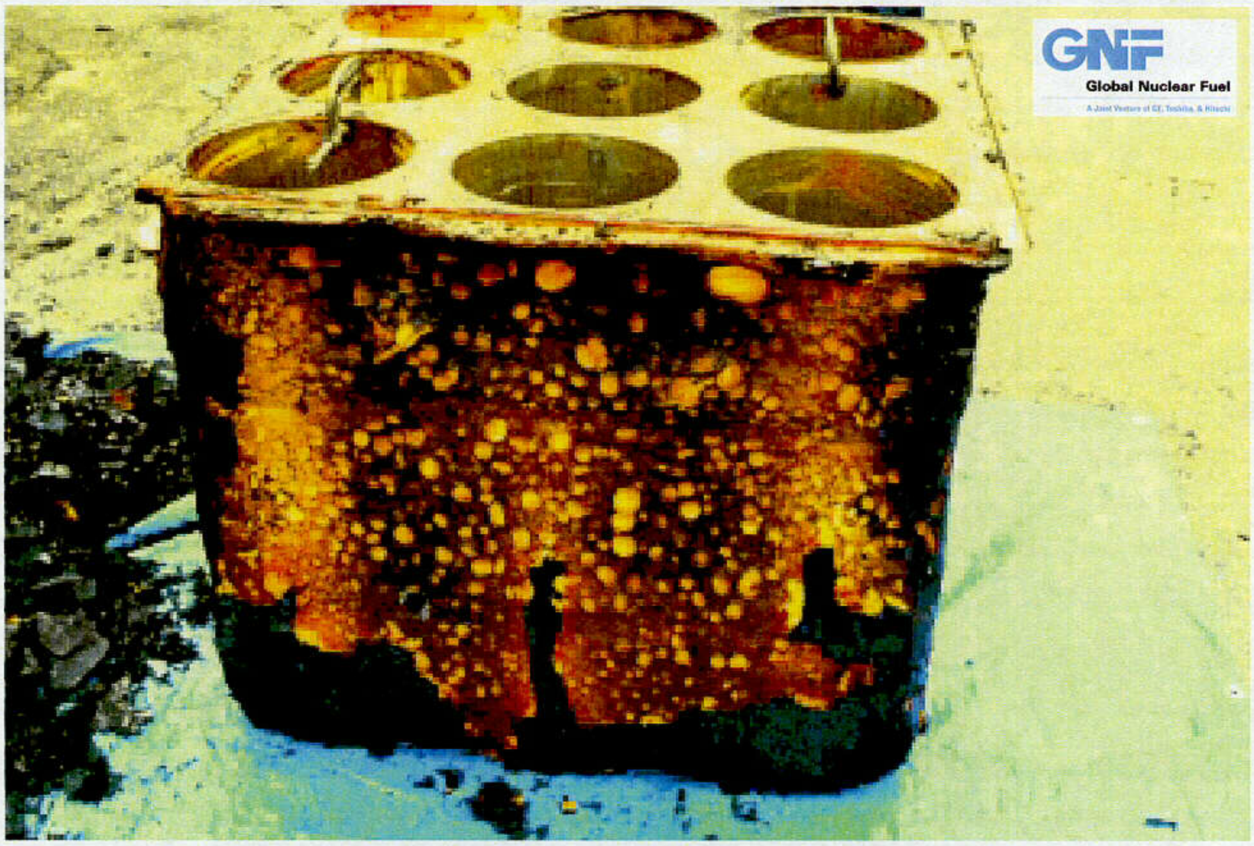


Figure 2.10.1-27 – CTU-1 Post-Test Disassembly; View of OCA Residual Foam Block

C/2

Figure 2.10.1-28 – CTU-1 Post-Test Disassembly; View of Foam Crack Near Impact Corner

C13

Figure 2.10.1-29 – CTU-1 Post-Test Disassembly; View of Bottom of OCA Residual Foam Block

Figure 2.10.1-30 – CTU-1 Post-Test Disassembly; View of Bottom Residual Foam from OCA Body

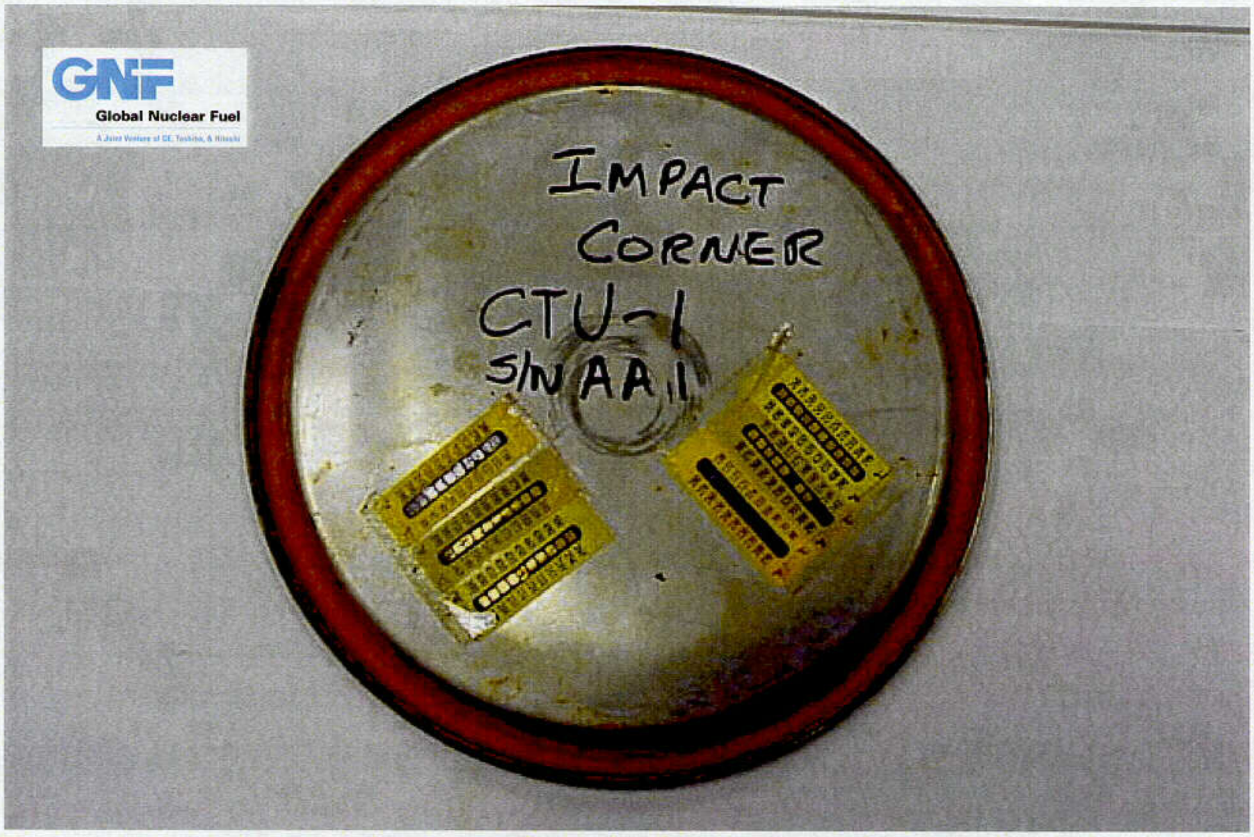


Figure 2.10.1-31 – CTU-1 Post-Test Disassembly; View of ICCA Closure Lid

Figure 2.10.1-32 – CTU-1 Post-Test Disassembly; Close-up View of ICCA Gasket

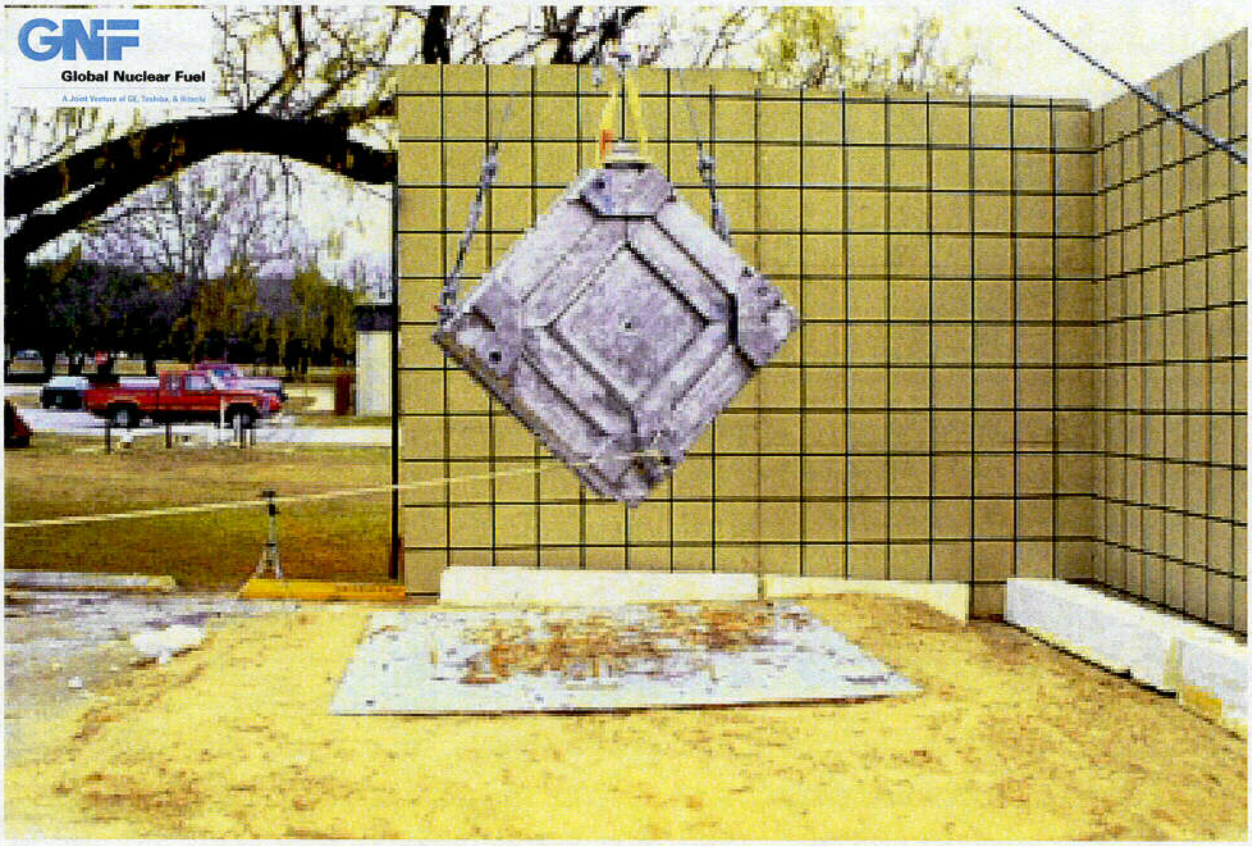


Figure 2.10.1-33 - CTU-2 Free Drop Test No. 3; NCT Drop on Side Edge

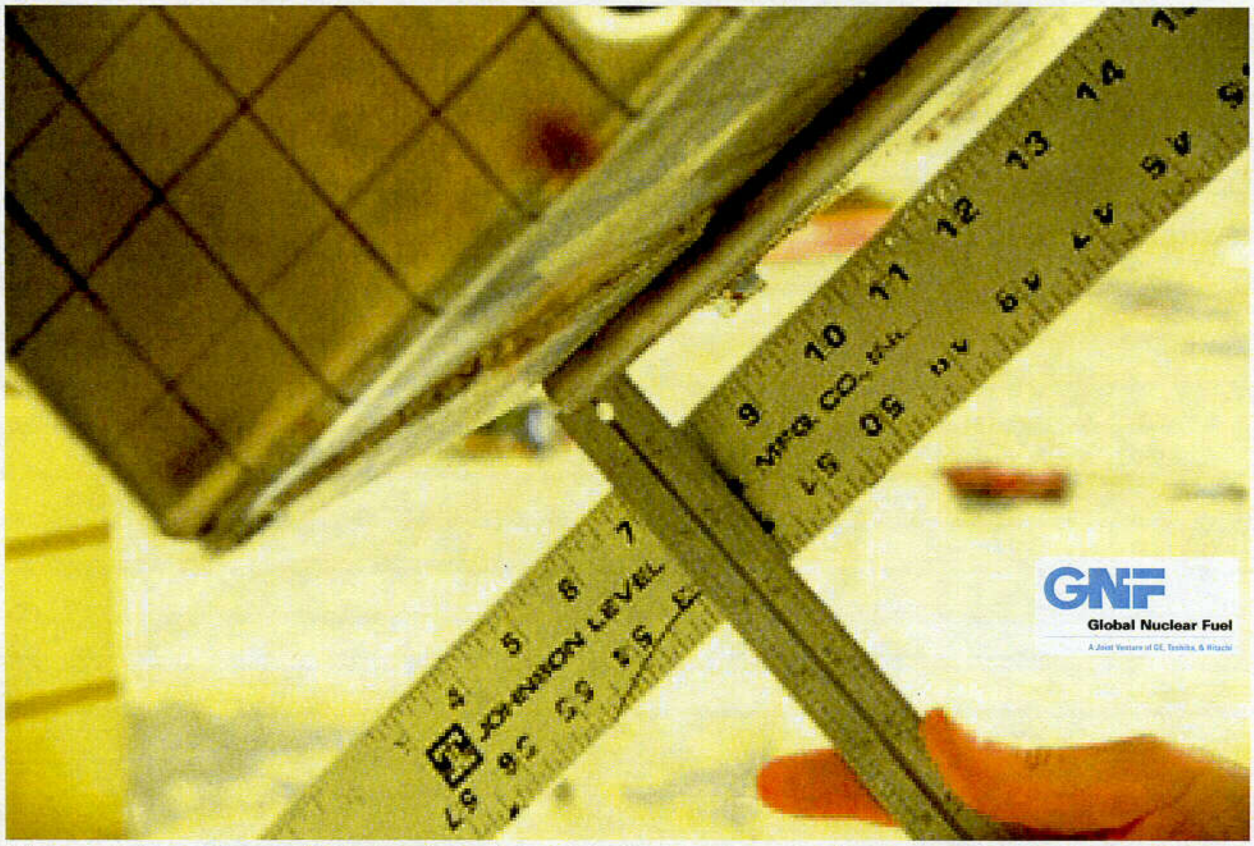


Figure 2.10.1-34 - CTU-2 Free Drop Test No. 3; Close-up Profile View of Damage; ~1" Deep

Figure 2.10.1-35 - CTU-2 Free Drop Test No. 4; HAC Drop on Side Edge

Figure 2.10.1-36 – CTU-2 Free Drop Test No. 4; OCA Side Edge Damage

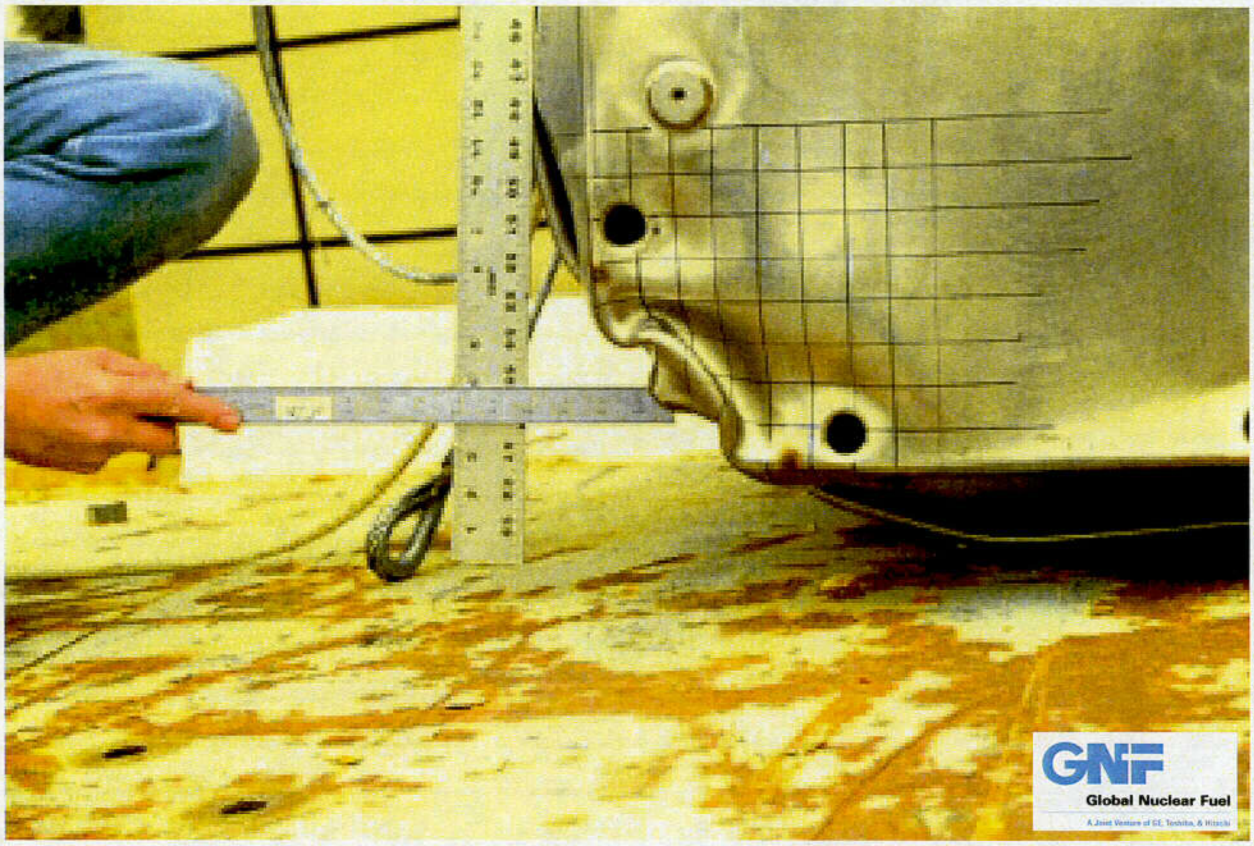


Figure 2.10.1-37 – CTU-2 Free Drop Test No. 4; Close-up View of Damage; ~4" Deep

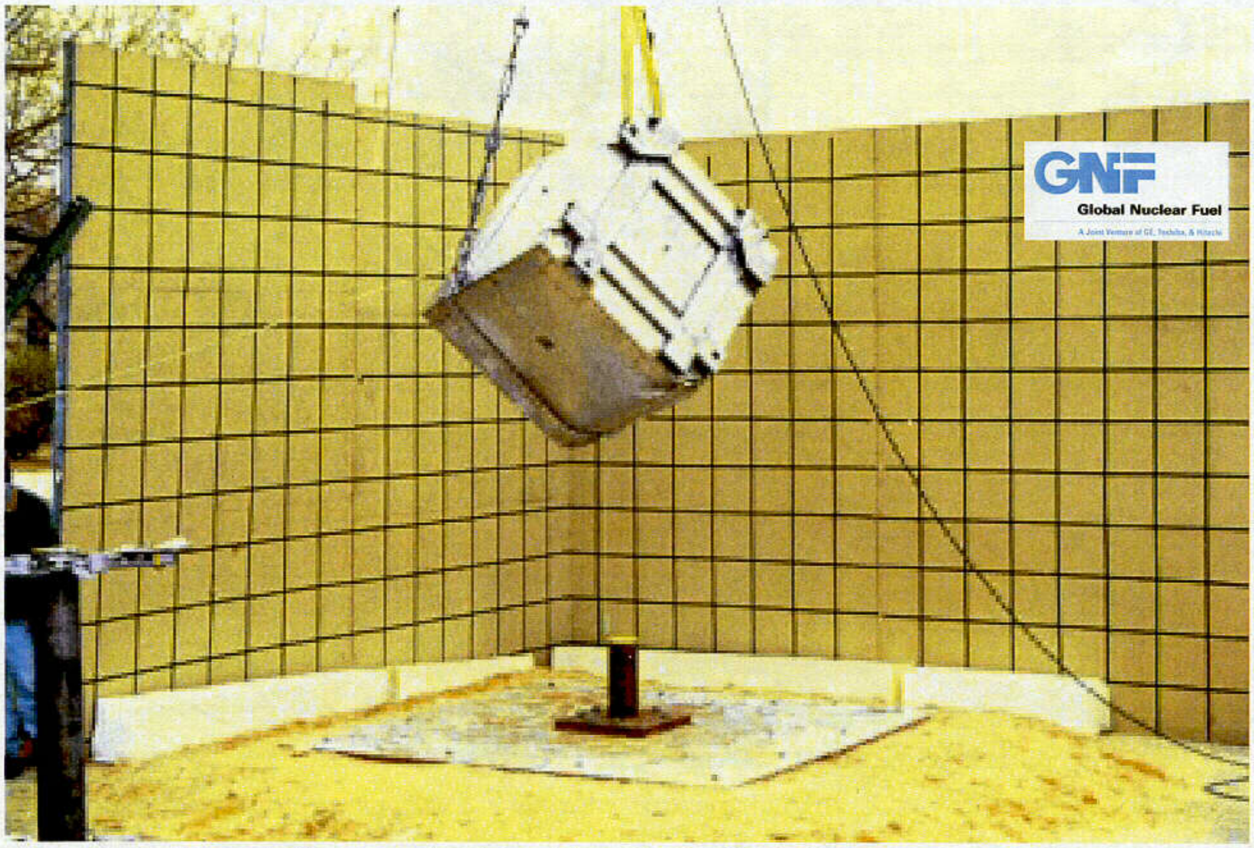


Figure 2.10.1-38 – CTU-2 Puncture Drop Test No. 9A & 9B; HAC Puncture, Lid/Body Interface

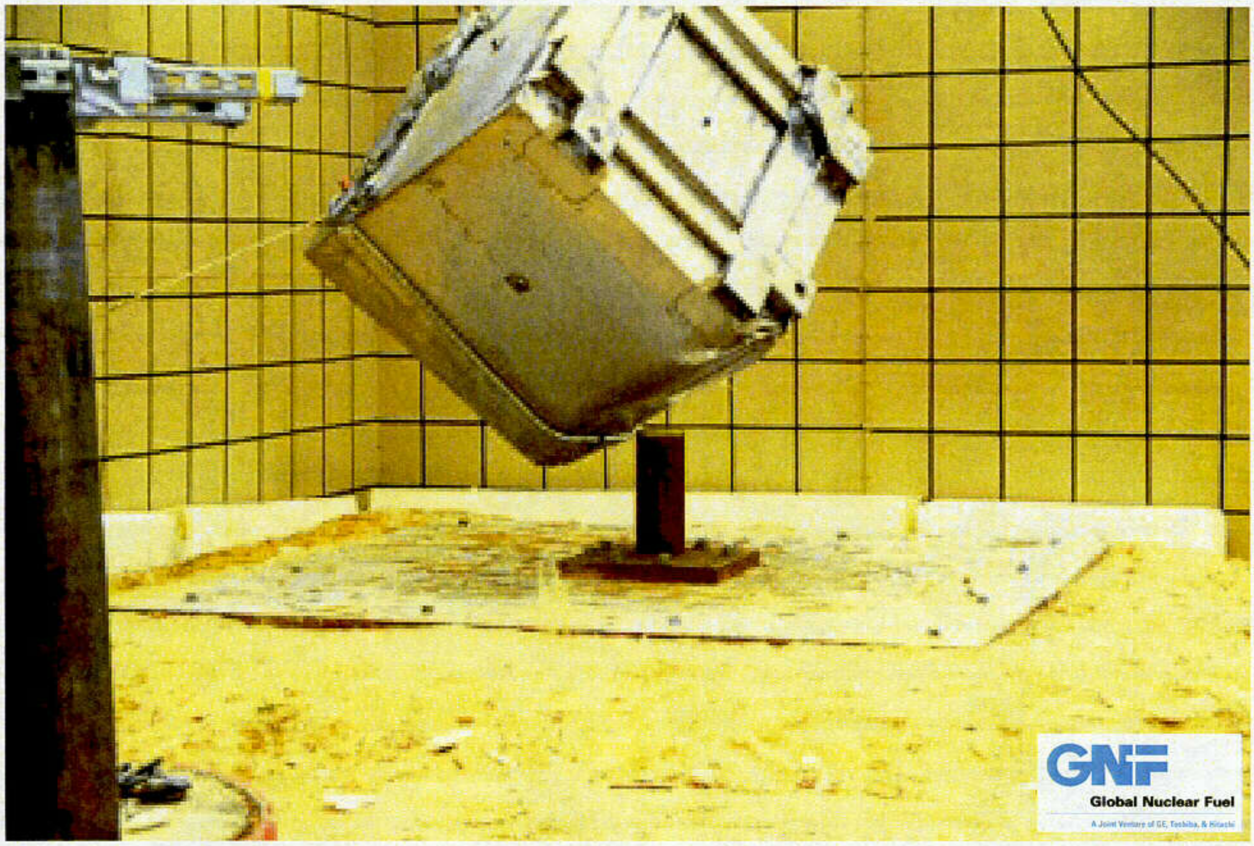


Figure 2.10.1-39 – CTU-2 Puncture Drop Test No. 9A, Immediately After Impact

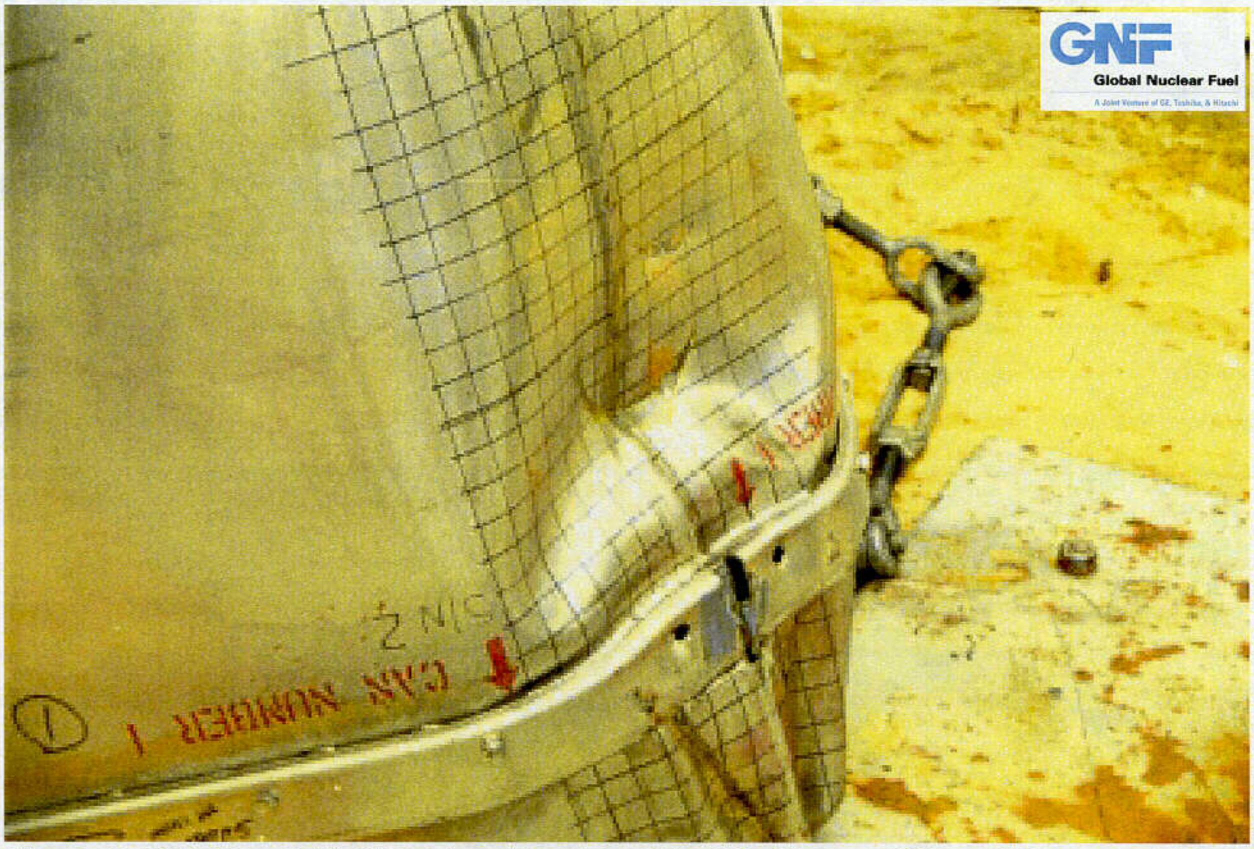


Figure 2.10.1-40 – CTU-2 Puncture Drop Test No. 9A; Close-up View of Damage

Figure 2.10.1-41 – CTU-2 Puncture Drop Test No. 9B; View of Damage

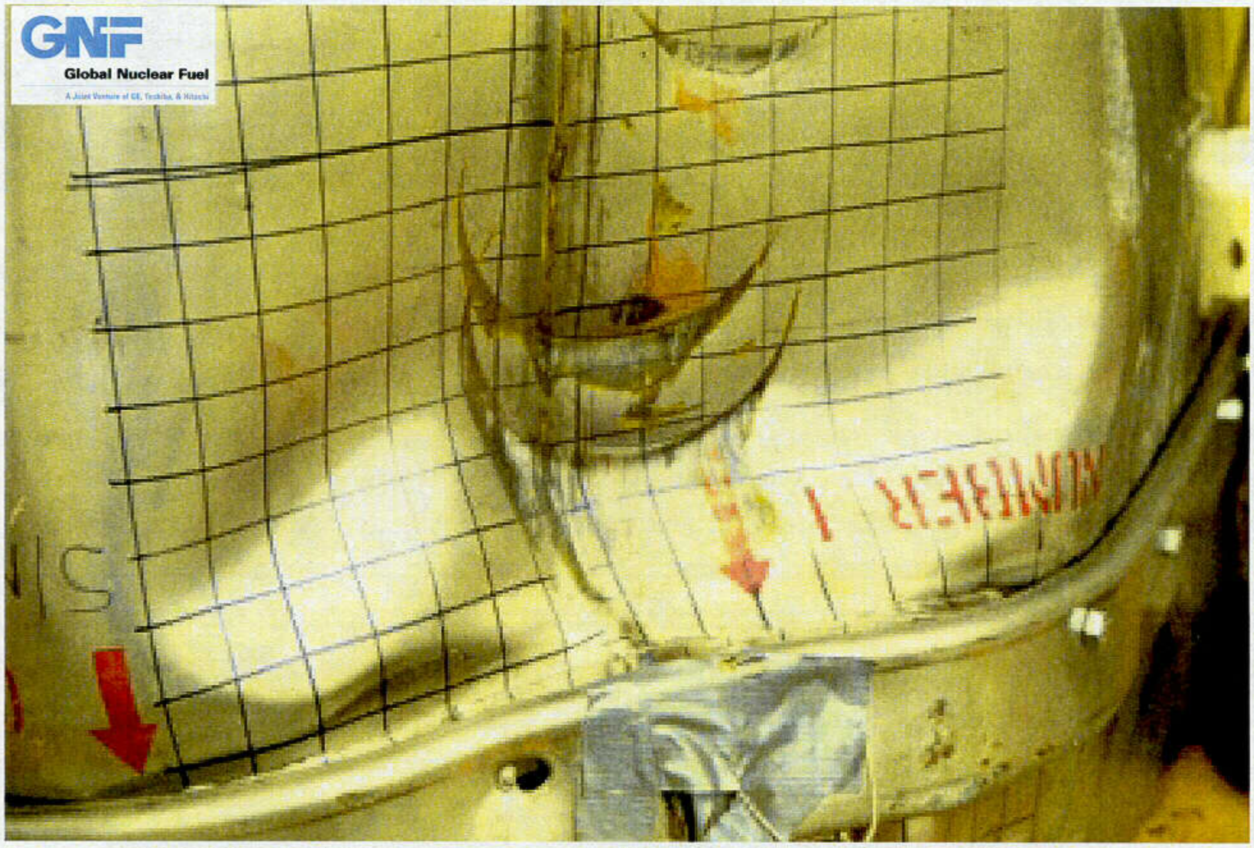


Figure 2.10.1-42 – CTU-2 Puncture Drop Test No. 9B; Close-up View of Damage

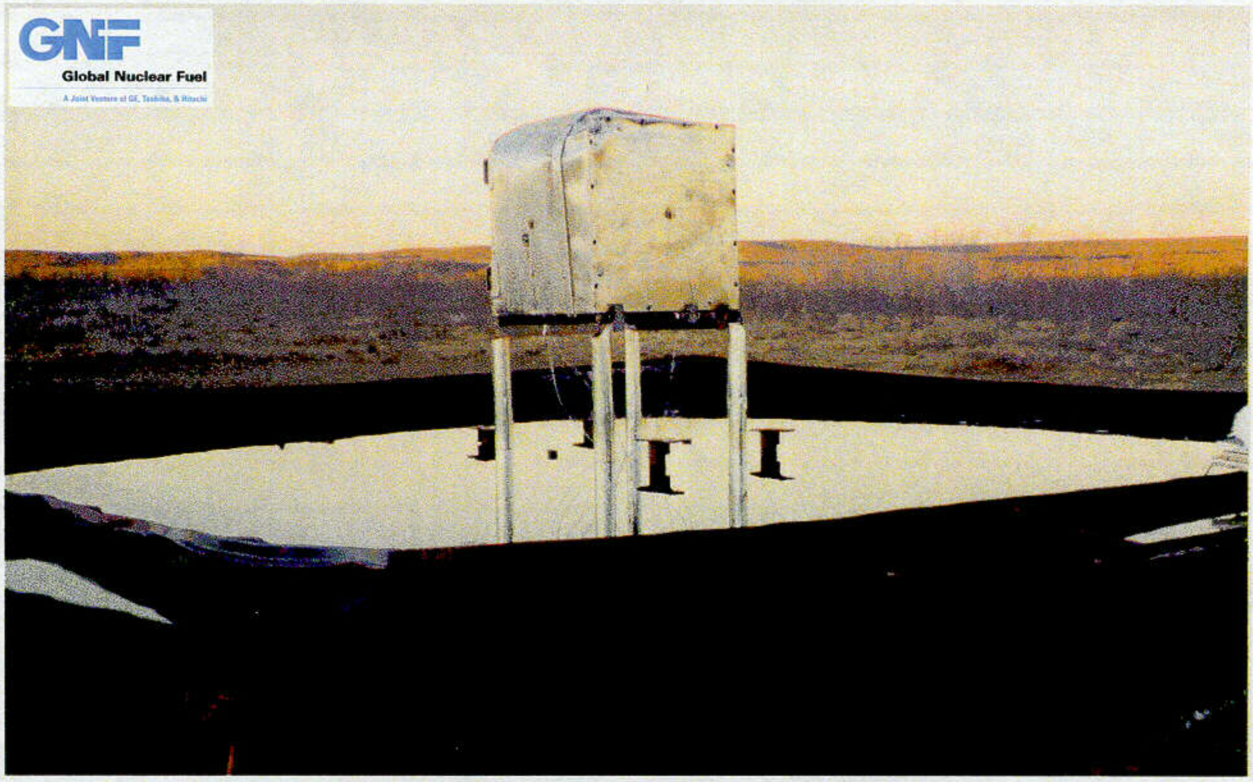


Figure 2.10.1-43 – CTU-2 Fire Test No. 15; View Before Fire Showing Tests 3, 4 & 9 Damage

Figure 2.10.1-44 – CTU-2 Fire Test No. 15; Initiation of Fire (00:00)

Figure 2.10.1-45 - CTU-2 Fire Test No. 15; View ~5 Minutes after Start

Figure 2.10.1-46 - CTU-2 Fire Test No. 15; View ~10 Minutes after Start

Figure 2.10.1-47 - CTU-2 Post-Test Disassembly; Overall View of Test Unit

Figure 2.10.1-48 – CTU-2 Post-Test Disassembly; View of OCA Body w/ OCA Lid Removed

Figure 2.10.1-49 – CTU-2 Post-Test Disassembly; Residual Foam with Foam Char Removed

Figure 2.10.1-50 – CTU-2 Post-Test Disassembly; View of ICCAs/Foam Block Structure

C25

Figure 2.10.1-51 – CTU-2 Post-Test Disassembly; View of Damage to ICCA Closest to Impact

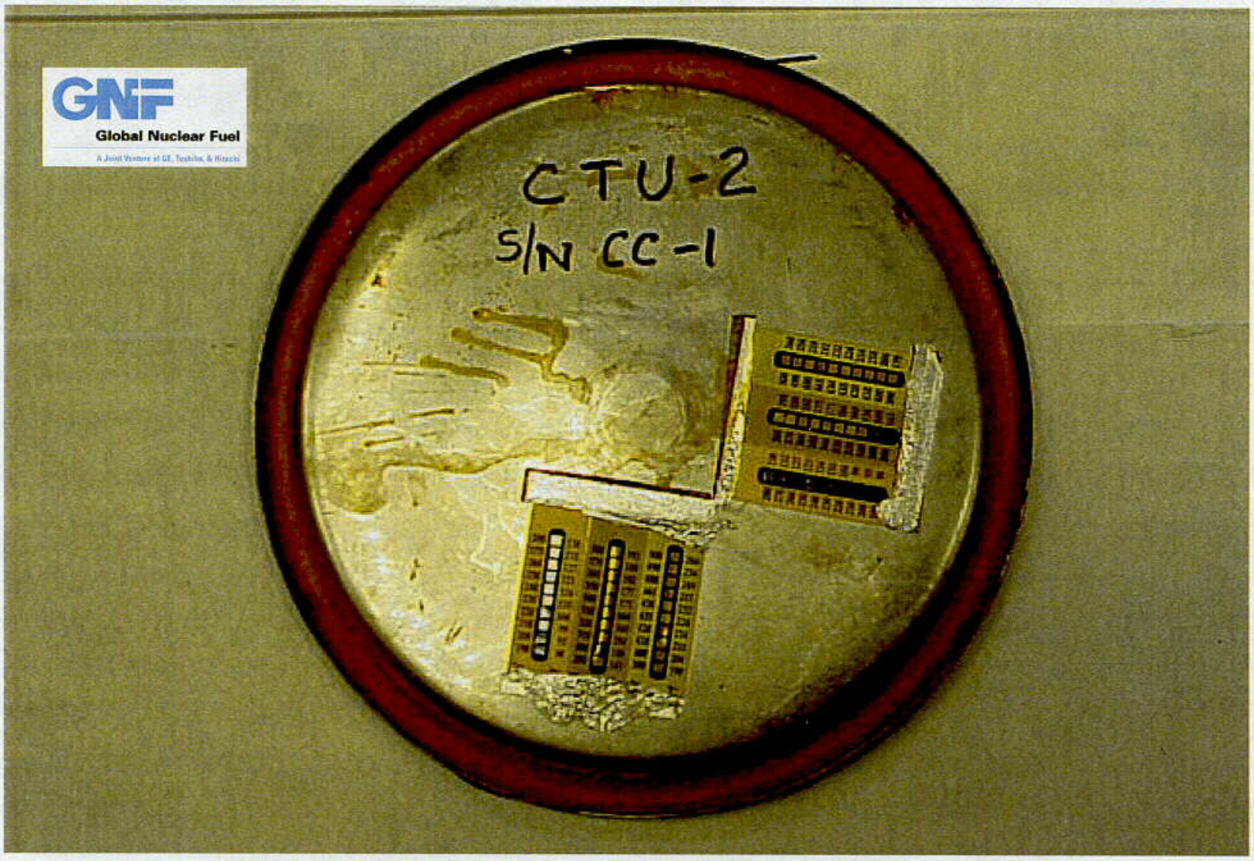


Figure 2.10.1-52 – CTU-2 Post-Test Disassembly; View of ICCA Closure Lid

Figure 2.10.1-53 – CTU-2 Post-Test Disassembly; View of ICCA Gasket

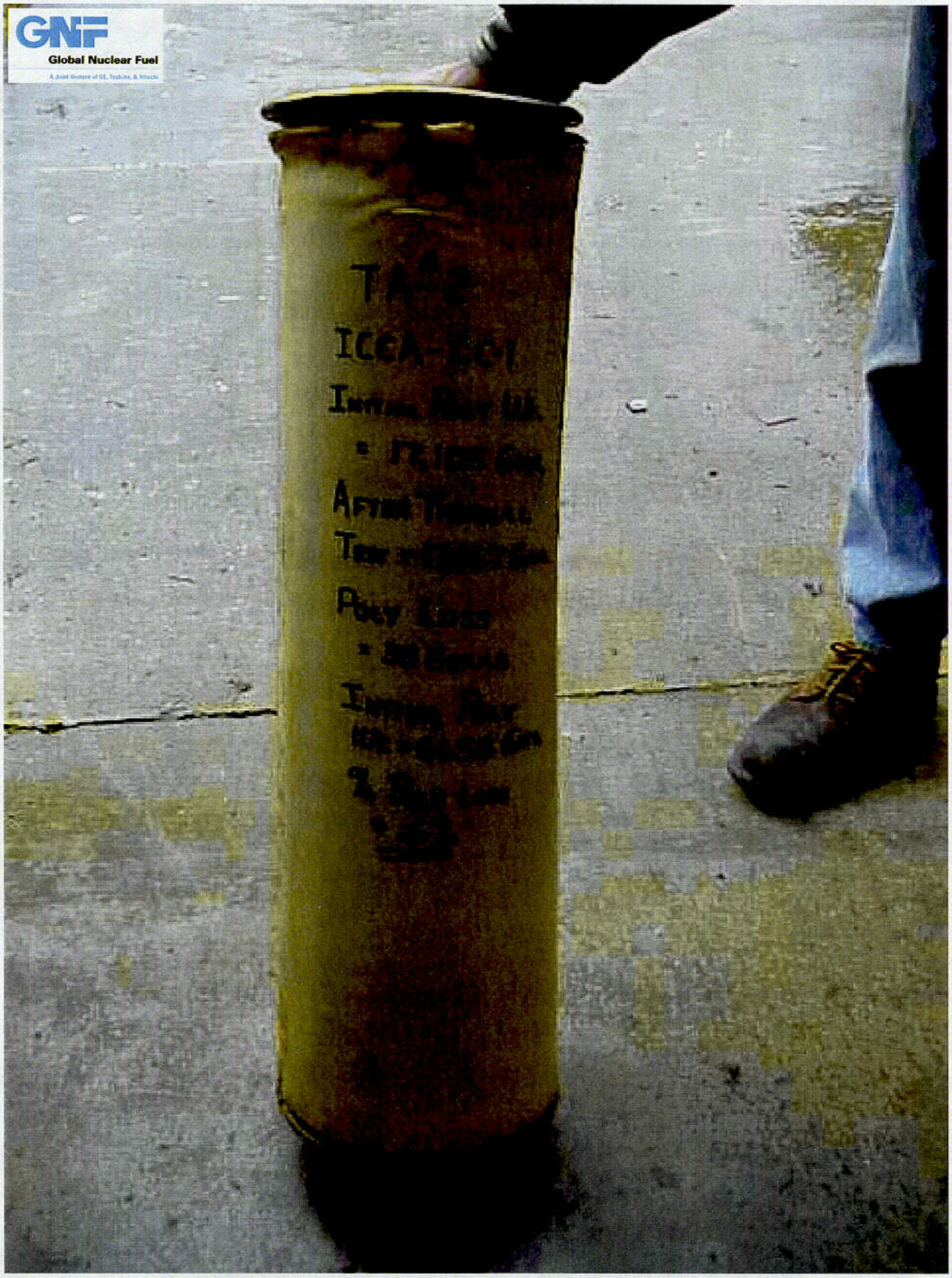


Figure 2.10.1-54 – CTU-2 Post-Test Disassembly; View of ICCA #1 Polyethylene Sheeting

Figure 2.10.1-55 – CTU-2 Post-Test Disassembly; View of OCA Residual Foam Block

Figure 2.10.1-56 – CTU-2 Post-Test Disassembly; View of Damage to OCA Foam Block

Figure 2.10.1-57 – CTU-3 Free Drop Test No. 1; NCT Drop onto OCA Lid Corner

Figure 2.10.1-58 – CTU-3 Free Drop Test No. 1; OCA Lid Corner Damage; ~5" Wide

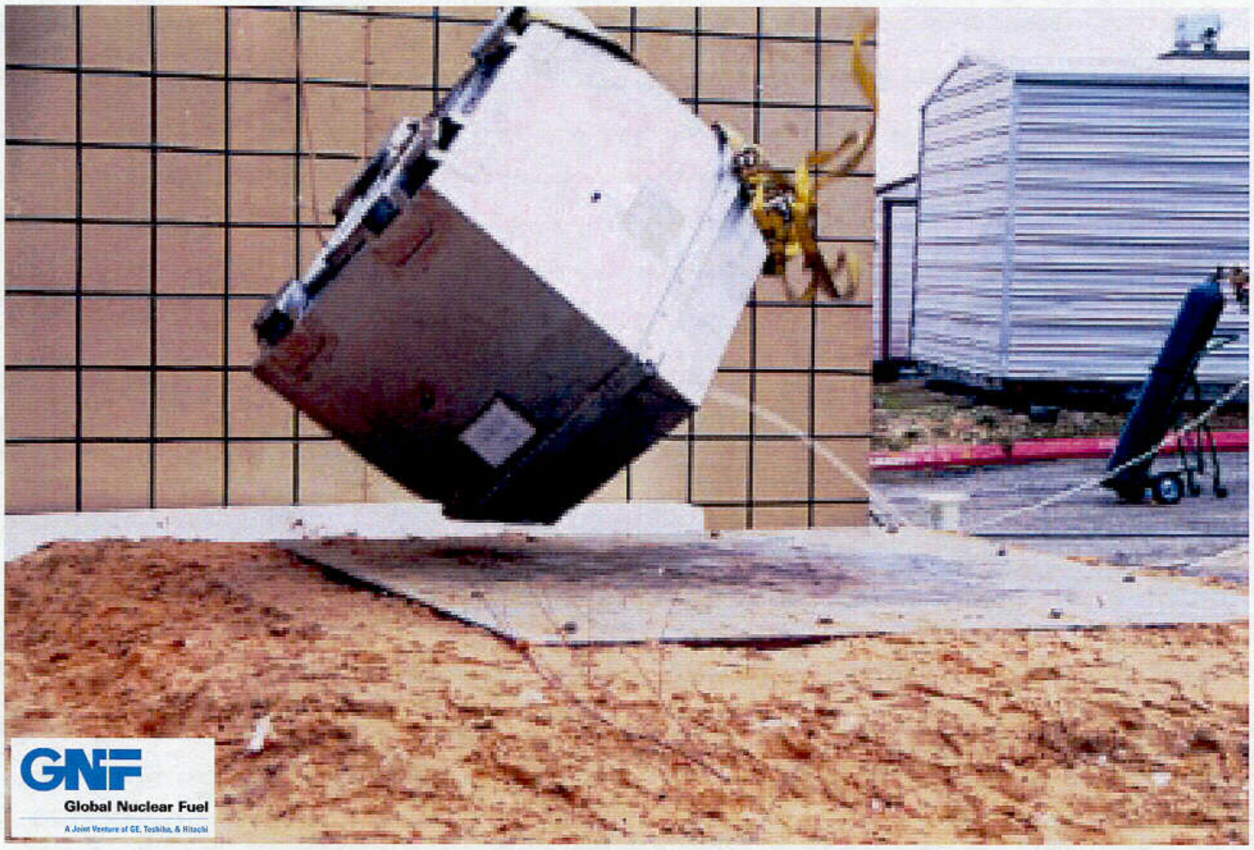


Figure 2.10.1-59 – CTU-3 Free Drop Test No. 2; View Immediately after Impact

Figure 2.10.1-60 – CTU-3 Free Drop Test No. 2; Close-up View of Damage

Figure 2.10.1-61 - CTU-3 Puncture Drop Test No. 11; Orientation of CTU Prior to Test

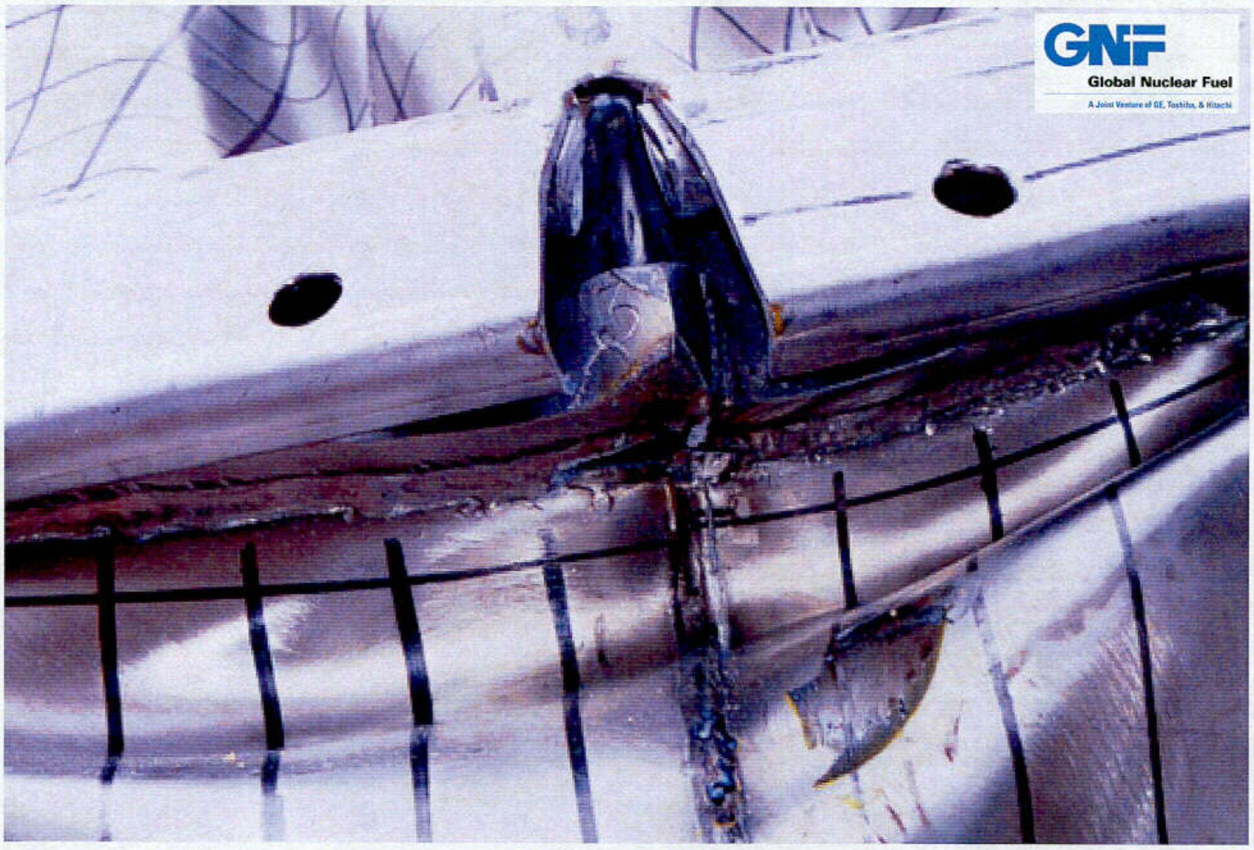


Figure 2.10.1-62 – CTU-3 Puncture Drop Test No. 11; Close-up View of Damage

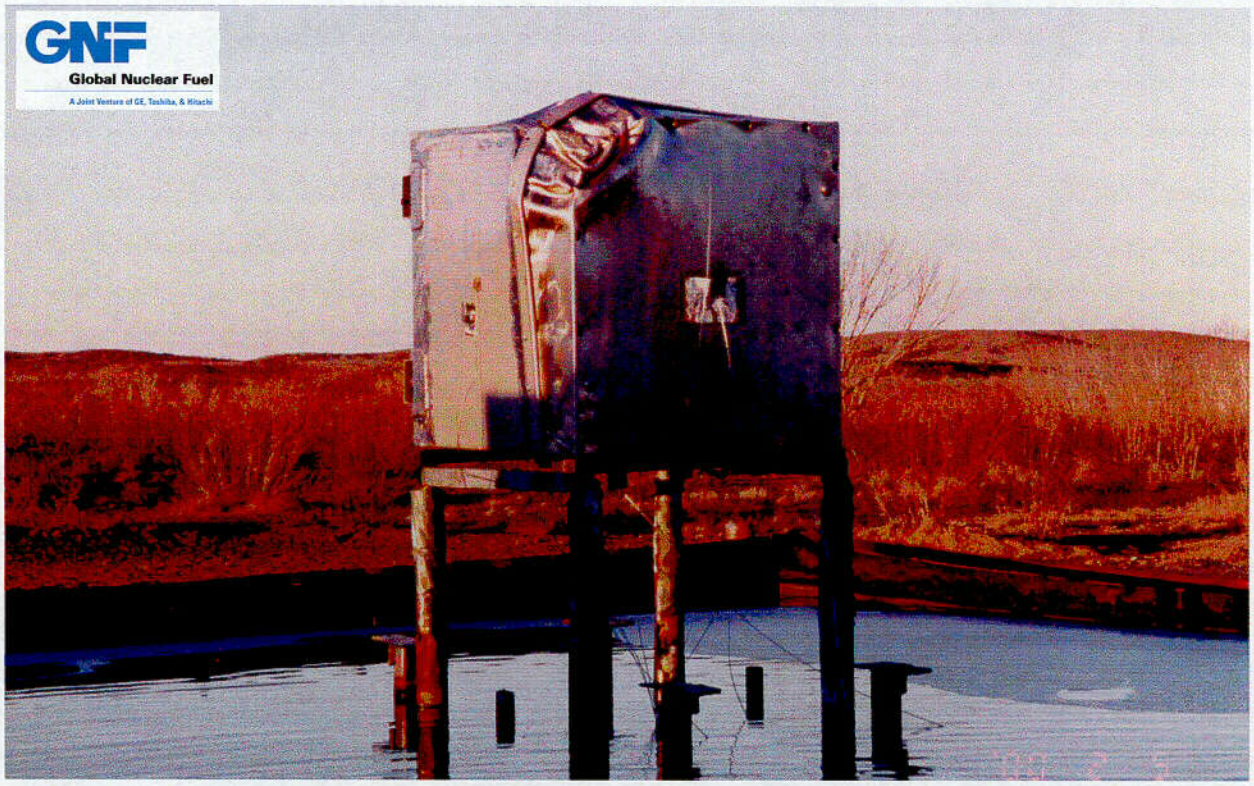


Figure 2.10.1-63 – CTU-3 Fire Test 15; View Before Fire Showing Tests 1, 2, & 11 Damage

Figure 2.10.1-64 – CTU-3 Fire Test 15; View ~ 6 Minutes after Start

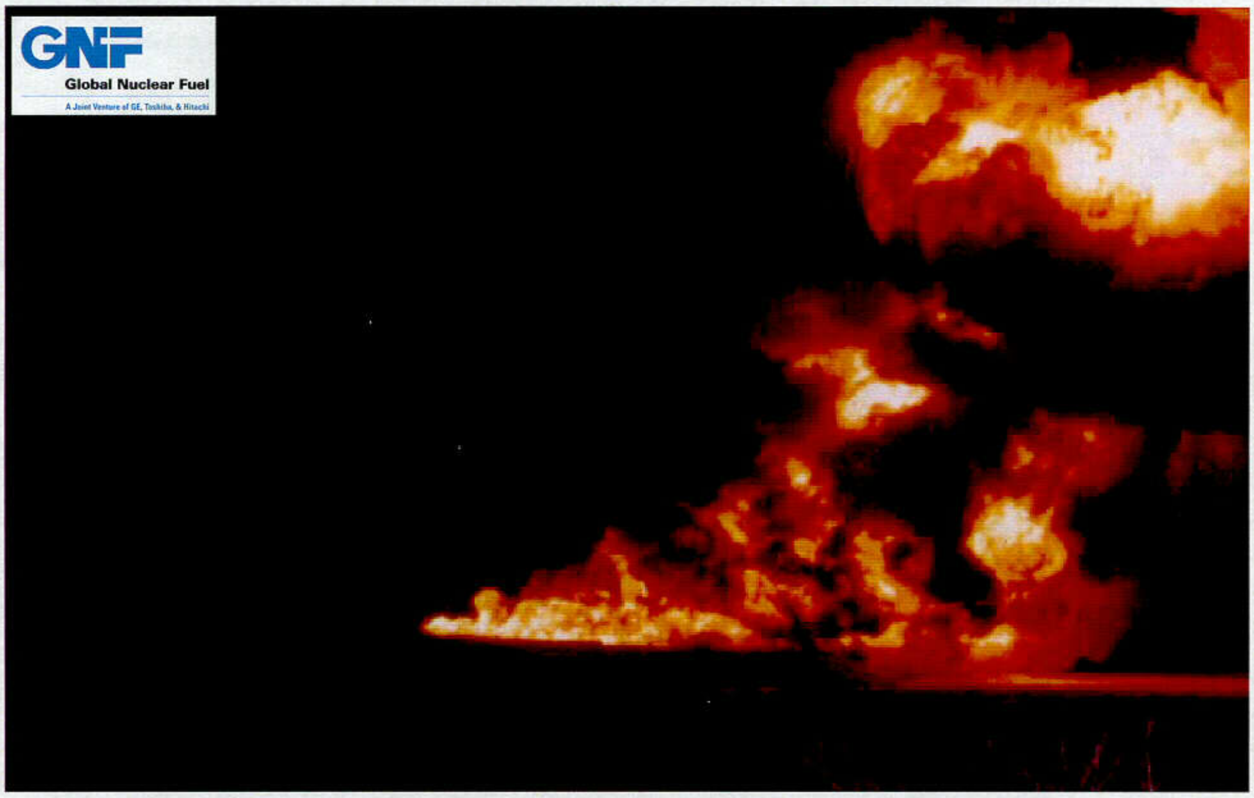


Figure 2.10.1-65 – CTU-3 Fire Test 15; View ~15 Minutes after Start

Figure 2.10.1-66 – CTU-3 Fire Test 15; View ~30 Minutes after Start

Figure 2.10.1-67 – CTU-3 Fire Test 15; View ~**15** Minutes after End of Fire (Note Flares)

Figure 2.10.1-68 – CTU-3 Post-Test Disassembly; Overall View of Test Unit

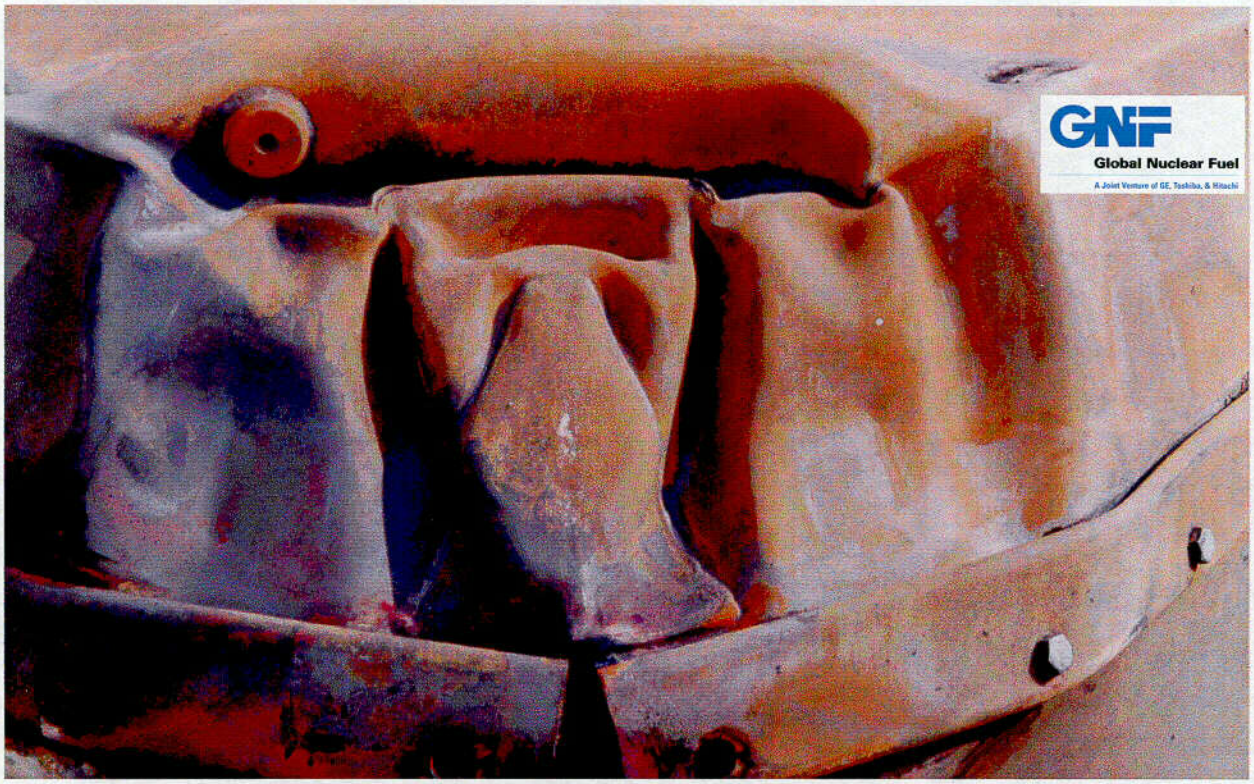


Figure 2.10.1-69 – CTU-3 Post-Test Disassembly; Close-up View of Damage

Figure 2.10.1-70 – CTU-3 Post-Test Disassembly; View of Burn-Through Hole

Figure 2.10.1-71 – CTU-3 Post-Test Disassembly; View with OCA Lid Removed

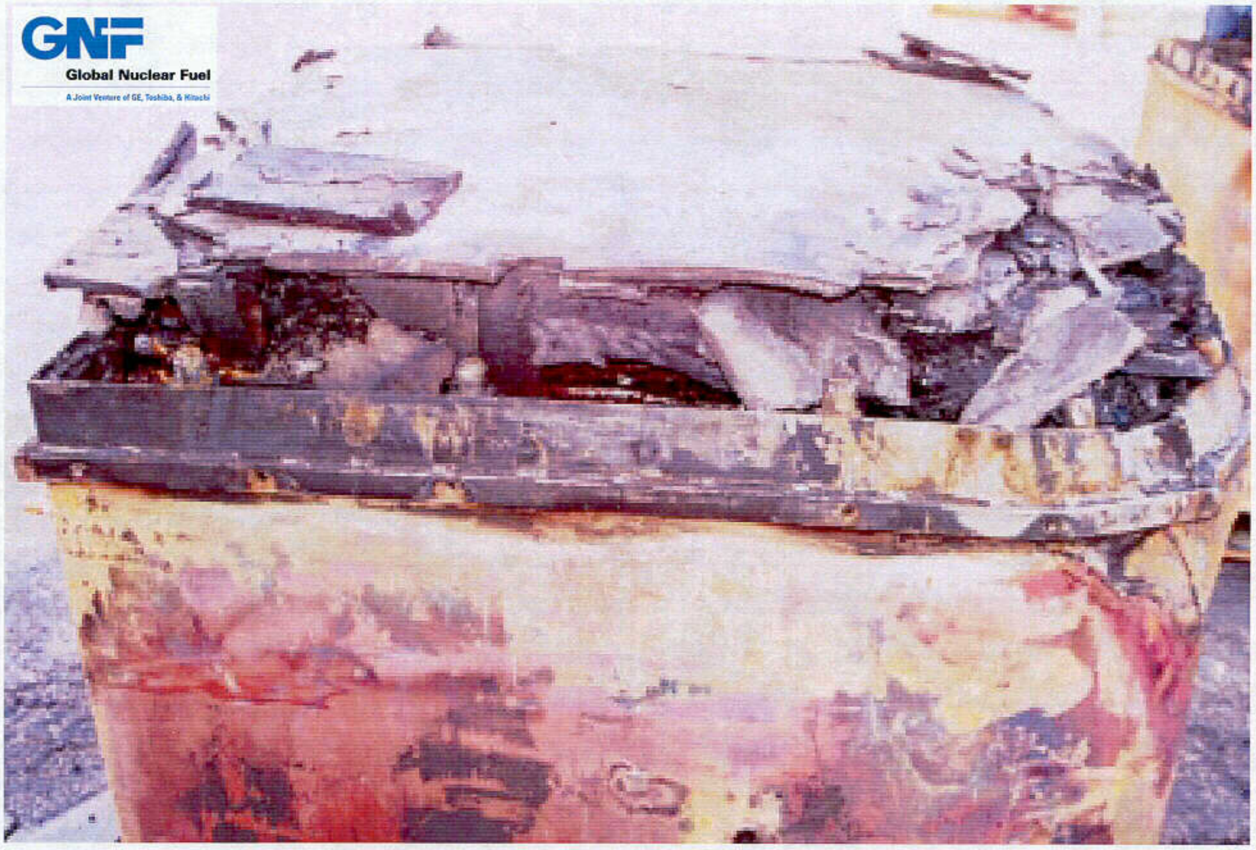


Figure 2.10.1-72 – CTU-3 Post-Test Disassembly; View with OCA Lid Removed

Figure 2.10.1-73 – CTU-3 Post-Test Disassembly; View of ICCAs/Foam Block Structure

Figure 2.10.1-74 – CTU-3 Post-Test Disassembly; Close-up View of Damaged ICCA Closure Lid

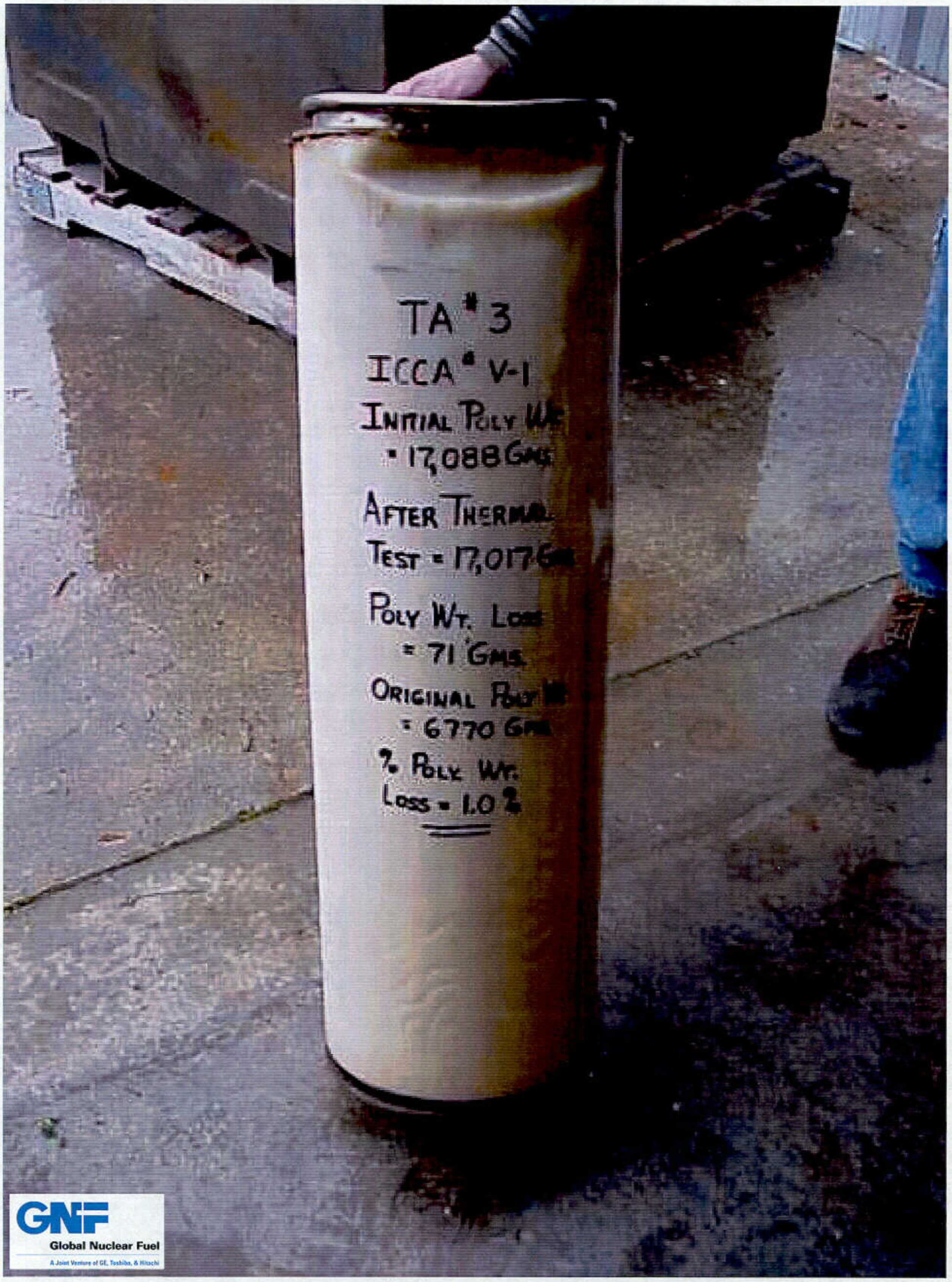


Figure 2.10.1-75 – CTU-3 Post-Test Disassembly; View of ICCA #1 Polyethylene Sheeting

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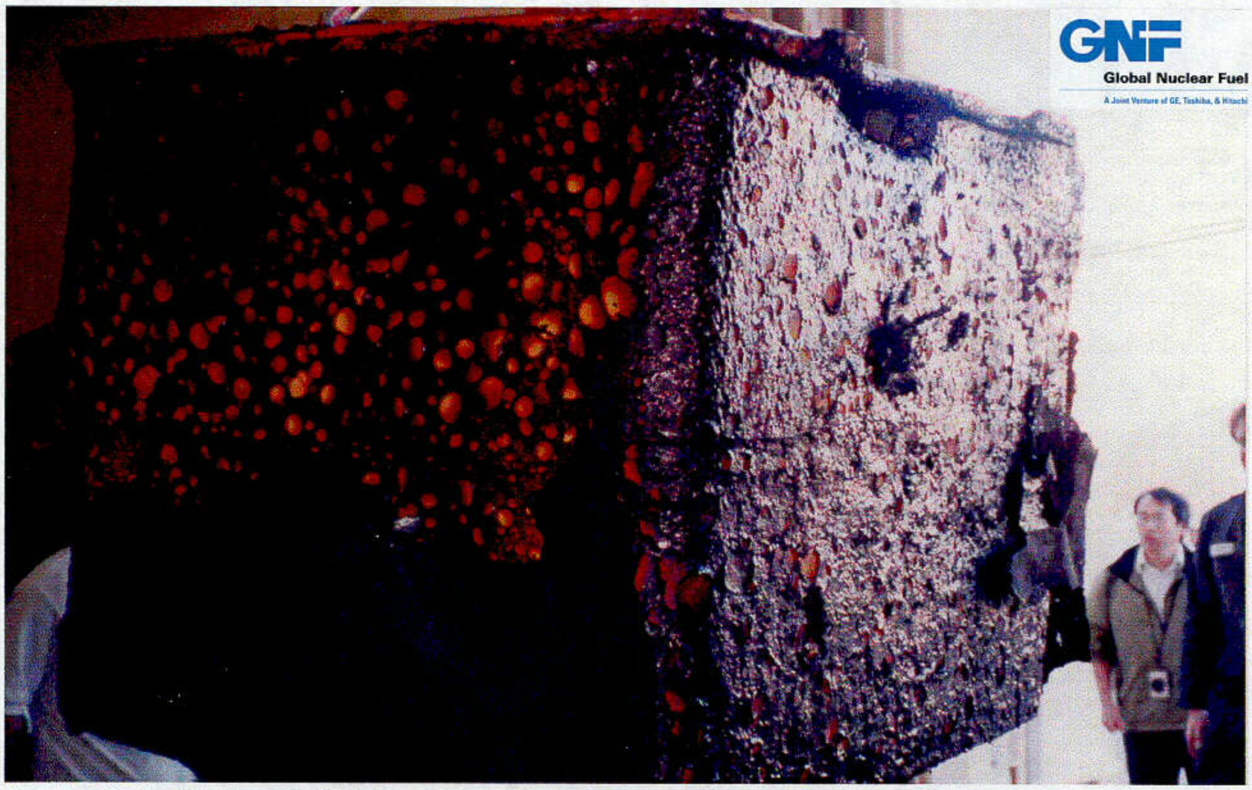

Figure 2.10.1-76 – CTU-3 Post-Test Disassembly; View of Residual OCA Foam Block

Figure 2.10.1-77 – CTU-3 Post-Test Disassembly; View of Residual OCA Bottom Foam

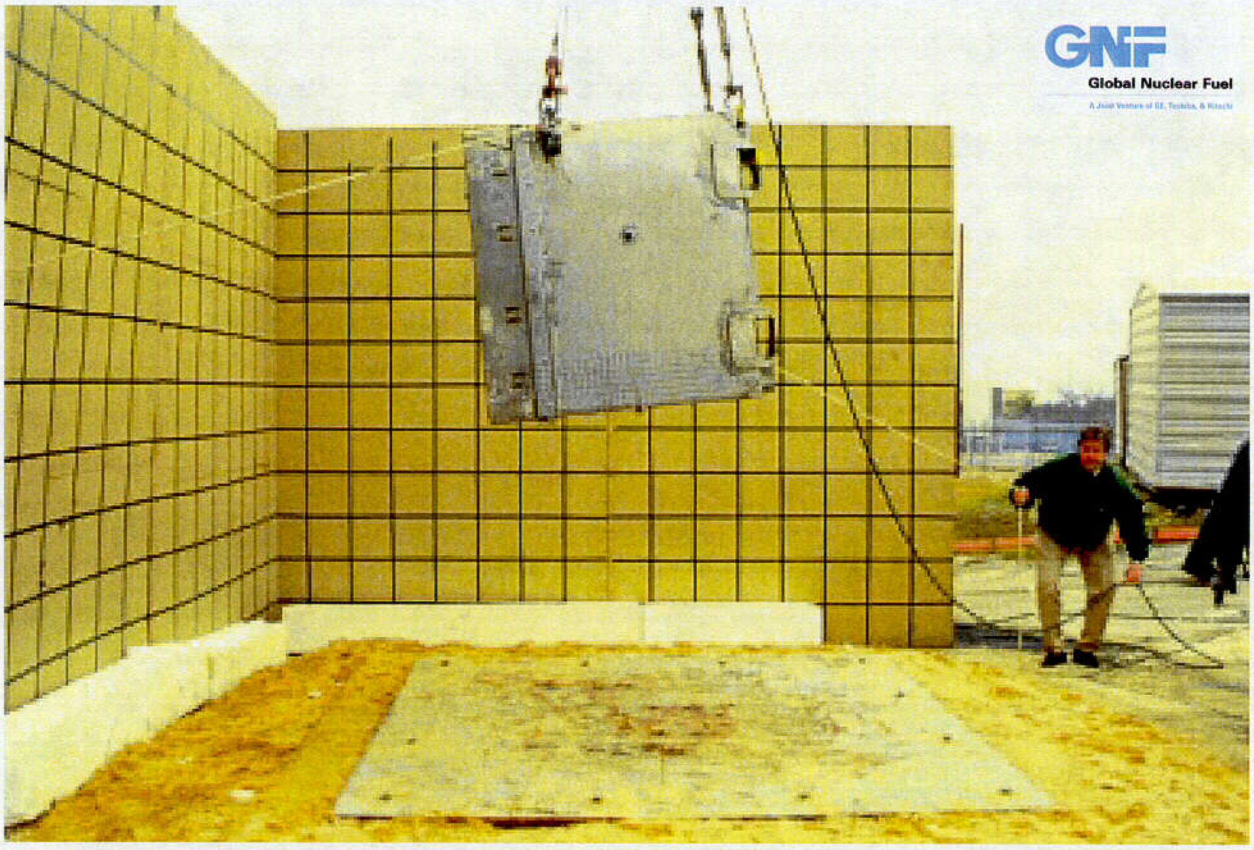

Figure 2.10.1-78 – CTU-4 Free Drop Test No. 5; NCT Shallow Angle Drop onto OCA Lid

Figure 2.10.1-79 – CTU-4 Free Drop Test No. 6; View of Damage

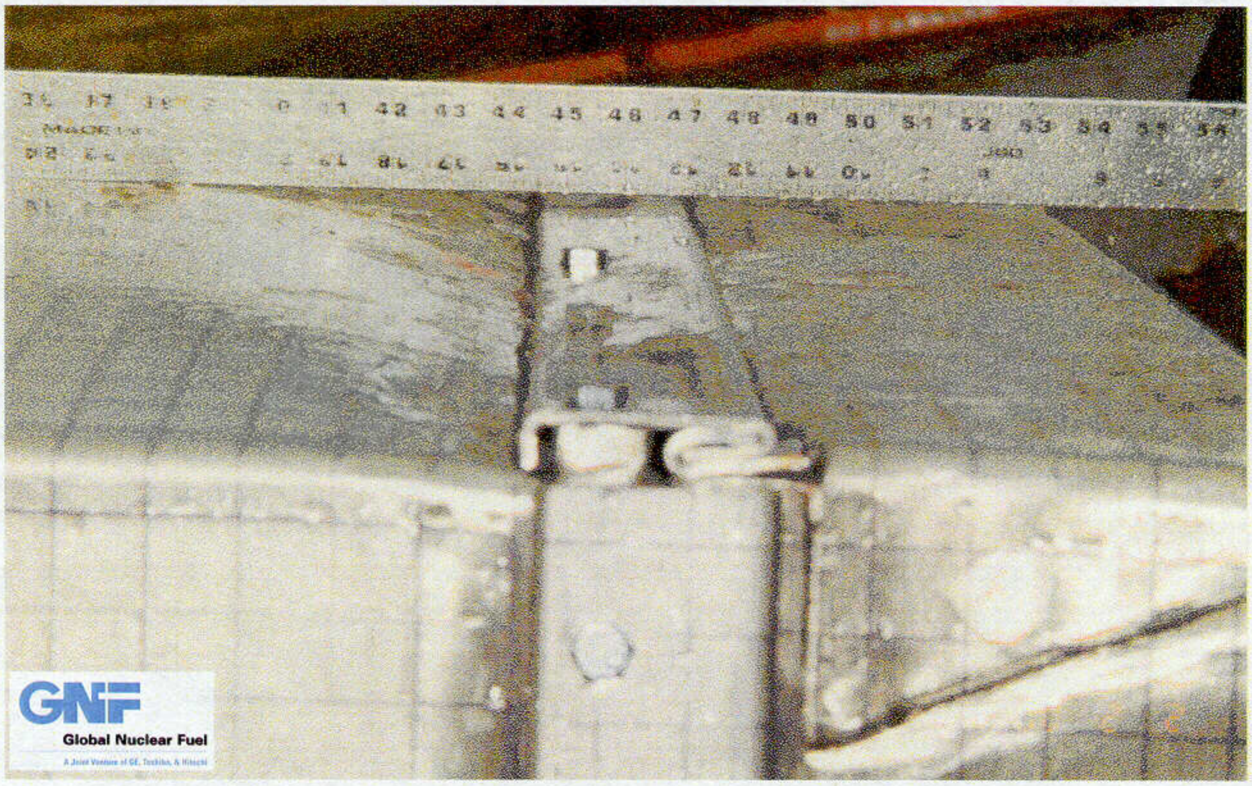

Figure 2.10.1-80 – CTU-4 Free Drop Test No. 6; Close-up View of Damage

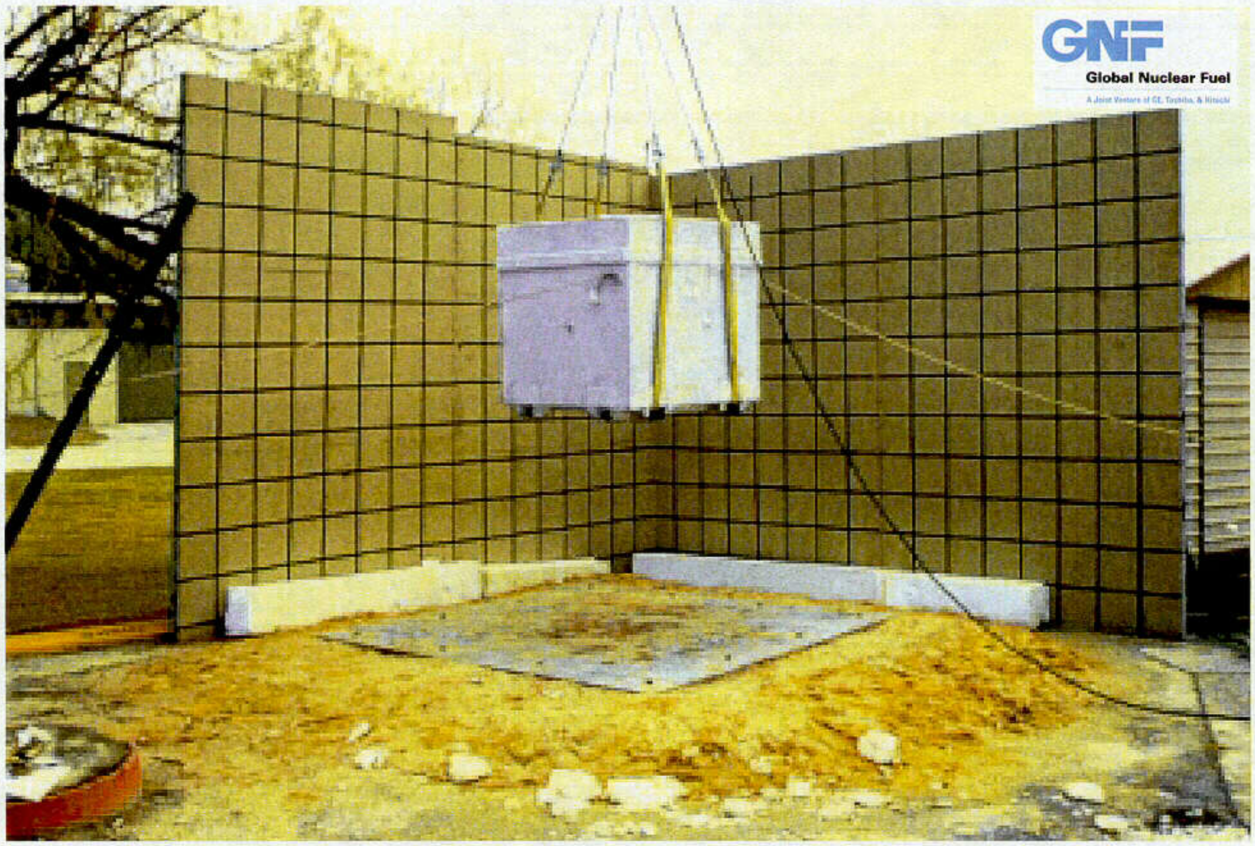

Figure 2.10.1-81 – CTU-4 Free Drop Test No. 7; NCT Drop onto OCA Bottom

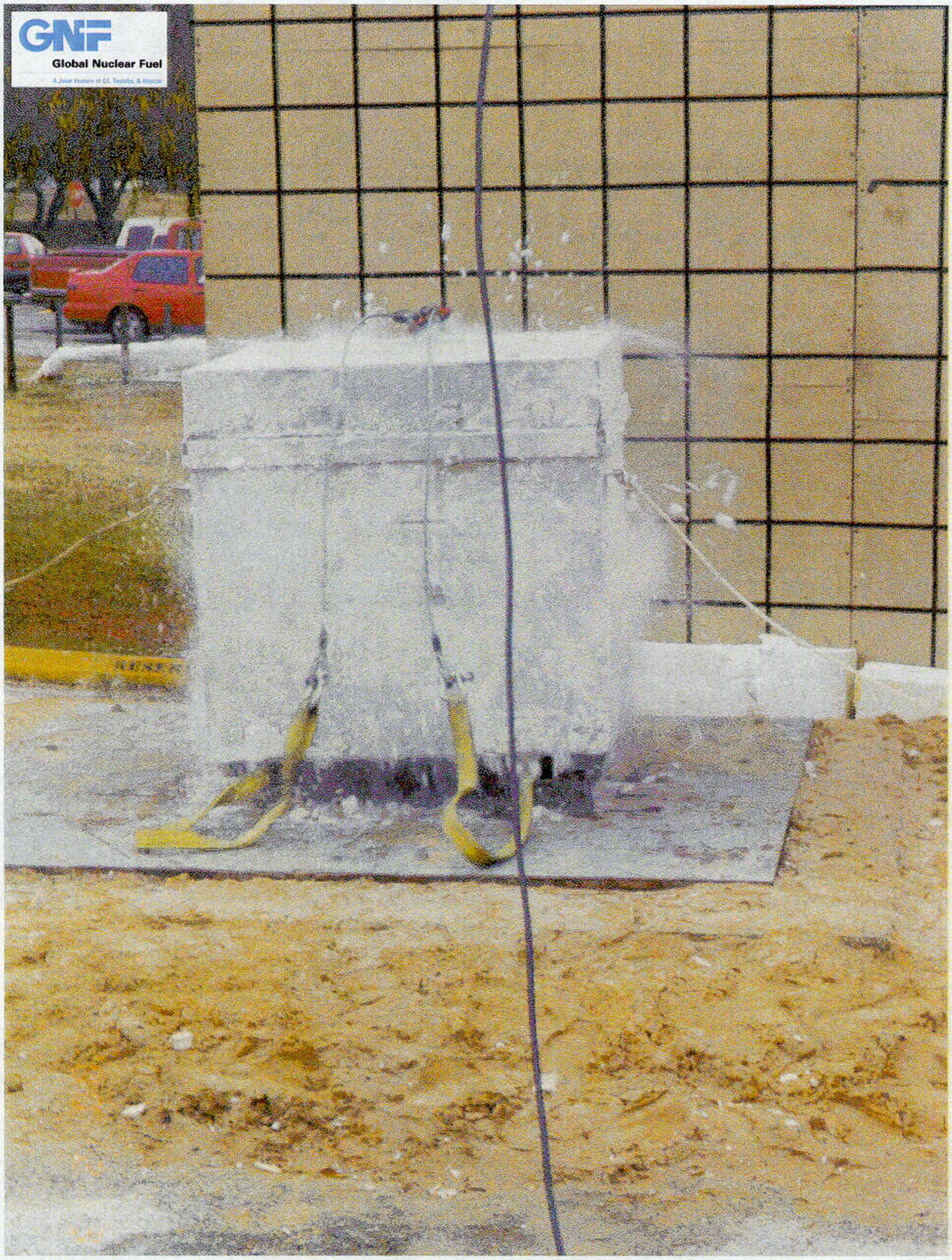

Figure 2.10.1-82 – CTU-4 Free Drop Test No. 7; NCT Drop at Impact

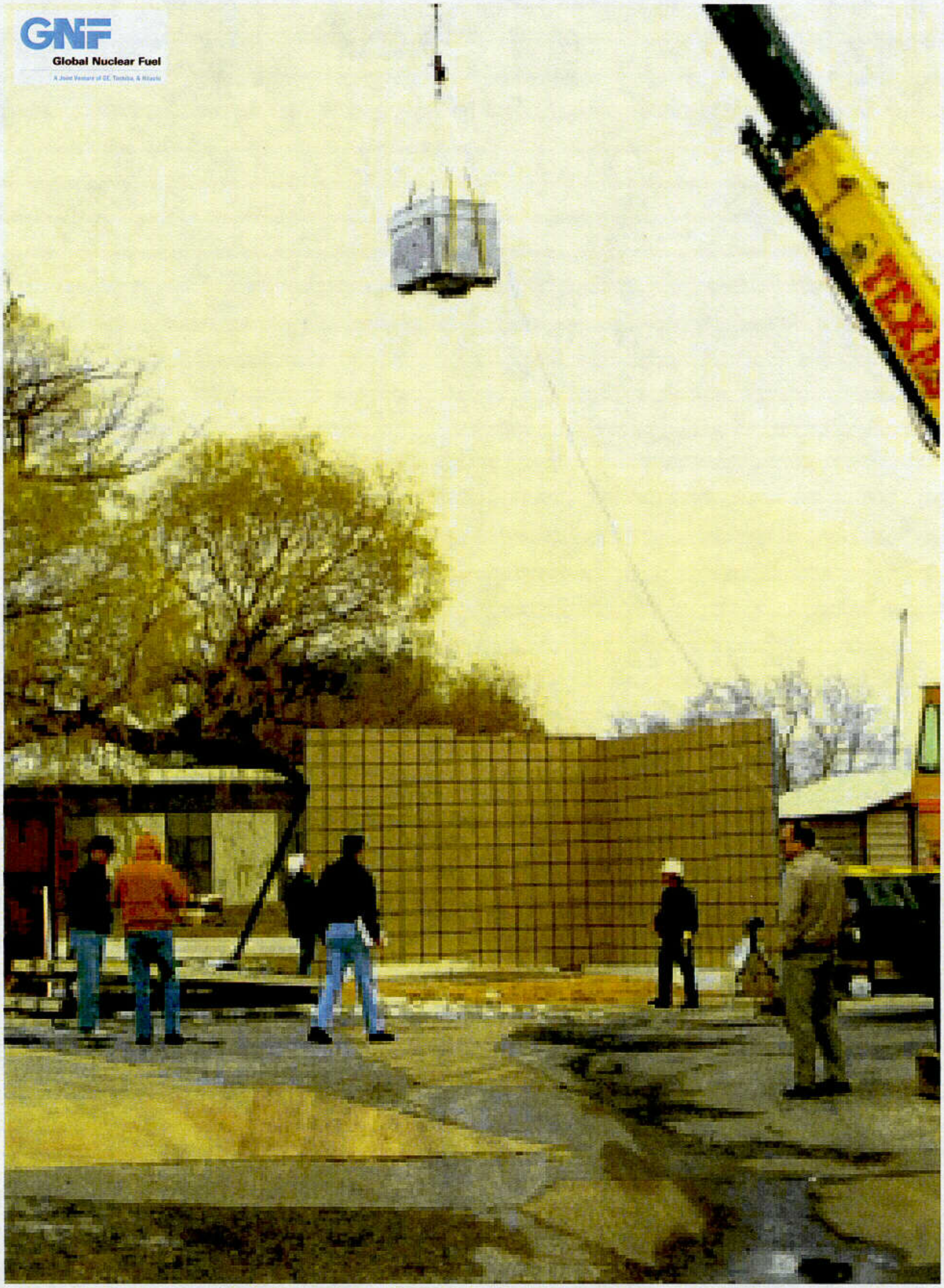

Figure 2.10.1-83 – CTU-4 Free Drop Test No. 8; HAC Drop onto OCA Bottom

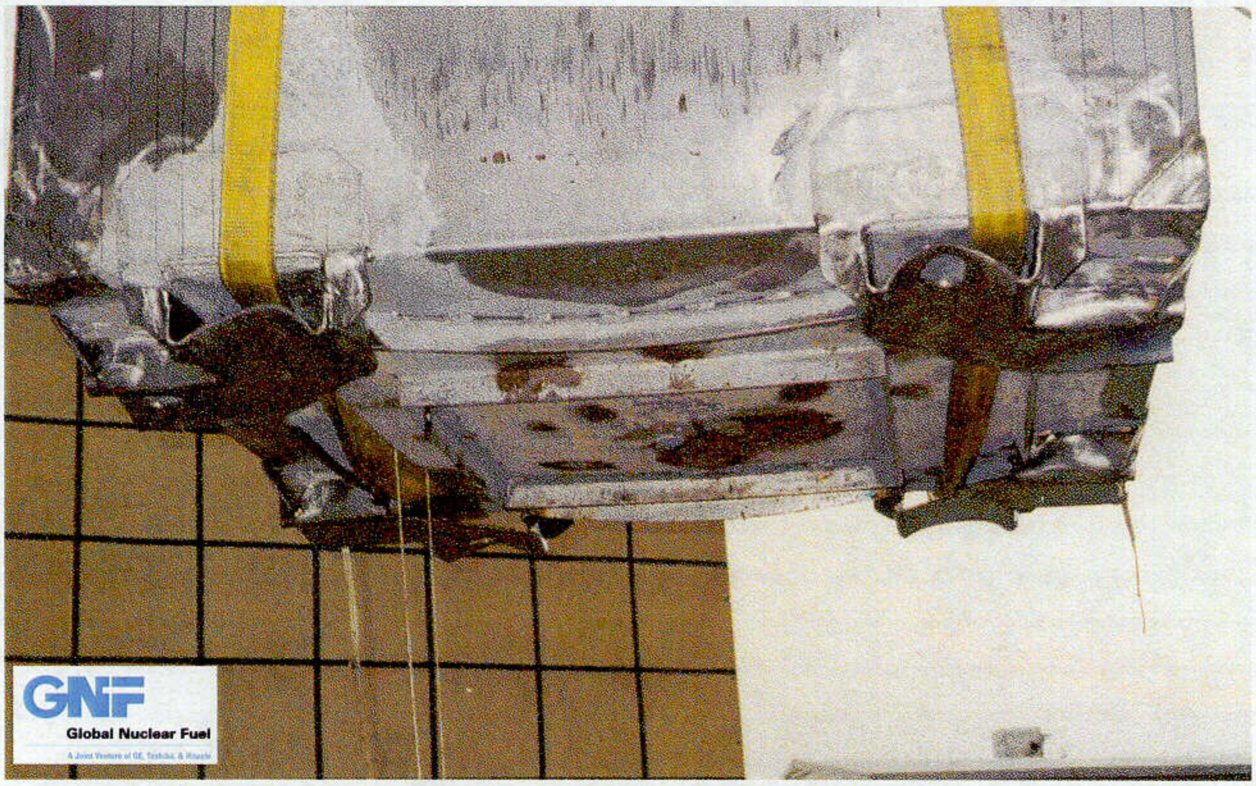

Figure 2.10.1-84 – CTU-4 Free Drop Test No. 8; View of Damage

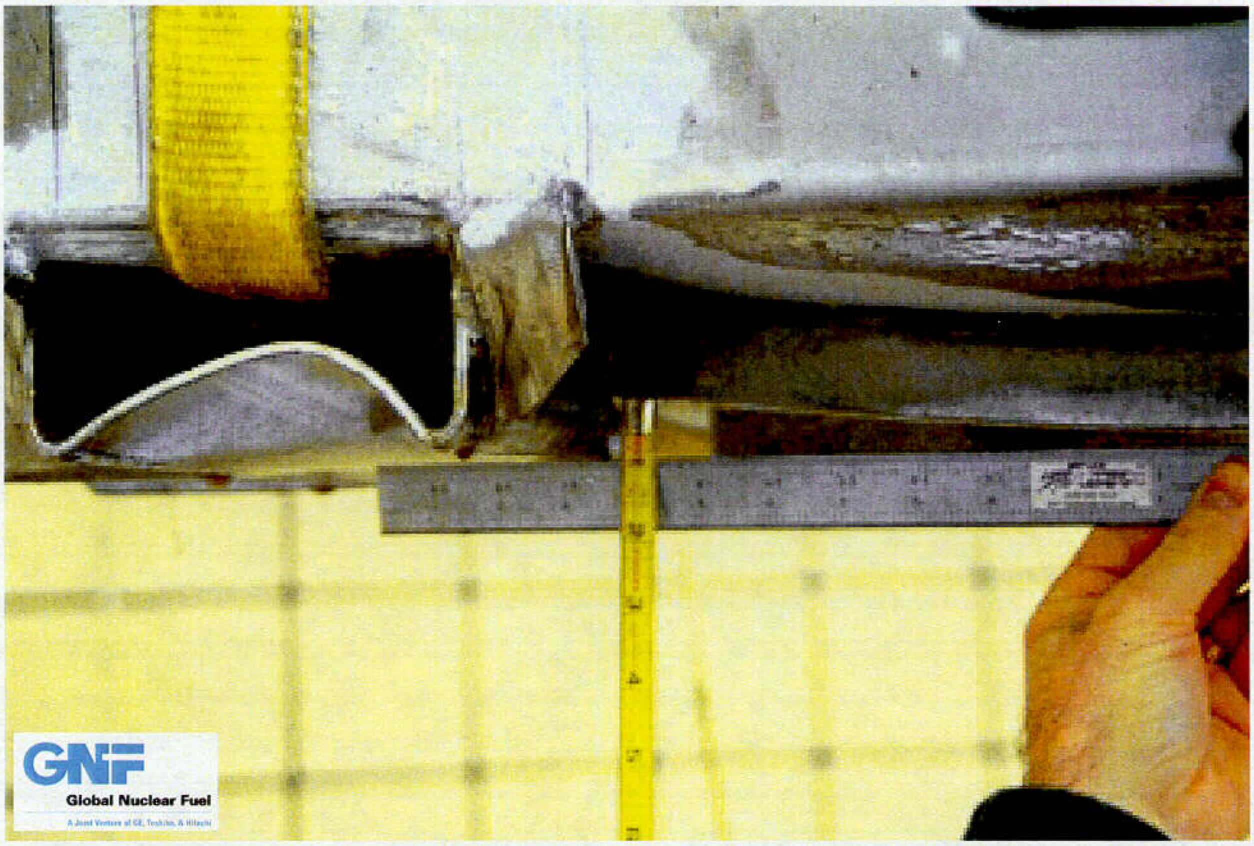

Figure 2.10.1-85 – CTU-4 Free Drop Test No. 8; Close-up View of Damage; ~1" Deep

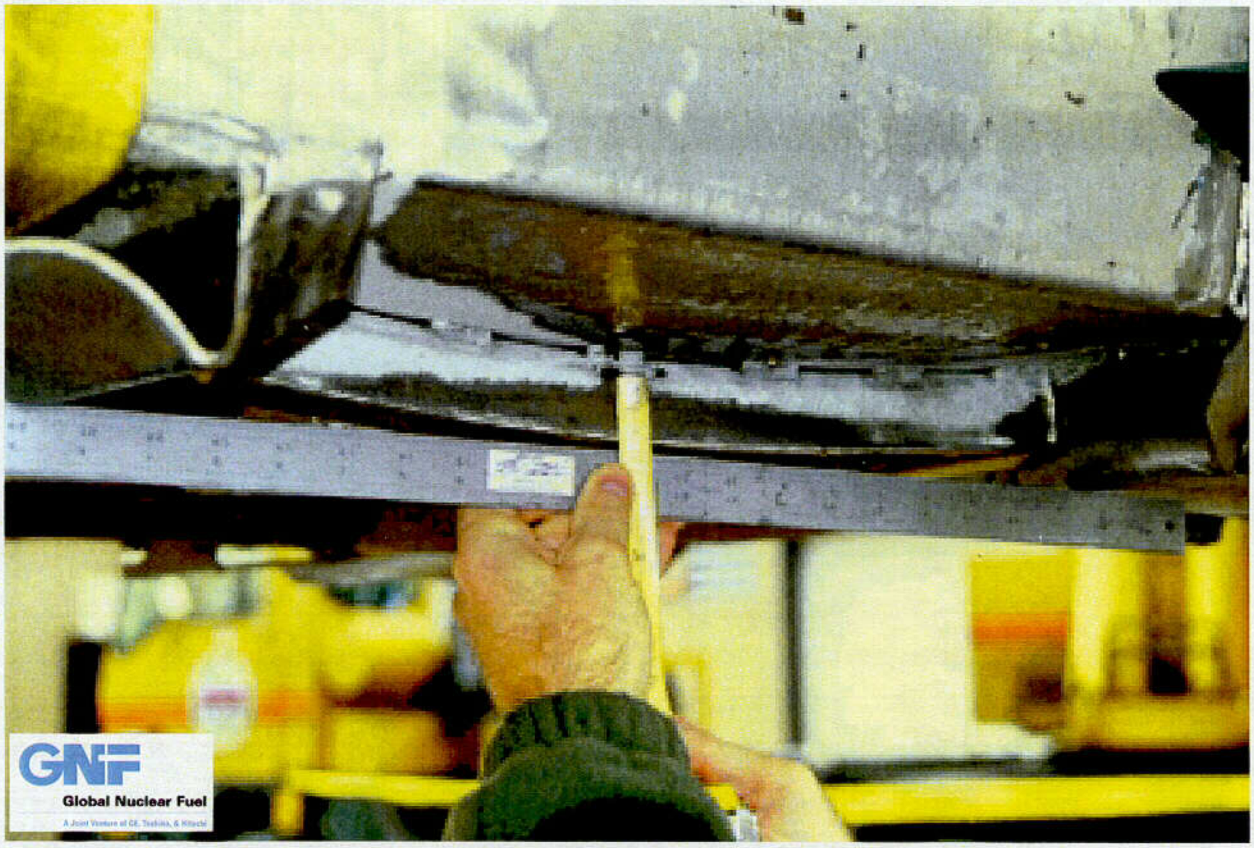

Figure 2.10.1-86 – CTU-4 Free Drop Test No. 8; Close-up View of Damage; ~1½" Deep

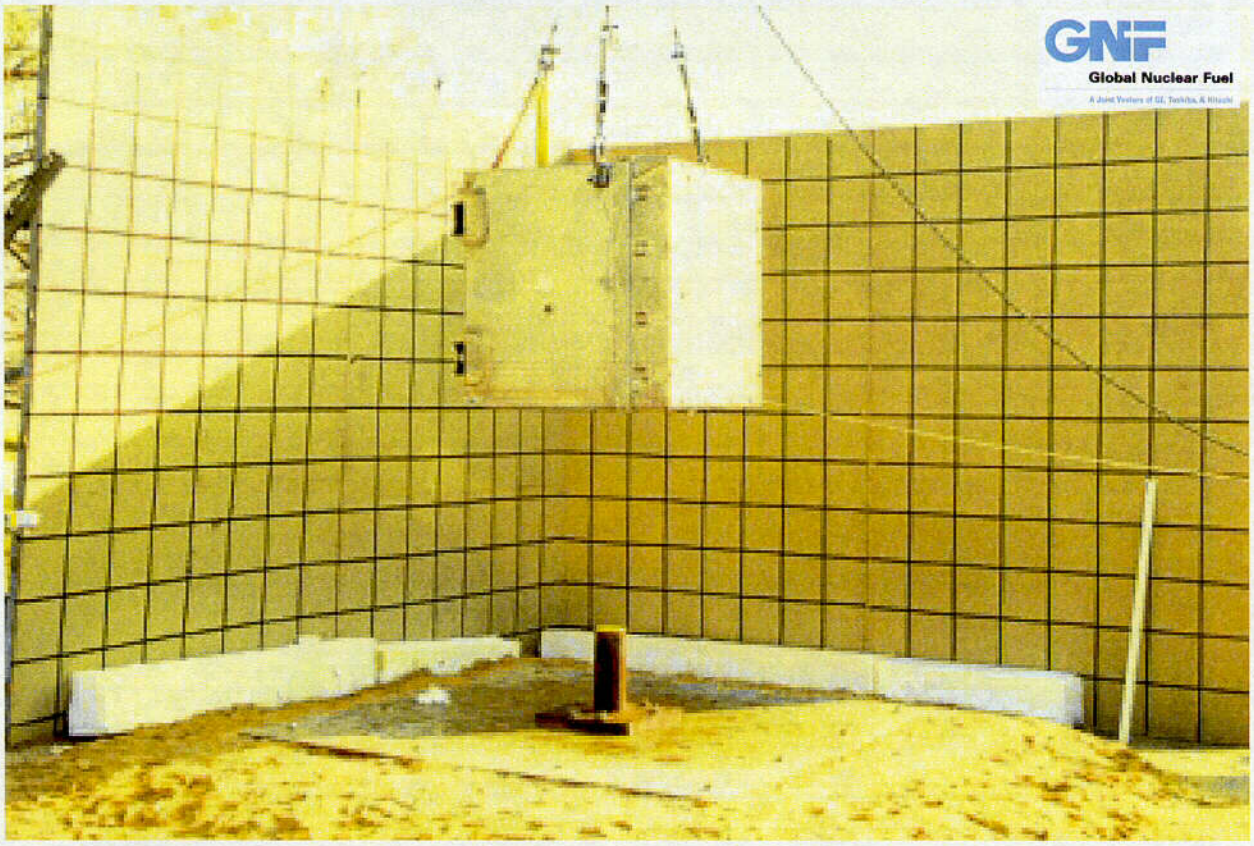

Figure 2.10.1-87 – CTU-4 Puncture Drop Test No. 12; HAC Puncture on Side

Figure 2.10.1-88 – CTU-4 Puncture Drop Test No. 12; Close-up View of Damage; ~1½" Deep

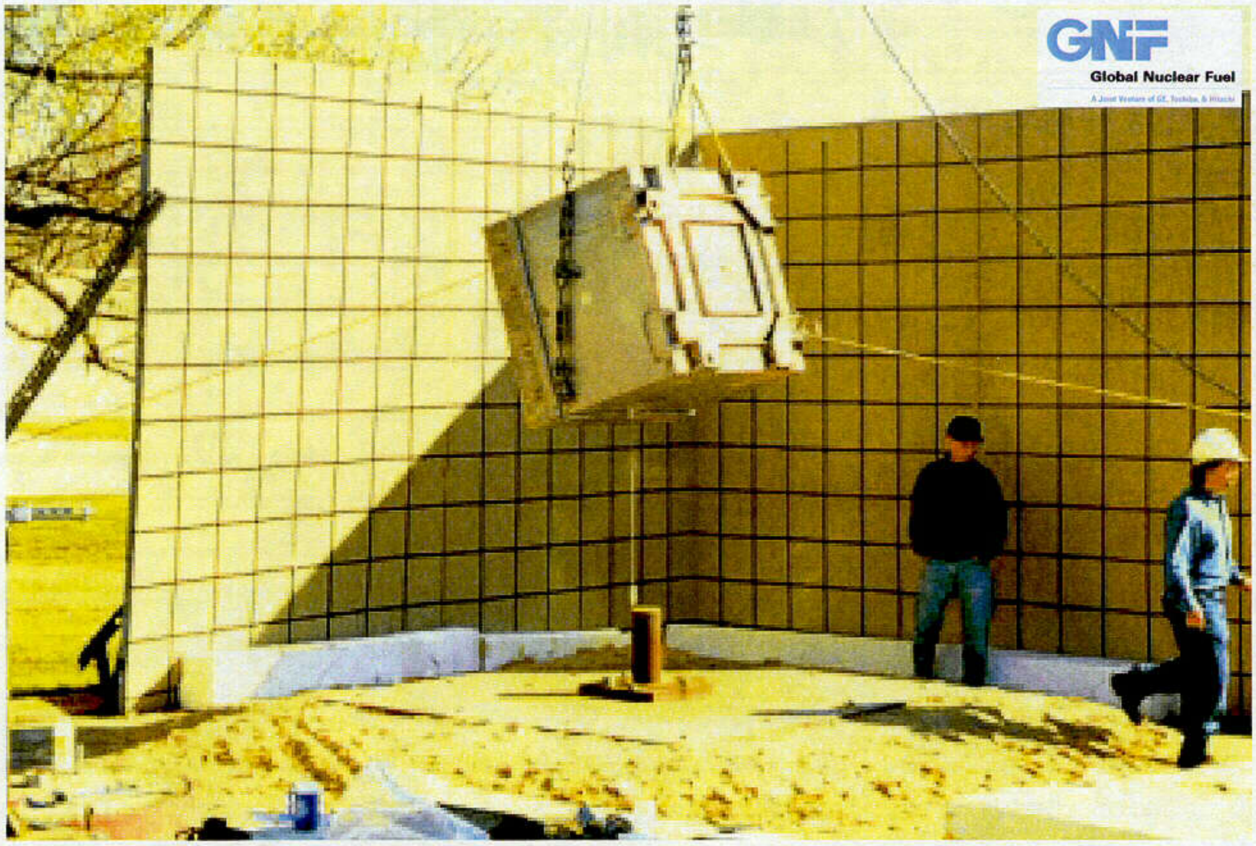

Figure 2.10.1-89 – CTU-4 Puncture Drop Test No. 13; HAC Oblique Drop on Side

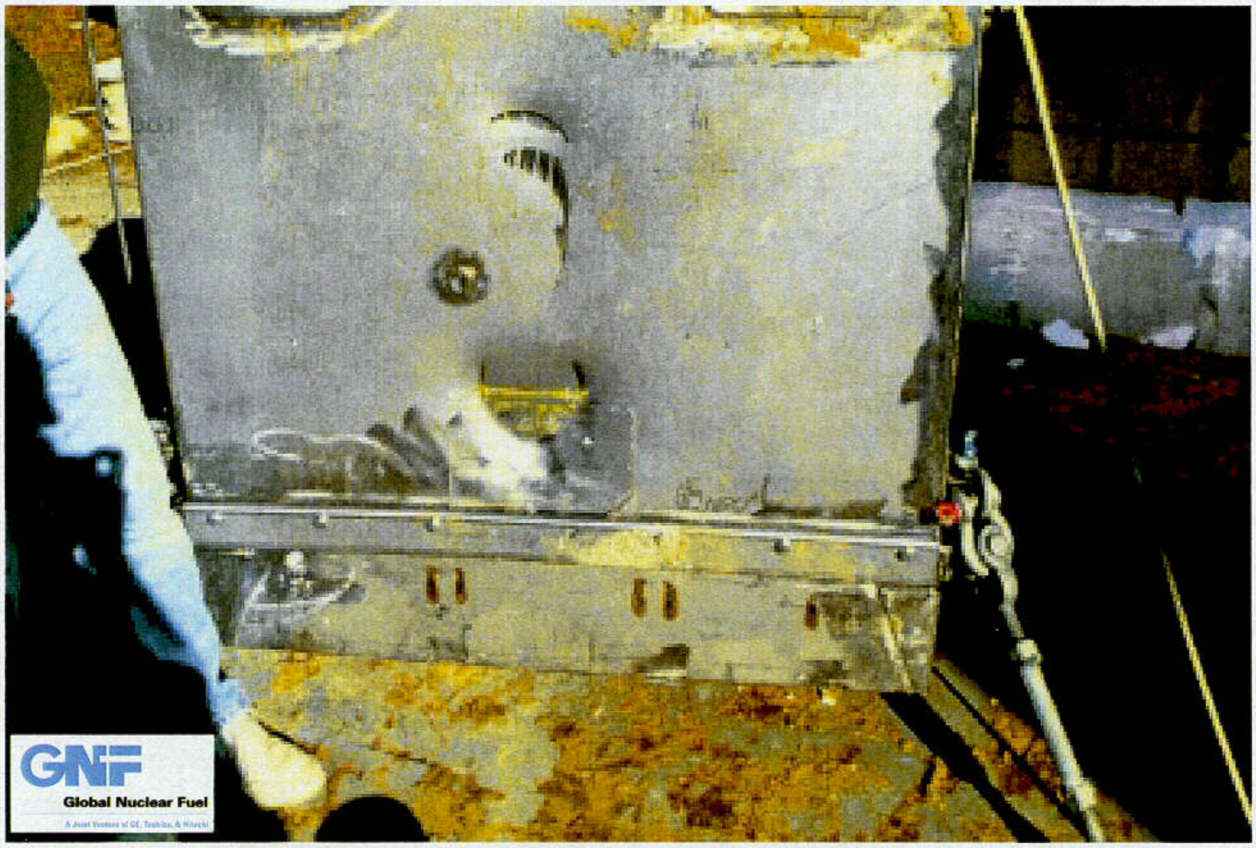

Figure 2.10.1-90 – CTU-4 Puncture Drop Test No. 13; View of Damage

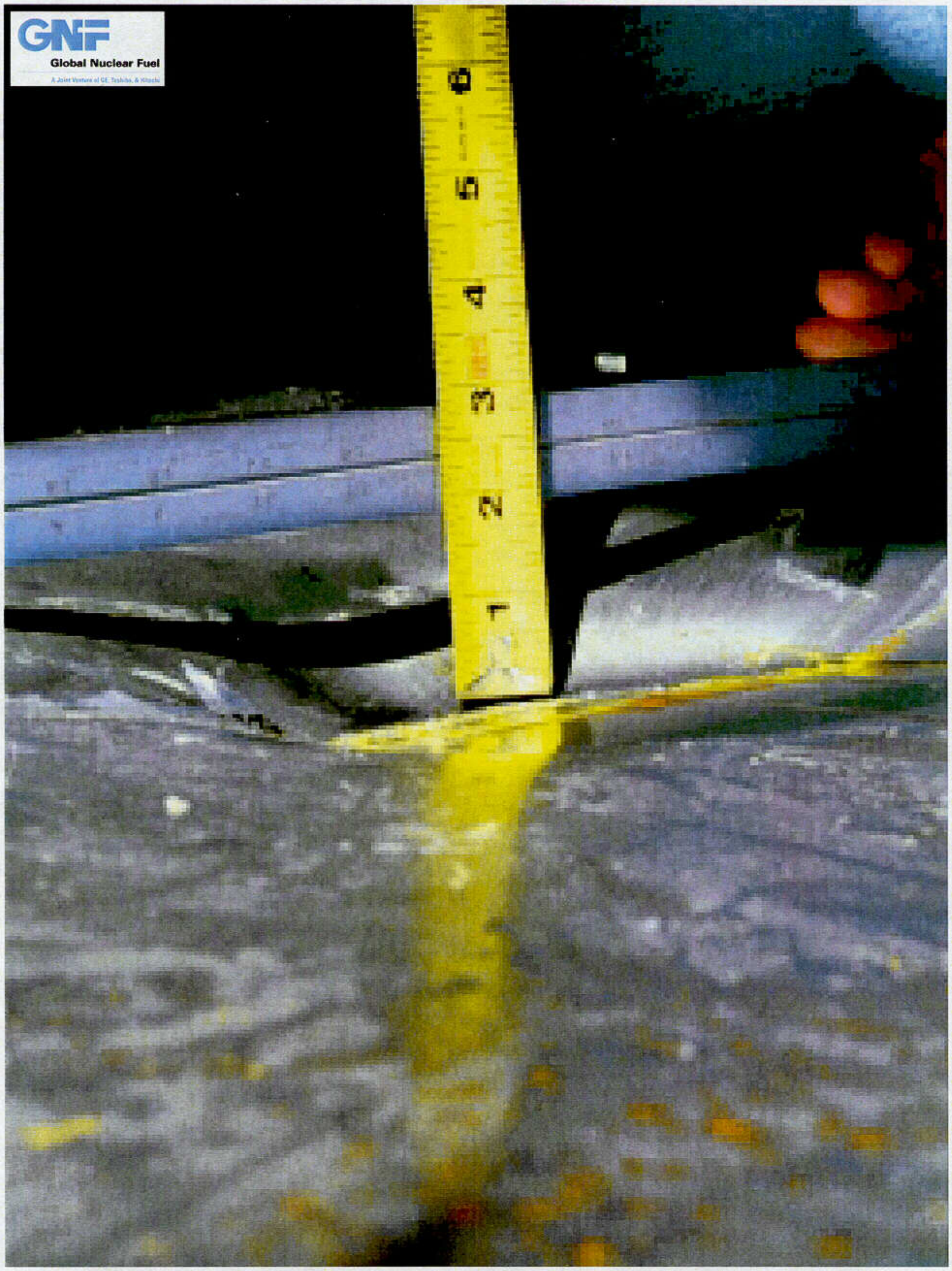

Figure 2.10.1-91 – CTU-4 Puncture Drop Test No. 13; Close-up View of Damage; ~1¾ Deep

Figure 2.10.1-92 – CTU-4 Puncture Drop Test No. 14; HAC Oblique Puncture on OCA Lid

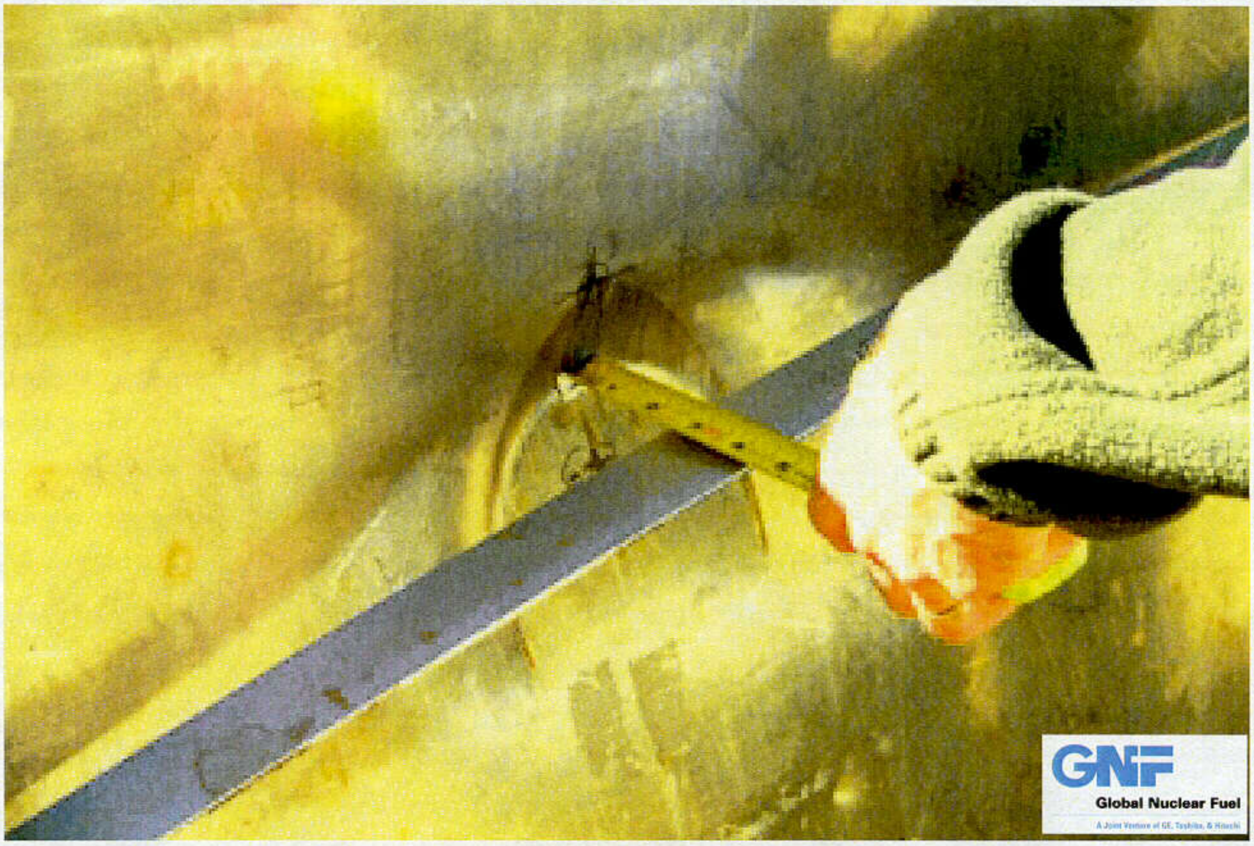

Figure 2.10.1-93 – CTU-4 Puncture Drop Test No. 14; Close-up of Damage; ~2½" Deep

Figure 2.10.1-94 – CTU-4 Post-Test Disassembly; View of Underside of OCA Lid

Figure 2.10.1-95 – CTU-4 Post-Test Disassembly; View of OCA Lid Foam Debris

Figure 2.10.1-96 – CTU-4 Post-Test Disassembly; View of Vertical Position of ICCAs

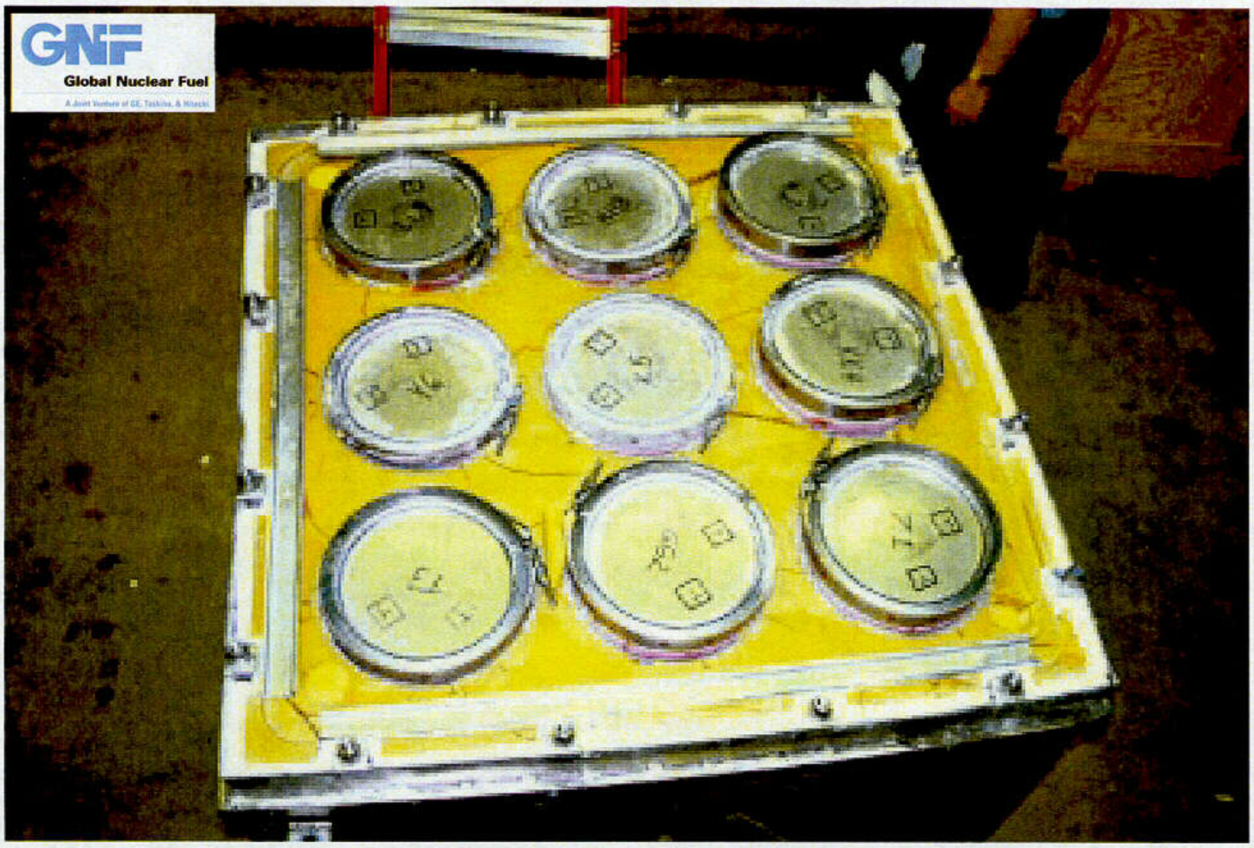

Figure 2.10.1-97 – CTU-4 Post-Test Disassembly; View of OCA Body and ICCAs

Figure 2.10.1-98 – CTU-4 Post-Test Disassembly; Close-up View of Damaged ICCA

2.10.2 Structural Dynamic Sensitivity Analysis

Presented herein are the results of a structural dynamic sensitivity analysis of the NPC package to demonstrate that the structural response of the NPC remains nearly the same across the tolerance range for the foam components of the package. The two most damaging orientations are presented.

The allowable material structural property variations for the polyurethane foam are stated in Section 8.1.4.1, Polyurethane Foam. In particular, the compressive strength variation of the polyurethane foam has the potential to affect the structural response of the NPC package to the HAC drop tests. In order to assess the effect of these deviations, a finite element analysis (FEA) was performed of the NPC package for the two most critical orientations: CG-over-OCA Lid, and OCA Side Edge.

The analysis utilized LS-DYNA[1] program to analyze the NPC package. The basic model was a full, 360-degree complete model of the NPC package. The model included elements for the OCA body (7,440 elements), the OCA lid (7,004 elements), the polyurethane foam (35,368 elements), the ceramic fiber board (13,324 elements), the ICCAs (63,072 elements), and the OCA socket head cap screws (3,456 elements). The total number of elements for the NPC package model was 129,664.

The sensitivity of the NPC package to the polyurethane foam compressive strength was evaluated by running the model with nominal, nominal - minus 15%, and nominal - plus 15% foam strengths. The amount of impact energy absorbed by each component of the package for a 30-foot HAC drop tests was then compared for the three data points. Each orientation will be discussed separately in the following sections.

2.10.2.1 CG-Over-OCA Lid Corner

This drop orientation was addressed by the testing of CTU-1. As discussed in Section 2.10.1.7.1.2, CTU-1 Free Drop Test No. 2, the impact resulted in severe buckling and folding of the OCA lid corner. The area of deformation was primarily limited to the lid reinforcement area. The resultant LS-DYNA analysis results of the NPC package for this orientation are illustrated in Figure 2.10.2-1 and Figure 2.10.2-2. As shown by these figures, the response of the model agrees well with the test results for this test orientation.

The model was run for the three polyurethane foam compressive strengths ranges. The percentages of the total impact energy absorbed by each major component are summarized for each compressive foam strength in Table 2.10.2-1. A summary of the percentage of the total energy absorbed by the individual foam densities is shown in Table 2.10.2-2.

Table 2.10.2-1 - Percentage of Total Kinetic Impact Energy Absorbed; CG-Over-OCA Lid

Compressive Foam Strength	Polyurethane Foam	OCA Lid	OCA Body	ICCAs	Ceramic Fiber Board
Nominal – 15%	11.7	63.0	6.0	0.3	6.0
Nominal	11.0	63.0	6.0	0.3	4.0
Nominal + 15%	10.2	62.0	6.0	0.3	3.0

[1] Livermore Software Technology Corporation, *LS-DYNA User's Manual*, Report 1082, June 1, 1997

Table 2.10.2-2 - Percentage of Kinetic Impact Energy Absorbed for Each Foam Density

Compressive Foam Strength	7 lbs/ft^3	11 lbs/ft^3	15 lbs/ft^3	40 lbs/ft^3
Nominal – 15%	2.0	2.9	3.8	3.0
Nominal	1.9	3.0	3.4	2.7
Nominal + 15%	1.6	2.8	3.4	2.4

As demonstrated by these values, the allowable compressive strength variations for the polyurethane foam have insignificant affect on the overall package response. Therefore, it can be concluded that the impact performance NPC package is not sensitive to the allowable compressive foam variations for the CG-over OCA lid corner orientation.

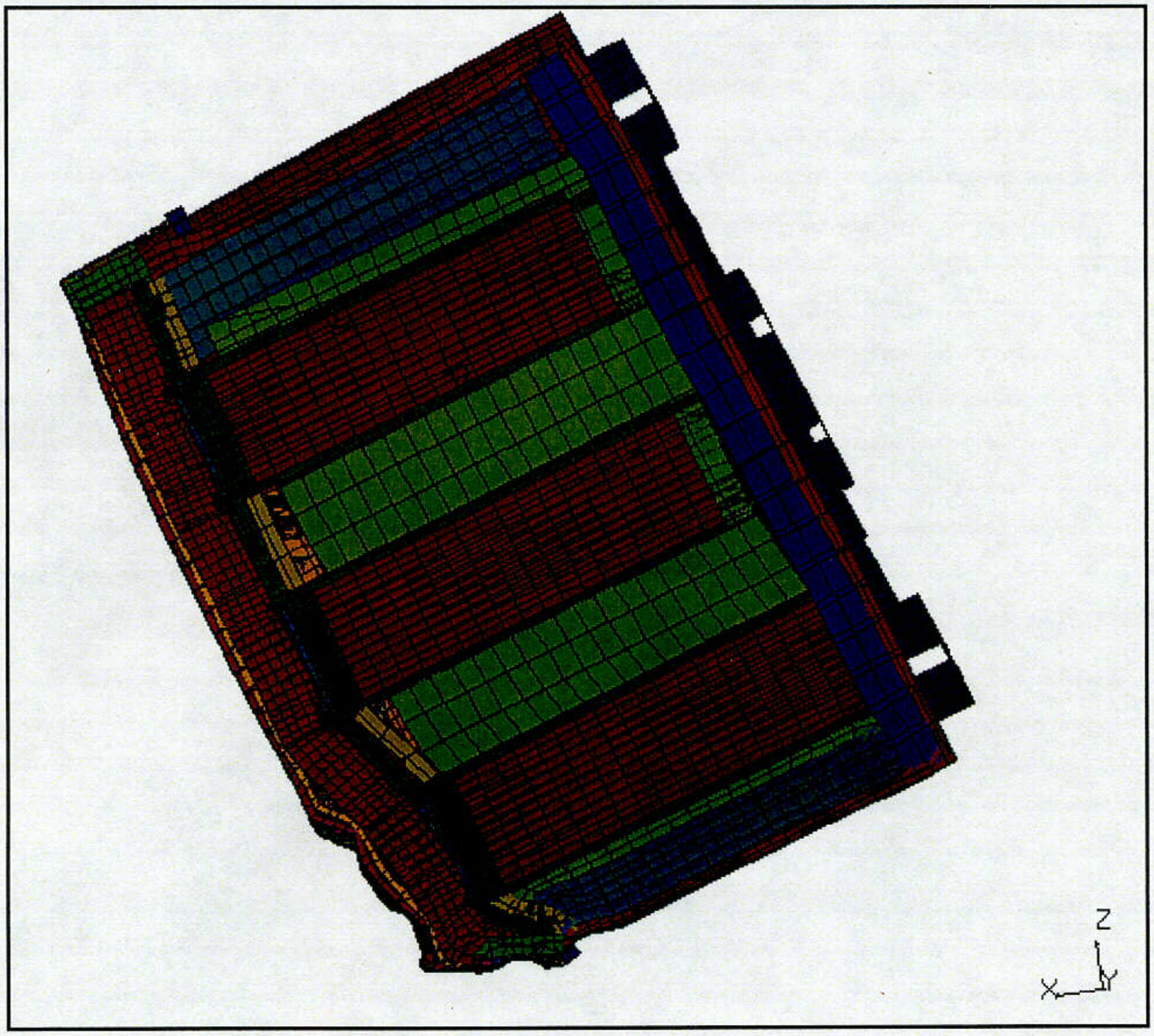

Figure 2.10.2-1 - LS-DYNA Model Results for CG-over-OCA Lid; Cross-section Side View

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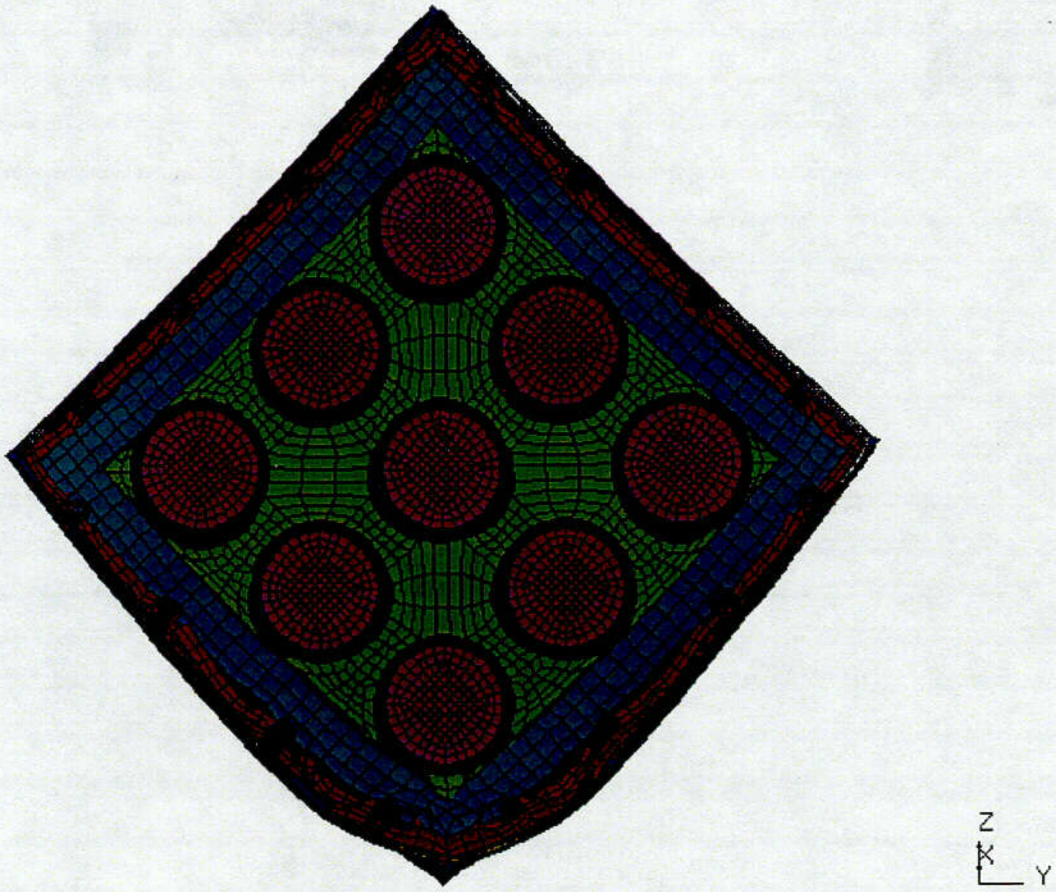

Figure 2.10.2-2 - LS-DYNA Model Results for CG-over-OCA Lid; Cross-section End View

2.10.2.2 OCA Side Edge

This drop orientation was addressed by the testing of CTU-2. As discussed in Section 2.10.1.7.2.2, CTU-2 Free Drop Test No. 4, the impact resulted in a flat measuring approximately 9 inches in width. The area of deformation was limited to the impacted side edge. The resultant LS-DYNA analysis results of the NPC package for this orientation are illustrated in Figure 2.10.2-3 and Figure 2.10.2-4. As shown by these figures, the response of the model agrees well with the test results for this test orientation.

The model was run for the three polyurethane foam compressive strengths ranges. The percentages of the total impact energy absorbed by each major component are summarized for each compressive foam strength in Table 2.10.2-3. A summary of the percentage of the total energy absorbed by the individual foam densities is shown in Table 2.10.2-4.

As demonstrated by these values, the allowable compressive strength variations for the polyurethane foam have insignificant affect on the overall package response. Therefore, it can be concluded that the impact performance NPC package is not sensitive to the allowable compressive foam variations for the OCA side edge orientation.

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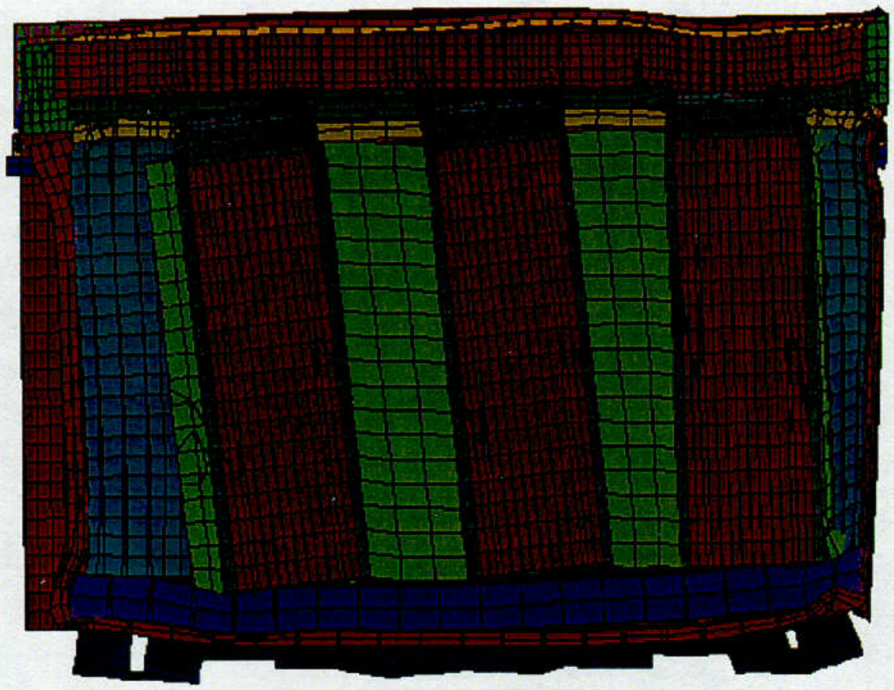


Figure 2.10.2-3 - LS-DYNA Model Results for OCA Side Edge; Cross-section Side View

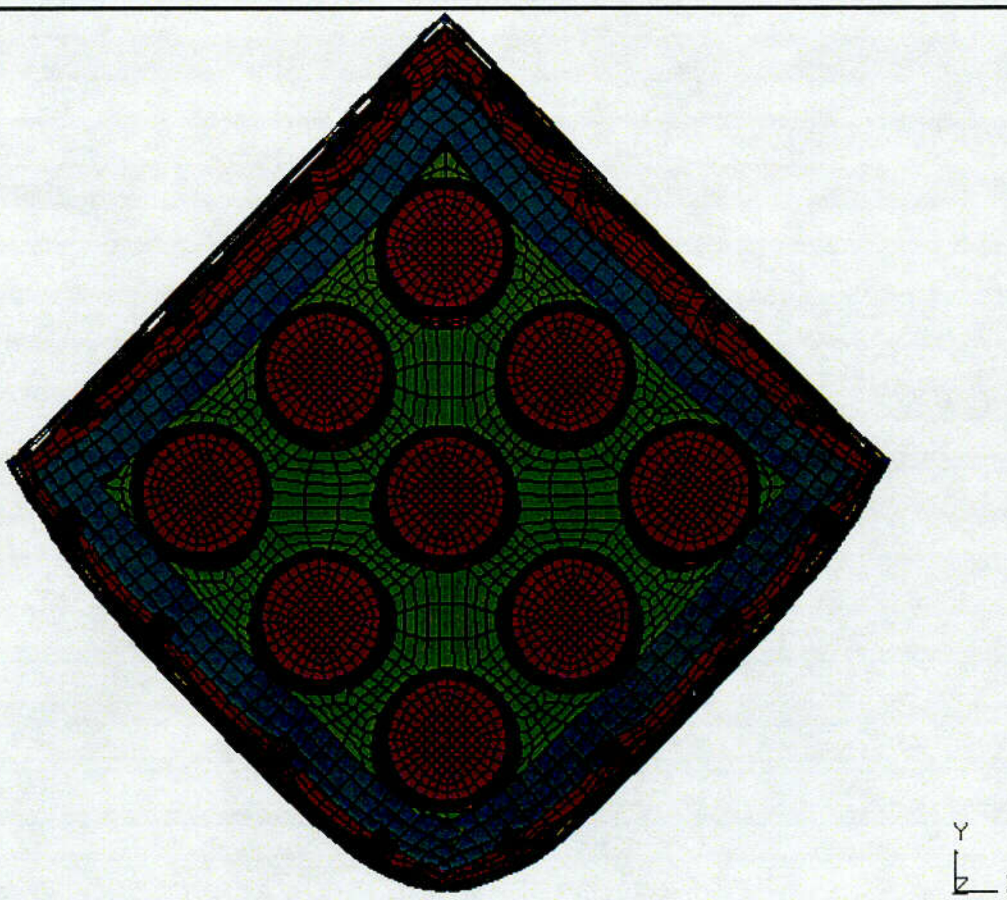


Figure 2.10.2-4 - LS-DYNA Model Results for OCA Side Edge; Cross-section End View

Table 2.10.2-3 - Percentage of Total Kinetic Impact Energy Absorbed; OCA Side Edge

Compressive Foam Strength	Polyurethane Foam	OCA Lid	OCA Body	ICCAs	Ceramic Fiber Board
Nominal – 15%	32.6	24.0	28.0	0.5	11.0
Nominal	31.2	25	29.0	0.4	10.0
Nominal + 15%	29.6	25.0	28.0	0.4	9.0

Table 2.10.2-4 - Percentage of Kinetic Impact Energy Absorbed for Each Foam Density

Compressive Foam Strength	7 lbs/ft^3	11 lbs/ft^3	15 lbs/ft^3	40 lbs/ft^3
Nominal – 15%	9.7	14.2	2.0	6.7
Nominal	9.7	13.7	2.1	5.7
Nominal + 15%	9.0	13.4	2.0	5.2

3.0 THERMAL

3.1 Discussion

This chapter establishes the compliance of the GNF NPC packaging to transport a payload of up to 1,190 pounds (540 kg) of 5 weight percent (w/o) maximum enrichment uranium oxide powder to the thermal requirements of 10 CFR 71[1].

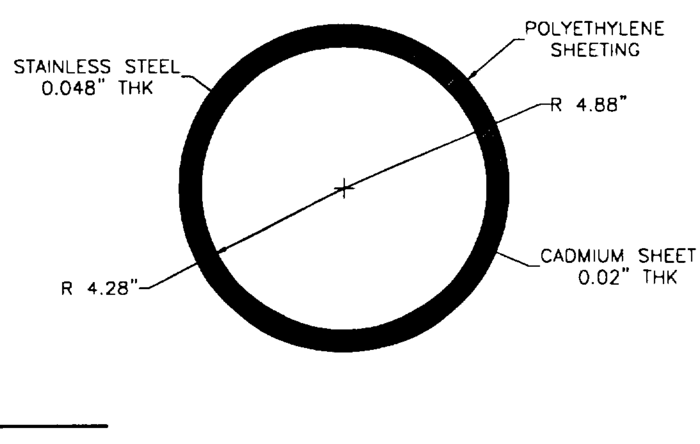
3.2 Summary of Thermal Properties of Materials

Analysis of the heat transfer within the NPC requires that thermal properties be defined for the materials used in their fabrication. Only properties for materials that constitute a significant heat transfer path are defined.

The NPC consists of an outer stainless steel sheet metal body and closure lid (OCA) that encases ceramic fiber insulation and polyurethane foam, and nine equally spaced individually sealed stainless steel canisters (ICCAs). The closure of each canister is provided by a closure lid with a silicone rubber gasket and a stainless steel bolted band clamp assembly. The cylindrical outer surface of each canister is wrapped with a minimum 0.020" cadmium sheet, a 0.015" High Density Polyethylene (HDPE) sheet (wrapped to achieve a minimum hydrogen areal density of 0.199 grams/cm^2), and a 24-gauge stainless steel wrapper.

The thermal properties of the principal materials used in the thermal evaluations are presented in Tables 3.2-1 and 3.2-2. The uranium oxide powder is not represented in this analysis as the worst case temperatures are achieved when the canisters are filled with lower conductivity air. Additionally, since the ceramic fiber board insulation has a conductivity commensurate with that of 11-15 lb/ft^3 foam, all portions of the package that contained ceramic fiber board were modeled with the same material properties as the adjacent foam. Since the material properties of the NPC package construction material do not vary significantly within the anticipated operational temperature range (-40 °F through 100 °F), the material properties are assumed to be constant for the purposes of this analysis.

The polyethylene and stainless steel in the canister walls was combined into a homogeneous material that would provide equivalent thermal mass and axial thermal conduction. The thermal effects of the cadmium sheeting were ignored, which conservatively increases the axial canister temperature gradients, as well as overpredicting the maximum canister and payload temperatures. The effective material properties are calculated as follows:



[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-98 Edition.

$$k_{eff} = \frac{A_1k_1+A_2k_2}{A_1+A_2} = \frac{1.29(0.725)+16.73(0.018)}{18.02} = 0.069\frac{\text{Btu}}{\text{hr}-\text{in}-°\text{F}}$$

$$\rho_{eff} = \frac{A_1\rho_1+A_2\rho_2}{A_1+A_2} = \frac{1.29(0.281)+16.73(0.035)}{18.02} = 0.053\frac{\text{lb}}{\text{in}^3}$$

$$c_{p_{eff}} = \frac{A_1\rho_1c_{p_1}+A_2\rho_2c_{p_2}}{(A_1+A_2)\rho_{eff}} = \frac{1.29(0.281)0.111+16.73(0.035)0.53}{18.02(0.053)} = 0.37\frac{\text{Btu}}{\text{lb}-°\text{F}}$$

Since the heat generation of the payload is negligible (Section 3.3), the radial conductivity of the canister will have a negligible effect on package temperatures. Therefore, it was not calculated.

Table 3.2-1 - Material Properties

Material	Temperature, °F	Thermal Conductivity, Btu/hr-in-°F	Specific Heat, Btu/lb$_m$-°F	Density, lb$_m$/in^3	Notes
Type 304L Stainless Steel	100.0	0.725	0.111	0.281	①
Polyurethane Foam 7 lb/ft^3 11 lb/ft^3 15 lb/ft^3 40 lb/ft^3	100.0	 0.0018 0.0020 0.0023 0.0040	0.47	 0.0041 0.0064 0.0087 0.0231	②
Ceramic Fiber Board	100.0	0.0022	0.28	0.0087	③
Polyethylene Sheeting	100.0	0.018	0.53	0.035	④
Air	100.0	0.0013	0.24		⑤
Canister Walls (SS/Polyethylene)	100.0	0.069	0.37	0.053	

Notes:

① ASME Code [6], Section II, Part D, Table TCD for Thermal Conductivity and Specific Heat. Density from Table NF-2.

② General Plastics, *Last-A-Foam FR-3700 for Crash and Fire Protection of Nuclear Material Shipping Containers*, Tacoma, WA, February 1999.

③ Rohsenow, W. M. and J. P. Hartnett, *Handbook of Heat Transfer*, Table 28, McGraw Hill Publishing, New York, 1973 provides a conductivity for ceramic fiber insulation of 0.0022 Btu/hr-in-°F at 100 °F, which is commensurate in value with polyurethane foam of 11-15 pcf. *Unifrax Duraboard LD Product Specifications*, Standard Oil Engineered Materials, reports a conductivity for Duraboard LD of 0.0037 Btu/hr-in-°F at 400 °F. Data at lower temperatures is not available.

④ MatWeb, Inc., *Material Properties of High Density Polyethylene (HDPE), Injection Molded*, 1999. Conductivity based on an average of three HDPE products varying in conductivity from 0.014 to 0.024 Btu/hr-in-°F.

⑤ Y.S. Touloukian, *Specific Heat – Nonmetallic Liquids and Gases*, Thermophysical Properties Research Center Data Series, Volume 6, Purdue University, 1970. Density of air increased to 0.0064 lb/in^3 to increase model stability for transient evaluation, which is beyond the scope of this report. Effect on model temperatures due to this assumption is negligible.

Table 3.2-2 - Material Properties, Surface Emittance, Absorptivity

Component	Material	Surface Emittance	Solar Absorptivity	Notes
Package Exterior	Type 304L SS	0.50	0.5	①
Package Interior Surfaces	Type 304L SS	0.50	NA	①

Note:

① Value from Gubareff, F. F., Janssen, J. E., and Torborg, R. H., *Thermal Radiation Properties Survey*, Honeywell Research Center, Minneapolis, Minnesota, 1960

3.3 Technical Specification for Components

The NPC may contain up to 0.05 Ci of U-235 and 0.15 Ci of U-238 based on a 1,190 pounds (540 kg) total payload of UO_2 with 5 w/o enrichment. Since U-235 generates 0.027 watts/Ci, and U-238 generates 0.025 watts/Ci the total radiolytic decay heat for the NPC will be 0.005 watts (0.017 Btu/hr), which is negligible.

The containment for the NPC package is provided by the ICCAs. The minimum and maximum allowable temperatures for the silicone rubber ICCA seals are -60 °F to 450 °F, respectively[2]. Since the structural integrity of the package is established by testing, the only pertinent temperature limits on the components are established by their melting temperatures for the fire-based Hypothetical Accident Condition (HAC). The melting temperatures for stainless steel, polyethylene and cadmium are 2,850 °F, 350 °F and 610 °F, respectively.

3.4 Thermal Evaluation for Normal Conditions of Transport

Although the total decay heat load of the NPC package is less than 0.1 Btu/hr, a detailed analysis of the package is required to determine the effects of insolation on the stainless steel outer shell and the impact absorbing foam. To accomplish this an analytical model of the package was constructed using the Heating 7.3 computer program[3]. Heating 7.3 is a finite difference thermal analysis code capable of solving steady-state and transient thermal analysis problems in one, two or three dimensions in a rectangular, cylindrical or spherical coordinate system. It is capable of modeling heat transfer via a combination of conduction, radiation and both natural and forced convection. Heating 7.3 was developed by Oak Ridge National Laboratories as part of the SCALE4.3 package and has been used extensively in the packaging industry for thermal evaluations of packages for both onsite transfer and storage.

The Heating 7.3 thermal model, Figure 3.4-1, utilizes quarter section symmetry in a X-Y-Z coordinate system. Accordingly, the canister walls were modeled with a rectangular cross section of equivalent area to provide equivalent axial conduction. In addition, as presented in Section 3.2, *Summary of Thermal Properties of Materials*, the material properties of the stainless steel and polyethylene of the ICCAs were homogenized. Certain package details, such as the bolting flange and the fork lift attachments, do not significantly affect the heat transfer characteristics of the

[2] Parker Seals, *O-Ring Handbook*, OR5700, Parker Seal Company, Lexington, KY.

[3] Oak Ridge National Laboratory, *Heating 7 Multidimensional, Finite Difference Heat Conduction Analysis System*, Version 7.3, PSR-199, Radiation Information Computational Center, Oak Ridge, TN.

package, and therefore were not modeled. The input and output files for the Heating 7.3 model are listed in Sections 3.6.1, *Heating 7.3 NCT Thermal Model Input for Maximum Surface Temperature*, and 3.6.2, *Payload Temperature During HAC Fire Event*, respectively.

Heat from insolation is transferred through the package via conduction and is dissipated from package surfaces via natural convection and radiation to the ambient environment. Natural convection heat transfer coefficients vary as a function of the surface temperature and orientation. Convective heat transfer from the base of the package will be considerably less than from the top and sides, and was conservatively neglected. Turbulent natural convective heat transfer coefficients for the top and vertical sides were conservatively assumed and are summarized in Table 3.4-1.

Per 10 CFR §71.71(c)(1), the worst-case high temperature conditions for the package consist of an ambient temperature of 100 °F and maximum insolation per Table 3.4-2, and the application of the stainless steel solar absorptivity value from Table 3.2-2. Under those conditions, the worst case surface temperature for the NPC package would be 174 °F, as presented in Table 3.4-3 and Figure 3.4-2. Bulk polyurethane foam temperatures for the OCA lid and OCA body are 149 °F and 131 °F, respectively. All NCT package temperatures are well within the material limits presented in Section 3.3, *Technical Specification for Components*.

Given the negligible decay heat, the maximum temperature for all surfaces of the NPC package in shade with an ambient temperature of 100 °F (38 °C) is 100 °F (38 °C). This temperature is below the maximum acceptable surface temperature of 122 °F for non-exclusive use shipments as stipulated in 10 CFR §71.43(g). Similarly, the package temperature will be equal to ambient under the low temperature conditions of -20 °F and -40 °F.

Table 3.4-1 - Natural Convective Heat Transfer Coefficients for NPC Package

Surface Orientation	Heat Transfer Coefficient (Btu/hr-in²-°F)①
Horizontal – Heated Surface Facing Up	$0.0015\Delta T^{1/3}$
Vertical	$0.0013\Delta T^{1/3}$

Note:

① Lindeburg, M. R., *Mechanical Engineering Reference Manual*, Table 10.7, Professional Publications, Belmont, CA, 1994

Table 3.4-2 - NPC Package NCT Maximum Insolation Values

Form and Location of Surface	Total Insolation for a 12-Hour Period (gcal/cm²)	(Btu/in²)
Flat surfaces transported horizontally:		
• Base	None	None
• Other surfaces	800	20.49
Flat surfaces not transported horizontally	200	5.12
Curved surfaces	400	10.24

Table 3.4-3 - NPC Package NCT Maximum Temperatures

Component	Maximum Temperature (°F)
OCA Lid Outer Skin	174
Bulk OCA Lid Foam	149
OCA Lid Braided Rope	135
ICCA Maximum Temperature	147
OCA Body Foam Maximum	143
Bulk OCA Body Foam	131
OCA Body Outer Skin	130
Bulk Payload	133

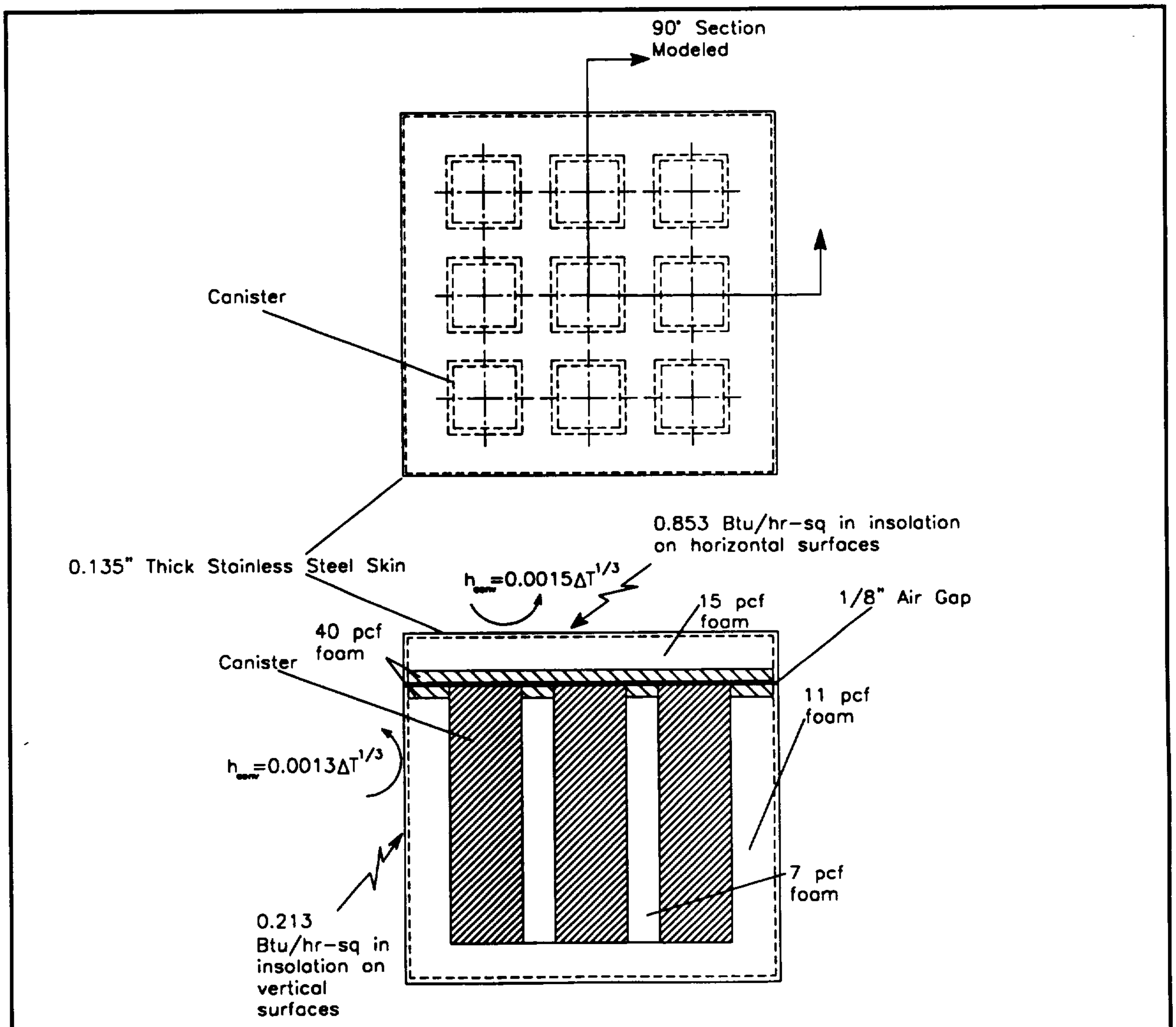


Figure 3.4-1 - Geometrical Assumptions for Heating 7.3 Thermal Model of NPC

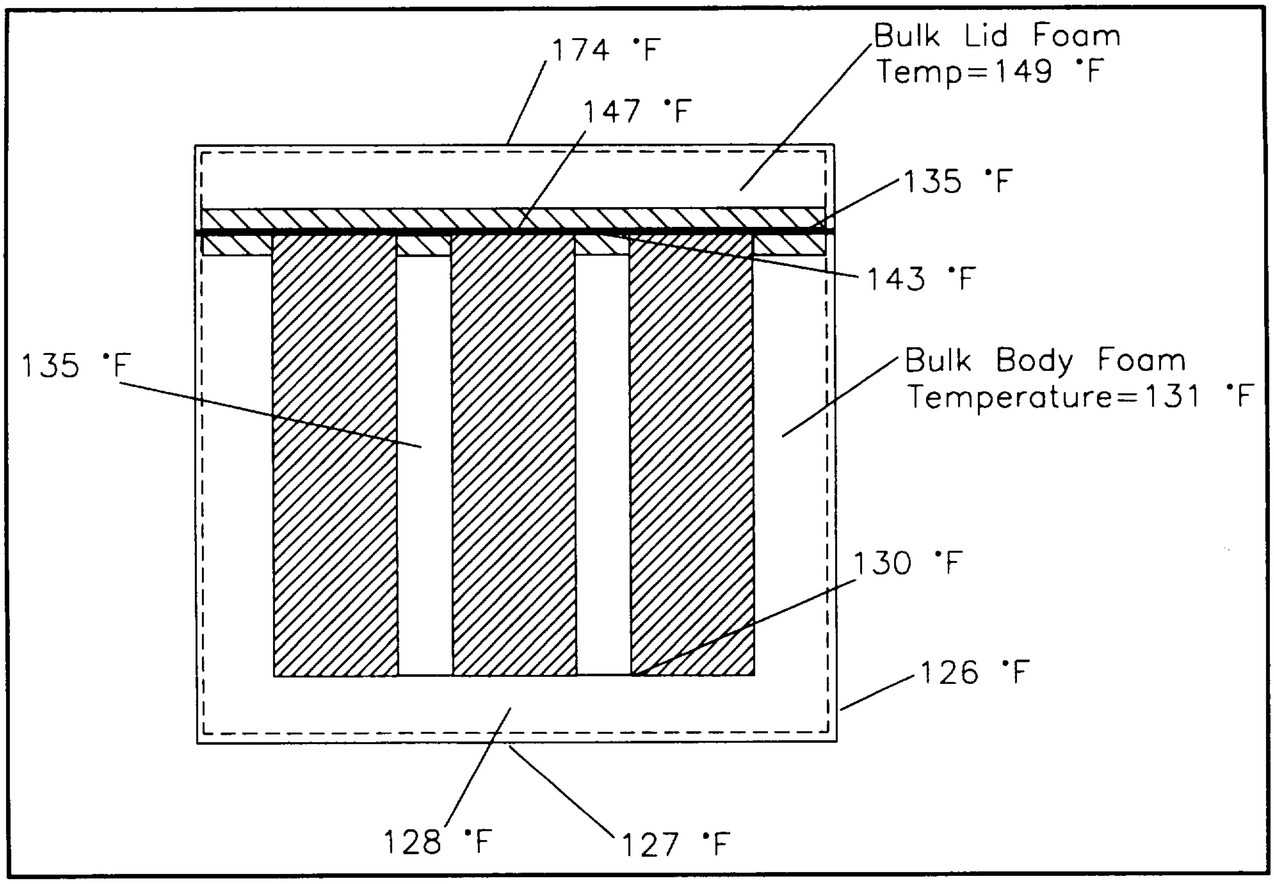


Figure 3.4-2 - NPC Package NCT Temperatures

3.4.1 Maximum Internal Pressures

The containment of the NPC package is provided by the nine ICCAs. The determination of the maximum internal pressure within the ICCAs is based on the ideal gas law. If an ICCA is filled at the minimum normal operating temperature, -40 °F and is allowed to reach the NCT maximum bulk temperature for the payload, 133 °F, the maximum pressure would be the product of the ratio of the absolute gas temperature to -40 °F and atmospheric pressure, 14.7 psia. Specifically,

$$\frac{P_{133^\circ F}}{P_{-40^\circ F}} = \frac{T_{airmax}}{T_{init}}$$

$$\frac{P_{133^\circ F}}{14.7 \text{ psia}} = \left[\frac{133+460}{-40+460}\right]$$

$$P_{133^\circ F} = 20.8 \text{ psia or } 6.1 \text{ psig (MNOP)}$$

3.4.2 Maximum Thermal Stresses

Due to the design of the package and the negligible decay heat load, the thermal stresses within the package are negligible.

3.4.3 Evaluation of Package Performance for Normal Conditions of Transport

As discussed in the previous sections, all of the temperatures that may be experienced by the NPC package during normal conditions of transport are within acceptable limits.

3.5 Thermal Evaluation for Hypothetical Accident Conditions

The performance of the NPC package under Hypothetical Accident Conditions (HAC) was determined via testing in accordance with 10 CFR §71.73. Specifically, an NPC package was placed into an open pool fire environment that resulted in the average surface temperature of the package to at least 1,475 °F. During the 30-minute fire test, the maximum surface temperatures of the test articles reached 2,029 °F (CTU-1), 2,184 °F (CTU-2), and 2,151 °F (CTU-3). Following the fire test, the packages were allowed to cool in air without any forced cooling.

A post-test examination of the CTUs indicated that the packages were intact, with no structural failures of the OCA or any ICCA. A significant amount of the polyurethane foam was consumed by the fire, adding its combustion energy to that of the forced convection from the flames. Additionally, the peak temperatures recorded in the test were well below the melting temperature of the stainless steel (2,850 °F).

As noted in Appendix 3.6.3, *Material Property Sensitivity Study*, the worst-case ICCA gasket temperature would increase by approximately 16% above the maximum recorded temperature for an ICCA. The maximum recorded gasket temperature for any ICCA was 340 °F, as discussed in Appendix 2.10.1, *Certification Tests*. Therefore, the worst-case peak ICCA gasket temperature would be 394 °F, which is below the maximum continuous-use temperature rating for silicone rubber of 450 °F.

3.5.1 Maximum Internal Pressure

The maximum ICCA external surface temperature during the fire test is 340 °F (Section 2.10.1). Internal cavity temperatures were not monitored. The worst case internal payload temperature was calculated in Appendix 3.6.2 by creating an axisymmetric model of the canister and payload in an inverted position that was exposed to the worst case ICCA surface temperatures per Section 2.10.1 for 30 minutes. This is conservative as it applies the maximum fire temperatures for the entire duration of the fire event.

The maximum calculated average payload temperature is 250°F. The partial pressure due to air is

$$\frac{P_{Air}}{P_{-40\,^{\circ}F}} = \frac{T_{airmax}}{T_{init}}$$

$$\frac{P_{Air}}{14.7 \text{ psia}} = \left[\frac{250 + 460}{-40 + 460}\right]$$

$$P_{Air} = 24.9 \text{ psia}$$

The partial pressure due to water is taken at the minimum payload cavity temperature, which is 202.7 °F, is 12.2 psia. The maximum HAC pressure in the canister is therefore:

$$P_{HAC} = P_{Air} + P_{water} = 24.9 + 12.2 = 37.1\,\text{psia} = 22.4\,\text{psig}$$

This maximum pressure is below the ICCA design pressure of 24.0 psig.

3.5.2 Maximum Thermal Stresses

The effects of HAC thermal stresses were addressed by the fire test. No damage due to thermal stresses was found during post-test examination of the test article.

3.5.3 Evaluation of the Package Performance for the Hypothetical Accident Thermal Conditions

Based the thermal tests performed on the NPC package, none of the components exceeds its temperature limit as described in Section 3.3. Specifically, the seals and polyethylene sheeting for all the nine ICCAs were observed to be intact, and operational after the fire and cool down period. This condition verifies that the NPC package satisfies the HAC thermal requirements set forth by 10 CFR §71.73(c)(4).

3.6 Appendix

3.6.1 Heating 7.3 NCT Thermal Model Input for Maximum Surface Temperature

Figures 3.6-1a and b provide a schematic drawing of the Heating 7.3 model of the NPC package. Appendix 3.6.1.1 provides the input file for the high temperature NCT case. Appendix 3.6.1.2 provides the temperature maps from the same case. Note that, per Section 3.2, the ceramic fiber board was modeled as having the same properties as the adjacent foam.

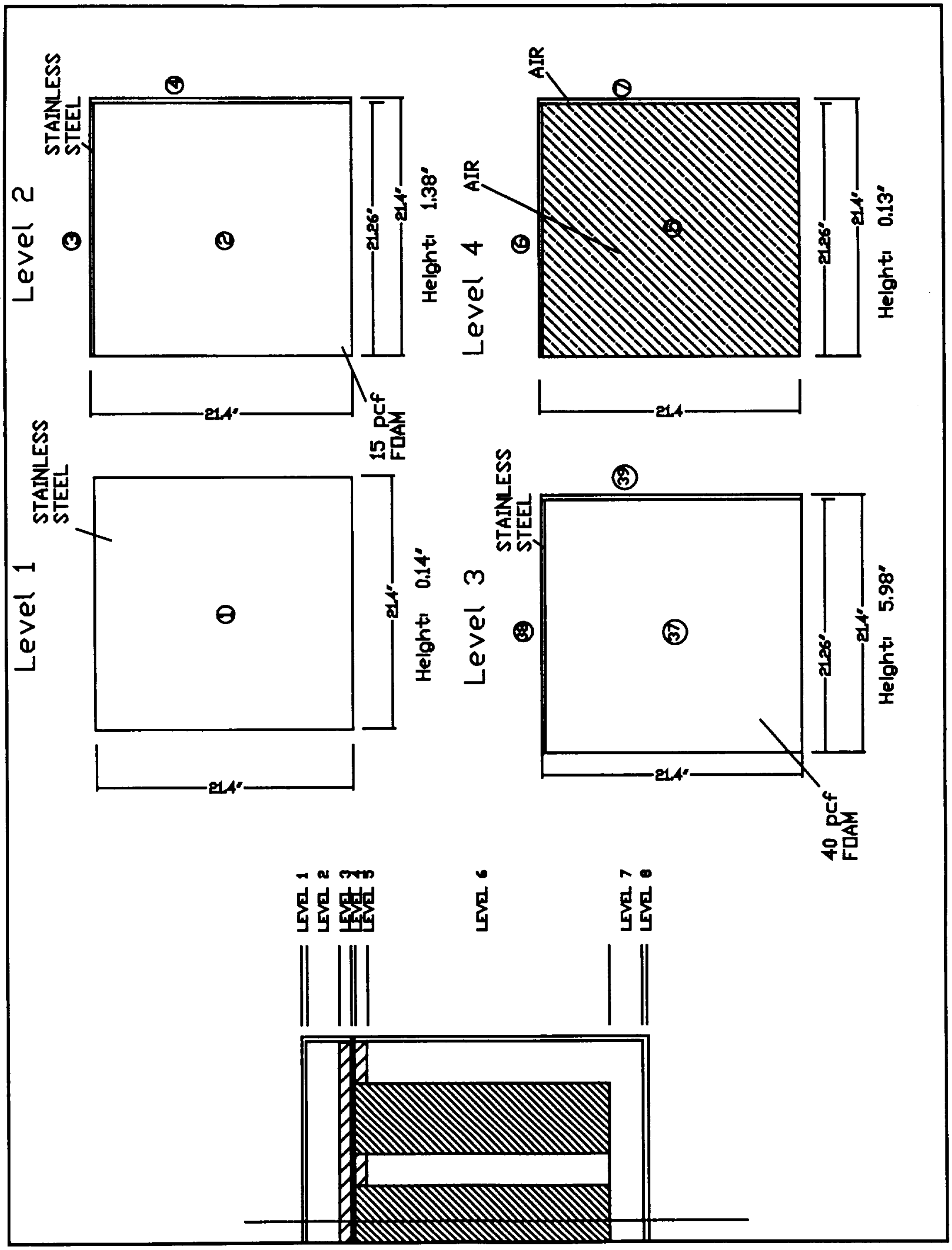


Figure 3.6-1a - Heating 7.3 Thermal Model Schematic, Level 1 through Level 4

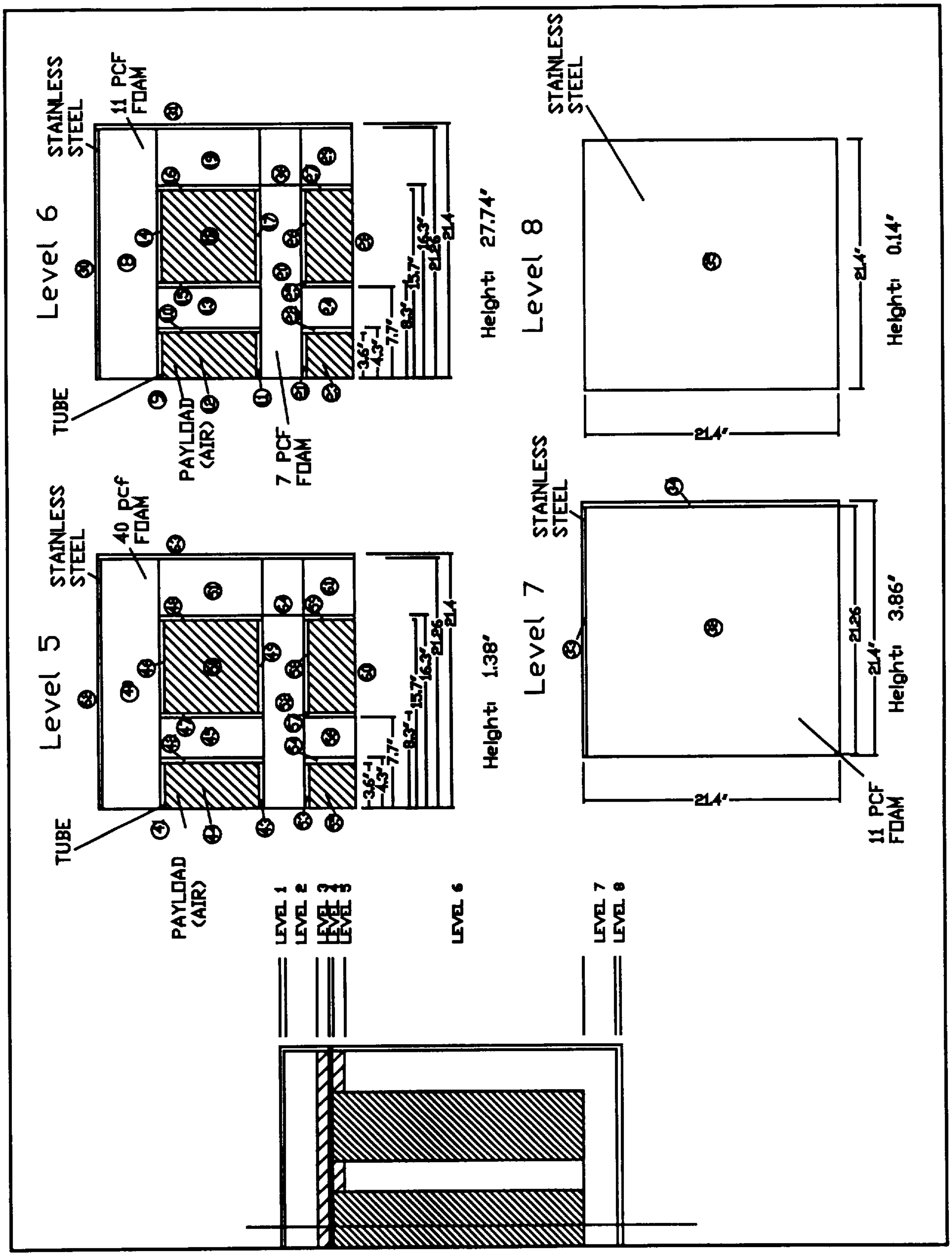


Figure 3.6-1b - Heating 7.3 Thermal Model Schematic Levels 5-8

3.6.1.1 NPC Package Heating 7.3 Input File

```
GNF NPC No Heat Load, Foam Block With Tubes and skin
* Unfinished SS skin (a=0.5, e=0.5), maximum insolation, 100 F
* Units:  lb, in, hr
100  6 0 0 0
h in lb Btu F
REGIONS
1  4  0.0  21.4 0.0 21.4 0.0 0.14
1  0   0   1   0   1  2   0
2  7  0.0  21.26 0.0 21.26 0.14 6.12
1  0   0   0   0   0  0   0
3  4  21.26 21.4 0.0 21.26 0.14 6.12
1  0   0    1   0   0   0   0
4  4   0.0  21.4 21.26 21.4 0.14 6.12
1  0   0    1   0   1   0   0
5  2  0.0  21.26 0.0 21.26 7.50 7.63
1  0   0   0   0   0  4   4
6  2  21.26 21.4 0.0 21.26 7.50 7.63
1  0   0    1   0   0   4   4
7  2   0.0  21.4 21.26 21.4 7.50 7.63
1  0   0    1   0   1   4   4
8  1   0.0  21.26  16.3 21.26 9.01 36.75
1  0   0     0     0  0     0    0
9  3   0.0  3.6    15.7 16.30 9.01 36.75
1  0   0     0     0    0     0    0
10 3   3.6  4.3    7.7  16.30 9.01 36.75
1  0   0     0     0    0     0    0
11 3   0.0  3.6     7.7  8.30 9.01 36.75
1  0   0    0      0    0     0    0
12 2   0.0  3.6     8.3  15.7 9.01 36.75
1  0    0   0       0    0    0    0
13 5   4.3  7.7     7.7  16.3 9.01  36.75
1  0    0   0       0    0    0    0
14 3   8.3  15.7    15.7  16.3 9.01 36.75
1  0    0   0       0    0    0    0
15 3   7.7   8.3    7.7   16.3 9.01 36.75
1  0    0   0       0    0    0    0
16 3   15.7  16.3   7.7   16.3 9.01 36.75
1  0    0   0       0     0    0    0
17 3    8.3  15.7   7.7    8.3  9.01 36.75
1  0    0   0       0     0    0    0
18 2   8.3   15.7   8.3   15.7  9.01 36.75
1  0    0   0       0     0    0    0
19 1   16.3  21.26  7.7   16.3  9.01 36.75
1  0    0   0       0     0    0    0
20 5    0.0  16.3   4.3    7.7  9.01 36.75
1  0    0   0       0     0    0    0
21 3    0.0  3.6    3.6    4.3  9.01 36.75
1  0    0   0       0     0    0    0
22 3    3.6  4.3    0.0    4.3  9.01 36.75
1  0    0   0       0     0    0    0
23 2    0.0  3.6    0.0    3.6  9.01 36.75
1  0    0   0       0     0    0    0
24 5    4.3  7.7    0.0    4.3  9.01 36.75
1  0    0   0       0     0    0    0
25 3    7.7  8.3    0.0  4.3    9.01 36.75
1  0    0   0       0    0      0    0
26 3    8.3  15.7   3.6  4.3    9.01 36.75
1  0    0   0       0    0      0    0
27 3    15.7 16.3   0.0  4.3    9.01 36.75
1  0    0   0       0    0      0    0
28 2    8.3  15.7   0.0  3.6    9.01 36.75
1  0    0   0       0    0      0    0
29 1    16.3 21.26  0.0  4.3    9.01 36.75
1  0    0   0       0    0      0    0
30 4    0.0  21.26  21.26 21.40 9.01 36.75
1  0    0   0       0     1    0    0
31 4    21.26 21.40  0.0  21.40 9.01 36.75
1  0    0   1       0     1    0    0
32 1    0.0   21.26  0.0  21.26 36.75 40.61
1  0    0   0       0     0    0    0
```

```
33 4    0.0    21.26 21.26 21.40 36.75 40.61
1  0    0    0       0     1     0     0
34 4    21.26 21.40 0.0    21.40 36.75 40.61
1  0    0    1       0     1     0     0
35 4    0.0    21.4    0.0    21.40  40.61 40.75
1  0    0    1       0     1      0     3
36 1    16.3  21.26  4.3    7.7   9.01 36.75
1  0    0    0       0     0     0     0
37  6  0.0  21.26 0.0 21.26 6.12 7.50
1  0   0    0    0    0    0    0
38  4  21.26 21.4 0.0 21.26 6.12 7.50
1  0   0     1    0    0    0    0
39  4   0.0   21.4 21.26 21.4 6.12 7.50
1  0   0     1    0    1    0    0
40  6   0.0   21.26  16.3 21.26 7.63 9.01
1  0   0     0      0    0     0    0
41  3   0.0   3.6    15.7 16.30 7.63 9.01
1  0   0      0     0    0     0    0
42 3   3.6  4.3    7.7  16.30 7.63 9.01
1  0   0      0    0    0     0    0
43 3   0.0  3.6     7.7  8.30 7.63 9.01
1  0   0    0      0    0     0    0
44 2   0.0  3.6     8.3  15.7 7.63 9.01
1  0    0   0       0    0    0    0
45 6   4.3  7.7     7.7  16.3 7.63 9.01
1  0    0   0       0    0     0    0
46 3   8.3  15.7    15.7  16.3 7.63 9.01
1  0    0   0       0    0     0    0
47 3   7.7   8.3    7.7   16.3 7.63 9.01
1  0    0    0      0     0    0    0
48 3   15.7  16.3   7.7   16.3 7.63 9.01
1  0    0    0      0      0   0    0
49 3    8.3  15.7   7.7    8.3  7.63 9.01
1  0    0    0      0      0    0    0
50 2   8.3   15.7   8.3   15.7  7.63 9.01
1  0    0    0      0      0    0    0
51 6   16.3  21.26  7.7   16.3  7.63 9.01
1  0    0    0      0      0    0    0
52 6    0.0  16.3   4.3    7.7  7.63 9.01
1  0    0    0      0      0    0    0
53 3    0.0  3.6    3.6    4.3  7.63 9.01
1  0    0    0      0      0    0    0
54 3    3.6  4.3    0.0    4.3  7.63 9.01
1  0    0    0      0      0    0    0
55 2    0.0  3.6    0.0    3.6  7.63 9.01
1  0    0    0      0      0    0    0
56 6    4.3  7.7    0.0    4.3  7.63 9.01
1  0    0    0      0      0    0    0
57 3    7.7  8.3    0.0  4.3    7.63 9.01
1  0    0    0      0    0      0    0
58 3    8.3  15.7   3.6  4.3    7.63 9.01
1  0    0    0      0    0      0    0
59 3    15.7 16.3   0.0  4.3    7.63 9.01
1  0    0    0      0    0      0    0
60 2    8.3  15.7   0.0  3.6    7.63 9.01
1  0    0    0      0    0      0    0
61 6    16.3 21.26  0.0  4.3    7.63 9.01
1  0    0    0      0    0      0    0
62 4    0.0  21.26  21.26 21.40 7.63 9.01
1  0    0    0      0     1     0    0
63 4    21.26 21.40  0.0  21.40 7.63 9.01
1  0    0    1      0     1     0    0
64 6    16.3  21.26  4.3    7.7  7.63 9.01
1  0    0    0      0      0    0    0
MATERIALS
1  Foam11   0.002  0.0064   0.47
2  Air      0.0013 0.0064   0.24
3  Tubes    0.069  0.053    0.37
4  Steel    0.725   0.281   0.111
5  Foam07   0.0018 0.0041   0.47
6  Foam40   0.0040 0.0231   0.47
7  Foam15   0.0023 0.0087   0.47
INITIAL TEMPERATURE
1  100.0
```

```
HEAT GENERATIONS
1  0.00
BOUNDARY CONDITIONS
1  1  100.0
0.0   5.95e-12 0.0013  0.333   0.213
2  1  100.0
0.0   5.95e-12 0.0015  0.333   0.853
3  1  100.0
0.0   5.95e-14
4  3
0.0   3.97e-12
XGRID
0.0  3.6  4.3  7.7  8.3  15.7  16.3  21.26  21.4
    2    1    2    1    2     1     2     1
YGRID
0.0  3.6  4.3  7.7  8.3  15.7  16.3  21.26  21.4
    2    1    2    1    2     1     2     1
ZGRID
0.0  0.14  6.12 7.5  7.63 9.01 36.75 40.61 40.75
    1    4    2    1     1   7     3     1
STEADY-STATE
1
%
```

3.6.1.2 GNF NPC Heating 7.3 Temperature Maps

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42
Steady-State Temperature Distribution at Time 0.0000E+00
Z = 0.0000E+00

13	21.40	152.69	152.68	152.68	152.67	152.64	152.60	152.57	152.29	151.37	151.03	148.94	144.55	144.50
12	21.26	152.79	152.79	152.78	152.78	152.75	152.70	152.68	152.39	151.47	151.13	149.04	144.61	144.55
11	18.78	165.17	165.17	165.16	165.15	165.12	165.05	165.02	164.63	163.26	162.68	158.91	149.04	148.94
10	16.30	170.39	170.38	170.36	170.35	170.31	170.23	170.19	169.72	168.02	167.31	162.68	151.13	151.03
9	15.70	171.20	171.20	171.18	171.17	171.12	171.04	170.99	170.51	168.75	168.02	163.26	151.47	151.37
8	12.00	173.25	173.25	173.22	173.21	173.15	173.06	173.01	172.45	170.51	169.72	164.63	152.39	152.29
7	8.30	173.86	173.85	173.83	173.81	173.75	173.65	173.59	173.01	170.99	170.19	165.02	152.68	152.57
6	7.70	173.92	173.91	173.88	173.87	173.81	173.70	173.65	173.06	171.04	170.23	165.05	152.70	152.60
5	6.00	174.03	174.02	173.99	173.97	173.91	173.81	173.75	173.15	171.12	170.31	165.12	152.75	152.64
4	4.30	174.09	174.08	174.05	174.03	173.97	173.87	173.81	173.21	171.17	170.35	165.15	152.78	152.67
3	3.60	174.11	174.10	174.07	174.05	173.99	173.88	173.83	173.22	171.18	170.36	165.16	152.78	152.68
2	1.80	174.14	174.13	174.10	174.08	174.02	173.91	173.85	173.25	171.20	170.38	165.17	152.79	152.68
1	.00	174.14	174.14	174.11	174.09	174.03	173.92	173.86	173.25	171.20	170.39	165.17	152.79	152.69
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42
Steady-State Temperature Distribution at Time 0.0000E+00
Z = 1.4000E-01

13	21.40	152.58	152.58	152.57	152.56	152.54	152.49	152.46	152.18	151.26	150.92	148.84	144.44	144.39
12	21.26	152.70	152.70	152.69	152.69	152.66	152.61	152.59	152.30	151.38	151.04	148.95	144.51	144.44
11	18.78	165.16	165.16	165.14	165.13	165.10	165.04	165.00	164.62	163.24	162.66	158.88	148.95	148.84
10	16.30	170.38	170.37	170.36	170.34	170.30	170.22	170.18	169.71	168.01	167.30	162.66	151.04	150.92
9	15.70	171.20	171.19	171.17	171.16	171.11	171.03	170.99	170.50	168.74	168.01	163.24	151.38	151.26
8	12.00	173.25	173.24	173.22	173.20	173.15	173.05	173.00	172.45	170.50	169.71	164.62	152.30	152.18
7	8.30	173.86	173.85	173.82	173.81	173.75	173.65	173.59	173.00	170.99	170.18	165.00	152.59	152.46
6	7.70	173.91	173.91	173.88	173.86	173.80	173.70	173.65	173.05	171.03	170.22	165.04	152.61	152.49
5	6.00	174.02	174.01	173.99	173.97	173.91	173.80	173.75	173.15	171.11	170.30	165.10	152.66	152.54
4	4.30	174.09	174.08	174.05	174.03	173.97	173.86	173.81	173.20	171.16	170.34	165.13	152.69	152.56
3	3.60	174.10	174.10	174.07	174.05	173.99	173.88	173.82	173.22	171.17	170.36	165.14	152.69	152.57
2	1.80	174.13	174.12	174.10	174.08	174.01	173.91	173.85	173.24	171.19	170.37	165.16	152.70	152.58
1	.00	174.14	174.13	174.10	174.09	174.02	173.91	173.86	173.25	171.20	170.38	165.16	152.70	152.58
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 1.6350E+00

13	21.40	142.99	142.99	142.98	142.98	142.95	142.91	142.89	142.65	141.94	141.72	140.41	138.56	138.54
12	21.26	143.01	143.01	143.00	143.00	142.97	142.93	142.91	142.67	141.96	141.73	140.43	138.58	138.56
11	18.78	155.34	155.33	155.30	155.28	155.22	155.11	155.06	154.52	152.87	152.27	148.55	140.43	140.41
10	16.30	161.55	161.54	161.48	161.45	161.35	161.20	161.12	160.38	158.09	157.28	152.27	141.73	141.72
9	15.70	162.60	162.58	162.52	162.48	162.38	162.21	162.13	161.35	158.95	158.09	152.87	141.96	141.94
8	12.00	165.75	165.70	165.59	165.54	165.39	165.19	165.10	164.22	161.35	160.38	154.52	142.67	142.65
7	8.30	166.76	166.73	166.64	166.60	166.45	166.21	166.11	165.10	162.13	161.12	155.06	142.91	142.89
6	7.70	166.87	166.84	166.76	166.71	166.56	166.32	166.21	165.19	162.21	161.20	155.11	142.93	142.91
5	6.00	167.12	167.09	167.00	166.96	166.80	166.56	166.45	165.39	162.38	161.35	155.22	142.97	142.95
4	4.30	167.30	167.26	167.17	167.12	166.96	166.71	166.60	165.54	162.48	161.45	155.28	143.00	142.98
3	3.60	167.36	167.32	167.23	167.17	167.00	166.76	166.64	165.59	162.52	161.48	155.30	143.00	142.98
2	1.80	167.49	167.45	167.32	167.26	167.09	166.84	166.73	165.70	162.58	161.54	155.33	143.01	142.99
1	.00	167.54	167.49	167.36	167.30	167.12	166.87	166.76	165.75	162.60	161.55	155.34	143.01	142.99
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 3.1300E+00

13	21.40	137.04	137.04	137.03	137.03	137.01	136.97	136.95	136.76	136.23	136.08	135.29	134.43	134.42
12	21.26	137.05	137.05	137.04	137.04	137.02	136.98	136.97	136.77	136.24	136.09	135.30	134.44	134.43
11	18.78	147.76	147.74	147.70	147.68	147.59	147.45	147.39	146.78	145.13	144.60	141.42	135.30	135.29
10	16.30	153.87	153.84	153.76	153.71	153.57	153.34	153.25	152.37	149.94	149.17	144.60	136.09	136.08
9	15.70	154.94	154.91	154.81	154.76	154.61	154.37	154.26	153.35	150.77	149.94	145.13	136.24	136.23
8	12.00	158.65	158.56	158.32	158.23	158.01	157.72	157.60	156.65	153.35	152.37	146.78	136.77	136.76
7	8.30	159.80	159.74	159.60	159.53	159.31	158.97	158.82	157.60	154.26	153.25	147.39	136.97	136.95
6	7.70	159.94	159.89	159.75	159.68	159.46	159.12	158.97	157.72	154.37	153.34	147.45	136.98	136.97
5	6.00	160.30	160.26	160.12	160.05	159.82	159.46	159.31	158.01	154.61	153.57	147.59	137.02	137.01
4	4.30	160.58	160.53	160.37	160.29	160.05	159.68	159.53	158.23	154.76	153.71	147.68	137.04	137.03
3	3.60	160.70	160.63	160.46	160.37	160.12	159.75	159.60	158.32	154.81	153.76	147.70	137.04	137.03
2	1.80	160.97	160.87	160.63	160.53	160.26	159.89	159.74	158.56	154.91	153.84	147.74	137.05	137.04
1	.00	161.08	160.97	160.70	160.58	160.30	159.94	159.80	158.65	154.94	153.87	147.76	137.05	137.04
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 4.6250E+00

13	21.40	133.40	133.40	133.39	133.39	133.37	133.34	133.32	133.16	132.76	132.67	132.17	131.74	131.73
12	21.26	133.41	133.41	133.40	133.40	133.38	133.35	133.33	133.17	132.77	132.67	132.18	131.75	131.74
11	18.78	141.86	141.85	141.80	141.77	141.67	141.50	141.43	140.81	139.35	138.92	136.43	132.18	132.17
10	16.30	147.18	147.15	147.05	147.00	146.83	146.53	146.41	145.51	143.29	142.64	138.92	132.67	132.67
9	15.70	148.17	148.12	147.99	147.93	147.76	147.43	147.30	146.38	143.98	143.29	139.35	132.77	132.76
8	12.00	152.11	151.91	151.42	151.27	151.01	150.63	150.51	149.84	146.38	145.51	140.81	133.17	133.16
7	8.30	152.98	152.90	152.68	152.60	152.37	151.89	151.72	150.51	147.30	146.41	141.43	133.33	133.32
6	7.70	153.14	153.06	152.87	152.79	152.56	152.08	151.89	150.63	147.43	146.53	141.50	133.35	133.34
5	6.00	153.62	153.55	153.39	153.30	153.04	152.56	152.37	151.01	147.76	146.83	141.67	133.38	133.37
4	4.30	153.96	153.88	153.68	153.58	153.30	152.79	152.60	151.27	147.93	147.00	141.77	133.40	133.39
3	3.60	154.14	154.04	153.78	153.68	153.39	152.87	152.68	151.42	147.99	147.05	141.80	133.40	133.39
2	1.80	154.69	154.50	154.04	153.88	153.55	153.06	152.90	151.91	148.12	147.15	141.85	133.41	133.40
1	.00	154.90	154.69	154.14	153.96	153.62	153.14	152.98	152.11	148.17	147.18	141.86	133.41	133.40
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 6.1200E+00

13	21.40	131.28	131.28	131.28	131.27	131.26	131.23	131.21	131.07	130.76	130.69	130.36	130.15	130.14
12	21.26	131.29	131.29	131.28	131.28	131.26	131.23	131.22	131.08	130.77	130.70	130.37	130.15	130.15
11	18.78	137.13	137.12	137.07	137.04	136.93	136.73	136.65	136.06	134.88	134.55	132.73	130.37	130.36
10	16.30	141.28	141.25	141.16	141.12	140.99	140.53	140.38	139.52	137.77	137.31	134.55	130.70	130.69
9	15.70	142.06	142.01	141.86	141.82	141.71	141.18	141.02	140.19	138.26	137.77	134.88	130.77	130.76
8	12.00	146.33	145.92	144.75	144.53	144.41	143.83	143.72	143.95	140.19	139.52	136.06	131.08	131.07
7	8.30	146.26	146.12	145.79	145.73	145.67	144.90	144.67	143.72	141.02	140.38	136.65	131.22	131.21
6	7.70	146.41	146.30	146.03	145.98	145.91	145.13	144.90	143.83	141.18	140.53	136.73	131.23	131.23
5	6.00	147.12	147.05	146.87	146.81	146.59	145.91	145.67	144.41	141.71	140.99	136.93	131.26	131.26
4	4.30	147.36	147.27	147.05	146.98	146.81	145.98	145.73	144.53	141.82	141.12	137.04	131.28	131.27
3	3.60	147.62	147.48	147.13	147.05	146.87	146.03	145.79	144.75	141.86	141.16	137.07	131.28	131.28
2	1.80	148.89	148.53	147.48	147.27	147.05	146.30	146.12	145.92	142.01	141.25	137.12	131.29	131.28
1	.00	149.33	148.89	147.62	147.36	147.12	146.41	146.26	146.33	142.06	141.28	137.13	131.29	131.28
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 6.8100E+00

13	21.40	130.68	130.68	130.67	130.67	130.65	130.62	130.61	130.48	130.19	130.13	129.84	129.71	129.70
12	21.26	130.68	130.68	130.68	130.67	130.66	130.63	130.62	130.48	130.20	130.13	129.85	129.71	129.71
11	18.78	136.03	136.02	135.97	135.94	135.83	135.62	135.54	134.95	133.85	133.55	131.84	129.85	129.84
10	16.30	139.85	139.83	139.76	139.75	139.65	139.08	138.92	138.06	136.50	136.12	133.55	130.13	130.13
9	15.70	140.50	140.45	140.32	140.30	140.31	139.60	139.43	138.61	136.89	136.50	133.85	130.20	130.19
8	12.00	145.10	144.60	142.91	142.70	142.79	142.02	141.93	142.70	138.61	138.06	134.95	130.48	130.48
7	8.30	144.45	144.30	143.89	143.86	144.01	142.97	142.75	141.93	139.43	138.92	135.54	130.62	130.61
6	7.70	144.58	144.45	144.15	144.14	144.27	143.23	142.97	142.02	139.60	139.08	135.62	130.63	130.62
5	6.00	145.51	145.44	145.27	145.22	145.06	144.27	144.01	142.79	140.31	139.65	135.83	130.66	130.65
4	4.30	145.54	145.45	145.26	145.24	145.22	144.14	143.86	142.70	140.30	139.75	135.94	130.67	130.67
3	3.60	145.79	145.66	145.31	145.26	145.27	144.15	143.89	142.91	140.32	139.76	135.97	130.68	130.67
2	1.80	147.61	147.17	145.66	145.45	145.44	144.45	144.30	144.60	140.45	139.83	136.02	130.68	130.68
1	.00	148.14	147.61	145.79	145.54	145.51	144.58	144.45	145.10	140.50	139.85	136.03	130.68	130.68
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 7.5000E+00

13	21.40	130.27	130.27	130.26	130.26	130.24	130.21	130.20	130.08	129.81	129.75	129.48	129.44	129.44
12	21.26	130.26	130.26	130.26	130.25	130.24	130.21	130.20	130.07	129.80	129.74	129.48	129.44	129.44
11	18.78	135.04	135.04	135.00	134.97	134.85	134.63	134.55	133.97	132.95	132.67	130.99	129.48	129.48
10	16.30	138.57	138.57	138.55	138.57	138.53	137.76	137.62	136.73	135.41	135.20	132.67	129.74	129.75
9	15.70	138.91	138.90	138.82	138.84	139.11	138.00	137.87	137.02	135.59	135.41	132.95	129.80	129.81
8	12.00	144.21	143.62	140.89	140.76	141.37	140.13	140.11	141.79	137.02	136.73	133.97	130.07	130.08
7	8.30	142.60	142.45	141.89	141.89	142.53	140.91	140.76	140.11	137.87	137.62	134.55	130.20	130.20
6	7.70	142.65	142.51	142.10	142.19	142.80	141.19	140.91	140.13	138.00	137.76	134.63	130.21	130.21
5	6.00	144.07	144.00	143.84	143.81	143.73	142.80	142.53	141.37	139.11	138.53	134.85	130.24	130.24
4	4.30	143.60	143.54	143.42	143.50	143.81	142.19	141.89	140.76	138.84	138.57	134.97	130.25	130.26
3	3.60	143.75	143.66	143.40	143.42	143.84	142.10	141.89	140.89	138.82	138.55	135.00	130.26	130.26
2	1.80	146.64	146.13	143.66	143.54	144.00	142.51	142.45	143.62	138.90	138.57	135.04	130.26	130.27
1	.00	147.27	146.64	143.75	143.60	144.07	142.65	142.60	144.21	138.91	138.57	135.04	130.26	130.27
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin   18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 7.6300E+00

13	21.40	127.62	127.62	127.62	127.61	127.60	127.58	127.58	127.50	127.34	127.31	127.13	126.83	126.83
12	21.26	127.63	127.63	127.63	127.62	127.61	127.59	127.58	127.51	127.35	127.32	127.14	126.84	126.83
11	18.78	134.64	134.63	134.60	134.57	134.44	134.22	134.14	133.57	132.58	132.30	130.62	127.14	127.13
10	16.30	138.08	138.09	138.09	138.13	138.12	137.24	137.11	136.20	134.99	134.89	132.30	127.32	127.31
9	15.70	138.18	138.19	138.15	138.19	138.66	137.25	137.19	136.29	135.02	134.99	132.58	127.35	127.34
8	12.00	143.91	143.31	139.91	139.89	140.83	139.27	139.31	141.49	136.29	136.20	133.57	127.51	127.50
7	8.30	141.79	141.64	141.00	141.00	141.97	139.94	139.90	139.31	137.19	137.11	134.14	127.58	127.58
6	7.70	141.75	141.60	141.12	141.29	142.24	140.21	139.94	139.27	137.25	137.24	134.22	127.59	127.58
5	6.00	143.53	143.46	143.30	143.28	143.22	142.24	141.97	140.83	138.66	138.12	134.44	127.61	127.60
4	4.30	142.73	142.68	142.59	142.73	143.28	141.29	141.00	139.89	138.19	138.13	134.57	127.62	127.61
3	3.60	142.76	142.71	142.54	142.59	143.30	141.12	141.00	139.91	138.15	138.09	134.60	127.63	127.62
2	1.80	146.34	145.81	142.71	142.68	143.46	141.60	141.64	143.31	138.19	138.09	134.63	127.63	127.62
1	.00	146.98	146.34	142.76	142.73	143.53	141.75	141.79	143.91	138.18	138.08	134.64	127.63	127.62
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin   18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 9.0100E+00

13	21.40	127.09	127.09	127.09	127.08	127.07	127.06	127.05	126.98	126.86	126.83	126.68	126.53	126.53
12	21.26	127.09	127.09	127.09	127.09	127.08	127.06	127.05	126.99	126.86	126.83	126.69	126.53	126.53
11	18.78	133.35	133.35	133.33	133.29	133.12	132.92	132.85	132.29	131.42	131.16	129.48	126.69	126.68
10	16.30	137.30	137.34	137.50	137.47	136.84	136.44	136.42	135.41	134.45	134.33	131.16	126.83	126.83
9	15.70	137.32	137.37	137.56	137.58	137.37	136.52	136.47	135.43	134.47	134.45	131.42	126.86	126.86
8	12.00	140.73	140.33	139.05	139.05	139.26	138.23	138.23	138.46	135.43	135.41	132.29	126.99	126.98
7	8.30	140.66	140.54	140.15	140.14	140.33	138.93	138.92	138.23	136.47	136.42	132.85	127.05	127.05
6	7.70	140.67	140.55	140.20	140.22	140.57	139.02	138.93	138.23	136.52	136.44	132.92	127.06	127.06
5	6.00	141.93	141.87	141.72	141.68	141.50	140.57	140.33	139.26	137.37	136.84	133.12	127.08	127.07
4	4.30	141.88	141.86	141.81	141.81	141.68	140.22	140.14	139.05	137.58	137.47	133.29	127.09	127.08
3	3.60	141.89	141.86	141.80	141.81	141.72	140.20	140.15	139.05	137.56	137.50	133.33	127.09	127.09
2	1.80	143.24	142.92	141.86	141.86	141.87	140.55	140.54	140.33	137.37	137.34	133.35	127.09	127.09
1	.00	143.66	143.24	141.89	141.88	141.93	140.67	140.66	140.73	137.32	137.30	133.35	127.09	127.09
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 1.2973E+01

13	21.40	126.34	126.34	126.34	126.34	126.33	126.31	126.31	126.27	126.19	126.18	126.10	126.04	126.04
12	21.26	126.34	126.34	126.34	126.34	126.33	126.31	126.31	126.27	126.19	126.18	126.10	126.04	126.04
11	18.78	131.00	131.00	130.96	130.91	130.65	130.51	130.46	130.00	129.38	129.16	127.74	126.10	126.10
10	16.30	135.19	135.25	135.43	135.39	134.21	134.22	134.23	133.34	132.68	132.58	129.16	126.18	126.18
9	15.70	135.20	135.27	135.49	135.50	134.69	134.30	134.27	133.35	132.70	132.68	129.38	126.19	126.19
8	12.00	136.88	136.80	136.60	136.60	136.10	135.53	135.53	134.79	133.35	133.34	130.00	126.27	126.27
7	8.30	137.79	137.71	137.46	137.44	136.91	136.11	136.10	135.53	134.27	134.23	130.46	126.31	126.31
6	7.70	137.79	137.71	137.49	137.47	137.07	136.14	136.11	135.53	134.30	134.22	130.51	126.31	126.31
5	6.00	138.59	138.54	138.38	138.26	137.74	137.07	136.91	136.10	134.69	134.21	130.65	126.33	126.33
4	4.30	139.30	139.28	139.24	139.21	138.26	137.47	137.44	136.60	135.50	135.39	130.91	126.34	126.34
3	3.60	139.30	139.28	139.25	139.24	138.38	137.49	137.46	136.60	135.49	135.43	130.96	126.34	126.34
2	1.80	139.53	139.46	139.28	139.28	138.54	137.71	137.71	136.80	135.27	135.25	131.00	126.34	126.34
1	.00	139.61	139.53	139.30	139.30	138.59	137.79	137.79	136.88	135.20	135.19	131.00	126.34	126.34
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 1.6936E+01

13	21.40	126.08	126.08	126.07	126.07	126.06	126.05	126.04	126.01	125.96	125.95	125.89	125.86	125.86
12	21.26	126.08	126.08	126.07	126.07	126.06	126.05	126.04	126.01	125.96	125.95	125.89	125.86	125.86
11	18.78	129.82	129.81	129.78	129.72	129.47	129.34	129.29	128.91	128.42	128.25	127.10	125.89	125.89
10	16.30	133.42	133.47	133.63	133.58	132.48	132.45	132.46	131.72	131.21	131.12	128.25	125.95	125.95
9	15.70	133.43	133.49	133.67	133.68	132.88	132.52	132.49	131.73	131.23	131.21	128.42	125.96	125.96
8	12.00	134.64	134.62	134.56	134.56	134.02	133.48	133.48	132.74	131.73	131.72	128.91	126.01	126.01
7	8.30	135.52	135.46	135.26	135.24	134.68	133.95	133.95	133.48	132.49	132.46	129.29	126.04	126.04
6	7.70	135.53	135.47	135.28	135.27	134.82	133.98	133.95	133.48	132.52	132.45	129.34	126.05	126.05
5	6.00	136.28	136.24	136.08	135.97	135.42	134.82	134.68	134.02	132.88	132.48	129.47	126.06	126.06
4	4.30	137.04	137.02	136.99	136.96	135.97	135.27	135.24	134.56	133.68	133.58	129.72	126.07	126.07
3	3.60	137.04	137.03	137.00	136.99	136.08	135.28	135.26	134.56	133.67	133.63	129.78	126.07	126.07
2	1.80	137.12	137.10	137.03	137.02	136.24	135.47	135.46	134.62	133.49	133.47	129.81	126.08	126.08
1	.00	137.15	137.12	137.04	137.04	136.28	135.53	135.52	134.64	133.43	133.42	129.82	126.08	126.08
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 2.0899E+01

13	21.40	125.96	125.95	125.95	125.95	125.94	125.92	125.92	125.89	125.85	125.85	125.81	125.78	125.78
12	21.26	125.96	125.95	125.95	125.95	125.94	125.93	125.92	125.89	125.85	125.85	125.81	125.78	125.78
11	18.78	129.00	129.00	128.96	128.91	128.69	128.56	128.52	128.20	127.81	127.67	126.75	125.81	125.81
10	16.30	131.98	132.03	132.15	132.11	131.15	131.08	131.08	130.47	130.06	129.99	127.67	125.85	125.85
9	15.70	131.99	132.04	132.19	132.19	131.48	131.13	131.11	130.48	130.08	130.06	127.81	125.85	125.85
8	12.00	132.96	132.95	132.92	132.91	132.41	131.91	131.91	131.27	130.48	130.47	128.20	125.89	125.89
7	8.30	133.72	133.67	133.50	133.48	132.97	132.30	132.29	131.91	131.11	131.08	128.52	125.92	125.92
6	7.70	133.73	133.67	133.52	133.50	133.09	132.33	132.30	131.91	131.13	131.08	128.56	125.93	125.92
5	6.00	134.43	134.39	134.25	134.14	133.63	133.09	132.97	132.41	131.48	131.15	128.69	125.94	125.94
4	4.30	135.14	135.12	135.09	135.06	134.14	133.50	133.48	132.91	132.19	132.11	128.91	125.95	125.95
3	3.60	135.14	135.13	135.10	135.09	134.25	133.52	133.50	132.92	132.19	132.15	128.96	125.95	125.95
2	1.80	135.20	135.18	135.13	135.12	134.39	133.67	133.67	132.95	132.04	132.03	129.00	125.95	125.95
1	.00	135.21	135.20	135.14	135.14	134.43	133.73	133.72	132.96	131.99	131.98	129.00	125.96	125.96
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 2.4861E+01

13	21.40	125.87	125.87	125.87	125.86	125.85	125.84	125.84	125.82	125.79	125.78	125.75	125.74	125.74
12	21.26	125.87	125.87	125.87	125.86	125.85	125.85	125.84	125.82	125.79	125.78	125.75	125.74	125.74
11	18.78	128.37	128.37	128.34	128.29	128.10	127.98	127.94	127.68	127.36	127.25	126.51	125.75	125.75
10	16.30	130.83	130.87	130.97	130.94	130.11	130.02	130.02	129.52	129.18	129.12	127.25	125.78	125.78
9	15.70	130.84	130.88	131.00	131.00	130.39	130.06	130.05	129.52	129.19	129.18	127.36	125.79	125.79
8	12.00	131.64	131.64	131.61	131.60	131.15	130.71	130.70	130.17	129.52	129.52	127.68	125.82	125.82
7	8.30	132.29	132.25	132.10	132.09	131.62	131.03	131.03	130.70	130.05	130.02	127.94	125.84	125.84
6	7.70	132.29	132.25	132.12	132.10	131.73	131.05	131.03	130.71	130.06	130.02	127.98	125.85	125.84
5	6.00	132.93	132.89	132.77	132.67	132.22	131.73	131.62	131.15	130.39	130.11	128.10	125.85	125.85
4	4.30	133.57	133.56	133.53	133.50	132.67	132.10	132.09	131.60	131.00	130.94	128.29	125.86	125.86
3	3.60	133.57	133.56	133.54	133.53	132.77	132.12	132.10	131.61	131.00	130.97	128.34	125.87	125.87
2	1.80	133.62	133.61	133.56	133.56	132.89	132.25	132.25	131.64	130.88	130.87	128.37	125.87	125.87
1	.00	133.64	133.62	133.57	133.57	132.93	132.29	132.29	131.64	130.84	130.83	128.37	125.87	125.87
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 2.8824E+01

13	21.40	125.81	125.81	125.81	125.81	125.80	125.79	125.79	125.77	125.75	125.75	125.72	125.71	125.71
12	21.26	125.81	125.81	125.81	125.81	125.80	125.79	125.79	125.77	125.75	125.75	125.72	125.71	125.71
11	18.78	127.88	127.88	127.85	127.81	127.64	127.54	127.51	127.28	127.02	126.93	126.33	125.72	125.72
10	16.30	129.92	129.95	130.04	130.01	129.31	129.21	129.21	128.78	128.50	128.45	126.93	125.75	125.75
9	15.70	129.93	129.96	130.06	130.07	129.53	129.24	129.23	128.78	128.51	128.50	127.02	125.75	125.75
8	12.00	130.60	130.60	130.58	130.58	130.17	129.78	129.78	129.32	128.78	128.78	127.28	125.77	125.77
7	8.30	131.17	131.13	131.00	130.99	130.58	130.06	130.06	129.78	129.23	129.21	127.51	125.79	125.79
6	7.70	131.17	131.13	131.02	131.01	130.68	130.08	130.06	129.78	129.24	129.21	127.54	125.79	125.79
5	6.00	131.73	131.70	131.59	131.51	131.10	130.68	130.58	130.17	129.53	129.31	127.64	125.80	125.80
4	4.30	132.31	132.30	132.27	132.25	131.51	131.01	130.99	130.58	130.07	130.01	127.81	125.81	125.81
3	3.60	132.31	132.30	132.28	132.27	131.59	131.02	131.00	130.58	130.06	130.04	127.85	125.81	125.81
2	1.80	132.34	132.33	132.30	132.30	131.70	131.13	131.13	130.60	129.96	129.95	127.88	125.81	125.81
1	.00	132.35	132.34	132.31	132.31	131.73	131.17	131.17	130.60	129.93	129.92	127.88	125.81	125.81
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 3.2787E+01

13	21.40	125.79	125.79	125.78	125.78	125.78	125.77	125.77	125.75	125.73	125.73	125.71	125.70	125.70
12	21.26	125.79	125.79	125.78	125.78	125.78	125.77	125.77	125.75	125.73	125.73	125.71	125.70	125.70
11	18.78	127.48	127.48	127.45	127.42	127.28	127.19	127.16	126.97	126.75	126.68	126.19	125.71	125.71
10	16.30	129.20	129.23	129.31	129.29	128.67	128.58	128.58	128.21	127.97	127.93	126.68	125.73	125.73
9	15.70	129.21	129.24	129.33	129.33	128.86	128.61	128.60	128.21	127.98	127.97	126.75	125.73	125.73
8	12.00	129.72	129.74	129.79	129.78	129.41	129.08	129.08	128.62	128.21	128.21	126.97	125.75	125.75
7	8.30	130.31	130.27	130.16	130.15	129.77	129.33	129.33	129.08	128.60	128.58	127.16	125.77	125.77
6	7.70	130.31	130.28	130.18	130.17	129.85	129.35	129.33	129.08	128.61	128.58	127.19	125.77	125.77
5	6.00	130.79	130.76	130.66	130.58	130.21	129.85	129.77	129.41	128.86	128.67	127.28	125.78	125.78
4	4.30	131.32	131.31	131.29	131.27	130.58	130.17	130.15	129.78	129.33	129.29	127.42	125.78	125.78
3	3.60	131.32	131.31	131.29	131.29	130.66	130.18	130.16	129.79	129.33	129.31	127.45	125.78	125.78
2	1.80	131.27	131.28	131.31	131.31	130.76	130.28	130.27	129.74	129.24	129.23	127.48	125.79	125.79
1	.00	131.24	131.27	131.32	131.32	130.79	130.31	130.31	129.72	129.21	129.20	127.48	125.79	125.79
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 3.6750E+01

13	21.40	125.79	125.79	125.79	125.78	125.78	125.77	125.77	125.75	125.72	125.72	125.70	125.69	125.69
12	21.26	125.79	125.79	125.79	125.78	125.78	125.77	125.77	125.75	125.72	125.72	125.70	125.70	125.69
11	18.78	127.04	127.04	127.02	126.99	126.86	126.81	126.79	126.63	126.45	126.40	126.03	125.70	125.70
10	16.30	128.63	128.66	128.75	128.71	128.01	128.11	128.12	127.77	127.55	127.50	126.40	125.72	125.72
9	15.70	128.63	128.67	128.78	128.78	128.17	128.15	128.14	127.77	127.56	127.55	126.45	125.72	125.72
8	12.00	128.61	128.72	129.22	129.22	128.66	128.58	128.58	127.78	127.77	127.77	126.63	125.75	125.75
7	8.30	129.67	129.65	129.58	129.57	128.98	128.85	128.85	128.58	128.14	128.12	126.79	125.77	125.77
6	7.70	129.68	129.66	129.59	129.56	129.03	128.85	128.85	128.58	128.15	128.11	126.81	125.77	125.77
5	6.00	129.81	129.79	129.70	129.61	129.21	129.03	128.98	128.66	128.17	128.01	126.86	125.78	125.78
4	4.30	130.59	130.59	130.56	130.51	129.61	129.56	129.57	129.22	128.78	128.71	126.99	125.78	125.78
3	3.60	130.59	130.59	130.58	130.56	129.70	129.59	129.58	129.22	128.78	128.75	127.02	125.79	125.79
2	1.80	129.89	130.02	130.59	130.59	129.79	129.66	129.65	128.72	128.67	128.66	127.04	125.79	125.79
1	.00	129.73	129.89	130.59	130.59	129.81	129.68	129.67	128.61	128.63	128.63	127.04	125.79	125.79
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 3.8037E+01

13	21.40	125.80	125.80	125.80	125.80	125.79	125.78	125.78	125.75	125.72	125.72	125.70	125.69	125.69
12	21.26	125.80	125.80	125.80	125.80	125.79	125.78	125.78	125.75	125.72	125.72	125.70	125.69	125.69
11	18.78	126.71	126.70	126.68	126.66	126.58	126.53	126.51	126.38	126.23	126.18	125.93	125.70	125.70
10	16.30	127.66	127.67	127.68	127.63	127.39	127.33	127.31	127.06	126.84	126.76	126.18	125.72	125.72
9	15.70	127.77	127.79	127.80	127.76	127.52	127.44	127.41	127.13	126.91	126.84	126.23	125.72	125.72
8	12.00	128.00	128.05	128.20	128.18	127.95	127.84	127.80	127.31	127.13	127.06	126.38	125.75	125.75
7	8.30	128.64	128.63	128.57	128.52	128.26	128.11	128.07	127.80	127.41	127.31	126.51	125.78	125.78
6	7.70	128.70	128.68	128.62	128.56	128.30	128.15	128.11	127.84	127.44	127.33	126.53	125.78	125.78
5	6.00	128.87	128.85	128.77	128.71	128.46	128.30	128.26	127.95	127.52	127.39	126.58	125.79	125.79
4	4.30	129.19	129.18	129.13	129.06	128.71	128.56	128.52	128.18	127.76	127.63	126.66	125.80	125.80
3	3.60	129.21	129.21	129.19	129.13	128.77	128.62	128.57	128.20	127.80	127.68	126.68	125.80	125.80
2	1.80	129.00	129.06	129.21	129.18	128.85	128.68	128.63	128.05	127.79	127.67	126.70	125.80	125.80
1	.00	128.93	129.00	129.21	129.19	128.87	128.70	128.64	128.00	127.77	127.66	126.71	125.80	125.80
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 3.9323E+01

13	21.40	125.83	125.82	125.82	125.82	125.81	125.80	125.79	125.76	125.72	125.72	125.70	125.69	125.69
12	21.26	125.83	125.82	125.82	125.82	125.81	125.80	125.79	125.76	125.72	125.72	125.70	125.69	125.69
11	18.78	126.37	126.36	126.35	126.33	126.29	126.24	126.23	126.12	126.00	125.97	125.83	125.70	125.70
10	16.30	126.90	126.90	126.89	126.86	126.76	126.70	126.67	126.49	126.31	126.26	125.97	125.72	125.72
9	15.70	126.99	126.99	126.98	126.96	126.85	126.78	126.75	126.55	126.37	126.31	126.00	125.72	125.72
8	12.00	127.28	127.30	127.32	127.31	127.20	127.11	127.07	126.76	126.55	126.49	126.12	125.76	125.76
7	8.30	127.68	127.67	127.63	127.59	127.46	127.36	127.32	127.07	126.75	126.67	126.23	125.79	125.79
6	7.70	127.73	127.72	127.67	127.63	127.50	127.39	127.36	127.11	126.78	126.70	126.24	125.80	125.80
5	6.00	127.86	127.85	127.79	127.75	127.62	127.50	127.46	127.20	126.85	126.76	126.29	125.81	125.81
4	4.30	128.00	128.00	127.95	127.91	127.75	127.63	127.59	127.31	126.96	126.86	126.33	125.82	125.82
3	3.60	128.03	128.02	127.99	127.95	127.79	127.67	127.63	127.32	126.98	126.89	126.35	125.82	125.82
2	1.80	127.98	128.00	128.02	128.00	127.85	127.72	127.67	127.30	126.99	126.90	126.36	125.82	125.82
1	.00	127.96	127.98	128.03	128.00	127.86	127.73	127.68	127.28	126.99	126.90	126.37	125.83	125.83
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 4.0610E+01

13	21.40	125.87	125.87	125.86	125.86	125.84	125.83	125.82	125.77	125.72	125.72	125.69	125.68	125.68
12	21.26	125.87	125.87	125.86	125.86	125.84	125.83	125.82	125.77	125.72	125.72	125.69	125.68	125.68
11	18.78	126.03	126.03	126.02	126.01	125.99	125.96	125.95	125.86	125.78	125.76	125.72	125.69	125.69
10	16.30	126.22	126.21	126.20	126.19	126.16	126.12	126.10	125.98	125.85	125.83	125.76	125.72	125.72
9	15.70	126.26	126.26	126.24	126.23	126.20	126.16	126.14	126.01	125.87	125.85	125.78	125.72	125.72
8	12.00	126.53	126.52	126.51	126.49	126.45	126.39	126.37	126.20	126.01	125.98	125.86	125.77	125.77
7	8.30	126.76	126.75	126.73	126.71	126.66	126.60	126.57	126.37	126.14	126.10	125.95	125.82	125.82
6	7.70	126.79	126.78	126.75	126.74	126.69	126.63	126.60	126.39	126.16	126.12	125.96	125.83	125.83
5	6.00	126.86	126.85	126.82	126.81	126.76	126.69	126.66	126.45	126.20	126.16	125.99	125.84	125.84
4	4.30	126.90	126.90	126.87	126.86	126.81	126.74	126.71	126.49	126.23	126.19	126.01	125.86	125.86
3	3.60	126.92	126.91	126.89	126.87	126.82	126.75	126.73	126.51	126.24	126.20	126.02	125.86	125.86
2	1.80	126.94	126.93	126.91	126.90	126.85	126.78	126.75	126.52	126.26	126.21	126.03	125.87	125.87
1	.00	126.95	126.94	126.92	126.90	126.86	126.79	126.76	126.53	126.26	126.22	126.03	125.87	125.87
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

GNF NPC No Heat Load, Foam Block With Tubes and skin 18 Jan 2000 11:08:42

Steady-State Temperature Distribution at Time 0.0000E+00

Z = 4.0750E+01

13	21.40	125.87	125.87	125.86	125.86	125.84	125.83	125.82	125.77	125.72	125.72	125.69	125.68	125.68
12	21.26	125.87	125.87	125.86	125.86	125.84	125.83	125.82	125.77	125.72	125.72	125.69	125.68	125.68
11	18.78	126.03	126.03	126.02	126.01	125.99	125.96	125.95	125.86	125.78	125.76	125.72	125.69	125.69
10	16.30	126.22	126.21	126.20	126.19	126.16	126.12	126.10	125.98	125.85	125.83	125.76	125.72	125.72
9	15.70	126.26	126.26	126.24	126.23	126.20	126.16	126.14	126.01	125.87	125.85	125.78	125.72	125.72
8	12.00	126.53	126.52	126.50	126.49	126.45	126.39	126.37	126.20	126.01	125.98	125.86	125.77	125.77
7	8.30	126.76	126.75	126.73	126.71	126.66	126.60	126.57	126.37	126.14	126.10	125.95	125.82	125.82
6	7.70	126.79	126.78	126.75	126.74	126.69	126.63	126.60	126.39	126.16	126.12	125.96	125.83	125.83
5	6.00	126.85	126.85	126.82	126.81	126.76	126.69	126.66	126.45	126.20	126.16	125.99	125.84	125.84
4	4.30	126.90	126.90	126.87	126.86	126.81	126.74	126.71	126.49	126.23	126.19	126.01	125.86	125.86
3	3.60	126.92	126.91	126.89	126.87	126.82	126.75	126.73	126.50	126.24	126.20	126.02	125.86	125.86
2	1.80	126.94	126.93	126.91	126.90	126.85	126.78	126.75	126.52	126.26	126.21	126.03	125.87	125.87
1	.00	126.95	126.94	126.92	126.90	126.85	126.79	126.76	126.53	126.26	126.22	126.03	125.87	125.87
		.00	1.80	3.60	4.30	6.00	7.70	8.30	12.00	15.70	16.30	18.78	21.26	21.40
		1	2	3	4	5	6	7	8	9	10	11	12	13

3.6.2 Payload Temperature During HAC Fire Event

Since no payload temperatures were available from the certification fire test, the maximum HAC payload temperatures were estimated analytically using an axisymmetrical model of the ICCA. The model used the following assumptions:

- Initial temperature of canister was set at the pretest temperature of 132 °F used for the tests (Appendix 2.10.1, *Certification Tests*).
- Payload consisted of 132.3 lbs. (60 kg) of UO_2 powder per canister.
- The volume of the powder is assumed to fill the entire interior of the canister (1,770 in^3), which is conservative as it maximizes payload contact with the heated canister walls. It also more closely approximates the simulated payload used in the certification tests.
- Powder density = 132.3/1,770=0.075 lb/in^3 (solid UO_2 is 0.395 lb_m/in^3 per NRC Matpro Database[4])
- Powder specific heat = 0.062 Btu/lb_m-°F per NRC Matpro Database
- Powder conductivity = 0.065 Btu/hr-in-°F (NRC Matpro Database predicts a conductivity of 0.337 Btu/hr-in-°F for solid UO_2 at moderate temperatures. Calculating using volumetric fraction k=0.337 x 0.075/0.395=0.064 Btu/hr-in-°F, use 0.065 Btu/hr-in-°F for conservatism)
- Temperatures at surface of ICCA are at the maximum temperatures derived from ICCA II-3 (Appendix 2.10.1, *Certification Tests*) for 30 minutes as shown in Figure 3.6-1. Note that the canister is positioned upside-down to more closely match the test configuration.
- All other material properties are per Section 3.2.
- Heating 7.3 input and output files are provided in Sections 3.6.2.1 and 3.6.2.2, respectively.

After 30 minutes exposed to these high temperatures, the bulk temperature of the payload is 250 °F, with a minimum payload temperature of 202.7 °F. Since water vapor condenses on the coolest surface available, the minimum payload temperature is used to determine the partial pressure due to moisture, which is 12.2 psia at 202.7 °F.

[4] NUREG-0497, *MATPRO – Version 11: A Handbook of Materials Properties for Use in the Analysis of Light Water Reactor Fuel Rod Behavior,* EG&G Idaho, Idaho Falls, February 1979, NUREG-CR/0497.

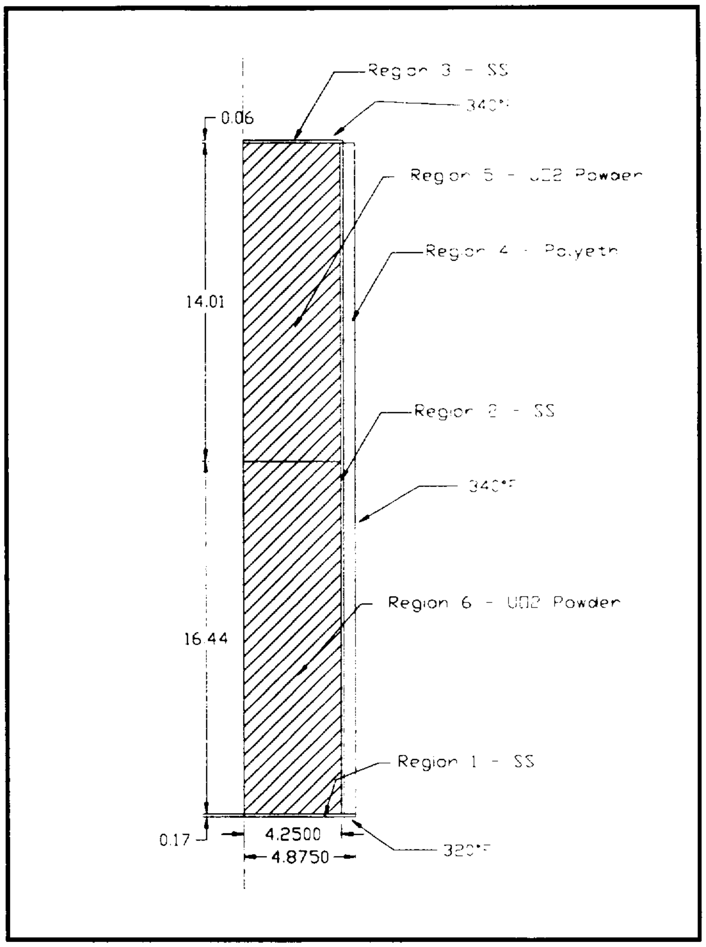


Figure 3.6-1 - ICCA Payload Thermal Model for HAC Thermal Event

3.6.2.1 Heating 7.3 Input File for Canister Payload Temperature Calculation

```
GNF NPC Canister, HAC temperature Calculation
* Unfinished SS skin (a=0.5, e=0.5), maximum insolation, 100 F
* Units:  lb, in, hr
100  3 0 0 0
h in lb Btu F
REGIONS
1  1    0.0  4.88   0.0  0.0  0.0  0.17
1  0    0    12     0    0     13   0
2  1    4.25 4.30   0.0  0.0  0.17 30.62
1  0    0    0      0    0     0   0
3  1    0.0  4.30   0.0  0.0  30.62 30.68
1  0    0    12     0    0     0   12
4  3    4.30 4.88   0.0  0.0  0.17 30.62
1  0    0    12     0    0     0    0
5  2    0.0  4.25   0.0  0.0 16.61 30.62
1  0    0     0     0    0     0    0
6  2    0.0  4.25   0.0  0.0  0.17 16.61
1  0    0     0     0    0     0    0
MATERIALS
1  Steel    0.725   0.281   0.111
2  UO2      0.065   0.076   0.062 (Conservative values used vs. 0.064, 0.075, 0.062)
3  polys    0.018  0.035     0.53
INITIAL TEMPERATURE
1  132.0
HEAT GENERATIONS
1  0.00
BOUNDARY CONDITIONS
1  1  1.0 -15
```

```
0.0    9.52e-12 1.0  0.333    0.213 1
-16 0 -17
2  1   1.0 -15
0.0    9.52e-12 1.0  0.333    0.853 1
-16 0 -17
3  1   100.0
0.0    5.95e-14
4  3
0.0    5.23e-12
11 2 340.0

12 2 340.0

13 2 320.0

XGRID
0.0   4.25 4.30 4.88
    4     1    2
YGRID
ZGRID
0.0 0.17 16.61 30.62 30.68
    2     2    6    1
TABULAR FUNCTIONS
15
0.0 100.0 0.01 100.0 0.02 1425.0 0.52 1425.0 0.54 100.0 100.0 100.0
16
0.0 0.0 0.01 0.0 0.02 0.035 0.052 0.035 0.054 0.00 100.0 0.00
17
0.0 0.0013 0.01 0.0013 0.02 0.0 0.52 0.0 0.54 0.0013 100. 0.0013
printout times
0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45
TRANSIENT
2 0.5
1.0
0.0002 1.0 0.1 1e5 20.0
%
```

3.6.2.2 Heating 7.3 Output File for Canister Payload Temperature Calculation

```
GNF NPC Canister, HAC temperature Calculation                24 Oct 2000 16:19:27
                                          Transient Temperature Distribution at Time 5.0000E-01

    12    30.68 |  340.00  340.00  340.00  340.00  340.00  340.00
    11    30.62 |  339.84  339.84  339.86  339.88  339.96  340.00  339.56  340.00
    10    28.29 |  269.54  271.44  277.13  286.43  298.87  298.93  317.28  340.00
     9    25.95 |  227.56  230.75  240.27  255.79  276.46  276.56  305.83  340.00
     8    23.62 |  209.93  213.74  225.06  243.47  267.88  268.00  301.75  340.00
     7    21.28 |  204.17  208.20  220.17  239.60  265.30  265.42  300.59  340.00
     6    18.95 |  202.71  206.80  218.94  238.64  264.69  264.81  300.33  340.00
     5    16.61 |  202.75  206.84  218.99  238.69  264.73  264.85  300.36  340.00
     4     8.39 |  211.80  215.56  226.73  244.90  269.01  269.12  302.41  340.00
     3      .17 |  319.80  319.81  319.83  319.90  320.43  320.45  324.69  340.00
     2      .09 |  319.90  319.90  319.92  319.95  320.23  320.37  322.99  340.00
     1      .00 |  320.00  320.00  320.00  320.00  320.00  320.00  320.00  324.59
                +---------------------------------------------------------------
                       .00    1.06    2.13    3.19    4.25    4.30    4.59    4.88
                         1       2       3       4       5       6       7       8
```

3.6.3 Material Property Sensitivity Study

Due to manufacturing tolerances, the thermal conductivity and density of the ceramic fiber board and polyurethane foam can vary by as much as -10%/+15%. Similarly, the specific heat of polyurethane foam could vary by as much as ±20%. To assess the impact of this uncertainty, the thermal model used to evaluate the GNF NPC in Section 3.4 was re-evaluated with minimum and maximum material properties for the maximum temperature NCT case. Additionally, a simplified HAC case was run with nominal material properties and maximum conductivity/minimum density to maximize predicted fire temperatures. The results of this study indicated that the uncertainties in material properties have a negligible effect on NCT temperatures, with a maximum increase of 25 °F in the ICCA gasket region for the HAC case. This temperature differential represents an approximate increase of 16% for the maximum-recorded temperature for any ICCA.

3.6.3.1 Material Properties

The polyurethane foam and ceramic fiber board are the only materials utilized in the design of the NPC package that have a significant variation in material properties. Table 3.6-1 provides the maximum and minimum values used in this study for the thermal conductivity, specific heat and density. Note that Table 3.2-1 demonstrates that the ceramic fiber board has similar material properties to the 11 pcf foam, and therefore is not specifically modeled. Specific heat for the ceramic fiber board will not vary significantly based on manufacturing tolerances.

Table 3.6-1 - Material Property Ranges for Sensitivity Study

Material	Thermal Conductivity, Btu/hr-in-°F	Specific Heat, Btu/lb$_m$-°F	Density, Lb$_m$/in^3
Polyurethane Foam			
7 lb/ft^3	0.0014 - 0.0021		0.00349 - 0.0041
11 lb/ft^3	0.0016 - 0.0024	0.38 – 0.47	0.00544 - 0.0064
15 lb/ft^3	0.0018 - 0.0027		0.0074 - 0.0087
40 lb/ft^3	0.0031 - 0.0047		0.01964 - 0.0231

3.6.3.2 Normal Conditions of Transport

The thermal model from Section 3.4 was evaluated with the maximum and minimum conductivities documented in Section 3.6.3.1. The resulting temperatures, shown in Figure 3.6-2, indicate that there is little difference in the NCT temperatures due to material property variation.

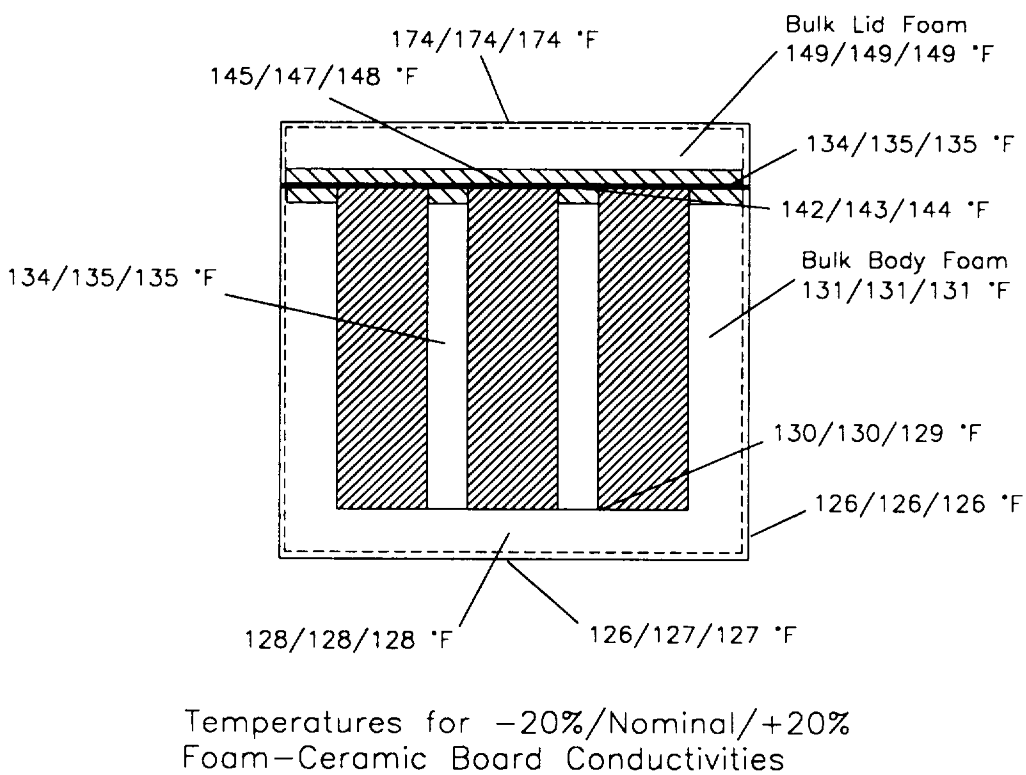


Figure 3.6-2 - NCT Temperature Variation Due to Material Property Uncertainty

3.6.3.3 Hypothetical Accident Conditions

To assess the impact of varying material properties on the peak HAC fire event temperatures, the thermal model from Section 3.4 was evaluated for conditions similar to those prescribed by 10 CFR §71.73(c)(3). Specifically, an undamaged package was exposed to a 30 minute, 1,475 °F (800 °C) fire event. The fire emittance of 0.9, which is recommended by the regulations, was simulated by lowering the boundary condition to 1,425 °F ($Q_{rad} \propto 0.9(1{,}475)^4 = 1.0(1{,}425)^4$). The package emissivity was 0.8. Natural convection was assumed for the pre-fire and post-fire portions of the study, while a forced convection heat transfer coefficient of 5.0 Btu/hr-ft^2-°F was used, which is commensurate with forced convection coefficients calculated from fire tests[5]. Since radiation dominates heat transfer from the fire to the package, the effect of using a 1,425 °F boundary temperature is minimal. The input file for the high conductivity, low density maximum temperature thermal model is provided in Section 3.6.3.3.1.

The resulting temperatures from the two fire cases evaluated, presented in Figure 3.6-3, demonstrate that the impact of material property variation on the package temperatures are minimal. The greatest temperature difference near the ICCA gaskets occurs for the OCA lid

[5] Burgess, M. H., *Heat Transfer Boundary Conditions in Pool Fires*, IAEA-SM-286/75P, Packaging and Transportation of Radioactive Materials, PATRAM '86 Symposium Proceedings, Volume 2, International Atomic Energy Agency, Vienna, Austria.

braided rope, which increases 25 °F with higher conductivity, lower density materials. The bulk polyurethane foam experiences a temperature increase of 29 °F.

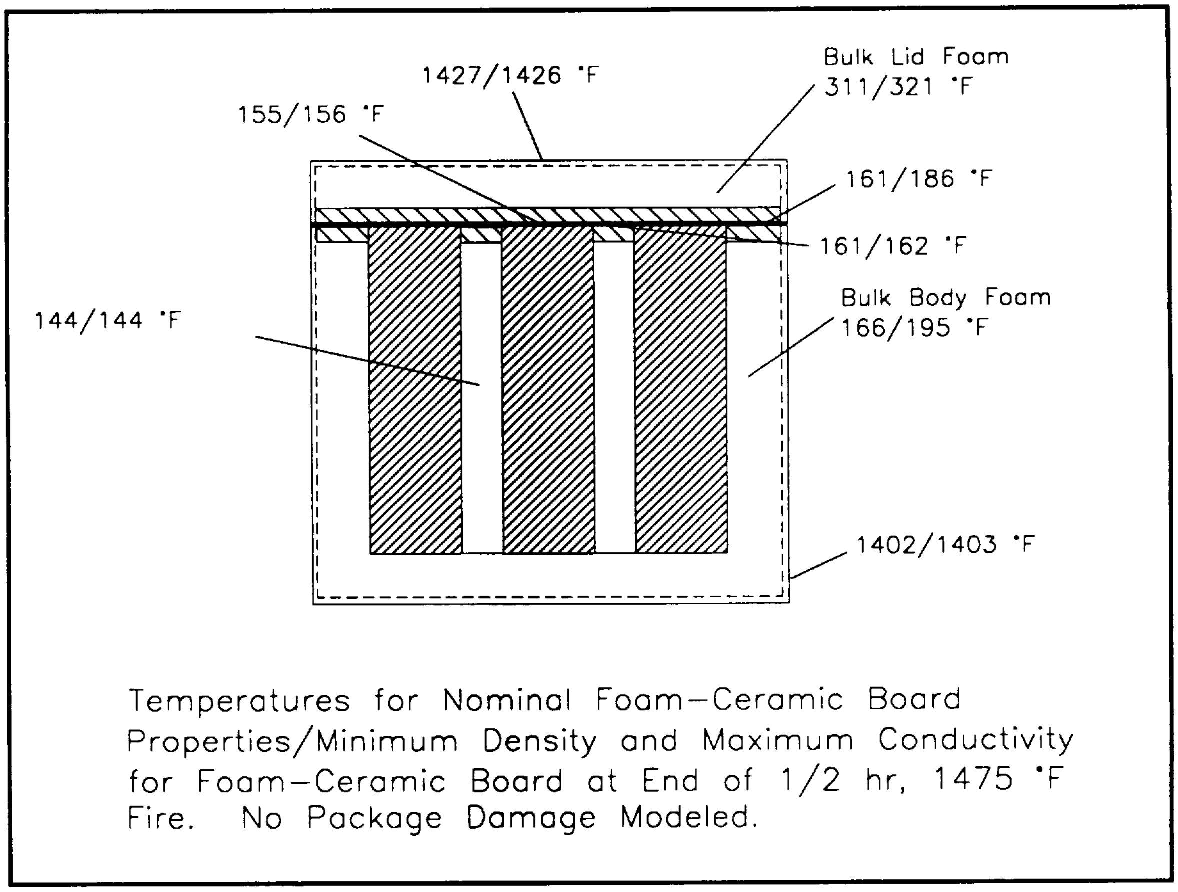


Figure 3.6-3 - Temperature Differences for Fire Event for Varying Material Properties

3.6.3.3.1 Heating 7.3 Input File for High Temperature Fire Case

```
GNF NPC No Heat Load, Max Fire
* Unfinished SS skin (a=0.5, e=0.5), maximum insolation, 100 F
* Units:  lb, in, hr
100  6 0 0 0
h in lb Btu F
REGIONS
1  4  0.0  21.4 0.0 21.4 0.0 0.14
1  0   0    1    0    1   2   0
2  7  0.0  21.26 0.0 21.26 0.14 6.12
1  0   0    0    0    0   0   0
3  4  21.26 21.4 0.0 21.26 0.14 6.12
1  0   0     1    0    0    0    0
4  4   0.0  21.4 21.26 21.4 0.14 6.12
1  0   0     1    0    1    0    0
5  2  0.0  21.26 0.0 21.26 7.50 7.63
1  0   0    0    0    0   4   4
6  2  21.26 21.4 0.0 21.26 7.50 7.63
1  0   0     1    0    0    4    4
7  2   0.0  21.4 21.26 21.4 7.50 7.63
1  0   0     1    0    1    4    4
8  1   0.0  21.26   16.3 21.26 9.01 36.75
1  0   0     0       0   0      0    0
9  3   0.0  3.6     15.7 16.30 9.01 36.75
1  0   0       0     0    0      0    0
10 3   3.6  4.3     7.7  16.30 9.01 36.75
1  0   0       0     0    0      0    0
11 3   0.0  3.6      7.7  8.30 9.01 36.75
1  0   0     0       0    0      0    0
12 2   0.0  3.6      8.3  15.7 9.01 36.75
1  0    0    0        0    0    0    0
13 5   4.3  7.7      7.7  16.3 9.01  36.75
1  0    0    0        0    0     0    0
14 3   8.3  15.7     15.7  16.3 9.01 36.75
1  0    0    0        0    0     0    0
15 3   7.7   8.3     7.7   16.3 9.01 36.75
1  0    0    0        0    0     0    0
16 3   15.7  16.3    7.7   16.3 9.01 36.75
1  0    0    0        0     0    0    0
17 3    8.3  15.7    7.7    8.3  9.01 36.75
1  0    0    0        0     0    0    0
18 2   8.3   15.7    8.3    15.7  9.01 36.75
1  0    0    0        0     0    0    0
19 1   16.3  21.26   7.7    16.3  9.01 36.75
1  0    0    0        0     0    0    0
20 5    0.0  16.3    4.3     7.7  9.01 36.75
1  0    0    0        0     0    0    0
21 3    0.0  3.6     3.6     4.3  9.01 36.75
1  0    0    0        0     0    0    0
22 3    3.6  4.3     0.0     4.3  9.01 36.75
1  0    0    0        0     0    0    0
23 2    0.0  3.6     0.0     3.6  9.01 36.75
1  0    0    0        0     0    0    0
24 5    4.3  7.7     0.0     4.3  9.01 36.75
1  0    0    0        0     0    0    0
25 3    7.7  8.3     0.0  4.3     9.01 36.75
1  0    0    0        0    0      0    0
26 3    8.3  15.7    3.6  4.3     9.01 36.75
1  0    0    0        0    0      0    0
27 3    15.7 16.3    0.0  4.3     9.01 36.75
1  0    0    0        0    0      0    0
28 2    8.3  15.7    0.0  3.6     9.01 36.75
1  0    0    0        0    0      0    0
29 1    16.3 21.26   0.0  4.3     9.01 36.75
1  0    0    0        0    0      0    0
30 4    0.0  21.26   21.26 21.40  9.01 36.75
1  0    0    0        0    1      0    0
31 4    21.26 21.40   0.0   21.40 9.01 36.75
1  0    0    1        0     1     0    0
32 1    0.0   21.26   0.0   21.26 36.75 40.61
1  0    0    0        0     0     0    0
```

```
33 4    0.0    21.26 21.26 21.40 36.75 40.61
1  0    0   0        0     1    0    0
34 4    21.26 21.40 0.0    21.40 36.75 40.61
1  0    0   1        0     1    0    0
35 4    0.0    21.4   0.0    21.40  40.61 40.75
1  0    0   1        0     1        0    3
36 1    16.3  21.26  4.3     7.7  9.01 36.75
1  0    0   0        0     0    0    0
37  6  0.0  21.26 0.0 21.26 6.12 7.50
1  0   0    0    0    0   0   0
38  4  21.26 21.4 0.0 21.26 6.12 7.50
1  0   0     1    0    0    0    0
39  4   0.0  21.4 21.26 21.4 6.12 7.50
1  0   0     1    0    1    0    0
40  6   0.0  21.26   16.3 21.26 7.63 9.01
1  0   0      0      0   0      0    0
41  3   0.0  3.6     15.7 16.30 7.63 9.01
1  0   0       0     0    0      0    0
42 3   3.6  4.3     7.7  16.30 7.63 9.01
1  0   0      0     0    0      0    0
43 3   0.0  3.6      7.7  8.30 7.63 9.01
1  0   0    0        0    0     0    0
44 2   0.0  3.6      8.3  15.7 7.63 9.01
1  0    0   0        0    0    0    0
45 6   4.3  7.7      7.7  16.3 7.63 9.01
1  0    0   0        0    0     0    0
46 3   8.3  15.7     15.7  16.3 7.63 9.01
1  0    0   0        0    0     0    0
47 3   7.7   8.3     7.7   16.3 7.63 9.01
1  0    0   0        0    0     0    0
48 3   15.7  16.3    7.7   16.3 7.63 9.01
1  0    0   0        0     0    0    0
49 3    8.3  15.7    7.7    8.3  7.63 9.01
1  0    0   0        0     0    0    0
50 2   8.3   15.7    8.3   15.7  7.63 9.01
1  0    0   0        0     0    0    0
51 6   16.3  21.26   7.7   16.3  7.63 9.01
1  0    0   0        0     0    0    0
52 6    0.0  16.3    4.3    7.7  7.63 9.01
1  0    0   0        0     0    0    0
53 3    0.0  3.6     3.6    4.3  7.63 9.01
1  0    0   0        0     0    0    0
54 3    3.6  4.3     0.0    4.3  7.63 9.01
1  0    0   0        0     0    0    0
55 2    0.0  3.6     0.0    3.6  7.63 9.01
1  0    0   0        0     0    0    0
56 6    4.3  7.7     0.0    4.3  7.63 9.01
1  0    0   0        0     0    0    0
57 3    7.7  8.3     0.0  4.3    7.63 9.01
1  0    0   0        0     0    0    0
58 3    8.3  15.7    3.6  4.3    7.63 9.01
1  0    0   0        0     0    0    0
59 3    15.7 16.3    0.0  4.3    7.63 9.01
1  0    0   0        0     0    0    0
60 2    8.3  15.7    0.0  3.6    7.63 9.01
1  0    0   0        0     0    0    0
61 6    16.3 21.26   0.0  4.3    7.63 9.01
1  0    0   0        0     0    0    0
62 4    0.0  21.26   21.26 21.40 7.63 9.01
1  0    0   0        0     1    0    0
63 4    21.26 21.40  0.0  21.40 7.63 9.01
1  0    0   1        0     1    0    0
64 6    16.3  21.26  4.3     7.7  7.63 9.01
1  0    0   0        0     0    0    0
MATERIALS
1  Foam11  0.0024  0.00544   0.38
2  Air     0.0013 0.0064   0.24
3  Tubes   0.069  0.053    0.37
4  Steel   0.725   0.281   0.111
5  Foam07  0.0021 0.00349   0.38
6  Foam40  0.0047 0.01964   0.38
7  Foam15  0.0027 0.00740   0.38
INITIAL TEMPERATURE
1  132.0
```

```
HEAT GENERATIONS
1  0.00
BOUNDARY CONDITIONS
1  1  1.0 -15
0.0   9.52e-12 1.0  0.333   0.213 1
-16 0 -17
2  1  1.0 -15
0.0   9.52e-12 1.0  0.333   0.853 1
-16 0 -17
3  1  100.0
0.0   5.95e-14
4  3
0.0   3.97e-12
XGRID
0.0  3.6  4.3  7.7  8.3  15.7  16.3  21.26  21.4
    2    1    2    1    2     1     2     1
YGRID
0.0  3.6  4.3  7.7  8.3  15.7  16.3  21.26  21.4
    2    1    2    1    2     1     2     1
ZGRID
0.0  0.14  6.12 7.5  7.63 9.01 36.75 40.61 40.75
    1    4     2    1     1   7     3     1
TABULAR FUNCTIONS
15
0.0 100.0 0.01 100.0 0.02 1425.0 0.52 1425.0 0.54 100.0 100.0 100.0
16
0.0 0.0 0.01 0.0 0.02 0.035 0.052 0.035 0.054 0.00 100.0 0.00
17
0.0 0.0013 0.01 0.0013 0.02 0.0 0.52 0.0 0.54 0.0013 100. 0.0013
printout times
0.02 0.52 1.02
STEADY-STATE
1
TRANSIENT
2 2.0
1.0
0.0002 1.0 0.1 1e5 20.0
%
```

4.0 CONTAINMENT

4.1 Containment Boundary

4.1.1 Containment Vessel

The NPC package is designed to contain the uranium oxide powder payload. Although not required by 10 CFR 71 for this payload, containment of radioactive material is provided by the sealed Inner Containment Canister Assemblies (ICCAs). The ICCAs are constructed primarily of ASTM A240, Type 304L, austenitic stainless steel. The exceptions to the use of ASTM A240, Type 304L, stainless steel include the silicone rubber gasket and the band clamp assembly of the ICCA closure lid.

4.1.2 Containment Penetrations

There are no containment penetrations in the NPC package.

4.1.3 Seals and Welds

4.1.3.1 Seals

The seal utilized in the ICCAs is the molded silicone rubber gasket on the closure lid. A summary of seal testing prior to first use, during routine maintenance, and upon assembly for transportation is as follows.

4.1.3.1.1 Fabrication Verification Pressure Tests

During fabrication, a pressure test of the ICCAs is performed per Section 8.1.2.2, *Containment Vessel Pressure Testing*. This pressure test verifies the containment integrity of the ICCAs.

4.1.3.1.2 Maintenance Verification Pressure Tests

No maintenance verification pressure tests are required for the NPC packaging.

4.1.3.1.3 Assembly Verification Pressure Tests

No assembly verification leak tests are required for the NPC packaging.

4.1.3.2 Welds

All containment boundary welds are continuous welds that have been visually examined per AWS D1.6[1]. All containment boundary welds are confirmed to be pressure tight as delineated in Section 8.1.2.2, *Containment Vessel Pressure Testing*.

[1] ANSI/AWS D1.6, *Structural Welding Code – Stainless Steel*, American Welding Society (AWS).

4.1.4 Closure

The closure of the NPC package is the ICCA lid. As discussed in Section 1.2.1.1.2, *Inner Containment Canister Assembly*, the ICCA closure lid is secured to the ICCA body by a stainless steel band clamp assembly. After the ICCA closure lid is placed on the ICCA body, the 5/16-inch diameter T-bolt of the band clamp is tightened.

4.2 Containment Requirements for Normal Conditions of Transport

4.2.1 Containment of Radioactive Material

Because the A_2 quantity for 5 or less w/o enriched uranium oxide powder is unlimited, there is no requirement for containment per 10 CFR §71.51. However, full-scale testing of the NPC package has demonstrated the containment function of the ICCAs when subjected to any NCT tests described in 10 CFR §71.71[2].

4.2.2 Pressurization of Containment Vessel

The Maximum Normal Operation Pressure (MNOP) of the ICCA is 6.1 psig (see Section 3.4.1, *Maximum Internal Pressure*). Based on the structural evaluations presented in Chapter 2.0, *Structural Evaluation*, pressure increases to 22.4 psig (see Section 3.5.1, *Maximum Internal Pressure*) will not reduce the effectiveness of the NPC package to maintain containment integrity (Section 4.2.1, *Containment of Radioactive Material*).

4.2.3 Containment Criterion

At the completion of fabrication, the ICCA shall be pressure tested as described in Section 4.1.3.1.1, *Fabrication Verification Pressure Test.*

4.3 Containment Requirements for Hypothetical Accident Conditions

4.3.1 Fission Gas Products

There are no fission gas products in the NPC package payload.

4.3.2 Containment of Radioactive Material

Because the A_2 quantity for 5 or less w/o enriched uranium oxide powder is unlimited, there is no requirement for containment per 10 CFR §71.51. However, full-scale testing of the NPC package has demonstrated the containment function of the ICCAs when subjected to any HAC tests described in 10 CFR §71.73[10].

4.3.3 Containment Criterion

The NPC package has been designed, and has been verified by pressure testing both prior to and following structural and thermal certification testing as presented in Appendix 2.10.1, *Certification Tests.*

---

[2] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-98 Edition.

4.4 Special Requirements

Because the NPC package does not transport plutonium, this section is not applicable.

5.0 SHIELDING EVALUATION

Due to the nature of the enriched uranium oxide payload, gamma radiation is not emitted by the payload. In addition, neutron radiation is not emitted by the oxide provided the payload remains in a sub-critical configuration. Therefore, the surface dose rate of the NPC package will be less than 200 millirem per hour (mrem/hr) at the package surface and less than 10 mrem/hr at a distance of 2 meters from the surface of the package.

6.0 CRITICALITY SAFETY EVALUATION

6.1 GENERAL DESCRIPTION

This criticality safety analysis is performed to demonstrate safety of the New Powder Container (NPC). This new transport package meets applicable IAEA and 10 CFR 71 requirements for a Type A fissile material-shipping container for homogeneous uranium powder in oxide form enriched to a maximum of 5% U-235.

The NPC transport package design features include an internal 3x3 array of stainless steel Inner Containment Canister Assemblies (ICCAs) enclosed in a near cubic stainless steel reinforced Outer Confinement Assembly (OCA) as described in Section 1.2, *Package Description*.

The uranium powder is contained within 8.515" (21.63-cm) maximum ID stainless steel canisters internally spaced on nominal 12.0" (30.48-cm) center-to-center positions within the OCA. Manufacturing tolerance effects on package reactivity are addressed later.

Water exclusion from the ICCAs under accident conditions is not required for this package design. Each cylindrical container within the package is analyzed in the damaged container array under optimal moderation conditions and is demonstrated to be a favorable geometry.

This analysis is performed at a maximum enrichment of 5 wt. percent U-235 for UO_2 powder. This analysis demonstrates safety up to a maximum of 60 kgs UO_2 per ICCA, for a total maximum package payload of 540 kgs UO_2 per NPC package.

For this package, the more restrictive value of "N" is derived from the damaged array calculations pursuant to 10 CFR §71.59(a)(2). The Transport Index for criticality control is then derived from this value of "N" pursuant to 10 CFR §71.59(b).

This analysis demonstrates safety for 2N=150 packages. The corresponding Transport Index (TI) for criticality control of non-exclusive vehicle is given by TI = 50/N. Since 2N = 150, it follows that N = 75, and TI = 50/75 = 0.6667 ≈ 0.7 [rounded to nearest tenth]. Using the rounded Transport Index result, the maximum allowable number of packages per non-exclusive use vehicle is 50/0.7 = 71.

6.2 PACKAGE DESCRIPTION

6.2.1 CONTENTS

The package shall be used to transport homogeneous uranium powder in oxide form (UO_2, U_3O_8, or $UO_{x,\ x>2}$) enriched to a maximum of 5 weight percent U-235. The modeled uranium isotopic distribution for this criticality safety demonstration is shown in Table 6.1.

Table 6.1 - Uranium Isotopic Distribution

Isotope	Modeled wt. %
^{235}U	5.0000
^{238}U	95.0000

This analysis conservatively demonstrates safety for UO_2 powder over the entire range of UO2 densities. The maximum net UO_2 equivalent payload demonstrated safe in the NPC is 60 kgs UO_2 per ICCA which corresponds to a maximum package payload of 540 kg total UO_2.

Other homogeneous forms of uranium powder in oxide form (e.g., U_3O_8, or $UO_{x,\ x>2}$) are also equally valid, provided the total uranium mass does not exceed 52.9 kgs U per ICCA (or 476.1 kgs U per NPC package).

Any mass distribution within the 3 × 3 array of ICCAs is also acceptable, provided the total contents including any packaging materials such as bags, bottles, cans used to contain the uranium powder in any one ICCA does not exceed 60 kgs total mass.

6.2.2 PACKAGING

A discussion of the NPC packaging designed for transportation of homogeneous uranium oxides enriched up to 5% U-235 is provided in Section 1.2.1, *Packaging*. A detailed set of drawings of the NPC packaging is provided in the Appendix 1.3.1, *Packaging General Arrangement Drawings*. The NPC packaging is comprised of two primary components: 1) an Outer Confinement Assembly (OCA) consisting of the body and lid sections, and 2) nine Inner Containment Canister Assemblies (ICCAs). These major components are described below.

Product containment occurs inside an 18 gauge (0.048" wall thickness) Type 304L stainless steel Inner Containment Canister Assembly (ICCA). This ICCA is sequentially wrapped in a 0.020" (minimum) thick cadmium sheath, followed by a 0.570- inch thick polyethylene wrap (minimum), followed by a 24-gauge (.024" wall thickness) outer Type 304L stainless steel containment sheath welded closed to effectively contain the cadmium and polyethylene.

The bottom of an ICCA consists of a 9.72" OD, 7-gauge (0.188" thick) Type 304L stainless steel plate. The top of an ICCA includes 7-gauge (0.188" thick) Type 304L stainless steel upper ring (8.620" ID x 9.72" OD) to facilitate the poly wrap and welding of the 24 gauge outer sheath. The ICCA lid is a 16-gauge (0.0595" thick) Type 304L stainless steel cylinder and contains a molded silicon rubber gasket. The closure of the ICCAs is provided by a stainless steel band clamp assembly that utilizes a 5/16-24UNF T-bolt.

Each ICCA is placed inside a 22-gauge Type 304L stainless steel cylindrical shield (silo), which is "foamed" in place on 12-inch x,y centers within the OCA body. The OCA body assembly includes a 10-gauge (0.135" wall thickness) Type 304L stainless steel 42.81x42.81x37.66 inch outer-dimension cubic box. The nominal 37.66-inch height includes the height of eight 6x3x3/16x8.4" Type 304L stainless steel rectangular channels located on each corner of the package to facilitate fork lifting of the package from four sides. The Type 304L stainless steel structures associated with the eight (8) tube channels and the connecting 6 × 1.5 × 3/16 × 19.6" cross member ties are conservatively ignored at the bottom of the body assembly.

The central region of the NPC housing the 3 × 3 array of ICCAs is polyurethane foam at a density of 7 lb/ft^3 (nominal). A 4-inch (x,y,z) periphery surrounds the inner 3 × 3 array of ICCAs housed within the stainless steel silos. On the bottom and sides, a 3-inch periphery polyurethane foam at a density of 11 lb/ft^3 (nominal) surrounds the 7 lb/ft^3 region. The upper-most region of the OCA body that mates to the lid includes a rigid 1-3/8" layer of 40 lb/ft^3 polyurethane foam. The final 1-inch periphery of the body assembly contains 1-inch layer of ceramic fiberboard. This material is utilized for its thermal performance (heat resistant) properties.

The OCA lid includes 10 gauge, 43.21 × 43.21 × 5.9-inch outer dimension Type 304L stainless steel box that is mated to the lower body assembly via 16 guide pins, which ensure proper lid seal alignment during closure. The outermost periphery again includes a 1-inch ceramic fiber board. The foam layer beneath the ceramic fiberboard includes a 3.5" layer of 15-lb/ft^3 (nominal) density polyurethane foam insulation. The lower 1-3/8" layer is rigid 40-lb/ft^3 (nominal) density polyurethane foam to protect the interface between the OCA body assembly and OCA lid assembly mating surfaces. This high-density 40 lb/ft^3 foam section in the lid includes cutouts to accommodate the upper lock ring closure of the ICCA.

The OCA lid dimensions include additional corner support structure, flanged edges, and ~2.3-inch overlap of 10-gauge stainless steel protecting the OCA body/lid interface (which are ignored in the final model construct). Closure of the OCA is provided by (16) 1/2-13UNC socket head cap screws. The closure is further secured by the OCA closure strips and (24) 7/16-14UNC hex head bolts. The NPC packaging is illustrated in Figure 1.1-1. Full details of the NPC packaging design are provided on the drawings in Appendix 1.3.1, Packaging General Arrangement Drawings. The OCA body containing the nine loaded ICCAs, coupled with the OCA lid constitutes the entire NPC package assembly.

6.2.2.1 MATERIAL SPECIFICATIONS

One of the important aspects of the criticality safety demonstration for this package is the hydrogen content in the foam and polyethylene regions. Hydrogen is important due to its moderating and neutron capture characteristics.

The minimum specified hydrogen content in the foam is 6.4 weight percent. Likewise, the polyethylene region surrounding the cadmium is based on stoichiometric CH_2, with nominal hydrogen content of 14.3%.

To account for the potential high-temperature off-gassing of hydrogen in the polyurethane foam and polyethylene regions, and to assure the hydrogen content in the modeled regions is no greater than the package after physical testing, sample analysis of both regions were conducted as described in Section 2.10.1, Certification Tests, of this application:

- Polyurethane Foam: The average measured hydrogen content of the foam regions used to fabricate the test units was 6.48%. The average of 12 replicate samples taken from residual foam in the certification test units resulted in measured hydrogen content of 6.40% with the lowest observed value at 6.07% hydrogen. The 6.07% hydrogen value corresponded to a sample taken from what appeared to be one of the hottest areas observed. This criticality safety demonstration is performed using 6% hydrogen content in the foam material regions for all undamaged and damaged models and is conservative relative to the observed physical package post HAC testing (refer to Section 2.10.1.2, Summary, regarding the significant results of the hydrogen stability in the foam).

- Polyethylene: The average measured value of the hydrogen content in the polyethylene material use to fabricate the certification test units was 14.23%. The average measured value from four post-test replicate samples strategically withdrawn from what was believed to be the hottest regions observed was 14.09% with the lowest observed value of 14.01%. The average of eight additional replicate samples taken from various locations showing some indications of heating in the moderator averaged 14.20% with the lowest observed value of 14.09%. The measured values show little change in the hydrogen content in the polyethylene region before and after the test even in the hottest regions. This criticality safety demonstration is performed using 14% hydrogen content in the polyethylene wrap region surrounding each ICCA for all undamaged and damaged models and is conservative relative to the observed physical package post HAC testing (refer to Section 2.10.1.2, Summary, regarding the significant results of the hydrogen stability in the polyethylene).

Table 6.2 provides a listing of the applicable material specifications used in the NPC model construct. The table conservatively applies the minimum measured hydrogen content of the NPC polyurethane foam (6%) and polyethylene wrap (14%) in the applicable packaging regions for all normal and damaged model constructs.

The minimum composition values for C, O, N, H shown in Section 8.1.4.1.1.1, Polyurethane Foam Chemical Composition, are applied. Other trace foam constituents (P, Si, Cl, and other) are ignored. Additional package material conservatism is later described in Section 6.3.1.5, Models – Actual Package Differences.

Table 6.2 - Material Specifications for the NPC Shipping Package

Material	Density (g/cm^3)	Constituent	Atomic density (atoms/b-cm)
$U(5.00)O_2$ Fuel	≤10.96	U-235 (max.)	1.2378E-03
		U-238 (max.)	2.3220E-02
		O (max.)	4.8916E-02
304L Stainless Steel	7.9	C	3.1691E-04
		Si	1.6940E-03
		Cr	1.6471E-02
		Fe	6.0360E-02
		Ni	6.4834E-03
		Mn	1.7321E-03
Cadmium	8.2175*	Cd	4.4000E-02
Polyethylene	0.92	H	7.6965E-02
		C	3.9504E-02
Polyurethane Foam	0.1122	C	2.8100E-03
(7 lb/ft^3)		O	5.9000E-04
		N	1.9000E-04
		H	4.0200E-03
Polyurethane Foam	0.1762	C	4.4200E-03
(11 lb/ft^3)		O	9.3000E-04
		N	3.0000E-04
		H	6.3200E-03
Polyurethane Foam	0.2404	C	6.0300E-03
(15 lb/ft^3)		O	1.2700E-03
		N	4.1000E-04
		H	8.6100E-03
Polyurethane Foam	0.6407	C	1.6080E-02
(40 lb/ft^3)		O	3.3800E-03
		N	1.1000E-03
		H	2.2970E-02
Full Density Water	1.00	H	6.68660E-02
		O	3.34330E-02

* 95% of theoretical density

6.3 CRITICALITY SAFETY ANALYSIS MODELS

6.3.1 GENERAL MODEL

6.3.1.1 Material Tolerance(s)

Table 6.3 provides sheet metal thickness dimensional tolerance from ASTM A240 and ASTM A480 (the former refers to the latter for specific tolerances). The maximum tolerance reductions in gauge sheet thickness are uniformly applied in all normal and damaged NPC model constructs.

The foam density distribution throughout the body assembly and lid assembly is varied as described in Section 6.2.2, *Packaging*. The manufacturers quality assurance program ensures the tolerance on the actual foam density is +15%/-10% at all times. For conservatism, the maximum 10% reduction in foam density is uniformly applied in all normal and damaged NPC model constructs.

Table 6.3 - Dimensional Tolerances

Type 304L Stainless Steel Sheet Gauge	Nominal Thickness (in.)	Permissible Variations* (in.)	Model Thickness Used (in.) [cm] (description)
7 ga.	0.188	± 0.014	0.1740 [0.4420 cm] (ICCA ring)
10 ga.	0.135	± 0.012	0.1230 [0.3124 cm] (OCA skin)
16 ga.	0.0595	± 0.006	0.0535 [0.1359] (ICCA lid)
18 ga.	0.048	± 0.005	0.0430 [0.1092] (ICCA inner skin)
22 ga.	0.029	± 0.004	0.0250 [0.0635] (ICCA silo)
24 ga.	0.0235	± 0.003	0.0205 [0.0521] (ICCA outer skin)

* ASTM-A240/A240M- 95a, Table A1.2, *Standard Specification for Heat Resisting Chromium and Chromium-Nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels*, August 1995.

6.3.1.2 Inner Containment Canister Assembly (ICCA)

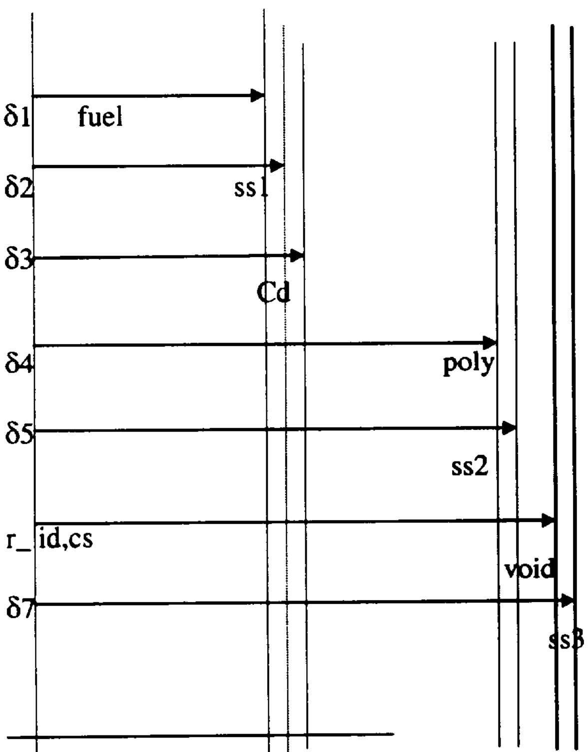
Figure 6.1 shows the material constituent radial dimensions from center of the ICCA ID (δ1) through outer radius of the contamination shield (δ7). Figure 6.2 depicts the axial version of the ICCA and contamination shield. The ICCA model construct consists of a stackup of 11 separate axial pieces. This is performed to explicitly include the 1/8" (0.3175 cm) gaps of the high denisty polyethylene wrap on each end, the maximum axial seam gap tolerance between the three separate 10-1/8" (25.7175 cm) nominal wide cadmium wraps, the axial foam distribution density changes, and the fact that the ICCA silo is installed only in the lower body assembly. The upper section of the ICCA also penetrates the lid assembly to accommodate the vertical ICCA height, lock ring and bolt closure.

The 8.515-inch (21.63 cm) ID of the 18-gauge ICCA includes the maximum manufacturing tolerance. Modeled sheet gauge dimensions incorporate the maximum manufacturing tolerance specified in ASTM–A240 specified in Table 6.3 above. Since iron, chrome, and nickel constituents of stainless steel exhibit thermal and resonance absorption, the use of minimum sheet thickness values is also conservative.

For cadmium, a 25% reduction is applied to the actual 20-mil (minimum) thickness, for a modeled thickness of 15-mils (0.0381 cm)[1] and section width of 10.025" (25.4635 cm). The as-built stackup of the axial cadmium wraps allow for a maximum seam gap of 0.1" (0.254 cm). This gap is conservatively modeled as 0.15" (0.381 cm).

The high density polyethylene (HDP) is 30.3-inch in height and uniformly surrounds the cadmium, with no gaps, and its thickness ensured to be a minimum 0.570" thickness (1.4478 cm) by continuous wrapping of 15-mil (nominal) sheets and a quality control weight confirmation. To account for the small density reduction in the layered polyethylene wrap, the HDP (0.94-0.98 g/cc density) sheet material is conservatively modeled as a uniform low density polyethylene (0.92 g/cc) over the 0.570" thick (1.4478 cm) wrap (min. hydrogen areal density = 0.199 g/cm^2). The minimum required thickness, height, and quality weight measurement confirm this effective poly thickness and density is achieved.

Figure 6.1 Inner Containment Canister Assembly – Radial Dimensions

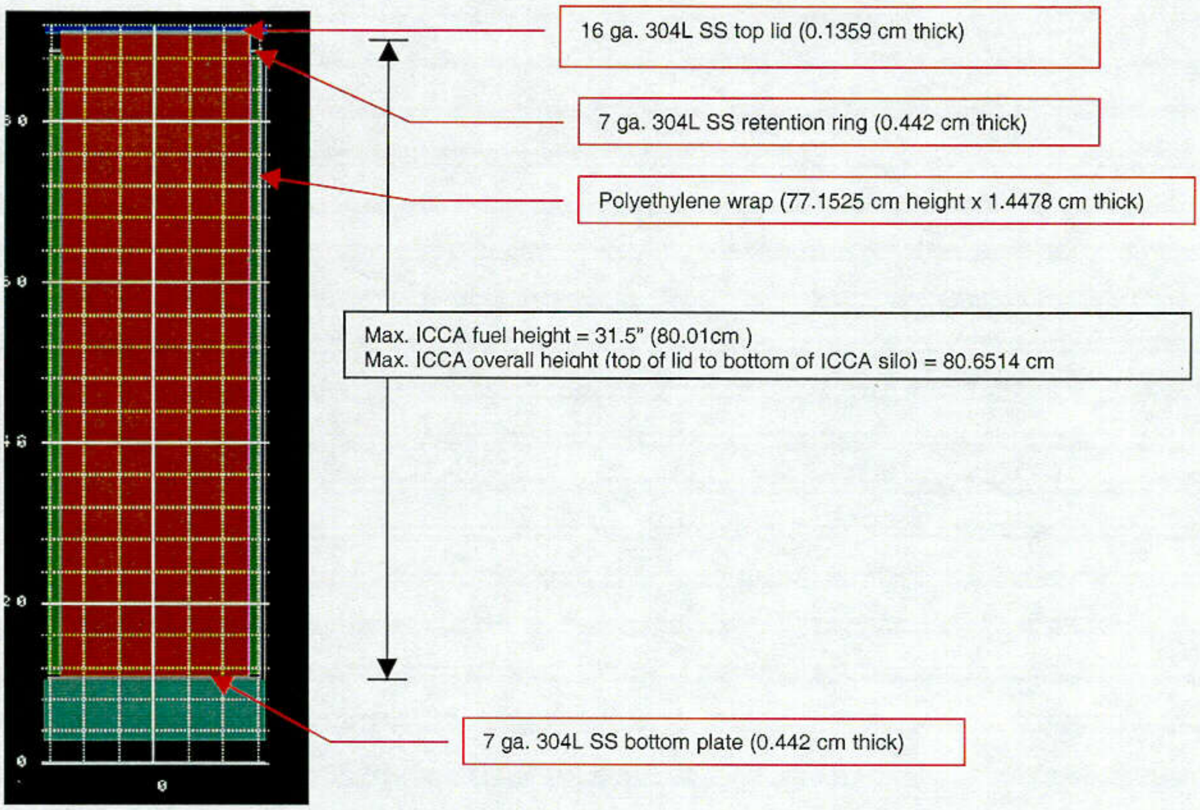


radial/material assignments:

δ1 = fuel region (e.g., UO_2+H20)
δ1 = 10.8141 cm (4.2575")
δ2 = δ1 + δss1 — δss1 = 0.1092 cm
δ3 = δ2 + δcadmium — δcad = 0.0381 cm
δ4 = δ3 + δpoly — δpoly = 1.4478 cm
δ5 = δ4 + δss2, — δss2 = 0.0521 cm
r_id = (10 x 2.54) / 2 = 12.7000 cm
δ7 = r_id, cs + δss3 — δss3 = 0.0635 cm
beyond δ7 is polyurethane foam....

[1] Note: Limiting added absorber material credit to 75% without comprehensive tests is based on concerns for potential "streaming" of neutrons due to non-uniformities. The 75% value demonstrated by this work is conservative for several reasons: (1) cadmium is elemental and therefore homogeneous and is not distributed in granular fashion, and (2) the experimental work is based on the use of a monodirectional beam of neutrons, while in this package design, an isotropic neutron source exists, reducing intragranular transmission effects (if any).

Figure 6.2 ICCA Modeled Axial dimensions



6.3.1.3 Body and Lid Assembly

For the basic model construct, the unit outer dimensions are modeled as a 42.81x42.81 inch square box. The inner height is computed based on the stack-up dimensions of the OCA body 34.573" (87.8154 cm) and lid 5.998" (15.2349 cm) for a total modeled package height of 40.571" (103.0503 cm). These outside dimensions of the near cubic package are conservative for the following reasons:

- the external corner support structure is ignored (x-y, x-z)
- the OCA locating buttons, and 16 ½-13UNC socket head cap screws are ignored (x-z)
- the lid flange overlap, OCA closure strip, and 24 7/16-14UNC hex head bolts are ignored (x-y)
- the heavy duty 6×3×3/16×8.4 rectangular fork-lift channel pocket structure is ignored (x-z)
- the affect of body/lid bowing due to HAC tests is ignored (x-y, x-z)

By ignoring the above effects, the NPC undamaged and damaged package array are modeled as close fitting and in contact, when in fact the aforementioned structure and OCA structure deformation and bowing would provide additional (x-y) and axial (x-z) spacing between individual package units.

The lighter 7-lb/ft^3 internal foam is modeled to encase the 3x3 Inner Containment Canister Assembly (ICCA) array. Important dimensions of the basic body + lid assembly, and foam density assignments are shown in the x-y and x-z cross-sectional slices of Figures 6.3a and 6.3b, respectively.

Figure 6.3a Body Assembly (x,y) Dimensions and Foam Distribution

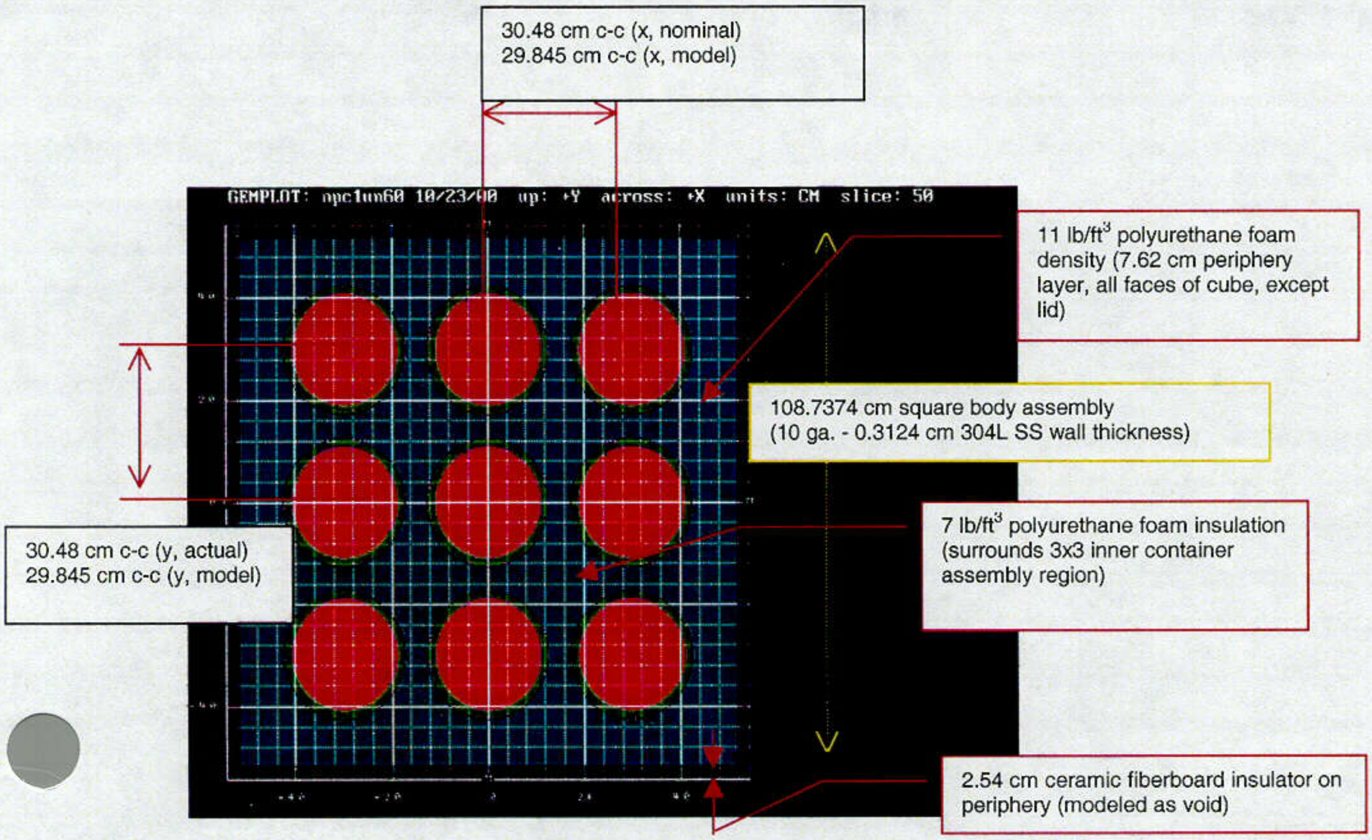
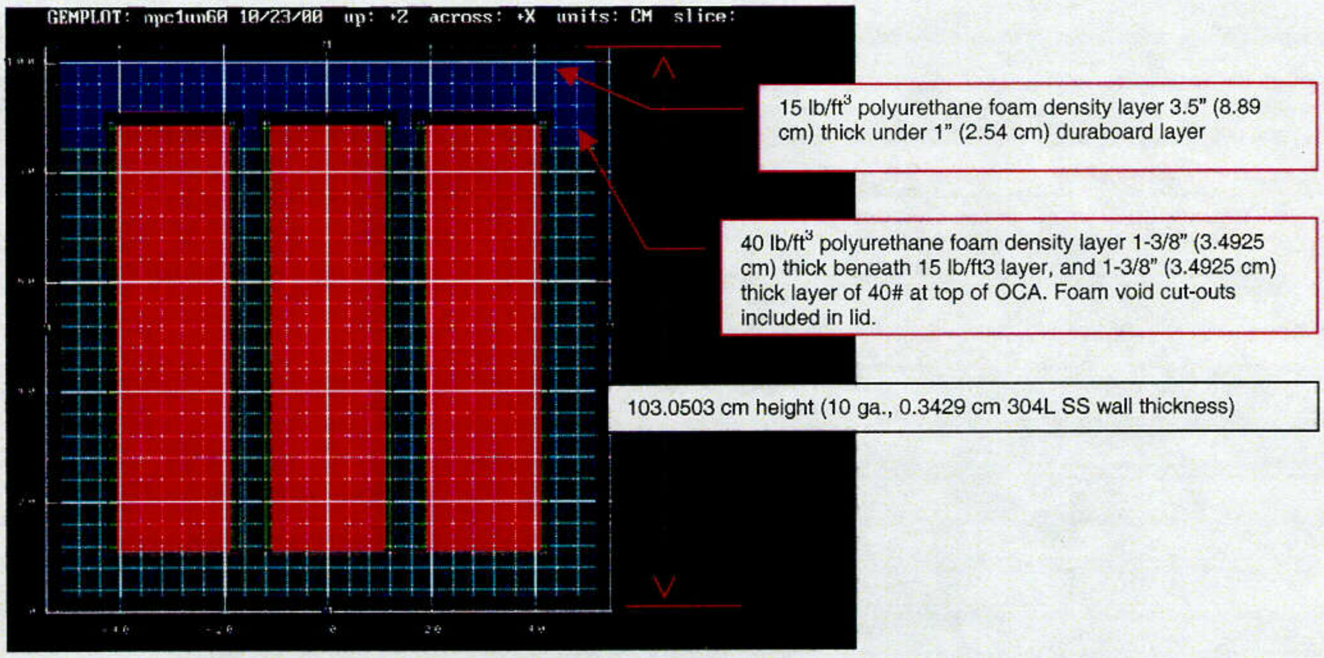


Figure 6.3b Body Assembly (x,z) Dimensions and Foam Distribution



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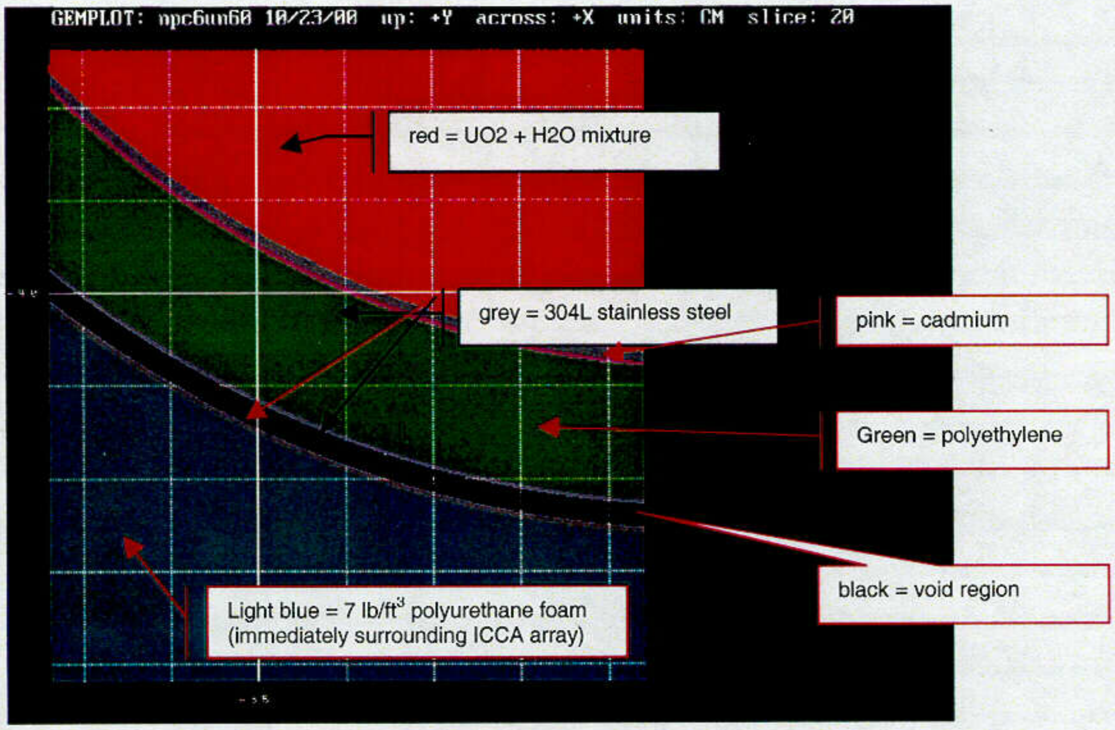
6.3.1.4 Materials

Figure 6.4 shows blown up cross-section material assignment(s) of the ICCA within stainless steel silo. These mixture assignments are shown in color for illustration purposes, and used throughout this report (unless otherwise noted).

Figure 6.4 Inner Containment Canister Assembly (ICCA) within Silo - Mixture Assignments



The UO_2 mixture (fuel) material specifications used in the NPC criticality safety demonstrations are dependent upon the case set being modeled. Currently the treatment of the fuel region is limited to the following three treatments:

1. Damaged single package – theoretical UO_2 and water mixture (through optimum moderation).
2. Undamaged package array - dry UO_2 powder with 5% H_2O (vary UO_2 compound density, mixture mass or compound mass fixed at 60 kgs).
3. Damaged package array - optimally moderated, mass limited UO_2 case for damaged package array geometry (vary UO_2 compound mass per ICCA).

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In the first damaged single package case set, the $UO_2 + H_2O$ mixture is modeled as a pure theoretical mixture of UO_2 (10.96 g/cc, maximum) and water. The weight fraction water is varied through optimum moderation for the fully reflected single-unit damaged package.

Table 6.4 provides the resulting mixture data summary derived from an internal utility code called UFACT. In this case a theoretical treatment of the fuel region is used, and the mixture height is not computed as the ICCA volume is modeled full (height fixed at 80.01 cm). Please also note that for theoretical UO_2, all voids are filled at approximately 11.5% water content – thus no density correction is required (e.g., DFACT = 1.0).

The corresponding compound identification (COM), weight fraction water (WF-W), U-235 fractional enrichment (ENR), density correction factor (DFACT), mixture density (RHOMIX), compound density (RHOC), and uranium density (RHOU), uranium fraction in the compound (UFACT), GEMER/GEKENO bias columns, H/5 (H/U-235) and H/U atom ratios, and HEIGHT are prescribed as follows (and equally valid for Tables 6.5 and 6.6):

- **DFACT** = density correction factor = [MINIMUM (1.0, $RHOC_{max-credible}$)]/RHOC
- **RHOMIX** = mixture density = RHO_MIX=DFACT/[(1-WTFR_H2O)/RHO_FUEL+WTFR_H2O]
  where, RHO_FUEL = RHOC = RHO_UO2 = compound density in mixture, and
  WTFR_H2O = WF-F = weight fraction water in mixture
- **RHOC** = uranium compound density in mixture = (1 – WTFR_H2O) * RHOMIX
- **$RHOC_{max-credible}$**= maximum credible density of uranium compound
- **RHOU** = uranium density in mixture = UFACT * RHOC = 0.88144 * RHOC
- **UFACT** = uranium fraction of compound = M_U / [M_U + (2*M_O)] = 0.88144
  where, Mi is the atomic mass of constituent i
- **H/5=H/U-235** = Atom ratio of hydrogen to U-235 = H_TO_U-235
  H_TO_U-235=W_TO_F*2*235.043928/(18.0153*RHO_FUEL*UFACT*ENR)
  where, W_TO_F=water-to-fuel ratio - WTFR_H2O*RHO_FUEL)/(1-WTFR_H2O)
  ENR=[N_U-235*235.043928]/(#+N_U-238*238.050788)
- **H/U** = Atom ratio of hydrogen to uranium = H_TO_U=WTFR_H2O*ATM_U/[UFACT*.5*18.0153*(1-WTFR_H2O)]
- **HEIGHT** = height of mixture in cylinder of specified radius and mixture mass [e.g, HEIGHT= MASS/(PI*RAD**2*RHO_MIX)] or compound mass (e.g, HEIGHT= MASS/(PI*RAD**2*RHOC)]

Table 6.4 Fuel Material Specifications – Damaged Single Package (theoretical $UO_2 + H_2O$ mixture)

COM	WF-W	FR.ENR	DFACT	RHOMIX gm/cc	RHOC gm/cc	RHOU gm/cc	UFACT	H/5	H/U x10	HEIGHT cm
UO2	.150	.05000	1.0000	4.3945	3.7354	3.2925	.88144	104	53	n/a
UO2	.200	.05000	1.0000	3.6631	2.9305	2.5830	.88144	148	75	n/a
UO2	.250	.05000	1.0000	3.1404	2.3553	2.0761	.88144	197	100	n/a
UO2	.300	.05000	1.0000	2.7482	1.9238	1.6957	.88144	254	128	n/a
UO2	.350	.05000	1.0000	2.4432	1.5881	1.3998	.88144	319	161	n/a
UO2	.400	.05000	1.0000	2.1990	1.3194	1.1630	.88144	395	200	n/a
UO2	.450	.05000	1.0000	1.9993	1.0996	0.9692	.88144	484	245	n/a

In the undamaged array case set, two models are used. In the first case, the dry UO_2 + H_2O mixture is modeled representative of real-world conditions in which the UO_2 powder is known to contain a small amount (<5%) of moisture – thus 60 kgs mixture is modeled as 57 kgs UO_2 and 3 kgs of H_2O. The second model explicitly models 60 kgs UO_2 compound plus 5% H_2O mass addition.

In either case, the maximum moisture content is fixed at 5% (50,000 ppm H_2O). NOTE: The UO_2 powder derived from conversion processes limit free moisture to 0.6% (6000 ppm H_2O) water content. Post-additive addition for powder pack limits the total equivalent water moderation to a maximum of 1.5%.

Table 6.5 provides the density factor (to account for voids), mixture, compound, and uranium densities for both 60 kg mixture and 60 kg UO_2 treatments. The table shows the calculated fuel height of 60 kgs UO_2 +5% H_2O mixture within the 8.515" (21.63 cm) ID ICCA as a function of UO_2 compound density (0.0 - 4.5 g/cc). In both fuel treatments, 4.5 g/cc is used as a conservative upper limit for unpressed UO_2 powder. As expected, the fuel height of the 60 kg fuel mass treatment is slightly greater than the mixture treatment.

Table 6.5 Fuel Material Specifications – Undamaged Array (60 kgs UO_2 + 5%H_2O mixture, variable UO_2 compound density)

COM	WF-W	FR.ENR	DFACT	RHOMIX gm/cc	RHOC gm/cc	RHOU gm/cc	UFACT	H/5	H/U x10	HEIGHT cm
	RADIUS = 10.8141 CM			MIXTURE MASS =			60.000 KG			
UO2	.050	.05000	0.2877	2.1053	2.0000	1.7629	.88144	31	16	77.574
UO2	.050	.05000	0.3597	2.6316	2.5000	2.2036	.88144	31	16	62.059
UO2	.050	.05000	0.4316	3.1579	3.0000	2.6443	.88144	31	16	51.716
UO2	.050	.05000	0.5036	3.6842	3.5000	3.0850	.88144	31	16	44.328
UO2	.050	.05000	0.5755	4.2105	4.0000	3.5258	.88144	31	16	38.787
UO2	.050	.05000	0.6474	4.7368	4.5000	3.9665	.88144	31	16	34.477
	RADIUS = 10.8141 CM				FUEL MASS =		60.000 KG			
UO2	.050	.05000	0.2877	2.1053	2.0000	1.7629	.88144	31	16	81.657
UO2	.050	.05000	0.3597	2.6316	2.5000	2.2036	.88144	31	16	65.325
UO2	.050	.05000	0.4316	3.1579	3.0000	2.6443	.88144	31	16	54.438
UO2	.050	.05000	0.5036	3.6842	3.5000	3.0850	.88144	31	16	46.661
UO2	.050	.05000	0.5755	4.2105	4.0000	3.5258	.88144	31	16	40.828
UO2	.050	.05000	0.6474	4.7368	4.5000	3.9665	.88144	31	16	36.292

In the damaged package array cases, the homogeneous UO_2 + H_2O mixture is modeled as a mass and geometry limited system. The UO_2 compound density is treated as theoretical (10.96 g/cc). The weight fraction water is computed such that the UO_2 + water mixture completely fills the Inner Containment Canister Assembly (ICCA). For the NPC package under accident (damaged array) conditions, this mass and geometry limited condition is demonstrated the most reactive condition.

Table 6.6 provides the corresponding mixture, compound, and uranium densities for this treatment of the fuel region. The weight fractions water for each UO_2 fuel mass is computed to just fill the ICCA volume. The UO_2 compound mass in the UO_2 + H_2O

mixture is varied to determine the maximum acceptable payload of the package under hypothetical accident conditions. In the case of 60 kgs UO_2, additional cases at lower weight fraction water were run to confirm the most reactive condition. Higher weight fraction water conditions resulting in lower UO_2 mass are included in this table.

Table 6.6 Fuel Material Specifications – Damage Package Array (UO_2 + H_2O , optimal moderation, variable UO_2 mass)

COM	WF-W	FR.ENR	DFACT	RHOMIX gm/cc	RHOC gm/cc	RHOU gm/cc	UFACT	H/5	H/U x10	HEIGHT cm
	RADIUS =	10.8141 CM			FUEL MASS =		40.000	KG		
UO2	.392	.05000	1.0000	2.2366	1.3608	1.1995	.88144	381	193	80.010
	RADIUS =	10.8141 CM			FUEL MASS =		45.000	KG		
UO2	.360	.05000	1.0000	2.3912	1.5309	1.3494	.88144	333	168	80.010
	RADIUS =	10.8141 CM			FUEL MASS =		50.000	KG		
UO2	.332	.05000	1.0000	2.5457	1.7009	1.4993	.88144	294	149	80.010
	RADIUS =	10.8141 CM			FUEL MASS =		55.000	KG		
UO2	.307	.05000	1.0000	2.7004	1.8711	1.6492	.88144	262	133	80.010
	RADIUS =	10.8141 CM			FUEL MASS =		60.000	KG		
UO2	.285	.05000	1.0000	2.8549	2.0411	1.7992	.88144	236	119	80.010
	RADIUS =	10.8141 CM			FUEL MASS =		65.000	KG		
UO2	.265	.05000	1.0000	3.0095	2.2113	1.9491	.88144	214	108	80.010
**** extra cases ******										
	RADIUS =	10.8141 CM			FUEL MASS =		60.000	KG		
UO2	.150	.05000	1.0000	4.3945	3.7354	3.2925	.88144	104	53	43.721
	RADIUS =	10.8141 CM			FUEL MASS =		60.000	KG		
UO2	.200	.05000	1.0000	3.6631	2.9305	2.5830	.88144	148	75	55.729
	RADIUS =	10.8141 CM			FUEL MASS =		60.000	KG		
UO2	.250	.05000	1.0000	3.1404	2.3553	2.0761	.88144	197	100	69.339

6.3.1.5 Models - Actual Package Differences

The criticality safety analysis model of the loaded NPC differs from the actual package in 1) the allowance for water intrusion into the ICCA containment, 2) center-to-center canister spacing, 3) insulating foam distribution, 4) the modeled stainless steel structure, 5) the modeled cadmium thickness, and 6) the modeled poly density.

1) The ICCA fuel region is modeled with variable UO_2 compound mass and variable H_2O content as described in the fuel material specifications above. In the limiting (damaged package array) models, the UO_2 compound mass is varied from 40-65 kgs UO_2 per ICCA. The water content is also varied to optimally moderate the ICCA for the mass limited damaged package array. This optimal internal moderation treatment is a known conservatism.

2) The center-to-center spacing of the ICCAs is also different from the as-built package. The nominal spacing (x,y) between the 3 × 3 array of ICCAs is 12-inches (30.48 cm). All models use a nominal conservative ICCA center-to-center spacing of 11.75" (29.845 cm). For the limiting damaged package array models, sensitivity of the canister center-to-center spacing is quantified, by modeling the ICCAs from 11.75" (29.845 cm) to 11.25" (28.575 cm) spacing for a specified foam burn condition. Effects on system reactivity are assessed.

3) The insulating foam distribution within the package also differs from the actual package contents. In all cases, the minimum chemical composition in the foam is assumed. In addition, the density of the polyurethane foam is reduced by the maximum 10% manufacturing tolerance. Thus, the 7, 11, 15, and 40 lb/ft^3 foam densities are actually modeled as 6.3, 9.9, 13.5, and 36 lb/ft^3, respectively. This 10% foam density reduction results in a corresponding reduction in the hydrogen atom density. This is a known conservatism, as sensitivity studies demonstrate the more hydrogen between the ICCAs, the lower the overall system reactivity (due to hydrogen moderating and capture characteristics).

The foam distribution also differs in the mass of foam included. In the damaged single package and arrays the effects of non-uniform foam burn are based on measured CTU-1 and CTU-2 test results. The limiting condition damaged array reactivity is based on the maximum burn observed in either certification test unit. The maximum burn treatment results in zero residual foam thickness on all 6-faces of the cube, as measured radially and axially from the ICCA centerline (refer to Sections 2.10.1.7.1.6 and 2.10.1.7.2.6).

The maximum burn condition, coupled with the minimum hydrogen content, uniform application of maximum foam density tolerance, and 2% reduction in poly density effectively results in conservative treatment of damaged package physical condition post HAC testing. The maximum foam burn results in minimum interstitial hydrogen between packages – which is shown to increase package reactivity.

The 1-inch periphery ceramic fiberboard is modeled as a void in all models. This material consists of approximately 44% Al2O3, and the balance as SiO2 –both compounds are neutronically insignificant.

4) The amount of stainless steel structure used in the model also differs from the actual package. Since the maximum sheet gauge tolerance reductions were applied (refer Table 6.3), and significant external structure ignored, the mass of stainless steel in the model is significantly lower than actual. Reducing amount of stainless steel in the model is conservative because there is less material to compete with the uranium for neutron absorption reactions (refer also Section 6.6.2.7, Sensitivity Study – Damaged Package Array Structure).

5) The nuclear poison cadmium thickness is modeled at 0.015" (0.0381 cm) thick, which represents only 75% of the minimum absorber thickness of 0.020" (0.0508 cm).

6) In all damaged package array models, a 2% reduction in polyethylene density (0.92 * 0.98) is uniformly applied. This reduction in density effectively covers the observed 0.6% weight loss post HAC testing and 0.25% mass allowance for minimum specified poly height of 30.3" verses the modeled 30.375" height (refer also Section 6.6.2.8, Sensitivity Study – Damaged Package Array Poly Gap).

6.3.2 CONTENTS MODEL

The package contents configured for normal (undamaged) transport condition and hypothetical (damaged) accident conditions are described in Section 6.3.1.4, *Materials*, Tables 6.4 through Table 6.6. In the damaged single package and damaged package array calculations, the foam burn distribution effects are assessed.

6.3.3 SINGLE-PACKAGE MODELS

A model of the single package damaged condition considers unlimited moderator intrusion into the ICCA containing UO_2 product. The single package was subjected to hypothetical accident condition tests per IAEA and 10 CFR §71.73 as specified in Section 2.7, *Hypothetical Accident Conditions*. The UO_2 contents of the single package were analyzed in accord with the Section 6.3.1.4, *Materials*, Table 6.4. The ICCAs within the package were modeled containing theoretical UO_2 and water mixtures, and the weight fraction H_2O varied through optimal moderation. In all damaged single package models, the unit is surrounded by a full 30.48-cm thick water reflector.

6.3.3.1 Damaged Single Package

Four sets of damaged single package model constructs are considered. Two damage single package models are run using the limiting CTU-1 and CTU-2 observed foam burn conditions in which the average residual foam is modeled on each face of the cube. The third case conservatively applies a maximum observed burn on each face of the cube. The fourth damaged single package model applies a tight water reflector to the package for the limiting condition derived from the first three case sets.

The first three cases replace observed foam burn region with void. The fourth and final case replaces the burned foam region with water to assess the impacts of a fully flooded damaged package (applied to limiting burn condition). Figures 6.5a – 6.5d show vertical slices of the CTU-1, CTU-2, maximum observed burn, and the flooded damaged single package models.

Figure 6.5a – Fully reflected damaged single package, theoretical UO_2 + H_2O mixture, CTU-1 observed burn

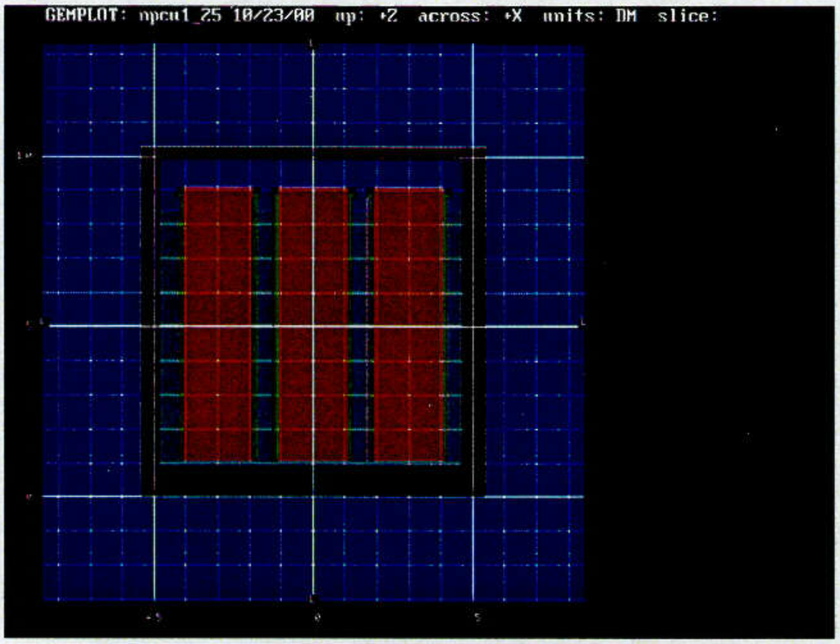

Figure 6.5b – Fully reflected damaged single package, theoretical UO_2 + H_2O mixture, CTU-2 observed burn

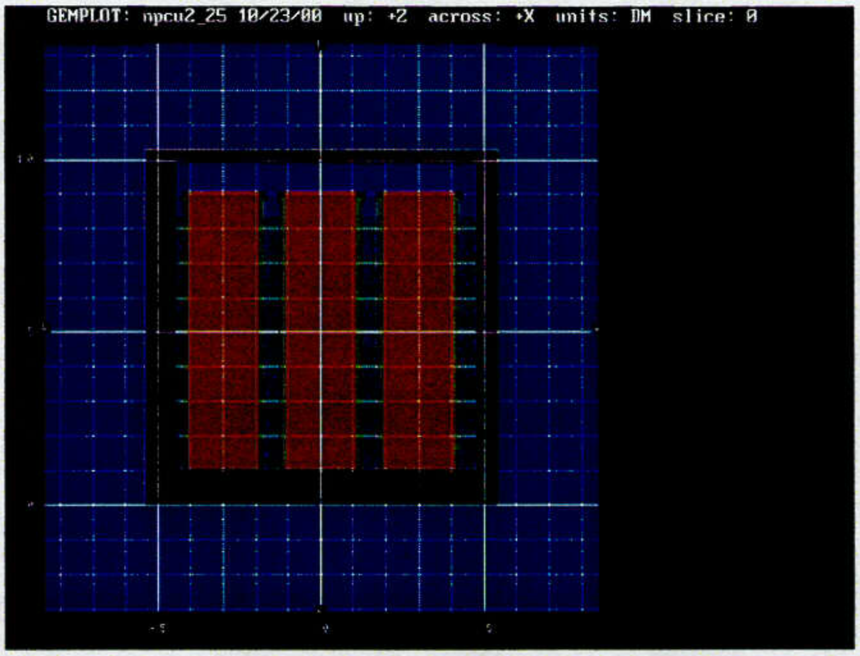

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Figure 6.5c – Fully reflected damaged single package, theoretical $UO_2 + H_2O$ mixture, maximum burn

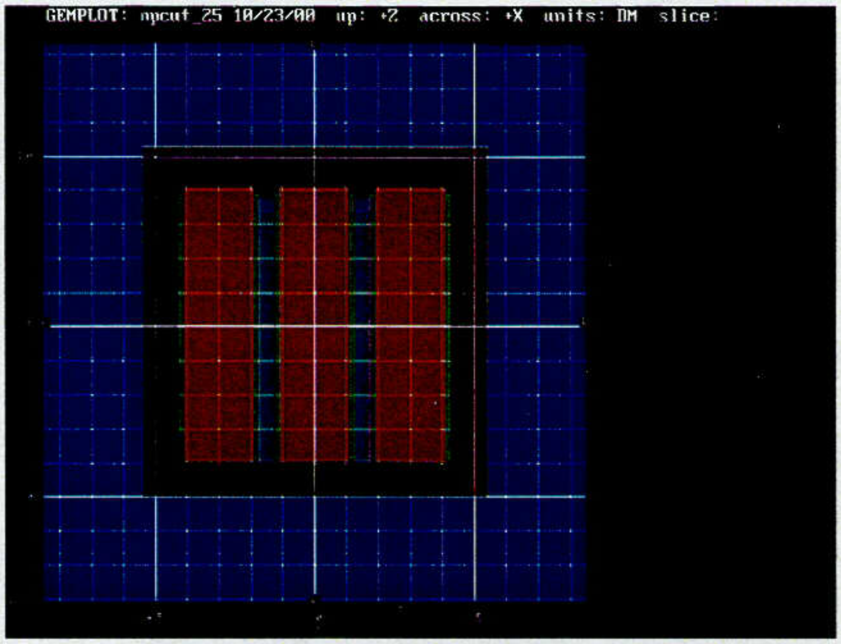
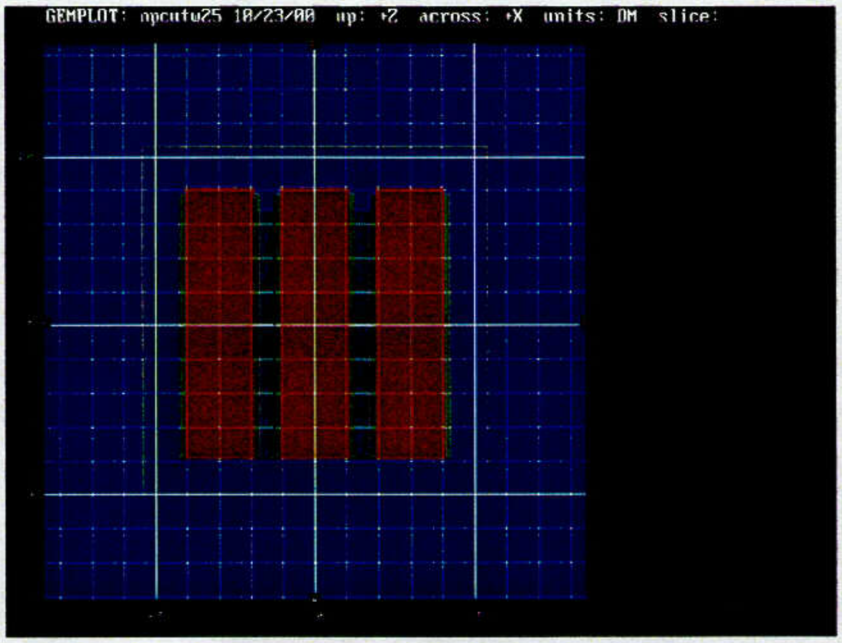


Figure 6.5d – Fully reflected damaged single package, theoretical $UO_2 + H_2O$ mixture, maximum burn, flooded package



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6.3.4 PACKAGE ARRAYS

Two basic package array model constructs are included in this evaluation - undamaged and damaged.

6.3.4.1 Undamaged Package Arrays

The first package array model consist of an infinite array of undamaged, normal condition, NPC packages. IAEA and 10 CFR §71.59, standards for arrays of fissile material packages, stipulate undamaged package arrays are to be evaluated with void between the packages, and fully reflected.

The undamaged array is modeled using a single unit with mirror boundary conditions. This effectively models an infinite array of close-packed undamaged NPC packages ($5N = \infty$) containing dry powder at 50,000 ppm H_2O. This infinite (zero neutron leakage) treatment of the undamaged package array is conservative relative to a fully reflected finite system.

The undamaged package array considers limited moderator content within the Inner Containment Canister Assembly (ICCA) containing UO_2 product as described in Section 6.3.1.4, *Materials*, Table 6.5. Each ICCA is modeled containing 60 kgs of UO_2 + 5% H_2O mixture, using variable UO_2 compound density.

Figures 6.6a-6.6f depicts the models used to assess normal conditions of transport, and show the resulting fuel height decrease as the UO2 compound density is increased to the maximum credible value. In these sample plots, the 60 kg UO_2 + 5% H_2O mixture is used.

The package was subjected to the tests specified in IAEA and 10 CFR §71.71, normal conditions of transport, and, as reported in Chapters 2, *Structural Evaluation* and Chapter 3, *Thermal*, the geometric form of the package was not substantially altered. No water leakage into the ICCAs occurred, and no substantial reduction in the effectiveness of the packaging was observed. The damage incurred will not affect the technical evaluation, and the package contents under normal conditions of transport will be less reactive than the contents under hypothetical accident (damaged) conditions.

Figure 6.6a – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO2 = 2.0 g/cc

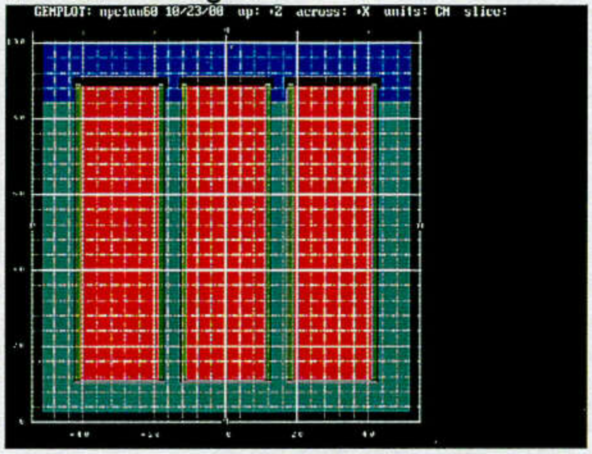

Figure 6.6b – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO2 = 2.5 g/cc

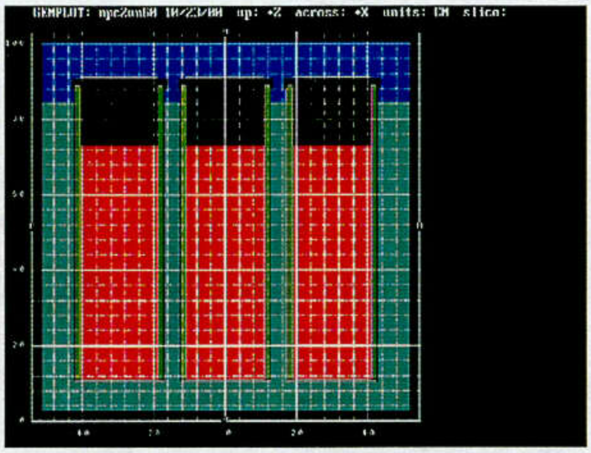

Figure 6.6c – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO2 = 3.0 g/cc

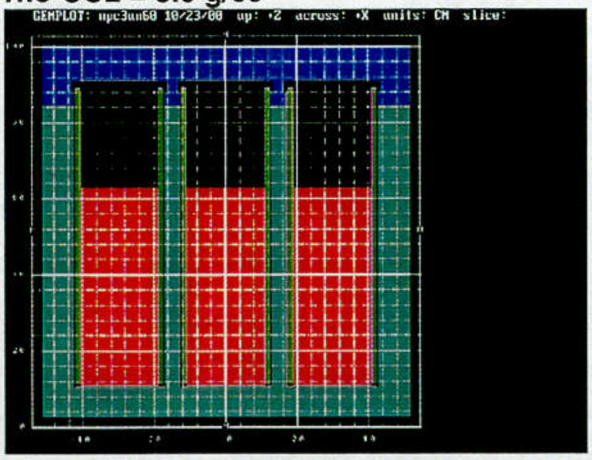

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Figure 6.6d – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO_2 = 3.5 g/cc

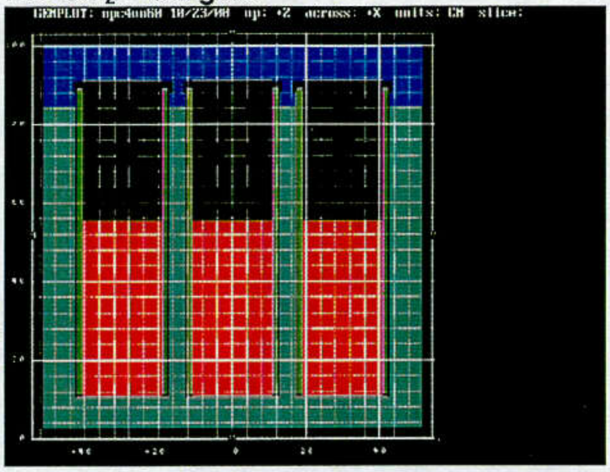


Figure 6.6e – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO_2 = 4.0 g/cc

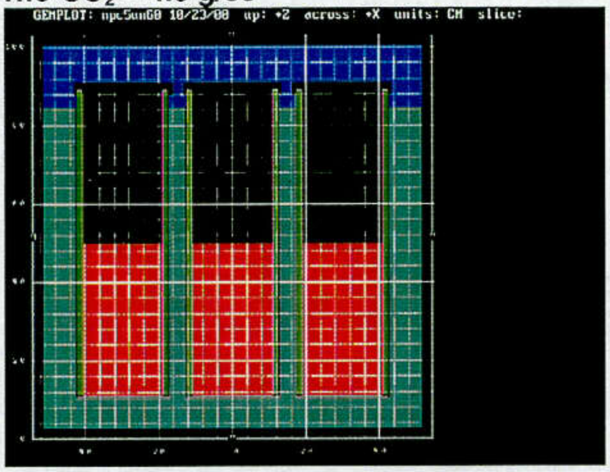
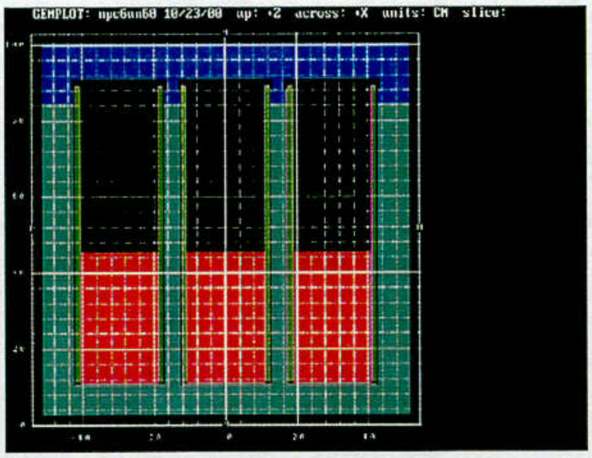


Figure 6.6f – Infinite undamaged array: 60 kgs UO_2 + 5% H_2O mixture, rho-UO_2 = 4.5 g/cc (max. credible density)



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6.3.4.2 Damaged Package Arrays

The NPC package was subjected to the tests specified in IAEA and 10 CFR §71.73, Hypothetical Accident Condition (HAC) testing and the geometric form of the package was not substantially altered. The four individual Certification Test Units (CTUs) were fabricated that underwent testing summarized in detail in Section 2.7, *Hypothetical Accident Conditions.*

Certification Test Units CTU-1 and CTU-2 were subjected to required IAEA and 10 CFR §71.73(c)(4) thermal excursion with an average flame temperature of 1,475 °F (800 °C) for a period of at least 30 minutes. In both tests, the fuel was ignited and the test item was subjected to a minimum of 30 minutes of a fully engulfing hydrocarbon pool fire.

A modified CTU-1 unit with reinforced corners was retest of the CTU-3 HAC test sequence (CG-over lid-corner orientation). A 10-guage (0.135-inch) doubler plate was added to reinforce the corners. CTU-1 was subjected to a Jet-A pool fire test. The Jet-A fuel was placed in the tank at a level sufficient to initiate the burn. Additional fuel was pumped into the tank during the testing as necessary to maintain the burn for 30-minutes. During the CTU-1 Jet-A burn test, the overall average flame temperature was 1,809 deg. F (in excess of the required 1,475 deg. F). The maximum surface temperature recorded was recorded as 2,319 deg. F.

The CTU-1 residual foam thickness measurements are reported in Appendix 2.10.1.7.1.6. The –x (left), +x (right), -y (rear), and +y (front) average cube face residual foam thickness values were determined to be 1.01, 1.71, 2.19, and 0.89-inches, respectively. The –z (bottom) and +z (top lid) average thickness' were 0.23, and 3.09-inches, respectively. The cube face averages were modeled to assess observed CTU-1 non-uniform foam burn effects on package reactivity.

For CTU-2, a diesel fuel pool fire test was used. During the CTU-2 diesel burn test, the overall average flame temperature was 1,972 °F (in excess of the required 1,475 °F). The maximum surface temperature recorded was recorded as 2,308 °F.

The CTU-2 residual foam thickness measurements are reported in Appendix 2.10.1.7.2.6. The –x (left), +x (right), -y (rear), and +y (front) average cube face residual foam thickness values were determined to be 0.26, 1.41, 0.23, and 0.58-inches, respectively (refer to Appendix 2.10.1.7.2.6). The –z (bottom) and +z (top lid) average thickness' were 0.0, and 3.0-inches, respectively. The cube face averages were modeled to assess observed CTU-2 non-uniform foam burn effects on package reactivity.

For the final damaged package array model, the maximum observed foam burn is uniformly applied on all six faces of the cube. This results in zero residual foam on all six faces of the cube as measured from the ICCA radial and axial centerline. The total face burn model construct conservatively bounds the observed package performance under HAC testing. This is underscored by the fact that the minimum hydrogen content in both the poly and foam regions is used, and the maximum 10% density tolerance is applied in all foam regions.

In all damaged package array models, a 2% reduction in polyethylene density (0.92 * 0.98) is uniformly applied. This reduction in density effectively covers the observed 0.6% weight loss and 0.25% mass allowance for minimum specified poly height of 30.3" verses the modeled 30.375" height.

The minor x-y and x-z movement of the 3 × 3 ICCA array contained within the OCA are compensated by the physical deformation of the OCA body itself, coupled with the conservatism's described in Section 6.3.1.5, Models- Actual Package Differences.

The observed damage incurred to the packaging and its contents did not affect this technical evaluation - as the packaging and its contents post HAC testing is determined to be within the bounding assumptions and analyzed conditions of this evaluation.

The damaged package array models consist of finite, near cubic 5x5x6 close packed arrays (2N = 150) to minimize neutron leakage. Additional close packed arrays using a 6x5x5 (2N = 150) and 9x9x2 (2N =162) are assessed to confirm the aspect ratio of the basic 5x5x6 array is most reactive.

In all cases, the close packed array is surrounded by 12" (30.48-cm) full-density water reflector. As required by IAEA and 10 CFR §71.59, the damaged packages are evaluated as if each package was subjected to the tests specified in 10 CFR §71.73, hypothetical accident conditions, with optimum interspersed moderation, and full water reflection.

The damaged package Inner Containment Canister Assembly (ICCA) contents are modeled per Section 6.3.1.4, *Materials*, Table 6.6.

The UO_2 compound mass per canister, internal moderation, observed foam burn conditions (CTU-1, CTU-2), and maximum foam burn conditions are modeled to determine an acceptable package Transport Index (TI) based on criticality control.

In addition, supplemental NPC damaged package array models are constructed based on the limiting acceptable payload and foam burn conditions derived above to study certain reactivity effects. These sensitivity studies include:

Effect of the package array shape (aspect ratio) on system reactivity. A 6 × 5 × 5 array (2N = 150) and a 9 × 9 ×x 2 array (2N = 162) are both assessed using the limiting burn condition and acceptable payload.

Effect of internal moderator content and payload contained in the UO_2 + H_2O mixture region contained within the ICCA.

Effect of 100% foam burn and subsequent replacement by optimal interspersed water moderation. In this set, the water density is varied from void through 12.5% of full density water to determine the hydrogen content necessary to demonstrate safety of the package, and determine if the damaged package is over or under-moderated.

Effect of ICCA center-to-center movement on reactivity for a specified damaged condition. For these cases, the nominal 11.75" (29.8450 cm) center-to-center ICCA spacing is uniformly reduced by 1/8" (0.3175 cm) increments to 11.25" (28.575 cm) to quantify the effect (if any) on ICCA spacing within the damaged package.

Effect of including external Type 304L stainless steel structure used for fork truck lifting of the package. This structure is quantified and effectively "smeared" onto the bottom layer of the OCA body.

Effect of polyethylene gap as determined from the physical measurements of the ICCA's post HAC testing is assessed to confirm the modeled poly height and density assumptions. The modeled poly height of is reduced by 75 mils to minimum specified height of 30.3". The maximum gap formation at top/bottom is also modeled and compared with the modeled limiting damaged package array calculation.

The following 2D images are provide to clarify the damaged package array model constructs and associated sensitivity studies:

- Figure 6.7a and 6.7b depicts horizontal/vertical slices of the damaged 5 × 5 × 6 package array to determine acceptable UO_2 equivalent payload under postulated damaged conditions of transport, using the observed CTU-1 and CTU-2 non-uniform foam burn conditions, respectively.

- Figure 6.7c depicts horizontal/vertical slices of the damaged 5 × 5 × 6 package array to determine acceptable UO_2 equivalent payload under postulated damaged conditions of transport, applying the maximum burn condition.

- Figures 6.7d and 6.6e depict horizontal/vertical slices of the damaged 6 × 5 × 5 and 9 × 9 × 2 package array size respectively, to confirm the close packed 5 × 5 × 6 aspect ratio is the most reactive array configuration.

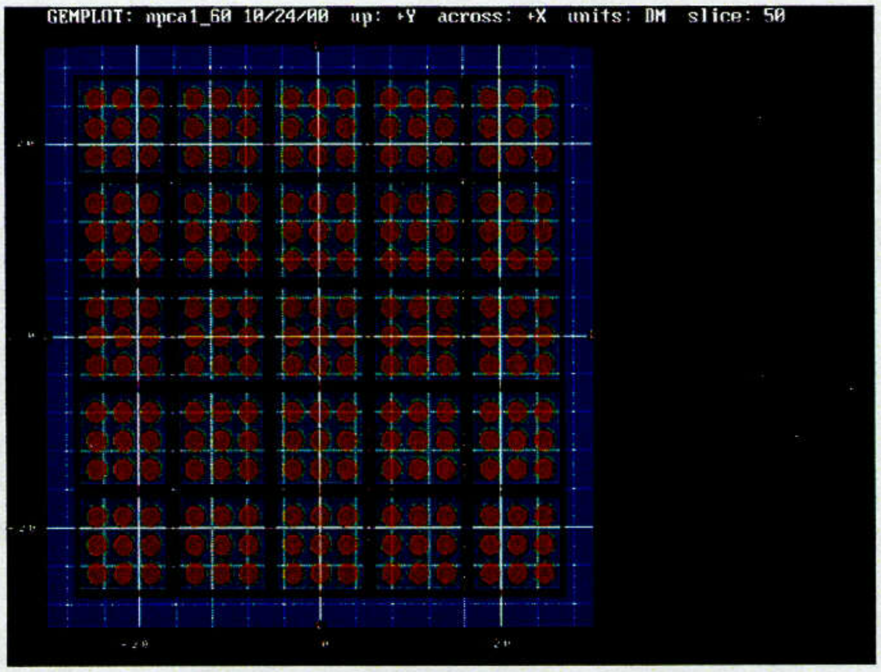
- Figure 6.7f depicts horizontal/vertical slices of the damaged 5 × 5 × 6 package array used to quantify the required hydrogen content necessary for demonstrating package safety.

- Figure 6.7g depicts horizontal zoom of the damaged 5 × 5 × 6 package array for the 11.25" (28.575 cm) ICCA center-to-center spacing to quantify the ICCA (x,y) movement effect.

- Figure 6.7h depicts vertical zoom of the damaged 5 × 5 × 6 damaged package array that include the additional external stainless steel structure.

- Figure 6.7i depicts vertical top/bottom zoom of the damaged 5 × 5 × 6 damaged package array that includes the maximum polyethylene gap formation.

Figure 6.7a – Fully reflected damaged 5x5x6 package array: 60 kgs UO_2 + H_2O mixture, CTU-1 observed non-uniform burn (horizontal and vertical views)



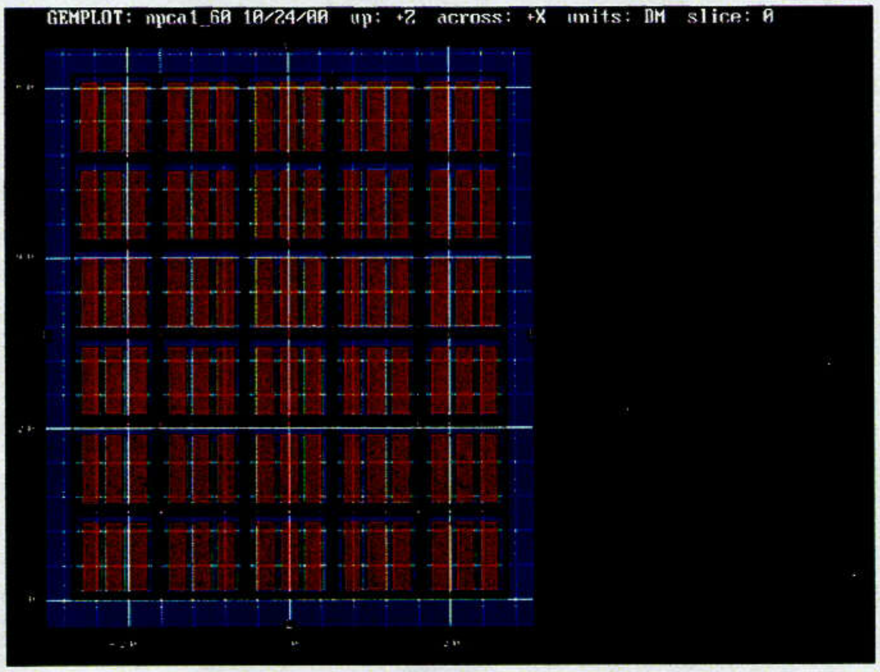


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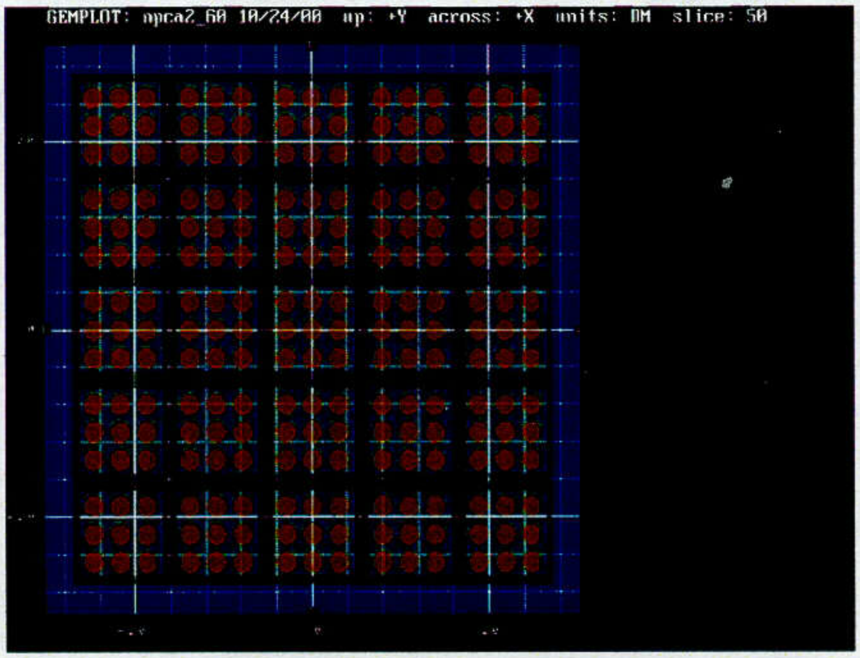
Figure 6.7b – Fully reflected damaged 5x5x6 package array: 60 kgs UO_2 + H_2O mixture, CTU-2 observed non-uniform burn (horizontal and vertical views)



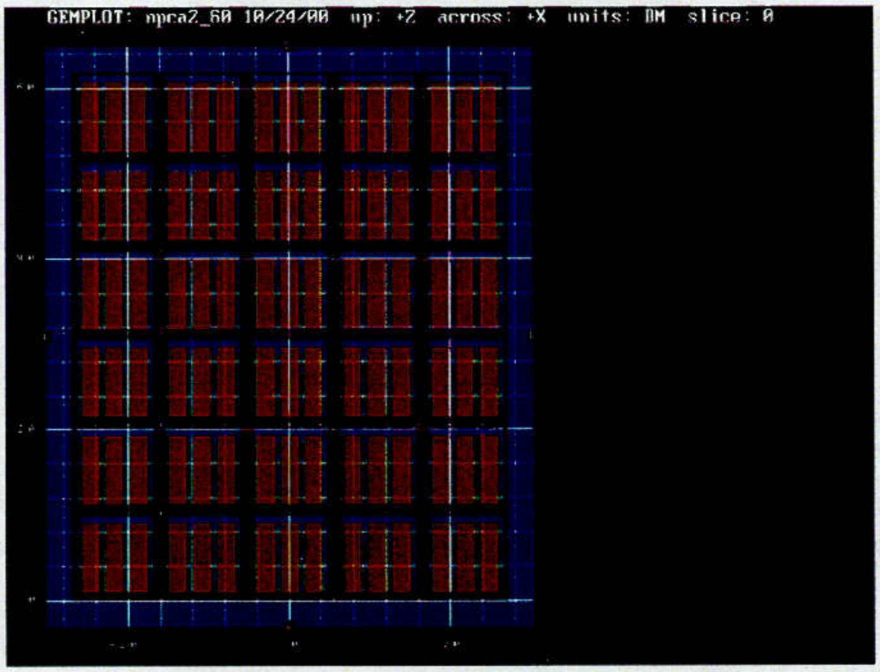
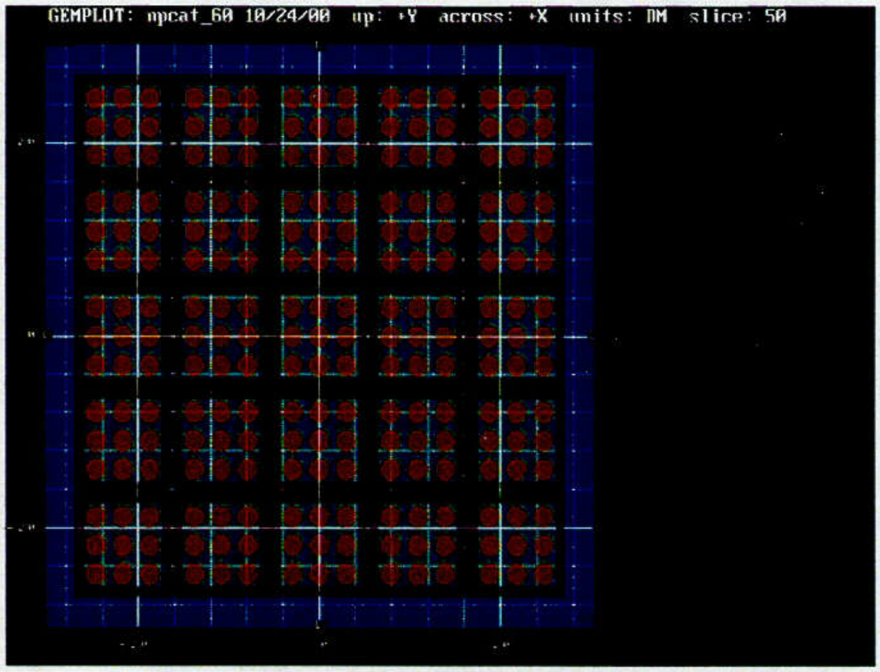


Figure 6.7c – Fully reflected damaged 5x5x6 package array: 60 kgs UO_2 + H_2O mixture, maximum burn (horizontal and vertical views)



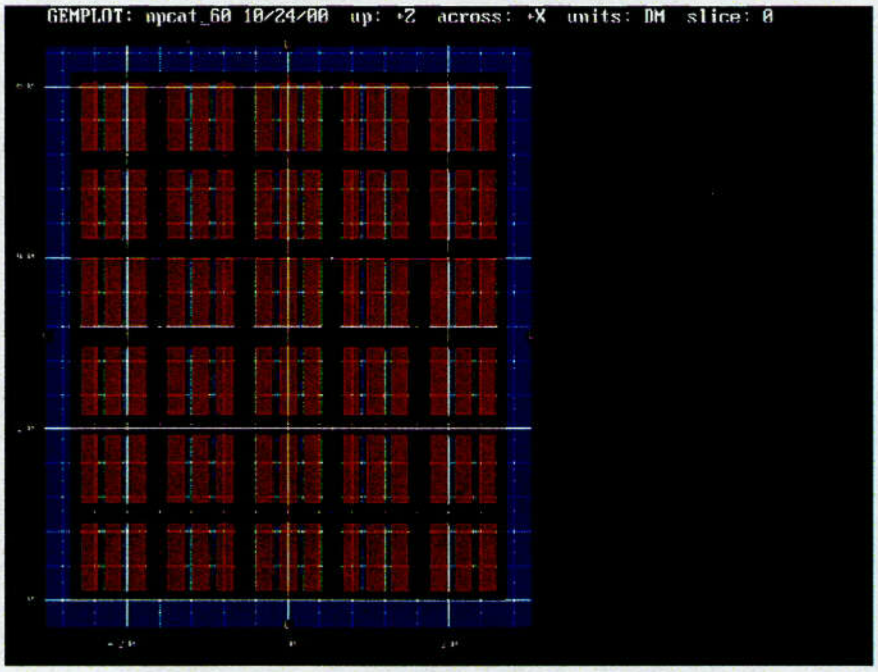


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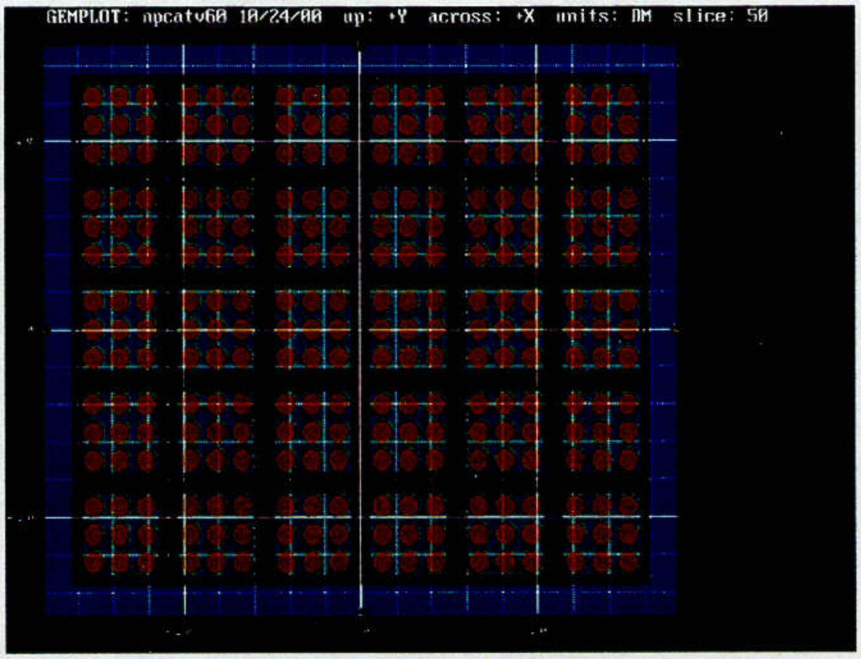
Figure 6.7d – Fully reflected damaged 6 × 5 × 5 package array: 60 kgs UO_2 + H_2O mixture, maximum burn (horizontal and vertical views)



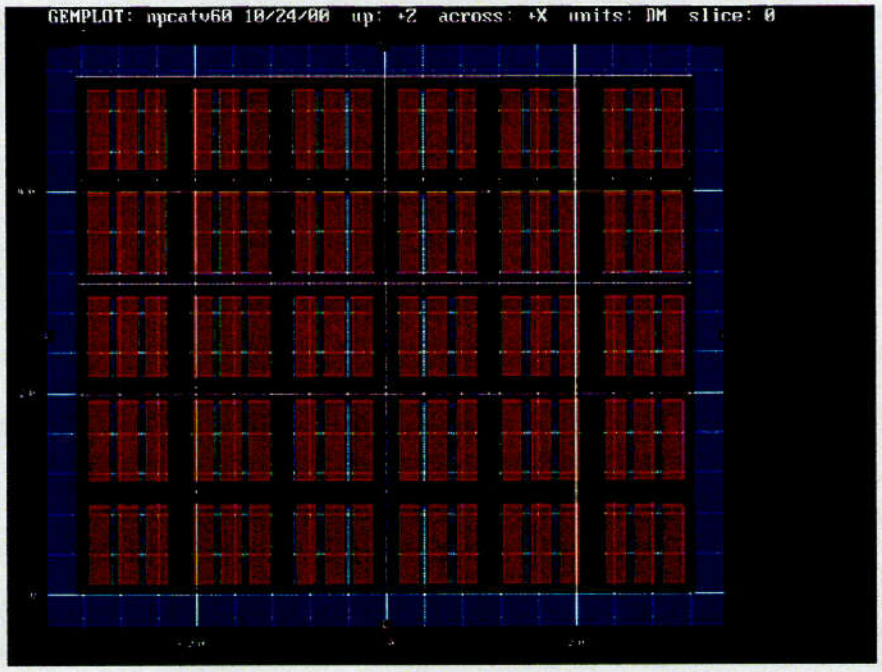
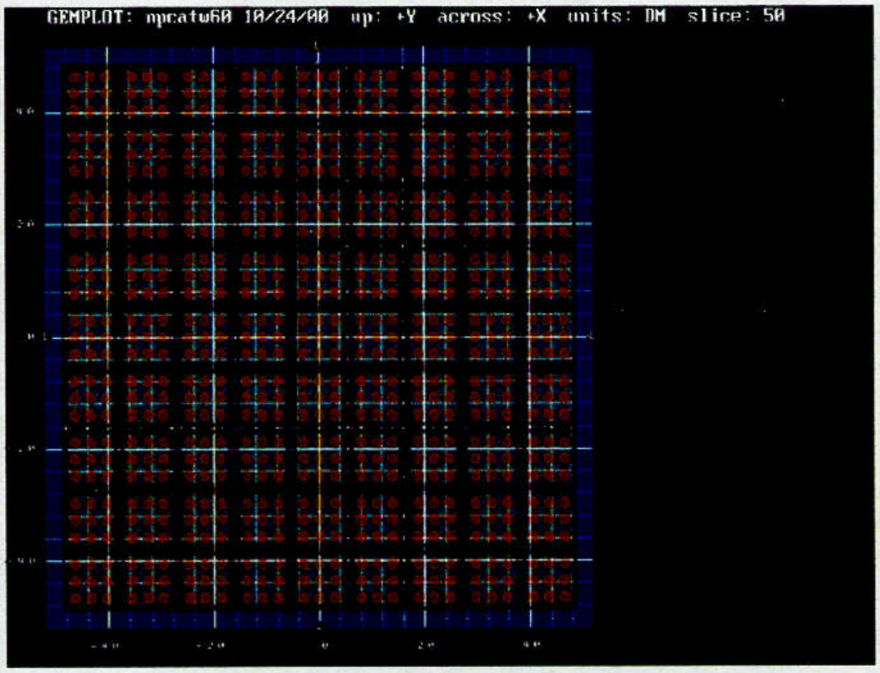
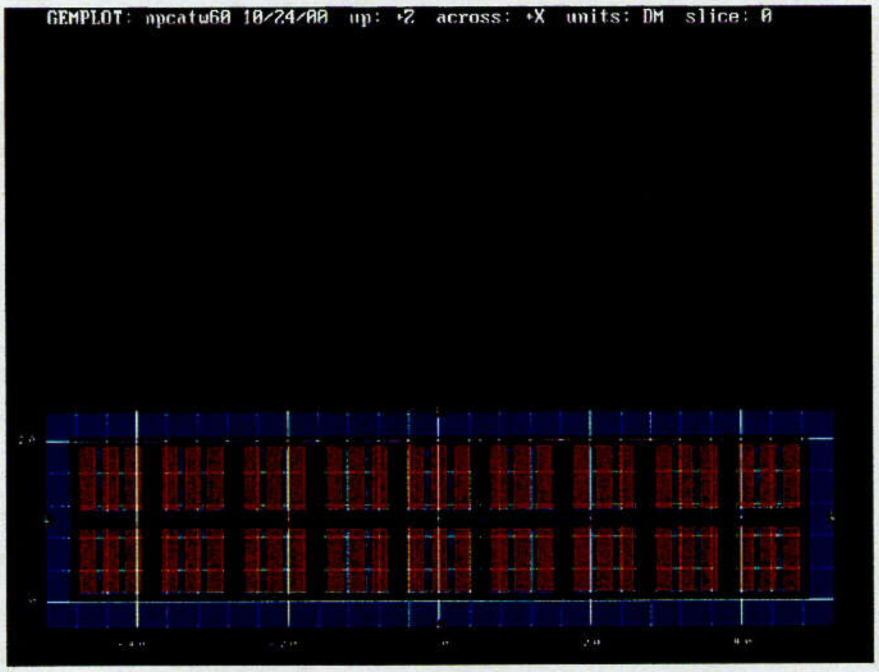


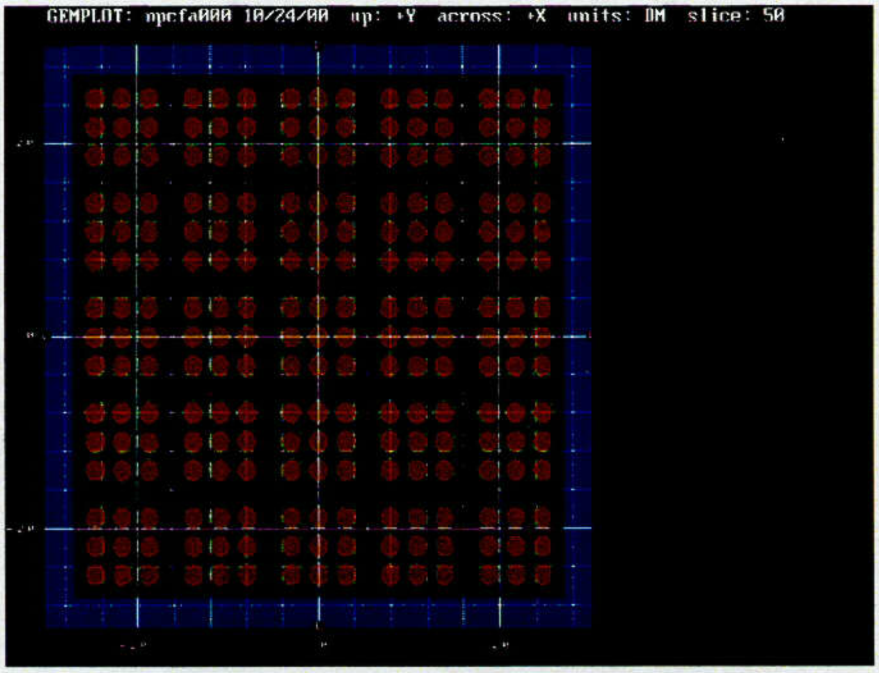
Figure 6.7e – Fully reflected damaged 9 × 9 × 2 package array: 60 kgs UO_2 + H_2O mixture, maximum burn (horizontal and vertical views)

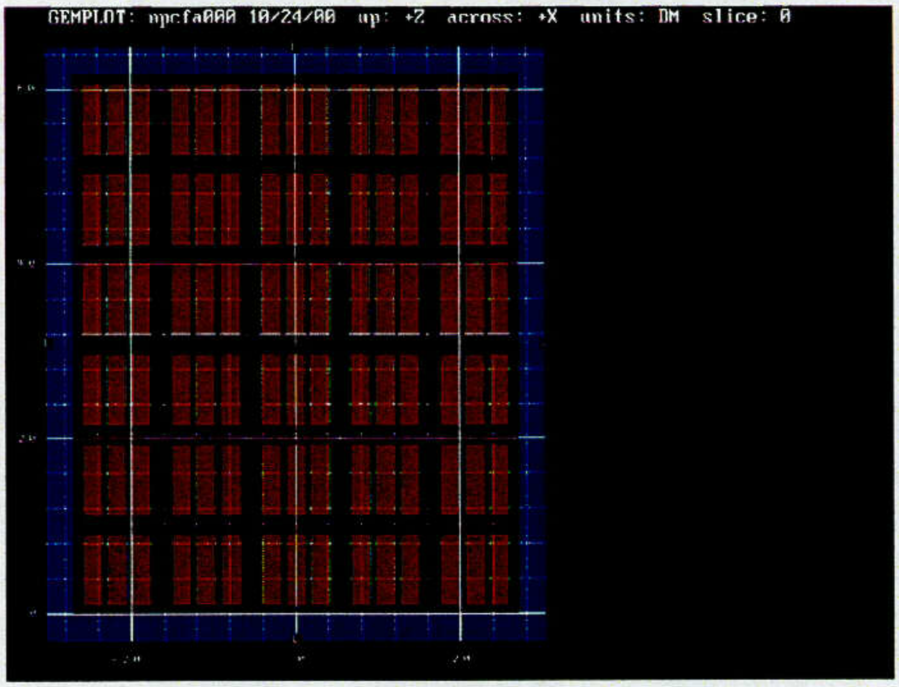




C69

Figure 6.7f – Fully reflected damaged 5 × 5 × 6 package array: 60 kgs UO_2 + H_2O mixture, 100% foam burn, void replacement (horizontal and vertical views)





C70

Figure 6.7g – Fully reflected damaged 5 × 5 × 6 package array: 60 kgs UO_2 + H_2O mixture, maximum burn, 11.25" c-c ICCA spacing (horizontal zoom, lower left array corner)

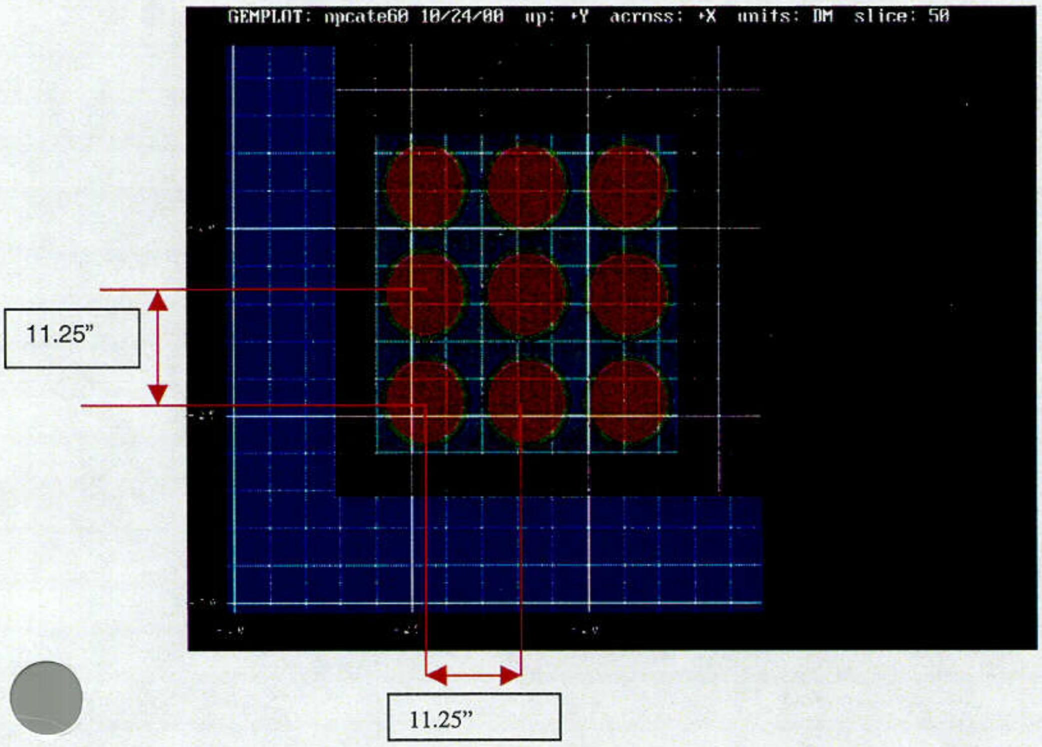
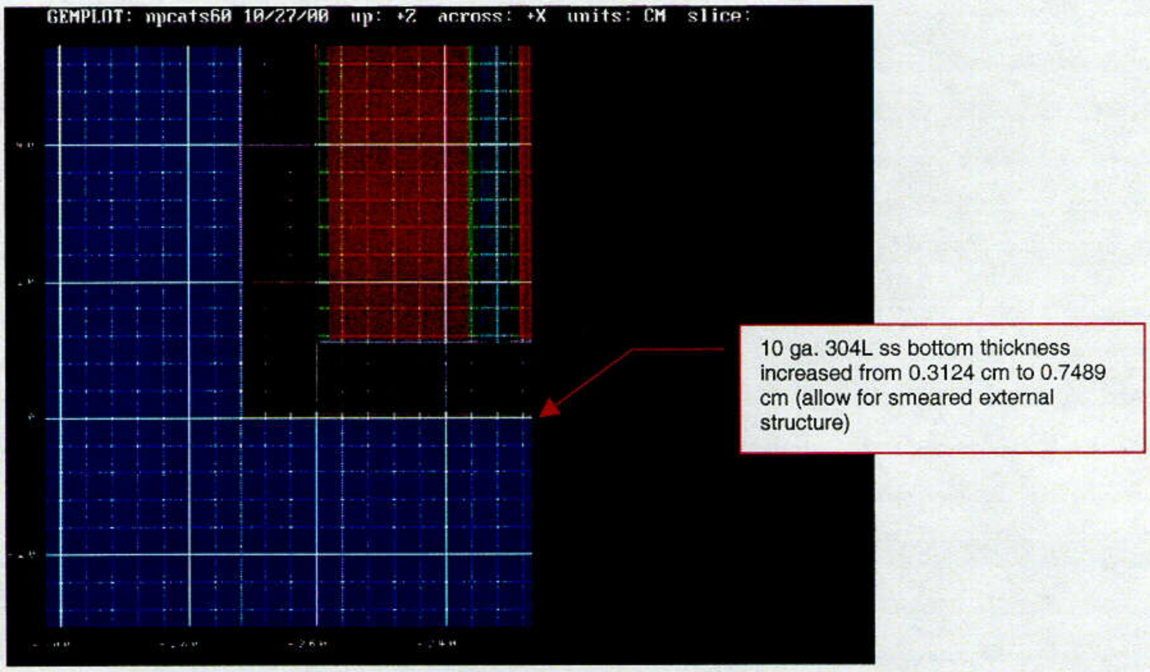
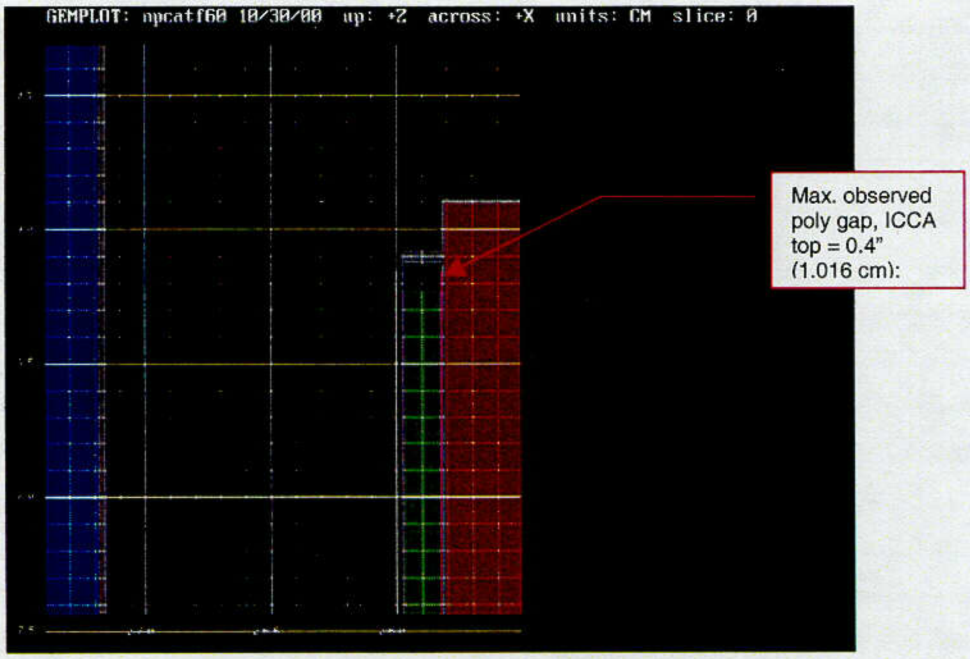


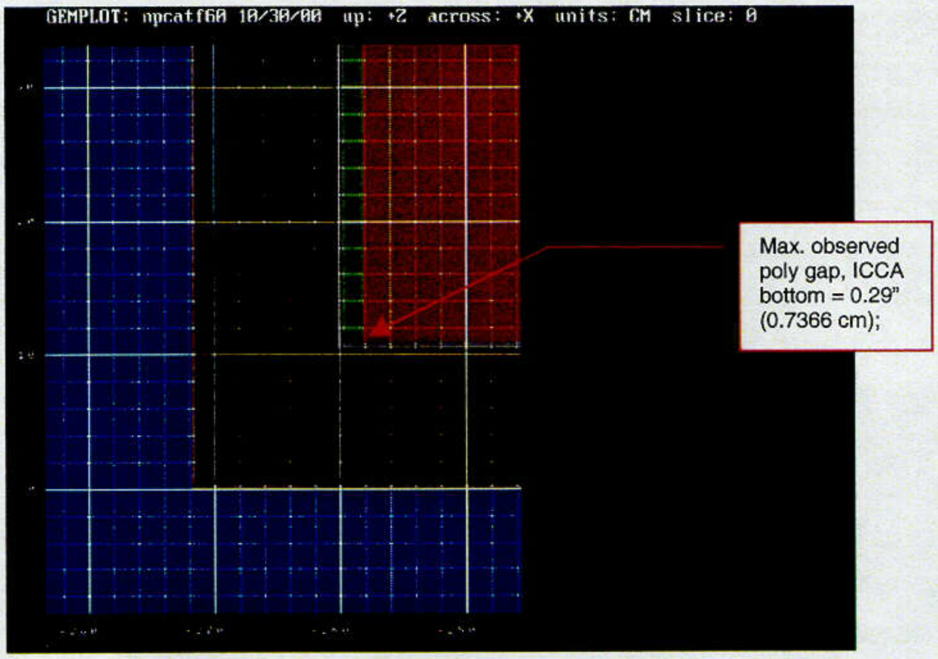
Figure 6.7h – Fully reflected damaged 5 × 5 × 6 package array: 60 kgs UO_2 + H_2O mixture, maximum burn, external structure add-on to bottom of OCA body (vertical zoom, lower left array corner)



C71

Figure 6.7i – Fully reflected damaged 5x5x6 package array: 60 kgs UO_2 + H_2O mixture, maximum burn, observed maximum poly gap at top/bottom (vertical zoom, ICCA)





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6.4 METHOD OF ANALYSIS

GEMER, a proprietary Global Nuclear Fuel company criticality analysis computer code was used in the analysis of these computational models (Ref. 1). All calculations were performed on verified workstations using Pentium processors running under Windows NT.

6.4.1 COMPUTER CODE SYSTEM

GEMER is a Monte Carlo program, which solves the neutron transport equation as an eigenvalue or a fixed source problem including the neutron-shielding problem. GEMER adds an advanced geometry input package to the problem solving capability of the Monte Carlo code that is very similar in capability to KENO Va.

6.4.2 CROSS SECTIONS AND CROSS-SECTION PROCESSING

GEMER uses cross-sections processed from the ENDF/B-IV library. These cross-sections are prepared in 190-group format and the values in the resonance region may have the form of the resonance parameters or Doppler broadened multigroup cross-section. Thermal scattering of hydrogen is represented by the $S(\alpha,\beta)$ data in the ENDF/B-IV library. The types of reactions considered in the Monte Carlo calculation are fission, elastic, inelastic, and (n,2n) reactions; the absorption is implicitly treated by reducing the neutron weight by the non-absorption probability on each collision.

6.4.3 CODE INPUT

All problems were started with a flat initial neutron distribution over the fissile material regions only. Calculations were nominally run with 200 generations at 2000 neutrons each, skipping the first 10 generations before starting the statistical output processing, for a total of 380,000 histories used in the final eigenvalue calculation. Figures 6.8a - 6.8d contain sample GEMER input files according to the description in Table 6.7 as follows:

Table 6.7 – Sample input summary

Figure No.	Case FILE ID	Description
6.8a	npcut_25.in	Damaged single package, theoretical UO_2 + H_2O mixture, wtfr H_2O = 0.25, maximum burn
6.8b	npc6um60.in	Infinite undamaged array: 60 kgs UO_2 compound + 5% H_2O added, rho-UO_2 = 4.5 g/cc
6.8c	npca2_60.in	Damaged package array: 60 kgs UO_2 + H_2O mixture per canister, CTU-2 observed burn
6.8d	npcat_60.in	Damaged package array: 60 kgs UO_2 + H_2O mixture per canister, maximum burn

Figure 6.8a – Sample input file = npcut_25.in

```
2000.NPC,,,,CYL,,UO2,5.00%,WTFR=VAR.,SS,,,CD,CE
/*ECHO
/*TITLE
  200 2000   10    0    0    1    0    0
    0  293    0    0
\CSXSEC\UO2\GUO2-50.25
\CSXSEC\NOU\GNOU-0.SS
\CSXSEC\NOU\GNOU-0.CAD
\CSXSEC\NOU\GNOU-0.POL 0.98
\CSXSEC\NOU\GNOU-0.F07 0.90
\CSXSEC\NOU\GNOU-0.WAT
\CSXSEC\NOU\GNOU-0.F11 0.90
\CSXSEC\NOU\GNOU-0.F15 0.90
\CSXSEC\NOU\GNOU-0.F40 0.90
\CSXSEC\NOU\GNOU-0.ORC
KENO GEOM
    0  /* # OF REGIONS OR ZERO
    0  /* # OF BOX TYPES OR ZERO
    1  /* # OF BOXES IN X DIRECTION
    1  /* # OF BOXES IN Y DIRECTION
    1  /* # OF BOXES IN Z DIRECTION
    1  /* BOUNDARY CONDITION OPTION
    1  /* STARTING SOURCE OPTION
    1  /* COMPLEX EMBEDDED OPTION
    0  /* # OF PRINT PLOTS
      0.0        0.0        0.0        0.0        0.0        0.0
BOX TYPE      1  /* inner canister: bottom fuel_region #1 w/ gap: body assy
CYLINDER      1  10.8141  0.31750  0.00000                          16*.5
CYLINDER      2  10.9233  0.31750  0.00000                          16*.5
CYLINDER      0  12.4092  0.31750  0.00000                          16*.5
CYLINDER      2  12.4092  0.31750 -0.44200                          16*.5
CYLINDER      2  12.4612  0.31750 -0.44200                          16*.5
CYLINDER      0  12.7000  0.31750 -0.44200                          16*.5
CYLINDER      2  12.7635  0.31750 -0.50550                          16*.5
BOX TYPE      2  /* inner canister: fuel_region #2: body assy
CYLINDER      1  10.8141  25.4635   0.0000                          16*.5
CYLINDER      2  10.9233  25.4635   0.0000                          16*.5
CYLINDER      3  10.9614  25.4635   0.0000                          16*.5
CYLINDER      4  12.4092  25.4635   0.0000                          16*.5
CYLINDER      2  12.4612  25.4635   0.0000                          16*.5
CYLINDER      0  12.7000  25.4635   0.0000                          16*.5
CYLINDER      2  12.7635  25.4635   0.0000                          16*.5
BOX TYPE      3  /* inner canister: fuel_region #3, 0.15" cd gap: body assy
CYLINDER      1  10.8141  0.38100  0.00000                          16*.5
CYLINDER      2  10.9233  0.38100  0.00000                          16*.5
CYLINDER      0  10.9614  0.38100  0.00000                          16*.5
CYLINDER      4  12.4092  0.38100  0.00000                          16*.5
CYLINDER      2  12.4612  0.38100  0.00000                          16*.5
CYLINDER      0  12.7000  0.38100  0.00000                          16*.5
CYLINDER      2  12.7635  0.38100  0.00000                          16*.5
BOX TYPE      4  /* inner canister: fuel_region #4: body assy
CYLINDER      1  10.8141  25.4635   0.0000                          16*.5
CYLINDER      2  10.9233  25.4635   0.0000                          16*.5
CYLINDER      3  10.9614  25.4635   0.0000                          16*.5
CYLINDER      4  12.4092  25.4635   0.0000                          16*.5
CYLINDER      2  12.4612  25.4635   0.0000                          16*.5
CYLINDER      0  12.7000  25.4635   0.0000                          16*.5
CYLINDER      2  12.7635  25.4635   0.0000                          16*.5
BOX TYPE      5  /* inner canister: fuel_region #5, 0.15" cd gap: body assy
CYLINDER      1  10.8141  0.38100  0.00000                          16*.5
CYLINDER      2  10.9233  0.38100  0.00000                          16*.5
CYLINDER      0  10.9614  0.38100  0.00000                          16*.5
CYLINDER      4  12.4092  0.38100  0.00000                          16*.5
CYLINDER      2  12.4612  0.38100  0.00000                          16*.5
CYLINDER      0  12.7000  0.38100  0.00000                          16*.5
CYLINDER      2  12.7635  0.38100  0.00000                          16*.5
BOX TYPE      6  /* inner canister: fuel region #6: body assy
CYLINDER      1  10.8141  21.3385   0.0000                          16*.5
CYLINDER      0  10.8141  21.3385   0.0000                          16*.5
CYLINDER      2  10.9233  21.3385   0.0000                          16*.5
CYLINDER      3  10.9614  21.3385   0.0000                          16*.5
CYLINDER      4  12.4092  21.3385   0.0000                          16*.5
CYLINDER      2  12.4612  21.3385   0.0000                          16*.5
CYLINDER      0  12.7000  21.3385   0.0000                          16*.5
CYLINDER      2  12.7635  21.3385   0.0000                          16*.5
BOX TYPE      7  /* inner canister: fuel region #7: body assy
CYLINDER      1  10.8141   3.4925   0.0000                          16*.5
CYLINDER      0  10.8141   3.4925   0.0000                          16*.5
CYLINDER      2  10.9233   3.4925   0.0000                          16*.5
CYLINDER      3  10.9614   3.4925   0.0000                          16*.5
CYLINDER      4  12.4092   3.4925   0.0000                          16*.5
CYLINDER      2  12.4612   3.4925   0.0000                          16*.5
CYLINDER      0  12.7000   3.4925   0.0000                          16*.5
CYLINDER      2  12.7635   3.4925   0.0000                          16*.5
BOX TYPE      8  /* inner canister - fuel region #8: lid assy
CYLINDER      1  10.8141  0.63250  0.00000                          16*.5
CYLINDER      0  10.8141  0.63250  0.00000                          16*.5
CYLINDER      2  10.9233  0.63250  0.00000                          16*.5
CYLINDER      3  10.9614  0.63250  0.00000                          16*.5
CYLINDER      4  12.4092  0.63250  0.00000                          16*.5
CYLINDER      2  12.4612  0.63250  0.00000                          16*.5
CYLINDER      0  12.7000  0.63250  0.00000                          16*.5
CYLINDER      2  12.7635  0.63250  0.00000                          16*.5
BOX TYPE      9  /* inner canister - fuel region #9 w/ gap: lid assy
CYLINDER      1  10.8141  0.31750  0.00000                          16*.5
CYLINDER      2  10.9233  0.31750  0.00000                          16*.5
CYLINDER      0  12.4092  0.31750  0.00000                          16*.5
CYLINDER      2  12.4612  0.31750  0.00000                          16*.5
BOX TYPE     10  /* inner canister - fuel region #10 w/ ring: lid assy
```

```
CYLINDER    1  10.8141  0.44200  0.00000                              16*.5
CYLINDER    2  10.9233  0.44200  0.00000                              16*.5
CYLINDER    2  12.4092  0.44200  0.00000                              16*.5
CYLINDER    2  12.4612  0.44200  0.00000                              16*.5
BOX TYPE   11  /* inner canister - fuel region #11 w/ top: lid assy
CYLINDER    1  10.8141  1.78050  0.00000                              16*.5
CYLINDER    2  10.9233  1.91640  0.00000                              16*.5
CYLINDER    0  12.4092  1.91640  0.00000                              16*.5
BOX TYPE   12  /* inner canister cuboid: body section (7# region)
CUBOID      5  12.7636 -12.7636  12.7636 -12.7636  73.3450  -0.5055  16*.5
BOX TYPE   13  /* inner canister cuboid: body section (40# region)
CUBOID      9  12.7636 -12.7636  12.7636 -12.7636  3.49260  0.00000  16*.5
BOX TYPE   14  /* inner canister upper cylinder: lid section
CYLINDER    0  12.7636  3.30840  0.00000                              16*.5
BOX TYPE   15  /* foam cutout (void) - 40 #/ft3 foam lid section
CYLINDER    0  13.5510  3.30840  0.00000                              16*.5
BOX TYPE   16  /* npc body or lid - 10 ga. 304ss layer
CUBOID      2  54.3687 -54.3687  54.3687 -54.3687  0.31240  0.00000  16*.5
BOX TYPE   17  /* npc body or lid - 1" duraboard (void) layer, 10 ga. 304ss
CUBOID      0  51.5163 -51.5163  51.5163 -51.5163  2.54000  0.00000  16*.5
CUBOID      0  54.0563 -54.0563  54.0563 -54.0563  2.54000  0.00000  16*.5
CUBOID      2  54.3687 -54.3687  54.3687 -54.3687  2.54000  0.00000  16*.5
BOX TYPE   18  /* npc body - 4" bot. foam layer (11 #/ft3)    - face burn
CUBOID      7  42.6086 -42.6086  42.6086 -42.6086  0.00000  0.00000  16*.5
CUBOID      0  54.0563 -54.0563  54.0563 -54.0563  0.00000 -7.62000  16*.5
CUBOID      2  54.3687 -54.3687  54.3687 -54.3687  0.00000 -7.62000  16*.5
BOX TYPE   19  /* npc body - 29.0750" foam layer (7,11 #/ft3) - face burn
CUBOID      5  42.6086 -42.6086  42.6086 -42.6086  73.8505   0.0000  16*.5
CUBOID      7  42.6086 -42.6086  42.6086 -42.6086  73.8505   0.0000  16*.5
CUBOID      0  54.0563 -54.0563  54.0563 -54.0563  73.8505   0.0000  16*.5
CUBOID      2  54.3687 -54.3687  54.3687 -54.3687  73.8505   0.0000  16*.5
BOX TYPE   20  /* npc body - 1.375 " foam layer (40 #/ft3)     - face burn
CUBOID      9  42.6086 -42.6086  42.6086 -42.6086  3.49250  0.00000  16*.5
CUBOID      0  54.0563 -54.0563  54.0563 -54.0563  3.49250  0.00000  16*.5
CUBOID      2  54.3687 -54.3687  54.3687 -54.3687  3.49250  0.00000  16*.5
BOX TYPE   21  /* npc body - 30.45" two-part body
CUBOID      0  54.3687 -54.3687  54.3687 -54.3687  77.3430   0.0000  16*.5
BOX TYPE   22  /* npc lid - 1.375 " foam layer (40 #/ft3)  - lid burn
CUBOID      0  43.8963 -43.8963  43.8963 -43.8963  3.49250  0.00000  16*.5
CUBOID      0  54.0563 -54.0563  54.0563 -54.0563  3.49250  0.00000  16*.5
CUBOID      2  54.3687 -54.3687  54.3687 -54.3687  3.49250  0.00000  16*.5
BOX TYPE   23  /* npc lid - 3.5" foam layer (15 #/ft3)      - lid burn
CUBOID      0  43.8963 -43.8963  43.8963 -43.8963  2.54000  0.00000  16*.5
CUBOID      0  54.0563 -54.0563  54.0563 -54.0563  8.89000  0.00000  16*.5
CUBOID      2  54.3687 -54.3687  54.3687 -54.3687  8.89000  0.00000  16*.5
BOX TYPE   24  /* complete npc - body assembly
CUBOID      0  54.3688 -54.3688  54.3688 -54.3688  87.8154   0.0000  16*.5
BOX TYPE   25  /* complete npc - lid assembly
CUBOID      0  54.3688 -54.3688  54.3688 -54.3688  15.2349   0.0000  16*.5
BOX TYPE   26  /* global unit: damaged unit, full h2o reflection
CUBOID      0  54.3688 -54.3688  54.3688 -54.3688  103.0503  0.0000  16*.5
CUBOID      6  84.8488 -84.8488  84.8488 -84.8488  133.5303 -30.480  16*.5
 26    1  1  1     1  1  1     1  1  1     1
BEGIN COMPLEX
/* build inner canister - main body section (7 #/ft3 region)
COMPLEX  12  1  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  12  2  0.00000  0.00000  0.31750   1   1   1  0.0   0.0   0.0
COMPLEX  12  3  0.00000  0.00000  25.7810   1   1   1  0.0   0.0   0.0
COMPLEX  12  4  0.00000  0.00000  26.1621   1   1   1  0.0   0.0   0.0
COMPLEX  12  5  0.00000  0.00000  51.6256   1   1   1  0.0   0.0   0.0
COMPLEX  12  6  0.00000  0.00000  52.0066   1   1   1  0.0   0.0   0.0
/* build inner canister - upper body section (40 #/ft3 section)
COMPLEX  13  7  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
/* build inner canister - lid section
COMPLEX  14  8  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  14  9  0.00000  0.00000  0.63250   1   1   1  0.0   0.0   0.0
COMPLEX  14 10  0.00000  0.00000  0.95000   1   1   1  0.0   0.0   0.0
COMPLEX  14 11  0.00000  0.00000  1.39200   1   1   1  0.0   0.0   0.0
/* embed 3x3 array of canisters into lid: 11.75"-centers
COMPLEX  15 14 -29.8450 -29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of foam cut_outs:11.75"-centers
COMPLEX  22 15 -29.8450 -29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of canisters into inner body: 11.75"-centers
COMPLEX  19 12 -29.8450 -29.8450  0.50550   3   3   1  29.8450  29.8450  0.0
COMPLEX  20 13 -29.8450 -29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed two-part body section stackup
COMPLEX  21 19  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  21 20  0.00000  0.00000  73.8505   1   1   1  0.0   0.0   0.0
/* build npc - body assembly
COMPLEX  24 16  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  24 17  0.00000  0.00000  0.31240   1   1   1  0.0   0.0   0.0
COMPLEX  24 18  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
COMPLEX  24 21  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
/* build npc - lid assembly
COMPLEX  25 22  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  25 23  0.00000  0.00000  3.49250   1   1   1  0.0   0.0   0.0
COMPLEX  25 17  0.00000  0.00000  12.3825   1   1   1  0.0   0.0   0.0
COMPLEX  25 16  0.00000  0.00000  14.9225   1   1   1  0.0   0.0   0.0
/* complete npc stackup - single unit
COMPLEX  26 24  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  26 25  0.00000  0.00000  87.8154   1   1   1  0.0   0.0   0.0
END GEOM
DEFAULTS=YES
END GEMER
```

Figure 6.8b – Sample input file = npc6um60.in

```
2000.NPC,,,,CYL,,UO2,5.00%,WTFR=0.05,SS,,,CD,CB
/*ECHO
/*TITLE
  200 2000   10    0    0    1    0    0
    0  293    0    0
\CSXSEC\UO2\GUO2-50.05 0.6474
\CSXSEC\NOU\GNOU-0.SS
\CSXSEC\NOU\GNOU-0.CAD
\CSXSEC\NOU\GNOU-0.POL
\CSXSEC\NOU\GNOU-0.F07 0.90
\CSXSEC\NOU\GNOU-0.WAT
\CSXSEC\NOU\GNOU-0.F11 0.90
\CSXSEC\NOU\GNOU-0.F15 0.90
\CSXSEC\NOU\GNOU-0.F40 0.90
\CSXSEC\NOU\GNOU-0.ORC
KENO GEOM
    0  /* # OF REGIONS OR ZERO
    0  /* # OF BOX TYPES OR ZERO
    1  /* # OF BOXES IN X DIRECTION
    1  /* # OF BOXES IN Y DIRECTION
    1  /* # OF BOXES IN Z DIRECTION
    1  /* BOUNDARY CONDITION OPTION
    1  /* STARTING SOURCE OPTION
    1  /* COMPLEX EMBEDDED OPTION
    0  /* # OF PRINT PLOTS
      -1.0      -1.0      -1.0      -1.0      -1.0      -1.0
BOX TYPE     1  /* inner canister: bottom fuel_region #1 w/ gap: body assy
CYLINDER     1  10.8141  0.31750  0.00000                              16*.5
CYLINDER     2  10.9233  0.31750  0.00000                              16*.5
CYLINDER     0  12.4092  0.31750  0.00000                              16*.5
CYLINDER     2  12.4092  0.31750 -0.44200                              16*.5
CYLINDER     2  12.4612  0.31750 -0.44200                              16*.5
CYLINDER     0  12.7000  0.31750 -0.44200                              16*.5
CYLINDER     2  12.7635  0.31750 -0.50550                              16*.5
BOX TYPE     2  /* inner canister: fuel_region #2: body assy
CYLINDER     1  10.8141  25.4635   0.0000                              16*.5
CYLINDER     2  10.9233  25.4635   0.0000                              16*.5
CYLINDER     3  10.9614  25.4635   0.0000                              16*.5
CYLINDER     4  12.4092  25.4635   0.0000                              16*.5
CYLINDER     2  12.4612  25.4635   0.0000                              16*.5
CYLINDER     0  12.7000  25.4635   0.0000                              16*.5
CYLINDER     2  12.7635  25.4635   0.0000                              16*.5
BOX TYPE     3  /* inner canister: fuel_region #3, 0.15" cd gap: body assy
CYLINDER     1  10.8141  0.38100  0.00000                              16*.5
CYLINDER     2  10.9233  0.38100  0.00000                              16*.5
CYLINDER     0  10.9614  0.38100  0.00000                              16*.5
CYLINDER     4  12.4092  0.38100  0.00000                              16*.5
CYLINDER     2  12.4612  0.38100  0.00000                              16*.5
CYLINDER     0  12.7000  0.38100  0.00000                              16*.5
CYLINDER     2  12.7635  0.38100  0.00000                              16*.5
BOX TYPE     4  /* inner canister: fuel_region #4: body assy
CYLINDER     1  10.8141  10.1300   0.0000                              16*.5
CYLINDER     0  10.8141  25.4635   0.0000                              16*.5
CYLINDER     2  10.9233  25.4635   0.0000                              16*.5
CYLINDER     3  10.9614  25.4635   0.0000                              16*.5
CYLINDER     4  12.4092  25.4635   0.0000                              16*.5
CYLINDER     2  12.4612  25.4635   0.0000                              16*.5
CYLINDER     0  12.7000  25.4635   0.0000                              16*.5
CYLINDER     2  12.7635  25.4635   0.0000                              16*.5
BOX TYPE     5  /* inner canister: fuel_region #5, 0.15" cd gap: body assy
CYLINDER     0  10.8141  0.38100  0.00000                              16*.5
CYLINDER     2  10.9233  0.38100  0.00000                              16*.5
CYLINDER     0  10.9614  0.38100  0.00000                              16*.5
CYLINDER     4  12.4092  0.38100  0.00000                              16*.5
CYLINDER     2  12.4612  0.38100  0.00000                              16*.5
CYLINDER     0  12.7000  0.38100  0.00000                              16*.5
CYLINDER     2  12.7635  0.38100  0.00000                              16*.5
BOX TYPE     6  /* inner canister: fuel region #6: body assy
CYLINDER     0  10.8141  21.3385   0.0000                              16*.5
CYLINDER     2  10.9233  21.3385   0.0000                              16*.5
CYLINDER     3  10.9614  21.3385   0.0000                              16*.5
CYLINDER     4  12.4092  21.3385   0.0000                              16*.5
CYLINDER     2  12.4612  21.3385   0.0000                              16*.5
CYLINDER     0  12.7000  21.3385   0.0000                              16*.5
CYLINDER     2  12.7635  21.3385   0.0000                              16*.5
BOX TYPE     7  /* inner canister: fuel region #7: body assy
CYLINDER     0  10.8141   3.4925   0.0000                              16*.5
CYLINDER     2  10.9233   3.4925   0.0000                              16*.5
CYLINDER     3  10.9614   3.4925   0.0000                              16*.5
CYLINDER     4  12.4092   3.4925   0.0000                              16*.5
CYLINDER     2  12.4612   3.4925   0.0000                              16*.5
CYLINDER     0  12.7000   3.4925   0.0000                              16*.5
CYLINDER     2  12.7635   3.4925   0.0000                              16*.5
BOX TYPE     8  /* inner canister - fuel region #8: lid assy
CYLINDER     0  10.8141  0.63250  0.00000                              16*.5
CYLINDER     2  10.9233  0.63250  0.00000                              16*.5
CYLINDER     3  10.9614  0.63250  0.00000                              16*.5
CYLINDER     4  12.4092  0.63250  0.00000                              16*.5
CYLINDER     2  12.4612  0.63250  0.00000                              16*.5
CYLINDER     0  12.7000  0.63250  0.00000                              16*.5
CYLINDER     2  12.7635  0.63250  0.00000                              16*.5
BOX TYPE     9  /* inner canister - fuel region #9 w/ gap: lid assy
CYLINDER     0  10.8141  0.31750  0.00000                              16*.5
CYLINDER     2  10.9233  0.31750  0.00000                              16*.5
CYLINDER     0  12.4092  0.31750  0.00000                              16*.5
CYLINDER     2  12.4612  0.31750  0.00000                              16*.5
BOX TYPE    10  /* inner canister - fuel region #10 w/ ring: lid assy
```

```
CYLINDER     0  10.8141  0.44200  0.00000                              16*.5
CYLINDER     2  10.9233  0.44200  0.00000                              16*.5
CYLINDER     2  12.4092  0.44200  0.00000                              16*.5
CYLINDER     2  12.4612  0.44200  0.00000                              16*.5
BOX TYPE    11  /* inner canister - fuel region #11 w/ top: lid assy
CYLINDER     0  10.8141  1.78050  0.00000                              16*.5
CYLINDER     2  10.9233  1.91640  0.00000                              16*.5
CYLINDER     0  12.4092  1.91640  0.00000                              16*.5
BOX TYPE    12  /* inner canister cuboid: body section (7# region)
CUBOID       5  12.7636 -12.7636  12.7636 -12.7636  73.3450  -0.5055  16*.5
BOX TYPE    13  /* inner canister cuboid: body section (40# region)
CUBOID       9  12.7636 -12.7636  12.7636 -12.7636  3.49260  0.00000  16*.5
BOX TYPE    14  /* inner canister upper cylinder: lid section
CYLINDER     0  12.7636   3.30840  0.00000                             16*.5
BOX TYPE    15  /* foam cutout (void) - 40 #/ft3 foam lid section
CYLINDER     0  13.5510   3.30840  0.00000                             16*.5
BOX TYPE    16  /* npc body or lid - 10 ga. 304ss layer
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  0.31240  0.00000  16*.5
BOX TYPE    17  /* npc body or lid - 1" duraboard (void) layer, 10 ga. 304ss
CUBOID       0  51.5163 -51.5163  51.5163 -51.5163  2.54000  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  2.54000  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  2.54000  0.00000  16*.5
BOX TYPE    18  /* npc body - 3" bot. foam layer (11 #/ft3), 10 ga. 304ss
CUBOID       7  51.5163 -51.5163  51.5163 -51.5163  7.62000  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  7.62000  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  7.62000  0.00000  16*.5
BOX TYPE    19  /* npc body - 29.0750" foam layer (7,11 #/ft3),10 ga. 304ss
CUBOID       5  43.8963 -43.8963  43.8963 -43.8963  73.8505   0.0000  16*.5
CUBOID       7  51.5163 -51.5163  51.5163 -51.5163  73.8505   0.0000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  73.8505   0.0000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  73.8505   0.0000  16*.5
BOX TYPE    20  /* npc body - 1.375 " foam layer (40 #/ft3), 10 ga. 304ss
CUBOID       9  51.5163 -51.5163  51.5163 -51.5163  3.49250  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  3.49250  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  3.49250  0.00000  16*.5
BOX TYPE    21  /* npc body - 30.45" two-part body
CUBOID       0  54.3687 -54.3687  54.3687 -54.3687  77.3430   0.0000  16*.5
BOX TYPE    22  /* npc lid - 1.375 " foam layer (40 #/ft3), 10 ga. 304ss
CUBOID       9  51.5163 -51.5163  51.5163 -51.5163  3.49250  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  3.49250  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  3.49250  0.00000  16*.5
BOX TYPE    23  /* npc lid - 3.5" foam layer (15 #/ft3), 10 ga. 304ss
CUBOID       8  51.5163 -51.5163  51.5163 -51.5163  8.89000  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  8.89000  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  8.89000  0.00000  16*.5
BOX TYPE    24  /* complete npc - body assembly
CUBOID       0  54.3688 -54.3688  54.3688 -54.3688  87.8154   0.0000  16*.5
BOX TYPE    25  /* complete npc - lid assembly
CUBOID       0  54.3688 -54.3688  54.3688 -54.3688  15.2349   0.0000  16*.5
BOX TYPE    26  /* global unit: npc infinite system
CUBOID       0  54.3700 -54.3700  54.3700 -54.3700  103.051    0.000  16*.5
 26    1  1  1    1  1  1    1  1  1   1
BEGIN COMPLEX
/* build inner canister - main body section (7 #/ft3 region)
COMPLEX  12  1  0.00000  0.00000  0.00000   1   1   1  0.0    0.0    0.0
COMPLEX  12  2  0.00000  0.00000  0.31750   1   1   1  0.0    0.0    0.0
COMPLEX  12  3  0.00000  0.00000  25.7810   1   1   1  0.0    0.0    0.0
COMPLEX  12  4  0.00000  0.00000  26.1621   1   1   1  0.0    0.0    0.0
COMPLEX  12  5  0.00000  0.00000  51.6256   1   1   1  0.0    0.0    0.0
COMPLEX  12  6  0.00000  0.00000  52.0066   1   1   1  0.0    0.0    0.0
/* build inner canister - upper body section (40 #/ft3 section)
COMPLEX  13  7  0.00000  0.00000  0.00000   1   1   1  0.0    0.0    0.0
/* build inner canister - lid section
COMPLEX  14  8  0.00000  0.00000  0.00000   1   1   1  0.0    0.0    0.0
COMPLEX  14  9  0.00000  0.00000  0.63250   1   1   1  0.0    0.0    0.0
COMPLEX  14 10  0.00000  0.00000  0.95000   1   1   1  0.0    0.0    0.0
COMPLEX  14 11  0.00000  0.00000  1.39200   1   1   1  0.0    0.0    0.0
/* embed 3x3 array of canisters into lid: 11.75"-centers
COMPLEX  15 14 -29.8450 -29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of foam cut_outs:11.75"-centers
COMPLEX  22 15 -29.8450 -29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of canisters into inner body: 11.75"-centers
COMPLEX  19 12 -29.8450 -29.8450  0.50550   3   3   1  29.8450  29.8450  0.0
COMPLEX  20 13 -29.8450 -29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed two-part body section stackup
COMPLEX  21 19  0.00000  0.00000  0.00000   1   1   1  0.0    0.0    0.0
COMPLEX  21 20  0.00000  0.00000  73.8505   1   1   1  0.0    0.0    0.0
/* build npc - body assembly
COMPLEX  24 16  0.00000  0.00000  0.00000   1   1   1  0.0    0.0    0.0
COMPLEX  24 17  0.00000  0.00000  0.31240   1   1   1  0.0    0.0    0.0
COMPLEX  24 18  0.00000  0.00000  2.85240   1   1   1  0.0    0.0    0.0
COMPLEX  24 21  0.00000  0.00000  10.4724   1   1   1  0.0    0.0    0.0
/* build npc - lid assembly
COMPLEX  25 22  0.00000  0.00000  0.00000   1   1   1  0.0    0.0    0.0
COMPLEX  25 23  0.00000  0.00000  3.49250   1   1   1  0.0    0.0    0.0
COMPLEX  25 17  0.00000  0.00000  12.3825   1   1   1  0.0    0.0    0.0
COMPLEX  25 16  0.00000  0.00000  14.9225   1   1   1  0.0    0.0    0.0
/* complete npc stackup - single unit
COMPLEX  26 24  0.00000  0.00000  0.00000   1   1   1  0.0    0.0    0.0
COMPLEX  26 25  0.00000  0.00000  87.8154   1   1   1  0.0    0.0    0.0
END GEOM
DEFAULTS=YES
END GEMER
```

Figure 6.8c – Sample input file = npca2_60.in

```
2000.NPC,,,,CYL,,UO2,5.00%,WTFR=VAR.,SS,,,CD,CE
/*ECHO
/*TITLE
  200 2000   10    0    0    1    0    0
    0  293    0    0
\CSXSEC\UO2\GUO2-50.285
\CSXSEC\NOU\GNOU-0.SS
\CSXSEC\NOU\GNOU-0.CAD
\CSXSEC\NOU\GNOU-0.POL 0.98
\CSXSEC\NOU\GNOU-0.F07 0.90
\CSXSEC\NOU\GNOU-0.WAT
\CSXSEC\NOU\GNOU-0.F11 0.90
\CSXSEC\NOU\GNOU-0.F15 0.90
\CSXSEC\NOU\GNOU-0.F40 0.90
\CSXSEC\NOU\GNOU-0.ORC
KENO GEOM
    0  /* # OF REGIONS OR ZERO
    0  /* # OF BOX TYPES OR ZERO
    1  /* # OF BOXES IN X DIRECTION
    1  /* # OF BOXES IN Y DIRECTION
    1  /* # OF BOXES IN Z DIRECTION
    1  /* BOUNDARY CONDITION OPTION
    1  /* STARTING SOURCE OPTION
    1  /* COMPLEX EMBEDDED OPTION
    0  /* # OF PRINT PLOTS
      0.0        0.0        0.0        0.0        0.0        0.0
BOX TYPE     1  /* inner canister: bottom fuel_region #1 w/ gap: body assy
CYLINDER     1  10.8141  0.31750  0.00000                                 16*.5
CYLINDER     2  10.9233  0.31750  0.00000                                 16*.5
CYLINDER     0  12.4092  0.31750  0.00000                                 16*.5
CYLINDER     2  12.4092  0.31750 -0.44200                                 16*.5
CYLINDER     2  12.4612  0.31750 -0.44200                                 16*.5
CYLINDER     0  12.7000  0.31750 -0.44200                                 16*.5
CYLINDER     2  12.7635  0.31750 -0.50550                                 16*.5
BOX TYPE     2  /* inner canister: fuel_region #2: body assy
CYLINDER     1  10.8141  25.4635   0.0000                                 16*.5
CYLINDER     2  10.9233  25.4635   0.0000                                 16*.5
CYLINDER     3  10.9614  25.4635   0.0000                                 16*.5
CYLINDER     4  12.4092  25.4635   0.0000                                 16*.5
CYLINDER     2  12.4612  25.4635   0.0000                                 16*.5
CYLINDER     0  12.7000  25.4635   0.0000                                 16*.5
CYLINDER     2  12.7635  25.4635   0.0000                                 16*.5
BOX TYPE     3  /* inner canister: fuel_region #3, 0.15" cd gap: body assy
CYLINDER     1  10.8141  0.38100  0.00000                                 16*.5
CYLINDER     2  10.9233  0.38100  0.00000                                 16*.5
CYLINDER     0  10.9614  0.38100  0.00000                                 16*.5
CYLINDER     4  12.4092  0.38100  0.00000                                 16*.5
CYLINDER     2  12.4612  0.38100  0.00000                                 16*.5
CYLINDER     0  12.7000  0.38100  0.00000                                 16*.5
CYLINDER     2  12.7635  0.38100  0.00000                                 16*.5
BOX TYPE     4  /* inner canister: fuel_region #4: body assy
CYLINDER     1  10.8141  25.4635   0.0000                                 16*.5
CYLINDER     2  10.9233  25.4635   0.0000                                 16*.5
CYLINDER     3  10.9614  25.4635   0.0000                                 16*.5
CYLINDER     4  12.4092  25.4635   0.0000                                 16*.5
CYLINDER     2  12.4612  25.4635   0.0000                                 16*.5
CYLINDER     0  12.7000  25.4635   0.0000                                 16*.5
CYLINDER     2  12.7635  25.4635   0.0000                                 16*.5
BOX TYPE     5  /* inner canister: fuel_region #5, 0.15" cd gap: body assy
CYLINDER     1  10.8141  0.38100  0.00000                                 16*.5
CYLINDER     2  10.9233  0.38100  0.00000                                 16*.5
CYLINDER     0  10.9614  0.38100  0.00000                                 16*.5
CYLINDER     4  12.4092  0.38100  0.00000                                 16*.5
CYLINDER     2  12.4612  0.38100  0.00000                                 16*.5
CYLINDER     0  12.7000  0.38100  0.00000                                 16*.5
CYLINDER     2  12.7635  0.38100  0.00000                                 16*.5
BOX TYPE     6  /* inner canister: fuel region #6: body assy
CYLINDER     1  10.8141  21.3385   0.0000                                 16*.5
CYLINDER     0  10.8141  21.3385   0.0000                                 16*.5
CYLINDER     2  10.9233  21.3385   0.0000                                 16*.5
CYLINDER     3  10.9614  21.3385   0.0000                                 16*.5
CYLINDER     4  12.4092  21.3385   0.0000                                 16*.5
CYLINDER     2  12.4612  21.3385   0.0000                                 16*.5
CYLINDER     0  12.7000  21.3385   0.0000                                 16*.5
CYLINDER     2  12.7635  21.3385   0.0000                                 16*.5
BOX TYPE     7  /* inner canister: fuel region #7: body assy
CYLINDER     1  10.8141   3.4925   0.0000                                 16*.5
CYLINDER     0  10.8141   3.4925   0.0000                                 16*.5
CYLINDER     2  10.9233   3.4925   0.0000                                 16*.5
CYLINDER     3  10.9614   3.4925   0.0000                                 16*.5
CYLINDER     4  12.4092   3.4925   0.0000                                 16*.5
CYLINDER     2  12.4612   3.4925   0.0000                                 16*.5
CYLINDER     0  12.7000   3.4925   0.0000                                 16*.5
CYLINDER     2  12.7635   3.4925   0.0000                                 16*.5
BOX TYPE     8  /* inner canister - fuel region #8: lid assy
CYLINDER     1  10.8141  0.63250  0.00000                                 16*.5
CYLINDER     0  10.8141  0.63250  0.00000                                 16*.5
CYLINDER     2  10.9233  0.63250  0.00000                                 16*.5
CYLINDER     3  10.9614  0.63250  0.00000                                 16*.5
CYLINDER     4  12.4092  0.63250  0.00000                                 16*.5
CYLINDER     2  12.4612  0.63250  0.00000                                 16*.5
CYLINDER     0  12.7000  0.63250  0.00000                                 16*.5
CYLINDER     2  12.7635  0.63250  0.00000                                 16*.5
BOX TYPE     9  /* inner canister - fuel region #9 w/ gap: lid assy
CYLINDER     1  10.8141  0.31750  0.00000                                 16*.5
CYLINDER     2  10.9233  0.31750  0.00000                                 16*.5
CYLINDER     0  12.4092  0.31750  0.00000                                 16*.5
CYLINDER     2  12.4612  0.31750  0.00000                                 16*.5
BOX TYPE    10  /* inner canister - fuel region #10 w/ ring: lid assy
```

```
CYLINDER     1  10.8141  0.44200  0.00000                              16*.5
CYLINDER     2  10.9233  0.44200  0.00000                              16*.5
CYLINDER     2  12.4092  0.44200  0.00000                              16*.5
CYLINDER     2  12.4612  0.44200  0.00000                              16*.5
BOX TYPE    11  /* inner canister - fuel region #11 w/ top: lid assy
CYLINDER     1  10.8141  1.78050  0.00000                              16*.5
CYLINDER     2  10.9233  1.91640  0.00000                              16*.5
CYLINDER     0  12.4092  1.91640  0.00000                              16*.5
BOX TYPE    12  /* inner canister cuboid: body section (7# region)
CUBOID       5  12.7636 -12.7636  12.7636 -12.7636  73.3450  -0.5055  16*.5
BOX TYPE    13  /* inner canister cuboid: body section (40# region)
CUBOID       9  12.7636 -12.7636  12.7636 -12.7636  3.49260  0.00000  16*.5
BOX TYPE    14  /* inner canister upper cylinder: lid section
CYLINDER     0  12.7636  3.30840  0.00000                              16*.5
BOX TYPE    15  /* foam cutout (void) - 40 #/ft3 foam lid section
CYLINDER     0  13.5510  3.30840  0.00000                              16*.5
BOX TYPE    16  /* npc body or lid - 10 ga. 304ss layer
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  0.31240  0.00000  16*.5
BOX TYPE    17  /* npc body or lid - 1" duraboard (void) layer, 10 ga. 304ss
CUBOID       0  51.5163 -51.5163  51.5163 -51.5163  2.54000  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  2.54000  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  2.54000  0.00000  16*.5
BOX TYPE    18  /* npc body - 3" bot. foam layer (11 #/ft3)   *** SN002 burn
CUBOID       7  47.4777 -44.5567  45.3695 -44.4805  0.00000  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  0.00000 -7.62000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  0.00000 -7.62000  16*.5
BOX TYPE    19  /* npc body - 29.0750" foam layer (7,11 #/ft3)***SN002 burn
CUBOID       5  43.8963 -43.8963  43.8963 -43.8963  73.8505   0.0000  16*.5
CUBOID       7  47.4777 -44.5567  45.3695 -44.4805  73.8505   0.0000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  73.8505   0.0000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  73.8505   0.0000  16*.5
BOX TYPE    20  /* npc body - 1.375 " foam layer (40 #/ft3)   *** SN002 burn
CUBOID       9  47.4777 -44.5567  45.3695 -44.4805  3.49250  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  3.49250  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  3.49250  0.00000  16*.5
BOX TYPE    21  /* npc body - 30.45" two-part body
CUBOID       0  54.3687 -54.3687  54.3687 -54.3687  77.3430   0.0000  16*.5
BOX TYPE    22  /* npc lid - 1.375 " foam layer (40 #/ft3)    *** SN002 burn
CUBOID       9  47.4777 -44.5567  45.3695 -44.4805  3.49250  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  3.49250  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  3.49250  0.00000  16*.5
BOX TYPE    23  /* npc lid - 3.5" foam layer (15 #/ft3)       *** SN002 burn
CUBOID       8  47.4777 -44.5567  45.3695 -44.4805  7.62000  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  8.89000  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  8.89000  0.00000  16*.5
BOX TYPE    24  /* complete npc - body assembly
CUBOID       0  54.3688 -54.3688  54.3688 -54.3688  87.8154   0.0000  16*.5
BOX TYPE    25  /* complete npc - lid assembly
CUBOID       0  54.3688 -54.3688  54.3688 -54.3688  15.2349   0.0000  16*.5
BOX TYPE    26  /* npc single-unit cuboid
CUBOID       0  54.3688 -54.3688  54.3688 -54.3688  103.0503  0.0000  16*.5
BOX TYPE    27  /* global unit: 2N=150:5x5x6 cuboid, 30.48-cm h2o refl.
CUBOID       0  271.8440 -271.8440 271.8440 -271.8440 618.3018  0.000  16*.5
CUBOID       6  302.3240 -302.3240 302.3240 -302.3240 648.7818 -30.48  16*.5
 27   1  1  1    1  1  1    1  1  1    1
BEGIN COMPLEX
/* build inner canister - main body section (7 #/ft3 region)
COMPLEX  12  1  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  12  2  0.00000  0.00000  0.31750   1   1   1  0.0   0.0   0.0
COMPLEX  12  3  0.00000  0.00000  25.7810   1   1   1  0.0   0.0   0.0
COMPLEX  12  4  0.00000  0.00000  26.1621   1   1   1  0.0   0.0   0.0
COMPLEX  12  5  0.00000  0.00000  51.6256   1   1   1  0.0   0.0   0.0
COMPLEX  12  6  0.00000  0.00000  52.0066   1   1   1  0.0   0.0   0.0
/* build inner canister - upper body section (40 #/ft3 section)
COMPLEX  13  7  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
/* build inner canister - lid section
COMPLEX  14  8  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  14  9  0.00000  0.00000  0.63250   1   1   1  0.0   0.0   0.0
COMPLEX  14 10  0.00000  0.00000  0.95000   1   1   1  0.0   0.0   0.0
COMPLEX  14 11  0.00000  0.00000  1.39200   1   1   1  0.0   0.0   0.0
/* embed 3x3 array of canisters into lid: 11.75"-centers
COMPLEX  15 14 -29.8450 -29.8450  0.00000   3   3   1  29.8450   29.8450   0.0
/* embed 3x3 array of foam cut_outs:11.75"-centers
COMPLEX  22 15 -29.8450 -29.8450  0.00000   3   3   1  29.8450   29.8450   0.0
/* embed 3x3 array of canisters into inner body: 11.75"-centers
COMPLEX  19 12 -29.8450 -29.8450  0.50550   3   3   1  29.8450   29.8450   0.0
COMPLEX  20 13 -29.8450 -29.8450  0.00000   3   3   1  29.8450   29.8450   0.0
/* embed two-part body section stackup
COMPLEX  21 19  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  21 20  0.00000  0.00000  73.8505   1   1   1  0.0   0.0   0.0
/* build npc - body assembly
COMPLEX  24 16  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  24 17  0.00000  0.00000  0.31240   1   1   1  0.0   0.0   0.0
COMPLEX  24 18  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
COMPLEX  24 21  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
/* build npc - lid assembly
COMPLEX  25 22  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  25 23  0.00000  0.00000  3.49250   1   1   1  0.0   0.0   0.0
COMPLEX  25 17  0.00000  0.00000  12.3825   1   1   1  0.0   0.0   0.0
COMPLEX  25 16  0.00000  0.00000  14.9225   1   1   1  0.0   0.0   0.0
/* complete npc stackup - single unit
COMPLEX  26 24  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  26 25  0.00000  0.00000  87.8154   1   1   1  0.0   0.0   0.0
/* embed 5x5x6 closed packed array
COMPLEX  27 26  -217.4752 -217.4752 0.000   5 5 6 108.7376 108.7376 103.0503
END GEOM
DEFAULTS=YES
END GEMER
```

Figure 6.8d – Sample input file = npcat_60.in

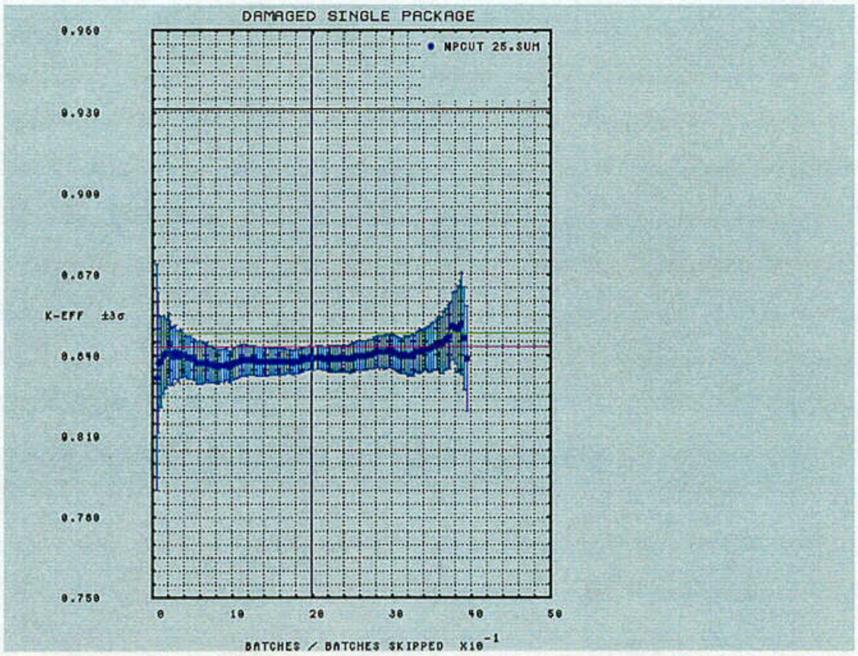
```
2000.NPC,,,,CYL,,UO2,5.00%,WTFR=VAR.,SS,,,CD,CE
/*ECHO
/*TITLE
 200 2000   10    0    0    1    0    0
   0  293    0    0
\CSXSEC\UO2\GUO2-50.285
\CSXSEC\NOU\GNOU-0.SS
\CSXSEC\NOU\GNOU-0.CAD
\CSXSEC\NOU\GNOU-0.POL 0.98
\CSXSEC\NOU\GNOU-0.F07 0.90
\CSXSEC\NOU\GNOU-0.WAT
\CSXSEC\NOU\GNOU-0.F11 0.90
\CSXSEC\NOU\GNOU-0.F15 0.90
\CSXSEC\NOU\GNOU-0.F40 0.90
\CSXSEC\NOU\GNOU-0.ORC
KENO GEOM
    0  /* # OF REGIONS OR ZERO
    0  /* # OF BOX TYPES OR ZERO
    1  /* # OF BOXES IN X DIRECTION
    1  /* # OF BOXES IN Y DIRECTION
    1  /* # OF BOXES IN Z DIRECTION
    1  /* BOUNDARY CONDITION OPTION
    1  /* STARTING SOURCE OPTION
    1  /* COMPLEX EMBEDDED OPTION
    0  /* # OF PRINT PLOTS
      0.0        0.0        0.0        0.0        0.0        0.0
BOX TYPE      1  /* inner canister: bottom fuel_region #1 w/ gap: body assy
CYLINDER      1  10.8141  0.31750  0.00000                              16*.5
CYLINDER      2  10.9233  0.31750  0.00000                              16*.5
CYLINDER      0  12.4092  0.31750  0.00000                              16*.5
CYLINDER      2  12.4092  0.31750 -0.44200                              16*.5
CYLINDER      2  12.4612  0.31750 -0.44200                              16*.5
CYLINDER      0  12.7000  0.31750 -0.44200                              16*.5
CYLINDER      2  12.7635  0.31750 -0.50550                              16*.5
BOX TYPE      2  /* inner canister: fuel_region #2: body assy
CYLINDER      1  10.8141  25.4635   0.0000                              16*.5
CYLINDER      2  10.9233  25.4635   0.0000                              16*.5
CYLINDER      3  10.9614  25.4635   0.0000                              16*.5
CYLINDER      4  12.4092  25.4635   0.0000                              16*.5
CYLINDER      2  12.4612  25.4635   0.0000                              16*.5
CYLINDER      0  12.7000  25.4635   0.0000                              16*.5
CYLINDER      2  12.7635  25.4635   0.0000                              16*.5
BOX TYPE      3  /* inner canister: fuel_region #3, 0.15" cd gap: body assy
CYLINDER      1  10.8141  0.38100  0.00000                              16*.5
CYLINDER      2  10.9233  0.38100  0.00000                              16*.5
CYLINDER      0  10.9614  0.38100  0.00000                              16*.5
CYLINDER      4  12.4092  0.38100  0.00000                              16*.5
CYLINDER      2  12.4612  0.38100  0.00000                              16*.5
CYLINDER      0  12.7000  0.38100  0.00000                              16*.5
CYLINDER      2  12.7635  0.38100  0.00000                              16*.5
BOX TYPE      4  /* inner canister: fuel_region #4: body assy
CYLINDER      1  10.8141  25.4635   0.0000                              16*.5
CYLINDER      2  10.9233  25.4635   0.0000                              16*.5
CYLINDER      3  10.9614  25.4635   0.0000                              16*.5
CYLINDER      4  12.4092  25.4635   0.0000                              16*.5
CYLINDER      2  12.4612  25.4635   0.0000                              16*.5
CYLINDER      0  12.7000  25.4635   0.0000                              16*.5
CYLINDER      2  12.7635  25.4635   0.0000                              16*.5
BOX TYPE      5  /* inner canister: fuel_region #5, 0.15" cd gap: body assy
CYLINDER      1  10.8141  0.38100  0.00000                              16*.5
CYLINDER      2  10.9233  0.38100  0.00000                              16*.5
CYLINDER      0  10.9614  0.38100  0.00000                              16*.5
CYLINDER      4  12.4092  0.38100  0.00000                              16*.5
CYLINDER      2  12.4612  0.38100  0.00000                              16*.5
CYLINDER      0  12.7000  0.38100  0.00000                              16*.5
CYLINDER      2  12.7635  0.38100  0.00000                              16*.5
BOX TYPE      6  /* inner canister: fuel region #6: body assy
CYLINDER      1  10.8141  21.3385   0.0000                              16*.5
CYLINDER      0  10.8141  21.3385   0.0000                              16*.5
CYLINDER      2  10.9233  21.3385   0.0000                              16*.5
CYLINDER      3  10.9614  21.3385   0.0000                              16*.5
CYLINDER      4  12.4092  21.3385   0.0000                              16*.5
CYLINDER      2  12.4612  21.3385   0.0000                              16*.5
CYLINDER      0  12.7000  21.3385   0.0000                              16*.5
CYLINDER      2  12.7635  21.3385   0.0000                              16*.5
BOX TYPE      7  /* inner canister: fuel region #7: body assy
CYLINDER      1  10.8141   3.4925   0.0000                              16*.5
CYLINDER      0  10.8141   3.4925   0.0000                              16*.5
CYLINDER      2  10.9233   3.4925   0.0000                              16*.5
CYLINDER      3  10.9614   3.4925   0.0000                              16*.5
CYLINDER      4  12.4092   3.4925   0.0000                              16*.5
CYLINDER      2  12.4612   3.4925   0.0000                              16*.5
CYLINDER      0  12.7000   3.4925   0.0000                              16*.5
CYLINDER      2  12.7635   3.4925   0.0000                              16*.5
BOX TYPE      8  /* inner canister - fuel region #8: lid assy
CYLINDER      1  10.8141  0.63250  0.00000                              16*.5
CYLINDER      0  10.8141  0.63250  0.00000                              16*.5
CYLINDER      2  10.9233  0.63250  0.00000                              16*.5
CYLINDER      3  10.9614  0.63250  0.00000                              16*.5
CYLINDER      4  12.4092  0.63250  0.00000                              16*.5
CYLINDER      2  12.4612  0.63250  0.00000                              16*.5
CYLINDER      0  12.7000  0.63250  0.00000                              16*.5
CYLINDER      2  12.7635  0.63250  0.00000                              16*.5
BOX TYPE      9  /* inner canister - fuel region #9 w/ gap: lid assy
CYLINDER      1  10.8141  0.31750  0.00000                              16*.5
CYLINDER      2  10.9233  0.31750  0.00000                              16*.5
CYLINDER      0  12.4092  0.31750  0.00000                              16*.5
CYLINDER      2  12.4612  0.31750  0.00000                              16*.5
BOX TYPE     10  /* inner canister - fuel region #10 w/ ring: lid assy
```

```
CYLINDER     1  10.8141  0.44200  0.00000                           16*.5
CYLINDER     2  10.9233  0.44200  0.00000                           16*.5
CYLINDER     2  12.4092  0.44200  0.00000                           16*.5
CYLINDER     2  12.4612  0.44200  0.00000                           16*.5
BOX TYPE    11  /* inner canister - fuel region #11 w/ top: lid assy
CYLINDER     1  10.8141  1.78050  0.00000                           16*.5
CYLINDER     2  10.9233  1.91640  0.00000                           16*.5
CYLINDER     0  12.4092  1.91640  0.00000                           16*.5
BOX TYPE    12  /* inner canister cuboid: body section (7# region)
CUBOID       5  12.7636 -12.7636  12.7636 -12.7636  73.3450  -0.5055  16*.5
BOX TYPE    13  /* inner canister cuboid: body section (40# region)
CUBOID       9  12.7636 -12.7636  12.7636 -12.7636  3.49260  0.00000  16*.5
BOX TYPE    14  /* inner canister upper cylinder: lid section
CYLINDER     0  12.7636  3.30840  0.00000                           16*.5
BOX TYPE    15  /* foam cutout (void) - 40 #/ft3 foam lid section
CYLINDER     0  13.5510  3.30840  0.00000                           16*.5
BOX TYPE    16  /* npc body or lid - 10 ga. 304ss layer
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  0.31240  0.00000  16*.5
BOX TYPE    17  /* npc body or lid - 1" duraboard (void) layer, 10 ga. 304ss
CUBOID       0  51.5163 -51.5163  51.5163 -51.5163  2.54000  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  2.54000  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  2.54000  0.00000  16*.5
BOX TYPE    18  /* npc body - 4" bot. foam layer (11 #/ft3)     - face burn
CUBOID       7  42.6086 -42.6086  42.6086 -42.6086  0.00000  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  0.00000 -7.62000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  0.00000 -7.62000  16*.5
BOX TYPE    19  /* npc body - 29.0750" foam layer (7,11 #/ft3) - face burn
CUBOID       5  42.6086 -42.6086  42.6086 -42.6086  73.8505   0.0000  16*.5
CUBOID       7  42.6086 -42.6086  42.6086 -42.6086  73.8505   0.0000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  73.8505   0.0000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  73.8505   0.0000  16*.5
BOX TYPE    20  /* npc body - 1.375 " foam layer (40 #/ft3)     - face burn
CUBOID       9  42.6086 -42.6086  42.6086 -42.6086  3.49250  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  3.49250  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  3.49250  0.00000  16*.5
BOX TYPE    21  /* npc body - 30.45" two-part body
CUBOID       0  54.3687 -54.3687  54.3687 -54.3687  77.3430   0.0000  16*.5
BOX TYPE    22  /* npc lid - 1.375 " foam layer (40 #/ft3)  - lid burn
CUBOID       0  43.8963 -43.8963  43.8963 -43.8963  3.49250  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  3.49250  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  3.49250  0.00000  16*.5
BOX TYPE    23  /* npc lid - 3.5" foam layer (15 #/ft3)     - lid burn
CUBOID       0  43.8963 -43.8963  43.8963 -43.8963  2.54000  0.00000  16*.5
CUBOID       0  54.0563 -54.0563  54.0563 -54.0563  8.89000  0.00000  16*.5
CUBOID       2  54.3687 -54.3687  54.3687 -54.3687  8.89000  0.00000  16*.5
BOX TYPE    24  /* complete npc - body assembly
CUBOID       0  54.3688 -54.3688  54.3688 -54.3688  87.8154   0.0000  16*.5
BOX TYPE    25  /* complete npc - lid assembly
CUBOID       0  54.3688 -54.3688  54.3688 -54.3688  15.2349   0.0000  16*.5
BOX TYPE    26  /* npc single-unit cuboid
CUBOID       0  54.3688 -54.3688  54.3688 -54.3688  103.0503  0.0000  16*.5
BOX TYPE    27  /* global unit: 2N=150:5x5x6 cuboid, 30.48-cm h2o refl.
CUBOID       0  271.8440 -271.8440 271.8440 -271.8440 618.3018  0.000  16*.5
CUBOID       6  302.3240 -302.3240 302.3240 -302.3240 648.7818 -30.48  16*.5
 27   1  1  1    1  1  1    1  1  1   1
BEGIN COMPLEX
/* build inner canister - main body section (7 #/ft3 region)
COMPLEX  12  1  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  12  2  0.00000  0.00000  0.31750   1   1   1  0.0   0.0   0.0
COMPLEX  12  3  0.00000  0.00000  25.7810   1   1   1  0.0   0.0   0.0
COMPLEX  12  4  0.00000  0.00000  26.1621   1   1   1  0.0   0.0   0.0
COMPLEX  12  5  0.00000  0.00000  51.6256   1   1   1  0.0   0.0   0.0
COMPLEX  12  6  0.00000  0.00000  52.0066   1   1   1  0.0   0.0   0.0
/* build inner canister - upper body section (40 #/ft3 section)
COMPLEX  13  7  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
/* build inner canister - lid section
COMPLEX  14  8  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  14  9  0.00000  0.00000  0.63250   1   1   1  0.0   0.0   0.0
COMPLEX  14 10  0.00000  0.00000  0.95000   1   1   1  0.0   0.0   0.0
COMPLEX  14 11  0.00000  0.00000  1.39200   1   1   1  0.0   0.0   0.0
/* embed 3x3 array of canisters into lid: 11.75"-centers
COMPLEX  15 14 -29.8450 -29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of foam cut_outs:11.75"-centers
COMPLEX  22 15 -29.8450 -29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed 3x3 array of canisters into inner body: 11.75"-centers
COMPLEX  19 12 -29.8450 -29.8450  0.50550   3   3   1  29.8450  29.8450  0.0
COMPLEX  20 13 -29.8450 -29.8450  0.00000   3   3   1  29.8450  29.8450  0.0
/* embed two-part body section stackup
COMPLEX  21 19  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  21 20  0.00000  0.00000  73.8505   1   1   1  0.0   0.0   0.0
/* build npc - body assembly
COMPLEX  24 16  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  24 17  0.00000  0.00000  0.31240   1   1   1  0.0   0.0   0.0
COMPLEX  24 18  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
COMPLEX  24 21  0.00000  0.00000  10.4724   1   1   1  0.0   0.0   0.0
/* build npc - lid assembly
COMPLEX  25 22  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  25 23  0.00000  0.00000  3.49250   1   1   1  0.0   0.0   0.0
COMPLEX  25 17  0.00000  0.00000  12.3825   1   1   1  0.0   0.0   0.0
COMPLEX  25 16  0.00000  0.00000  14.9225   1   1   1  0.0   0.0   0.0
/* complete npc stackup - single unit
COMPLEX  26 24  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
COMPLEX  26 25  0.00000  0.00000  87.8154   1   1   1  0.0   0.0   0.0
/* embed 5x5x6 closed packed array
COMPLEX  27 26  -217.4752 -217.4752 0.000   5 5 6 108.7376 108.7376 103.0503
END GEOM
DEFAULTS=YES
END GEMER
```

6.4.4 CONVERGENCE OF CALCULATION

Problem convergence was determined by examining plots of k_{eff} by generation run and skipped, as well as the final k_{eff} edit tables. No abnormal trends were observed to indicate non-convergence of the eigenvalue solution. Representative convergence plots for the individual damaged single package, undamaged array, and damaged array models are shown in Figures 6.9a- 6.9d.

Figure 6.9a – Sample k_{eff} convergence: damaged unit – npcut_25.in



C73

Figure 6.9b – Sample k_{eff} convergence: undamaged array - npc6um60.in

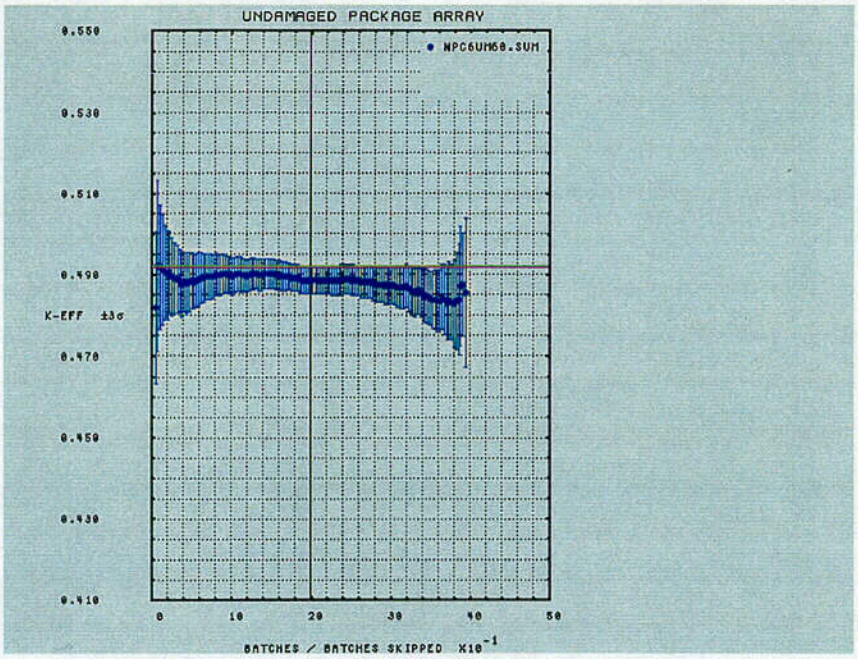
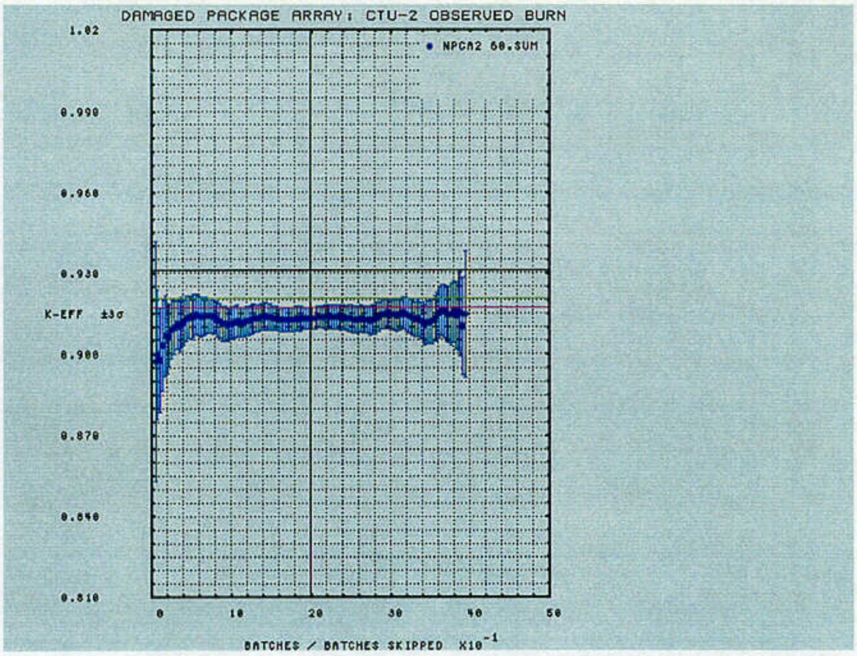
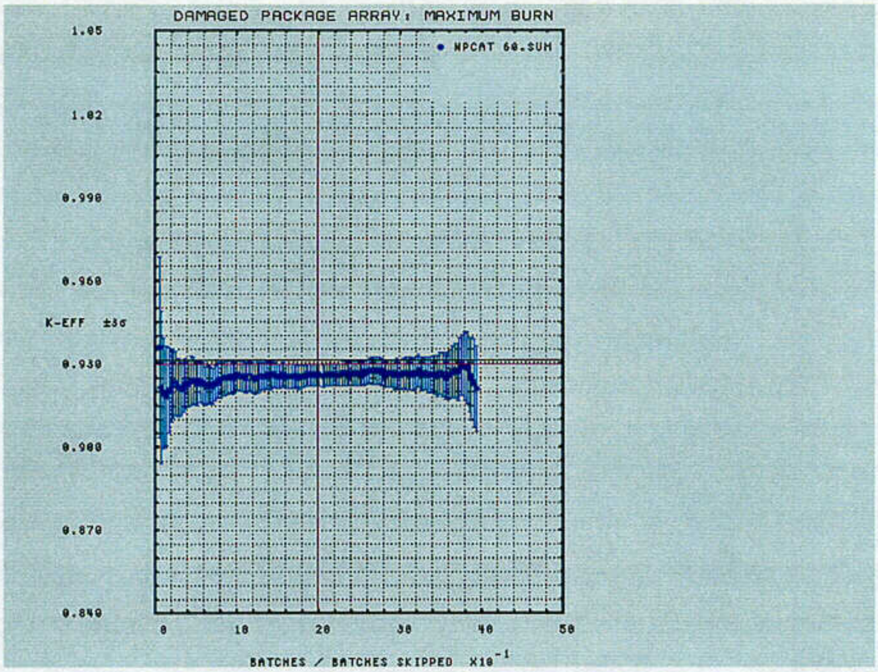


Figure 6.9c – Sample k_{eff} convergence: damaged array – npca2_60.in (CTU-2 observed burn)



C74

Figure 6.9d – Sample k_{eff} convergence: damaged array - npcat_60.in (maximum burn)



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6.5 VALIDATION

The following general relationship for establishing the acceptance criteria for the NPC package (Ref. 4).

$$k_c - \Delta k_u \geq k_{eff} + 2\sigma + \Delta k_m$$

where,

k_c = mean value of *keff* resulting from calculation of benchmark critical experiments
Δk_u = an allowance for the calculational uncertainty
Δk_m = a required margin of subcriticality (0.05 used)
k_{eff} = the calculated value obtained for the package or array of packages
σ = is the standard deviation of the keff value obtain with Monte Carlo analysis

If the calculational bias $\beta = k_c - 1$, the bias is negative if $k_c < 1$, and positive if $k_c > 1$. Thus, the acceptance criteria may be rewritten as,

$$1.00 + \beta - \Delta k_u \geq k_{eff} + 2\sigma + 0.05$$

or

$$k_{eff} + 2\sigma \leq 0.95 - \Delta k_u + \beta.$$

Validation of GEMER consists of performing calculation of benchmark experiments including the area of applicable to the uranium oxides. Bias for GEMER and the ENDF/B-IV library has been established for the area of applicability for the NPC package (refer Appendix). The uranium oxide bias determined is no greater than 0.009 $(\Delta k_u - \beta)$ at a 99% confidence level (Ref. 2). The uranium oxide bias with cadmium is no greater than 0.01888 $(\Delta k_u - \beta)$ at a 95% confidence level (refer Appendix 6.8, Validation of GEMER).

The area of applicability for the uranium oxide benchmark calculations are enrichment ranges from 1.29 to 9.83 weight percent U-235 and H/U-235 ratio 41 to 866. The area of applicability for the uranium oxide with cadmium benchmark calculations are enrichment ranges from 2.35 to 4.98 weight percent U-235 and H/U-235 ratio 260-488.

Using the above general equation for the upper safety limit (USL) and requirements of 10 CFR 71, calculations are considered subcritical, if the following condition is satisfied:

$$k_{eff} + 2\sigma \leq 0.95 - \Delta k_u + \beta$$

For this evaluation, the NPC package and it contents are considered subcritical if the following condition is satisfied:

$$k_{eff} + 2\sigma \leq 0.931$$

6.6 CRITICALITY CALCULATIONS AND RESULTS

This evaluation demonstrates the subcriticality of a single package (Section 6.6.1) and an array of packages (Section 6.6.2) during normal conditions of transport and hypothetical accident conditions. The determined Transport Index (TI) for criticality control of damaged and undamaged shipment is given in Section 6.6.3, *Transport Index.*

All calculations were performed at the maximum allowable U-235 enrichment (5.00 wt %) to ensure maximum reactivity, and summarized in Table 6.8.

6.6.1 SINGLE PACKAGE

Calculations show that a single package remains subcritical under general requirements for fissile material packages, under both normal conditions of transport, and under hypothetical accident conditions. To meet the general requirements for fissile material package, a package must be designed and its contents so limited, that it would be subcritical under the most reactive configuration of material, optimum moderation, and close reflection of the containment system by water on all sides or surrounding materials of the packaging.

6.6.1.1 Damaged Single Package

Figure 6.10 shows the reactivity of a damaged single package for CTU-1, CTU-2, and maximum observed foam burn conditions. A third order regression fit of the Keff $\pm 2\sigma$ results are shown for each fit. The figure demonstrate the damaged single package remains subcritical under the most reactive configuration of material, optimum moderation, and close reflection of the containment system by water on all sides or surrounding materials of the packaging. The damaged single package is demonstrated to be a favorable geometry unit. The limiting condition occurs for the maximum foam burn condition.

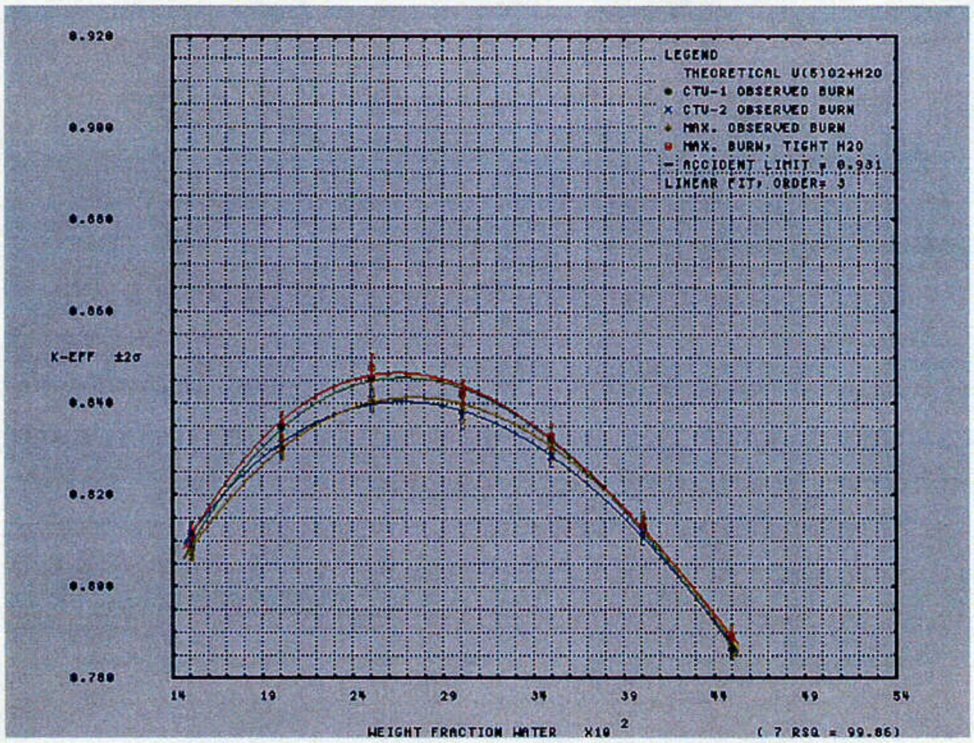
The effect of replacing the void (burn region) with full density water is also demonstrated to have a small effect for the damaged single package. This is expected due to optimal internal fuel moderation treatment and close proximity of the water reflector.

From Table 6.8, the maximum calculated $k_{eff} + 2\sigma$ - bias results for the damaged single package are:

FILENAME	K-EFF	SIGMA	K+2S	BIAS	K+2S-B	# HIST	LOST	DATE
npcu1_25	0.8452	0.0013	0.8478	-.0189	0.8666	380000	572	10/20/00
npcu2_25	0.8407	0.0013	0.8433	-.0189	0.8622	380000	572	10/20/00
npcut_25	0.8405	0.0014	0.8432	-.0189	0.8621	380000	493	10/20/00
npcutw25	0.8476	0.0015	0.8506	-.0189	0.8694	380000	158	10/20/00

In these cases, homogeneous theoretical UO_2 (max. density = 10.96) of unlimited mass remains subcritical under optimum moderation. The reactivity of the single package system depends the effectiveness of the fuel in competing with other materials, such as the cadmium, hydrogen, stainless steel or water reflector, for absorption of thermal neutrons.

Figure 6.10 – NPC damaged single package results



6.6.2 PACKAGE ARRAYS

Calculations show that an undamaged package array remains subcritical under general requirements for fissile material packages, for normal conditions of transport, and under hypothetical accident conditions. To meet the general requirements for fissile material packages, a fissile material package must be controlled to assure that an array of packages remains subcritical.

To enable this control, the designer shall derive a number "N" based on all of the following conditions being satisfied, assuming packages are stacked together in any arrangement and with close full reflection on all sides of the array by water such that: (a) 5N undamaged packages with nothing between the packages would be subcritical; (b) 2N damaged packages, if each package were subjected to tests specified in 10 CFR §71.73 would be subcritical with optimum interspersed hydrogenous moderation.

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6.6.2.1 Undamaged Package Array

Figure 6.11 demonstrates an undamaged NPC package array of unlimited size ($5N = \infty$) remains subcritical provided the UO_2 equivalent payload is restricted to 60 kgs per ICCA. Both the fuel mixture conditions described in section 6.3.1.4, *Materials*, Table 6.5, are evaluated. In both conditions, a third order regression fit of the Keff $\pm$ 2σ results are plotted as a function of UO_2 compound density (up to the maximum credible powder density). The 60 kgs UO_2 fuel containing 5% added H_2O is slightly more reactive than the 60 kg mixture of UO_2 + 5% H_2O.

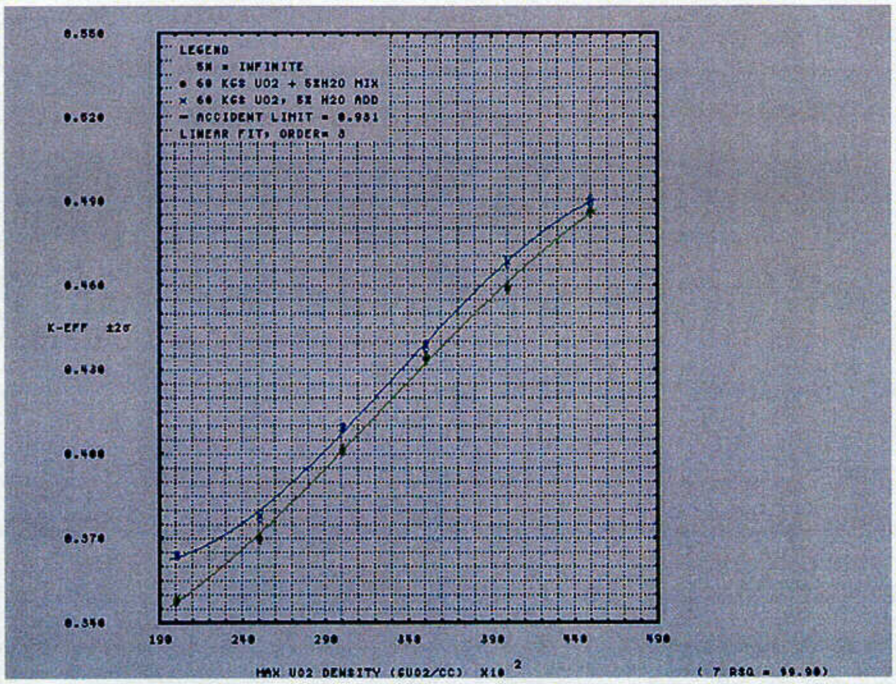
The reactivity of the undamaged package array shows an almost linear dependence on compound density. However, the reactivity of an infinitely sized undamaged package system remains very low due to the under-moderated (dry) condition of the UO_2 equivalent fuel region.

From Table 6.8, the maximum calculated $k_{eff} + 2\sigma$ - bias results for the undamaged package array are:

FILENAME	K-EFF	SIGMA	K+2S	BIAS	K+2S-B	# HIST	LOST	DATE
npc6un60	0.4863	0.0009	0.4882	-.0189	0.5071	380000	600	10/20/00
npc6um60	0.4899	0.0011	0.4920	-.0189	0.5109	380000	715	10/20/00

Therefore, under normal conditions of transport, the UO_2 equivalent product shall contain not more than 5% H_2O water equivalent moderation. Each NPC ICCA is restricted to not greater than 60 kgs UO_2 equivalent, for a total package payload of 9x60 = 540 kgs UO_2 equivalent.

Figure 6.11 – NPC undamaged package array K*eff* vs. UO_2 density



C77

6.6.2.2 Damaged Package Array

Figure 6.12 demonstrates a damaged NPC package array of size 5x5x6 (2N = 150) remains subcritical under CTU-1, CTU-2 observed non-uniform foam burn conditions. This figure also demonstrates the damaged package array remains subcritical under maximum foam burn conditions. A third order regression fit of the $k_{eff} \pm 2\sigma$ results are plotted as a function of ICCA payload.

The reactivity of the damaged package array depends on the effectiveness of the fuel in competing with other materials, such as the cadmium, hydrogen, stainless steel or water reflector for absorption of thermal neutrons. For damaged package array conditions, the amount of interstitial foam between packages becomes important to creating the required thermal spectrum necessary for effective thermal capture by cadmium.

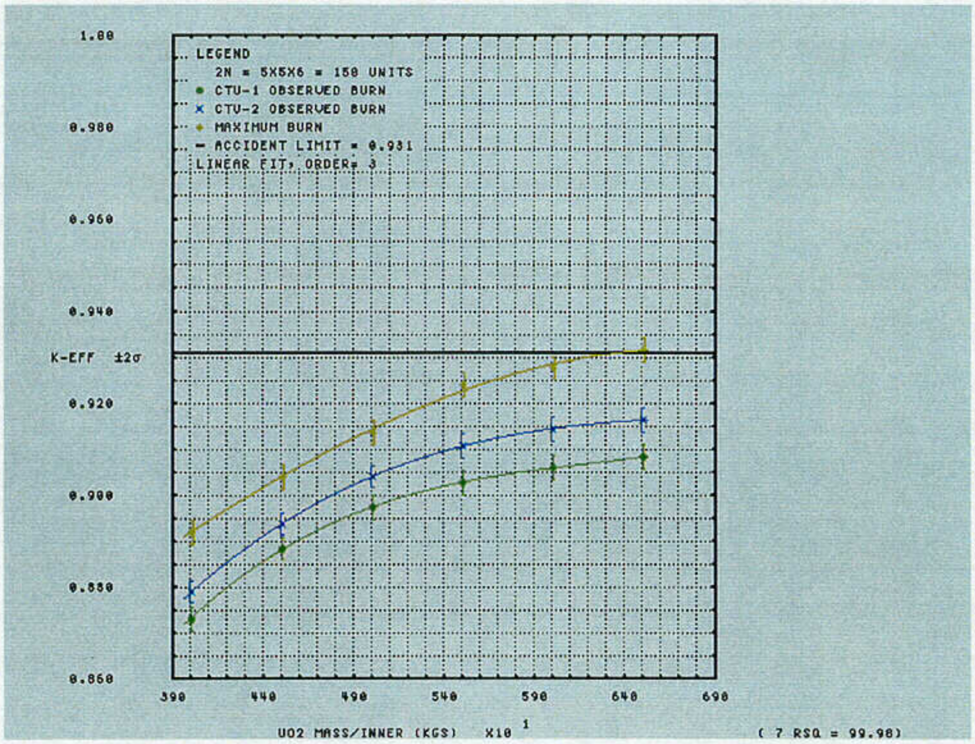
The UO_2 payload is varied from 40 - 65 kgs UO_2 equivalent per ICCA (360 – 585 kgs UO_2 per NPC package). In these damaged package array cases, the system becomes mass and geometry limited. The ICCA spacing is modeled at 11.75" (29.845 cm), while the nominal spacing between ICCAs is 12.00" (30.48 cm). All damaged package array models remain below the accident limit $k_{eff,USL} = 0.931$ for up to 60 kgs UO_2 per ICCA.

From Table 6.8, the maximum calculated $k_{eff} + 2\sigma$ - bias results for the undamaged package array at 60 kgs UO2 per ICCA are:

FILENAME	K-EFF	SIGMA	K+2S	BIAS	K+2S-B	# HIST	LOST	DATE
npca1_60	0.9059	0.0013	0.9084	-.0189	0.9273	380000	750	10/20/00
npca2_60	0.9141	0.0013	0.9167	-.0189	0.9356	380000	743	10/21/00
npcat_60	0.9275	0.0012	0.9299	-.0189	0.9488	380000	798	10/25/00

As expected, the maximum burn condition is demonstrated the most reactive damaged package array model, though the interstitial 7-lb/ft^3 foam region between ICCAs and the 0.570-inch polyethylene are sufficient to maintain the damaged package array subcritical (e.g., $k_{eff} + 2\sigma$ - bias < 0.95).

Figure 6.12 – NPC damaged package array k_{eff} vs. UO_2 mass per canister (CTU-1, CTU-2, and maximum observed foam burn conditions)



6.6.2.3 Sensitivity Study - Damaged Package Array Shape

As described in section 6.3.4.2, cases were run to confirm the most reactive aspect ratio of the damaged package array shape. The standard near cubic 5x5x6 array (case npcat_60.in) is confirmed representative of the most reactive configuration relative to the 6x5x5 (case npcatv60.in) and the 9x9x2 array (case npcatw60.in) for equivalent package payload and foam burn conditions. Though it is noted that there is little statistical difference between the 5x5x6 and 6x5x5 damaged package array models. From summary Table 6.8, the maximum calculated $k_{eff} + 2\sigma$ - bias results for the damaged package array shape study (60 kgs UO_2 per ICCA) are:

FILENAME	K-EFF	SIGMA	K+2S	BIAS	K+2S-B	# HIST	LOST	DATE
npcat_60	0.9275	0.0012	0.9299	-.0189	0.9488	380000	798	10/25/00
npcatv60	0.9274	0.0012	0.9298	-.0189	0.9487	380000	766	10/23/00
npcatw60	0.9132	0.0012	0.9156	-.0189	0.9345	380000	695	10/23/00

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6.6.2.4 Sensitivity Study - Damaged Package Array Moderator Content and Payload

As described in section 6.3.1.4, Materials, Table 6.6, cases were also run to confirm the most reactive damaged package array internal ICCA moderation condition. Lower weight fraction water cases were run to confirm the most reactive condition occurs when the mixture height for this mass just fills the internal volume of the ICCA. From summary Table 6.8, the results are:

FILENAME	K-EFF	SIGMA	K+2S	BIAS	K+2S-B	# HIST	LOST	DATE	
npcatx60	0.8102	0.0013	0.8128	-.0189	0.8317	380000	778	10/24/00	(wf_h2o=0.15)
npcaty60	0.8671	0.0013	0.8697	-.0189	0.8886	380000	258	10/24/00	(wf_h2o=0.20)
npcatz60	0.9081	0.0014	0.9108	-.0189	0.9297	380000	603	10/24/00	(wf_h2o=0.25)
npcat_60	0.9275	0.0012	0.9299	-.0189	0.9488	380000	798	10/25/00	(wf_h2o=0.28504)

The above results confirm the most reactive condition occurs when the mixture height just fills the ICCA volume (limiting damaged array case npcat_60.in, wtfr. H_2O = 0.28504).

If additional water is added such that UO_2 mass is driven out of the ICCA, Figure 6.12 above demonstrates system reactivity will decrease. These results support the fact that any UO2 payload distribution is acceptable provided the maximum mass in any one of the nine ICCAs does not exceed 60 kgs UO2 (52.9 kgs U). Relative to 60 kgs UO2, by lowering the UO2 payload in any ICCA would result in a less reactive damaged package array.

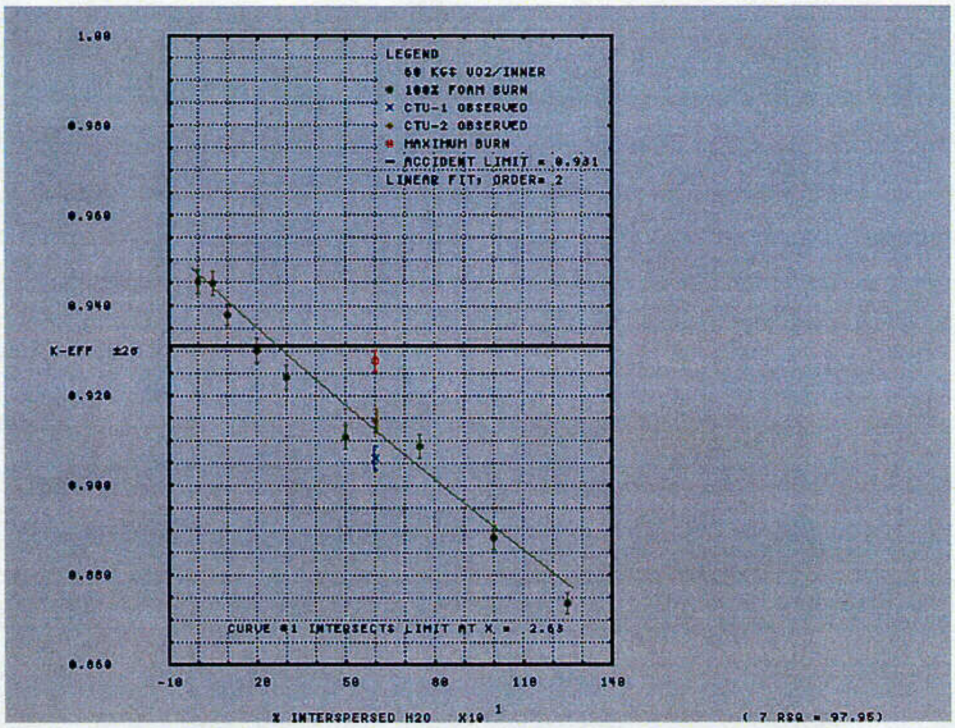
6.6.2.5 Sensitivity Study - Damaged Package Array 100% Foam Burn

Figure 6.13 determines the worth of the foam for the limiting damaged package array determined in Section 6.6.2, Package Arrays. In this figure, 100% internal foam burn is assumed, and replaced with variable density H_2O. The figure shows the void condition is the most reactive, and the damaged package array becomes safe ($k_{eff} + 2\sigma$ - bias < 0.931) when the interspersed hydrogenous reaches ~ 2.63% water equivalent (or greater).

The 60 kg UO_2 per ICCA damaged package array results for CTU-1, CTU-2, and maximum burn models are provided in Figure 6.13 for comparison purposes. The 6% hydrogen content in the inner 7-lb/ft^3-foam region is demonstrated sufficient to maintain the damaged package subcritical. In general, increasing hydrogen content between packages reduces the reactivity of the NPC damaged package containing optimally moderated UO_2 canisters. The damaged package therefore exhibits an over-moderated behavior.

This is substantiated by the fact that package reactivity increases as the foam burn depth (see Figure 6.12 above) is increased to its maximum observed condition. This effect also underscores the use of void for the ceramic fiberboard around the periphery, and the use of void for the postulated burn regions instead of low interspersed water moderation.

Figure 6.13 – NPC damaged package array k_{eff} vs. interspersed H_2O (100% foam burn condition)



6.6.2.6 Sensitivity Study - Damaged Package Array ICCA Spacing

Figure 6.14 demonstrates the damaged package reactivity behavior as a function of ICCA spacing. A second-order regression fit of the K ± 2σ results is shown. The 60 kg UO_2 per ICCA payload, maximum burn model is used as the basis for the center-to-center canister spacing study.

This figure demonstrates little sensitivity from movement of the ICCA from the standard center-to-center spacing of 11.75” (29.845 cm) to 11.25” (28.575 cm). Therefore, the 11.75” standard spacing is sufficiently conservative representation of the nominal ICCA spacing of 12” (30.48 cm). The reactivity of the damaged package array is not adversely affected by ICCA center-to center movement of up to ¾”.

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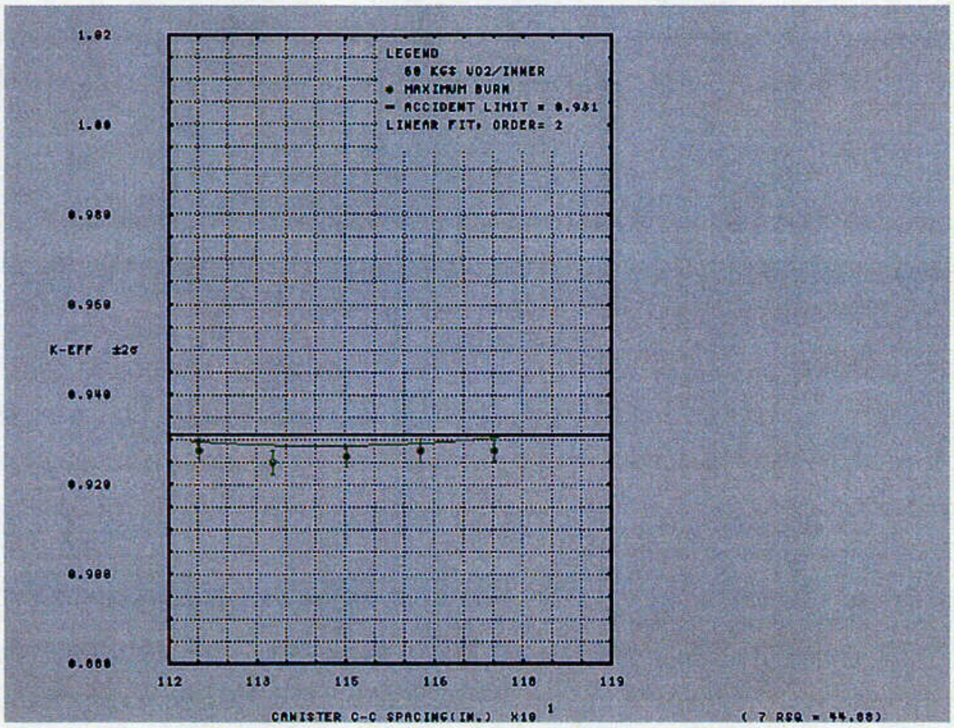
Figure 6.14 – NPC damaged package array k_{eff} vs. canister spacing



6.6.2.7 Sensitivity Study - Damaged Package Array Structure

The effect of adding certain external 304L stainless steel structure into the limiting condition model is made to determine effect package reactivity. In particular the bottom of each NPC package is comprised of eight (8) 6x3x3/16" rectangular tubes, four (4) 6x1-1/2x19.25" connecting channels, and a 16-ga. 18x18" square doubler plate. A conservative estimate that includes maximum manufacturing tolerance of this structure mass associated is determined to be 40.8 kgs.

If this mass of 40.8 kgs is then "smeared" over the bottom layer of the package, an additional thickness of 0.4365 cm may be included in the modeled bottom plate thickness [e.g., δh = mass_ss/(rho_ss*l*w) = 40,800/(7.9*108.7743*108.7743) = 0.4365 cm]. The reactivity comparison is made for the limiting damaged package array case using the acceptable 60 kg UO_2 per ICCA. From Table 6.8, the result is:

FILENAME	K-EFF	SIGMA	K+2S	BIAS	K+2S-B	# HIST	LOST	DATE
npcat_60	0.9275	0.0012	0.9299	-.0189	0.9488	380000	798	10/25/00
npcats60	0.9240	0.0012	0.9264	-.0189	0.9453	380000	2776	10/27/00

Relative to the limiting damaged package array model (npcat_60), the additional external Type 304L stainless steel (npcats60.in) structure on the bottom of the package results in a ~0.4% delta-k/k reactivity reduction.

6.6.2.8 Sensitivity Study - Damaged Package Array Poly Gap

The effect of polyethylene gap as determined from the physical measurements of the ICCAs post HAC testing is assessed to confirm the modeled poly height and density assumptions.

In the first case (npcatg60.in), the modeled polyethylene height of is reduced by 75 mils to the minimum specified height of 30.3" (the density remains constant at 0.92*0.98 to offset the 0.6 wt% maximum observed poly weight loss under accident conditions). No statistical change in reactivity relative to the limiting condition damaged package array model (npcat_60.in) resulted.

In the second case (npcatf60.in), the modeled polyethylene height surrounding all 9 ICCAs is reduced to correspond to the maximum observed gap conditions post HAC testing. The cumulative gap at the top plus bottom of the polyethylene wrap was measured for all ICCAs in CTU-1 and CTU-2. Maximum gap measurements for CTU-1 and CTU-2 test units are reported in Sections 2.10.1.7.1.6 and 2.10.1.7.2.6, respectively.

The maximum observed total gap was 0.40" top + 0.29" bottom = 0.69" and reported in certification test results Section 2.10.1.2, Summary. For this study, the top gap was increase from 1/8" (0.3175 cm) to its maximum of 0.4" (1.016 cm). The bottom gap was increased from 1/8" (0.3175 cm) to its maximum of 0.29" (0.7366 cm). Since the gap is explicitly modeled, the poly density of 0.92 g/cc is applied. Again, no statistical change in reactivity relative to the limiting condition damaged package array model resulted.

From Table 6.8, reactivity comparisons are as follows:

FILENAME	K-EFF	SIGMA	K+2S	BIAS	K+2S-B	# HIST	LOST	DATE
npcat_60	0.9275	0.0012	0.9299	-.0189	0.9488	380000	798	10/25/00
npcatg60	0.9271	0.0012	0.9296	-.0189	0.9484	380000	797	10/30/00
npcatf60	0.9273	0.0013	0.9299	-.0189	0.9488	380000	801	10/30/00

These results support the assumption that the 2% polyethylene density reduction factor applied to the damaged package array models are conservative and adequately address the observed polyethylene weight loss and model height.

Table 6.8 provides a summary listing of all calculations made for the NPC package criticality safety demonstration.

Table 6.8 – NPC Calculated *Keff* Summary

Limit = 0.9500

npc calculation summary

FILENAME	K-EFF	SIGMA	K+2S	BIAS	K+2S-B	# HIST	LOST	DATE
damaged single unit, CTU-1 observed burn, theoretical uo2+h2o mixture								
npcu1_15	0.8085	0.0014	0.8113	-.0189	0.8301	380000	552	10/20/00
npcu1_20	0.8344	0.0013	0.8370	-.0189	0.8558	380000	522	10/20/00
npcu1_25	0.8452	0.0013	0.8478	-.0189	0.8666	380000	572	10/20/00
npcu1_30	0.8416	0.0013	0.8443	-.0189	0.8632	380000	524	10/20/00
npcu1_35	0.8318	0.0014	0.8346	-.0189	0.8535	380000	535	10/20/00
npcu1_40	0.8126	0.0012	0.8151	-.0189	0.8339	380000	519	10/20/00
npcu1_45	0.7860	0.0012	0.7884	-.0189	0.8073	380000	504	10/20/00
damaged single unit, CTU-1 observed burn, theoretical uo2+h2o mixture								
npcu2_15	0.8112	0.0013	0.8139	-.0189	0.8328	380000	606	10/24/00
npcu2_20	0.8307	0.0014	0.8336	-.0189	0.8525	380000	576	10/20/00
npcu2_25	0.8407	0.0013	0.8433	-.0189	0.8622	380000	572	10/20/00
npcu2_30	0.8369	0.0014	0.8397	-.0189	0.8586	380000	574	10/20/00
npcu2_35	0.8280	0.0012	0.8305	-.0189	0.8494	380000	582	10/20/00
npcu2_40	0.8115	0.0014	0.8142	-.0189	0.8331	380000	477	10/20/00
npcu2_45	0.7866	0.0013	0.7893	-.0189	0.8082	380000	537	10/20/00
damaged single unit, maximum burn, theoretical uo2+h2o mixture								
npcut_15	0.8078	0.0012	0.8103	-.0189	0.8292	380000	570	10/20/00
npcut_20	0.8301	0.0014	0.8328	-.0189	0.8517	380000	481	10/20/00
npcut_25	0.8405	0.0014	0.8432	-.0189	0.8621	380000	493	10/20/00
npcut_30	0.8386	0.0015	0.8416	-.0189	0.8605	380000	488	10/20/00
npcut_35	0.8302	0.0014	0.8329	-.0189	0.8518	380000	499	10/20/00
npcut_40	0.8134	0.0014	0.8162	-.0189	0.8351	380000	528	10/20/00
npcut_45	0.7872	0.0013	0.7898	-.0189	0.8087	380000	510	10/20/00
damaged single unit, maximum burn, theoretical uo2+h2o mixture, tight h2o								
npcutw15	0.8110	0.0013	0.8136	-.0189	0.8325	380000	170	10/20/00
npcutw20	0.8349	0.0015	0.8379	-.0189	0.8568	380000	169	10/20/00
npcutw25	0.8476	0.0015	0.8506	-.0189	0.8694	380000	158	10/20/00
npcutw30	0.8420	0.0014	0.8448	-.0189	0.8636	380000	147	10/20/00
npcutw35	0.8324	0.0013	0.8349	-.0189	0.8538	380000	167	10/20/00
npcutw40	0.8127	0.0012	0.8151	-.0189	0.8340	380000	167	10/20/00
npcutw45	0.7887	0.0013	0.7912	-.0189	0.8101	380000	128	10/20/00
undamaged array, 5N = infinite (60 kgs uo2 + 5% h2o mixture)								
npc1un60	0.3476	0.0008	0.3491	-.0189	0.3680	380000	1907	10/20/00
npc2un60	0.3699	0.0009	0.3717	-.0189	0.3906	380000	597	10/20/00
npc3un60	0.4013	0.0009	0.4032	-.0189	0.4220	380000	250	10/20/00
npc4un60	0.4339	0.0010	0.4359	-.0189	0.4548	380000	1083	10/20/00
npc5un60	0.4588	0.0010	0.4608	-.0189	0.4797	380000	872	10/20/00
npc6un60	0.4863	0.0009	0.4882	-.0189	0.5071	380000	600	10/20/00
undamaged array, 5N = infinite (60 kgs uo2 compound, 5% h2o added)								
npc1um60	0.3636	0.0008	0.3652	-.0189	0.3841	380000	2065	10/20/00
npc2um60	0.3778	0.0009	0.3795	-.0189	0.3984	380000	777	10/20/00
npc3um60	0.4094	0.0009	0.4111	-.0189	0.4300	380000	330	10/20/00
npc4um60	0.4384	0.0009	0.4403	-.0189	0.4592	380000	1194	10/20/00
npc5um60	0.4683	0.0010	0.4703	-.0189	0.4892	380000	979	10/20/00
npc6um60	0.4899	0.0011	0.4920	-.0189	0.5109	380000	715	10/20/00
damaged 5x5x6 array (2N = 150), CTU-1 observed burn, uo2 mass/ICCA								
npca1_40	0.8730	0.0013	0.8756	-.0189	0.8945	380000	689	10/20/00
npca1_50	0.8970	0.0013	0.8997	-.0189	0.9185	380000	720	10/20/00
npca1_55	0.9026	0.0013	0.9052	-.0189	0.9241	380000	701	10/20/00
npca1_60	0.9059	0.0013	0.9084	-.0189	0.9273	380000	750	10/20/00
npca1_65	0.9081	0.0013	0.9106	-.0189	0.9295	380000	703	10/20/00

```
damaged 5x5x6 array (2N = 150), CTU-2 observed burn, uo2 mass/ICCA
npca2_40  0.8787  0.0011  0.8809  -.0189  0.8998  380000   734  10/20/00
npca2_45  0.8933  0.0012  0.8958  -.0189  0.9147  380000   751  10/21/00
npca2_50  0.9039  0.0012  0.9063  -.0189  0.9252  380000   767  10/21/00
npca2_55  0.9106  0.0014  0.9133  -.0189  0.9322  380000   726  10/21/00
npca2_60  0.9141  0.0013  0.9167  -.0189  0.9356  380000   743  10/21/00
npca2_65  0.9162  0.0013  0.9189  -.0189  0.9377  380000   778  10/21/00

damaged 5x5x6 array (2N = 150), maximum burn, uo2 mass/ICCA
npcat_40  0.8920  0.0013  0.8946  -.0189  0.9135  380000   773  10/24/00
npcat_45  0.9040  0.0013  0.9065  -.0189  0.9254  380000   749  10/25/00
npcat_50  0.9135  0.0014  0.9162  -.0189  0.9351  380000   703  10/25/00
npcat_55  0.9237  0.0013  0.9263  -.0189  0.9452  380000   828  10/25/00
npcat_60  0.9275  0.0012  0.9299  -.0189  0.9488  380000   798  10/25/00
npcat_65  0.9316  0.0013  0.9342  -.0189**0.9531**380000   795  10/25/00

damaged 5x5x6 array (2N = 150), max.burn, var. h2o content (60 kgs UO2/ICCA)
npcatx60  0.8102  0.0013  0.8128  -.0189  0.8317  380000   778  10/24/00
npcaty60  0.8671  0.0013  0.8697  -.0189  0.8886  380000   258  10/24/00
npcatz60  0.9081  0.0014  0.9108  -.0189  0.9297  380000   603  10/24/00

damaged 6x5x5 array (2N = 150), max. burn, shape study (60 kgs uo2/ICCA)
npcatv60  0.9274  0.0012  0.9298  -.0189  0.9487  380000   766  10/23/00

damaged 9x9x2 array (2N = 162), max. burn, shape study (60 kgs uo2/ICCA)
npcatw60  0.9132  0.0012  0.9156  -.0189  0.9345  380000   695  10/23/00

damaged 5x5x6 array (2N =150), max. burn, c-c spacing study (60 kgs uo2/ICCA)
npcat_60  0.9275  0.0012  0.9299  -.0189  0.9488  380000   798  10/25/00
npcatb60  0.9274  0.0014  0.9301  -.0189  0.9490  380000   747  10/21/00
npcatc60  0.9263  0.0012  0.9287  -.0189  0.9476  380000   788  10/21/00
npcatd60  0.9248  0.0014  0.9276  -.0189  0.9464  380000   815  10/23/00
npcate60  0.9275  0.0013  0.9301  -.0189  0.9489  380000   757  10/23/00

damaged array, 100% foam burn vs. interspersed h2o (60 kgs uo2/ICCA)
npcfa000  0.9451  0.0013  0.9477  -.0189**0.9666**380000   811  10/23/00
npcfa005  0.9448  0.0013  0.9473  -.0189**0.9662**380000   895  10/23/00
npcfa010  0.9377  0.0012  0.9401  -.0189**0.9590**380000   794  10/23/00
npcfa020  0.9298  0.0013  0.9324  -.0189**0.9513**380000   834  10/23/00
npcfa030  0.9237  0.0014  0.9265  -.0189  0.9454  380000   812  10/23/00
npcfa050  0.9104  0.0013  0.9130  -.0189  0.9318  380000   724  10/23/00
npcfa075  0.8983  0.0014  0.9011  -.0189  0.9200  380000   803  10/25/00
npcfa100  0.8883  0.0013  0.8909  -.0189  0.9098  380000   703  10/23/00
npcfa125  0.8734  0.0012  0.8759  -.0189  0.8947  380000   672  10/23/00

damaged 5x5x6 array (2N =150), max. burn, structure study (60 kgs uo2/ICCA)
npcats60  0.9240  0.0012  0.9264  -.0189  0.9453  380000  2776  10/27/00

damaged 5x5x6 array (2N =150), max. burn, poly gap study (60 kgs uo2/ICCA)
npcat_60  0.9275  0.0012  0.9299  -.0189  0.9488  380000   798  10/25/00
npcatg60  0.9271  0.0012  0.9296  -.0189  0.9484  380000   797  10/30/00
npcatf60  0.9273  0.0013  0.9299  -.0189  0.9488  380000   801  10/30/00
```

6.6.3 TRANSPORT INDEX

The number of packages that remain below the upper safety limit determines the Transport Index (TI) for criticality control. For normal conditions of transport, an infinite array size ($5N = \infty$) remains subcritical. Under hypothetical accident conditions, the contents of 2N=150 packages would remain subcritical.

$$TI = 50/75 = 0.6667 \approx 0.7.$$

6.7 REFERENCES

1. "GEMER - Microcomputer Version Users Guide," JT Taylor, 4/20/94.
2. "Validation of the GEMER Monte Carlo Code for Applications with Enriched Uranium Fuels at GE Nuclear Fuels in Wilmington, NC", GENE Technical Report, WC Peters, 12/8/97.
3. "Criticality Safety Analysis: Evaluation of Cadmium Bias in the GEMER Code," rev. 01, JF Zino, 1/27/2000.
4. "Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages," NUREG/CR-5661, ORNL/TM-11936, H.R. Dyer, C.V. Parks, April 1997.
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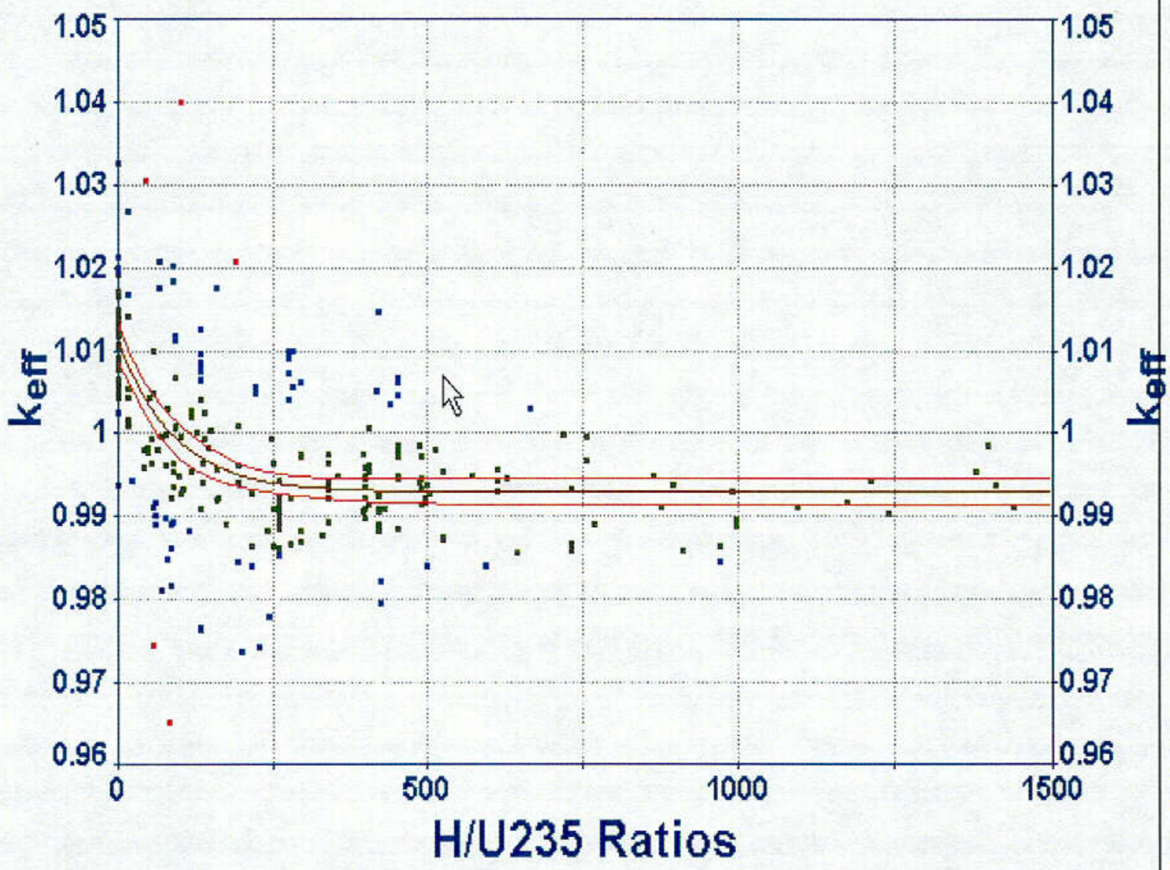
6.8 APPENDIX – VALIDATION OF GEMER

6.8.1 GEMER URANIUM BIAS

The GEMER Monte Carlo Code has been validated against an extensive set of critical benchmark experiments covering a broad range of enrichments, forms and densities of uranium, degrees of moderation and reflection, and types and amounts of neutron poisons (Ref. 2). Figure 6.15 shows a plot of this benchmark data along with a least square analysis of the code bias and statistical uncertainty.

Figure 6.15 – GEMER K_{eff}s vs. H/U-235 Ratios: 269 Benchmark Validation Set Rank 1 Eqn. 8002 [EXPONENTIAL] y = a + bexp(-x/c), where a= 0.99290588, b= 0.018116949, c= 90.332388



C81

The dark red (center) curve in Figure 6.15 is the least square fit of the data and the bright red curves are the upper and lower 99% confidence intervals for the fit. As indicated, the complete benchmark data consists of the GEMER calculated k_{eff}s of 269 different critical experiments that has been fit with an exponential curve (y = a + b•exp(-b/c), with y = k_{eff} and x = H/U-235 ratio and a, b and c as given in the figure). The H/U-235 ratio is the ratio of the average atom densities of hydrogen and U-235 in the fuel region for each of the critical experiments.

For the complete 269-benchmark validation set, the H/U-235 ratios vary between 0.0 and approximately 1450. Optimum moderation is typically in the range of 150 to 500. From Figure 6.15, the maximum bias + bias uncertainty is 0.00868. Here, the "bias + bias uncertainty" is defined to be the value (1.0 – lower 95% confidence interval of the GEMER critical k_{eff} curve). The σ corresponding to the bias uncertainty is in the range of about 0.0006 to 0.0008. The calculated results are consistent with a constant bias over a broad H/U-235 range. This range starts somewhere between an H/U-235 of 250 to 500 and continues out to the maximum ~1450.

For uranium oxides only, bias for GEMER and the ENDF/B-IV library has been established to be no greater than 0.009 (Δk_u - β) at a 99% confidence level. The area of applicability for the benchmark calculations are enrichment ranges from 1.29 to 9.83 weight percent U-235 and H/U-235 ratio 41 to 866.

6.8.2 GEMER CADMIUM BIAS

The above documents 269 critical experiments used to establish the bias for the GEMER code for a variety of applications involving enriched uranium. Since most of these experiments do not contain cadmium, the effect of cadmium on the bias is significantly diluted by the non-cadmium experiments. Hence, it was considered prudent to quantify any "bias adjustment" required to allow for the presence of cadmium poison in the NPC package.

A total of sixteen (16) benchmark experiments for UO_2 systems containing cadmium have been analyzed and used to derive the cadmium bias in the GEMER computer code. Of these 16, ten were performed by Sid Bierman et. al., and involved clusters of 4.31% enriched UO_2 rods in water with cadmium plates of varying thickness' placed in between the clusters. Of the remaining six experiments, five were also performed by Bierman et. al., and involved 2.35% enriched UO_2 rod clusters in water also with cadmium plates. The last experiment performed by Handley and Hopper involved 4.98% enriched UO_2F_2 solution inside a steel/cadmium/water reflected cylinder. Table 6.9 provides a description of the names of each experiment as described in ICSBEP Vol. IV and Reference 2 for cross-reference comparison purposes.

Table 6.9 - Bierman Experiments with Cadmium Used in GEMER Validation

No.	ICSBEP Vol. IV Identification	ICSBEP Table #	ICSBEP Experiment #	Reference 4 ID
1	LEU-COMP-THERM-009	4	019	BIER-31
2	LEU-COMP-THERM-009	4	020	BIER-32
3	LEU-COMP-THERM-009	5	021	BIER-33
4	LEU-COMP-THERM-009	5	022	BIER-34
5	LEU-COMP-THERM-009	5	023	BIER-35
6	LEU-COMP-THERM-009	5	024	BIER-36
7	LEU-COMP-THERM-009	5	025	BIER-37
8	LEU-COMP-THERM-009	5	026	BIER-38
9	LEU-COMP-THERM-009	5	027	BIER-39
10	LEU-COMP-THERM-009	5	028	BIER-40
11	LEU-COMP-THERM-016	5	036	RSIC-14
12	LEU-COMP-THERM-016	5	037	RSIC-15
13	LEU-COMP-THERM-016	5	050	RSIC-24
14	LEU-COMP-THERM-016	5	052	RSIC-25
15	LEU-COMP-THERM-016	5	054	RSIC-26
16	-	-	-	HH-33

Figure 6.16a provides a diagram of the arrangement of the pin clusters and the absorber plates used for ten of the experiments involving cadmium. This figure is based on data taken from Volume IV (LEU-COMP-THERM-009) of the International Criticality Safety Benchmark Evaluation Project (ICSBEP) handbook (Ref. 7).

Figure 6.16b shows the arrangement of the 2.35% enriched UO_2 fuel pin clusters and the relative locations of the absorber plates for experiments with cadmium plates. Of these seven, five are used for validation of the GEMER code with cadmium. This figure is based on data taken from Volume IV (LEU-COMP-THERM-016) of the International Criticality Safety Benchmark Evaluation Project (ICSBEP) handbook (Ref. 7).

Figure 6.16a – Typical Arrangement of Fuel Pin Clusters and Absorber Plates for 4.31% Enriched Experiments

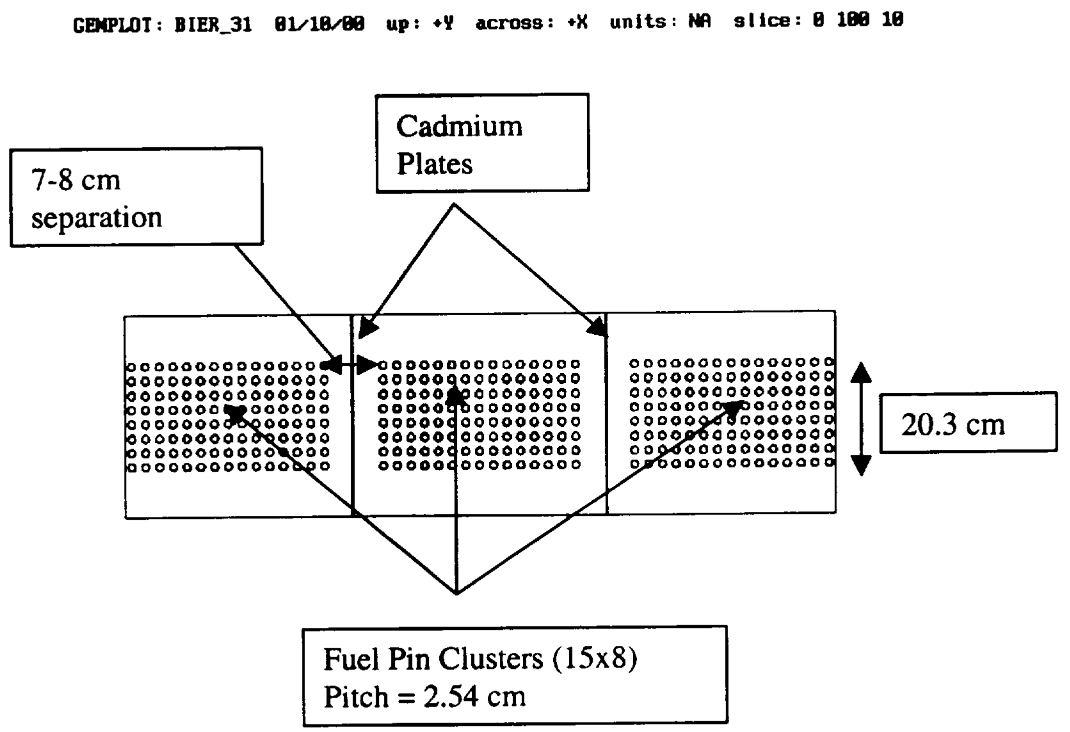
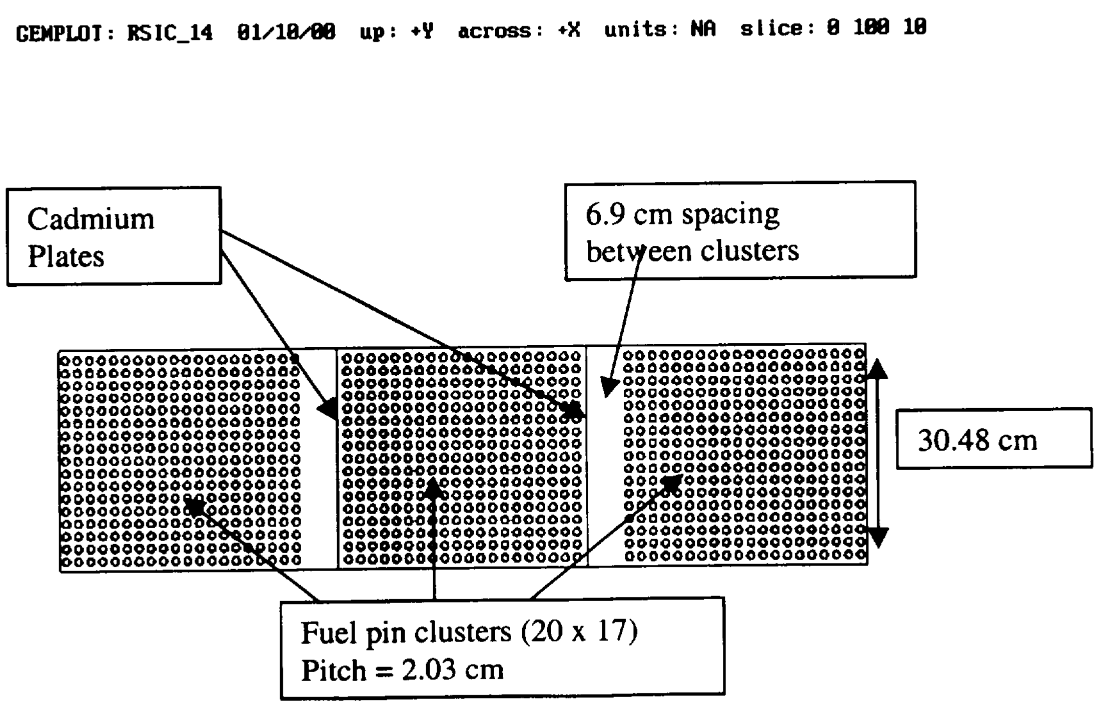


Figure 6.16b - Arrangement of Fuel Pin Clusters and Absorber Plates for 2.35% Enriched Experiments



In order to make a determination of the applicability of the existing 16 benchmark experiments with cadmium to the NPC shipping container, a comparison of important neutron physics properties in made in Table 6.10. This table provides a comparison of enrichment, size, uranium moderation, cadmium plate dimensions, and moderation between uranium units and cadmium for the NPC package. A total of 15 Bierman fuel rod experiments are used as a basis for the benchmark comparison data, while the limiting damaged single package and damaged array results are used for the NPC data.

Table 6.10 - Comparison of Benchmark Experiments to NPC Package

Characteristic	Bierman Experiments	NPC Package
Uranium Enrichment	2.35% – 4.31%	5.00%
Geometry	UO_2 fuel lattice clusters 20.32cm x 38.1 cm x 91.44 cm 32.5 cm x 40.64 cm x 91.44 cm	3x3 cylinder array 21.628 cm dia. 81.01 cm max. height
Moderation of Uranium	Heterogeneous fuel pins in water Pin dia. ~1 cm, pitch ~ 2 cm H/U-235 range: 260 – 488	Homogeneous UO_2 + H_2O wtfr. water ~ 0.29 H/U-235 range: 236-254
Moderation between Uranium and Cd plates	3-6 cm H_2O	~3 cm polyethylene and ~5 cm foam
Absorber Plate thickness	Cadmium plates Thks. 0.30 mm – 2.0 mm	Cadmium wrap Thks. 0.381 mm

By comparing the properties that most directly affect the neutron physics behavior of each system, the following conclusions are reached about the applicability of these benchmark experiments to deriving a GEMER bias for the NPC shipping package.

- Both systems are low enriched, and therefore resonance absorption effects present with systems containing relatively large amounts of U-238 are similar.

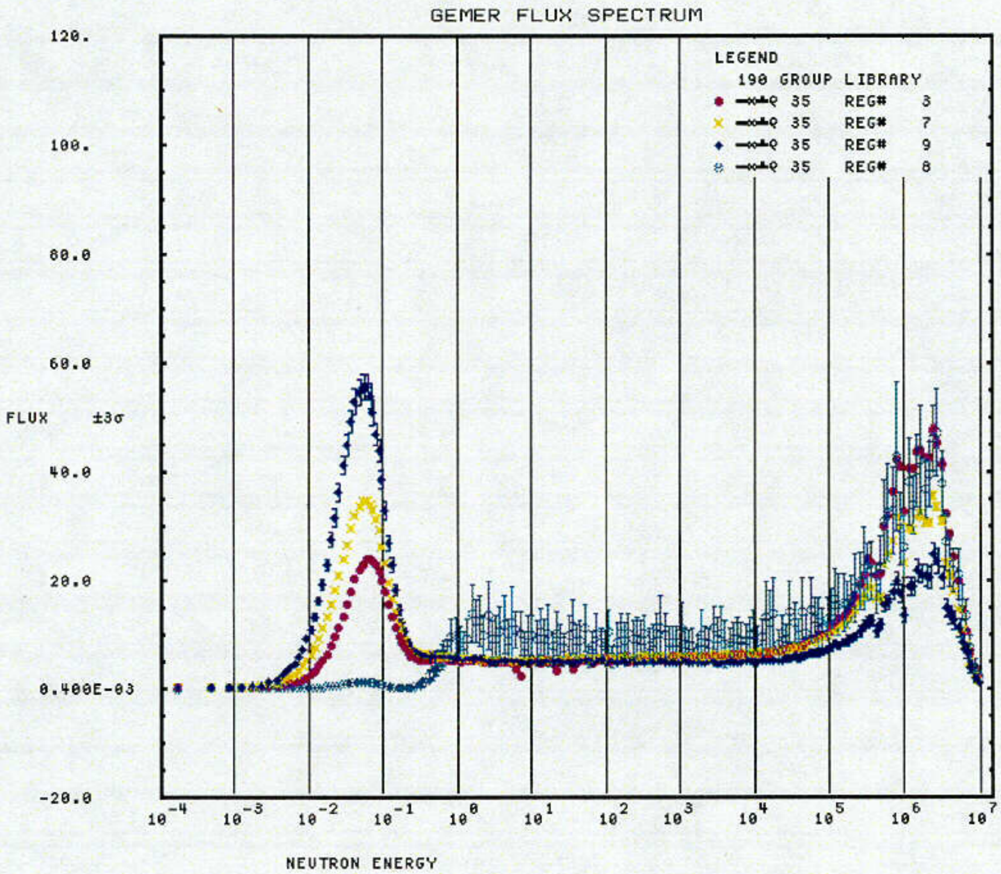
- The overall dimensions of the two systems are similar (e.g., fuel regions are ~3 feet in length). The NPC cadmium wrap thickness is within the range of of thickness of the Bierman experiments. This is expected since very thin regions of cadmium provide the same effective neutron absorption properties as thick regions (i.e., large resonance self-shielding absorption).

- The two systems have very similar H/U-235 ratios over the fissile volume. The H/U-235 ratio determines the neutron energy spectrum inside the fissile region. The effectiveness of the cadmium plates to act as thermal neutron absorbers is directly related to the energy spectrum of the neutrons leaving the fissile assemblies. Sample neutron spectra comparisons between critical experiment and the NPC package are provided in Figures 6.18a-6.18d.

- The overall qualitative effect of the hydrogen and carbon in both the polyethylene and foam regions of the NPC package provide some reasonable degree of thermal neutron moderation between ICCAs. Consequently, the effectiveness of the cadmium to act as a thermal neutron absorber in both systems is roughly equivalent (refer also to spectra comparisons).

Based on these observations, the neutron physics properties of the experiments and the NPC package compare favorably. The GEMER cadmium bias resulting from these benchmark experiments can therefore be successfully applied to criticality calculations involving uranium compounds for the NPC shipping package.

Figure 6.17a - Neutron Energy Spectra for BIER-35 (4.31%)



Legend:

Region 3 – Fuel pins
Region 7 – Moderator surrounding fuel pins
Region 8 – Cadmium plates (2.006 mm)
Region 9 – Moderator between fuel bundles and cadmium plates

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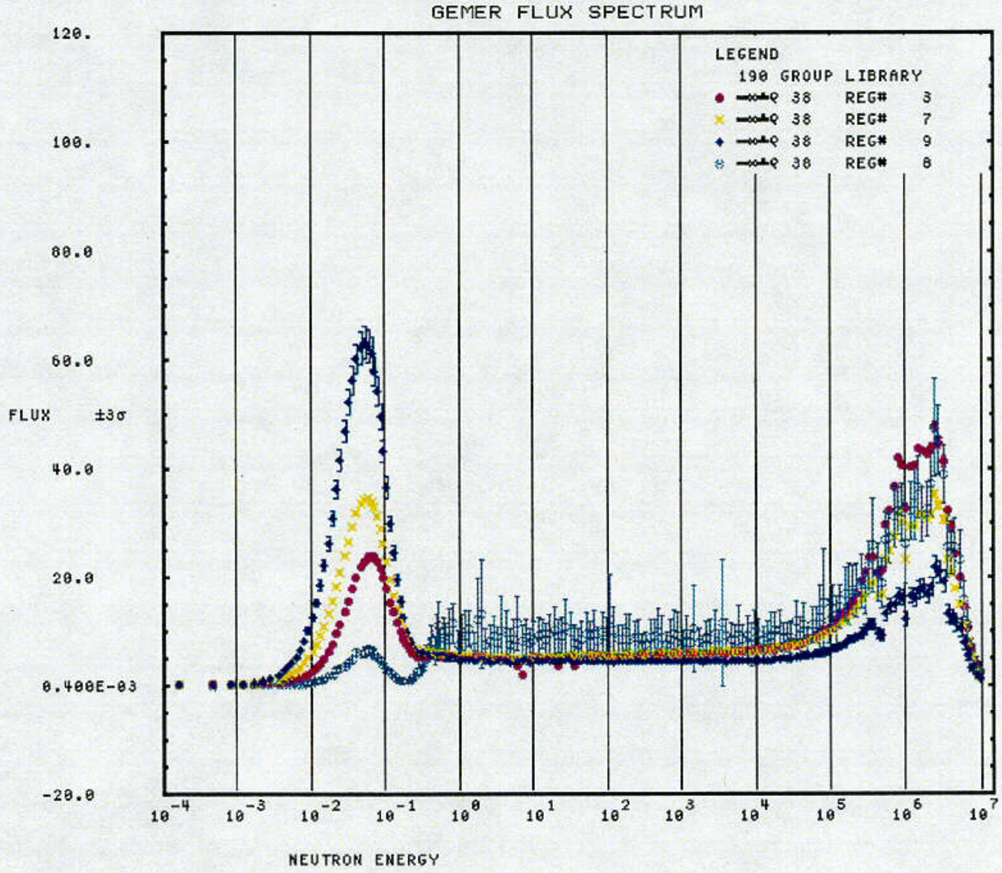
Figure 6.17b - Neutron Energy Spectra for BIER-38 (4.31%)

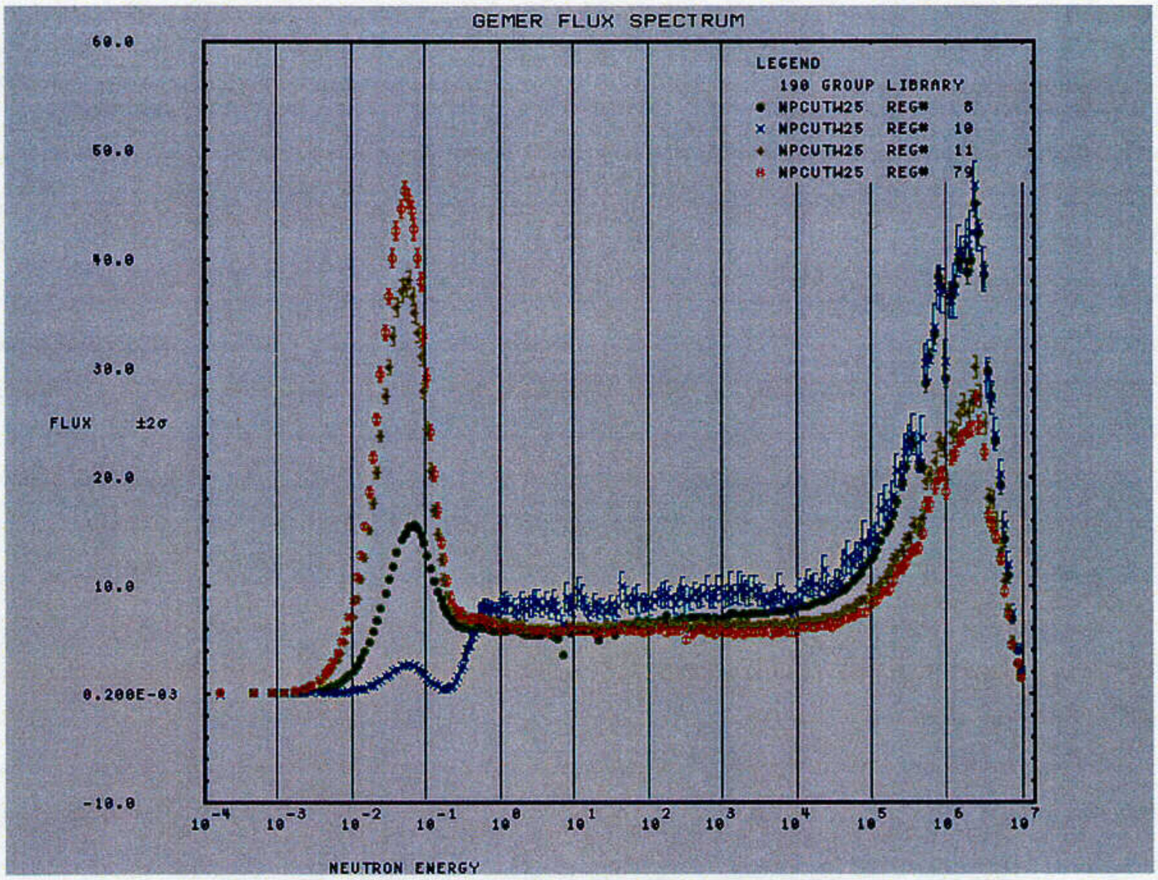


Legend:

Region 3 – Fuel pins
Region 7 – Moderator surrounding fuel pins
Region 8 – Cadmium plates (0.291 mm)
Region 9 – Moderator between fuel bundles and cadmium plates

C83

Figure 6.17c - Neutron Energy Spectra for NPC – Damaged Single Package

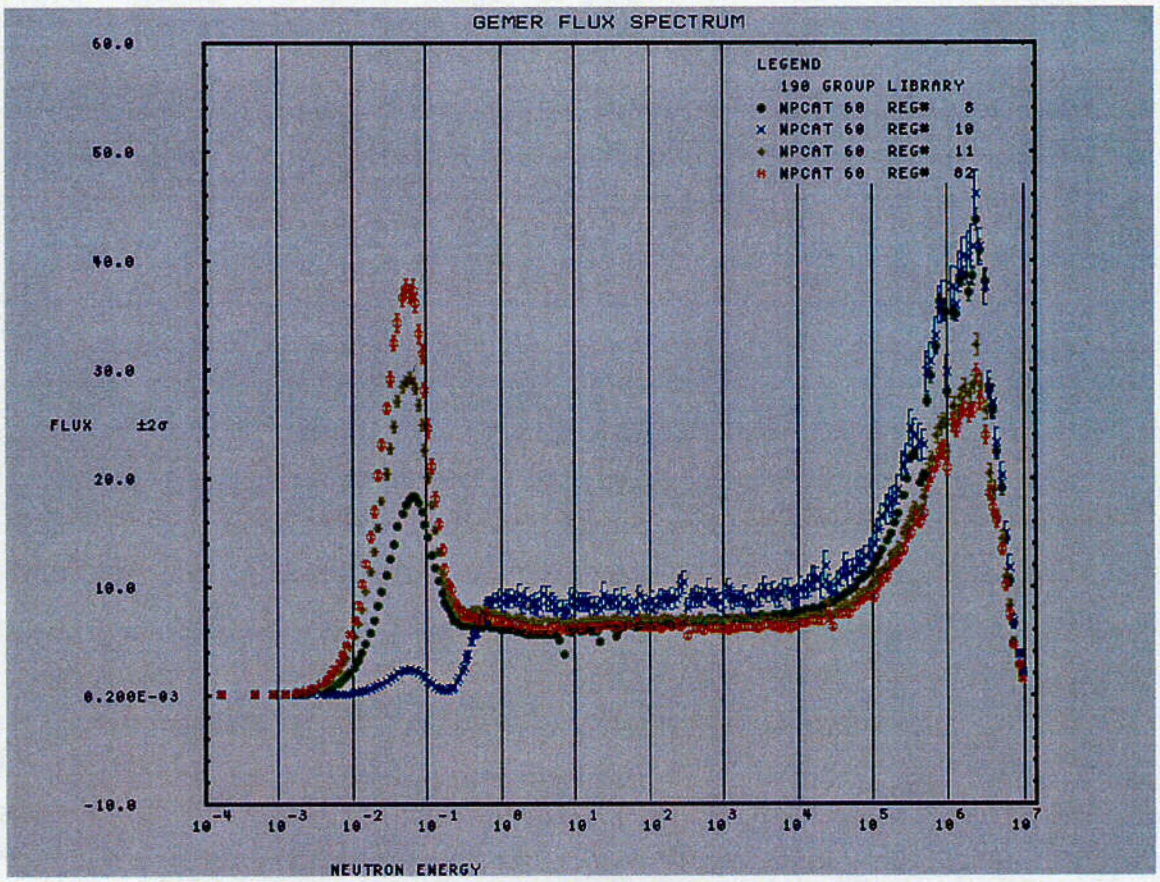


Legend:

Region 8 – ICCA Fuel Region
Region 10 – Cadmium wrap (0.381 mm)
Region 11 – Poly Region between ICCAs
Region 79 – Foam Region between ICCAs

C84

Figure 6.17d - Neutron Energy Spectra for NPC – Damaged Package Array



Legend:

Region 8 – ICCA Fuel Region
Region 10 – Cadmium wrap (0.381 mm)
Region 11 – Poly Region between ICCAs
Region 82 – Foam Region between ICCAs

C85

6.8.2.1 GEMER Cadmium Bias Determination

Table 6.11 presents the results of the GEMER calculated eigenvalues and 1σ statistical uncertainties for the sixteen benchmark experiments. Bias values for a given computer code and cross-section set are ordinarily tabulated (for a given set of benchmark experiments), as a function of an independent variable which directly influences the calculated value of k_{eff}. Examples of such variables would be H/U-235 ratio, water-to-fuel ratio, absorber/poison concentration, fuel unit spacing, etc. Due to the limited moderation range, dependence on an independent variable for the 16 benchmark experiments was not performed. Consequently, the 16 data points for each eigenvalue estimator will be treated as continuous statistical data normally distributed about a mean (μ) with a population variance (σ^2) and standard deviation (σ).

Table 6.11 - GEMER Benchmark Validation Results

GEMER Benchmark Experiment	Flux Weighted Calculated Keff	1σ uncertainty
BIER-31	0.99125	0.00122
BIER-32	0.99007	0.00116
BIER-33	0.98951	0.00110
BIER-34	0.98846	0.00112
BIER-35	0.99228	0.00125
BIER-36	0.98938	0.00104
BIER-37	0.99153	0.00114
BIER-38	0.99012	0.00111
BIER-39	0.98603	0.00129
BIER-40	0.98871	0.00126
RSIC-14	0.9945	0.00105
RSIC-15	0.99352	0.00099
RSIC-24	0.99347	0.00109
RSIC-25	0.99598	0.00102
RSIC-26	0.99469	0.00104
HH-33	0.99405	0.00114

Based on the data provided in Table 6.11, calculations can be performed with the following equations to derive the population mean (μ), population variance (σ^2) and population standard deviation (σ) for the sixteen calculated eigenvalues (N=16). This is done for the flux weighting distribution. This approach is consistent with the derivation of the existing GEMER bias (ref. 2).

$$\mu = \frac{\sum X_i}{N}$$

$$\sigma^2 = \frac{\sum (X_i - \mu)^2}{N}$$

$$\sigma = \sqrt{\sigma^2}$$

Having computed these values, the total bias and 2σ uncertainty is computed as:

Total Bias = $(\mu - 1.0) - 2\sigma$

Based on the sixteen data points provided in Table 6.11, the flux weighted mean k_{eff} and σ values are computed to be:

Flux Weighted

$\mu = 0.991472$

$\sigma = 0.002666$

From this, a total bias for the GEMER code with cadmium is computed to be:

Flux Weighted

Bias = – 0.01386

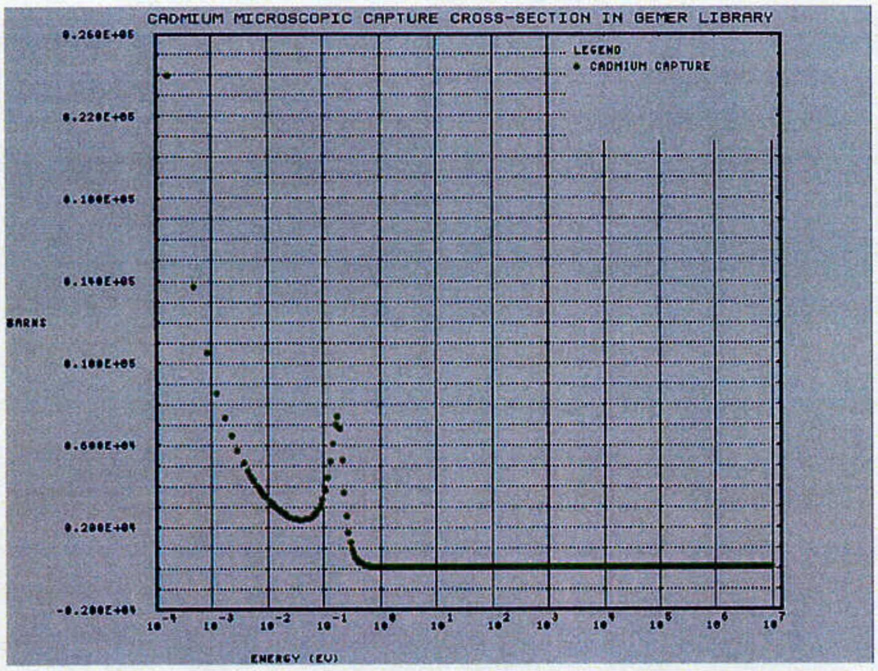
For purposes of the NPC package, the initial estimate of the flux weighted bias based on the critical benchmark data alone is equal to -0.01368.

However, an additional cadmium "bias adjustment" due to the difference between the experimental benchmark reactivity worth of the cadmium and the package reactivity worth is developed in the following sections to account for this extrapolation.

6.8.2.2 Cadmium Worth: Experiments vs. NPC

The GEMER ENDF/B-IV cross-section library treatment of cadmium is based on the 190- multigroup structure, as shown in Figure 6.18. This figure is generated directly from GEMER cross-section library. Explicit resonance parameter solution using single-level Breit-Wigner equation is not used for cadmium in GEMER (Ref. 1).

Figure 6.18 – GEMER Cadmium Total Microscopic Capture Cross-section vs. Neutron Energy



The accuracy of the cadmium cross-section behavior as a function of neutron energy has been well known and published since 1955. The above GEMER cross-section behavior compares well with published data for cadmium for peak resonance, 0.1, and 0.01 eV neutron energies (e.g., pp. 217-219, BNL-325, 2nd Edition, Hughes and Schwartz, 1958).

Table 6.12 presents the results of the GEMER calculated eigenvalues for 14$^{\Phi}$ of the critical benchmarks and limiting condition cases for the NPC single package and package arrays - with and without cadmium. This table quantifies the relative neutronic "worth" of the cadmium in benchmark experiments and in the NPC package application. As a confirmation, edits of the total captures by cadmium are also summed over appropriate regions and included for both sets of data.

$^{\Phi}$ *BIER-31 and BIER-32 omitted since they involved Cu plates with <1% Cd.*

Table 6.12 – Cadmium Benchmark vs. NPC Reactivity Worth Studies

Benchmark experiments – effect of cadmium on Keff						
Case ID	w/ Cd	w/o Cd	%Δk/k	Cd thks.(mm)	Cd captures	Percent Removed
BIER-33	0.9908	1.0009	1.019	0.901	72.3	3.62
BIER-34	0.9887	1.0115	2.306	0.901	69.8	3.49
BIER-35	0.9897	1.0013	1.172	2.006	71.0	3.55
BIER-36	0.9878	1.0124	2.490	2.006	67.4	3.37
BIER-37	0.9891	0.9995	1.051	0.291	72.9	3.64
BIER-38	0.9881	1.0106	2.277	0.291	65.0	3.25
BIER-39	0.9889	1.0006	1.183	0.610	74.1	3.70
BIER-40	0.9879	1.0092	2.156	0.610	68.0	3.40
RSIC-14	0.9931	1.0143	2.135	0.610	50.8	2.54
RSIC-15	0.9913	0.9986	0.736	0.610	58.8	2.94
RSIC-24	0.9947	1.0066	1.195	0.291	50.6	2.53
RSIC-25	0.9951	1.0096	1.452	0.901	56.0	2.80
RSIC-26	0.9921	1.0088	1.683	0.610	50.2	2.51
HH-33	0.9886	1.0072	1.881	0.081	129.4	6.47
NPC package analysis – effect of cadmium on Keff						
Case ID	w/ Cd	w/o Cd	%Δk/k	Cd thks.(mm)	Cd captures	Percent Removed
Damaged single package - limiting cases:						
npcu1_25	0.8452	1.0195	20.622	0.381	434.2	21.710
npcu2_25	0.8407	1.0155	20.792	0.381	433.6	21.680
npcut_25	0.8405	1.0114	20.333	0.381	420.6	21.030
npcutw25	0.8476	1.0344	22.039	0.381	370.4	18.520
Damaged package array – limiting cases:						
npca1_60	0.9059	1.1239	24.064	0.381	420.4	21.020
npca2_60	0.9141	1.1306	23.684	0.381	422.9	21.145
npcat_60	0.9275	1.1468	23.644	0.381	426.2	21.310

Table 6.12 demonstrates the relative worth of the cadmium in the experiments is in the range of ~1-2.5%, while the relative worth for the NPC package is in the range of 20-24%. This suggests that an additional cadmium bias adjustment due to cross-section uncertainty might be warranted due to this extrapolation.

Specifically, the more conservative of the following two approaches are considered an appropriate means to quantify the required "bias adjustment" due to extrapolating the validation benchmarks for low-worth cadmium absorber to a high-worth application such as the NPC package. Both of these methodologies are evaluated.

1. The change in k_{eff} corresponding to substituting the chosen neutron absorber with equivalent boron and reducing the boron by 10 percent; or

2. The difference between the neutron absorber worth calculated by GEMER and an independent continuous-energy code (e.g,. MCNP4C).

6.8.2.3 Boron Substitution Method

The boron substitution methodology was applied to the limiting condition NPC damaged package array (npcat_60.in). To begin the study, the limiting damage package array model was re-run two additional times to allow for statistical comparison of results.

To determine equivalent boron-10 areal density, 1/v-absorber equivalents of 0.008, 0.0085, and 0.009 gB^{10}/cm^2 were modeled in place of the 15-mil cadmium to study the 1/v absorber behavior for the limiting damaged package array. From these cases, the 1/v-absorber cross-section treatment using boron-10 at an areal density of 0.008 gB^{10}/cm^2 was demonstrated to yield statistically equivalent results as shown below. These cases were in turn re-run using a 10% reduction in the boron-10 areal density to quantify the actual bias adjustment using the boron substitution approach.

```
combined statistics for following cases (limiting case - damaged package array)
case     k-eff          sigma           # of batches

     1      0.927480      0.122000e-02    190 (npcat_60.in)
     2      0.927670      0.127000e-02    190 (npcati60.in, repeat)
     3      0.926890      0.127000e-02    190 (npcatj60.in, repeat)

 kbar =  0.927347            sbar =  0.722601e-03
 # of observations =   570

combined statistics for following cases (boron subst. = 0.008 gb10/cm2)
   case     k-eff          sigma           # of batches

     1      0.930150      0.128000e-02    190 (bor08a.in)
     2      0.927430      0.126000e-02    190 (bor08b.in, repeat)
     3      0.928510      0.129000e-02    190 (bor08c.in, repeat)

 kbar =  0.928697            sbar =  0.737314e-03
 # of observations =   570

combined statistics for following cases (boron subst. = (0.90)*(0.008 gb10/cm2)
   case     k-eff          sigma           # of batches

     1      0.932670      0.118000e-02    190 (bor08x.in)
     2      0.931160      0.136000e-02    190 (bor08y.in, repeat)
     3      0.932340      0.122000e-02    190 (bor08z.in, repeat)

 kbar =  0.932057            sbar =  0.724217e-03
 # of observations =   570
```

Using the boron substitution methodology, the following statistical comparison can be made between the equivalent boron (0.008 gB^{10}/cm^2) and the 10% reduced values.

```
statistical comparison - reactivity worth of 10% reduction in b-10

kbar1 =  0.928697
sbar1 = 0.000737314
n1 = 3

kbar2 =  0.932057
sbar2 = 0.000724217
n2 = 3
```

Assuming the true variance of the two distributions is the same, then the 100 (1- α)% confidence interval on the difference between means is:

$$[(xbar2 - xbar1) \pm t_{n1+n2-2;\alpha/2}\ sw * sqrt((1/n1) + (1/n2))]$$

where,

$$sw^{**}2 = \frac{(n1-1)sbar1^{**}2 + (n2 - 1)sbar2^{**}2}{n1 + n2 - 2}$$

using above data_ α = 5, a 95% ci yields_

$$sw^{**}2 = \frac{(3-1)(0.000737314)^{**}2 + (3-1)(0.000724217)^{**}2}{(3+3-2)}$$

```
sw**2 = 5.34061e-07

sw = 0.0007308
```

95% ci = (0.932057 - 0.928697) ± $t_{4,0.025}$ *(0.0007308)* sqrt(2/3)
95% ci = (0.932057 - 0.928697) ± 2.776 *(0.0007355)* (0.81650)
95% ci = 0.00336 ± 0.001656

Thus, with a 97.5% confidence (upper limit on CI) expect a 10% reduction in b-10 content to yield a difference in k_{eff} that does not exceed

0.00336 + 0.001656 = 0.005016

The total cadmium bias from critical benchmarks + bias adjustment due to worth extrapolation is given by:

Total Bias + Bias Adjustment = -(0.01386 + 0.005016) = -0.01888

The final adjusted upper spec limit (USL) is therefore,

$k_{eff,\,USL}$ = 0.95 - (0.01888) = 0.93112

or

$k_{eff,\,USL}$ = 0.931

6.8.2.4 Reactivity Worth Comparison Between GEMER Vs. MCNP4C

A series on Monte Carlo calculations were performed with both the GEMER code and an independent Monte Carlo transport code MCNP4C (ref. 8). The historical lineage and development of both codes and the neutron cross-section data sets are different. As such, a comparison of the results of these two Monte Carlo codes will provide an independent assessment of the evaluated nuclear data used by each.

The GEMER code is based on the Battelle Memorial Institute's MERIT program and utilizes a 190-group cross-section data set (multi-group library) based on ENDF/B-IV evaluated nuclear data for unresolved resonances and a continuous energy treatment based on a first-level Breit-Wigner approximation for resolved resonances.

MCNP4C utilizes a point-wise continuous energy treatment for all cross-sections and is based on ENDF/B-V evaluated nuclear data (for this comparison).

The benchmark problem created to compare the results of these two codes is a 2-D infinite array of ICCAs spaced on a 29.845-cm square pitch. The material and geometric compositions used for both codes was taken from the limiting damaged package array model and is intended to exaggerate the reactivity worth of the cadmium to provide a bounding case comparison. The only minor difference is the treatment of the poly region – the 2% reduction in poly density is not included in this infinite ICCA lattice comparison.

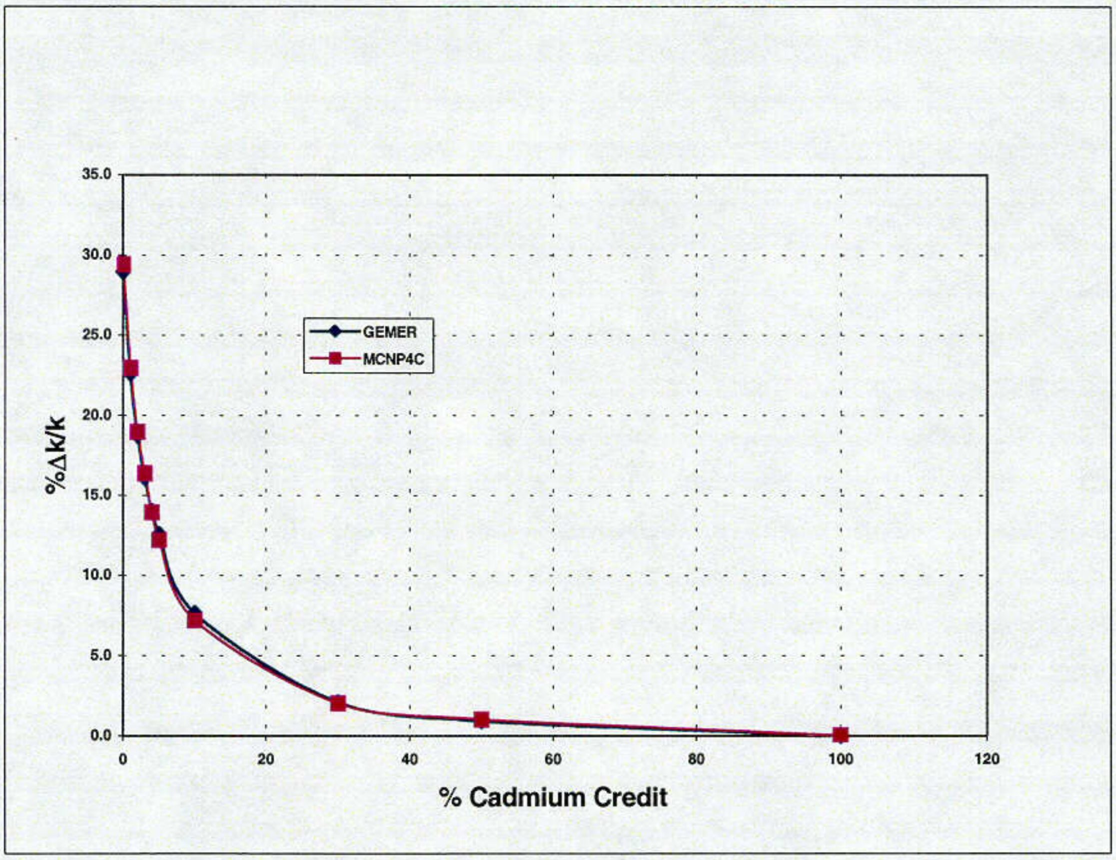
Care was taken to ensure that the input models for both codes numerically simulated the exact same geometric and material compositions. Both codes were executed for the case of 100% cadmium credit (i.e., full cadmium atom density) as a starting point. Nine cases were run with each code simulating a reduction in the cadmium atom density starting with 50% credit and decreasing to 0% credit (i.e., no cadmium). Only the cadmium atom density was changed in each case (i.e., no change to the cadmium region thickness was made) in order to assess the reactivity effects of the removal of absorber atoms only (i.e., no geometry effects). Sample GEMER and MCNP4C input files are also provided.

Table 6.13 and Figure 20 shows the results of the GEMER and MCNP4C comparison calculations.

Table 6.13 – Cadmium Reactivity Evaluation Between GEMER and MCNP4C

	GEMER	GEMER	MCNP4C	MCNP4C	
% Cd Credit	Keff	(%Δk/k)	keff	(%Δk/k)	d_i
100	0.9437	0.0000	0.9581	0.0000	0.0000
50	0.9524	0.9219	0.9677	1.0020	-0.0801
30	0.9634	2.0875	0.9774	2.0144	0.0731
10	1.0157	7.6295	1.0268	7.1704	0.4591
5	1.0620	12.5358	1.0748	12.1804	0.3554
4	1.0755	13.9663	1.0915	13.9234	0.0429
3	1.0954	16.0750	1.1147	16.3448	-0.2698
2	1.1206	18.7454	1.1395	18.9333	-0.1879
1	1.1570	22.6025	1.1780	22.9517	-0.3492
0	1.2168	28.9393	1.2397	29.3915	-0.4522

Figure 6.19 – Comparison of GEMER and MCNP4C Reactivity Worth of Cadmium Replacement (0.570" poly wrap)



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The results of Figure 20 show excellent agreement between the calculated cadmium reactivity worth for GEMER and MCNP4C. However, a paired, one-sample t-test can be performed to determine if there is a statistically significant difference between the reactivity worth calculated by GEMER and that calculated by MCNP4C. The following hypothesis tests can be performed:

- Null hypothesis (H_o): No statistical difference between GEMER and MCNP4C
- Alternative hypothesis (H_a): A statistical difference does exist between the two

In order to test these two hypotheses, a paired one-sample t-test using the following equations can be performed using the MINITAB program (ref. 9). The assumptions include a) n = 9 = number of pairs of data, and b) mean = average values of the difference between the GEMER and MCNP results.

$$\overline{D} = \sum_{i=1}^{N} \frac{d_i}{n} \qquad s_d = \sqrt{\frac{\sum_{i=1}^{n} (d_i - \overline{D})^2}{n-1}}$$

From this, the acceptance region for the (T) value becomes:

$$\overline{D} - t_{\alpha/2,n-1} \frac{s_d}{\sqrt{n}} < T < \overline{D} + t_{\alpha/2,n-1} \frac{s_d}{\sqrt{n}}$$

Where (α) is the confidence interval that the alternative hypothesis is true and t is the student t factor from a standard t-distribution table. Using the MINITAB program, the following is calculated:

T-Test of the Mean

Test of mu = 0.000 vs mu not = 0.000

Variable	N	Mean	StDev	SE Mean	T	P
di	9	-0.045	0.310	0.103	-0.44	0.67

For $\alpha = 0.05$, a **p value** of 0.67 for the difference of the means ($\mu = 0$) is calculated. Since $p > \alpha$, we can accept the null hypothesis (Ho) and conclude that there is no statistical difference between calculated reactivity worth for the GEMER and MCNP4C computer codes given the sample of paired data evaluated in this study.

The boron substitution methodology is therefore the more conservative approach when compared with the difference between the neutron absorber worth calculated by GEMER and an independent continuous-energy code MCNP4C.

GEMER – sample input

```
2000.NPC,,,,CYL,,UO2,5.00%,WTFR=VAR.,SS,,,CD,CE
/*ECHO
/*TITLE
  200 2000   10    0    0    1    0    0
    0  293    0    0
\CSXSEC\UO2\GUO2-50.285
\CSXSEC\NOU\GNOU-0.SS
\CSXSEC\NOU\GNOU-0.CAD
\CSXSEC\NOU\GNOU-0.POL
\CSXSEC\NOU\GNOU-0.F07 0.90
KENO GEOM
    0  /* # OF REGIONS OR ZERO
    0  /* # OF BOX TYPES OR ZERO
    1  /* # OF BOXES IN X DIRECTION
    1  /* # OF BOXES IN Y DIRECTION
    1  /* # OF BOXES IN Z DIRECTION
    1  /* BOUNDARY CONDITION OPTION
    1  /* STARTING SOURCE OPTION
    1  /* COMPLEX EMBEDDED OPTION
    0  /* # OF PRINT PLOTS
      -1.0      -1.0      -1.0      -1.0      -1.0      -1.0
BOX TYPE      1  /* Main Body Region
CYLINDER      1  10.8141  73.8505   0.0000                                16*.5
CYLINDER      2  10.9233  73.8505   0.0000                                16*.5
CYLINDER      3  10.9614  73.8505   0.0000                                16*.5
CYLINDER      4  12.4092  73.8505   0.0000                                16*.5
CYLINDER      2  12.4612  73.8505   0.0000                                16*.5
CYLINDER      0  12.7000  73.8505   0.0000                                16*.5
CYLINDER      2  12.7635  73.8505   0.0000                                16*.5
BOX TYPE      2  /* Unit Cell
CUBOID        5  14.9225  -14.9225  14.9225  -14.9225  73.8505  0.0       16*.5
 2    1  1  1    1  1  1    1  1  1   1
BEGIN COMPLEX
/* Entire System
COMPLEX  2  1  0.00000  0.00000  0.00000   1   1   1  0.0   0.0   0.0
END GEOM
DEFAULTS=YES
END GEMER
```

MCNP4C – sample input

```
Test Input Model for NAS60
1     1 0.09543202  -1      u=1   imp:n=1
2     2 0.08705741   1 -2   u=1   imp:n=1
3     3 0.04400000   2 -3   u=1   imp:n=1
4     4 0.11646900   3 -4   u=1   imp:n=1
5     2 0.08705741   4 -5   u=1   imp:n=1
6     0              5 -6   u=1   imp:n=1
7     2 0.08705741   6 -7   u=1   imp:n=1
8     5 0.00684900   7      u=1   imp:n=1
9     0      -8 9 -10 11 -12 13  fill=1  imp:n=1
10    0       (8:-9:10:-11:12:-13)       imp:n=0

1     cz    10.8141
2     cz    10.9233
3     cz    10.9614
4     cz    12.4092
5     cz    12.4612
6     cz    12.7000
7     cz    12.7635
8*    px    14.9225
9*    px   -14.9225
10*   py    14.9225
11*   py   -14.9225
12*   pz    36.92525
13*   pz   -36.92525

kcode 2000 1.0 10 200
ksrc  0.0 0.0 0.0
m1    92235.50c  2.3052e-04  $ U(5%)O2 + 0.285H2O
      92238.50c  4.3245e-03
       1001.50c  5.4511e-02
       8016.50c  3.6366e-02
mt1   lwtr.01t
m2     6012.50c  3.1691e-04  $ 304SS
      14000.50c  1.6940e-03
      24000.50c  1.6471e-02
      26000.50c  6.0360e-02
      28000.50c  6.4834e-03
      25055.50c  1.7321e-03
m3    48000.50c  4.4000e-02  $ Cd
m4     1001.50c  7.6965e-02  $ Poly
       6012.50c  3.9504e-02
mt4   poly.01t
m5     6012.50c  2.5290e-03  $ 0.90 F07
       8016.50c  5.3100e-04
       7014.50c  1.7100e-04
       1001.50c  3.6180e-03
mt5   poly.01t
```

6.8.3 VALIDATION SUMMARY – NPC PACKAGE

Validation of GEMER and the ENDF/B-IV cross-section library consist of performing calculation of critical benchmark experiments. The range of applicability includes uranium oxides involving the nuclear poison cadmium.

The uranium oxide bias (Δk_u - β) determined is no greater than -0.009 at a 95% confidence level. The area of applicability for the uranium oxide benchmark calculations are enrichment ranges from 1.29 to 9.83 weight percent U-235 and H/U-235 ratio 41 to 866.

The uranium oxide bias from critical benchmarks involving cadmium and bias adjustment due to extrapolating the validation benchmarks for low-worth cadmium absorber to a high-worth application such as the NPC package (Δk_u - β) is demonstrated to be no greater than -0.01888 at a 95% confidence level. The area of applicability for the uranium oxide with cadmium benchmark calculations are enrichment ranges from 2.35 to 4.98 weight percent U-235 and H/U-235 ratio 260-488.

The cadmium bias resulting from these benchmark experiments can therefore be successfully applied to criticality calculations involving uranium compounds for the NPC shipping package. For this evaluation, the NPC package and it contents are considered subcritical if the following condition is satisfied:

$$k_{eff} + 2\sigma \leq 0.95 - 0.01888$$
$$or$$
$$k_{eff} + 2\sigma \leq 0.93112$$

Conservatively rounding this result down, the acceptance criteria becomes:

$$k_{eff} + 2\sigma \leq 0.931$$

6.8.4 ANALYSIS AND VERIFICATION SIGNOFF

Global Nuclear Fuel

A Joint Venture of GE, Toshiba, & Hitachi

DRF No. J11-03749-00
Criticality Safety Analysis
New Powder Container (NPC)
(Revision 01)

Analysis By: [signature] Date: 11/10/00
Lon E. Paulson

Verified By: [signature] Date: 11/10/00
William C. Peters

7.0 OPERATING PROCEDURES

7.1 Procedure for Loading the NPC Packaging

This section delineates the procedures for loading a payload into the NPC packaging. Reference to specific NPC packaging components may be found in Appendix 1.3.1, *Packaging General Arrangement Drawings.*

7.1.1 Preparation of the NPC for Loading

1. Outer Confinement Assembly (OCA) Body – Visually inspect the silos for the ICCAs and verify they are clean and dry. A silicon rubber pad must be located in the bottom of each silo.
2. OCA Body – Visually inspect the 16 threaded lugs for damage and verify a threaded insert is present in each lug, fully seated and undamaged.
3. OCA Body – Visually verify that each of the 24 holes for attaching the four OCA closure strips contain a thread insert which is fully seated and undamaged.
4. OCA Body – Visually inspect all external surfaces for damage. The maximum acceptable dent or bulge is a 1/2-inch deflection.
5. OCA Body – Visually verify that the plastic vent plug on each container side (4 total) is in place and tightly secured.
6. OCA Body – Visually verify that the exposed polyurethane foam is in good condition and the outlines for the ICCA lock ring locations are clearly stenciled on the foam.
7. OCA Body – Visually verify the stainless steel channel receptacle for the ceramic fiber braided rope in the lid is in place and undamaged.
8. OCA Lid – Visually inspect the external surfaces of the lid for handling damage. Maximum acceptable dent or bulge is a 1/2-inch deflection.
9. OCA Lid – Visually verify the presence of the ceramic fiber braided rope around the inside periphery of the lid and inspect that it has no tears, deterioration or other damage and is tightly adhering.
10. OCA Lid – Visually verify the exposed polyurethane foam is in good condition.
11. Inner Containment Canister Assembly (ICCA) – Visually verify no dents in ICCA exterior greater than 1/4-inch deep.
12. ICCA – Visually verify the silicon rubber gasket in the lid is clean, in good condition with no tears or cuts, and is tightly adhering. Visually verify the rolled edge mating gasket surface at the top of the ICCA body is clean, smooth and undamaged.
13. ICCA – Visually verify the ICCA interior is clean and dry.
14. ICCA – Visually verify the lock ring is undamaged and the 5/16-inch bolt threads are not stripped or deformed. Replace the lock ring bolt nut with a new one after each use.
15. When deviations to items 1, 5 and 13 are found, the item is corrected before release to loading.

16. When deviations to items 2, 3, 4, 6, 7, 8, 9, 10, 11, 12 and 14 are identified, the package or packaging component is immediately removed from service, identified as non-conforming material, and dispositioned in accord with written procedures including the10 CFR 71, Subpart approved QA Plan.

7.1.2 Loading the Payload into the NPC

1. The uranium oxide payload will be secured in plastic or metal receptacles (e.g. bags, bottles, cans). Each ICCA is limited to 60 kg (powder plus powder packaging).
2. After loading the payload inside the ICCA body, the ICCA lid shall be positioned on top of the ICCA body. Visually verify the silicon rubber gasket is clean, without tears or cuts and is tightly adhering. Install the lock ring around the lid and tighten up the lock ring bolt while tapping the outer circumference of the lock ring with a small rubber hammer to assure the lock ring is fully and tightly secured. Torque the lock ring bolt to 35 – 50 lb-in.
3. Unless the ICCAs are already positioned in the OCA, pick up the loaded ICCA with a special lifting harness attached to the periphery of the lock ring and insert it carefully into the OCA silo. Insert the balance of the ICCAs in a like manner.
4. Assure that the lock ring bolt for each ICCA is oriented within the outline stenciled around the top of the silo.
5. Using a special lifting sling, attach a lifting eye to each of the four threaded holes located near the corners of the OCA lid. Lift the lid and position it over the OCA body so that the alignment marks on the side of the OCA lid and body line up correctly.
6. Lower the OCA lid in place and secure with sixteen (16) 1/2-inch socket head cap screws. Visually verify prior to assembly that the bolt threads are not stripped or deformed. Tighten the bolts around the periphery of the OCA lid and then final torque to 50 ± 5 lb-ft.
7. Install the four OCA closure strips and secure with twenty- four (24) 7/16-inch hex bolts. Visually verify prior to assembly that the bolt threads are not stripped or deformed. Final torque the bolts to 40 ± 5 lb-ft.
8. Install 5/16-18 screws into the four stainless steel locating "buttons" on the OCA lid to prevent them from being used as lifting devices for the NPC package during transport.
9. Install plastic or rubber weather plugs in sixteen (16) bolt hole locations in top of OCA lid.

7.1.3 Final Package Preparations for Transport

1. Install the two tamper-indicating seals near the OCA closure strips located on opposite sides of the container.
2. Monitor external radiation for each package per 49CFR §173.441[1].
3. Determine the surface contamination levels for each NPC package per 49CFR §173.443.
4. Determine the transport index for the loaded NPC package per 49 CFR §173.403.
5. Complete all necessary shipping papers in accordance with Subpart C of 49 CFR 172[2].

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[1] Title 49, Code of Federal regulations Part 173 (49CFR 173), *Shippers – General Requirements for Shipments and Packagings*, 1-1-97 Edition

6. Utilizing only the forklift pockets, raise and move the NPC package into the transport vehicle (i.e., sea-land container, enclosed truck, etc.). The NPC package may be stacked up to a height of two packages.

7. Install and secure the stainless steel covers over each forklift pocket using the 1/4-20UNC machine screws and washers.

8. Install a minimum of one horizontal restraint having a minimum width of 2.18 inches on each side and top of the NPC package. When using a single side restraint configuration, the restraint shall be installed at least 23 inches above the base of the NPC package. A single top restraint shall be installed proximate to the centerline of the package.

7.2 Procedures for Unloading the Package

This section delineates procedures for unloading the NPC.

7.2.1 Unloading the Transport Vehicle

1. Open the transport vehicle and carefully remove the restraints from around the NPC package to facilitate unloading.

2. Remove the stainless steel covers from two adjacent forklift pockets to provide access for handling equipment. The remaining stainless steel covers over the other forklift pockets may be removed as necessary to handle the NPC package.

3. Utilizing only the forklift pockets, remove the package from the transport vehicle using appropriate handling equipment and the forklift pockets on the bottom of the NPC package.

7.2.2 Removal of the Payload from the NPC Package

1. Remove the two tamper safe seals and the twenty-four (24) hex bolts securing the four OCA closure strips.
2. Remove the OCA closure strips
3. Remove the sixteen (16) socket head cap screws securing the OCA lid to the OCA body.
4. Using a special lifting sling, attach a lifting eye to each of the four threaded holes located near the corners of the OCA lid. Carefully lift and remove the OCA lid from the OCA body. It may be necessary to tap the sides of the lid with a rubber hammer to facilitate the lid removal.
5. Attach a special lifting sling to the periphery of an ICCA and pull it up and out of the OCA silo. Repeat for the remainder of the ICCAs.
6. Use a wrench to loosen and remove the nut securing the lock ring bolt on the ICCA. Remove the lock ring and ICCA lid.

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[2] Title 49, Code of Federal Regulations, Part 172 (49 CFR 172), *Hazardous Materials Tables and Hazardous Communications Regulations*, 1-1-97 Edition.

7. Remove the uranium oxide contents by carefully lifting the powder receptacle and packing material out of the ICCA or by upending the ICCA with a special fixture and allowing the receptacles to be pulled/slide out.

7.2.3 Final Package Preparations for Transport of Unloaded NPC

1. Complete all required shipping papers in accordance with Subpart C of 49 CFR 172.
2. NPC package marking shall be in accordance with 10 CFR §71.85(c) and Subpart D of 49 CFR 172. Package labeling shall be in accordance with Subpart E of 49 CFR 172. Packaging placarding shall be in accordance with Subpart F of 49 CFR 172.

7.3 Preparation of an Empty Packaging for Transport

Previously used and empty NPC packagings shall be prepared and transported per the requirements of 49 CFR §173.428, Subpart I.

8.0 ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

8.1 Acceptance Tests

Per the requirements of 10 CFR §71.85(c)[1], this section discusses the inspections and tests to be performed prior to first use of the NPC package.

8.1.1 Visual Inspections

All NPC packaging materials of construction and welds shall be examined in accordance with the requirements delineated on the drawings in Appendix 1.3.1, *Packaging General Arrangement Drawings*, per the requirements of 10 CFR §71.85(a).

8.1.2 Structural and Pressure Tests

8.1.2.1 Lifting/Tie-Down Device Load Testing

The NPC packaging does not contain any lifting/tiedown devices that require load testing.

8.1.2.2 Containment Vessel Pressure Testing

Per the requirements of 10 CFR §71.85(b), the Inner Containment Canister Assemblies (ICCAs), prior to wrapping with cadmium and polyethylene, shall be pressure tested to 150% of the Maximum Normal Operation Pressure (MNOP) to verify structural integrity. The MNOP of the ICCAs is equal to the 6.1 psig. Thus, each ICCA is required to be pressure tested to $6.1 \times 1.5 =$ 9.1 psig minimum. However, since the ICCA design pressure is greater than this pressure, each ICCA shall be tested to the 24.0-psig design pressure.

Following containment vessel pressure testing, the base material and the welds directly related to the pressure testing of the containment vessels shall be visually inspected for plastic deformation or cracking in accordance with AWS D1.6[2], as delineated on the drawings in Appendix 1.3.1, *Packaging General Arrangement Drawings*. Indications of cracking or distortion shall be recorded on a nonconformance report and dispositioned prior to final acceptance with the cognizant quality assurance program.

8.1.3 Fabrication Verification Leak Tests

The NPC packaging does not contain any seals or containment boundaries that require leak testing.

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[1] Title 10, Code of Federal Regulations, Part 71 (10 CFR 71), *Packaging and Transportation of Radioactive Material*, 1-1-98 Edition.

[2] ANSI/AWS D1.6, *Structural Welding Code – Stainless Steel*, American Welding Society (AWS).

8.1.4 Component Tests

8.1.4.1 Polyurethane Foam

This section establishes the requirements and acceptance criteria for installation, inspection, and testing of rigid, closed-cell, polyurethane foam utilized within the NPC packaging.

8.1.4.1.1 Introduction and General Requirements

The polyurethane foam utilized within the NPC packaging is comprised of a specific "formulation" of foam constituents (i.e., mix of chemical constituents) that defines the foam's characteristics such as density, compressive stress and specific heat. Based on the foam's physical requirements, chemical constituents are combined into batches containing multiple parts (e.g., parts A and B) for easier handling. Therefore, a foam "batch" is defined as mixing into vats a specific foam formulation for each part. Based on the foam's physical requirements, portions from each batch part are combined to produce the liquid foam material for pouring into the component to be foamed. Thus, a foam "pour" is defined as apportioning the pouring batch parts into a desired quantity of liquid foam material for subsequent installation (pouring).

8.1.4.1.1.1 Polyurethane Foam Chemical Composition

The foam supplier shall certify that the chemical composition of the polyurethane foam is as delineated below, with the chemical component weight percents falling within the specified ranges. In addition, the foam supplier shall certify that the finished (cured) polyurethane foam does not contain halogen-type flame retardants or trichloromonofluoromethane (Freon 11).

Carbon	50% - 70%	Phosphorus	0% - 2%
Oxygen	14% - 34%	Silicon	< 1%
Nitrogen	4% - 12%	Chlorides	< 0.18%
Hydrogen	6.4% - 10%	Other	< 1%

8.1.4.1.1.2 Polyurethane Foam Constituent Storage

The foam suppliers shall certify that the polyurethane foam constituents have been properly stored prior to use, and that the polyurethane foam constituents have been used within their shelf life.

8.1.4.1.1.3 Foamed Component Preparation

Prior to the in-situ foam installation, the foam supplier shall visually verify that adequate bracing/shoring of the component shells is provided to maintain the dimensional configuration throughout the foam pouring/curing process. This bracing/shoring is required to resist the internal pressures generated during the foam pouring/curing process.

8.1.4.1.1.4 In-Situ Polyurethane Foam Installation

The direction of foam rise for in-situ foam installation and prefabricated foam slabs shall be parallel with the vertical axis of the package. The surrounding walls of each part, OCA body and OCA lid, where the liquid foam material is to be installed shall be between 55 °F and 95 °F prior to foam installation. Measure and record the component wall temperature to an accuracy of ±2 °F prior to foam installation.

In the case of multiple pours into a single foamed component, no pour-to-pour interface shall occur within eight inches of the closure interface on the OCA body. In addition, the cured level of each pour shall be measured and recorded to an accuracy of ±1-inch.

Measure and record the weight of liquid foam material installed during each pour to an accuracy of ±10 pounds.

For in-situ foam, all test samples shall be poured into disposable containers at the same time as the actual pour it represents, clearly marking the test sample container with the pour date and a unique pour identification number. For foam slabs, all test samples shall be taken from the actual foam slabs that will be utilized in the NPC packaging. All test samples shall be cut from a larger block to obtain freshly cut faces. Prior to physical testing, each test sample shall be cleaned of superfluous foam dust.

8.1.4.1.1.5 Polyurethane Foam Pour and Test Data Records

A production pour and testing record shall be compiled by the foam supplier during the foam pouring operation and subsequent physical testing. Upon completion of production and testing, the foam supplier shall issue a certification referencing the production record data and test data pertaining to each foamed component. At a minimum, relevant pour and test data shall include:

- Formulation, batch, and pour numbers, with foam material traceability, and pour date.
- Foamed component description, part number, and serial number.
- Instrumentation description, serial number, and calibration due date.
- Pour and test data (e.g., date, temperature, dimensional and/or weight measurements.
- Technician and Quality Assurance/Quality Control (QA/QC) sign-off.

8.1.4.1.2 Physical Characteristics

The following subsections delineate the required physical characteristics of the polyurethane foam material utilized for the NPC packaging design. All pertinent data, as identified in the following subsections, shall be recorded.

Testing for the various polyurethane foam physical characteristics is based on a "formulation", "batch", or "pour", as defined in Section 8.1.4.1.1, *Introduction and General Requirements*.

8.1.4.1.2.1 Physical Characteristics Determined for a Foam Formulation

Foam material physical characteristics for the following parameters shall be determined once for a particular foam formulation. If multiple components are to be foamed utilizing a specific foam formulation, then additional physical testing, as defined below, need not be performed.

8.1.4.1.2.1.1 Thermal Expansion Coefficient

1. Three (3) test samples shall be taken from the sample pour. Each test sample shall be a rectangular prism with a minimum cross-section of 1.0-inch square and a minimum length of 6.0-inches.
2. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature (T_{RT}) to an accuracy of ±2 °F.

3. Measure and record the room temperature length (L_{RT}) of each test sample to an accuracy of ±0.001 inches.
4. Place the test samples in a -40 °F to -60 °F cold environment for a minimum of three hours. Measure and record the cold environment temperature (T_C) to an accuracy of ±2 °F.
5. Measure and record the cold environment length (L_C) of each test sample to an accuracy of ±0.001 inches.
6. Determine and record the thermal expansion coefficient for each cold environment test sample as follows:

$$\alpha_C = \frac{(L_{RT} - L_C)}{(L_{RT})(T_{RT} - T_C)}, \ \text{in / in/°F}$$

7. Place the test samples in a 180 °F to 200 °F hot environment for a minimum of three hours. Measure and record the hot environment temperature (T_H) to an accuracy of ±2 °F.
8. Measure and record the hot environment length (L_H) of each test sample to an accuracy of ±0.001 inches.
9. Determine and record the thermal expansion coefficient for each hot environment test sample as follows:

$$\alpha_H = \frac{(L_H - L_{RT})}{(L_{RT})(T_H - T_{RT})}, \ \text{in / in/°F}$$

10. Determine and record the average thermal expansion coefficient of each cold and hot environment test sample as follows:

$$\alpha = \frac{\alpha_C + \alpha_H}{2}, \ \text{in/in/°F}$$

11. Determine and record the thermal expansion coefficient of each test sample. The thermal expansion coefficient of each test sample shall nominally be 3.5×10^{-5} in/in/°F ±25% (i.e., within the range of 2.6×10^{-5} to 4.4×10^{-5} in/in/°F).
12. Determine and record the average thermal expansion coefficient of the three test samples. The numerically averaged thermal expansion coefficient of the three test samples shall nominally be 3.5×10^{-5} in/in/°F ±20% (i.e., within the range of 2.8×10^{-5} to 4.2×10^{-5} in/in/°F).

8.1.4.1.2.1.2 Thermal Conductivity

1. The thermal conductivity test shall be performed using a Heat Flow Meter (HFM) apparatus. The HFM establishes steady state unidirectional heat flux through a test specimen between two parallel plates at constant but different temperatures. By measurement of the plate temperatures and plate separation, Fourier's law of heat conduction is used by the HFM to automatically calculate thermal conductivity. Description of a typical HFM is provided in ASTM C518[3]. The HFM shall be calibrated against a traceable reference specimen per the HFM manufacturer's operating instructions.

[3] ASTM C518, *Standard Test Method for Steady-State Heat Flux Measurement and Thermal Transmission Properties by Means of the Heat Flux Meter Apparatus*, American Society of Testing and Materials (ASTM).

2. Three (3) test samples shall be taken from the sample pour. Each test sample shall be of sufficient size to enable testing per the HFM manufacturer's operating instructions.
3. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples.
4. Measure and record the necessary test sample parameters as input data to the HFM per the HFM manufacturer's operating instructions.
5. Perform thermal conductivity testing and record the measured thermal conductivity for each test sample following the HFM manufacturer's operating instructions.
6. Determine and record the thermal conductivity of each test sample. The thermal conductivity of each test sample shall lie within ±25% of the nominal value as shown in Table 8-1.1.
7. Determine and record the average thermal conductivity of the three test samples. The numerically averaged thermal conductivity of the three test samples shall lie within ±20% of the nominal value as shown in Table 8-1.1.

8.1.4.1.2.1.3 Specific Heat

1. The specific heat test shall be performed using a Differential Scanning Calorimeter (DSC) apparatus. The DSC establishes a constant heating rate and measures the differential heat flow into both a test specimen and a reference specimen. Description of a typical DSC is provided in ASTM E1269[4]. The DSC shall be calibrated against a traceable reference specimen per the DSC manufacturer's operating instructions.
2. Three (3) test samples shall be taken from the sample pour. Each test sample shall be of sufficient size to enable testing per the DSC manufacturer's operating instructions.
3. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples.
4. Measure and record the necessary test sample parameters as input data to the DSC per the DSC manufacturer's operating instructions.
5. Perform specific heat testing and record the measured specific heat for each test sample following the DSC manufacturer's operating instructions.
6. Determine and record the specific heat of each test specimen. The specific heat of each test sample shall nominally be 0.47 Btu/lb_m-°F ±25% (i.e., within the range of 0.35 to 0.59 Btu/lb_m-°F).
7. Determine and record the average specific heat of the three test specimens. The numerically averaged specific heat of the three test samples shall nominally be 0.47 Btu/lb_m-°F ±20% (i.e., within the range of 0.38 to 0.56 Btu/lb_m-°F).

8.1.4.1.2.1.4 Leachable Chlorides

1. The leachable chlorides test shall be performed using an Ion Chromatograph (IC) apparatus. The IC measures inorganic anions of interest (i.e., chlorides) in water. Description of a

[4] ASTM E1269, *Standard Test Method for Determining Specific Heat Capacity by Differential Scanning Calorimetry*, American Society of Testing and Materials (ASTM).

typical IC is provided in EPA Method 300.0[5]. The IC shall be calibrated against a traceable reference specimen per the IC manufacturer's operating instructions.

2. One (1) test sample shall be taken from a pour from each foam batch. The test sample shall be a cube with dimensions of 2.00 ±0.03 inches.
3. Place the test sample in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test sample. Measure and record the room temperature to an accuracy of ±2 °F.
4. Obtain a minimum of 550 ml of distilled or deionized water for testing. The test water shall be from a single source to ensure consistent anionic properties for testing control.
5. Obtain a 400 ml, or larger, contaminant free container that is capable of being sealed. Fill the container with 262 ±3 ml of test water. Fully immerse the test sample inside the container for a duration of 72 ±3 hours. If necessary, use an inert standoff to ensure the test sample is completely immersed for the full test duration. Seal the container.
6. Obtain a second, identical container to use as a "control". Fill the control container with 262 ±3 ml of the same test water. Seal the control container.
7. At the end of the test period, measure and record the leachable chlorides in the test water per the IC manufacturer's operating instructions. The leachable chlorides in the test water shall not exceed one part per million (1 ppm).
8. Should leachable chlorides in the test water exceed 1 ppm, measure and record the leachable chlorides in the test water from the "control" container. The difference in leachable chlorides from the test water and "control" water sample shall not exceed 1 ppm.

8.1.4.1.2.2 Physical Characteristics Determined for a Foam Pour

Foam material physical characteristics for the following parameters shall be determined for each foam pour based on the formulation defined in Section 8.1.4.1.2.1, *Physical Characteristics Determined for a Foam Formulation.*

8.1.4.1.2.2.1 Density

1. Three (3) test samples shall be taken from the foam pour. Each test sample shall be a rectangular prism with nominal dimensions of 1.0-inch thick (T), minimum, × 2.0-inches wide (W) × 2.0-inches long (L).
2. Place the test samples in a room (ambient) temperature environment (i.e., 65 to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.
3. Measure and record the weight of each test sample to an accuracy of ±0.01 grams.
4. Measure and record the thickness, width, and length of each test sample to an accuracy of ±0.001 inches.

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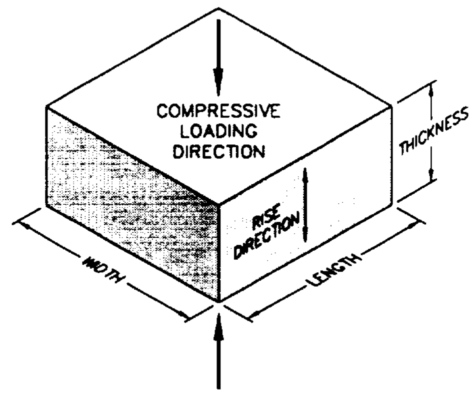
[5] EPA Method 300.0, *Determination of Inorganic Anions in Water by Ion Chromatography*, U.S. Environmental Protection Agency.

5. Determine and record the room temperature density of each test sample utilizing the following formula:

$$\rho_{foam} = \frac{\text{Weight, g}}{453.6 \text{ g/lb}} \times \frac{1{,}728 \text{ in}^3/\text{ft}^3}{T \times W \times L \text{ in}^3}, \text{ lb/ft}^3$$

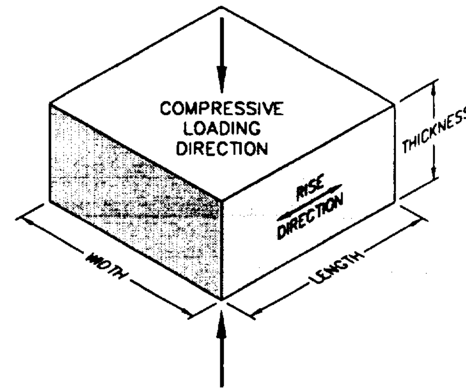
6. Determine and record the density of each test sample. The density of each test sample shall be +20%/-15% of specified nominal density.
7. Determine and record the average density of the three test samples. The numerically averaged density of the three test samples shall be +15%/-10% of specified nominal density.

8.1.4.1.2.2.2 Parallel-to Rise Compressive Stress



1. Three (3) test samples shall be taken from the foam pour. Each test sample shall be a rectangular prism with nominal dimensions of 1.0-inch thick (T) × 2.0-inches wide (W) × 2.0-inches long (L). The thickness dimension shall be the parallel-to-rise direction.
2. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.
3. Measure and record the thickness, width, and length of each test sample to an accuracy of ±0.001 inches.
4. Compute and record the surface area of each test sample by multiplying the width by the length (i.e., W × L).
5. Place a test sample in a Universal Testing Machine. Lower the machine's crosshead until it touches the test sample. Set the machine's parameters for the thickness of the test sample.
6. Apply a compressive load to each test sample at a rate of 0.10 ±0.05 inches/minute until a strain of 70%, or greater, is achieved. For each test sample, plot the compressive stress versus strain and record the compressive stress at strains of 10%, 40%, and 70%.
7. Determine and record the parallel-to-rise compressive stress of each test sample from each batch pour for each foam density. As delineated in Tables 8-1.2 through 8-1.4, the parallel-to-rise compressive stress for each batch pour shall be the nominal compressive stress ±25% at strains of 10%, 40%, and 70%.
8. Determine and record the average parallel-to-rise compressive stress of the three test samples from each batch pour for each foam density. As delineated in Tables 8-1.2 through 8-1.4, the average parallel-to-rise compressive stress for each batch pour shall be the nominal compressive stress ±20% at strains of 10%, 40%, and 70%.
9. Determine and record the average parallel-to-rise compressive stress of all test samples from each foamed component. As delineated in Tables 8-1.2 through 8-1.4, the average parallel-to-rise compressive stress for a foamed component shall be the nominal compressive stress ±15% at strains of 10%, 40%, and 70%. Note that the strength for the 40 lb/ft^3 foam need not be tested.

8.1.4.1.2.2.3 Perpendicular-to-Rise Compressive Stress



1. Three (3) test samples shall be taken from the foam pour. Each test sample shall be a rectangular prism with nominal dimensions of 1.0-inch thick (T) × 2.0-inches wide (W) × 2.0-inches long (L). The thickness dimension shall be the perpendicular-to-rise direction.
2. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.
3. Measure and record the thickness, width, and length of each test sample to an accuracy of ±0.001 inches.
4. Compute and record the surface area of each test sample by multiplying the width by the length (i.e., W × L).
5. Place a test sample in a Universal Testing Machine. Lower the machine's crosshead until it touches the test sample. Set the machine's parameters for the thickness of the test sample.
6. Apply a compressive load to each test sample at a rate of 0.10 ±0.05 inches/minute until a strain of 70%, or greater, is achieved. For each test sample, plot the compressive stress versus strain and record the compressive stress at strains of 10%, 40%, and 70%.
7. Determine and record the perpendicular-to-rise compressive stress of each test sample from each batch pour for each foam density. As delineated in Tables 8-1.2 through 8-1.4, the perpendicular-to-rise compressive stress for each batch pour sample shall be the nominal compressive stress ±25% at strains of 10%, 40%, and 70%.
8. Determine and record the average perpendicular-to-rise compressive stress of the three test samples from each batch pour for each foam density. As delineated in Tables 8-1.2 through 8-1.4, the average perpendicular-to-rise compressive stress for each batch pour shall be the nominal compressive stress ±20% at strains of 10%, 40%, and 70%.
9. Determine and record the average perpendicular-to-rise compressive stress of all test samples from each foamed component. As delineated in Tables 8-1.2 through 8-1.4, the average perpendicular-to-rise compressive stress for a foamed component shall be the nominal compressive stress ±15% at strains of 10%, 40%, and 70%. Note that the strength for the 40 lb/ft^3 foam need not be tested.

8.1.4.2 Ceramic Fiber Board and Braided Rope

This section establishes the requirements and acceptance criteria for inspection and testing of Ceramic Fiber Board (CFB) and Ceramic Fiber Braided Rope (CFBR) utilized within the NPC packaging.

8.1.4.2.1 Ceramic Fiber Board and Braided Rope Composition

The ceramic fiber supplier shall certify that the composition of the Ceramic Fiber Board (CFB) and Ceramic Fiber Braided Rope (CFBR) has a fiber content of 100% amorphous alumina-silca fibers.

8.1.4.2.2 Ceramic Fiber Board Density

1. Three (3) test samples shall be taken from each lot of ceramic fiber board. Each test sample shall be one-square foot with nominal dimensions of 12.0-inches wide (W) × 12.0-inches long (L).
2. Place the test samples in a room (ambient) temperature environment (i.e., 65 to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.
3. Measure and record the weight of each test sample to an accuracy of ±0.01 grams.
4. Measure and record the width and length of each test sample to an accuracy of ±0.10 inches.
5. Measure and record the thickness (T) by utilizing a 4 lb_m/ft^2 plate and a digital indicator equipped with a blunt or pointed foot mounted on the contact stem.
6. Determine and record the room temperature density of each test sample utilizing the following formula:

$$\rho_{cfb} = \frac{\text{Weight, g}}{453.6 \text{ g/lb}} \times \frac{1{,}728 \text{ in}^3/\text{ft}^3}{T \times W \times L \text{ in}^3}, \text{ lb/ft}^3$$

7. Determine and record the density of each test sample. The density of each test sample shall be nominally be 17.5 lb/ft^3 ±25% (i.e., within the range of 13.1 to 21.9 lb/ft^3).
8. Determine and record the average density of the three test samples. The numerically averaged density of the three test samples shall be nominally be 17.5 lb/ft^3 ±20% (i.e., within the range of 14.0 to 21.0 lb/ft^3).

8.1.4.2.3 Ceramic Fiber Braided Rope Density

1. Three (3) test samples shall be taken from each lot of 1-inch × 1-inch ceramic fiber braided rope. Each test sample shall be 12.0 inches long (L).
2. Place the test samples in a room (ambient) temperature environment (i.e., 65 to 85 °F) for sufficient time to thermally stabilize the test samples. Measure and record the room temperature to an accuracy of ±2 °F.
3. Measure and record the weight of each test sample to an accuracy of ±0.1 grams.
4. Measure and record the length of each test sample to an accuracy of ±0.1 inches.
5. Determine and record the room temperature density of each test sample utilizing the following formula:

$$\rho_{cfb} = \frac{\text{Weight, g}}{453.6 \text{ g/lb}} \times \frac{1{,}728 \text{ in}^3/\text{ft}^3}{1.0 \times 1.0 \times L \text{ in}^3}, \text{ lb/ft}^3$$

6. Determine and record the density of each test sample. The numerically density of each test sample shall be nominally be 36 lb/ft^3 ±25% (i.e., within the range of 25.0 to 45.0 lb/ft^3).
7. Determine and record the average density of the three test samples. The numerically averaged density of the three test samples shall be nominally be 36 lb/ft^3 ±20% (i.e., within the range of 28.8 to 43.2 lb/ft^3).

8.1.4.2.4 Thermal Conductivity

1. The thermal conductivity test shall be performed using a Guarded-Hot-Plate (GHP) apparatus. The GHP is an absolute (or primary) method of measurement that establishes steady state unidirectional heat flux through a test specimen between two parallel plates at constant but different temperatures. By measurement of the plate temperatures and plate separation, Fourier's law of heat conduction is used by the GHP to calculate thermal conductivity. Description of a typical GHP test method is provided in ASTM C177. The GHP shall be calibrated against a traceable reference specimen per the GHP manufacturer's operating instructions.
2. Three (3) test samples shall be taken from a ceramic fiber board lot and a braided rope lot. Each test sample shall be of sufficient size to enable testing per the GHP manufacturer's operating instructions.
3. Place the test samples in a room (ambient) temperature environment (i.e., 65 °F to 85 °F) for sufficient time to thermally stabilize the test samples.
4. Measure and record the necessary test sample parameters as input data to the GHP per the GHP manufacturer's operating instructions.
5. Perform thermal conductivity testing and record the measured thermal conductivity for each test sample following the GHP manufacturer's operating instructions.
6. Determine and record the thermal conductivity of each test sample. The thermal conductivity of each test sample shall be within ±25% of the nominal value.
7. Determine and record the average thermal conductivity of the three test samples. The numerically averaged thermal conductivity of the three test samples shall be within ±20% of the nominal value.

8.1.4.3 Cadmium Sheeting

This section establishes the requirements and acceptance criteria for inspection and testing of cadmium sheeting utilized within the NPC packaging.

8.1.4.3.1 Cadmium Purity

The cadmium sheets used to wrap the exterior of the ICCA shall be purchased to ASTM B440-98[6]. except the cadmium supplier shall certify that the cadmium purity is 99.9% minimum. A sample of cadmium from each lot shall be independently analyzed to verify the 99.9% minimum cadmium purity has been met.

8.1.4.3.2 Cadmium Thickness

Prior to installation, each cadmium sheet used to wrap the ICCA shall be inspected for thickness at a minimum of two locations to verify the .020 inch minimum requirement. In addition, the cadmium sheets used to wrap a single ICCA shall be weighed to ±3 grams. Based upon the total cadmium weight, the initial ICCA average OD, the length of the cadmium wrap, and the density

[6] ASTM B440-98, Standard Specification for Cadmium, American Society of Testing and Materials (ASTM)

of cadmium (8.65 grams/cc), a calculation shall be made to determine the average cadmium thickness which shall be .021 inch minimum.

8.1.4.4 Polyethylene Sheeting

This section establishes the requirements and acceptance criteria for inspection and testing of High Density Polyethylene (HDPE) sheeting utilized within the NPC packaging.

8.1.4.4.1 Polyethylene Composition

The supplier shall certify that the polyethylene is High Density Polyethylene (HDPE).

8.1.4.4.2 Density

Each lot of HDPE shall be verified to have a density value between 0.941 and 0.985 grams/cc.

8.1.4.4.3 Hydrogen Content

A sample of each lot of HDPE shall be analyzed for hydrogen content. The result of this analysis shall be 14.0 weight percent minimum.

8.1.4.4.4 Wrapped ICCA Polyethylene Weight Density

Each ICCA shall be weighed before and after polyethylene wrapping to ±3 grams. Based upon the pre-wrap average outer diameter of the ICCA, the wrapped polyethylene length, and the net polyethylene weight, a calculation shall be made to ensure that an equivalent polyethylene density minimum of 0.92 grams/cc for a minimum 0.57 inch thickness is satisfied.

8.1.4.4.5 Wrapped ICCA Hydrogen Areal Density

1. Measure and record the outer diameter of the ICCA shell with the cadmium sheet installed to an accuracy of ±0.03 inches. This diameter is the inner diameter (ID) of the polyethylene wrapping.
2. After installation of the polyethylene sheet, measure and record the height (H) of the polyethylene wrapping to an accuracy of ±0.1 inches.
3. Utilizing the polyethylene weight (W) determined in §8.1.4.4.4, *Wrapped ICCA Polyethylene Weight Density*, determine and record the hydrogen areal density of each ICCA utilizing the following formula:

$$\rho_{H\text{-areal}} = \frac{0.14\,(W)}{\pi\,(ID)\,(H)(6.452\,cm^2/in^2)},\ grams/cm^2$$

4. The hydrogen areal density of each ICCA shall be a minimum of 0.199 grams/cm^2. This areal density value is based on minimum polyethylene thickness of 0.57 inches, a minimum polyethylene height of 30.3 inches, a minimum polyethylene density of 0.92 grams/cc, and a minimum polyethylene hydrogen content of 14.0%.

8.1.5 Test for Shielding Integrity

The NPC package does not contain any biological shielding.

8.1.6 Thermal Acceptance Tests

The material properties utilized in Chapter 3.0, *Thermal*, are consistently conservative for the Normal Conditions of Transport (NCT) thermal analysis performed. The Hypothetical Accident Condition (HAC) fire certification testing of the NPC package (see Section 2.10.1, *Certification Tests*) served to verify material performance in the HAC thermal environment. As such, with the exception of the tests required for specific packaging components, as discussed in Section 8.1.4, *Component Tests*, specific acceptance tests for material thermal properties are not required or performed.

8.1.7 ICCA Neutronic Confirmation

Prior to first use, each ICCA shall be evaluated utilizing neutron reflectometry techniques to confirm that the neutronic configuration is correct.

8.1.8 Neutron Moderating Stability of Polyurethane Foam

The polyurethane foam is highly durable and the stability of the hydrogen content (neutron moderating component) has been demonstrated for both NCT and HAC. Since the hydrogen is molecular in nature, there is no reason to suspect that its content or functionality will change. Notwithstanding these facts, archive samples of the 7-lb/ft^3 slab foam will be collected at the rate of one slab at random for each group of 50 packages fabricated. These archive samples will be sealed and retained so that in case of any suspected degradation of the packages during their life, the material will be quickly available for evaluation.

Table 8-1.1 - Foam Thermal Conductivity at 65 °F to 85 °F

	Thermal Conductivity (BTU-in)/(hr-ft^2 - °F)				
Density (lb/ft^3)	Nominal -25%	Nominal -20%	Nominal	Nominal +20%	Nominal +25%
7	0.188	0.200	0.250	0.300	0.313
11	0.217	0.231	0.289	0.347	0.361
15	0.245	0.262	0.327	0.392	0.409
40	0.420	0.448	0.560	0.672	0.700

Table 8-1.2 - Acceptable Compressive Strength Ranges for 7 lb/ft^3 Foam (psi)

	Parallel-to-Rise at Strain, $\varepsilon_{//}$			Perpendicular-to-Rise at Strain, $\varepsilon_{\perp}$		
Sample Range	ε = 10%	ε = 40%	ε = 70%	ε = 10%	ε = 40%	ε = 70%
Nominal –25%	145	156	369	120	140	363
Nominal –20%	154	166	394	128	150	387
Nominal –15%	164	177	418	136	159	411
Nominal	193	208	492	160	187	484
Nominal +15%	222	239	566	184	215	557
Nominal +20%	232	250	590	192	224	581
Nominal +25%	241	260	615	200	234	605

Table 8-1.3 – Acceptable Compressive Strength for 11 lb/ft^3 Foam (psi)

Sample Range	Parallel-to-Rise at Strain, $\varepsilon_{//}$			Perpendicular-to-Rise at Strain, $\varepsilon_{\perp}$		
	ε = 10%	ε = 40%	ε = 70%	ε = 10%	ε = 40%	ε = 70%
Nominal –25%	298	350	1013	271	338	1070
Nominal –20%	318	374	1080	289	360	1142
Nominal –15%	337	397	1148	307	383	1213
Nominal	397	467	1350	361	450	1427
Nominal +15%	457	537	1553	415	518	1641
Nominal +20%	476	560	1620	433	540	1712
Nominal +25%	496	584	1688	451	563	1784

Table 8-1.4 – Acceptable Compressive Strength for 15 lb/ft^3 Foam (psi)

Sample Range	Parallel-to-Rise at Strain, $\varepsilon_{//}$			Perpendicular-to-Rise at Strain, $\varepsilon_{\perp}$		
	ε = 10%	ε = 40%	ε = 70%	ε = 10%	ε = 40%	ε = 70%
Nominal –25%	518	648	2048	505	643	2090
Nominal –20%	553	691	2185	538	686	2230
Nominal –15%	587	734	2321	572	728	2369
Nominal	691	864	2731	673	857	2787
Nominal +15%	795	994	3141	774	986	3205
Nominal +20%	829	1037	3277	808	1028	3344
Nominal +25%	864	1080	3414	841	1071	3484

8.2 Maintenance Program

This section describes the maintenance program used to ensure continued performance of the NPC package.

8.2.1 Structural and Pressure Tests

8.2.1.1 Lifting/Tie-Down Device Load Testing

The NPC package does not contain any lifting/tie-down devices that require load testing.

8.2.1.2 Containment Boundary Pressure Testing

No pressure tests are necessary to ensure continued performance of the NPC packaging.

8.2.2 Leak Tests

No leak tests are necessary to ensure continued performance of the NPC packaging.

8.2.3 Subsystem Maintenance

8.2.3.1 Fasteners

All threaded components shall be inspected prior to each use for deformed or stripped threads. Damaged components shall be repaired or replaced prior to further use. The threaded components to be visually inspected are the OCA closure lid bolts, the OCA closure strip socket head cap screws, and the T-bolts on the band clamp assembly for the ICCA closure lids. The nylon locking nut utilized on the T-bolt for the band clamp assemblies shall be replaced after each use.

8.2.3.2 Ceramic Fiber Braided Rope

Prior to each use, inspect the ceramic fiber braided rope for tears, damage, or deterioration.

8.2.4 Valves, Rupture Disks, and Gaskets on Containment Vessel

8.2.4.1 Valves

The NPC packaging does not contain any valves.

8.2.4.2 Rupture Disks

The NPC packaging does not contain any rupture disks.

8.2.4.3 Gaskets

The gaskets on the ICCAs shall be replaced when damaged, per the size and material requirements delineated on the drawings in Appendix 1.3.1, *Packaging General Arrangement Drawings*.

8.2.5 Shielding

The NPC packaging does not contain any biological shielding.

8.2.6 Thermal

No thermal tests are necessary to ensure continued performance of the NPC packaging.

8.2.7 ICCA Neutronic Confirmation

Five (5) years after the initial service date and every 5 years thereafter, a 1% random sample of the ICCAs will be re-evaluated using neutron reflectometry (or equivalent) techniques to confirm that the neutronic configuration remains correct. If any ICCA is rejected, the entire population representative of the suspect production batch shall be 100% re-evaluated and all nonconforming items eliminated from use.