GNF-A – Americas, LLC

New Powder Container (NPC) Safety Analysis Report

NRC Docket No. 71-9294

Global Nuclear Fuel

A Joint Venture of GE, Toshiba, & Hitachi

Revised: January, 2001
September, 2002
October, 2006
July, 2007
October, 2007

January, 2001 Revision to NPC SAR

1. All references to proprietary information have been removed.
2. 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.
3. Revision 2 changes affect the Table of Contents, Chapters 1.0 (including the drawings), 2.0 and 7.0.

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.

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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 ±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.

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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.

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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.

The changes primarily involve revising Chapter 6.0, Criticality Safety Evaluation, in its entirety for approval to ship heterogeneous materials in addition to the current content authorization. (Each page is identified with the docket number, Revision 2 and the date of 9/2002.) Also requested changing the drawing numbers in the SAR to agree with current engineering department practice and various other corrections that do not affect the package's safety as tested.

Table of Contents (page iii, iv and v)	The Table of Contents was revised to reflect title and pages changes. Also, page v was added due to repagination.
Section 1.1, Introduction (Page 1-1)	Added provision to include heterogeneous as well as homogeneous material. Changed the term "uranium powder" to "uranium bearing material". Changed the term "uranium oxide powder" to "uranium oxides or compounds". Also, changed the words "powder plus powder packaging" to "…per package (includes packaging)".
Section 1.2.1.1, Packaging Description and Section 1.2.1.1.1, Outer Confinement Assembly (page 1-4)	Added wording to expand authorized content to include homogeneous or heterogeneous uranium bearing material. Changed "uranium oxide powder" to "uranium bearing material". Also, changed description of payload from "uranium oxide powder" to "uranium oxides and compounds".
Section 1.2.1.1.2, Inner Containment Canister Assembly (page 1-5)	Removed the word "powder" from "powder receptacles".
Section 1.2.1.3, Neutron Moderation and Absorption (page 1-5)	Changed "uranium oxide powder payload" to "uranium bearing payload". Also, changed the words "powder plus powder packaging" to "uranium bearing material".
Section 1.2.1.5, Heat Dissipation (page 1-5)	Changed the words "uranium oxide powder" to "uranium oxides and compounds".
Section 1.2.1.10, Shielding (page 1-6)	Changed the word "uranium oxide powder" to uranium oxides and compounds".
Section 1.2.3, Contents of Packaging (page 1-7)	Changed the wording to include a table that provides the type, form and maximum quantity of material per package. This table includes footnotes showing metal exclusions and a statement that

	the material form within every NPC must be the same. Also, provided clarification wording in the last paragraph.

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Appendix 1.3, Section 1.3.1 (page 1-8)	The drawing numbers have been changed from 0019D0001 through 0019D0008 to 177D4970, Sheets 1 through 8, Revision 0, in order to be consistent with current GNF engineering department practice.
Appendix 1.3 (Drawings)	The sheets described above are included in this Appendix. Changes include: (1) The phrase "Essential to Safety" has been added to the first seven sheets of the packaging drawing. This is consistent with our internal procedures and Regulatory Guide 7.10, Appendix A requirements. (2) The title block format has been revised. (3) The drawing number and sheet number have been added to the top right and right margin of each sheet. (4) The scale designations were removed, because they apply to the 24" x 36" drawing not the 11" x 17" drawing. Actual measurements of components are provided elsewhere on the drawings. The size of the lettering on the drawings was standardized.
Appendix 1.3, Drawing 177D4970, Sheet 2, Revision 0	Coordinates C-2 formerly called out the cover (item 50) but pointed to the lift tube (Item 5). The cover was not clearly shown in the side view at coordinates C-3. Also, the 2-15/16" length dimension of the cover plate was incorrect. To clarify the cover, "Detail U" was added at coordinates F-10. This Detail shows the relationship between the guard (Item 9) and the cover. The cover plate is now accurately depicted at coordinates C-2 and C-6 (side views) as well as the frontal view at C-3. The 2-15/16" is corrected to the actual dimension of 2-5/8". (continued on next page)

Appendix 1.3, Drawing 177D4970, Sheet 2, Revision 0 (continued from previous page)	The changes are merely a clarification of the presentation and the correction of the length dimension. There is a slight gap between the lift tube (Item 5) and the cover plate that can be seen in the frontal view. The gap is only 3/16" wide, which is too small to insert any item capable of moving the 2870 lb NPC. The package's margin of safety has not been reduced in any way by this clarification and dimensional correction. The lift pockets are still disabled for transport.
Appendix 1.3, Drawing 177D4970, Sheet 6, Revision 0	The following four items are to clarify material designations and thread specifications. (1) Detail "T" formerly specified the retainer (coordinates F-10) as AMS 5517. The material designation and descriptive characteristics have been changed to the actual material used, AMS 5510. AMS 5510 has a lower yield strength than AMS 5517. However, AMS 5510 was used in the original four certified test units and in the production run of the NPCs. AMS 5510 having been the material used in the test units validates the material's ability to perform its safety function in maintaining the lid of the ICCA in place during accident conditions. The vendor changed the material callout shortly before production began, and the change was not reflected in the SAR. This material specification clarification does not reduce the safety of the container in any way as demonstrated by the certification tests. (2) The material specification for the T-bolt (coordinates C-4) was originally labeled A-268. A-268 applies to tubing. A-286 applies to bar stock, which is the material the T-bolt is made from. The specification has been changed to A-286. This appears to have been a transposing error. The vendor has always specified and used A-286. (continued on next page)

Appendix 1.3, Drawing 177D4970, Sheet 6, Revision 0 (continued from previous page)	(3) The thread specification for the T-bolt SAR (coordinates C-4) was incorrectly translated to the NPC drawing as a 5/16-24UNF thread. The vendor specified a 5/16-24UNJF T-bolt for this application. The UNF has been corrected to UNJF for the T-bolt. The specification for the nut has also been changed to UNJF (coordinates C-3). The *dedicated* 5/16-24UNF nuts were felt to be causing unnecessary galling of the bolt because of the slight difference in thread design. This change should eliminate the operational problem. (4) The material specification for the trunnion (coordinates C-2) was originally labeled AMS 5523. AMS 5523 is a specification for 309S stainless steel sheet strip and plate. However, AMS 5525 is for A-286 super alloy sheet strip and plate. The A-286 is part of the material call out. The vendor used AMS 5525 in all retainer clamps furnished for the NPCs for both the band clamps used on the qualifying test units and the production run of the NPCs. This also is a transposing error that is being corrected with this submittal. None of the above corrections change any hardware. Therefore, there is no reduction in the safety of the package introduced by these corrections.
Section 2.1, Structural Design (page 2-1)	Changed “uranium oxide powder payload” to uranium bearing payload”.
Section 2.1.1, Discussion (page 2-1)	Changed the T-bolt callout from UNF to UNJF to conform to the drawing change on Sheet 6.

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Section 2.4.4 and 2.5 (page 2-5)	The 3/4/02 submittal corrected the material specification of Item 5 (Lift Tube) on drawing 0019D0001 to 304 stainless steel. The text of sections 2.4.4 and 2.5 are revised to reflect this correction. Additionally, the affected physical properties in the table in Section 2.5 have been changed to show 304 stainless steel values and the appropriate ASME B&PV Code references.
Section 2.4.5 (page 2-5)	Changed the term "uranium oxide powder radioactive material" to "uranium bearing radioactive material".
Section 2.5.1 (page 2-6)	The original weight of the NPC submitted in the Revision 0 (5/16/00) application was 2850 lbs. The weight was later revised to 2870 lbs to reflect the addition of corner reinforcements and increasing the ICCA moderator thickness. Sections 1.2.1.1, 1.2.1.2, 2.2, and 2.6.9 state the NPC weight as 2870 lbs. Section 2.5.1 has been revised to reflect the 20 lb weight increase and the change in the yield strength of the 304 stainless steel used in the lift tube. The yield strength is taken from the physical properties table in Section 2.5. The equations have been modified to reflect these changes.
Section 2.5.2 (pages 2-6 and 2-7)	This section develops the minimum area of any restraint used on the NPC assuming a full line of contact equal to the length (or width) of the NPC. The development was based on the use of a 10g load being applied to any side or to the top surface of an NPC. 10CFR 71.45 (b) (1) requires consideration be made for a 10g longitudinal (to the conveyance's direction of travel), a 5g transverse, or a 2g vertical loading. This section has been revised to separate the loadings in the horizontal plane (10g and 5g) from the loading in the vertical direction (2g). The lift tubes which connect to the bottom of the NPC and support the NPC are designed to provide sufficient bearing area to meet 10CFR 71.45(b)(1) requirements. (continued on next page)

Section 2.5.2 (pages 2-6 and 2-7) (continued from previous page)	The section now calculates the minimum restraint contact area for a 10g load, but the load is restricted to occur on any side of the NPC (in the horizontal plane). The NPC is geometrically square and can therefore be loaded with any side facing the direction of the conveyance's travel. Hence, the minimum contact area determined by the10g load can occur on any side of the NPC. The calculation for the minimum restraint contact area on the top of the NPC based on a 2g vertical load is added to the section. The NPC will always be maintained upright. Thus the 10CFR 71.45(b)(1) maximum 2g load may be used to specify a smaller minimum contact area for restraints bearing on the top surface of the NPC. The smaller allowable contact area on the top surface of the NPC enables the use of more efficient packing and bracing to maintain the NPCs in place during transport. The use of 2g loading in the vertical direction more closely aligns the restraint system to the regulatory requirements. There is not reduction in the restraint system to a level less than that required by 10CFR 71.45(b)(1). Therefore, the package is still safe with this new vertical loading. The foam compressive stress in this section has also been revised to conform to the foam compressive stress values in the 8/1/01 submittal. The adjustment to the compressive stresses reduces the required amount of the contact area. Hence, the presently designed NPC packing and bracing is conservative in bearing area applied to the NPC. In the second paragraph of Section 2.5.2, Tie-Down Devices, the first two sentences have been combined to correct a grammatical error.
Section 2.7.2, Crush (page 2-11, first paragraph)	Changed "uranium oxide payload" to "uranium oxides and compounds payload".

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Section 3.3 Technical Specification for Components (page 3-3)	Changed "UO_2" to "uranium bearing material".
Section 4.1.1 Containment Vessel (page 4-1)	Changed "uranium oxide powder payload" to "uranium bearing payload".
Section 7.1.2, 1., Loading the Payload into the NPC (page 7-2)	Changed "uranium oxide payload" to "uranium oxides and compounds payload". Changed "powder plus powder packaging" to "uranium compounds plus packaging".
Section 7.2.2, 7., Removal of the Payload from the NPC Package (page 7-4)	Changed "uranium oxide contents" to "uranium contents". Changed "powder receptacle" to "receptacle".
Section 8.1.4.1.2.2.1, Density (page 8-6)	This section describes the method used to determine the density of the foam. The method is to measure the height, width, length and weight of the sample, then calculate the density by dividing the sample weight by volume. Because the weight and the dimensions of the sample are accurately measured, the density calculated will be the same on a sample that has the nominal dimensions given in this section, or a smaller or larger sample. The use of the word "minimum" is contradictory to the word "nominal". The word "minimum" has been removed from the second sentence in the first line item. The sentence now requires a rectangular sample with nominal dimensions of 1 " x 2 " x 2 ". Small variations about the nominal dimensions e.g. $\pm$ 0.1" will be compensated for by the calculation using the accurately determined dimensions and sample weight. Thus, the change does not affect the calculated and reported density of any sample. There is no impact to safety associated with this change. The change is merely clarifying of wording.

October, 2006 Revision to NPC SAR

Location in SAR	Description/Explanation
Section 1.1, Introduction (Page 1-1)	Modified the wording to make clear that the package is authorized for Type A quantities of uranium bearing material.
Section 1.2.3, Contents of Packaging (Page 1-7)	Modified the wording to make clear that the package is authorized for Type A quantities of uranium bearing material. Updated the authorized contents table to provide more internationally acceptable definitions and limits.
Appendix 1.3, Section 1.3.1, Packaging General Arrangement Drawings (Page1-8)	Added reference for Drawing Number SK105E4037, Revision 1 for the high-density plastic bottle that is currently used as receptacles for the payload and the drawing.
Table 6.1, UO_2 and Uranium Equivalent Mass Limits* per NPC Package (Page 6-1)	Revised the heterogeneous pellet limits to be consistent with the current Nuclear Safety recommended limits in this request for approval.
Section 7.1.2 (1), Loading the Payload into the NPC (Page 7-2)	Modified the first loading step to make it clear what is intended regarding the limitations placed on the package by the designer and approval in the U.S. Certificate of Compliance.

<u>July, 2007 Revision to NPC SAR</u>

Three pages from Chapter 1, Section 1.1, Chapter 6, Sections 6.1 and 6.6.5 of the Safety Analysis Report (SAR) were revised to incorporate the corrected Criticality Safety Index (CSI) nomenclature which has replaced the Transport Index (TI)

Chapter 1, Section 1.1
Chapter 6, Sections 6.1 and 6.6.5

October, 2007 Revision to NPC SAR

Updated drawings No. 177D4970, Sheet 1, Revision 1 and No. 177D4970, Sheet 8, Revision 1 updated to reflect the "-96" designation on the package label.

- No. 177D4970, Sheet 1, Revision 1
- No. 177D4970, Sheet 8, Revision 1

Four (4) revised pages of the Safety Analysis Report (SAR)

- Page 1-7, Chapter 1, Section 1.2.3 - updated to delete a metal receptacle and hydrogenous material footnote
- Page 1-8, Chapter 1, Section 1.3.1 - updated drawing list
- Page 6-1, Chapter 6, Sections 6.1 - revised to incorporate the corrected NPC package mass limits consistent with other sections of the application
- Page 7-2, Chapter 7, Section 7.1.2 - revised to delete the reference to metal receptacles

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 or heterogeneous forms of Type A quantities of uranium bearing material 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 bearing material 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 oxides or compounds per package (includes packaging) as a Type A(F)-96, fissile material package per the definitions delineated in 10 CFR §71.4[1]. The criticality safety index (CSI) for the package, determined in accordance with the definitions of 10 CFR §71.4, is determined for each shipment. The CSI is based on the number of packages for criticality control purposes (method for the criticality safety 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.

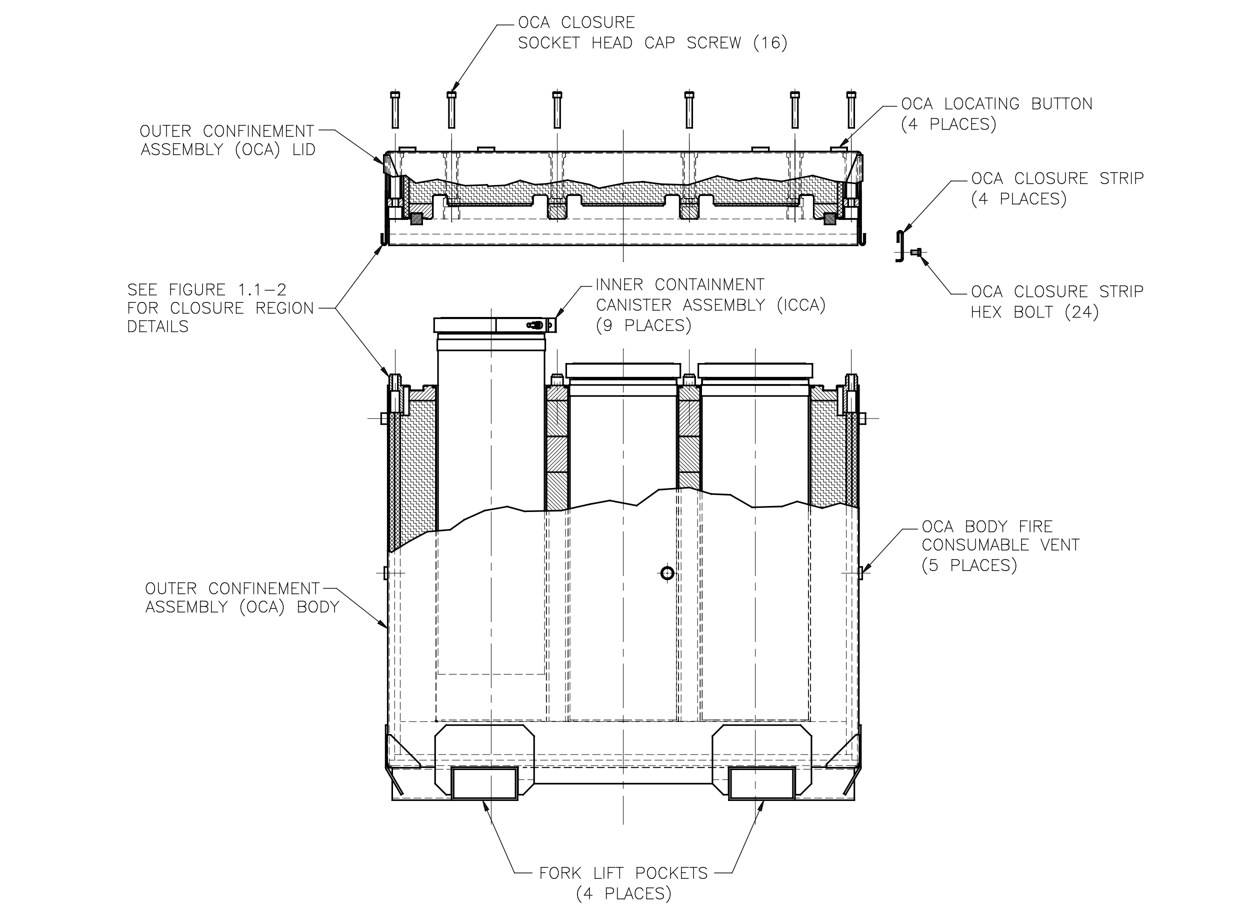

Figure 1.1-1 - GNF NPC Package Assembly (Patent #6,166,391)

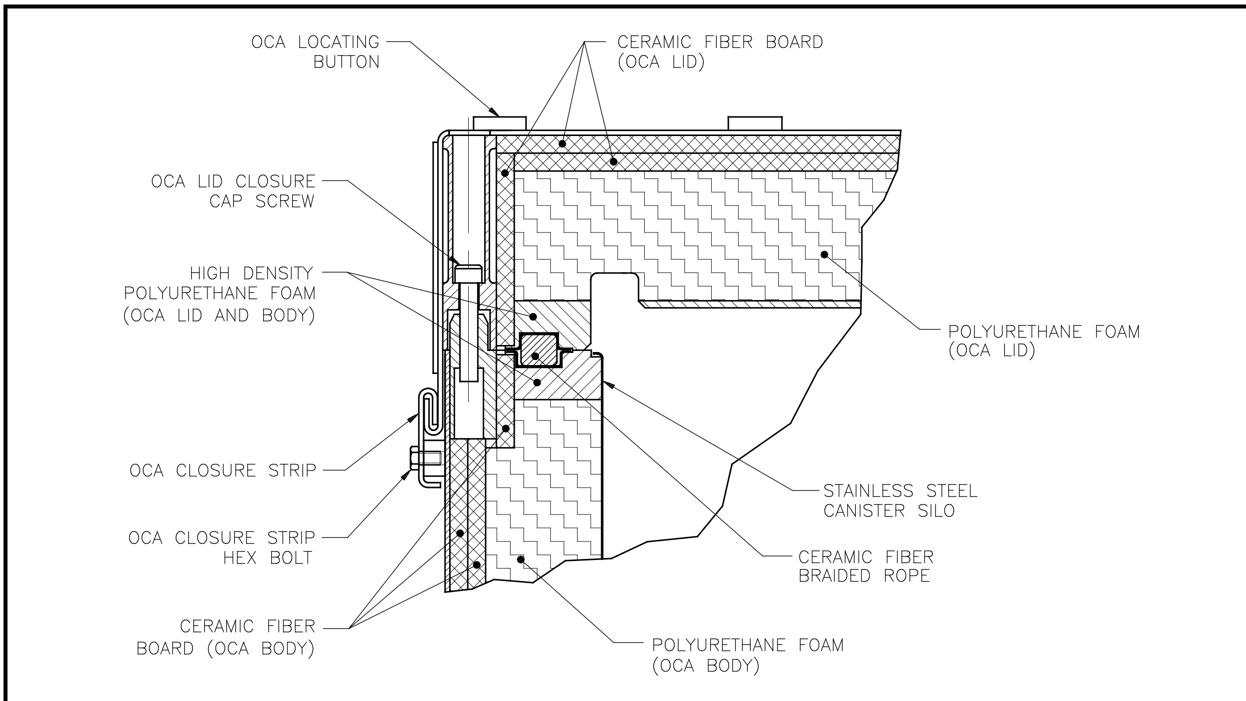

Figure 1.1-2 - GNF NPC Package Closure Region Details (Patent #6,166,391)

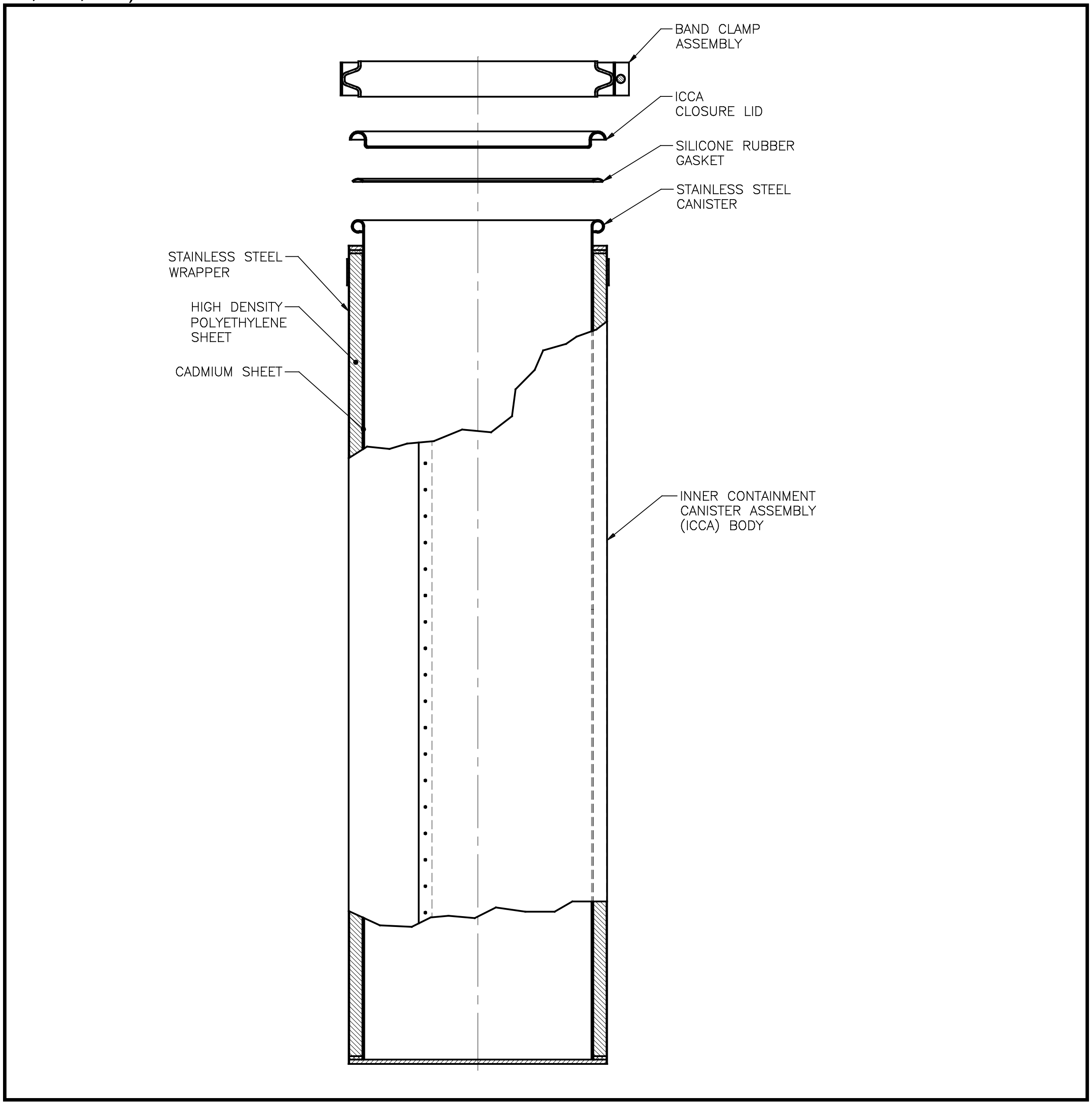

Figure 1.1-3 - GNF NPC Packaging Inner Containment Canister (Patent #6,166,391)

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 homogeneous or heterogeneous uranium bearing material 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 oxides and compounds 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 bearing material, 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 (receptacles, etc.) in the ICCA.

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 bearing 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 bearing material. 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 oxides and compounds 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 oxides and compounds 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 kg) of uranium bearing payload, including receptacles and packing material in the ICCA in accordance with the table below. The radionuclide content is Type A quantities of uranium.

Type, Form, and Maximum Quantity of Material Per Package

Material Forms[1] (<5.00 wt.% U-235)	Particle Size Restriction Minimum OD (inches)	Max. loading per ICCA (kgs)		Max. loading per NPC (kgs)	
		Net[4]	U	Net[4]	U
Homogeneous Uranium Oxide Compounds[2]	N/A	60.0	52.89	540.0	476.1
Heterogeneous UO_2 Pellets (BWR)	0.342	60.0	40.54	540.0	364.8
Heterogeneous UO_2 Pellets (PWR)	0.300	60.0	40.54	540.0	364.8
Heterogeneous Uranium Compounds[3]	Unrestricted Particle Size	60.0	40.54	540.0	364.8

[1] No solutions or liquids are authorized and there shall be no free liquid present. The Material Form within any NPC must be the same.
[2] Homogeneous compounds limited to UO_2, U_3O_8, $UO_{2\ x>2}$, dried calcium-containing sludges, $UO_2(NO_3)_2\ 6H_2O$, and uranium oxide bearing ash.
[3] Heterogeneous compounds limited to UO_2, U_3O_8, $UO_{2\ x>2.}$
[4] Maximum content weight of any ICCA including plastic receptacles (e.g., bags, bottles, etc.).

The payload within an NPC 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), and the maximum uranium payload of Table 6.1 are met. Within an ICCA, the payload is enclosed in plastic receptacles (e.g. bags, bottles, etc.).

1.3 Appendix

1.3.1 Packaging General Arrangement Drawings

This section contains the following GNF NPC packaging general arrangement drawings[2].

Drawing Number 177D4970, Sheet 1, Revision 1

Drawing Number 177D4970, Sheet 2, Revision 0

Drawing Number 177D4970, Sheet 3, Revision 0

Drawing Number 177D4970, Sheet 4, Revision 0

Drawing Number 177D4970, Sheet 5, Revision 0

Drawing Number 177D4970, Sheet 6, Revision 0

Drawing Number 177D4970, Sheet 7, Revision 0

Drawing Number 177D4970, Sheet 8, Revision 1

Drawing Number SK105E4037, Sheet 2, Revision 1

[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).

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	DESCRIPTION	BY	APPROVAL	DATE
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

GNF Global Nuclear Fuel		177D4970
J.W. MOODY	23-SEP-02	REV 0
R.P. GONZALES	23-SEP-02	SH 7 CONT ON 8

177D4970 7

177D4970 6

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	DESCRIPTION	BY	APPROVAL	DATE
0	FIRST ISSUE RMCN01146	O. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

GNF Global Nuclear Fuel	DATE	177D4970	0
J.W. MOODY	23-SEP-02		
R.P. GONZALES	23-SEP-02	SH 6	SHEET 7

F-M-AD

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	DESCRIPTION	BY	APPROVAL	DATE
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

GNF Global Nuclear Fuel	SIZE	177D4970	0
J.W. MOODY	23-SEP-02		
R.P. GONZALES	23-SEP-02	SH 5	CONT ON 6

F-IV-AC

177D4970 5

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	DESCRIPTION	BY	APPROVAL	DATE
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

GNF Global Nuclear Fuel

J.W. MOODY	23-SEP-02	177D4970	0
R.P. GONZALES	23-SEP-02	4	5

F-N-AC

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	DESCRIPTION	BY	APPROVAL	DATE
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

GNF Global Nuclear Fuel		177D4970	0
J.W. MOODY	23-SEP-02		
R.P. GONZALES	23-SEP-02	3	4

F-IV-AC

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	DESCRIPTION	BY	APPROVAL	DATE
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

GNF Global Nuclear Fuel	DATE	177D4970	0
J.W. MOODY	23-SEP-02		
R.P. GONZALES	23-SEP-02	2	3

F-N-AC

177D4970 | 1

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	DESCRIPTION	BY	APPROVAL	DATE
1	REVISED PER RMCN12448	A. LANGSTON	B.J. MILES	9/28/07
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

SAFETY-RELATED CLASSIFICATION CODE Q

SIGNATURES	DATE
J.W. MOODY	.3-SEP-0.
R.P. GONZALES	23-SEP-02
J.F. SCHARDT	25-SEP-02
D. BROWN	.5-SEP-0.

APPLIED PRACTICES N/A

ALL SURF. 125√

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

GNF
Global Nuclear Fuel

GNF NEW POWDER CONTAINER (NPC) PACKAGING

.6-SEP-02 | 177D4970 | 1

RMCN01146 | C | SH 1 | CONT ON 2

F-IV-AC

Security-Related Information
Figure Withheld Under 10 CFR 2.390

REV	DESCRIPTION	BY	APPROVAL	DATE
1	REVISED PER RMCN12448	A. LANGSTON	B.J. MILES	9/28/07
0	FIRST ISSUE RMCN01146	D. BROWN	M.T. KIERNAN	9/25/02

REVISIONS

GNF Global Nuclear Fuel

	DATE	DWG NO	REV
DRAWN J.W. MOODY	23-SEP-02	177D4970	1
CHECKED R.P. GONZALES	23-SEP-02	SH 8	CONT ON F

F-N-AC

SK105E4037 2

Security-Related Information
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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 criteria 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 bearing 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 5/16-24UNJF 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].

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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 D1.1, *Structural Welding Code – Stainless Steel*, American Welding Society (AWS).

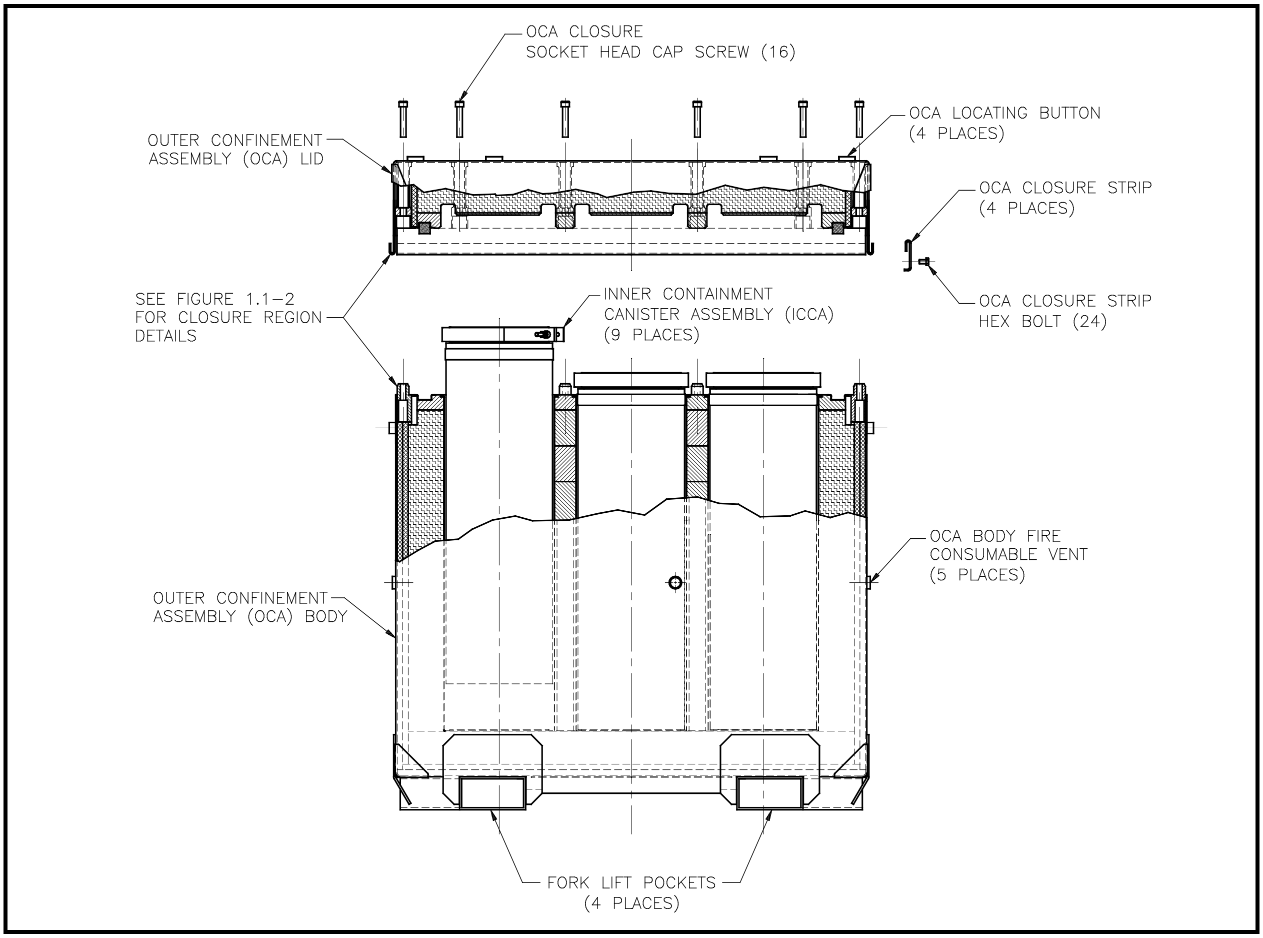

Figure 2.1-1 - Sectional View of the GNF NPC Packaging (Patent #6,166,391)

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 ºF (-40 ºC)], 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, ($x10^6$, 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 and 304 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 bearing 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 ºF. Since no surface temperature exceeds 122 ºF (50 ºC), 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 ºF, 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, except for the forklift pockets that are 304 stainless steel.

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

Material Property	Value	Reference
Elastic Modulus, E	27.6×10^6 psi	See Table 2.3.1, Note 4
Yield Strength, S_y	25,000 psi	See Table 2.3.1, Note 1
Shear Stress, equal to (0.6) S_y	15,000 psi	N/A

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 2,870 pounds, as specified in Section 2.2, *Weights and Center of Gravity*.

$$F_L = (3)\,(2{,}870) = 8{,}610 \text{ pounds}$$

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:

$$\sigma_c = \frac{F_L}{A} = \frac{8{,}610}{360} = 24 \text{ psi}$$

The allowable yield stress for the Type 304 material is 25,000 psi. Therefore, the margin of safety (MS) is:

$$MS = \frac{25{,}000}{24} - 1.0 = +\text{Large}$$

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 and the thin layer of ceramic fiber board insulation. 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 338 psi. Conservatively using the 10g requirement of §10CFR 71.45(b)(1) for both directions in the horizontal plane, and the 2g requirement for loads in the vertical plane, the minimum contact surface area (SA) is determined as follows:

$$SA_{10g} = \left[\frac{(10g)(2{,}870 \text{ lbs})}{338}\right] = 84.91 \text{ in}^2 \qquad SA_{2g} = \left[\frac{(2g)(2{,}870\ lbs)}{338}\right] = 16.98\ in^2$$

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 in the horizontal plane is:

$$Width_{\min 10g} = \frac{84.91}{42.0} = 2.02 \text{ inches}$$

Similarly, the minimum width of any blocking/bracing to resist forces in the vertical direction will be:

$$Width_{\min 2g} = \frac{16.98}{42.0} = 0.41\ in^2$$

Therefore, any structural member used as a tie-down restraint bearing on the sides of an NPC and having a width of 2.02 inches or more will not result in a foam compressive stress in excess of 338 psi. Any structural member acting as a restraint on the top surface of an NPC having a minimum width of 0.41 inches will also not result in a compressive stress within the NPC package in excess of 338 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 ºF 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 ºF (38 ºC) and full insolation is 174 ºF (79 ºC).

2.6.1.2 Differential Thermal Evaluation

Thermal conditioning of three, full scale test specimens to a steady state temperature of 132 ºF (56 ºC) 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 ºF (-40 ºC). Insolation is assumed to be zero. A NPC package was chilled to a steady-state temperature of –40 ºF (-40 ºC). 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 oxides and compounds 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 compounds. 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 ºF (800 ºC), 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 ºF (171 ºC) (lid), 330 ºF (166 ºC) (top of the outer stainless steel wrapper), and 340 ºF (171 ºC) (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 ºF (121 ºC). The ICCA pressure increase, ΔP_{ICCA}, using an initial temperature of -40 ºF (-40 ºC), 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.

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

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

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

The partial pressure due to water vapor is based on the minimum payload cavity temperature, which is 202.7 ºF (94.8 ºF). 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:

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

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.

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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.

- 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 ºF (1,260 ºC).

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/ft^3)	Thermal Conductivity [(BTU-in)/hr-ft^2- ºF)]		Specific Heat (BTU/Lb$_m$-ºF)	
	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/ft^3)	14.0 – 21.0	17.0 – 17.2 – 17.6
Thermal Conductivity [(BTU-in/hr-ft^2) - ºF]		
@ 600 ºF	0.50 – 0.74	0.546 – 0.55 – 0.555
@ 1000 ºF	0.68 – 1.02	0.795 – 0.831 – 0.858

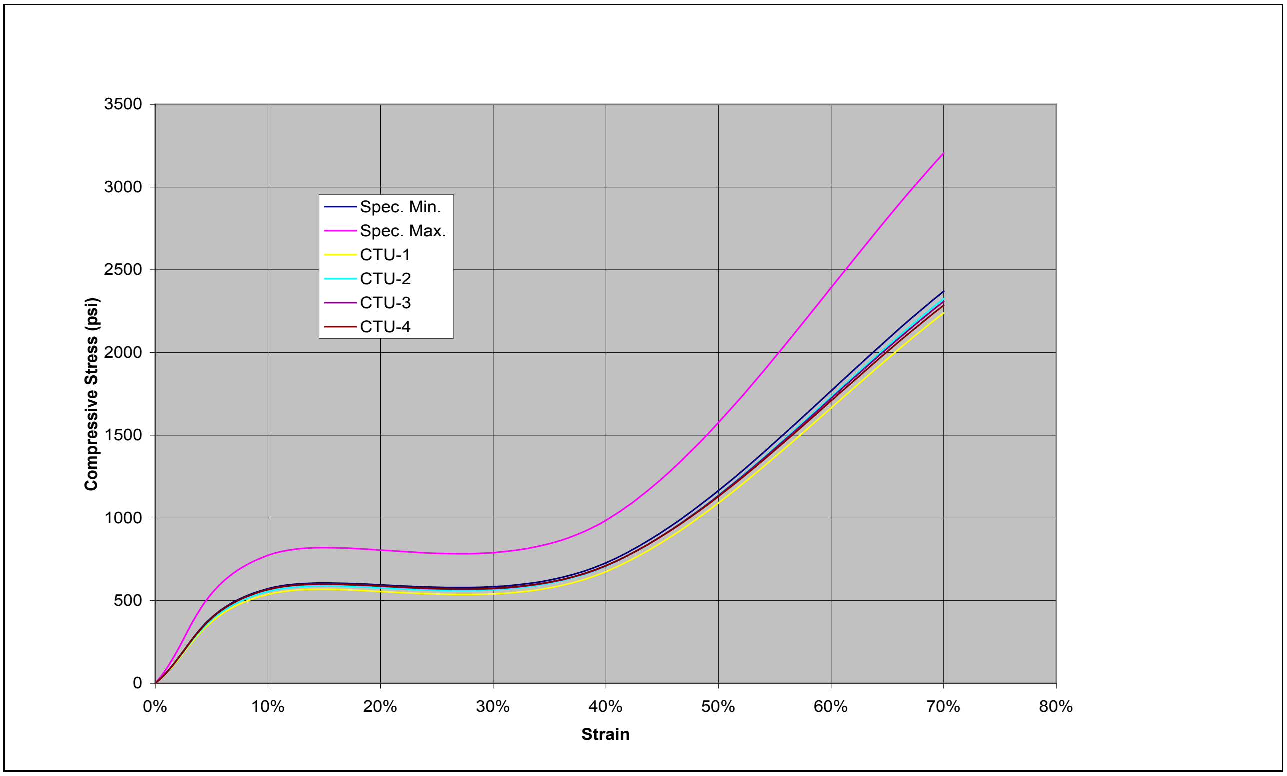


Figure 2.10.1-1 - OCA Lid Perpendicular-to-Foam Rise (15 Lbs./Ft^3)

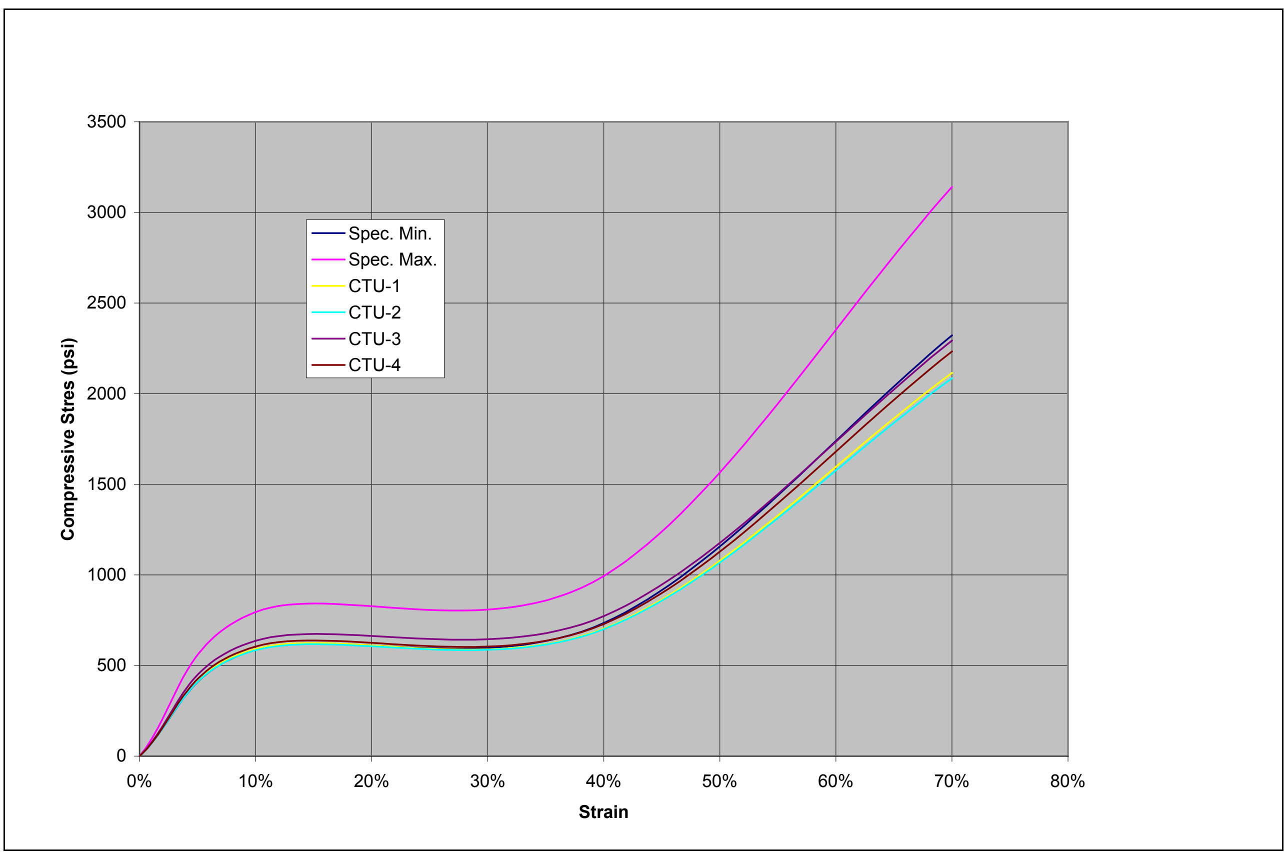


Figure 2.10.1-2 - OCA Lid Parallel-to-Foam Rise (15 Lbs./Ft^3)

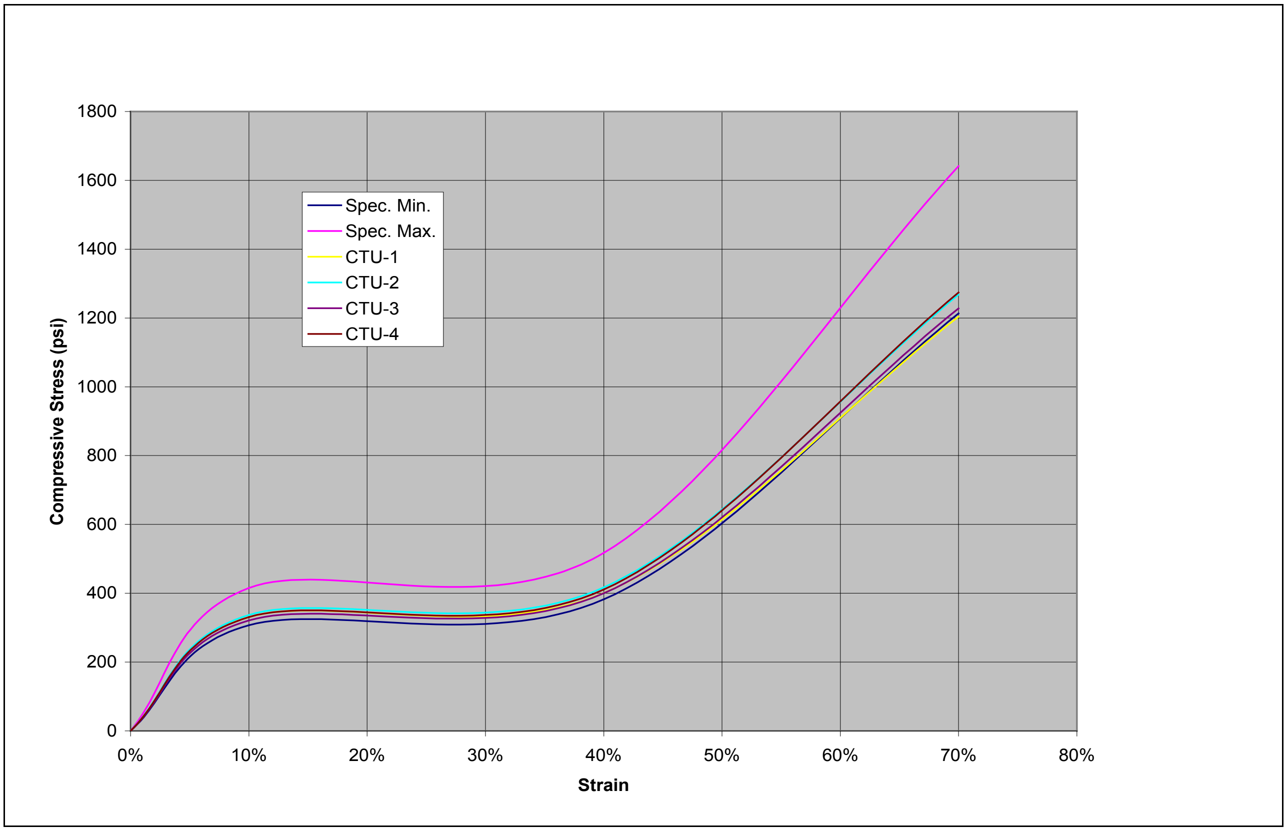


Figure 2.10.1-3 - OCA Body Perpendicular-to-Foam Rise (11 Lbs./Ft^3)

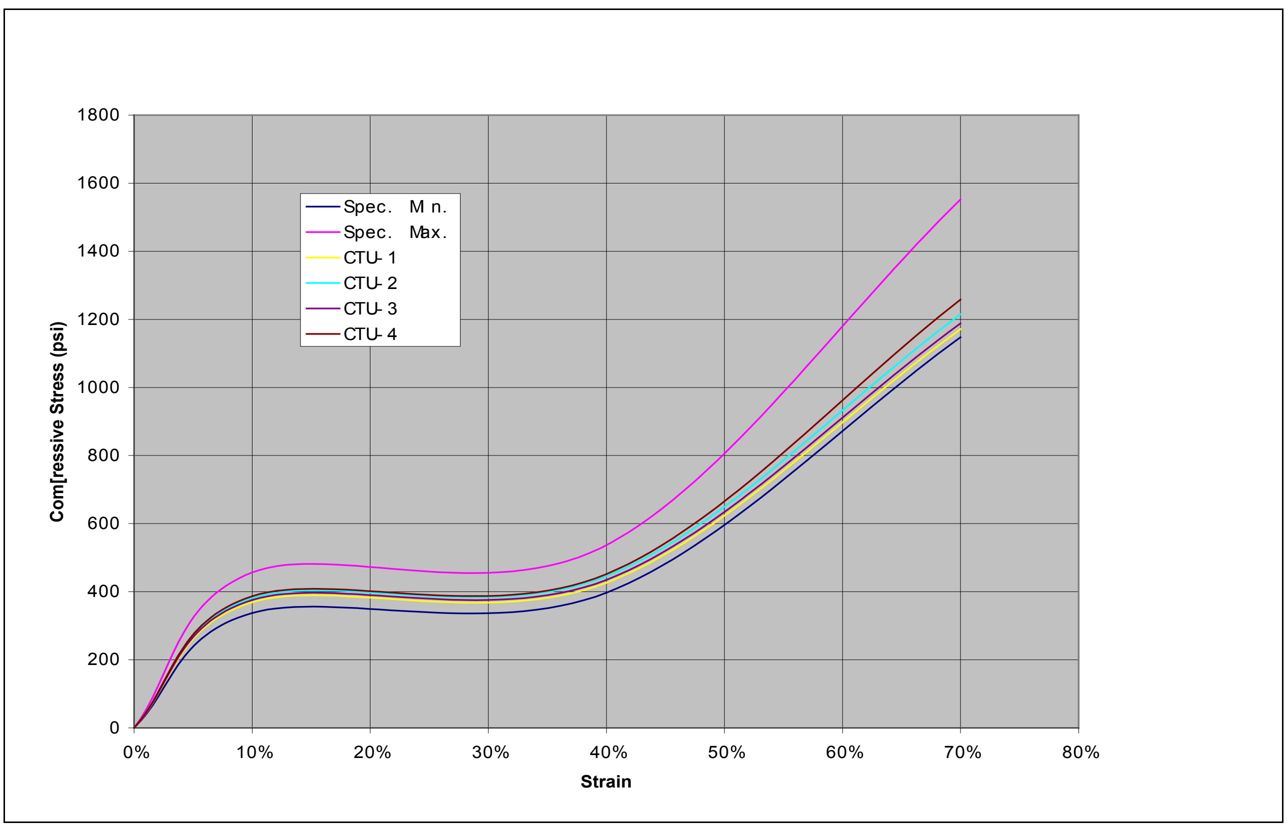


Figure 2.10.1-4 - OCA Body Parallel-to-Foam Rise (11 Lbs./Ft^3)

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)

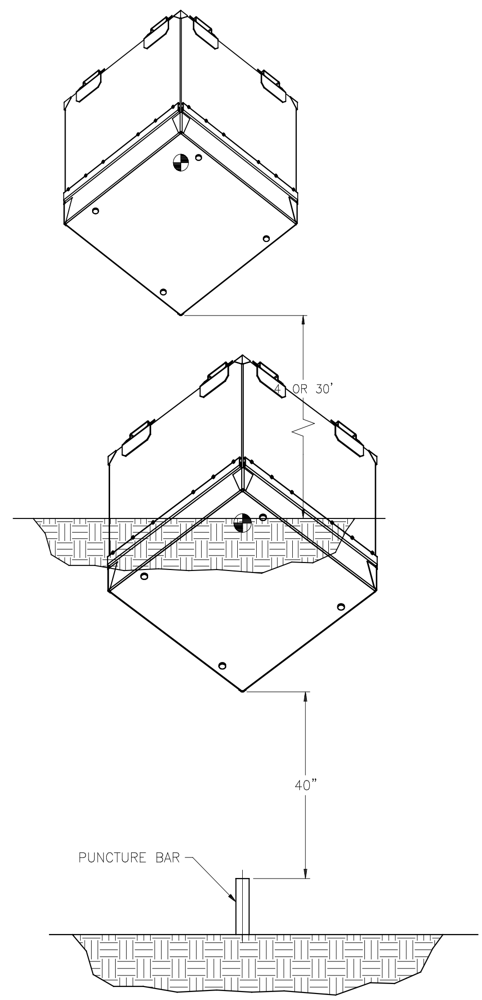
In the test on CTU-3, excessive deformation on the corner was determined to be a problem. To alleviate the excessive deformation problem, the corner of the CTU-1 OCA lid was reinforced with a 10-gauge (0.135 inch) doubler plate. CTU-1 was a re-test of the CTU-3 test sequence (CTU-3 test results were 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.

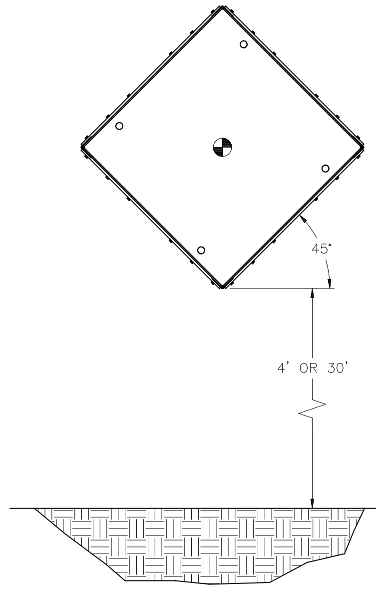
Puncture Drop No. 10 impacts adjacent to the damage created by Free Drop Tests 1 and 2, on the corner of the OCA lid. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 10 is to cause maximum damage to the most vulnerable feature (OCA Lid/Body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



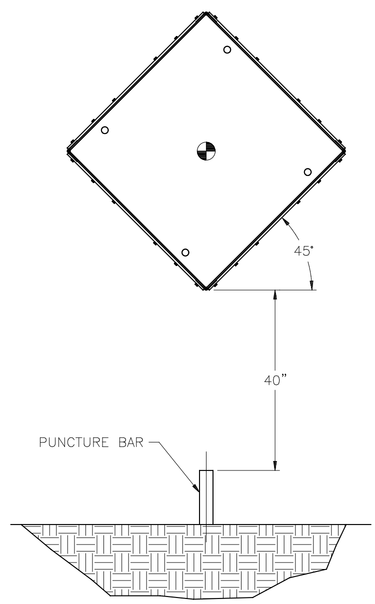
2.10.1.6.2 Certification Test Unit No. 2 (CTU-2)

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.

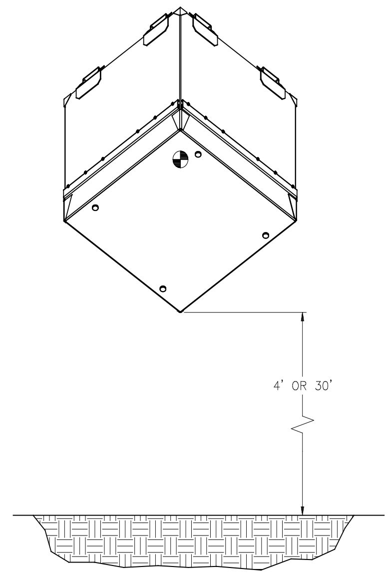


Fire Test No. 15 is performed by orientating the cumulative damage from Free Drop Tests 3 and 4, and Puncture Drop Test 9. Agricultural diesel fuel was utilized for the pool fire test. Orientation of the packaging is based on the observed damaged.

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

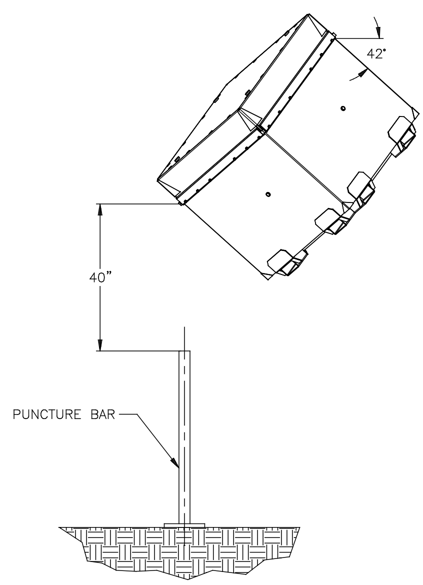
NOTE: The results from the tests on CTU-3 were not used because the lid corner damage produced unacceptable results. CTU-1 was modified to the final design configuration and tested to the same conditions as CTU-3. CTU-1 test results were used as the basis to demonstrate compliance to 10 CFR 71 requirements.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



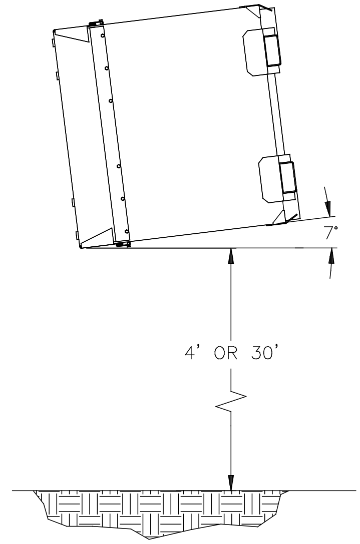
Free Drop No. 2 is a HAC free drop from a height of 30 feet, impacting the corner of the OCA lid, which is the same impact point as the NCT Free Drop No. 1. In this way, NCT and HAC free drop damage is cumulative. The 30 foot drop height is based on the requirements of 10 CFR §71.73(c)(1). The purpose 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.



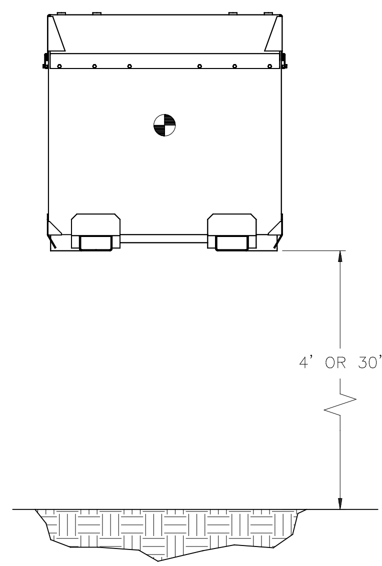
Fire Test No. 15 is performed by orientating the cumulative damage from Free Drop Tests 1 and 2, and Puncture Drop Test 11. Agricultural diesel fuel was utilized for the pool fire test. Orientation of the packaging is based on the observed damaged.

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.

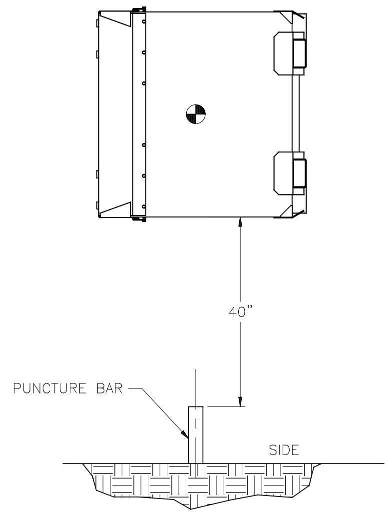
Free Drop No. 6 is a HAC free drop from a height of 30 feet, first impacting the corner of the OCA lid, followed by a slapdown of the OCA body. This test is the same impact point as the NCT Free Drop No. 5. In this way, NCT and HAC free drop damage is cumulative. The 30 foot drop height is based on the 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.



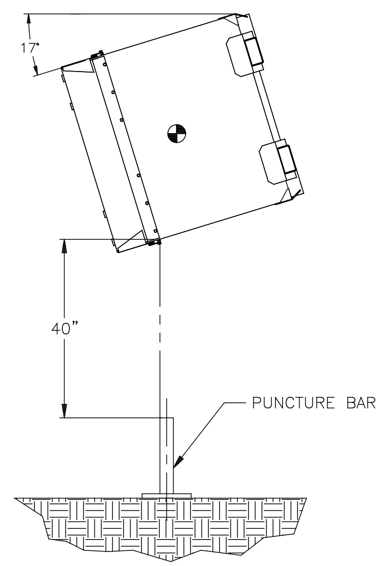
Free Drop No. 7 is a NCT free drop from a height of four feet, impacting the bottom of the OCA. The four foot drop height is based on the requirements of 10 CFR §71.71(c)(7) for a package weight not exceeding 11,000 pounds. The purpose of this test is to produce the maximum inertia loading on the packaging.

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.

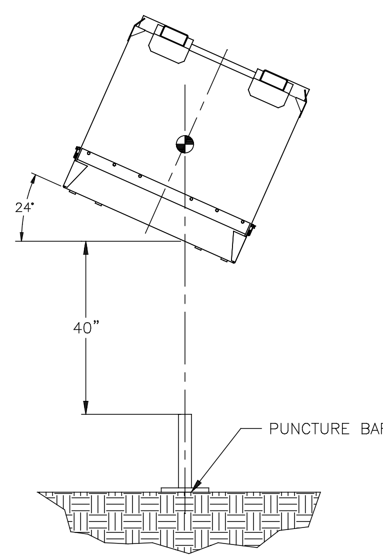
Puncture Drop No. 12 directly impacts the side of the OCA. The puncture drop height is based on the requirements of 10 CFR §71.73(c)(3). The purpose of Puncture Drop No. 12 is to cause maximum damage to the thermal protection design features of the OCA body.



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 127º, vertical axis angle 45º, and z-axis angle 45º). The following list summarizes the test parameters:

- verified x-axis angle as 127º ±1º
- verified vertical axis angle as 45º ±1º
- verified z-axis angle as 45º ±1º
- verified drop height as 4 feet, +3/-0 inches (actual drop height 4 feet)
- measured ambient temperature as 73 ºF
- 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 127º, vertical axis angle 45º, and z-axis angle 45º). The following list summarizes the test parameters:

- verified x-axis angle as 127º ±1º
- verified vertical axis angle as 45º ±1º
- verified z-axis angle as 45º ±1º
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient temperature as 70 ºF
- 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 78º, vertical axis angle 45º, and z-axis angle 45º). 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 78º ±1º
- verified vertical axis angle as 45º ±1º
- verified z-axis angle as 45º ±1º
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 75 ºF
- 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 90º, vertical axis angle 0º, and z-axis angle 0º), 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 ºF (987 ºC).
- Commenced fire testing at 5:20 p.m. on Thursday, 3/2/00. The ambient temperature was 80 ºF 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 ºF to 500 ºF.

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 ºF 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 0º, vertical axis angle 0º, and z-axis angle 0º).
- 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 ºF (149 - 154 ºC).

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 45º with respect to the horizontal impact surface (x-axis angle 135º, vertical axis angle 0º, and z-axis angle 0º). The following list summarizes the test parameters:

- verified x-axis angle as 135º ±1º

- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- verified drop height as 4 feet, +3/-0 inches (actual drop height 4 feet)
- measured ambient temperature as 52 ºF
- 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 45º with respect to the horizontal impact surface (x-axis angle 135º, vertical axis angle 0º, and z-axis angle 0º). The following list summarizes the test parameters:

- verified x-axis angle as 135º ±1º
- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient temperature as 53 ºF
- 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 19º with respect to the horizontal impact surface (x-axis angle 109º, vertical axis angle 0º, and z-axis angle 0º). The following list summarizes the test parameters:

- verified x-axis angle as 109º ±1º
- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 59 ºF
- 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 109º ±1º
- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 62 ºF
- 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 90º, vertical axis angle 0º, and z-axis angle 0º), 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 ºF (1,078 ºC).
- Commenced fire testing at 7:41 p.m. on Thursday, 2/3/00. The ambient temperature was 58 ºF 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 ºF to 500 ºF.

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 ºF 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 0º, vertical axis angle 0º, and z-axis angle 0º).
- 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 ºF (166 - 171 ºC). For the inner surface of the ICCA closure lids, the maximum temperature of any the temperature indicating labels was 310 - 320 ºF (154 - 160 ºC).

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 127º, vertical axis angle 45º, and z-axis angle 45º). The following list summarizes the test parameters:

- verified x-axis angle as 127º ±1º
- verified vertical axis angle as 45º ±1º
- verified z-axis angle as 45º ±1º
- verified drop height as 4 feet, +3/-0 inches (actual drop height 4 feet)
- measured ambient temperature as 50 ºF
- 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 127º, vertical axis angle 45º, and z-axis angle 45º). The following list summarizes the test parameters:

- verified x-axis angle as 127º ±1º

- verified vertical axis angle as 45º ±1º
- verified z-axis angle as 45º ±1º
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient temperature as 51 ºF
- 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 42º with respect to the horizontal impact surface (x-axis angle 132º, vertical axis angle 0º, and z-axis angle 0º). The following list summarizes the test parameters:

- verified x-axis angle as 132º ±1º
- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 60 ºF
- 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 90º, vertical axis angle 0º, and z-axis angle 0º), 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 ºF (1,107 ºC).
- Commenced fire testing at 6:28 p.m. on Friday, 2/4/00. The ambient temperature was 58 ºF 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 ºF to 500 ºF.

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 ºF 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 0º, vertical axis angle 0º, and z-axis angle 0º).
- 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 ºF (182 - 188 ºC). For the inner surface of the ICCA closure lids, the maximum temperature of any the temperature indicating labels was 450 - 465 ºF (232 - 241 ºC).

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 7º 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 7º with respect to the horizontal impact surface (x-axis angle 97º, vertical axis angle 0º, and z-axis angle 0º). The following list summarizes the test parameters:

- verified x-axis angle as 97º ±1º
- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- 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 7º 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 7º with respect to the horizontal impact surface (x-axis angle 97º, vertical axis angle 0º, and z-axis angle 0º). The following list summarizes the test parameters:

- verified x-axis angle as 97º ±1º
- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- 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 0º, vertical axis angle 0º, and z-axis angle 0º). The following list summarizes the test parameters:

- verified x-axis angle as 0º ±1º
- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- verified drop height as 4 feet, +3/-0 inches (actual drop height 4 feet)
- measured ambient temperature as 49 ºF
- 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 0º, vertical axis angle 0º, and z-axis angle 0º). The following list summarizes the test parameters:

- verified x-axis angle as 0º ±1º
- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- verified drop height as 30 feet, +3/-0 inches (actual drop height 30 feet)
- measured ambient temperature as 49 ºF
- 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 90º with respect to the horizontal impact surface (x-axis angle 90º, vertical axis angle 0º, and z-axis angle 0º). The following list summarizes the test parameters:

- verified x-axis angle as 90º ±1º
- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 48 ºF
- 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 17º with respect to the horizontal impact surface (x-axis angle 107º, vertical axis angle 0º, and z-axis angle 0º). The following list summarizes the test parameters:

- verified x-axis angle as 107º ±1º
- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 59 ºF
- 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 66º with respect to the horizontal impact surface (x-axis angle 156º, vertical axis angle 0º, and z-axis angle 0º). The following list summarizes the test parameters:

- verified x-axis angle as 156º ±1º
- verified vertical axis angle as 0º ±1º
- verified z-axis angle as 0º ±1º
- verified drop height as 40-inches, +1/-0 inches (actual drop height 40-inches)
- measured ambient temperature as 61 ºF
- 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 (ºF)	Test Unit Angular Orientation			Remarks
			X-Axis (0º = horizontal)	Vertical Axis (0º = upright)	Z-Axis (0º = horizontal)	
1	4 foot, CG over Lid Corner (CTU-1, CTU-3)	132	127º	45º	45º	NCT impact on most vulnerable location.
2	30 foot, CG over Lid Corner (CTU-1, CTU-3)	132	127º	45º	45º	Drop orientation on region to cause maximum deformation of most vulnerable location.
3	4 foot, CG over Lid/Side Edge (CTU-2)	132	135º	45º	0º	NCT impact on OCA closure lid/body interface.
4	30 foot, CG over Lid/Side Edge (CTU-2)	132	135º	45º	0º	Drop orientation on OCA closure lid/body interface.
5	4 foot, Shallow Angle Side Drop (CTU-4)	-40	97º	0º	0º	NCT impact to produce maximum secondary impact (slapdown).
6	30 foot, Shallow Angle Side Drop (CTU-4)	-40	97º	0º	0º	Drop orientation to produce maximum secondary impact (slapdown).
7	4 foot Bottom Drop (CTU-4)	-40	NA	0º	NA	NCT impact to produce maximum inertia loading.
8	30 foot Bottom Drop (CTU-4)	-40	NA	0º	NA	Drop orientation to produce maximum inertia loading.
9	Puncture drop, CG adjacent to Lid/Side Edge (CTU-2)	132	109º	0º	0º	Attempt to increase damage resulting from Test No. 4 free drop.
10	Puncture drop near Lid Reinforcement (CTU-1)	132	78º	45º	45º	Attempt to produce maximum damage to thermal protection design features of OCA lid.
11	Puncture drop below Lid/Body Interface (CTU-3)	-40	132º	0º	0º	Attempt to increase damage resulting from Test No. 2 free drop.
12	Puncture drop on Side (CTU-4)	-40	90º	0º	0º	Attempt to produce maximum damage to thermal protection design features of OCA body.
13	Puncture drop, CG over Lid/Body Interface (CTU-4)	-40	107º	45º	45º	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	156º	0º	0º	Attempt to produce maximum damage to thermal Protection design features of OCA lid.
15	HAC Fire Test (CTU-1, CTU-2, CTU-3)	132	90º	0º	0º	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 (ºF)	Test Unit Angular Orientation			Results
			X-Axis (0º = horizontal)	Vertical Axis (0º = upright)	Z-Axis (0º = horizontal)	
1	4 foot, CG over Lid Corner (CTU-1, CTU-3)	132	127º	45º	45º	CTU-1: ~2½" wide flat, ~1" deep CTU-3: ~5" wide flat
2	30 foot, CG over Lid Corner (CTU-1, CTU-3)	132	127º	45º	45º	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	135º	45º	0º	~3/4" × ~3/4" on each OCA lid side edge
4	30 foot, CG over Lid/Side Edge (CTU-2)	132	135º	45º	0º	~11" × ~11", ~9" wide flat on OCA lid side edge
5	4 foot, Shallow Angle Side Drop (CTU-4)	-40	97º	0º	0º	~3/16" dent on OCA lid edge
6	30 foot, Shallow Angle Side Drop (CTU-4)	-40	97º	0º	0º	~1/2" dent on OCA lid edge
7	4 foot Bottom Drop (CTU-4)	-40	0º	0º	0º	~3/4" deformation of forklift pockets
8	30 foot Bottom Drop (CTU-4)	-40	0º	0º	0º	~1/2" to 2" deformation of forklift pockets
9	Puncture drop, CG adjacent to Lid/Side Edge (CTU-2)	132	109º	0º	0º	1st test: ~10½" wide dent 2nd test: increased damage due to 1st test
10	Puncture drop near Lid Reinforcement (CTU-1)	132	78º	45º	45º	Crescent-shaped dent in OCA lid.
11	Puncture drop below Lid/Body Interface (CTU-3)	-40	132º	0º	0º	Minor damage to OCA.
12	Puncture drop on Side (CTU-4)	-40	90º	0º	0º	~1½" deep × ~16" wide dent
13	Puncture drop, CG over Lid/Body Interface (CTU-4)	-40	107º	45º	45º	~1¾ " deep × ~10" wide × ~12" long dent
14	Puncture, Oblique CG drop thru Lid (CTU-4)	-40	156º	0º	0º	~2½" deep dent in OCA lid
15	HAC Fire Test (CTU-1, CTU-2, CTU-3)	132	90º	0º	0º	CTU-1: ~1,809 ºF temperature, ~32 minutes CTU-2: ~1,972 ºF temperature, ~36 minutes CTU-3: ~2,025 ºF temperature, ~30 minutes

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

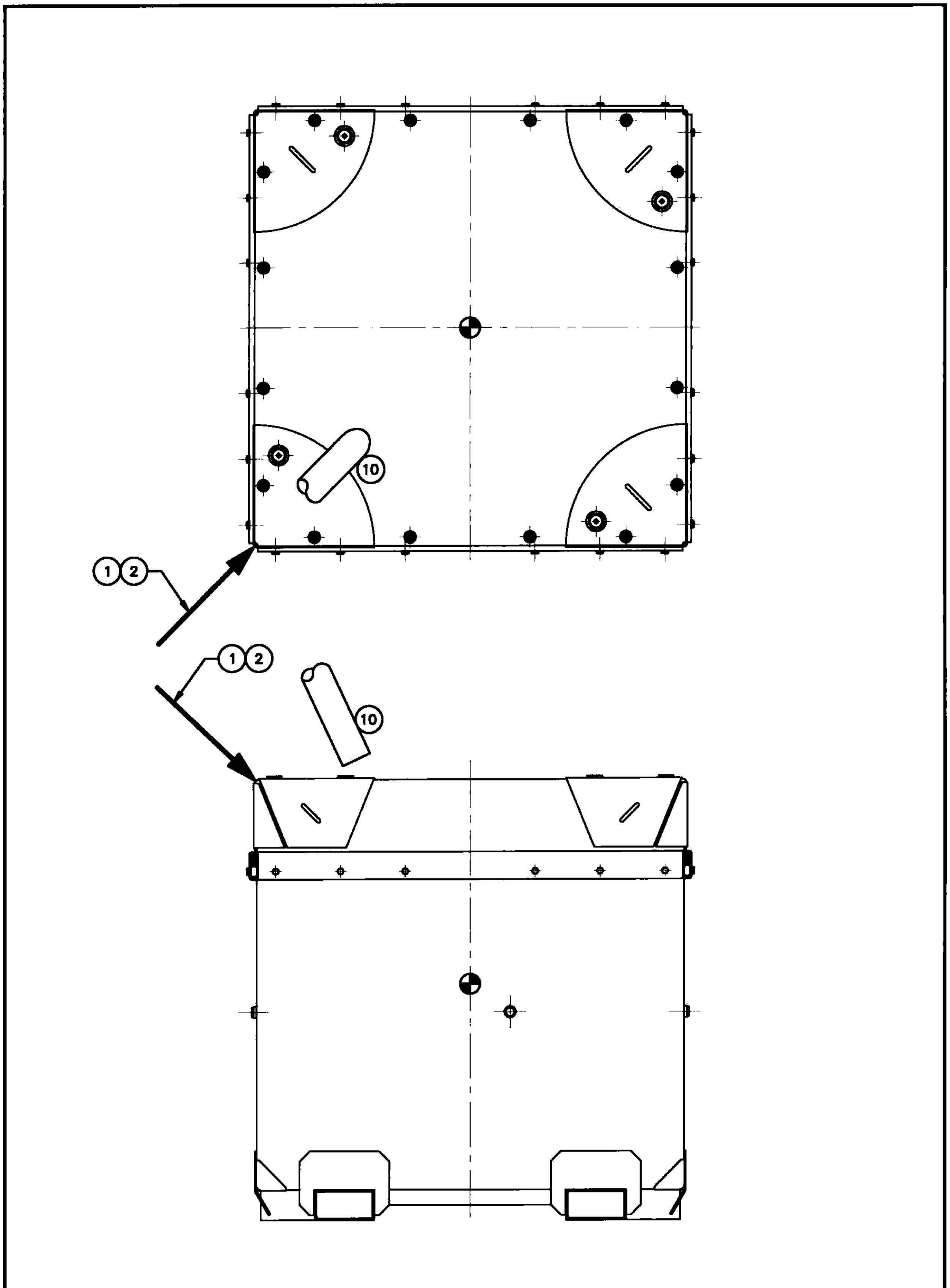


Figure 2.10.1-5 - Schematic Summary of CTU-1 Testing

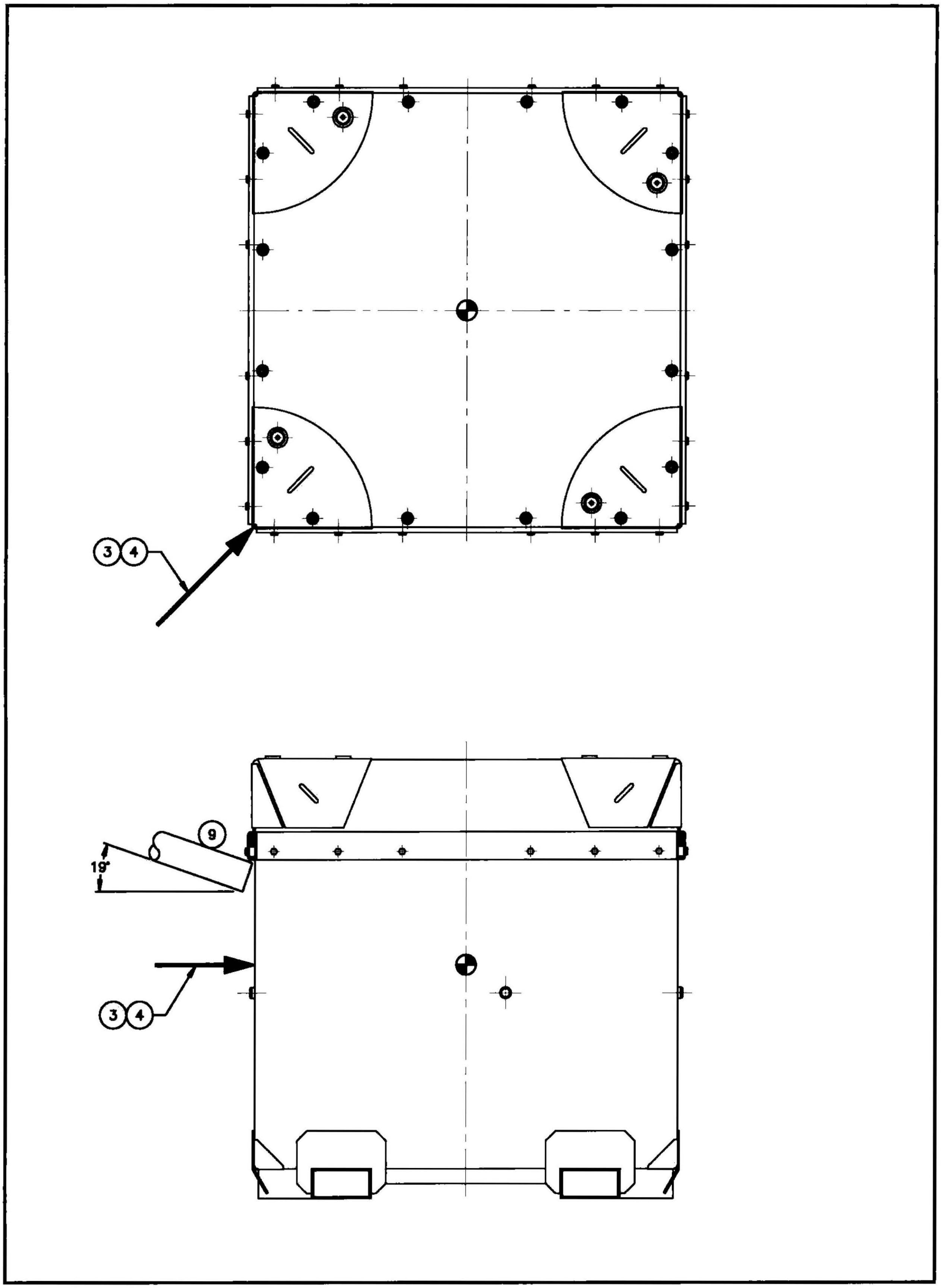


Figure 2.10.1-6 - Schematic Summary of CTU-2 Testing

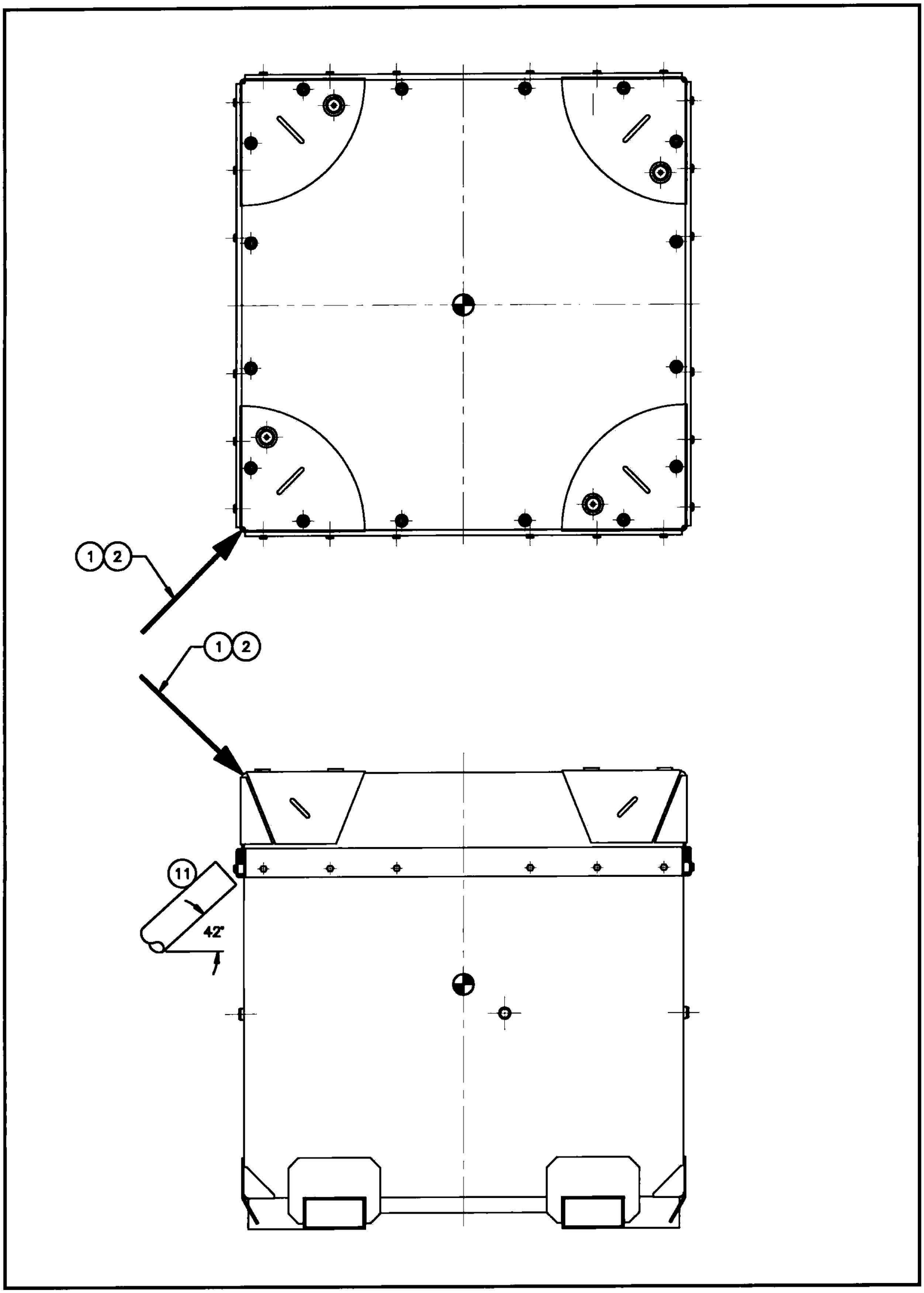


Figure 2.10.1-7 – Schematic Summary of CTU-3 Testing

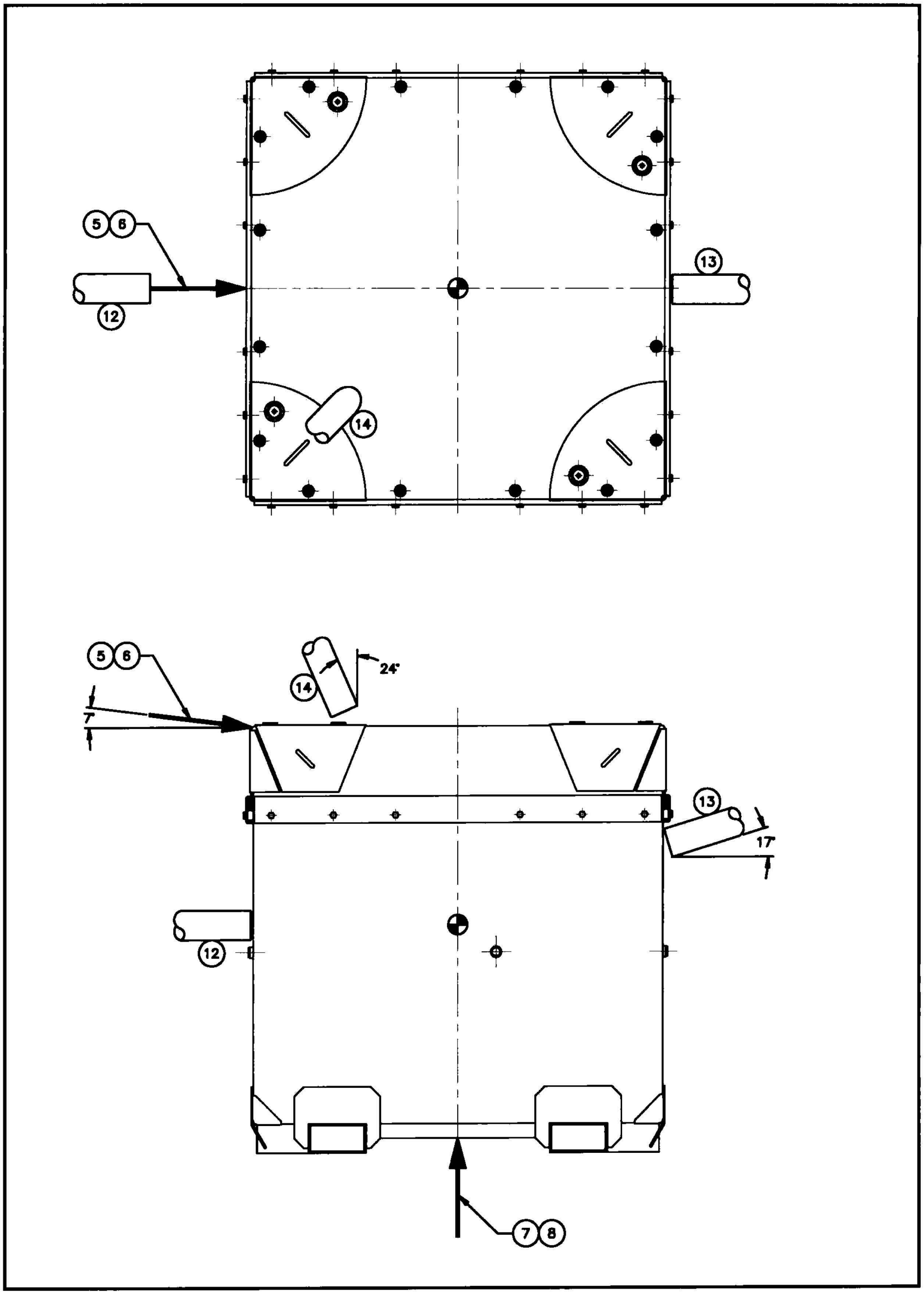


Figure 2.10.1-8 – Schematic Summary of CTU-4 Testing

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

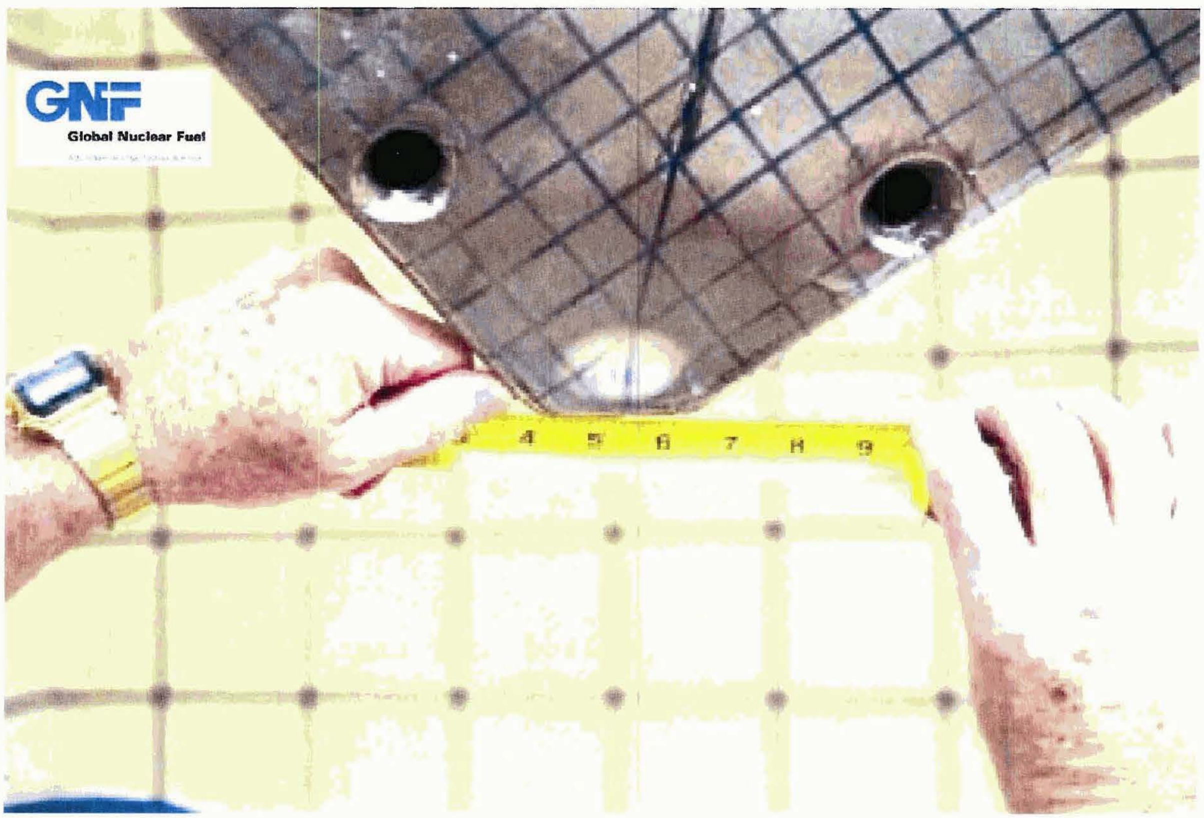


Figure 2.10.1-10 - CTU-1 Free Drop Test No. 1; OCA Lid Corner Damage; ~2½" Wide

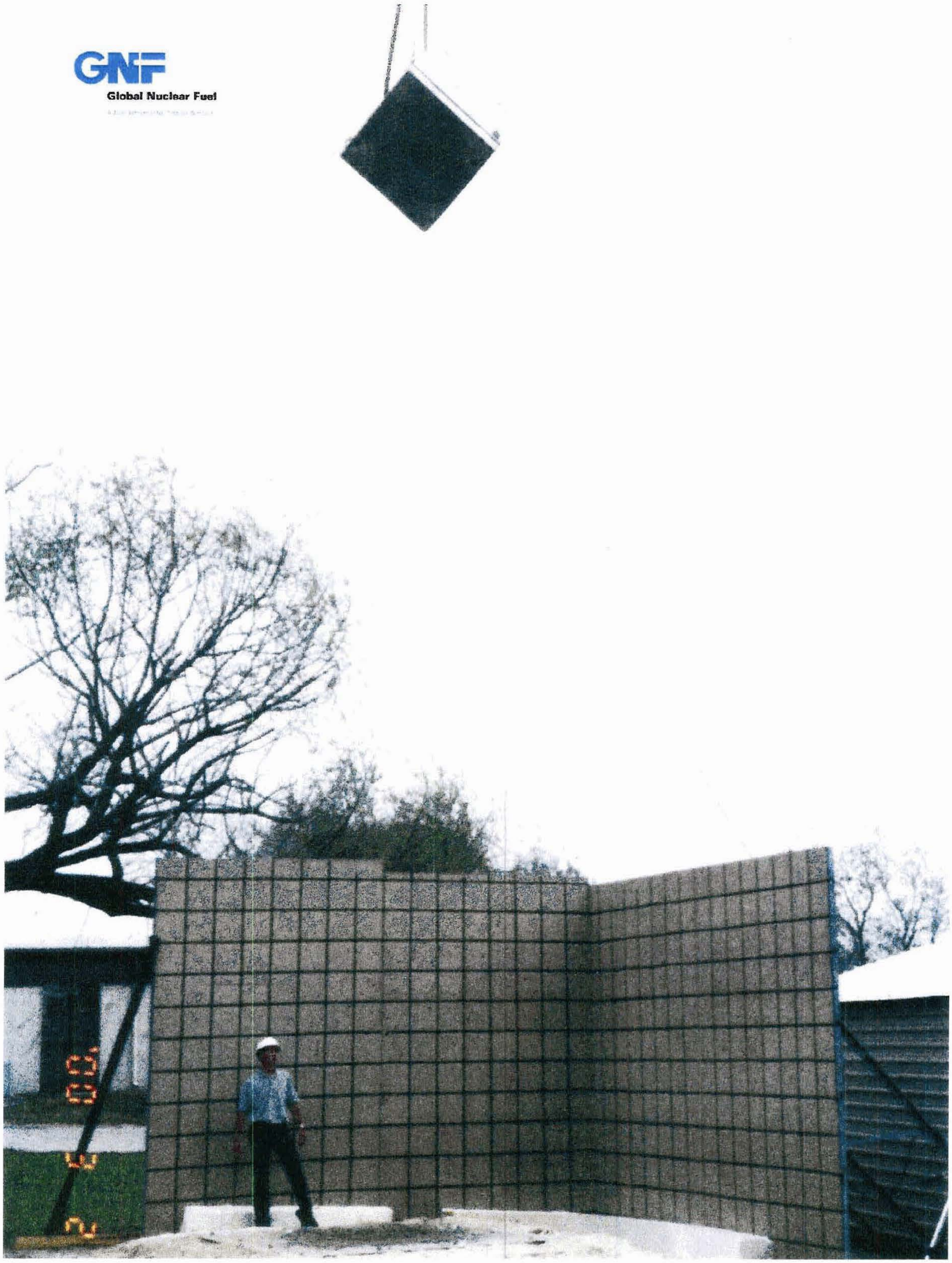


Figure 2.10.1-11 - CTU-1 Free Drop Test No. 2; HAC Drop onto OCA Lid Corner

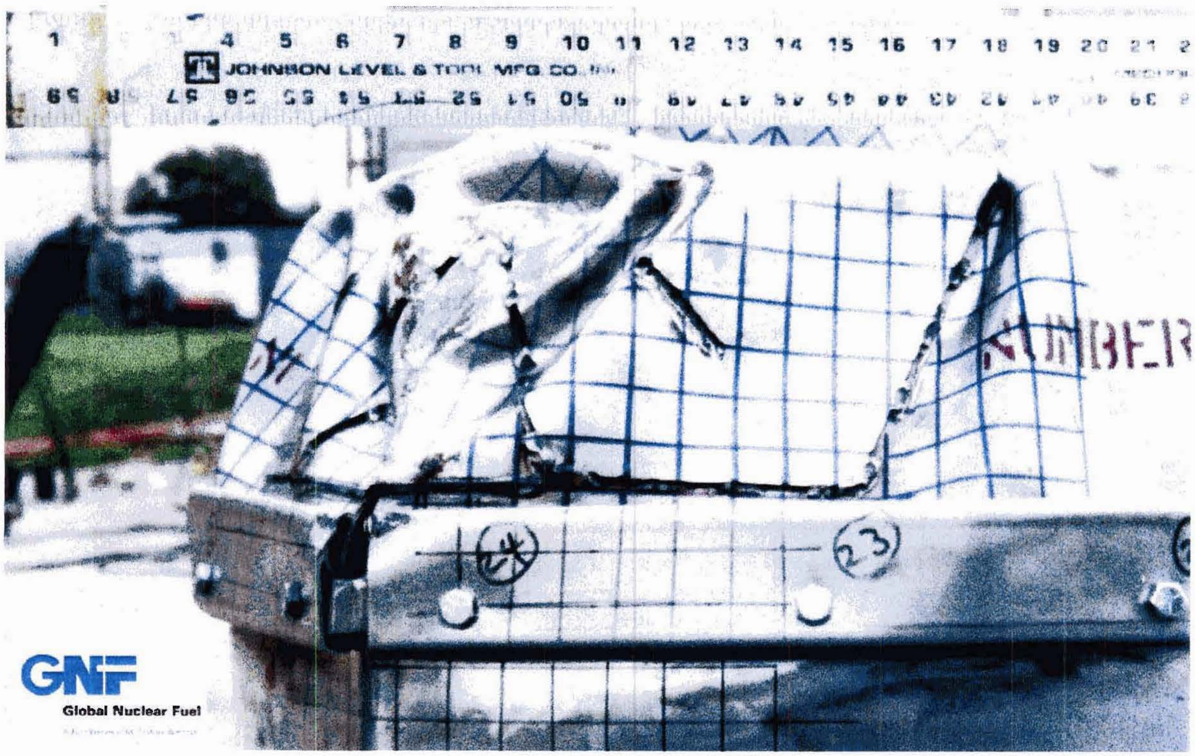


Figure 2.10.1-12 - CTU-1 Free Drop Test No. 2; Close-up View of Damage

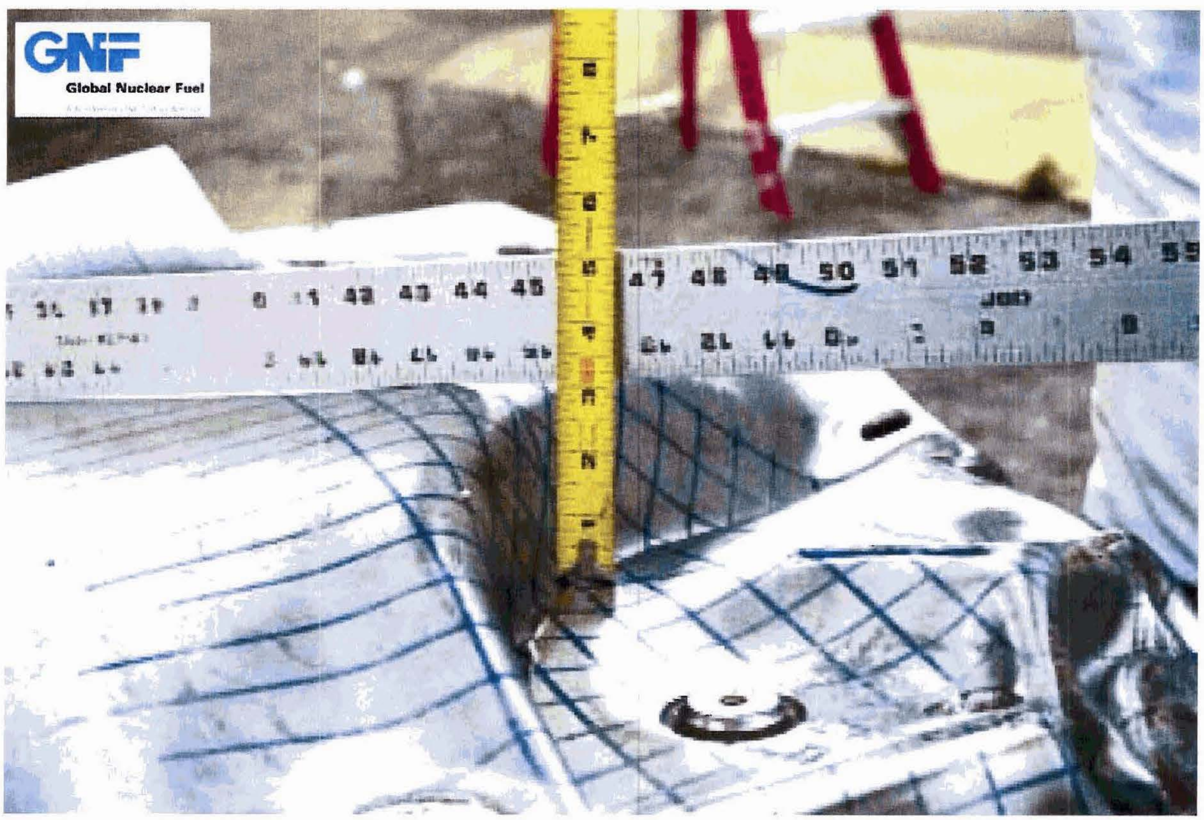


Figure 2.10.1-13 – CTU-1 Free Drop Test No. 2; Height of Buckle of OCA Lid Corner

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

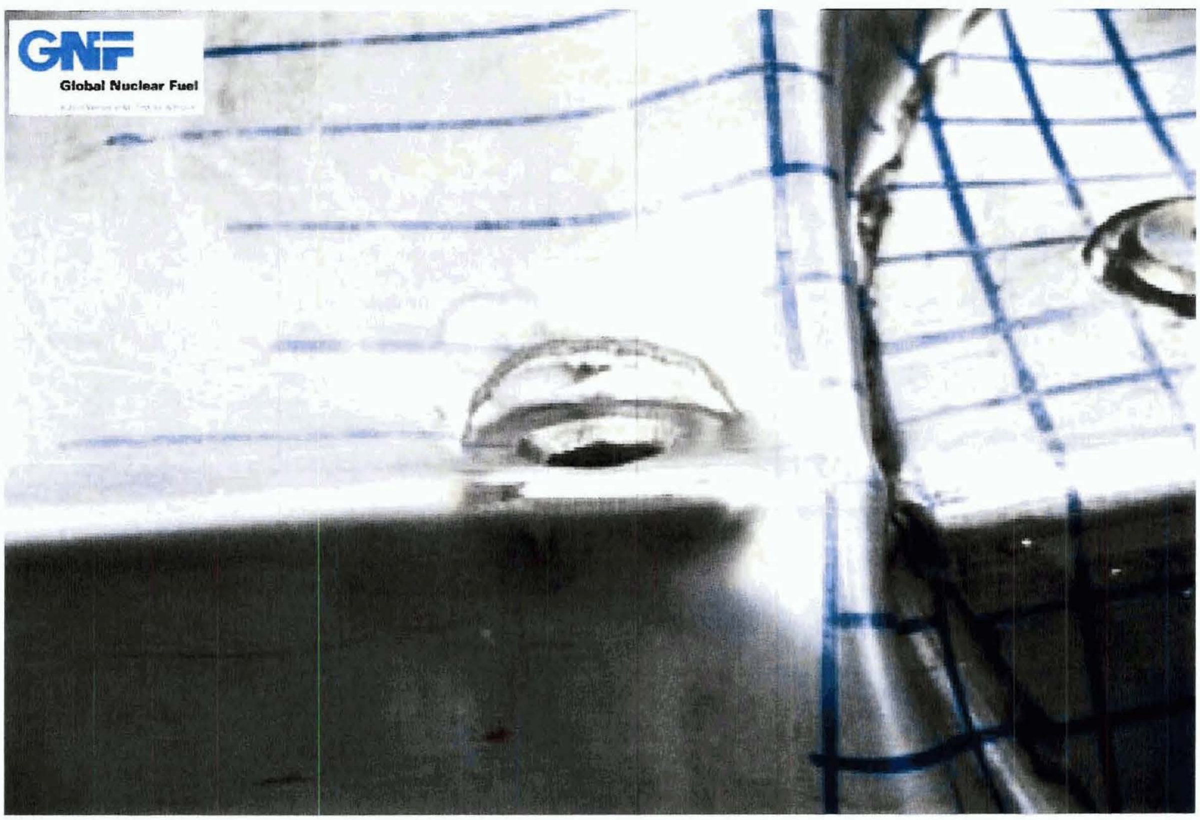


Figure 2.10.1-15 – CTU-1 Free Drop Test No. 2; Tear of OCA Lid Around Closure Bolt

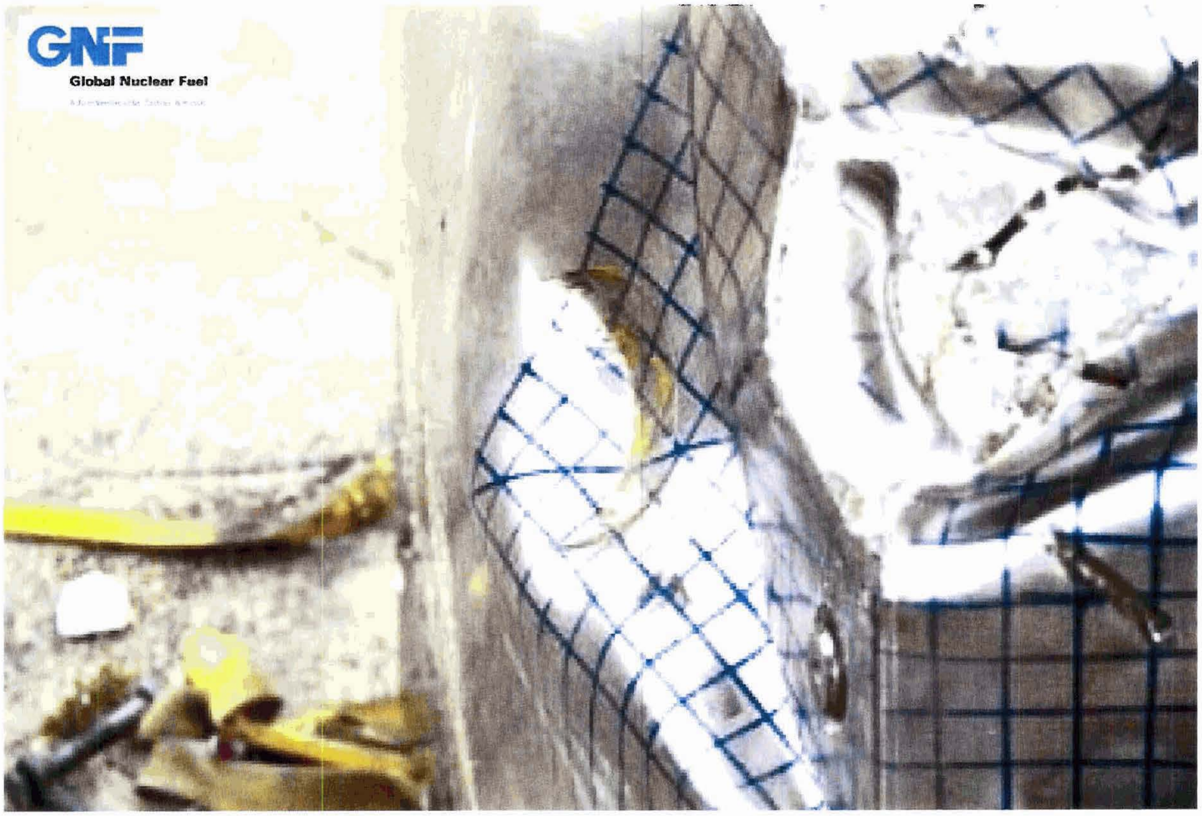


Figure 2.10.1-16 - CTU-1 Puncture Drop Test No. 10; Close-up of Damage

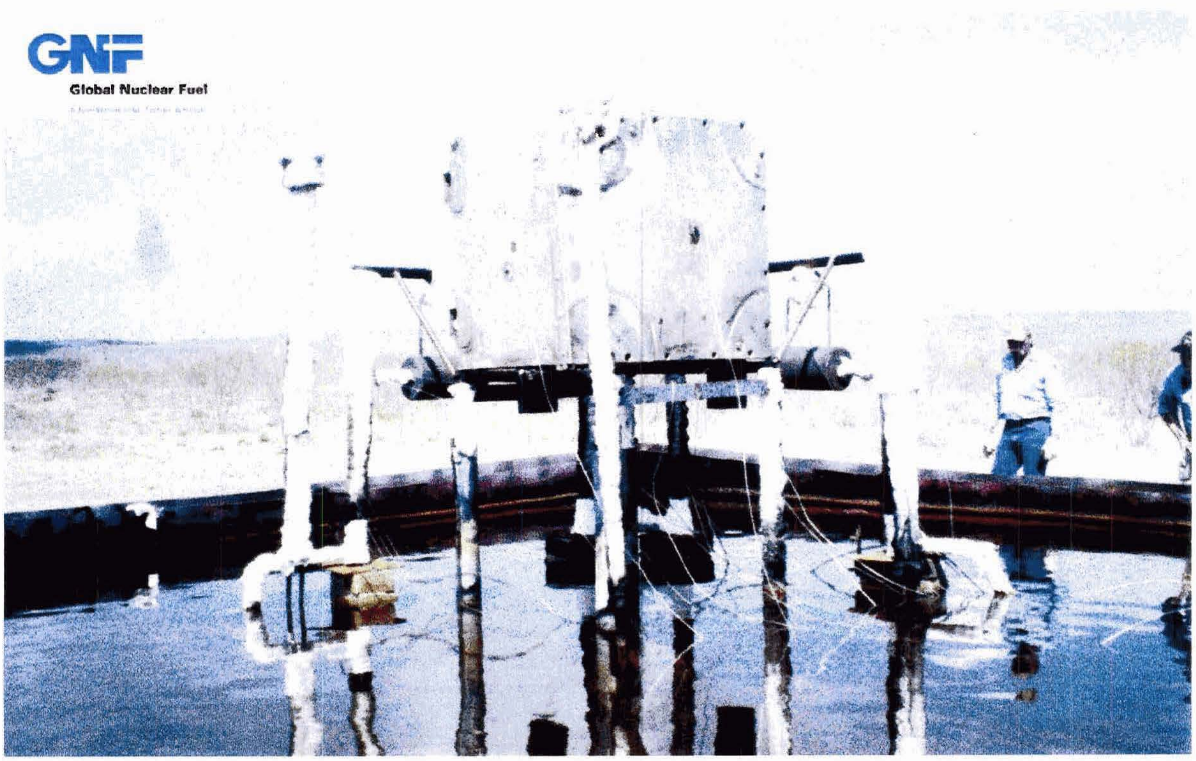


Figure 2.10.1-17 – CTU-1 Fire Test No. 15; View Before Fire Showing Tests 1, 2 & 8 Damage

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

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)

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

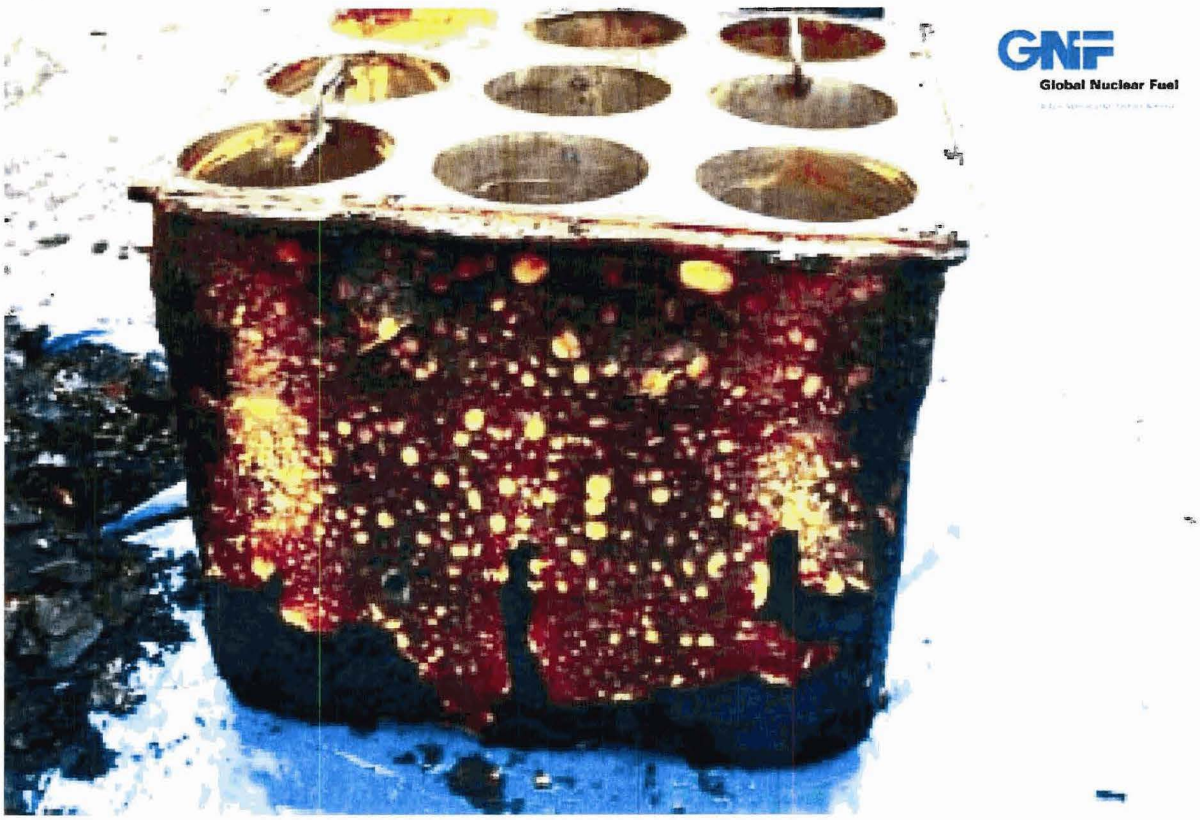


Figure 2.10.1-27 – CTU-1 Post-Test Disassembly; View of OCA Residual Foam Block

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

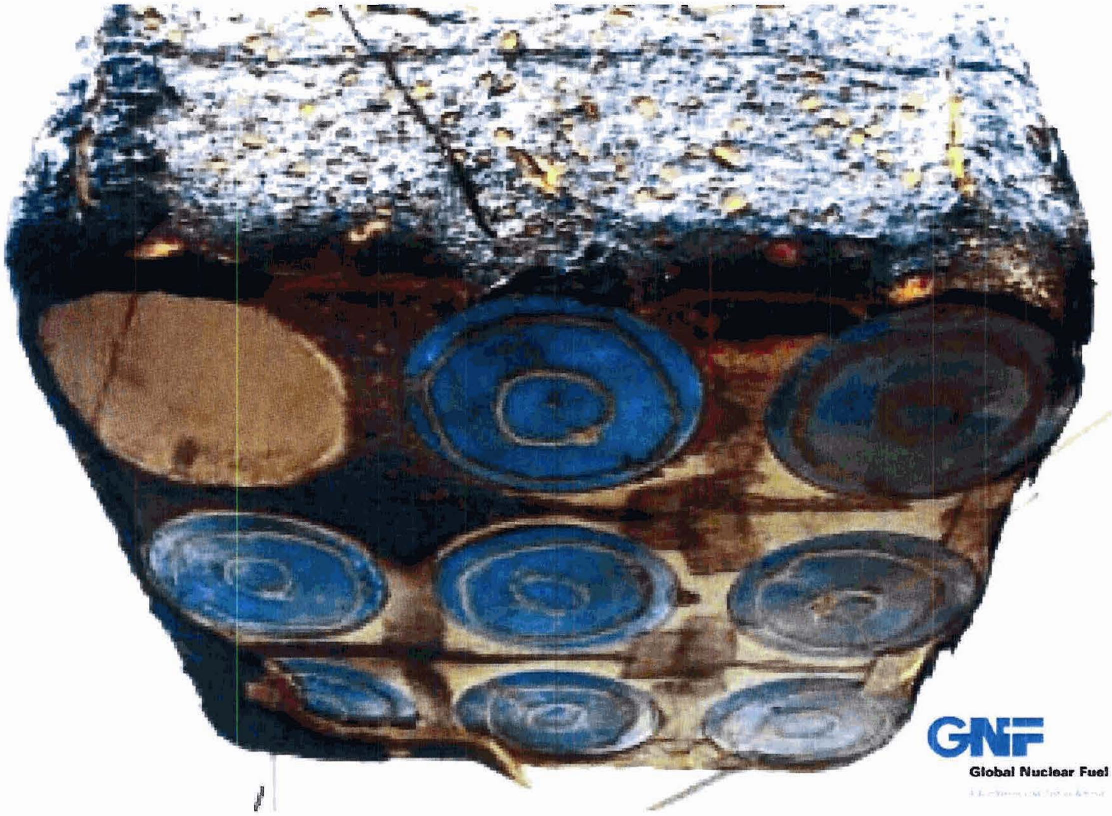


Figure 2.10.1-29 – CTU-1 Post-Test Disassembly; View of Bottom of OCA Residual Foam Block

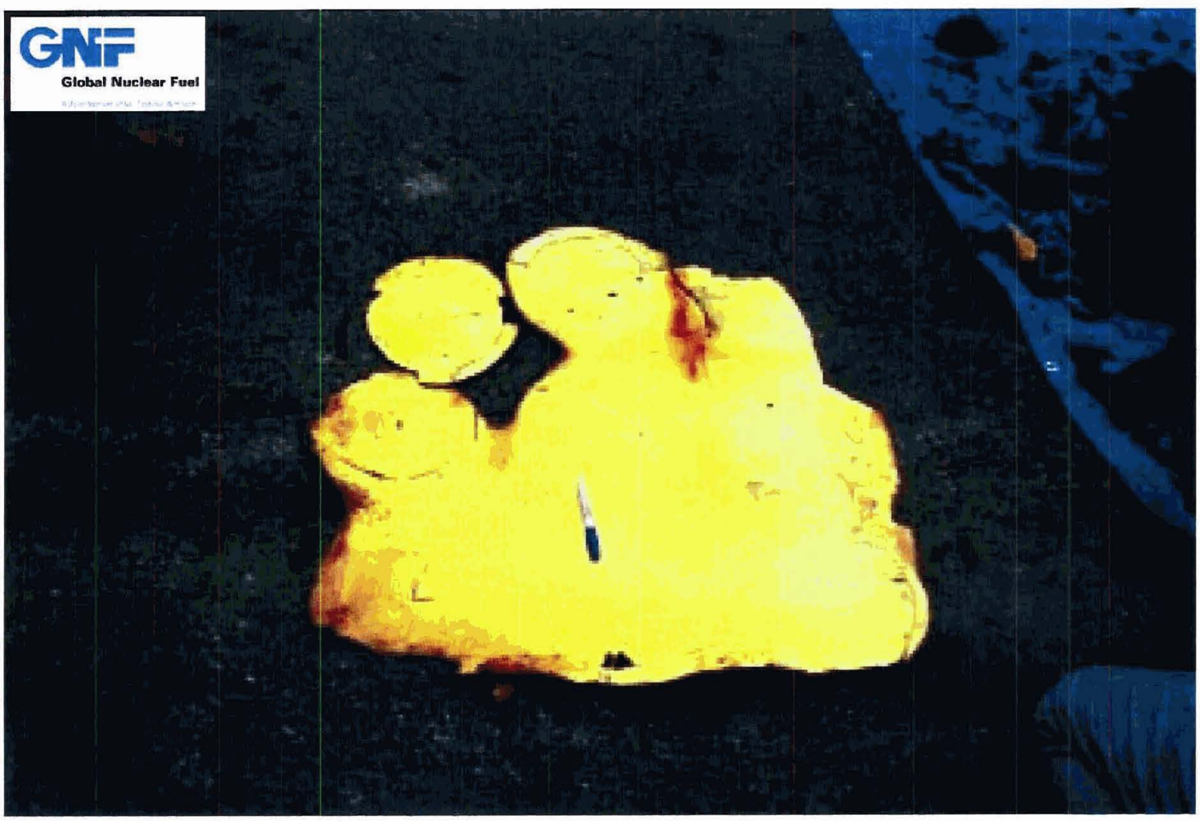


Figure 2.10.1-30 – CTU-1 Post-Test Disassembly; View of Bottom Residual Foam from OCA Body

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

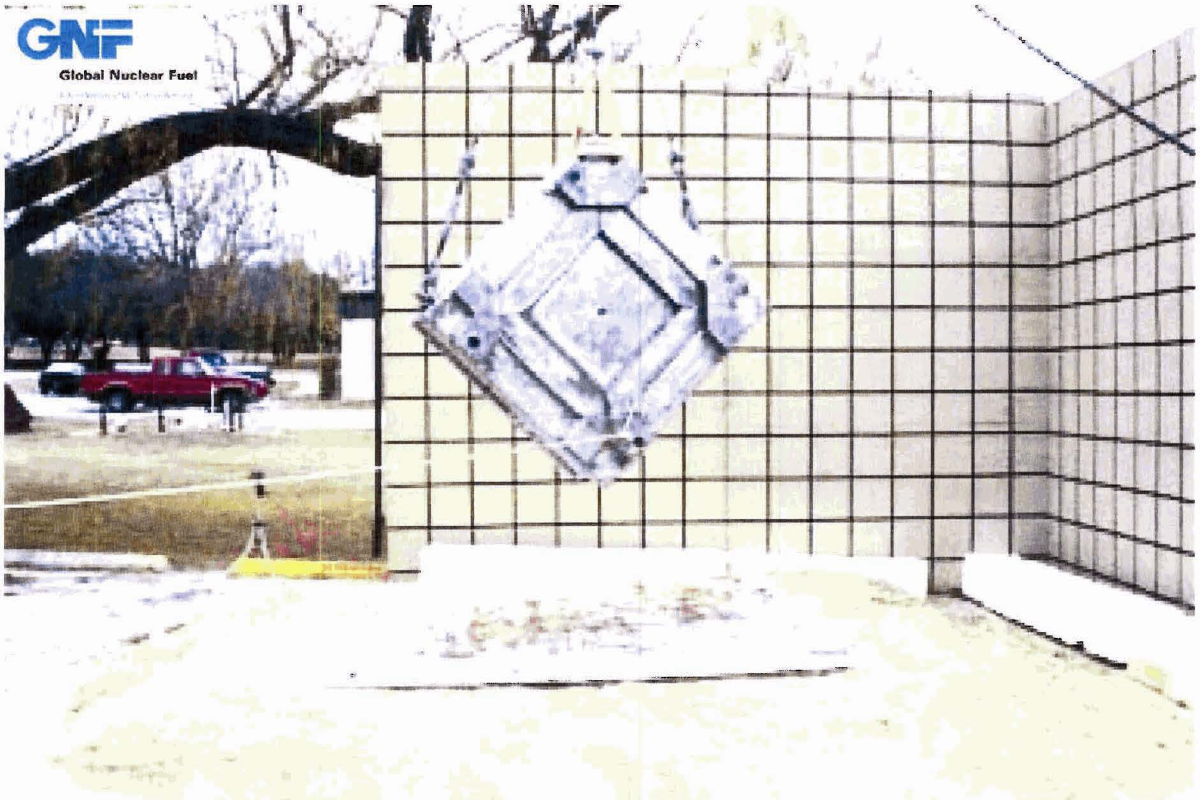


Figure 2.10.1-33 - CTU-2 Free Drop Test No. 3; NCT Drop on Side Edge

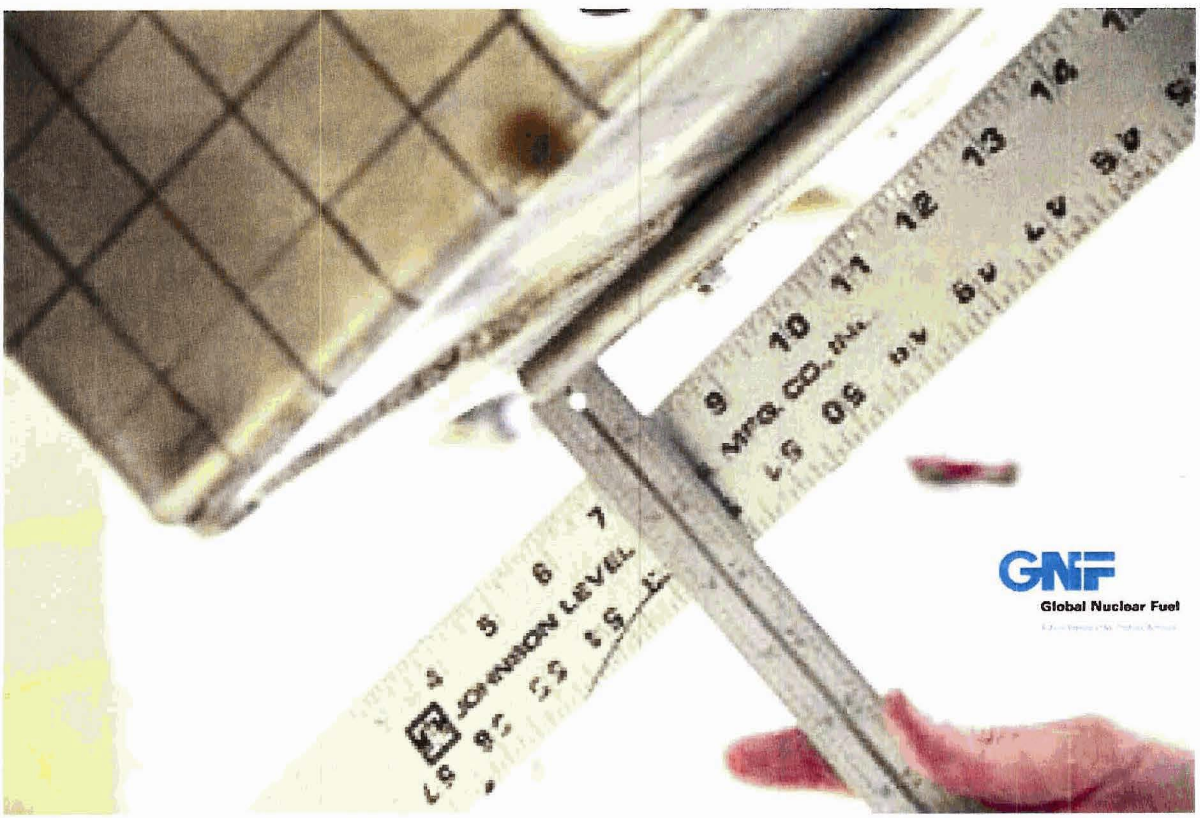


Figure 2.10.1-34 - CTU-2 Free Drop Test No. 3; Close-up Profile View of Damage; ~1" Deep

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

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

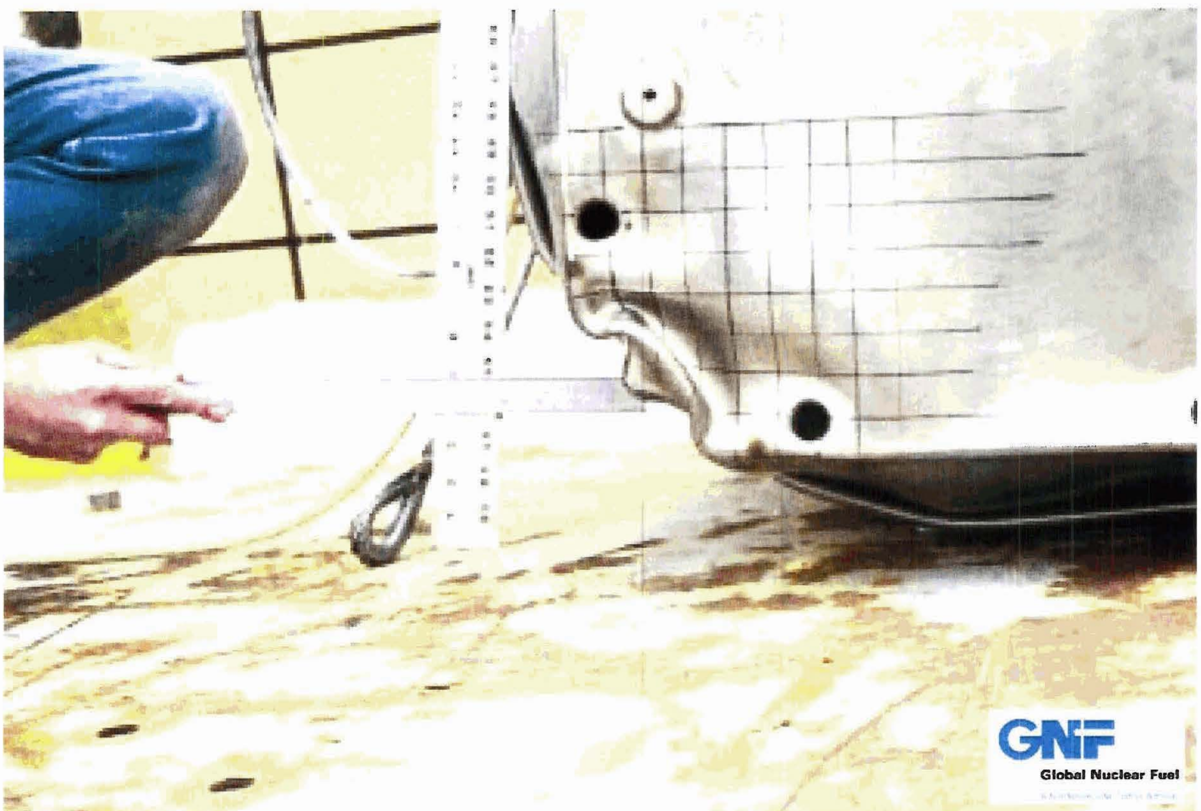

Figure 2.10.1-37 – CTU-2 Free Drop Test No. 4; Close-up View of Damage; ~4" Deep

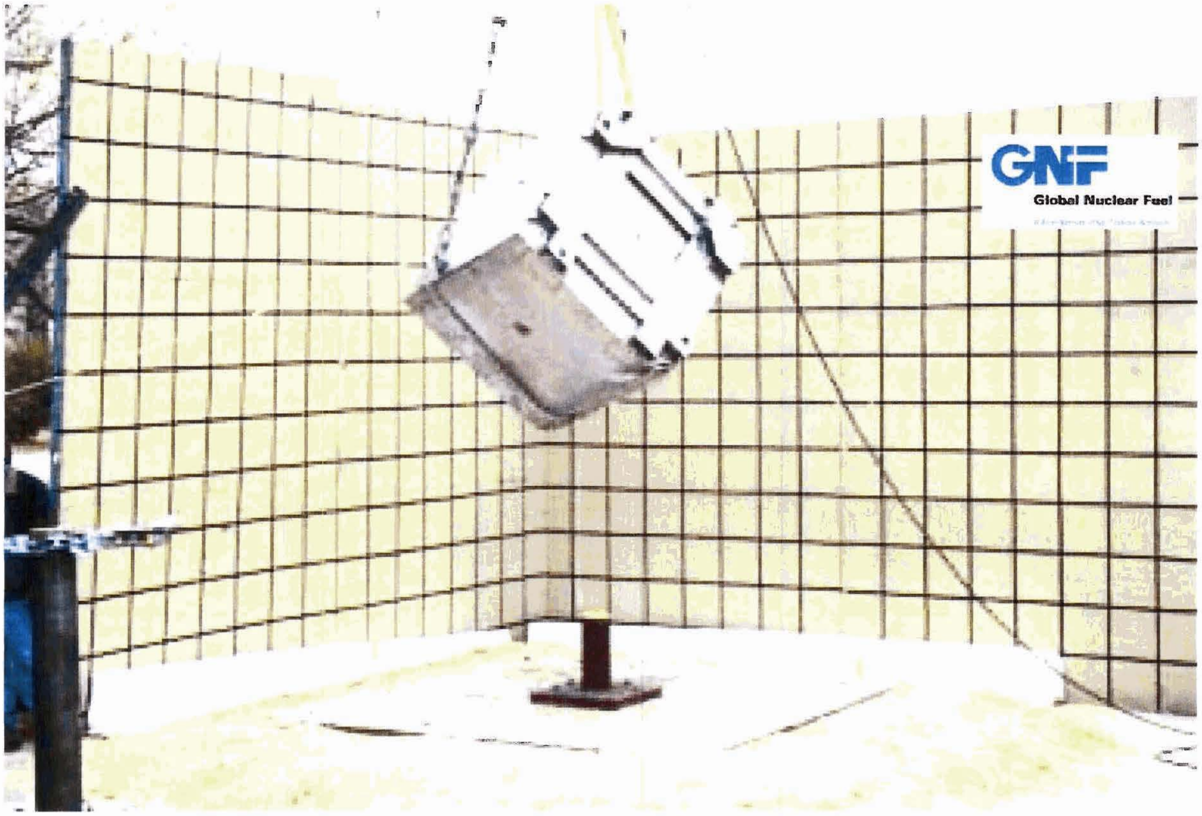

Figure 2.10.1-38 – CTU-2 Puncture Drop Test No. 9A & 9B; HAC Puncture, Lid/Body Interface

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

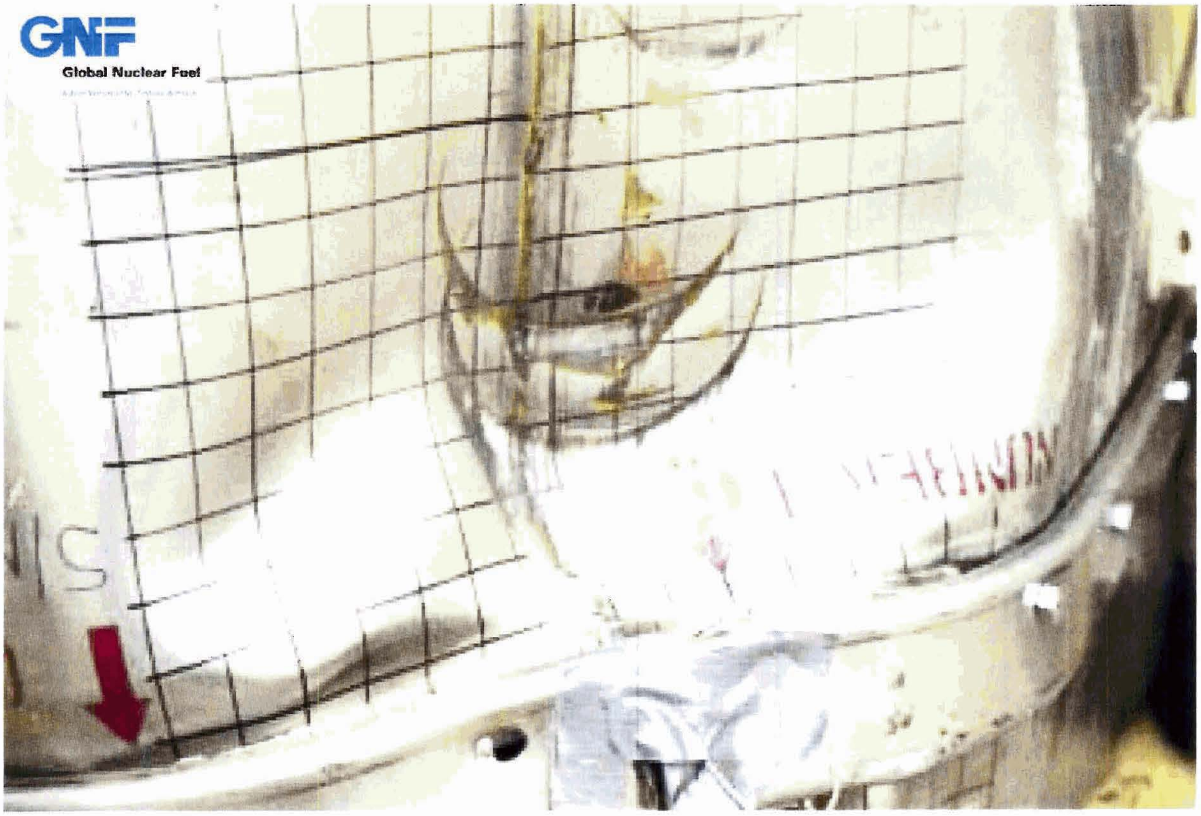

Figure 2.10.1-42 – CTU-2 Puncture Drop Test No. 9B; Close-up View of Damage

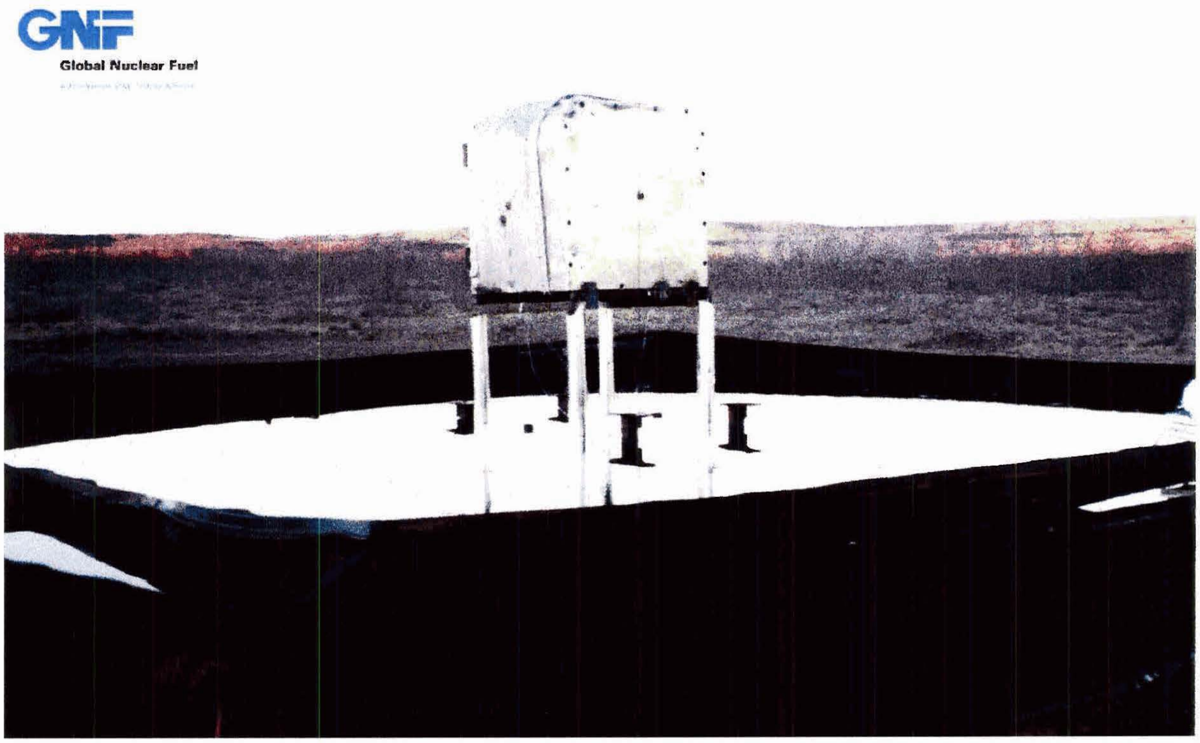

Figure 2.10.1-43 – CTU-2 Fire Test No. 15; View Before Fire Showing Tests 3, 4 & 9 Damage

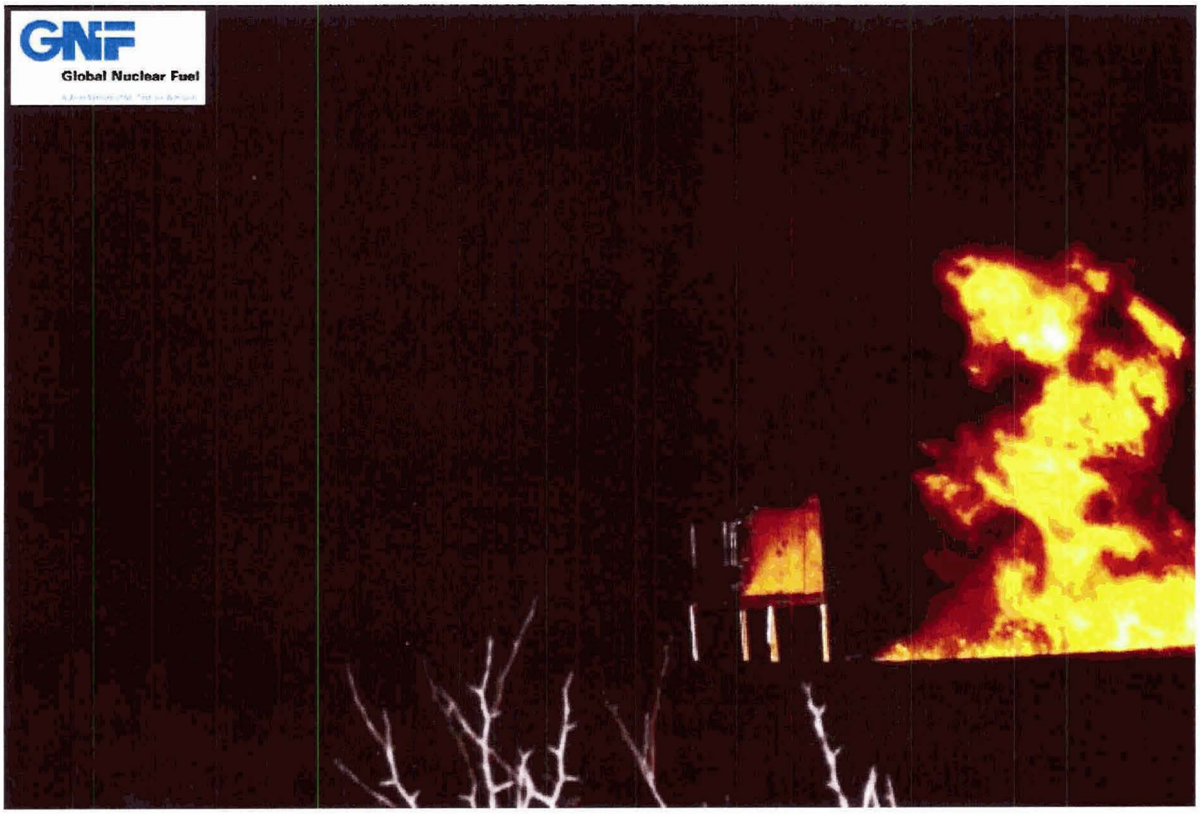

Figure 2.10.1-44 – CTU-2 Fire Test No. 15; Initiation of Fire (00:00)

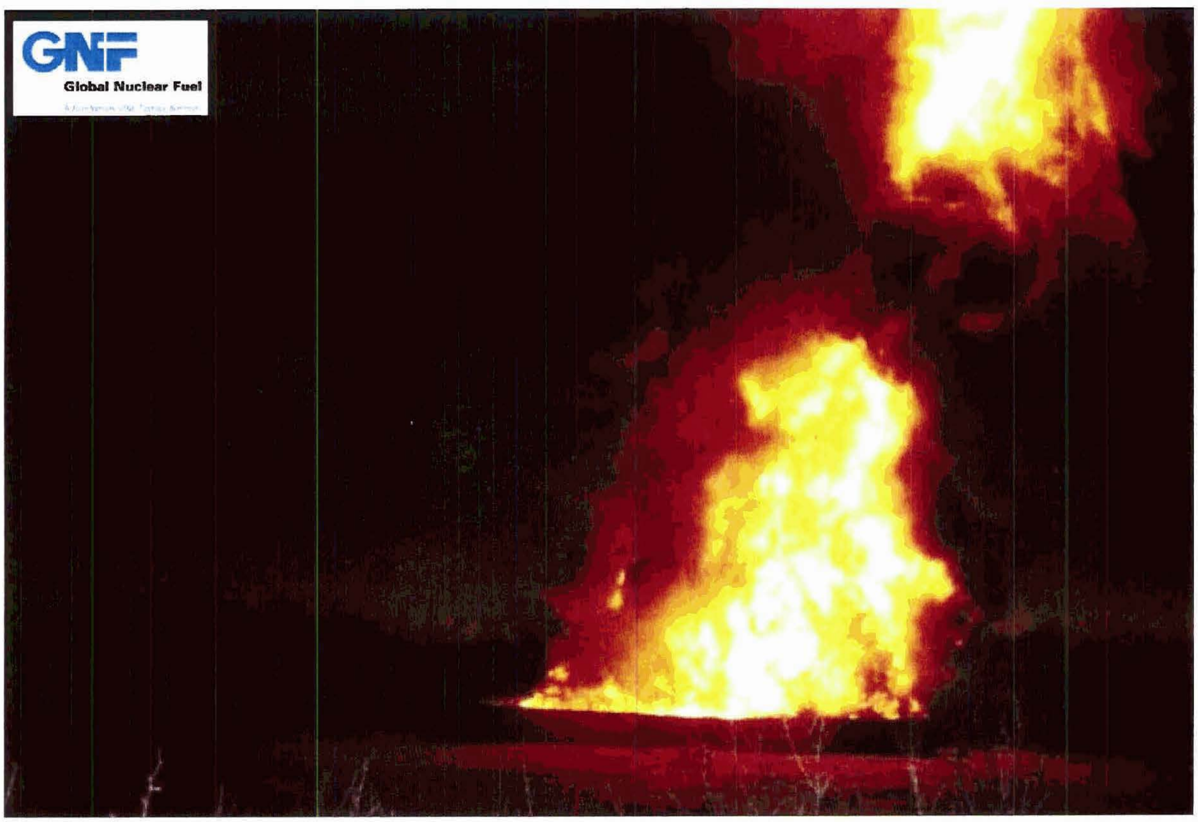

Figure 2.10.1-45 - CTU-2 Fire Test No. 15; View ~5 Minutes after Start

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

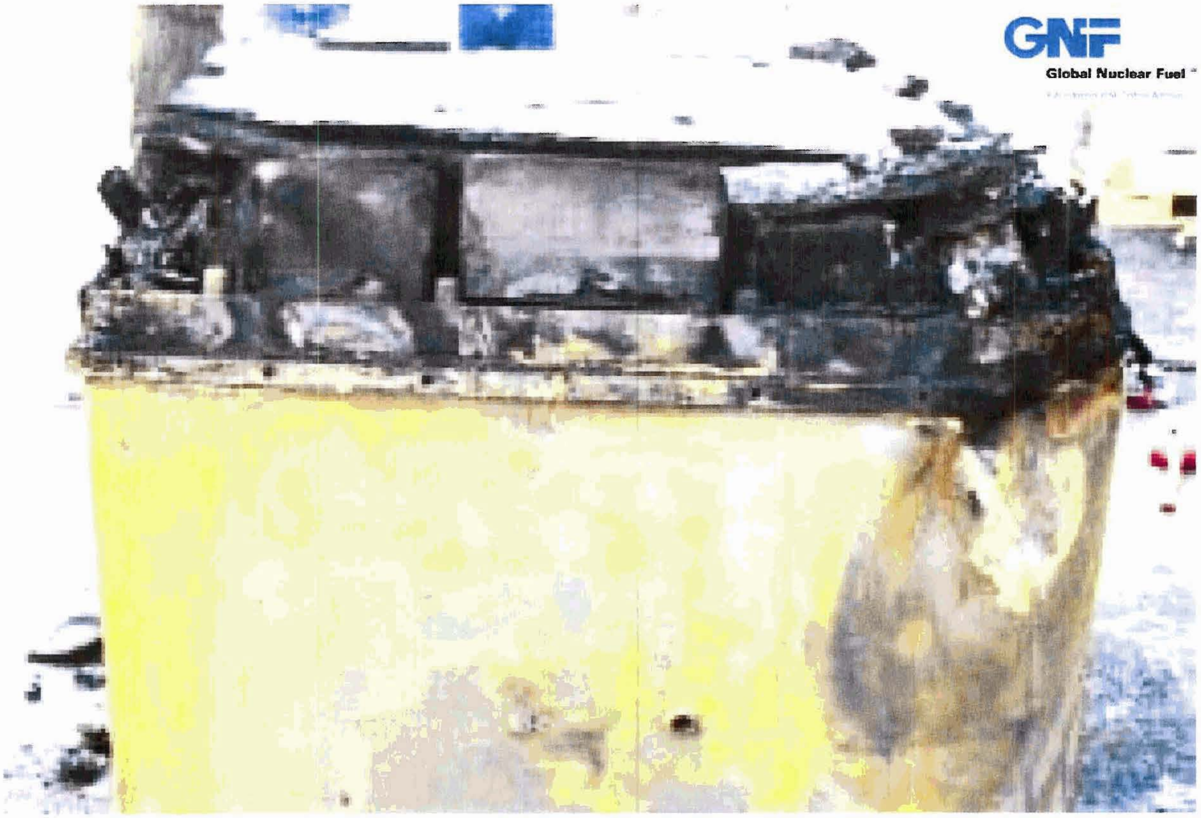

Figure 2.10.1-48 – CTU-2 Post-Test Disassembly; View of OCA Body w/ OCA Lid Removed

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

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

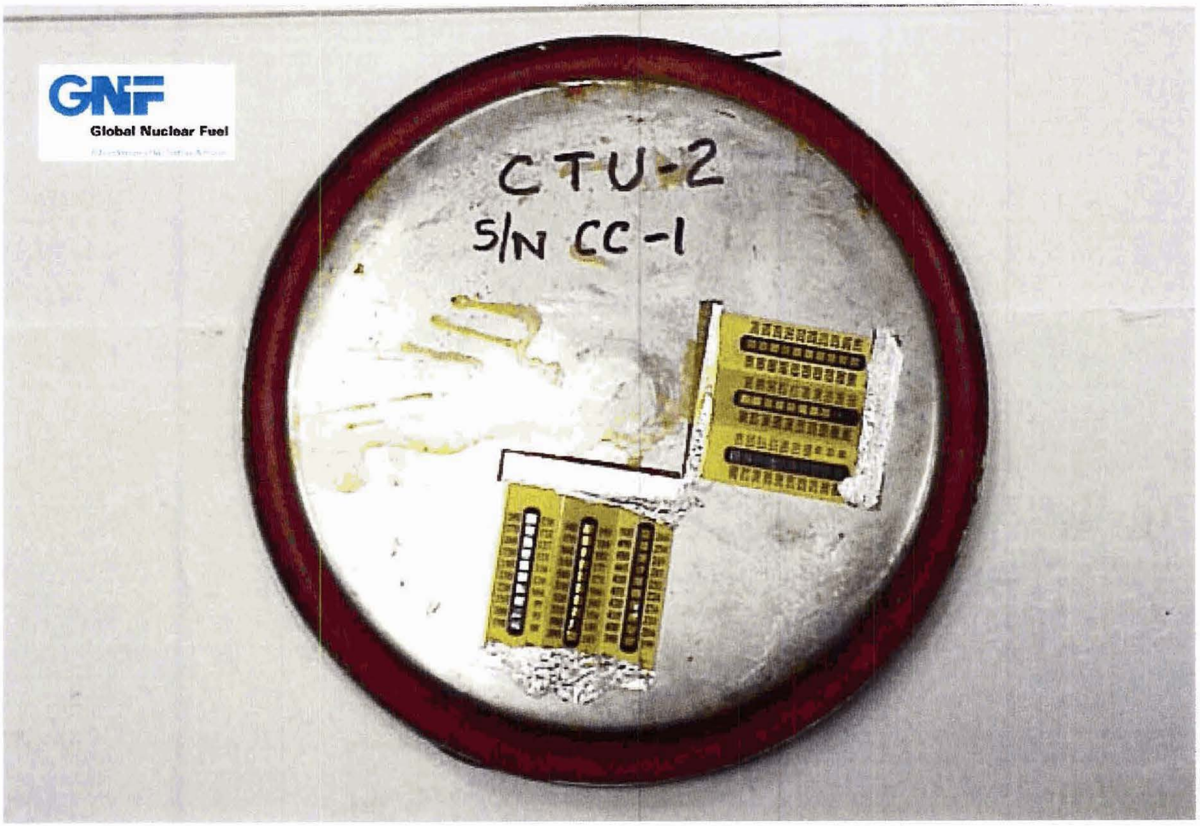

Figure 2.10.1-52 – CTU-2 Post-Test Disassembly; View of ICCA Closure Lid

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

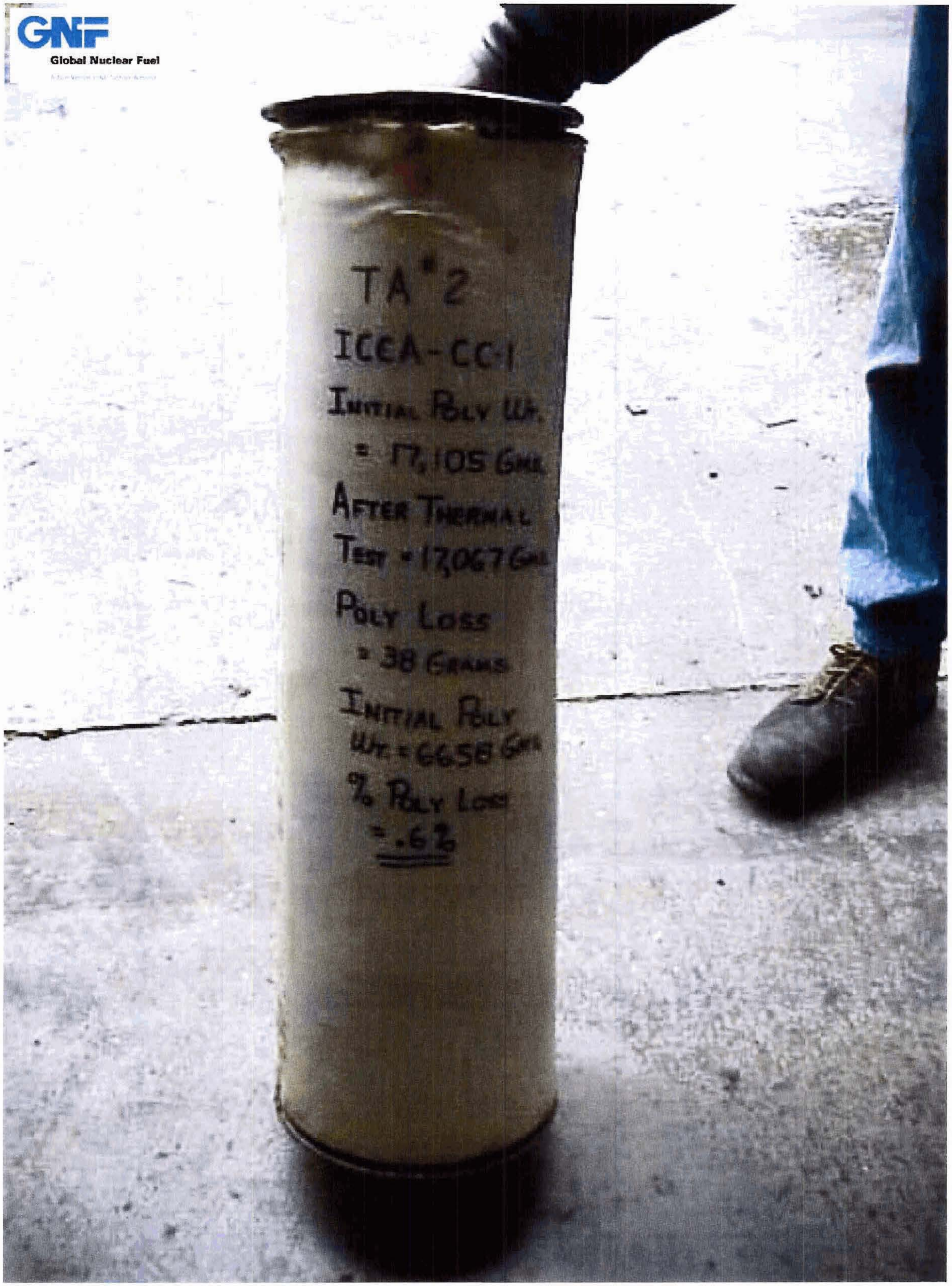

Figure 2.10.1-54 – CTU-2 Post-Test Disassembly; View of ICCA #1 Polyethylene Sheeting

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

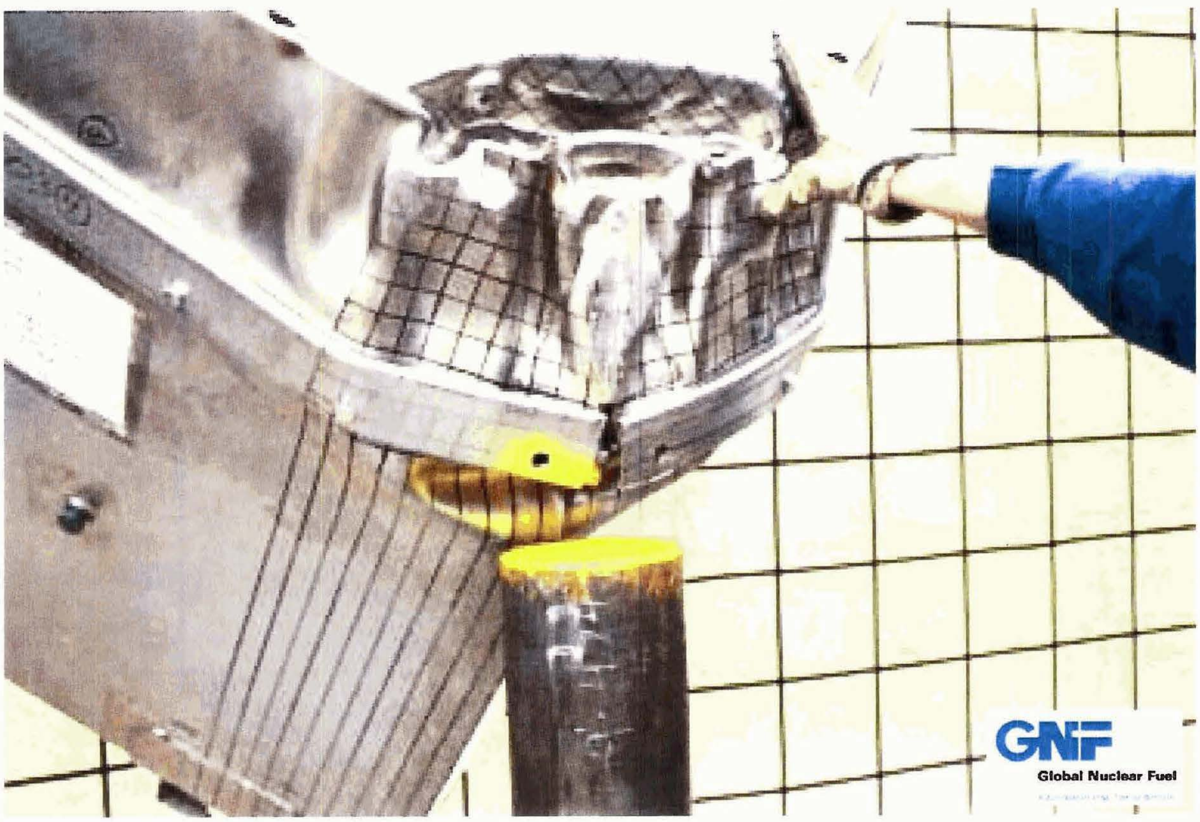

Figure 2.10.1-61 - CTU-3 Puncture Drop Test No. 11; Orientation of CTU Prior to Test

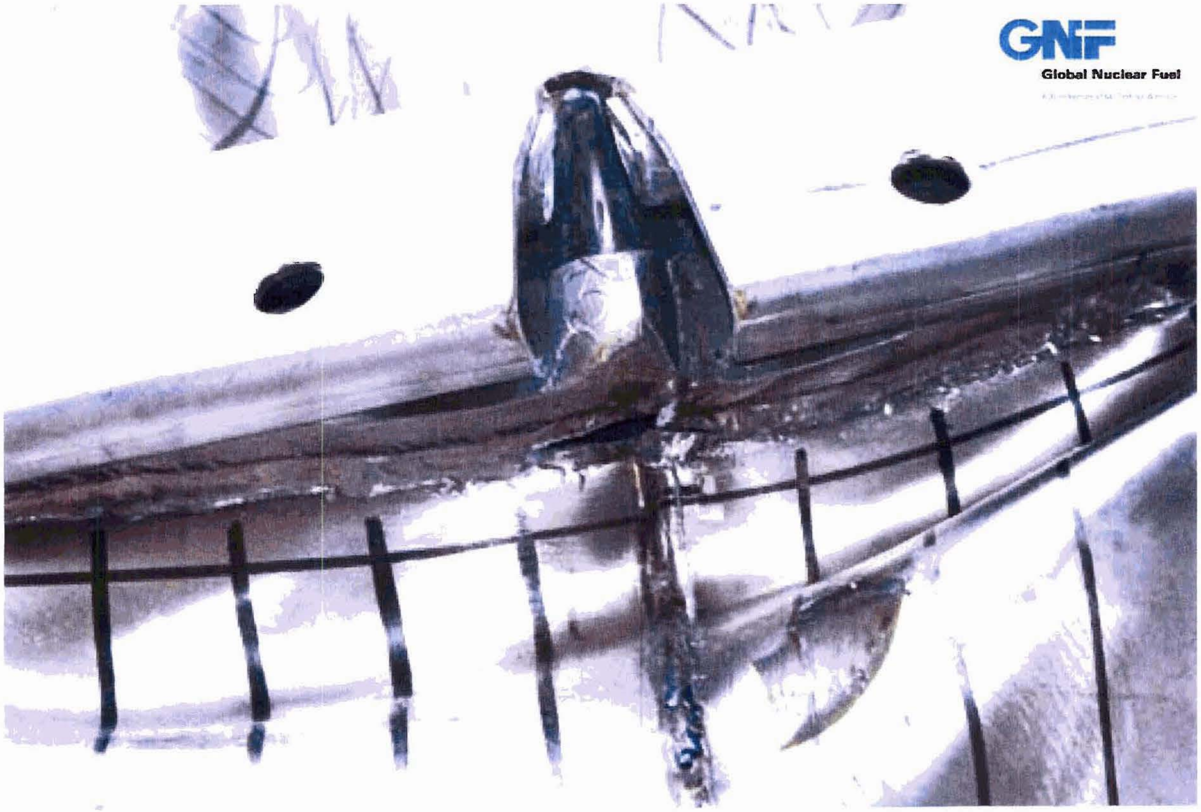

Figure 2.10.1-62 – CTU-3 Puncture Drop Test No. 11; Close-up View of Damage

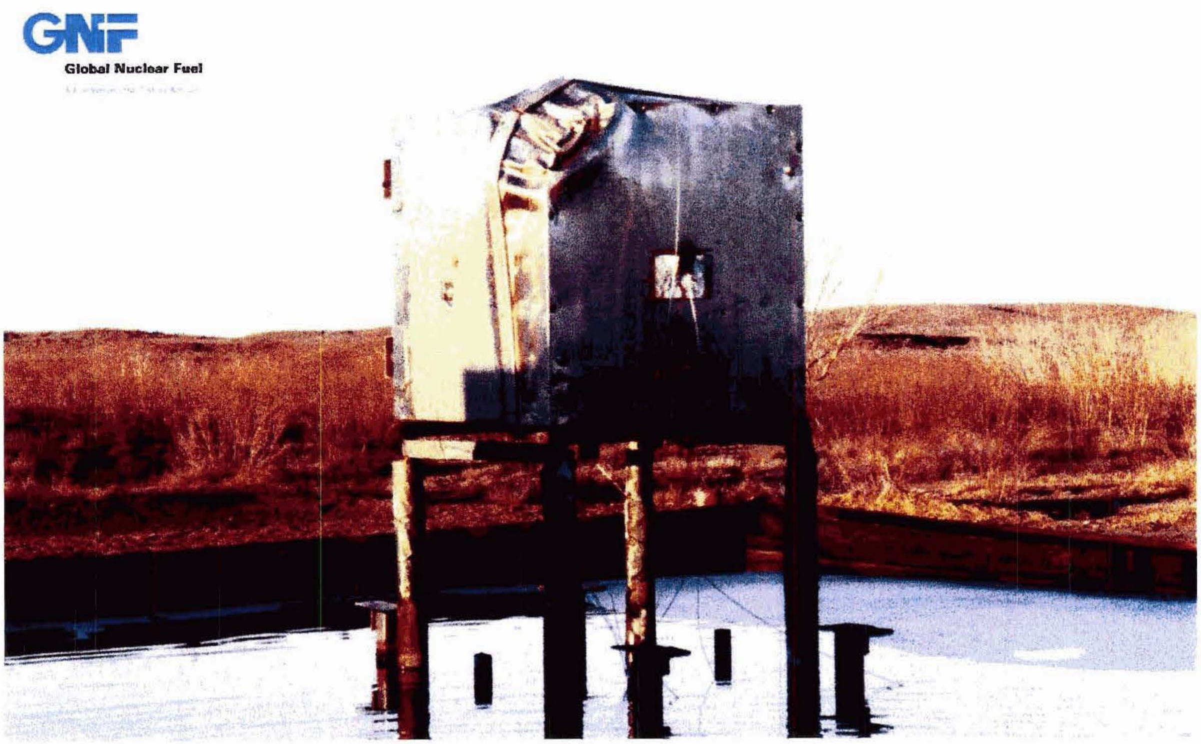

Figure 2.10.1-63 – CTU-3 Fire Test 15; View Before Fire Showing Tests 1, 2, & 11 Damage

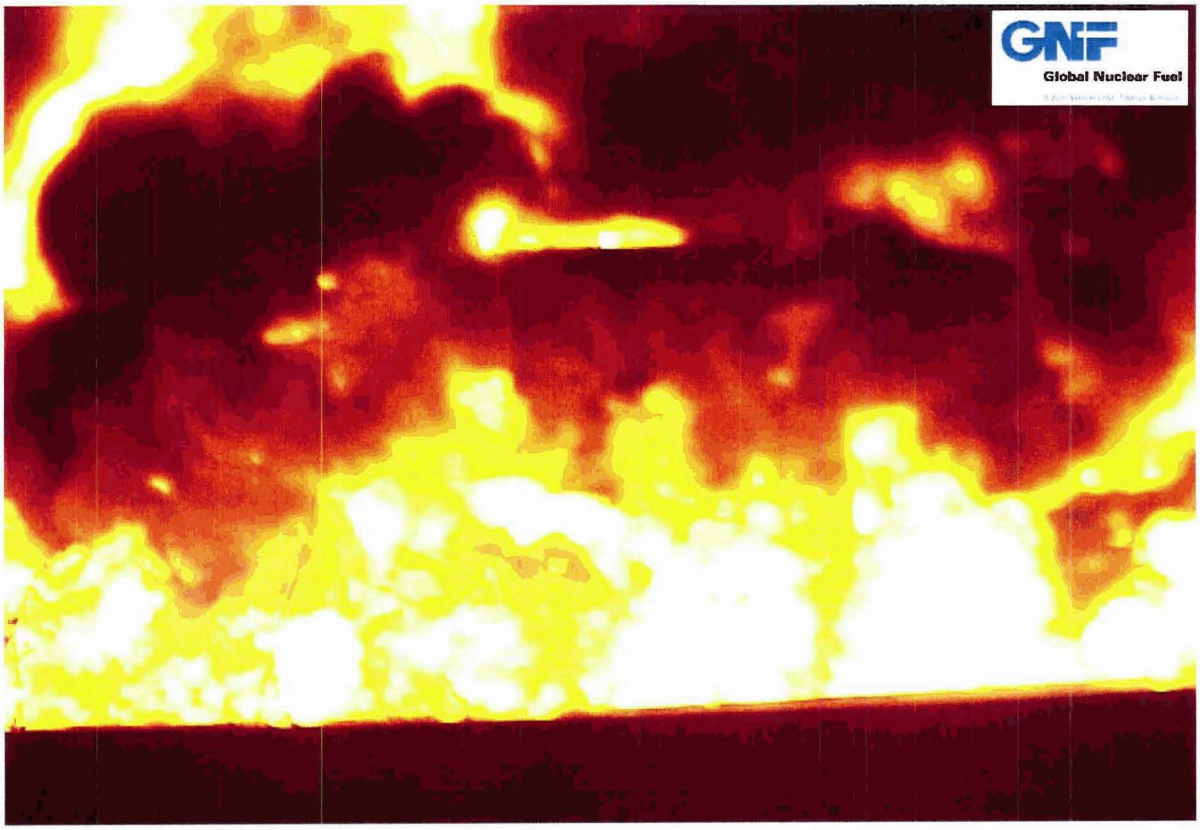

Figure 2.10.1-64 – CTU-3 Fire Test 15; View ~ 6 Minutes after Start

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

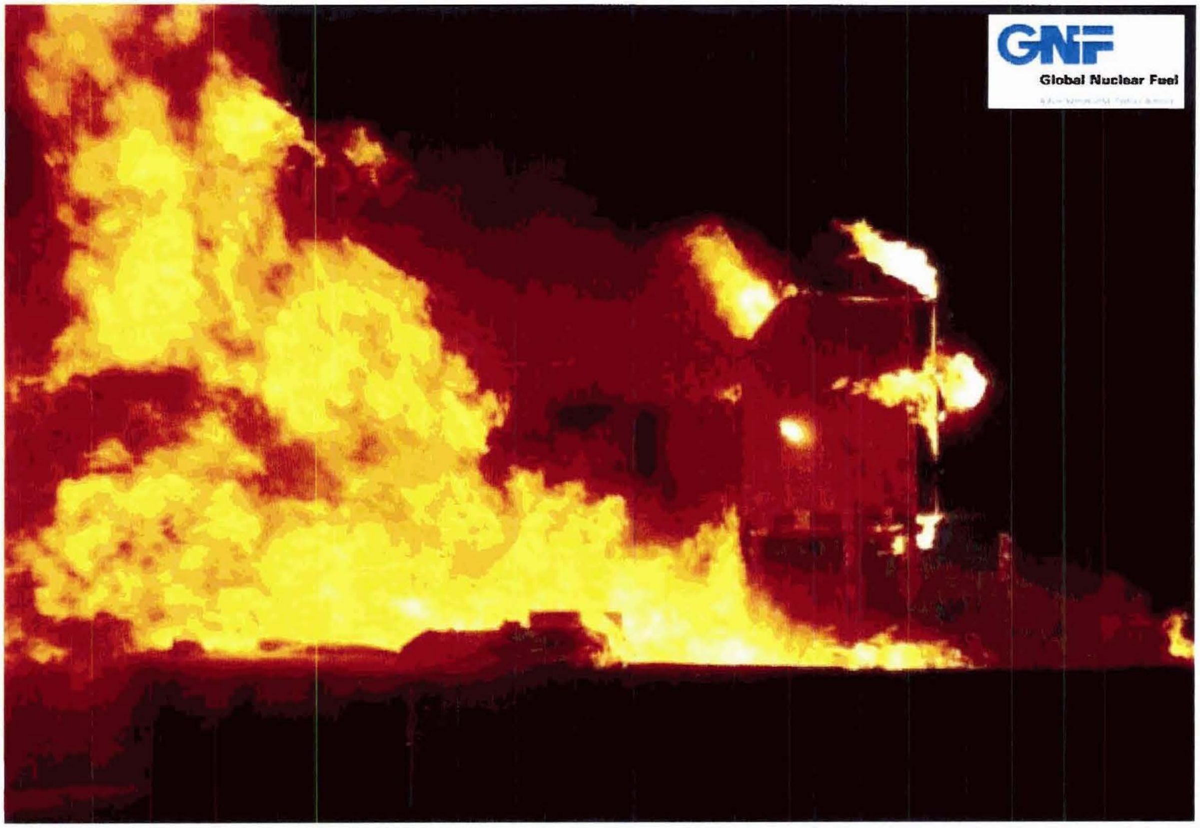

Figure 2.10.1-66 – CTU-3 Fire Test 15; View ~30 Minutes after Start

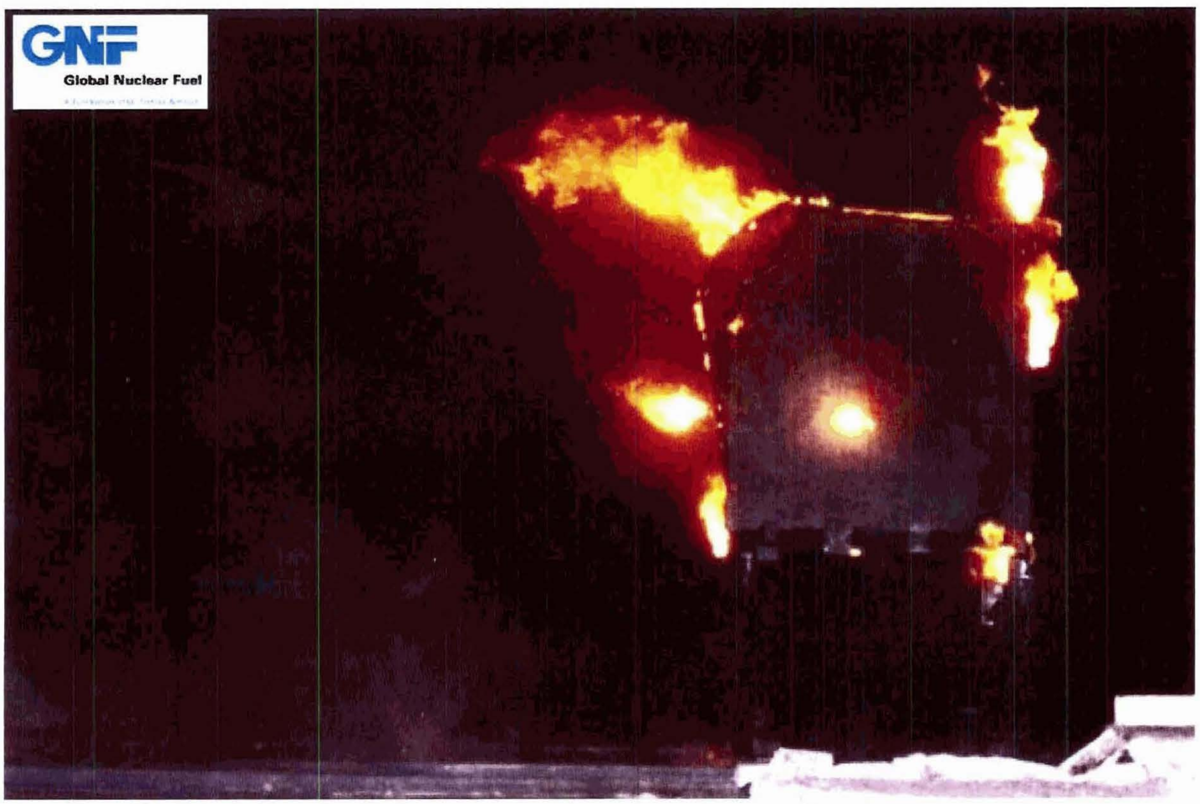

Figure 2.10.1-67 – CTU-3 Fire Test 15; View **~15** Minutes after End of Fire (Note Flares)

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

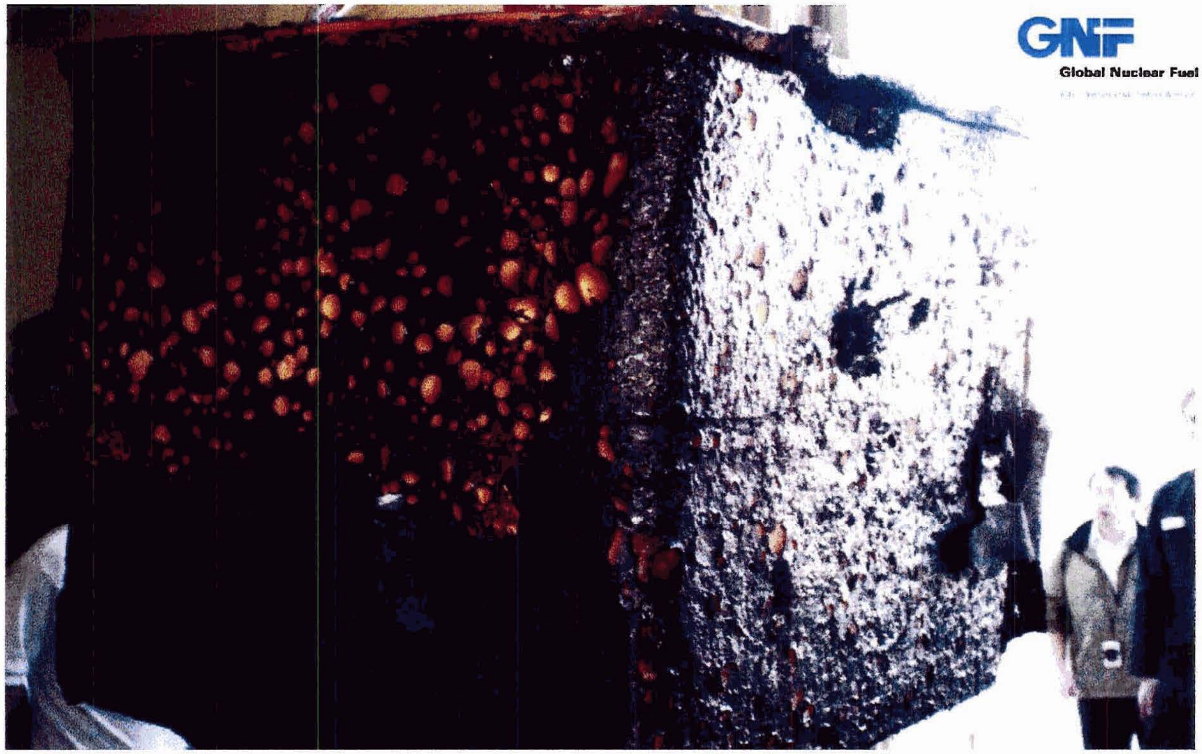

Figure 2.10.1-76 – CTU-3 Post-Test Disassembly; View of Residual OCA Foam Block

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

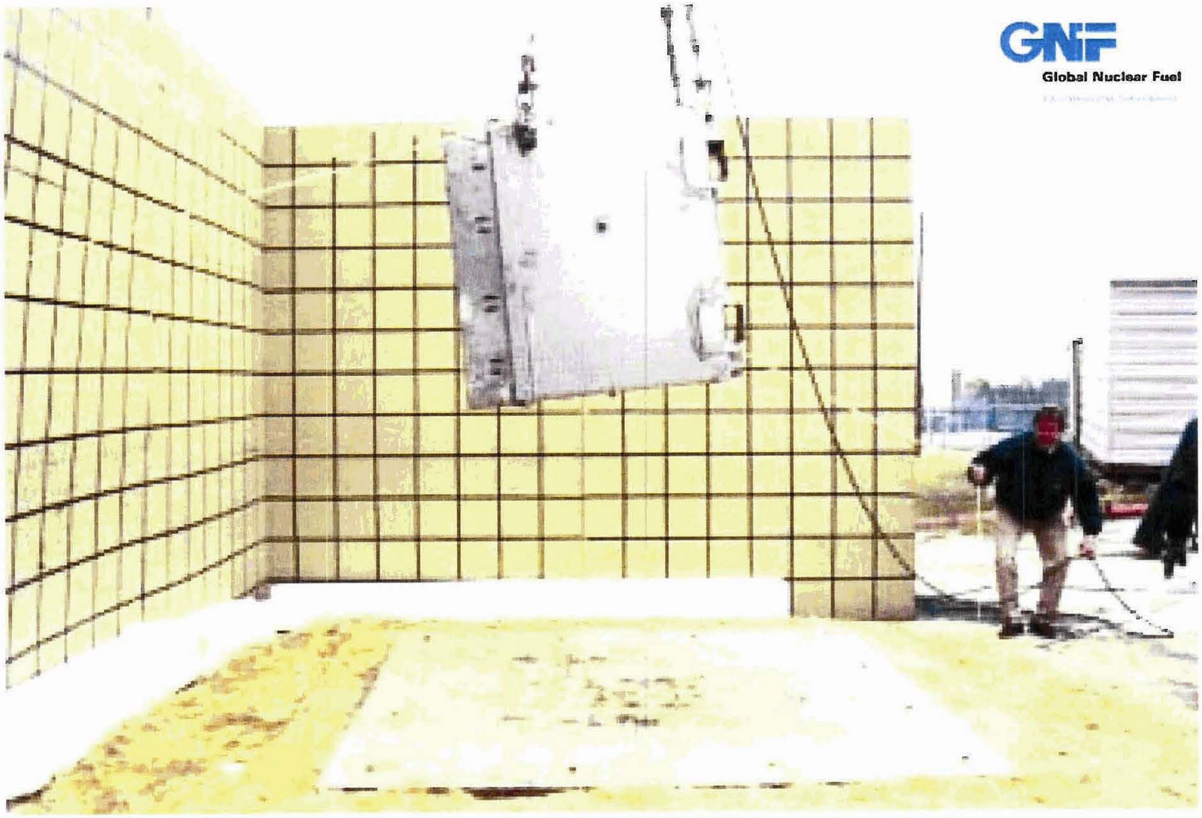

Figure 2.10.1-78 – CTU-4 Free Drop Test No. 5; NCT Shallow Angle Drop onto OCA Lid

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

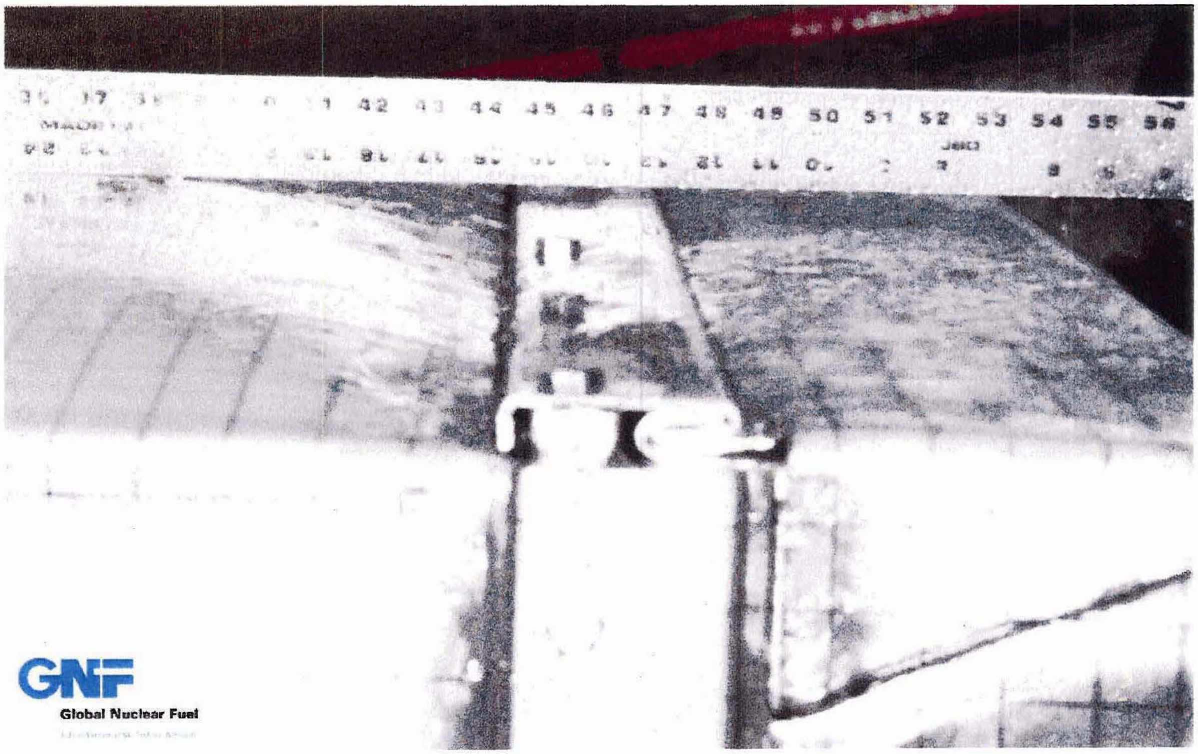

Figure 2.10.1-80 – CTU-4 Free Drop Test No. 6; Close-up View of Damage

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

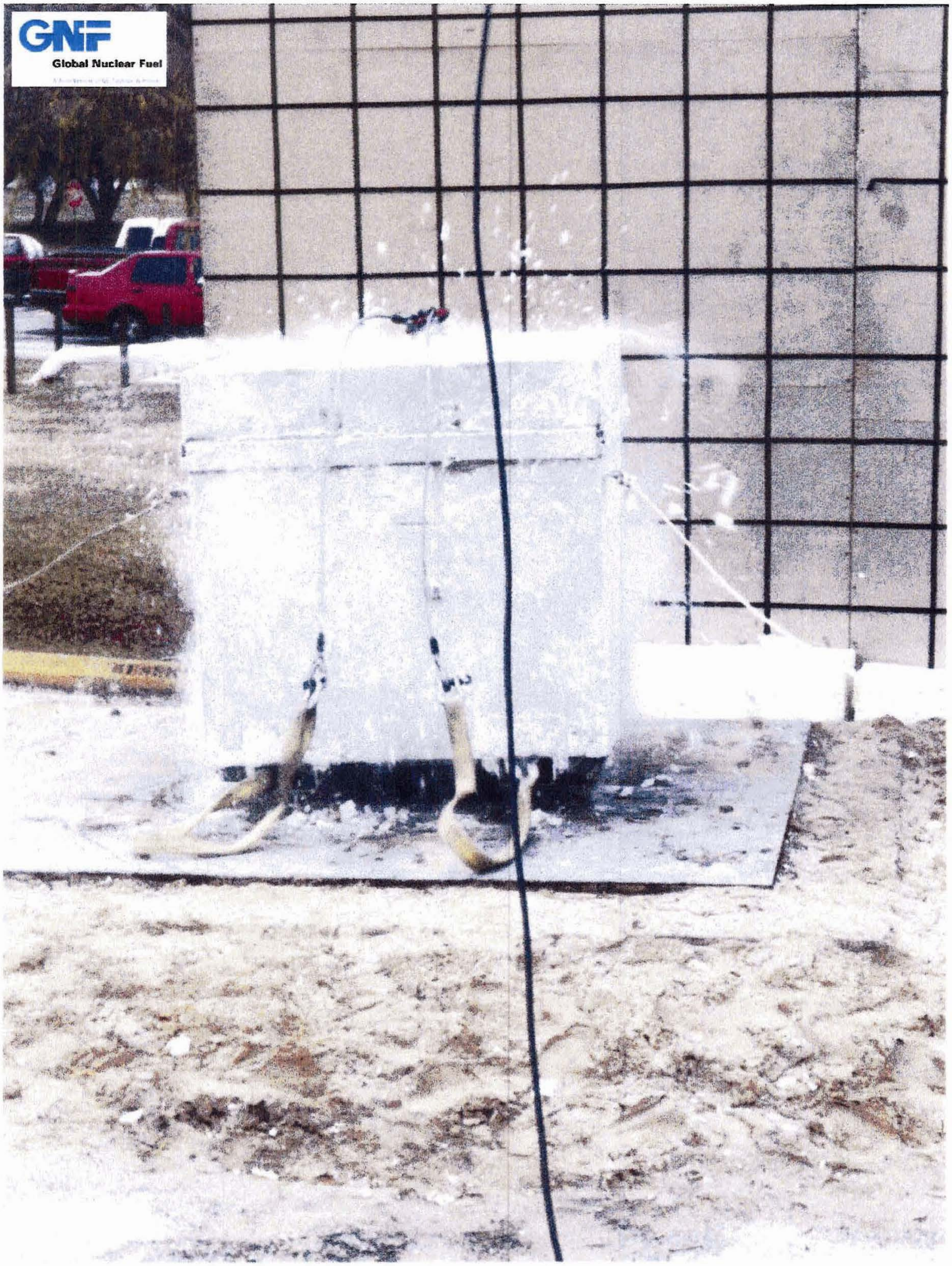

Figure 2.10.1-82 – CTU-4 Free Drop Test No. 7; NCT Drop at Impact

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

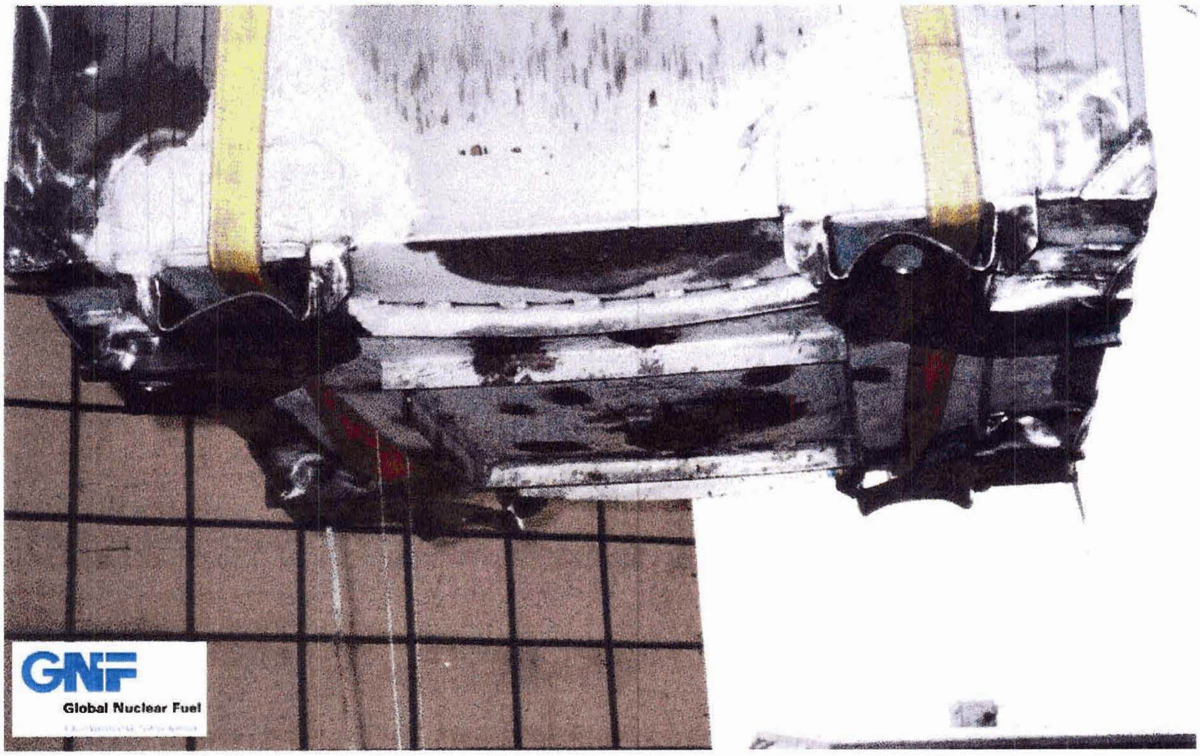

Figure 2.10.1-84 – CTU-4 Free Drop Test No. 8; View of Damage

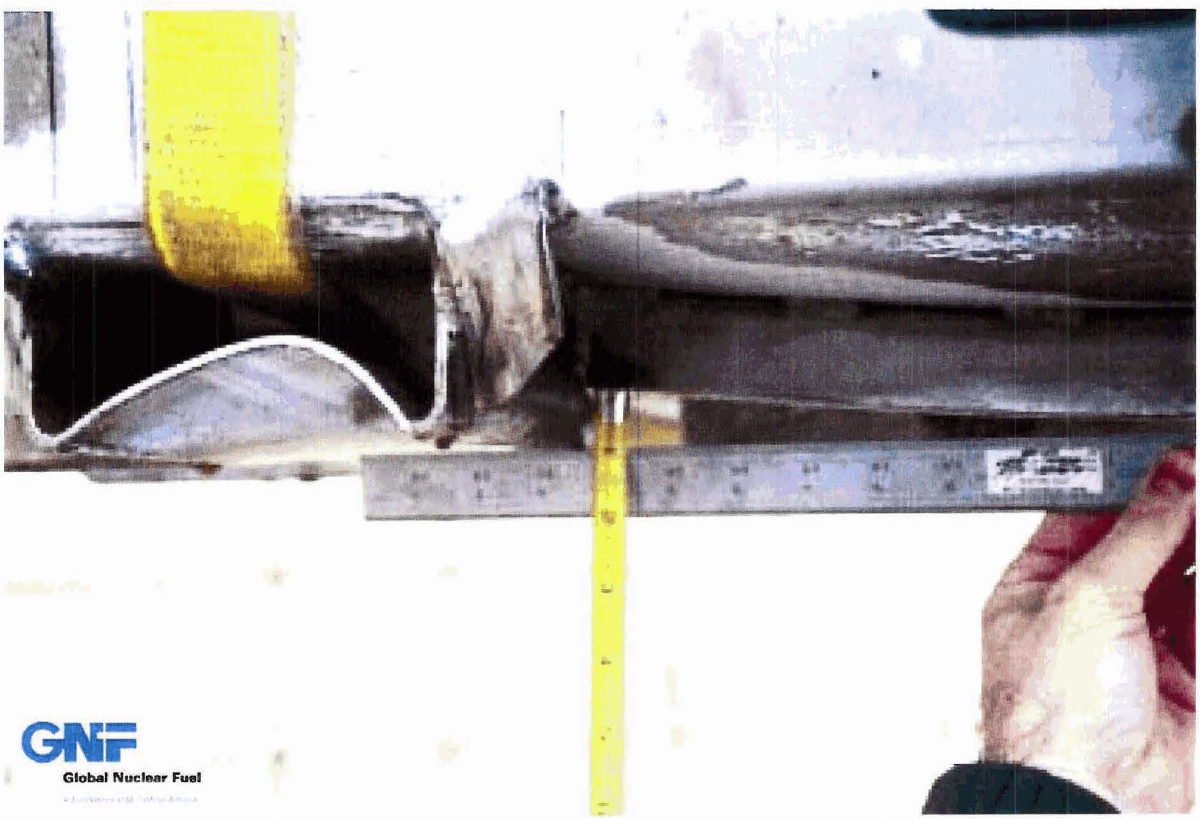

Figure 2.10.1-85 – CTU-4 Free Drop Test No. 8; Close-up View of Damage; ~1" Deep

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

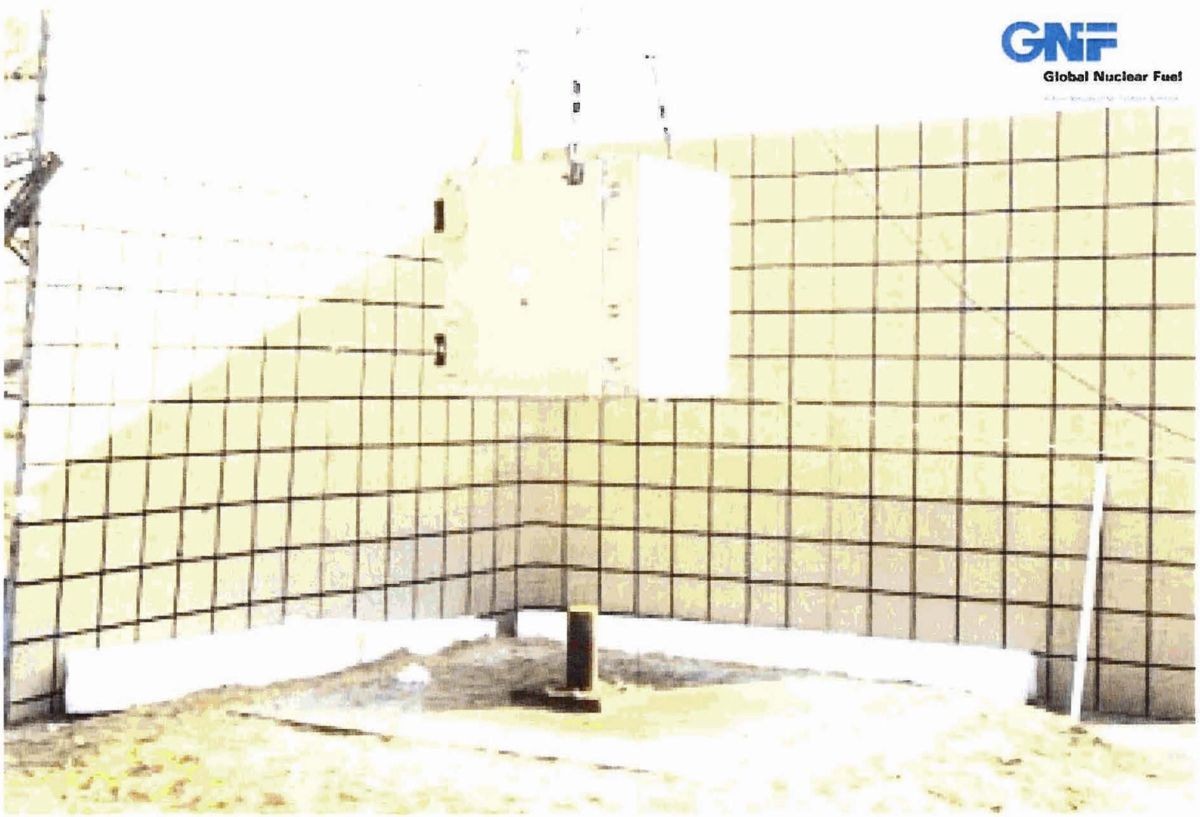

Figure 2.10.1-87 – CTU-4 Puncture Drop Test No. 12; HAC Puncture on Side

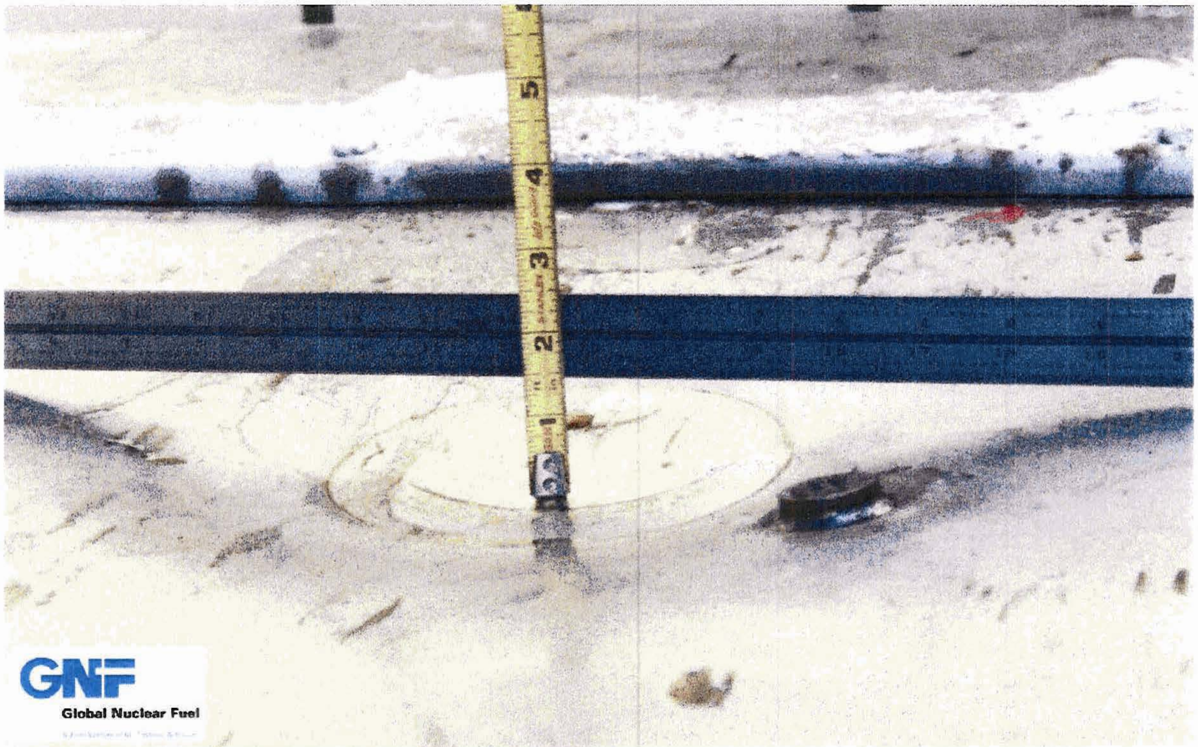

Figure 2.10.1-88 – CTU-4 Puncture Drop Test No. 12; Close-up View of Damage; ~1½" Deep

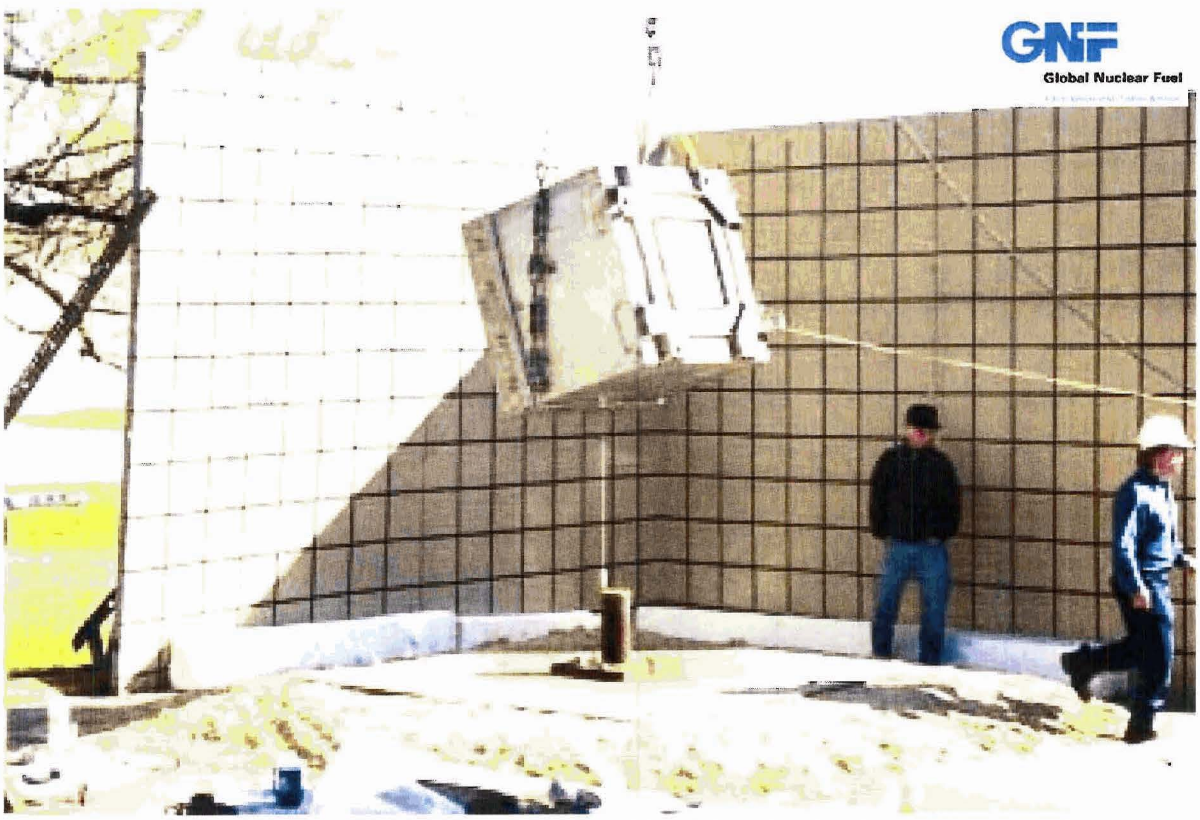

Figure 2.10.1-89 – CTU-4 Puncture Drop Test No. 13; HAC Oblique Drop on Side

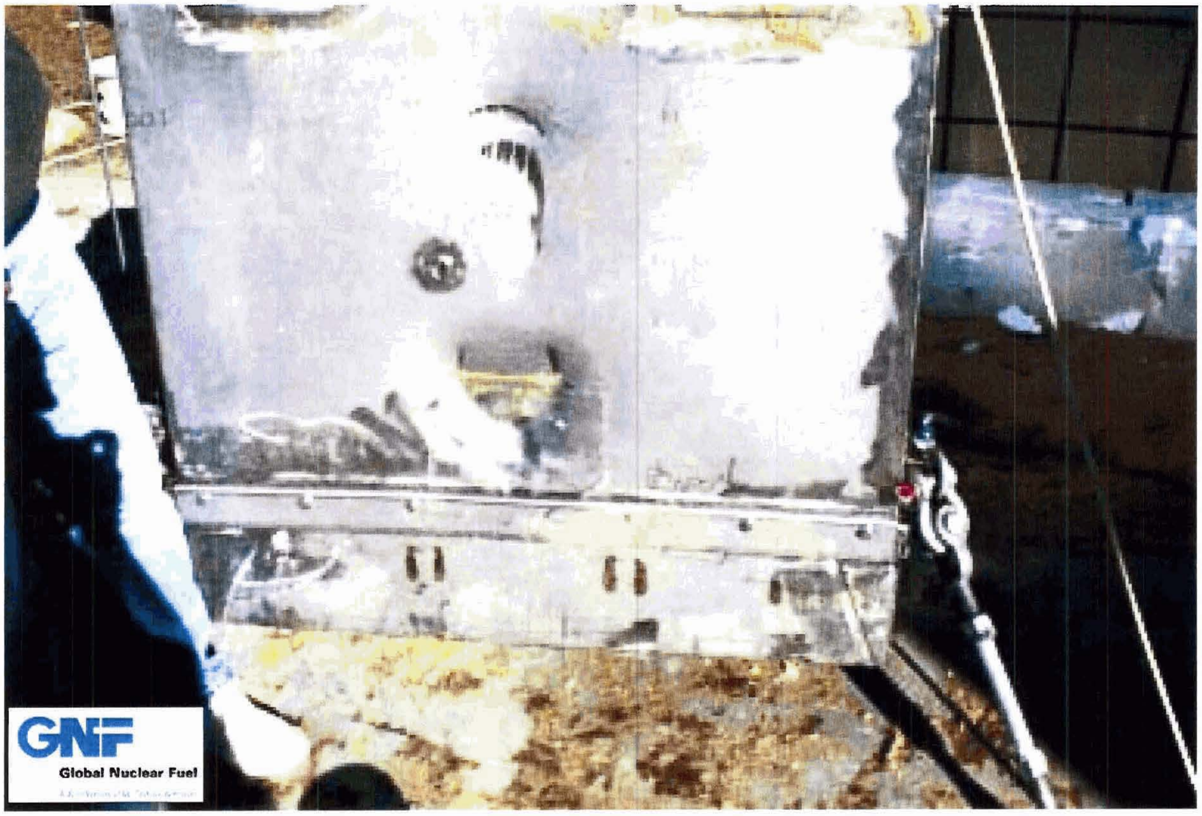

Figure 2.10.1-90 – CTU-4 Puncture Drop Test No. 13; View of Damage

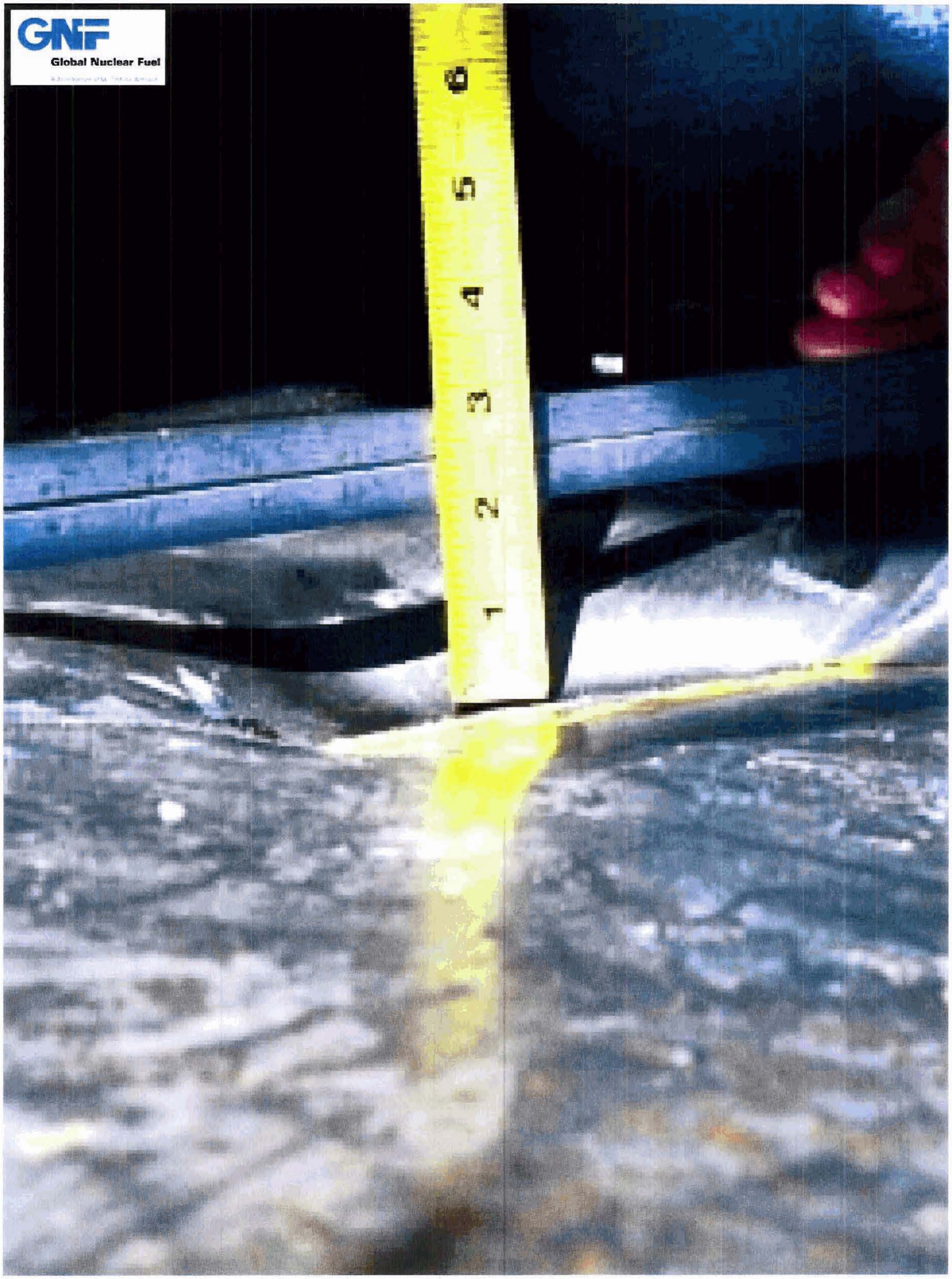

Figure 2.10.1-91 – CTU-4 Puncture Drop Test No. 13; Close-up View of Damage; ~1¾ Deep

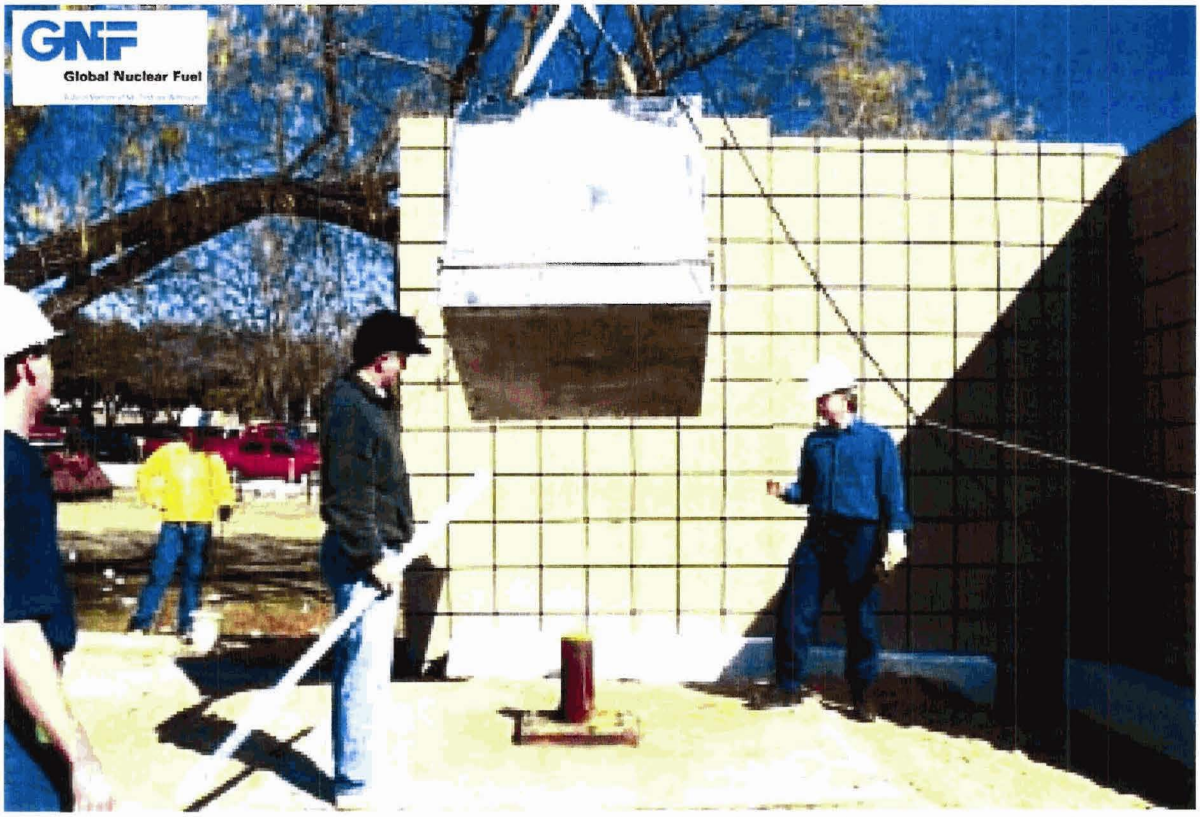

Figure 2.10.1-92 – CTU-4 Puncture Drop Test No. 14; HAC Oblique Puncture on OCA Lid

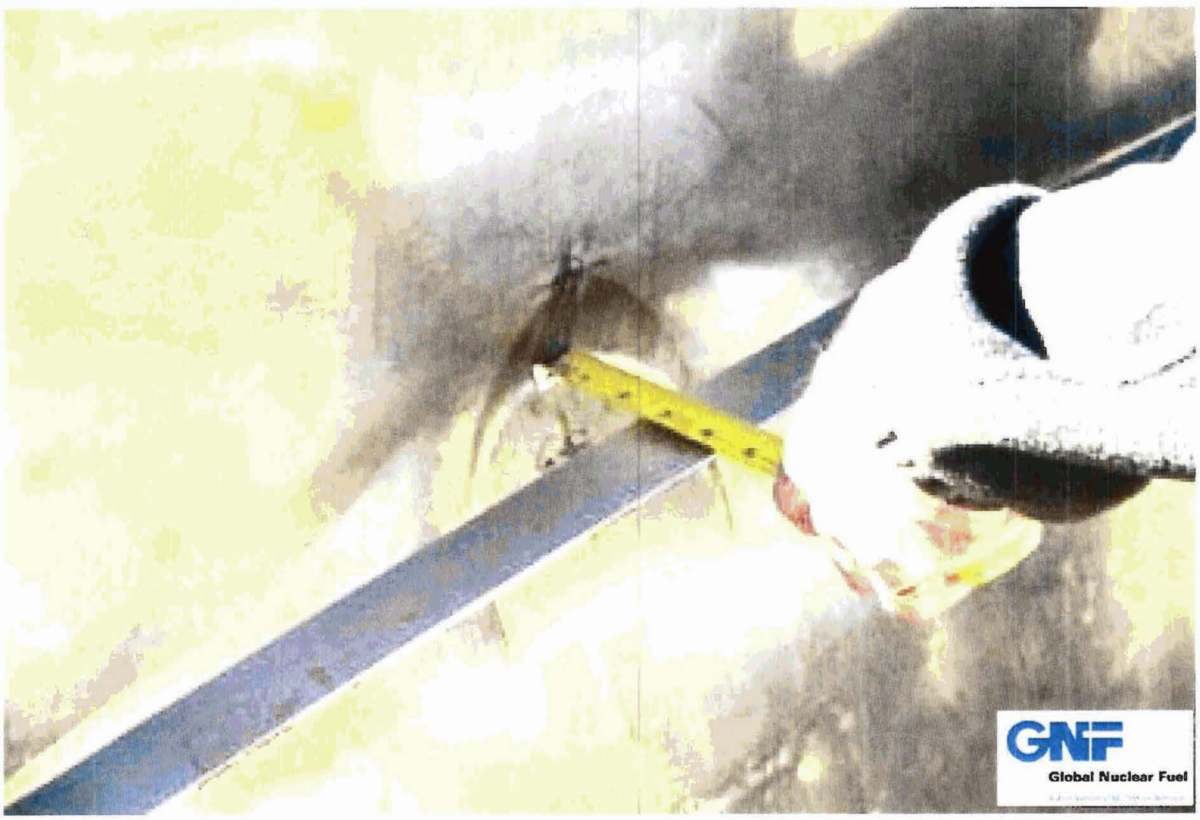

Figure 2.10.1-93 – CTU-4 Puncture Drop Test No. 14; Close-up of Damage; ~2½" Deep

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

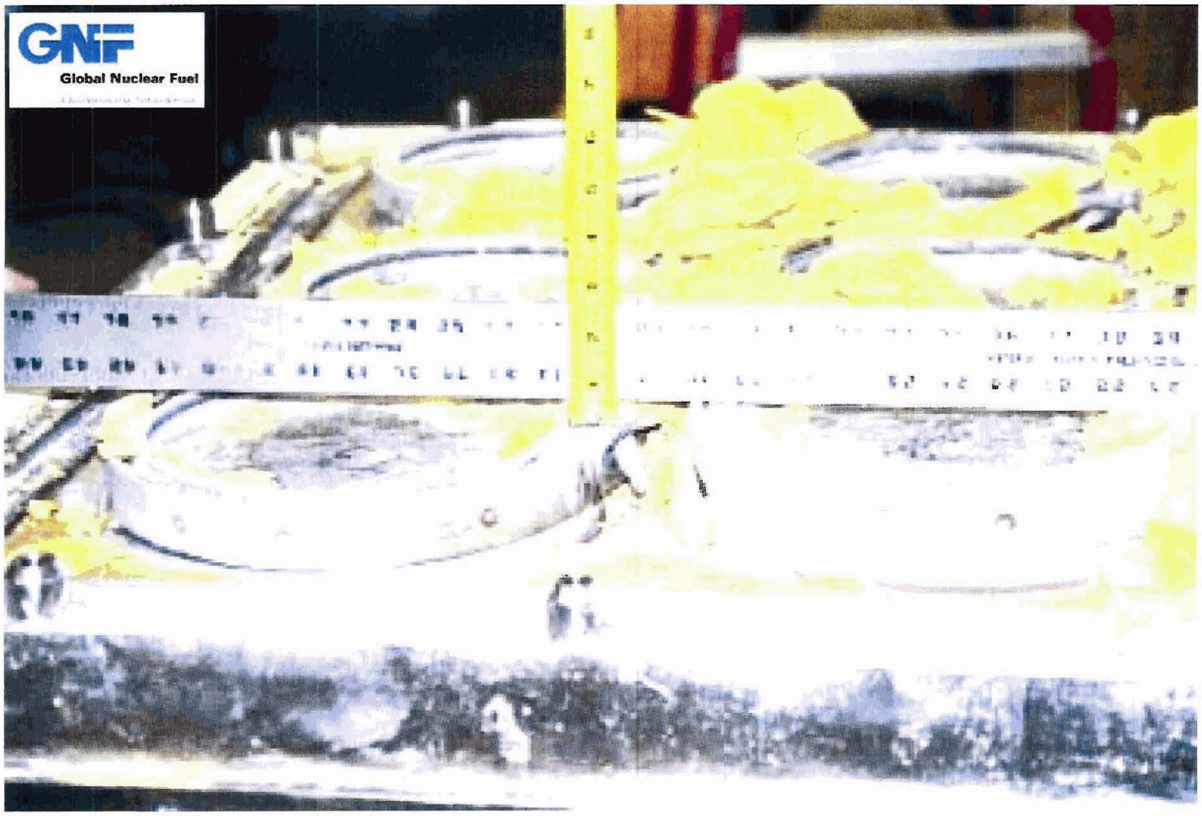

Figure 2.10.1-96 – CTU-4 Post-Test Disassembly; View of Vertical Position of ICCAs

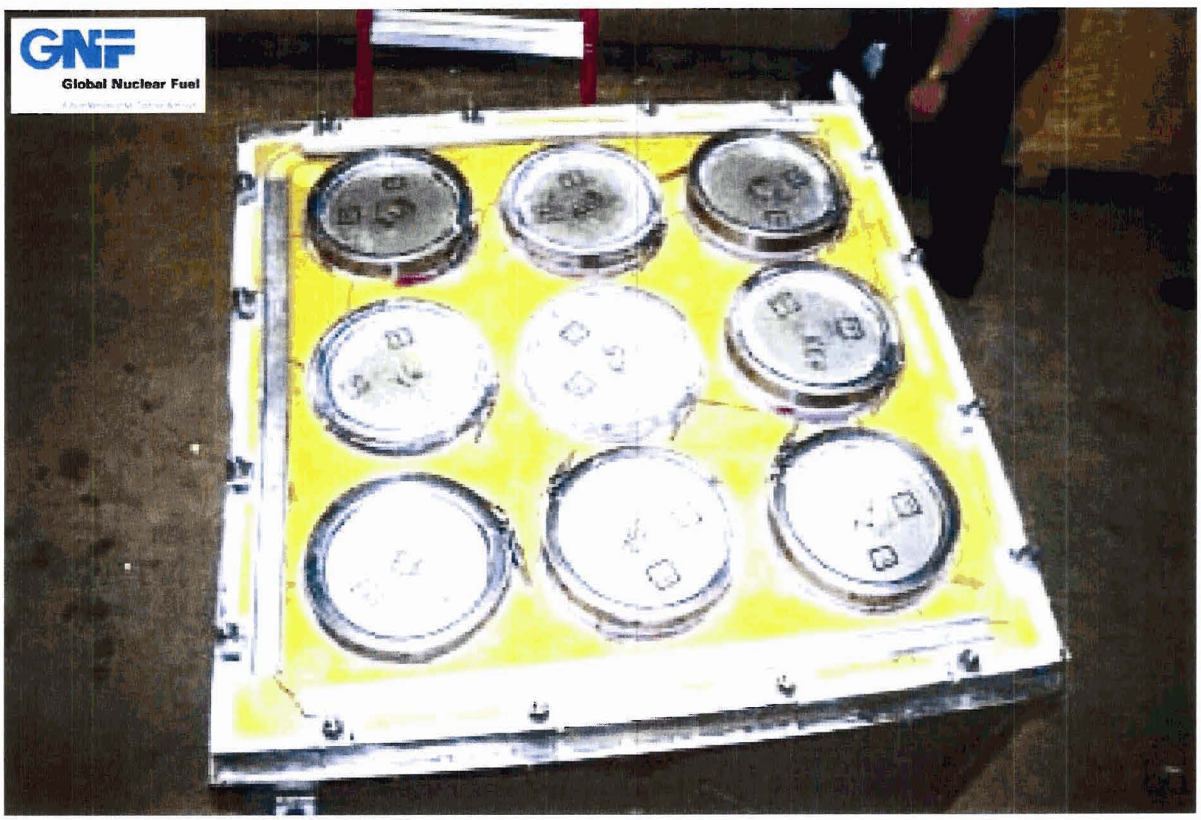

Figure 2.10.1-97 – CTU-4 Post-Test Disassembly; View of OCA Body and ICCAs

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.

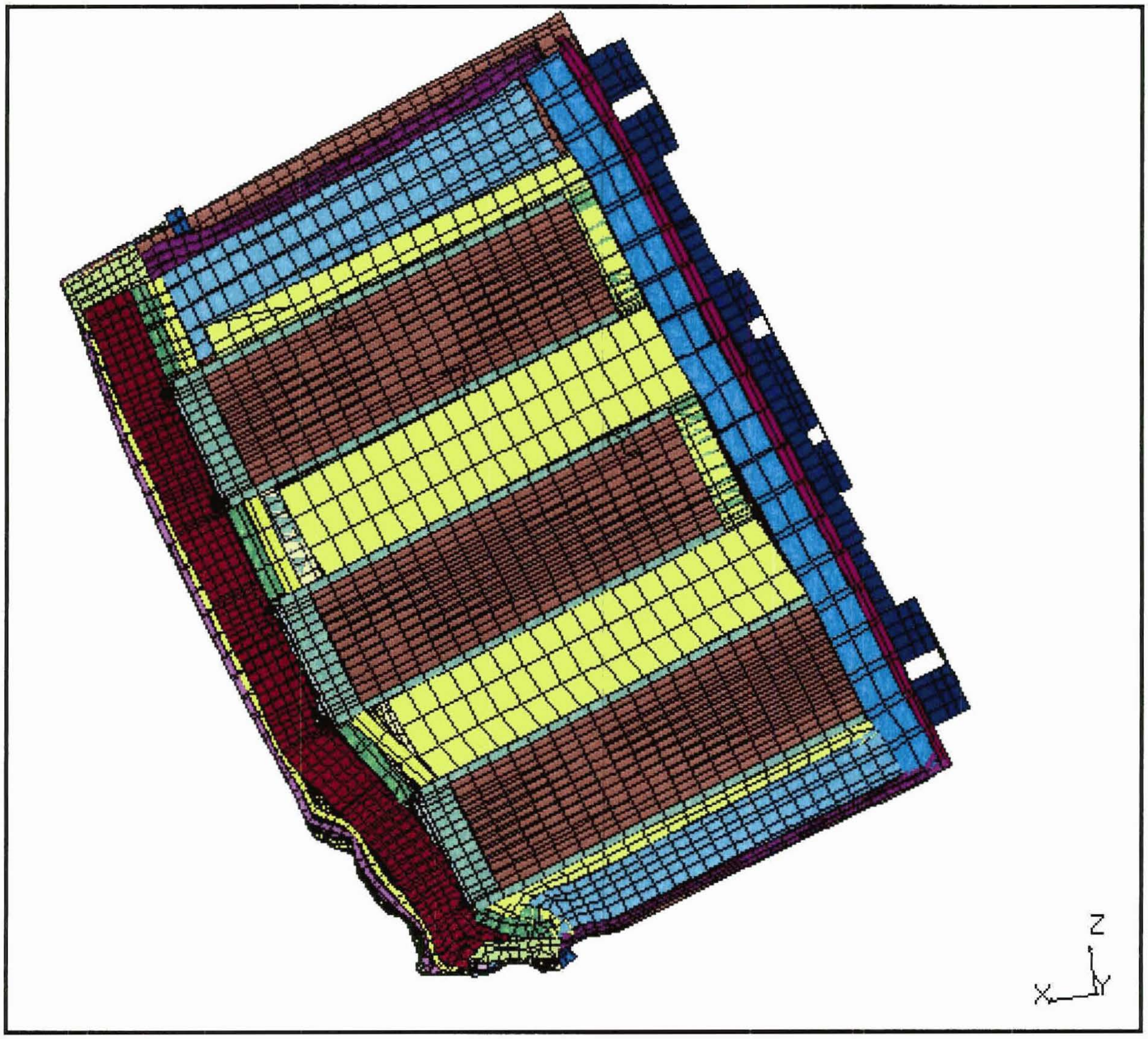

Figure 2.10.2-1 - LS-DYNA Model Results for CG-over-OCA Lid; Cross-section Side View

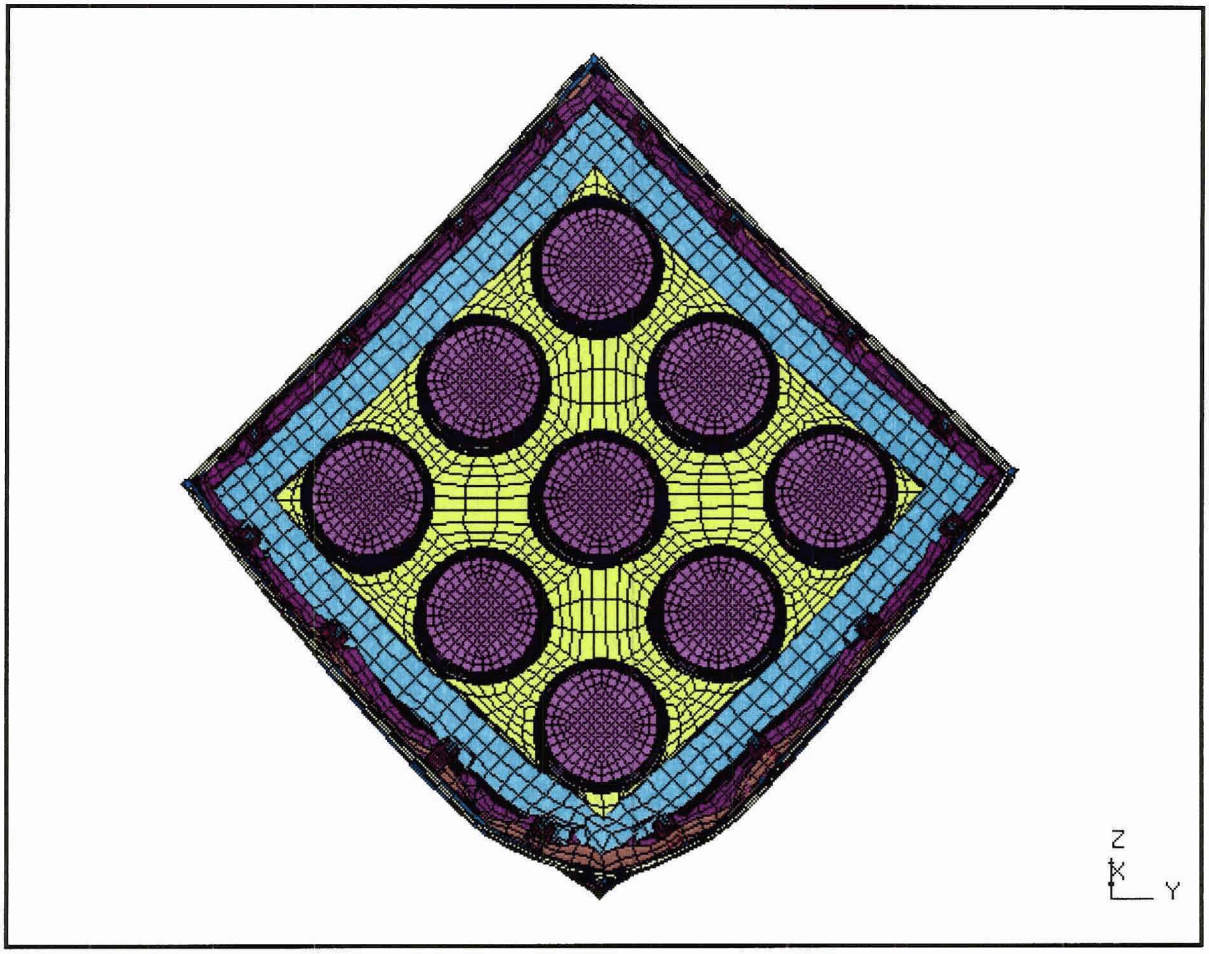

Figure 2.10.2-2 - LS-DYNA Model Results for CG-over-OCA Lid; Cross-section End View

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.

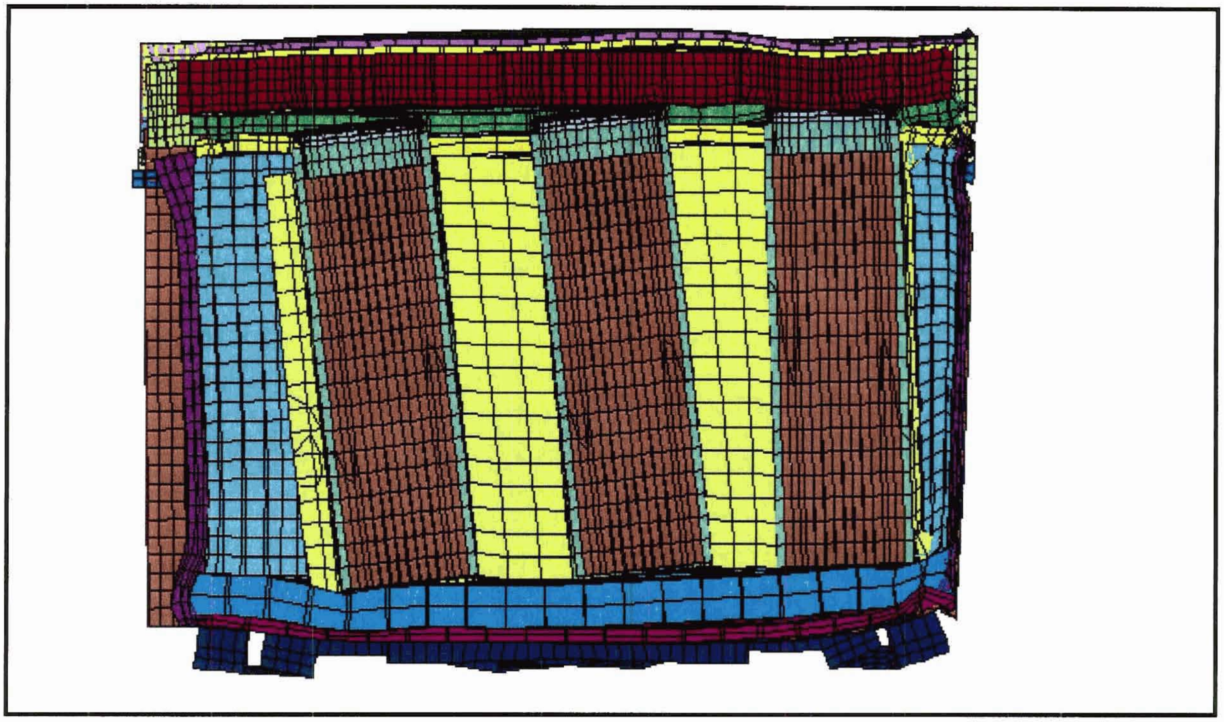

Figure 2.10.2-3 - LS-DYNA Model Results for OCA Side Edge; Cross-section Side View

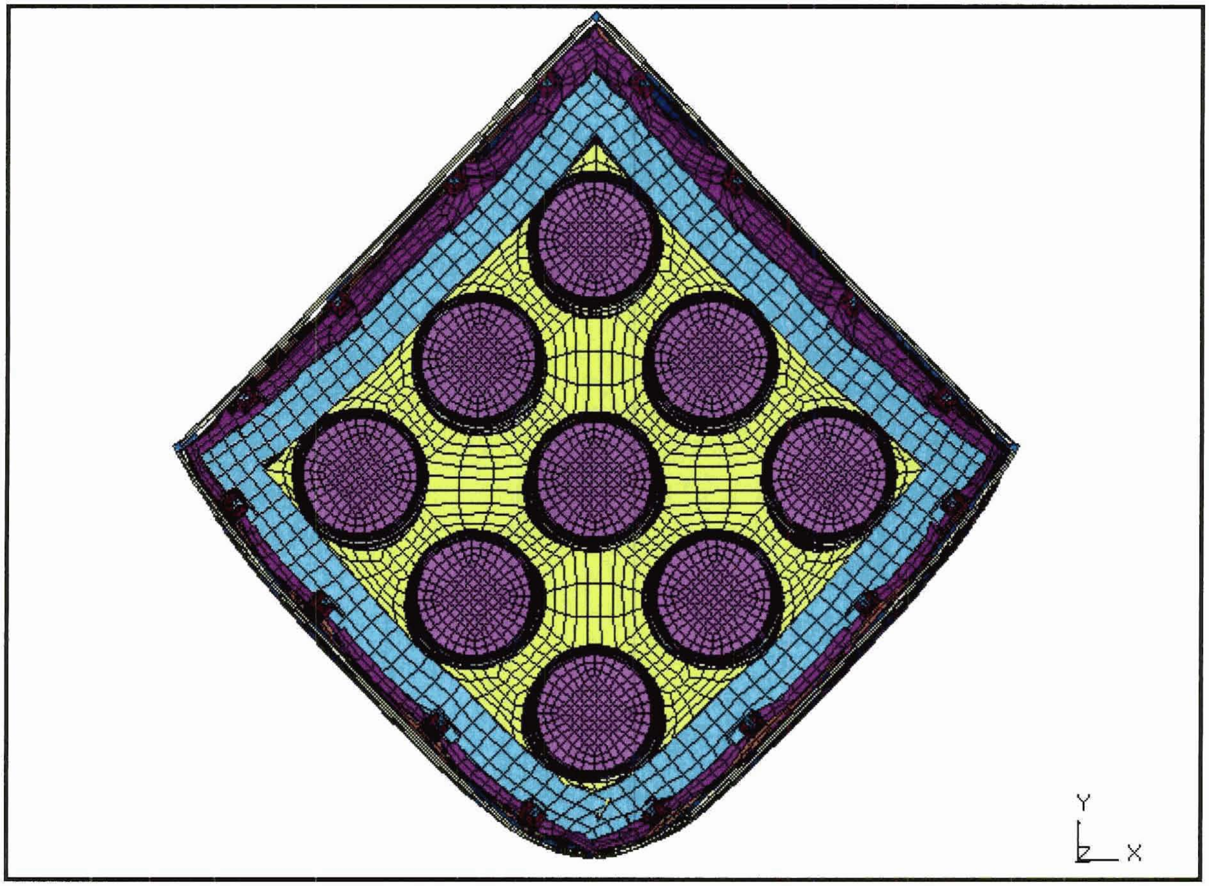

Figure 2.10.2-4 - LS-DYNA Model Results for OCA Side Edge; Cross-section End View

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