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ATTN: Document Control Desk
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Project Management Branch Section B
Division of High-Level Waste Repository Safety
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
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11545 Rockville Pike
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YUCCA MOUNTAIN – REQUEST FOR ADDITIONAL INFORMATION – VOLUME 2, CHAPTER 2.1.1.4, SET 2 AND SET 9; CHAPTER 2.1.1.5, SET 1 – REFERENCES

References:

1. Ltr, Williams to Jacobs, dtd 08/19/09, "Yucca Mountain - Request For Additional Information – Volume 2, Chapter 2.1.1.4, Set 2 (Department of Energy's Safety Analysis Report Sections 1.7) – Identification of Event Sequences"
2. Ltr, Williams to Jacobs, dtd 08/19/09, "Yucca Mountain - Request For Additional Information – Volume 2, Chapter 2.1.1.4, Set 7, Set 8 & Set 9 (Department of Energy's Safety Analysis Report Sections 1.7) – Identification of Event Sequences"
3. Ltr, Williams to Jacobs, dtd 08/21/09, "Yucca Mountain - Request For Additional Information – Volume 2, Chapter 2.1.1.2, Set 1 & Set 2; Chapter 2.1.1.5, Set 1 & Set 2; and Chapter 2.1.1.6, Set 1"

The purpose of this letter is to transmit six (6) U.S. Department of Energy (DOE) documents, not previously provided to the NRC, which were cited in responses to Requests for Additional Information (RAIs) identified in the above-referenced letters. Three of the documents contain electronic attachments that consist of complex data files available only on optical storage media (OSM) and are not appropriate for electronic information exchange (EIE) transmittal, but are required by NRC in reviewing RAI responses. The documents and electronic attachments are provided on optical storage media and will be provided to the public upon request.

One document, *Shielding Calculation for Canister Receipt and Closure Facility 1 and Receipt Facility*, contains information that DOE has determined to be Official Use Only (OUO) information. Such information is exempt from public disclosure under the Freedom of Information Act and 10 CFR 2.390. This OUO document contains electronic attachments that are also OUO. The OUO document and its electronic attachments are provided on a separate optical storage media, appropriately marked OUO.

HMSS25

There are no commitments in this letter. If you have any questions regarding this letter, please contact me at (202) 586-9620, or by email to jeff.williams@rw.doe.gov.

Jeffrey R. Williams, Supervisor
Licensing Interactions Branch
Regulatory Affairs Division
Office of Technical Management

OTM: SEG-1022

Enclosures (2)

1. Optical Storage Media disk titled, "Shielding Calculation for Canister Receipt and Closure Facility 1 and Receipt Facility, 100-00C-WHS0-00600-000-00C CACN 001, Official Use Only"
2. Optical Storage Media disk titled, "060-SYC-CR00-01100-000-00A, EDF-NSNF-082, EDF-NSNF-007, EDF-NSNF-029, EDF-NSNF-085"

cc w/encls:
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Ron Damele, Eureka County, Eureka, NV
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Joe Kennedy, Timbisha Shoshone Tribe, Death Valley, CA
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Barbara Byron, California Energy Commission, Sacramento, CA
Susan Durbin, California Attorney General's Office, Sacramento, CA
Charles Fitzpatrick, Egan, Fitzpatrick, Malsch, PLLC

EIE Document Components:

Enclosure 1 Optical Storage Media Disk

100-00C-WHS0-00600-000-00C_CACN1_part1_OUO.pdf	42,739 kB
100-00C-WHS0-00600-000-00C_CACN1_part2_OUO.pdf	40,232 kB
100-00C-WHS0-00600-000-00C_CACN1_part3_OUO.pdf	35,305 kB
Folder "Attachment G_OUO" (for NRC reviewers)	

Enclosure 2 Optical Storage Media Disk

Folder "169137" [169137]_EDF-NSNF-007 Rev2.pdf	47,578 kB
Folder "169138" [169138]_EDF-NSNF-029.pdf	22,250 kB
Folder "184998" EDF-NSNF-085.pdf	28,296 kB
Folder "185233" [185233]_060-SYC-CR00-01100-000-00A_w-CACN1.pdf Folder "Attachments" (for NRC reviewers)	6,547 kB
Folder "186328" [186328]_EDF-NSNF-082.pdf Folder "Attachments" (for NRC reviewers)	26,406 kB

Note: These PDF files for supporting responding to Yucca Mountain Repository License Application RAIs were prepared with Adobe Acrobat Version 8 using the current job options file provided by the NRC on its website. Some files included in this submittal may have been initially prepared with another version of Acrobat and another job options file. All files were reviewed using the NRC preflight profile provided on its website and have been determined to meet NRC specifications in the June 2009 revision of Guidance for Electronic Submissions to the NRC. As discussed with NRC staff, the addition of accessibility tagging for compliance with Section 508 of the Rehabilitation Act frequently causes the preflight to return "fonts not embedded" error messages. Specifically, the content is usually flagged as unembedded Times-Roman font. The Adobe preflight errors for unembedded fonts have been reviewed and represent nonprinting and nondisplaying Section 508 tagging information.

Several PDF files for supporting responding to Yucca Mountain Repository License Application RAIs were created before January 1, 2004 or were created after January 1, 2004 but contain images created before January 1, 2004. As such, the color and/or grayscale PDF resolution for images may be below 300 ppi, but greater than 150 ppi, which is allowable in accordance with the Section 2.8 of the June 2009 revision of Guidance for Electronic Submissions to the NRC

Crosswalk of August 26, 2009 Reference Submittal to RAI Response Submittals

Enclosure 2 OSM Disk (Reference Submittal to NRC 8/26/09)		Correlating RAI Number and Submittal Date	
Folder "169137" [169137]_EDF-NSNF-007 Rev2.pdf	47,578 kB	2.2.1.1.4-2-004 2.2.1.1.4-2-011	8/19/2009
Folder "169138" [169138]_EDF-NSNF-029.pdf	22,250 kB	2.2.1.1.4-2-002 2.2.1.1.4-2-004	8/19/2009
Folder "184998" EDF-NSNF-085.pdf	28,296 kB	2.2.1.1.4-2-002	8/19/2009
Folder "185233" [185233]_060-SYC-CR00-01100-000-00A_w-CACN1.pdf Folder "Attachments" (for NRC reviewers)	6,547 kB	2.2.1.1.4-9-001	8/19/2009
Folder "186328" [186328]_EDF-NSNF-082.pdf Folder "Attachments" (for NRC reviewers)	26,406 kB	2.2.1.1.4-2-002 2.2.1.1.4-2-004	8/19/2009

Engineering Design File Cover Sheet

EDF No: EDF-NSNF-007, Rev. 2	
CWBS No.: C.1.07.02.01.02.01	Work Package Title: Canister/Basket Specification
QA Affecting: ☒ Yes ☐ No	Lifetime Records: ☒ Yes ☐ No

EDF Title: **FY1999 DROP TESTING REPORT FOR THE 18-INCH STANDARDIZED DOE SNF CANISTER**

Summary:

EDF-NSNF-007 Revision 0 originally released this report. Revision 1 supplemented the original release by making minor corrections to 4 pages. This current revision, Revision 2, adds a new appendix (Appendix I) to document additional post-drop test canister measurements. Minor changes to several pages (identified by a vertical bar in the right-side column of a modified page) were also made as follows:

- -Cover Sheets, pages 1 and 3, added Appendix I to the list of appendices
- -Part II, page 18, added a clarification note to Table 5
- -Part II, page 19, corrected a Table 6 entry to agree with the Appendix E page E-3 measured value
- -Part II, page 20, modified text to agree with corrected Table 6 entry, added a comment about residual stresses
- -Part II, page 36, corrected a Table 17 entry to agree with the Appendix E page E-3 measured value
- -Part II, page 37, added a comment about residual stresses
- -Part II, page 57, corrected a Table 29 entry to agree with the Appendix E page E-3 measured value, modified text to agree with the corrected Table 29 entry
- -Added Appendix I to satisfy Deficiency Report 00-NSNF-AU-011-DR-002.

The above modifications do not change the results or conclusions of the original EDF. Only the above modified pages are attached to this EDF-NSNF-007 Revision 2.

The work described in this report was a joint research effort between Sandia National Laboratories (SNL) and the Idaho National Engineering and Environmental Laboratory (INEEL). The information and data generated at SNL was produced in accordance with an approved QARD compliant QA system. The information and data generated at the INEEL was produced under an INEEL QA program.

Total Attachments:	Attachment Nos.:	No. of pages in each:	Total Pages:
8	Cover Sheets, pages 1 & 3 Part II, above listed pages Appendix I	2 6 12	20 total pages

	Printed Name	Signature	Date
Originator	Part I: D. K. Morton Part II and Appendices A, B, C, E, and I: S. D. Snow Appendices D, F, G, and H: T. E. Rahl	D. K. Morton S D Snow T. E. Rahl / DKM	9/5/2002 9/5/2002 9/5/2002
Reviewer	R. K. Blandford (Rev. 2 changes only)	R K Blandford	9/5/2002
NSNFP PM/TL	T. J. Hill	T J Hill	9/5/2002
NSNFP PSO QE	N. S. Mackay	N S MacKay	9/5/2002

Distribution (Complete package): Project File	NSNFP File Log No.: 4724.11
S. D. Snow, T. E. Rahl, D. K. Morton (5 copies), T. J. Hill (2 copies), B. W. Carlsen, R. K. Blandford	
Distribution (cover sheet only): EDF Log, P. D. Wheatley	

EDF-NSNF-007 Revision 2 attached sheets are incorporated into the Revision 1 report body.

Engineering Design File Cover Sheet

NOTE: Click on this link [Form Instructions] to view the instructions for this form.

EDF No: EDF-NSNF-007, Rev. 1		
CWBS No.: C.1.07.02.01.02.01	**Work Package Title:** Canister/Basket Specification	
QA Affecting: ☒ Yes ☐ No		**Lifetime Records:** ☒ Yes ☐ No

EDF Title: FY1999 DROP TESTING REPORT FOR THE 18-INCH STANDARDIZED DOE SNF CANISTER

Summary:

EDF-NSNF-007 Revision 0 originally released this report. This Revision 1 supplements the original release by making minor corrections to 4 pages (identified by a vertical bar in the right-side column of a modified page):

-Part I, page 28, modified one paragraph to satisfy Deficiency Report 00-NSNF-AU-011-DR-002
-Part II, page 12, replaced an incorrect coefficient of friction value of 0.05 with the correct value of 0.10
-Part II, page 33, added a sentence to clarify the post-drop coefficient of friction value used for canister 04
-Appendix B, page B-47, corrected a measurement value.

Only the above modified pages are attached to this EDF-NSNF-007 Revision 1.

Total Attachments:	Attachment Nos.:	No. of pages in each:	Total Pages:
4	Part I, page 28 Part II, pages 12 and 33 Appendix B, page B-47	1 2 1	4 total pages

	Printed Name	Signature	Date
Originator	Part I: D. K. Morton	D. K. Morton	8/22/01
	Part II and Appendices A, B, C, and E: S. D. Snow	S D Snow	8/22/01
	Appendices D, F, G, and H: T. E. Rahl	T E Rahl	8/22/01
Reviewer	R. K. Blandford (Rev. 1 changes only)	R K Blandford	8/22/01
NSNFP PM/TL	T. J. Hill	T Hill	8/22/01
Remarks:			

Distribution (Complete package): Project File — NSNFP File Log No.: 4724.11

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EDF-NSNF-007 Revision 1 attached sheets are incorporated into the Revision 0 report body.

Engineering Design File Cover Sheet

NOTE: Click on this link [Form Instructions] to view the instructions for this form.

EDF No: EDF-NSNF-007, Rev. 0			
CWBS No.: C.1.07.02.01.02.01	**Work Package Title:** Canister/Basket Specification		
QA Affecting: ☒ Yes ☐ No		**Lifetime Records:** ☒ Yes ☐ No	

EDF Title:

FY1999 DROP TESTING REPORT FOR THE 18-INCH STANDARDIZED DOE SNF CANISTER

Summary:

Part I of the attached report gives an overview of the testing program, summarizing the test canister construction, inspection, loading of internal components, drop testing, post-drop pressure and helium leak testing, post-drop inspections, etc. Part II of the report details pre-drop and post-drop test analytical evaluations of the test canisters. Part II demonstrates the capability of finite element methods to accurately predict canister response during accidental drop events. The Appendices include details supporting the Part I and II report sections.

A draft copy of this report was submitted to the NSNF program for review on September 30, 1999. This EDF releases the official version (Rev. 0) of this report which includes the NSNF program and reviewer comments.

Total Attachments:	Attachment Nos.:	No. of pages in each:	Total Pages:
11	Report Cover Sheets, Part I, Part II, and 8 Appendices	Report cover sheets: 3 Part I: 58 pages Part II: 156 pages Appendices: 327 pages	544 total pages

	Printed Name		Signature	Date
Originator	Part I:	D. K. Morton	D. K. Morton	3/20/2000
	Part II and Appendices A, B, C, and E:	S. D. Snow	SD Snow	3/20/2000
	Appendices D, F, G, and H:	T. E. Rahl	Tom E Rahl	3/20/2000
Reviewer	A. G. Ware		AG Ware	3/20/00
NSNFP PM/TL	S. C. Gladson		Scott C. Gladson	3/20/00
Remarks:				

Distribution (Complete package): Project File — NSNFP File Log No.: 4724.11

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Distribution (cover sheet only): EDF Log

P. D. Wheatley

FY1999 DROP TESTING REPORT FOR THE STANDARDIZED 18-INCH DOE SNF CANISTER

Authors

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PART II: S. D. Snow

Appendices A, B, C, E, & I: S. D. Snow

Appendices D, F, G, & H: T. E. Rahl

Prepared for the
U.S. Department of Energy
Office of Environmental Management
Under DOE Idaho Operations Office
Contract DE-AC07-99ID13727

Executive Summary

During FY1999, nine 18-inch diameter test canisters were fabricated at the Idaho National Engineering & Environmental Laboratory (INEEL) to represent the standardized DOE Spent Nuclear Fuel canister design with various "worst case" internal loadings. Seven of the test canisters were 15-foot long and weighed about 6000 pounds, while two were 10-foot long and weighed 3000 and 3800 pounds. Seven of the test canisters were dropped from thirty feet onto an essentially unyielding flat surface, and one of the canisters was dropped from 40-inches onto a 6-inch diameter puncture post. The final test canister was dropped from 24-inches onto a 2-inch thick vertically oriented steel plate, and then tipped over to impact another 2-inch thick vertically oriented steel plate. All drop testing was performed at Sandia National Laboratories. The nine test canisters experienced varying degrees of damage to their skirts, lifting rings, and pressure boundary components (heads and main body). However, all of the canisters were shown to have maintained their pressure boundary (through pressure testing), and the four most heavily damaged canisters were also shown to be leaktight (through helium leak testing performed at the INEEL).

Pre-drop and post-drop test canister finite element (FE) modeling was performed at the INEEL in support of the canister drop test program. All model evaluations were performed using the ABAQUS/Explicit software. The FE models were shown to have accurately (though at times, slightly conservatively) predicted the response of the actual test canisters.

Contents

Appendices

PART I

PROGRAMMATIC HIGHLIGHTS OF ACTIVITIES ASSOCIATED WITH THE DROP TEST PROGRAM FOR 18-INCH DIAMETER REPRESENTATIVE STANDARDIZED DOE SPENT NUCLEAR FUEL CANISTERS

ACKNOWLEDGMENT

In addition to the faithful and consistently excellent work performed by Mr. Spencer D. Snow and Mr. Tom E. Rahl, the author would like to acknowledge the many INEEL personnel who helped plan, build, examine, and test the nine test canisters used for this effort. Special acknowledgement is given to Mr. Lyle Powell (welder), Mr. Gary L. Powell (welder), and Mr. Stan K. Jacobson (heavy equipment operator) for their skills and dedication to the project, without which this effort would not have been successful.

PART I CONTENTS

PART I

PROGRAMMATIC HIGHLIGHTS OF ACTIVITIES ASSOCIATED WITH THE DROP TEST PROGRAM FOR 18-INCH DIAMETER REPRESENTATIVE STANDARDIZED DOE SPENT NUCLEAR FUEL CANISTERS

1. PROGRAM OBJECTIVES

The National Spent Nuclear Fuel Program (NSNFP) developed the standardized Department of Energy (DOE) spent nuclear fuel (SNF) canister (Reference 1). This canister design incorporates an energy-absorbing skirt (Figures 1 and 2) that deforms on impact during accidental drop events, providing a significant amount of protection to the actual pressure boundary or containment system of the canister. This deformed skirt can even be removed (cut off) if necessary without disrupting the canister containment, enhancing the canister's ability to still fit into other containers. The skirt helps to protect the canister containment system in virtually all accidental drop events excluding the horizontal (flat) impact orientation and various potential puncture events.

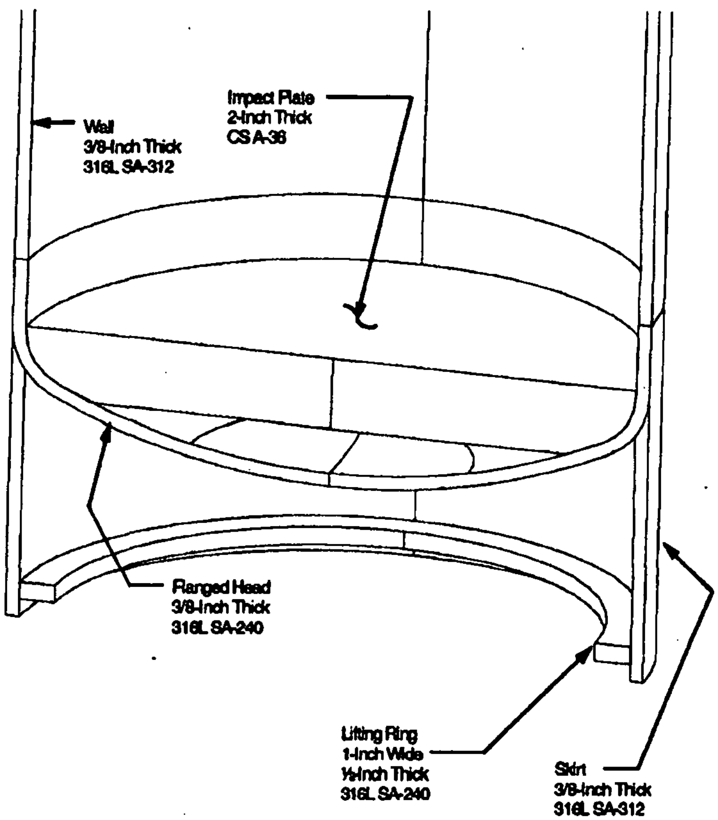

Figure 1. Close-up of 18-Inch Canister Drop-Resistant End Design

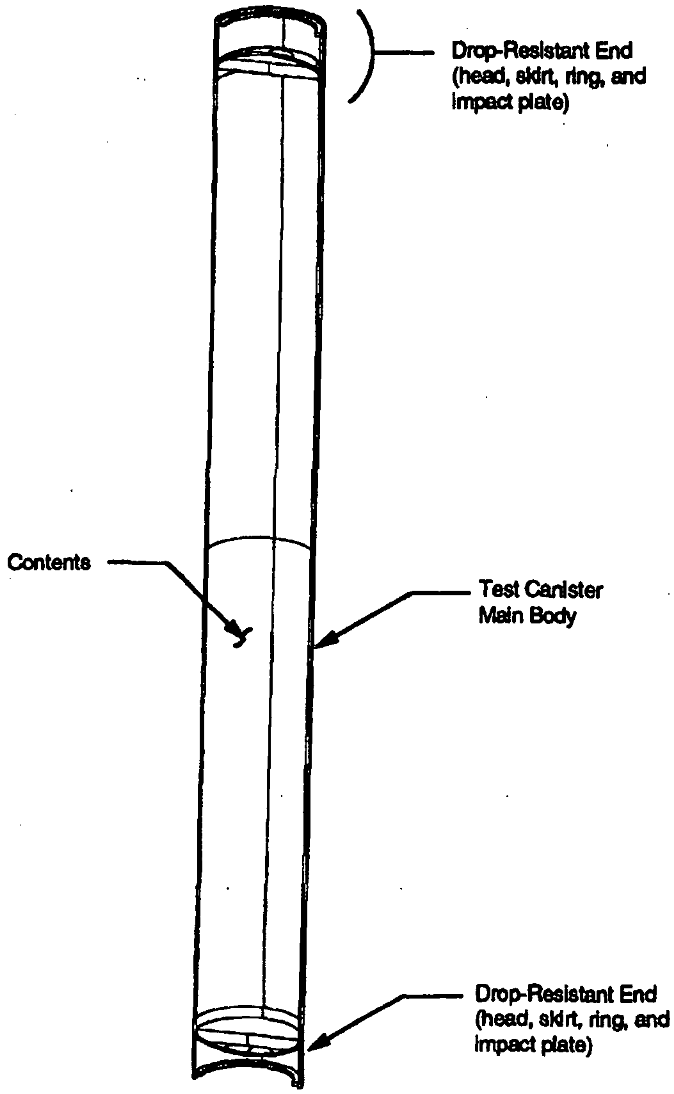

Figure 2. Section View of 18-Inch Canister Design

One of the goals of the NSNFP for fiscal year 1999 (FY99) was to demonstrate the canister's robust design by drop testing a number of combinations of representative canisters (hereafter called test canisters) and contents [internals plus simulated (non-radioactive) SNF] that most significantly challenged the canisters from a containment viewpoint. Canister and internals deformations were not important with respect to SNF criticality for this drop testing effort. Proposed internal geometries were reviewed to select the internals that would result in the worst possible damage on canister containment. Carbon steel material for the internals was utilized rather than ductile stainless steel to increase possible damage to the test canisters. Even the orientation of the internals within the canisters was specified in order to inflict maximum possible damage to the containment system of the test canisters. All possible situations were adjusted to inflict the most damage to the test canisters during their drop tests. The test canisters contained a number of weld joints that did not receive any post-weld heat treatment. Even the pipe used to fabricate the test canister bodies and skirts was longitudinally welded pipe. If a problem were to develop, the weld joints would be a logical first location to check. If desired, seamless pipe can be used but this test effort used welded pipe to demonstrate that the welds are adequate. Hence, the main focus of the drop testing, performed at Sandia National Laboratories (SNL), was the demonstration of maintaining a containment system, regardless of the impact orientation of the canister.

The secondary objective of the drop testing effort was to determine the ability to adequately predict the structural response of the test canisters and certain internals due to the drop testing. Using finite element methods and fully plastic analyses, pre- and post-test analysis predictions were completed and comparisons made (Part II of this report). This effort not only provides validation of the unique computer models developed but also allows increased confidence in prediction of canister responses to situations not specifically tested.

Other program objectives included (1) demonstrating that the canisters could indeed be fabricated as indicated on program drawings, making improvements where possible to improve the fabrication effort, (2) demonstrating that the canister internals could be easily loaded into the canister, confirming that during actual use, the internals identified could be easily loaded using remote handling techniques, (3) gaining insights into the use of ultrasonic examination for the final closure weld with a permanent backing ring, and (4) clearly demonstrating the magnitudes of the resulting deformations so that it could be determined if, after being dropped, the deformed canisters could be loaded into other containers, if necessary. These other containers could include an interim storage canister, a transportation cask, a repository waste package, or a larger standardized DOE SNF canister.

2. BACKGROUND

During FY98 and the first month of FY99, the NSNFP funded both small- and full-scale drop testing efforts. These initial drop tests (References 2 and 3) were preliminary and scoping in nature, performed to give initial insights into the adequacy of the proposed canister design. The FY98 effort culminated in the successful drop testing of full-scale simulated canisters from 30 feet onto a hardened surface (two-inch thick steel plate placed on a thick concrete slab). Successful puncture testing was accomplished during the first month of FY99 by dropping simulated canisters 40 inches onto an essentially rigid, six-inch diameter bar. These preliminary tests performed at the Idaho National Engineering and Environmental Laboratory (INEEL), although limited in number and drop orientation, demonstrated that the proposed standardized DOE SNF canister design was indeed robust and could survive 10 CFR 71.73(c) (1) and (3) (Reference 4) type testing and still maintain a containment system. With the success of the preliminary drop testing, the NSNFP felt justified in proceeding with a larger testing effort that would provide qualified drop test data results acceptable to itself, DOE, and regulatory agencies.

During the remainder of FY99, the NSNFP funded the effort to fabricate, at the INEEL, nine full-scale representative standardized DOE SNF canisters. These test canisters (loaded with carbon steel reinforcement bars to represent SNF) were drop-tested at SNL during the summer of 1999 and returned to the INEEL for post-drop test examinations and leak testing.

3. SCOPE OF WORK

In order to achieve the program objectives, many activities had to be accomplished before and after the actual drop testing occurred. At the INEEL, these activities included purchasing proper materials, fabricating the test canisters using best practices possible, fabricating the internals using appropriate practices, assembling and preparing the test canisters for drop testing, and shipping the test canisters to SNL. After SNL completed their drop testing efforts, the test canisters were shipped back to the INEEL for post-drop test examinations and leak testing. Many of these activities were discussed in a NSNFP test plan document (Reference 5).

With the available funding, only nine test canisters could be fabricated and drop tested. Therefore, the test program was planned so as to obtain as many insights as possible. The scope of work necessary to achieve the desired qualified drop test data results considered the following six phases:

1. Phase I was the procurement of materials.
2. Phase II was the fabrication and examination of both the test canisters and the internals at the INEEL.
3. Phase III was the assembly of the test canisters and the internals and the preparation of the assembled test canisters for the actual drop tests.
4. Phase IV was the actual drop testing and the post-drop pressure testing performed by SNL.
5. Phase V was the post-drop test examinations and additional leak testing activities that occurred once the test canisters were shipped back to the INEEL.
6. Phase VI was the generation of the final report that documents all of the activities, provides insights into the prediction capabilities of the finite element analyses performed, and provides the work packages and the SNL report to the NSNFP to complete the documentation of the FY99 activities.

4. PHASE I – MATERIAL PROCUREMENT

The first phase of this more rigorous drop testing effort was to procure the materials necessary to fabricate the canisters, the internals, and the representative SNF. Basically, 316L stainless steel was purchased for the canisters while carbon steel was utilized for the internals and reinforcement bar (hereafter called rebar). The only exception for the internals was the material obtained for the simulated High Integrity Cans (HICs) (Reference 6) which utilized 316L stainless steel.

The 316L stainless steel canister material that was purchased satisfied the American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel (B&PV) Code, Section III, Division 3 requirements (Reference 7). Material certifications and certificates of compliance were obtained for the stainless steel materials. These were purchased following Quality Level 3 requirements, per the INEEL (LMITCO) Quality Assurance (QA) Program (Reference 8). Eighteen-inch nominal diameter, schedule 40s, SA-312 pipe (longitudinally welded), 3/16- and ½-inch thick SA-240 plate (including the flanged and dished pressure vessel heads), and SA-479 round bar (2-5/8-inch diameter) material was purchased for the canister fabrication effort. The SA-312 pipe was purchased using the normal material specification defaults. This included the requirement that each pipe length be hydrotested to 600 psig. This was done as a proof test for the pipe and the longitudinal seam weld. Eighteen ASME flanged and dished heads were purchased, made from SA-240 plate such that the head thickness was a nominal 3/8-inch thick. All of the stainless steel 316L materials were required to be annealed and pickled. All of these items passed the receiving inspection performed by the INEEL's quality receiving group. Appendix D contains more details on the stainless steel materials purchased.

A-36 carbon steel plate was obtained for fabricating the 2-inch thick impact plates located inside of the canisters (considered part of the internals). For the remaining internals such as the spoked-wheel baskets, the sleeves, and the simulated Shippingport fuel bundles, A-36 plate and angle, A-500 Grade B structural tubing, and A-106 Grade B schedule 80 pipe were used. The rebar material was A-615, Grade 60 and was used to increase the test canister weight and represent the SNF. The simulated HICs (Reference 6) were fabricated from 5-inch nominal diameter, schedule 40s, welded SA-312, type 316L stainless steel pipe. Appendix D contains more details on some of the carbon steel materials purchased.

5. PHASE II – FABRICATION AND EXAMINATION EFFORTS

5.1. Test canisters

The fabrication and examination of the test canisters were performed at the INEEL under a Quality Level 3 effort with enhancements in order to as closely approximate nuclear vessel construction as possible. The actual fabrication of the test canisters was not subject to the NSNFP QA requirements. Although the INEEL does not have an "N-stamp", welders qualified to the INEEL Weld Program (Reference 9) that invokes ASME Section IX (Reference 10) procedures and nondestructive examination personnel qualified to procedures which conform to the requirements of SNT-TC-1A (Reference 11) were utilized. Fabrication and examination procedures from Section III, Division 3 of the 1998 Edition of the ASME B&PV Code were used as guidance. Appropriate INEEL Weld Program welding procedures were invoked. A combination of manual Tungsten Inert Gas (TIG) and manual pulse metal arc (wire feed) welding techniques per INEEL welding procedures S2.0 or S6.9 were utilized. Proper marking of the heat numbers on specific components and also the marking of assembly numbers on the finished components maintained material traceability. All of the pressure boundary welds existing before loading the test canisters with internals were volumetrically examined using radiography testing (RT) [per LMITCO examination procedure TPR-4970 (Reference 12)] and liquid penetrant (LP) examinations [per LMITCO examination procedure TPR-4975 (Reference 13)] of the final pass. Appendix B contains examination results from the RT and LP examinations. A non-conformance report (Appendix B) was issued when a portion of one longitudinal seam weld (part of the pressure boundary) was examined using RT. Indications included: "*aligned rounded indications ranging from approximately 0.050 to 0.150 inches separated by 0.040 to 0.375 inches. Approximately 25 indications in a 6-inch length of weld. Several of the rounded indications have linear tails extending from the indication. Linear indications up to 0.100 inches in length.*" These indications were near the bottom head.

However, since the pipe had been subjected to the 600 psig hydrotest, the pipe was accepted on an "as-is" basis. This piece of pipe became part of the canister that was ultimately labeled 18-15-80-05. [This test canister had, after drop testing, the most deformation of any weld made by the INEEL (during slapdown) and this canister also had the highest pre-test predicted strains.] The assembly numbers were also used to identify the radiographs generated. All of these efforts were documented in LMITCO work order package #6839 (Reference 14) as the test canisters were being fabricated and examined.

During the fabrication and examination efforts, certain improvements were recognized that would make the canisters easier to fabricate and examine. Although limited, these changes were mainly associated with a slight geometry change of the plug thread plate and the elimination of requiring radiography examination for the welds attaching the skirt to the vessel head and the lifting ring to the skirt. The ASME B&PV Code, Section III, Division 3 requires these structural attachment welds to be examined using liquid penetrant.

The test canisters fabricated were 18-inch nominal diameter and were either 10 or 15 feet long (nominally). Appendix A contains the canister drawings. The entire canister exterior is fabricated using 316L stainless steel. The test canisters themselves were fabricated mainly at the INEEL's Central Facilities Area (CFA) machine and weld shops. One item noticed during fabrication was that the full penetration weld attaching the lifting ring to the skirt caused the remaining skirt beyond or outboard of the lift ring to pull radially inward. This initial inward curving basically "controls" the deformation of the skirt during a drop accident event. Rather than deforming outward, the skirt most assuredly will now deform inward during drop events, especially the 0° or vertical drop.

5.2. Internals

By definition, the internals were components placed into the canisters. The function of most of the internals is to orient the SNF inside of the canister and to prevent excessive SNF movement during canister movement situations. The desire is to load the SNF so that the total center-of-gravity is at or near the centroid of the canister. Internals consisted of both the upper and lower two-inch thick impact plates, a full cavity length 3/16-inch thick sleeve (where used), the most potentially damaging SNF basket referred to as the spoked-wheel basket (Figure 9), and any spacer plates necessary to properly position the SNF or the two-inch thick impact plates. Appendix C contains the detailed design sketches used to fabricate the internals. All of these internals were made of A-36 carbon steel plate or A-106 Grade B schedule 80 carbon steel pipe.

The sleeve, employed on five of the canisters, was intended to separate the spoked-wheel basket and rebar from direct contact with the canister wall. It was suggested that, during a drop event, contents with sharp edges or points might initiate a crack on the canister wall. If that crack were to propagate through the wall, then the containment would be breached. However, with a sleeve separating the contents from the actual canister wall, a potential crack could initiate in the sleeve but have no mechanism to propagate into the canister wall. It is expected that all canisters with contents having possible "sharp" edges or points would have an internal sleeve for this reason. The sleeve physically provides the margin of safety that is desired to be maintained in the canister design.

For the two 10-foot canisters, special internals were used (Figure 10). One test canister contained two simulated Shippingport fuel bundles placed side-by-side into the canister without any sleeve. These simulated SNF elements were fabricated by welding four A-36 3x3x3/16 angles onto the outside corners of A-500 7x7x3/8 structural tubing. The other 10-foot canister contained simulated HICs. The design and purpose of the HICs is currently identified in NSNFP report DOE/SNF/RD-004 (Reference 6). SA-312 welded stainless steel pipe was used to fabricate the HICs, including SA-240, 316L, ½-inch thick endplates.

Since the internals have not been identified as needing to perform any safety related function, such as criticality spacing control, the techniques used to fabricate them were not as rigidly documented as for the canisters. However, qualified INEEL welders and inspectors were again utilized. Appropriate INEEL Weld Program welding procedures (S2.0 and C3.4) were also invoked using manual TIG (for the simulated stainless steel HICs) and shielded metal arc welding techniques (for the remaining carbon steel internals). All welds were inspected using liquid penetrant techniques on the final pass. All of these efforts were documented in the LMITCO work order package #6874 (Reference 15) as the internals were fabricated and examined.

The two-inch thick impact plates (Figure 3) that fit inside of the canisters were machined at the INEEL's Test Reactor Area (TRA) under LMITCO work order package #6839. The plates were machined to a shape (Figure 4) that corresponded to the interior dimensions of the top and bottom dished heads. The machining permitted a greater area of contact and better load distribution during potential accidental drop events while still having a flat area for the SNF and other internals to rest on during loading. INEEL Test Area North (TAN) personnel fabricated the remaining internals.

6. PHASE III – CANISTER ASSEMBLY AND DROP TEST PREPARATIONS

Once the test canisters and internals were fabricated, all of these items were transported to the Water Reactor and Research Test Facility (WRRTF) at TAN. The South High Bay in Building 640 was used to assemble the canisters and make test preparations. This activity was performed under LMITCO work order package #9554 (Reference 16). Where appropriate, still pictures and videotape of the test canisters and internals were taken, showing how the canisters were loaded, welded, tested, measured, etc.

Figure 3. Impact Plates

Figure 4. Cut-Away View of Canister End

Table 1 contains information regarding the number of test canisters, their unique identifiers, lengths, test weights, internals configurations, and the reasons for each specific test. This test matrix information was developed in order to achieve as much insight as possible into the structural response of the test canisters subjected to an accidental drop event. Again, the major goal of this entire drop test effort was to demonstrate (via the post-drop pressure and leak testing) that the test canisters could indeed maintain containment after being drop tested.

Table 1. Canister information

Canister Label	Nominal Length	Desired Impact	Total Weight	Canister Internals	Test Purpose
18-15-00-01	15 feet	0°	6,033 lbs.	Sleeve and spoked-wheel basket	Worst case internals with sleeve at multiple impact angles
18-15-06-02	15 feet	6°	5,948 lbs.	Sleeve and spoked-wheel basket	Worst case internals with sleeve at multiple impact angles
18-15-90-03	15 feet	90°	5,995 lbs.	Sleeve and spoked-wheel basket	Worst case internals with sleeve at multiple impact angles
18-15-45-04	15 feet	45°	5,995 lbs.	Sleeve and spoked-wheel basket	Worst case internals with sleeve at multiple impact angles
18-15-80-05	15 feet	80°	5,965 lbs.	Sleeve and spoked-wheel basket	Worst case internals with sleeve at multiple impact angles
18-10-90-06	10 feet	90°	3,802 lbs.	Simulated High Integrity Cans	Round-shaped internals and simulated HICs response without sleeve
18-10-90-07	10 feet	90°	2,997 lbs.	Simulated Shippingport Fuel Bundles	Margin test with sharp-edged internals directly impacting on canister interior without sleeve
18-15-PW-08	15 feet	Initially 0° then tip over for puncture	5,972 lbs.	Spoked-wheel basket	Determine actual response to proposed accidental drop during canister loading scenario
18-15-PP-09	15 feet	Puncture	6,085 lbs.	Spoked-wheel basket	Demonstrate puncture-resistance

Before the actual loading of the canisters began, personnel qualified under the NSNFP [per NSNFP PMP 2.04 (Reference 17)] recorded a number of dimensional and weight measurements, obtaining basic "as-built" information about each canister component. This information was recorded on data sheets that identified each canister by both the unique test canister identifier and the assembly numbers used during fabrication. Component and material traceability was maintained by noting which assembly was used for each test canister. The accuracy of measurements depended on the measuring device being used. Measurements obtained using a tape measure had an estimated +1/8 / -1/8 inch accuracy. (Tape measures were not calibrated.) Micrometer and caliper measurements had a +0.010 / -0.010 inch accuracy. Weight measurements had an accuracy that depended on the load range involved. For lighter loads (less than 1000 lbs.), the accuracy was +/- 5 lbs. For heavier loads, (greater than or equal to 1000 lbs.), the accuracy was +/- 10 lbs. Greater accuracy of all measurements was attained where possible. Measurement devices were calibrated at the INEEL and were tagged with unique identifying numbers. Details are contained in Appendix B.

The actual loading of the canister internals took place in a methodical fashion in order to obtain the necessary "as-built" information and to document the loading process. Due to the importance of positioning the internals in unique orientations with respect to the desired impact point, qualified NSNFP personnel directed the placement of all internals. An overhead crane was used extensively during the loading of each canister. Typically (for the five canisters 18-15-00-01 through 18-15-80-05), the two-inch thick lower impact plate was first installed by lowering it into the bottom canister assembly. The threaded eye bolt and sling were removed using a long-handled tool developed specifically for that removal process. Note that the threaded hole for the eyebolt was drilled through the entire impact plate thickness (Figure 5). This permitted access to the canister interior for pressure and leak testing. During actual usage, this also permits water drainage if necessary and access to the interior if visual inspections were desired. [Note that the design drawings also specify small grooves that can be machined into the curved surfaces of the impact plates. This can be done when desired to enhance water drainage out through the threaded plug opening.]

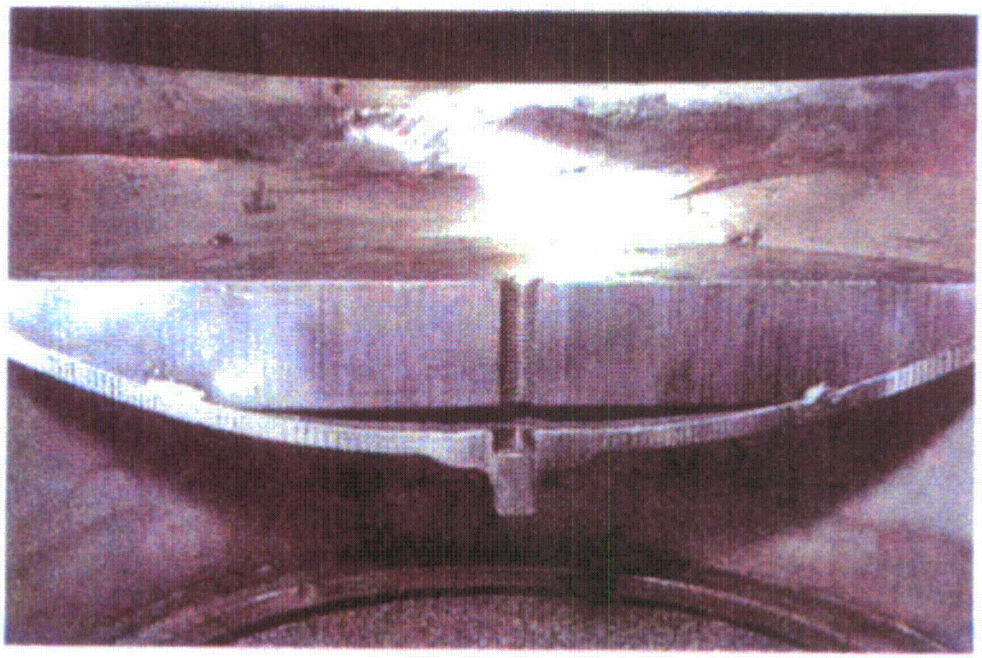

Figure 5. Closeup of Cut-Away

Next the 3/16-inch thick sleeve (Figure 6) was lowered into the canister. It rested on the top flat surface of the lower impact plate. At this time, when required, positioning lugs were welded to the canister inside wall, through the sleeve (Figure 7). By holding the sleeve in position, the other internals, namely the spoked-wheel basket could also be held in the desired position for the drop test. Then the spoked-wheel basket was lowered into the canister bottom assembly (inside the sleeve) and also rested on the top flat surface of the lower impact plate. Although the pipe material used for the canisters was not perfectly round (as one would expect during actual usage), the impact plates, sleeves, and spoked-wheel baskets all loaded with exceptional ease and did not require any force to position them. The dimensions specified on the engineering sketches were correctly specified to allow easy loading yet still provide adequate space for the SNF. The remote loading of these internals can indeed be performed with ease. The only recommended change would be to shorten the sleeve so that it doesn't overlap with the top head assembly backing ring (see Appendix A drawings). In this way, the backing ring would still protect the canister inside wall from impacting internals and there would not be any interference between the backing ring and the sleeve while the top head assembly is being positioned for final welding.

Figure 6. Sleeves

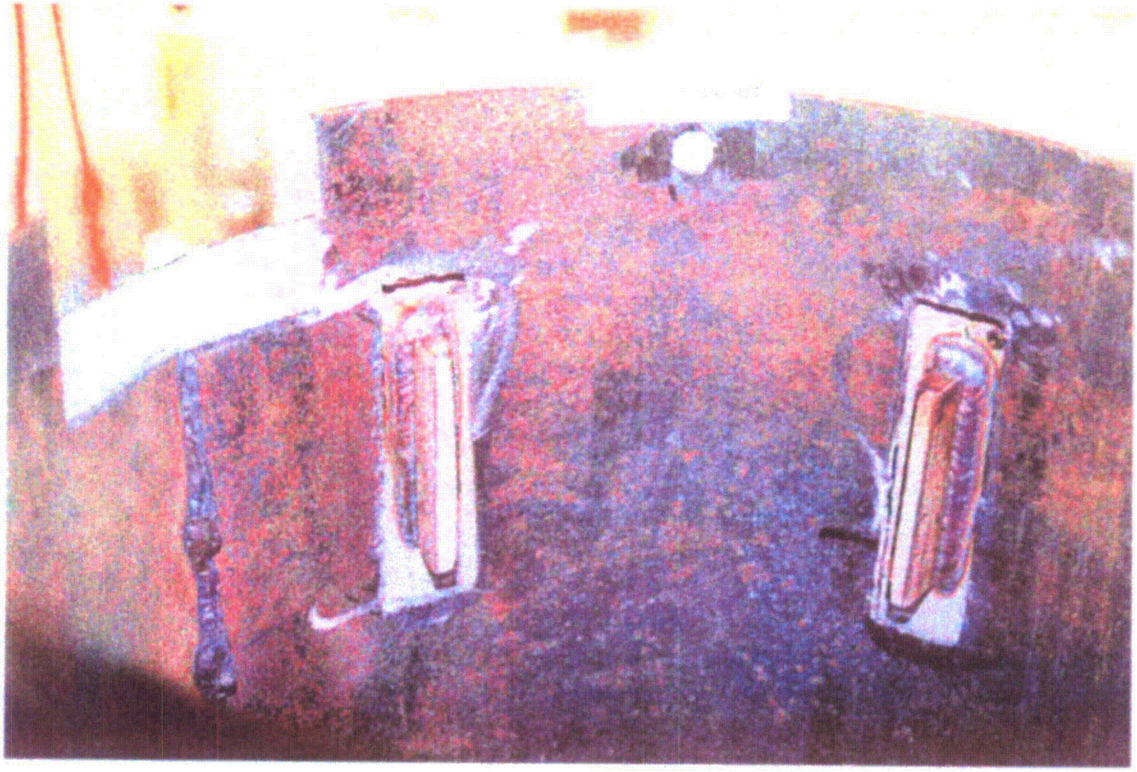

Figure 7. Positioning Lugs

For the remaining four canisters, the loading sequence was very similar. Canisters 18-15-PW-08 and 18-15-PP-09 were loaded just like the other 15-footers but without a sleeve. Since these canisters were being puncture tested, it was decided to perform those tests without a sleeve. This was done in an effort to achieve a worst case situation since the sleeve would more likely help the canister resist the effects of the puncture.

The two ten-foot long canisters were also loaded without sleeves. However, the spoked-wheel baskets were not used on the ten-footers. 18-10-90-06 had seven simulated HICs placed into the canister. A sleeve was not considered necessary since the round shape of the HICs does not create a situation where large localized strains could occur, as would be the case with the spoked-wheel internals. For canister 18-10-90-07, the initial NSNFP plan was to load two Shippingport fuel bundles side-by-side into a canister (Figure 8). The dimensions of the Shippingport fuel bundles would not allow a sleeve to be installed into the canister. However, the NSNFP later decided, based on criticality concerns, to only load one Shippingport fuel bundle per canister. Since the canisters and internals had already been fabricated when this change occurred, the decision was made to proceed with the test as originally planned. Instead of testing what was initially considered to be a unique loading scenario because a sleeve would not fit, this test was treated as a demonstration of safety margins because the simulated Shippingport fuel bundles would bear directly on the test canister pressure boundary material, along two separate lines nearly the full length of the canister, during a horizontal impact orientation.

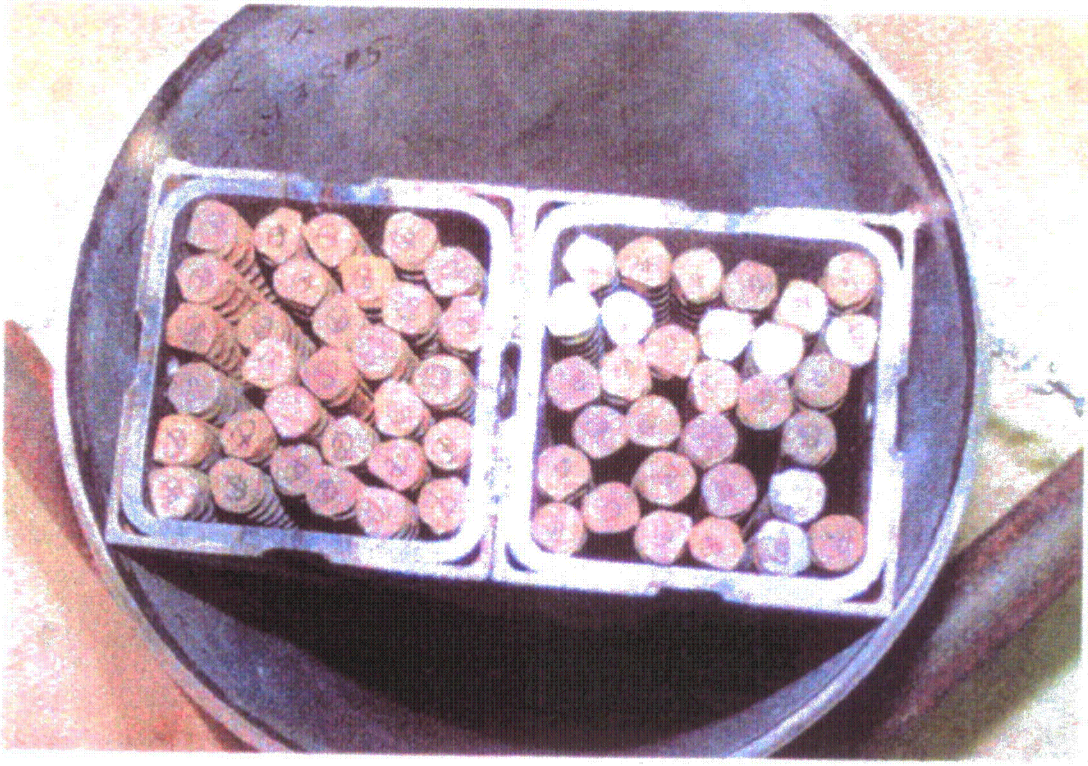

Figure 8. Simulated Shippingport Fuel Bundles (Canister 18-10-90-07)

After the fabricated internals were loaded into the test canisters, the rebar was loaded. Care was taken to properly orient the internals and rebar with respect to where the test canisters were designated to impact during the drop tests. Figures 9 and 10 identify the internals configuration for each test canister and how the rebar was positioned. Whenever the most significant impact occurred on a canister skirt, the canister internals were positioned to cause the most potential damage to the canister containment, and the canister was marked so that the initial impact occurred on the longitudinal weld seam of the skirt. Whenever the most significant impact occurred on the canister pressure boundary, the canister internals were positioned to cause the most potential damage to the canister, and the canister was marked so that the initial impact occurred on the longitudinal weld seam of the canister pressure boundary. For the two test canisters being subjected to puncture tests (18-15-PW-08 and 18-15-PP-09), rebar was omitted from that local puncture region in order to permit as much canister deformation as possible. This is clearly illustrated in Figure 11.

For canister 18-10-90-06 with the simulated HICs, the bottom simulated HIC (aligned with the canister longitudinal weld seam) was left empty while all of the other simulated HICs were filled with rebar (Figure 12). This would produce more damage in the bottom simulated HIC. Finite element predictions were also made for these specific internals in order to ascertain how to best determine accurate internals deformations. After loading the rebar into the simulated HICs, ½-inch-thick endplates were welded into all seven of the simulated HICs, including the empty one (Figure 13). Except for the two canisters subjected to puncture testing and the canister with the simulated HICs, the goal was to always uniformly distribute the rebar placement across the canister (Figure 14).

After each test canister was loaded, the top impact plate and spacer plates (where necessary) were positioned. Figure 15 shows an example of the impact plate and spacer plates properly positioned. Next, the top head assembly was positioned onto the bottom canister assembly. After a quality examination checked for proper alignment, TAN personnel then completed the final closure weld that sealed each test canister. Manual TIG welding using INEEL weld procedure S2.0 was utilized for the final closure welds.

Using a manually adjustable lifting fixture, each test canister was then vertically lifted out from the scaffolding used for loading. This lifting fixture (Figure 16) had two plates that extended out and engaged underneath the lifting ring on the test canister. The lifting ring functioned as intended, safely lifting each canister. The canisters were then positioned horizontally across large concrete blocks onto wooden cradles to prevent rolling. These 2 ft. x 2 ft. x 6 ft. concrete blocks (weighing approximately 3600 lbs. each) also provided a significant personnel safety feature while the loaded canisters were being worked on, examined, and measured. Figure 17 shows a typical setup where canisters were positioned on the concrete blocks.

As indicated in the canister drawings contained in Appendix A, the final closure weld incorporates a permanent backing ring. The backing ring has four distinct purposes. First, it provides a guide to aid in the installation and final alignment of the top head during final assembly. Second, the presence of the backing ring allows the full penetration butt weld to be made easier, especially since the weld will have to be made remotely. Third, the backing ring helps to protect the canister inside wall and final closure weld from impacting internals. Finally, the presence of the permanent backing ring also helps protect the SNF inside the canister during the welding of the final closure weld.

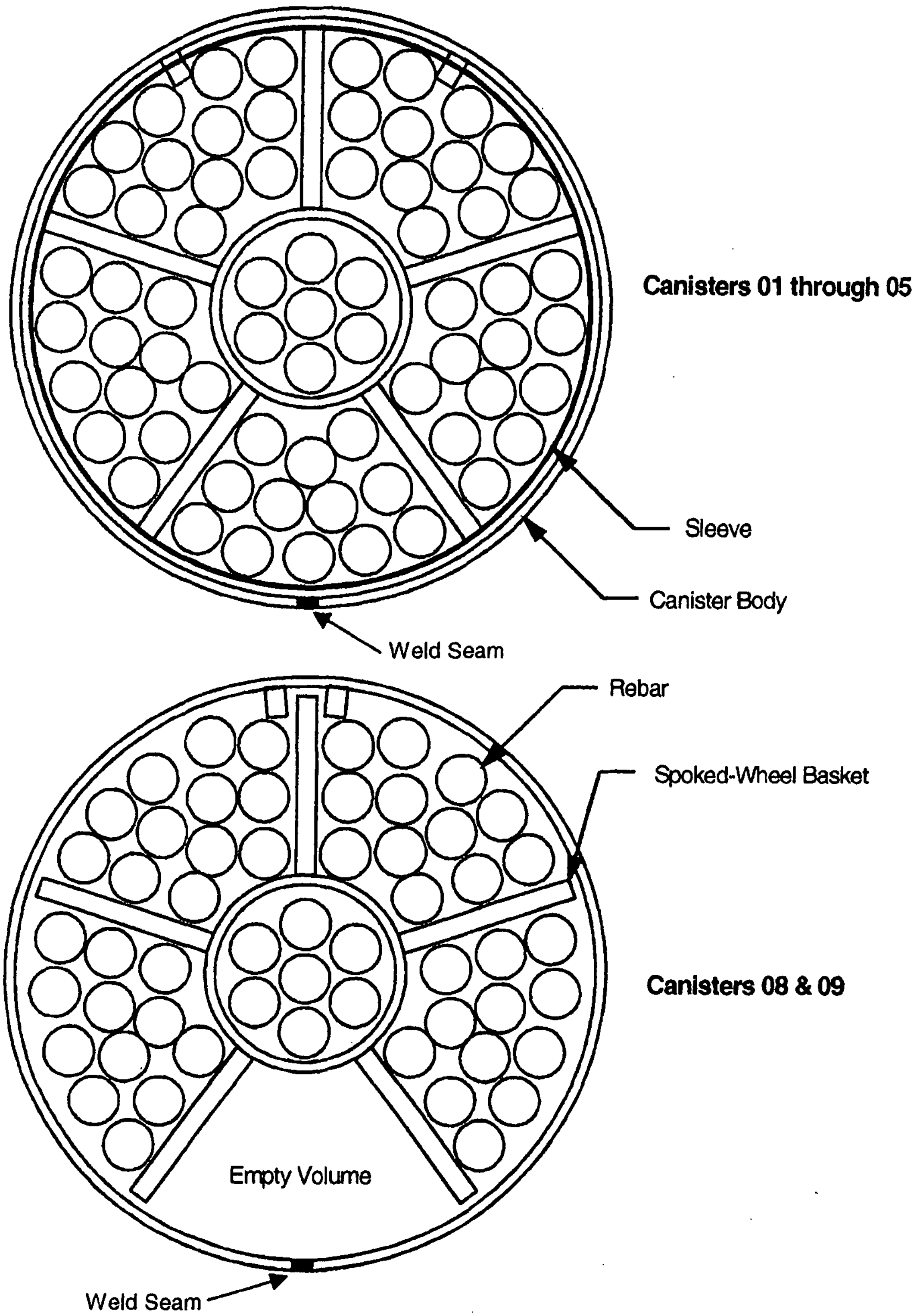

Figure 9. Cross-Section of Test Canisters 01 - 05, 08 and 09 Internal Components

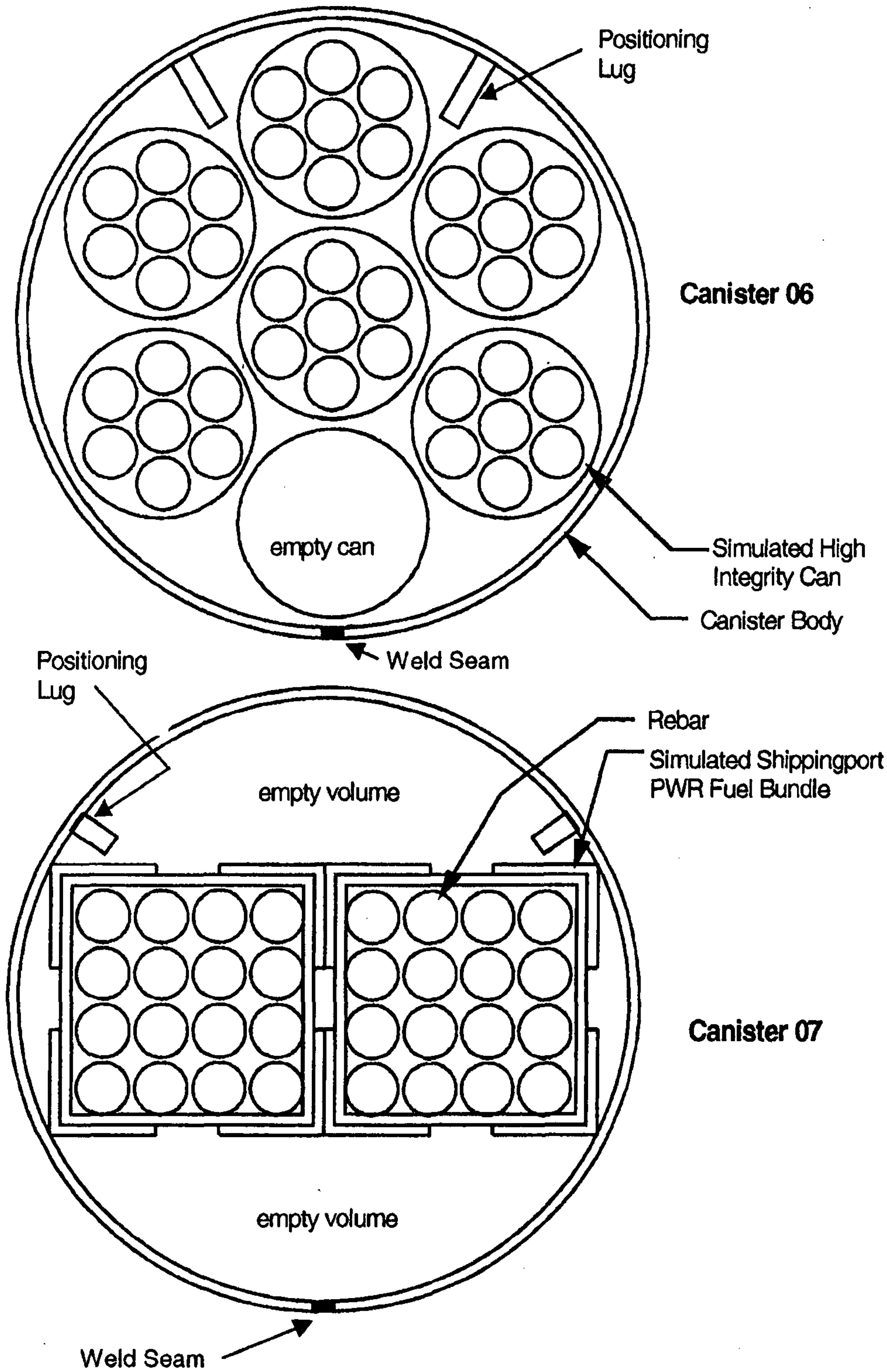

Figure 10. Cross-Section of Test Canisters 06 and 07 Internal Components

Figure 11. Empty Slot in Spoked Assembly (Canister 18-15-PP-09)

Figure 12. Six Loaded HICs and One Empty HIC (Canister 18-10-90-06)

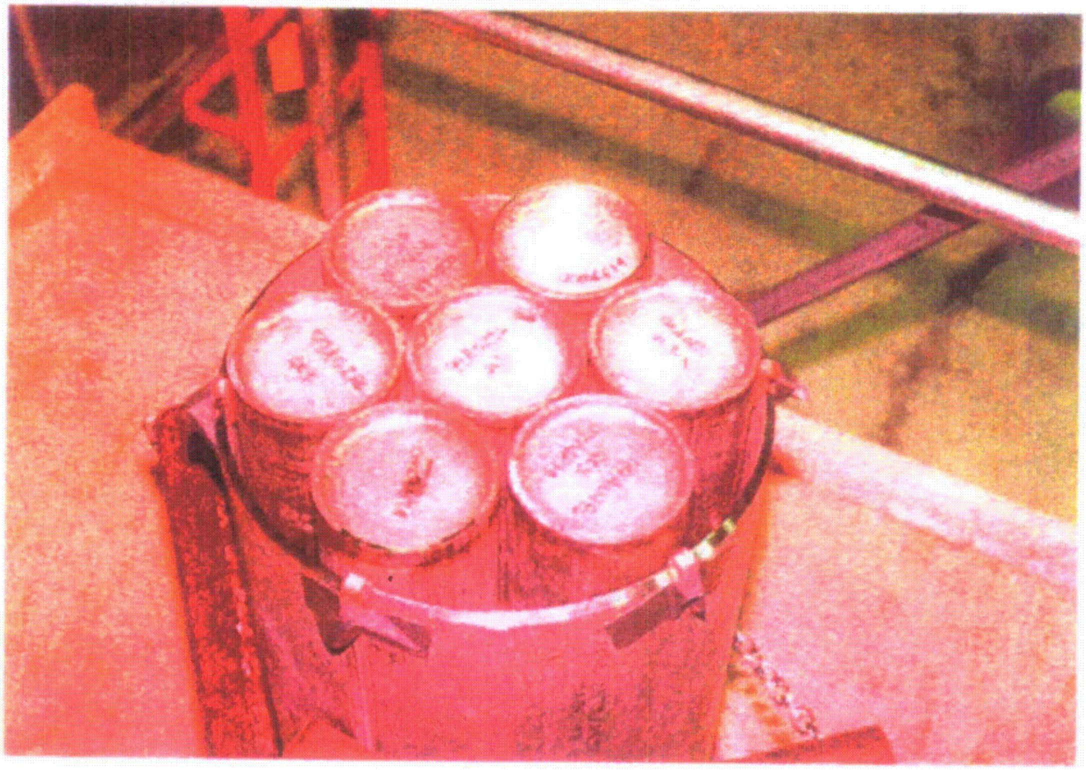

Figure 13. HICs End Plates In-Place and Welded (Canister 18-10-90-06)

Figure 14. Uniform Rebar Distribution (Canister 18-15-80-05)

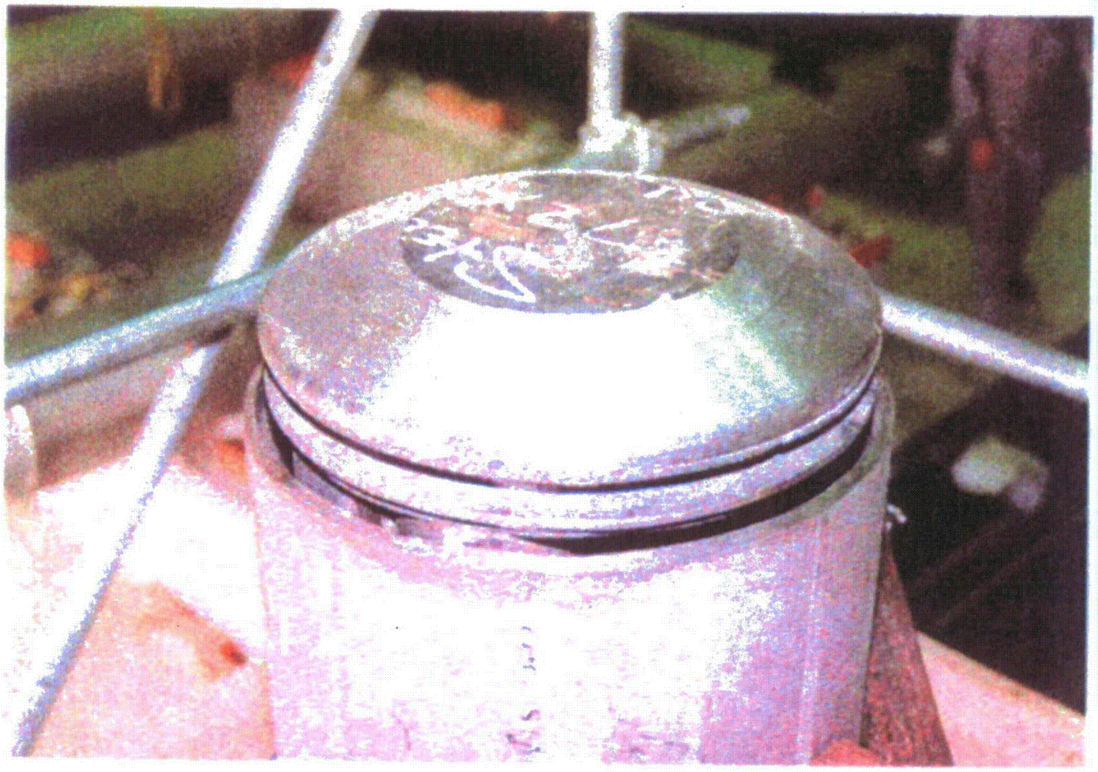

Figure 15. Impact Plate and Spacer Plates (Canister 18-10-90-07)

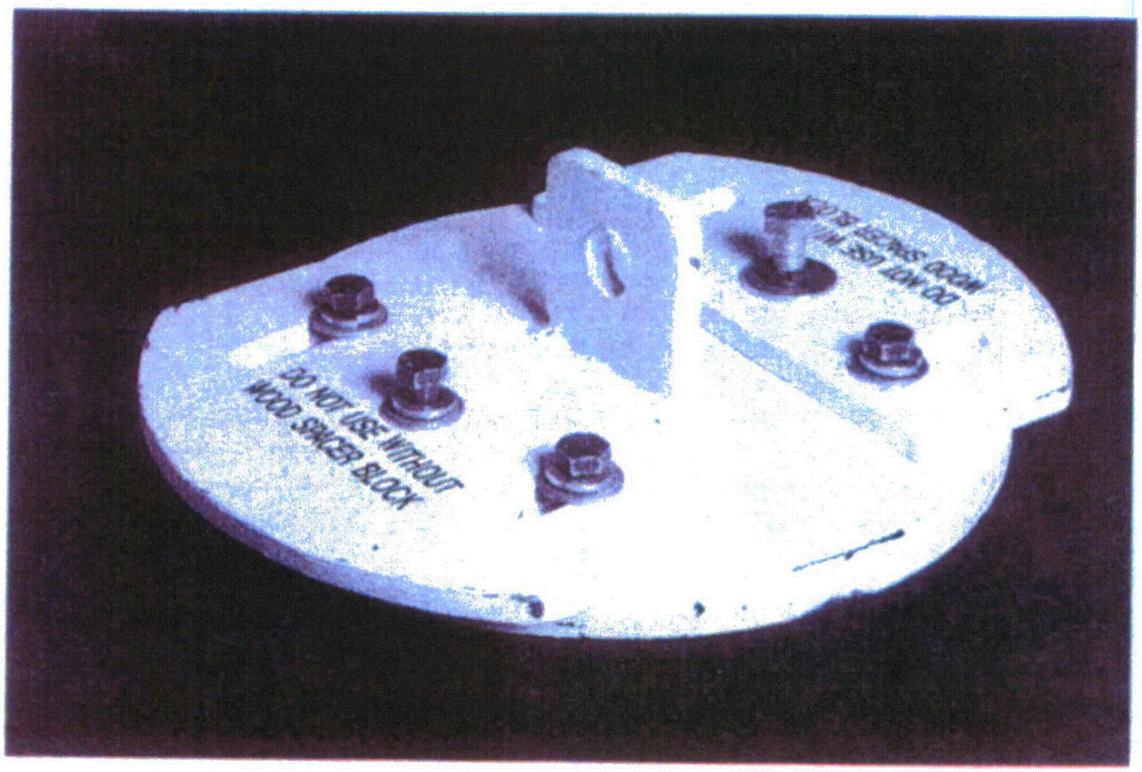

Figure 16. Manually Adustable Lifting Fixture for Test Canisters

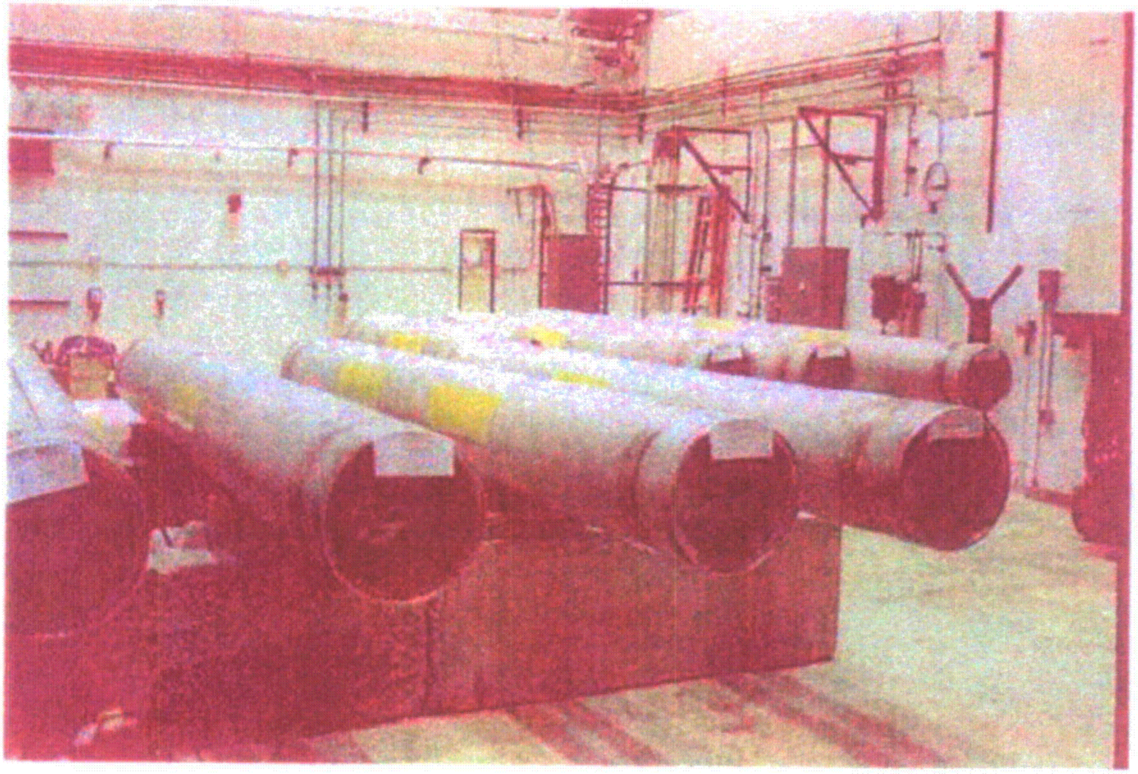

Figure 17. Canisters Positioned on Concrete Blocks

Volumetric examinations of the final closure welds were planned using ultrasonic testing (UT) methods (Figure 18). After a substantial number of indications [per LMITCO examination procedure TPR-4974 (Reference 18)] were recorded by the UT examiner, a significant portion of the closure welds were ground out on the first five test canisters (18-15-00-01 through 18-15-80-05). However, during this laborious grinding process, few if any actual defects were noticed. After re-welding these canisters, the UT examiner indicated problems in the exact same locations as before. This result was truly surprising and the validity of the examination process being utilized was questioned. Additional efforts to determine the validity of the UT indications were made; however, no clear assurances were provided that the apparent UT indications were actually valid or significant. There was speculation that the backing ring was causing some sort of misinterpretation of the UT readings, especially since the calibration standard used did not include a backing ring. In addition, all of the initial UT examinations used just a 45°-beam transducer. After consultations with another inspector with higher qualifications (Level III), both 45° and 60°-beam transducers were tried to clarify the interpretations of the UT examinations.

Based on the known abilities of the welders being used and the many insights gained from the re-welding effort, the true capability of the welds to take the anticipated drop test loads was not deemed to be a concern. Therefore, it was decided to "map" (i.e., determine and note the location of any significant UT indications around the full circumference of the weld) two separate test canister closure welds (canisters 18-15-80-05 and 18-10-90-06) and proceed with the drop test preparations. The results of these two "mapping" examinations are contained in Appendix B. The final closure weld for canister 18-15-80-05 was deemed to satisfy the TPR-4974 criteria but the weld for canister 18-10-90-06 did not. After the drop tests were completed, these same two welds would then be re-examined using both UT and RT. This would provide a chance to obtain a very interesting set of comparisons between UT and RT examinations of welds with permanent backing rings.

Figure 18. UT Inspection in Progress

A threaded plug was incorporated into both the top and bottom head of each test canister. The threaded plugs are optional design features. The threaded plugs allow for access to the canister interior. This design feature provided many optional uses. Fluids or gases can be either added or released from the canister interior. For example, as previously mentioned with respect to the two-inch thick impact plates, water can be drained from the canister interior if necessary. Due to uncertainties regarding the generation of hydrogen gases during interim storage, the plugs can be either installed or left uninstalled, providing options to the user. However, the threaded plugs are expected to be installed prior to transportation to the repository. In addition, access is possible through these plugs for visual inspections using remote fiber optic cameras.

Figure 19 shows an installed threaded plug on one of the test canisters. The reason for installing the bottom head threaded plug on the test canisters was to create a worst case situation with respect to the deforming skirt potentially hitting the extended threaded plug assembly. The reason for installing the top head threaded plug assembly in the test canisters was to still provide a means to perform pressure and leak testing. The bottom threaded plug was seal-welded in place while the top head threaded plug was not seal-welded to maintain access to the canister interior.

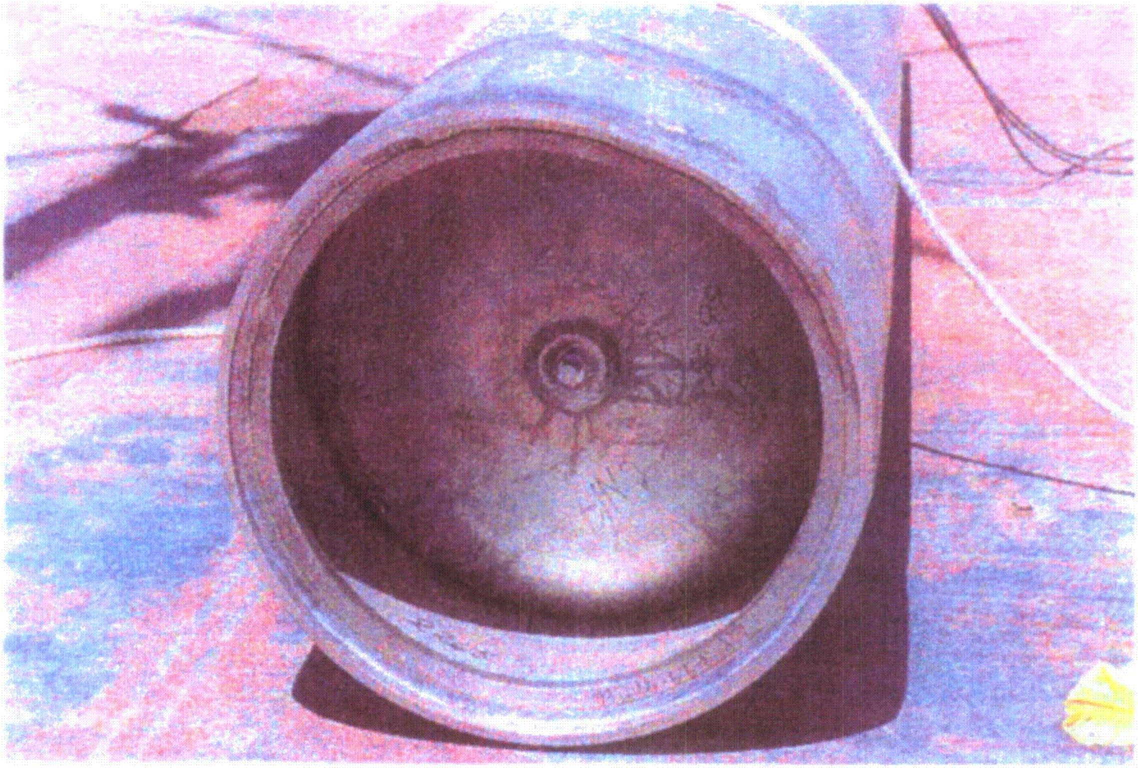

Figure 19. Installed Threaded Plug in a Top Head

At this stage, pneumatic pressure tests (50 psig air held steady for one hour at ambient conditions) were performed to assure that all of the test canisters provided containment prior to the drop tests. The pressure tests followed these five steps:

1. After each test canister had been prepared, the canister was placed inside a facility so that the canister could attain a steady-state temperature. Once a canister achieved a steady-state temperature, the canister was pressurized to 50 psig.

2. The pressure test lasted at least one hour in duration after all connections were tightened to prevent leakage and a steady pressure had been achieved.

3. If leakage (50 psig pressure not capable of being held steady for one hour) was indicated, all attempts were made to eliminate all sources of leakage other than the canister itself. The goal was to eliminate leaking connections so that if any leakage were present, it would be attributable only to the canister.

4. During the hour-long pressure test, the canisters were not subjected to any significant temperature change that would affect the accuracy of the pressure test.

5. A pressure drop of no more than 0.5 psig over the one-hour test duration was acceptable.

The results of the pressure tests clearly indicated that no measurable pressure loss was experienced by any of the canisters.

The canisters also needed to be marked in various locations in preparation of the drop tests. These marks would permit before- and after-drop-test measurements to be taken at the same locations. Qualified NSNFP personnel utilized a variety of markers or tools to perform this task, including etching tools and permanent markers. Marking was based on tape measurement accuracy. Final total weight and "as-built" dimensional measurements were taken while the canisters were still positioned across the concrete blocks. The two ten-foot long canisters when loaded weighed approximately 3,000 and 3,800 lbs. (18-10-90-07 and 18-10-90-06 respectively) and all seven of the fifteen-foot long canisters weighed approximately 6,000 lbs. when loaded. Appendix B contains all of the data sheets that identify the measurements taken at this time.

Final labeling of each canister was achieved by painting large black and yellow labels on each canister. This was done to make canister identification easier and to provide labeling that could be read in the videotapes and still pictures taken. Figure 20 illustrates this labeling. Finally, as a backup to the large painted labeling, each top and bottom canister lifting ring was etched with the exact same label as that painted on the main canister body. Each canister was labeled using a unique sequence of alphanumeric characters with an AA-BB-CC-DD format. AA represented the nominal diameter of the test canister in inches, which for this series of testing, was always 18. The BB characters reflected the nominal length in feet of the test canister, either 10 or 15 for these test canisters. CC indicated the desired impact orientation in degrees, with 0 representing a vertical drop and 90 representing a flat or horizontal drop. In cases where there was not an impact angle but a puncture type test, the CC represented alpha characters that indicted the type of puncture test. For the two test canisters that were affected, PP represented the 40-inch drop onto a six-inch diameter puncture post. PW represented the potential scenario of dropping a canister while loading the canister into a repository waste package or transportation cask or other similar larger container. Finally, DD was an additional numerical identifier that was necessary to achieve a unique canister number. For this series of test canisters, the DD was simply numbers 01 through 09.

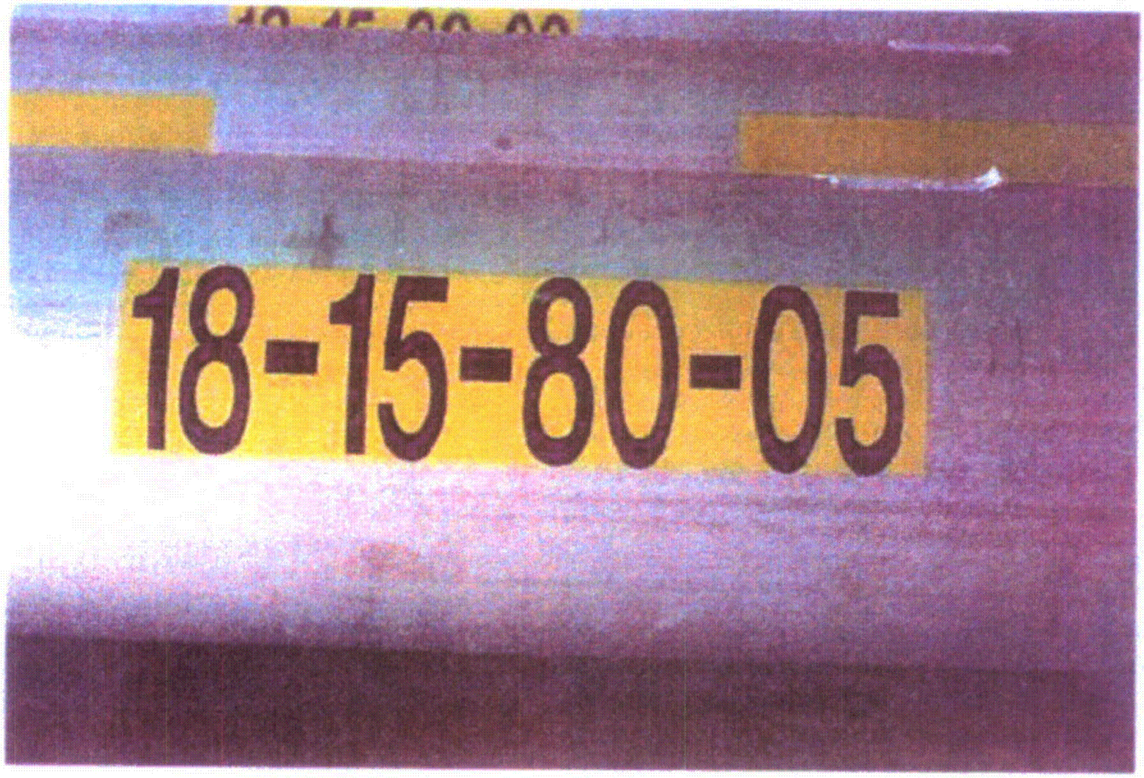

Figure 20. Example of Canister Labeling

After this, the test canisters were loaded onto a flatbed trailer and trucked to SNL.

Material testing was also performed during this phase. Although material certifications were obtained for the materials used to fabricate the canisters, the actual stress-strain relationship was not accurately known. Therefore, limited material testing was completed to more fully define appropriate strain behavior for the canister materials utilized. CFA test personnel using a calibrated tensile testing machine performed this testing. The material testing data reports contained in Appendix D indicate the type of machine used and its calibration data as well as the actual results from the tensile tests completed.

7. PHASE IV – DROP AND PRESSURE TESTING AT SNL

SNL, operating under a QA program based on NQA-1 (Reference 19), has an ongoing, qualified drop testing program in place that has been utilized by numerous organizations, including the Department of Defense, the U.S. Nuclear Regulatory Commission, the Department of Energy, and others. This facility contains an essentially unyielding flat surface, capable of dropping very large test specimens (up to approximately 80,000 pounds) from heights up to 100 feet. Smaller items can be raised to almost a 700-foot drop height. Their mobile instrumentation data acquisition system (MIDAS) is a self-contained data acquisition facility that can produce fully qualified data documentation. Records of equipment parameters and performance can be produced, providing a computer-generated audit trail.

SNL was provided a Statement of Work (Reference 20) that outlined the NSNFP requirements for this nine-canister drop testing effort. SNL responded with a test plan (Reference 21) that identified their proposed test procedures and a quality document (Reference 22) that described the quality assurance efforts associated with the testing.

SNL received the nine test canisters on May 4, 1999. Any canister movement activities were to be performed so that excessive or undue harsh treatment of the canisters was prevented. The goal was to attribute any damage received by the canisters to the drop testing only. SNL spent the rest of May and most of June making pre-test measurements and applying the instrumentation as indicated in Reference 21. The actual drop testing (Figure 21) began June 23 and finished June 30, 1999. Post-drop pressure testing was performed on July 1, 1999 and post-drop measurements began later in July. The canisters were loaded onto a flat bed trailer July 20, 1999, and trucked back to the INEEL.

Testing is a process where individuals plan as best as possible to achieve the desired objectives. However, at times, events take place during testing that are simply not anticipated. That is simply the nature of testing. SNL was able to fully execute their intended test plan and the results obtained were extremely valuable to the NSNFP. However, SNL was not able to precisely hit the intended target point on a number of canisters. The main cause of not hitting the desired targets was the excessive tension in the tag lines used to align some of the test canisters before the actual drop. Table 2 lists the canisters and whether or not the intended target was achieved. If not, the magnitude of discrepancy is provided. Although it can be seen that SNL did not hit the "precise target" on a number of the canisters, the test results obtained were still good.

Seven test canisters were dropped from 30 feet onto an essentially unyielding flat surface. One test canister was dropped 40 inches onto an essentially rigid 6-inch diameter, 24-inch high bar. These tests duplicated the drop tests specified in 10 CFR 71.73 (c) (1) and (3). The last remaining test canister was tested per NSNFP specifications. It was dropped two feet onto a 2-inch thick plate (18 inches high and 36 inches long) positioned vertically for an initial impact, and then left to tip over and impact another 2-inch thick plate (12 inches high by 96 inches long) positioned vertically, approximately 2 meters (78 inches center-to-center) away from the first plate. See Figure 22 for additional test details. This last test was developed to demonstrate what could occur if an actual standardized DOE SNF canister were accidentally dropped while being loaded into a repository waste package (or a transportation cask or interim storage canister).

Figure 21. Canister 18-10-90-07 Being Rigged for Drop At SNL

Figure 22. Canister 18-15-PW-08 at End-of-Test Showing the Vertical Impact Plates

Table 2. Accuracy of Canister Impact

Canister Label	Target Achieved	Discrepancy
18-15-00-01	Very Close	About 1/2° from vertical
18-15-06-02	Yes	---
18-15-90-03	No	About 24° rotation about the canister longitudinal axis
18-15-45-04	Yes	---
18-15-80-05	Yes	---
18-10-90-06	No	About 24° rotation about the canister longitudinal axis
18-10-90-07	No	About 19° rotation about the canister longitudinal axis
18-15-PW-08*	No	About –1° from vertical and about 15° rotation about the canister longitudinal axis
18-15-PP-09	No	About ½-inch towards the lower head and about 1 1/4-inch off the longitudinal weld seam

* - An accurate secondary impact was very difficult to achieve for the specific test.

All nine of the test canisters adequately survived the drop tests from a deformation standpoint. All nine of the test canisters were able to pass the pressure test, holding 50 psig of air pressure steady for one hour without any visible loss of pressure.

There were a few highlights that occurred during the drop testing at SNL. Canister 18-15-00-01 dropped 30 feet, bounced a couple of times, and then remained standing. This result was surprising but did indeed reflect the accuracy with which SNL dropped this particular canister and also how uniformly the canister was loaded at the INEEL. The puncture post canister, 18-15-PP-08, impacted the six-inch diameter bar twice before it rolled off the bar. However, the 24-inch long bar was welded to a larger plate with large eyebolts welded to the plate. These eyebolts were used to lift the puncture bar into position. After the test canister rolled off the bar, the canister impacted one of the eyebolts, resulting in a second (but unintentional) puncture test. The result was another significant "dent" but no containment system concern. Finally, test canister 18-15-80-05 was dropped from an 80-degree orientation in order to achieve the slapdown effect. The videos taken by SNL clearly show an increased rotational acceleration of the top portion of the canister just prior to top head impact. Slapdown was achieved.

SNL's final report (Reference 23) was provided to the NSNFP.

8. PHASE V – POST-DROP TEST ACTIVITIES

The nine test canisters arrived back at the INEEL for post-drop examination and testing on July 22, 1999. The canisters were unloaded at the TAN-640 South High Bay at WRRTF (Figure 23). As with the initial loading and unloading activities prior to the drop tests, the loading and unloading activities after the drop tests were intended to prevent excessive or undue harsh treatment of the canisters such that any damage received by the canisters could be attributed to the drop tests only.

The post-drop examination and testing activities included helium leak testing of the four worst damaged test canisters, detailed measuring of all the deformed test canisters and recording the information onto data record sheets, cutting open all the test canisters, and making brief visual observations of the internals and inside surfaces of the test canisters. NSNFP qualified personnel (per Reference 17) completed the visual observations. Other non-destructive examinations were performed by INEEL qualified NDE personnel. All of these efforts were documented in LMITCO work order package #14578 (Reference 24).

Once the test canisters were back at the INEEL, the canisters were placed horizontally across the same concrete blocks in an effort to duplicate the conditions when the pre-drop test measurements were recorded. Various examinations were made to better understand the structural response of each test canister during its drop test and how the test canister geometry changed. Many of the measurements taken were identical to those taken prior to the drop tests. As with the pre-drop measurements, these post-drop measurements were taken using calibrated measuring devices (except the measuring tape), using the same measuring tolerances, and recorded on similar data sheets. These post-drop data sheets are included in Appendix E. These examinations and measurements were typically canister specific due to the varying structural responses.

Figure 23. Truck Backing into TAN 640 South High Bay

None of the deforming skirts touched the pressure boundary or containment system of the test canisters during their drop testing, including the extended threaded plugs. Post-drop inspections clearly indicated that the deforming skirts provided their intended energy-absorbing function. Post-drop NDE examinations of certain skirts did not reveal any cracks or material tearing, even on skirts that were subjected to significant deformation (See Figure 24). The pressure boundary or containment system of all nine canisters did not experience extreme deformations. The most significant change in any outer diameter of the pressure boundary was on test canister 18-15-90-03. That canister's maximum deformed diameter after dropping was slightly less than 19 inches.

The canisters that had the most significant damage were chosen to be helium leak tested. At first, two canisters were thought to have been adequately damaged to undergo helium leak testing. However, after second consideration, it was decided to test the four most damaged test canisters. This would not only minimize concerns over a very limited number of canisters being leak tested, but more canisters would cover a wider range of canister impact angles. The canisters chosen for helium leak testing were 18-15-00-01, 18-15-45-04, 18-15-80-05, and 18-15-PP-09. The leak testing effort (Figures 25 and 26) utilized procedure TPR-4976 (Reference 25) which ties back to the ASME B&PV Code, Section V, Article 10 (Reference 26). A full vacuum was pulled inside the test canister and the outside surface was "bagged" in order to permit a 99% pure helium environment to exist on the outside surface of the test canister. The acceptance criteria of leaktight or 10^{-7} std cc/sec leak rate are discussed in the ANSI N14.5 standard (Reference 27). The results of the leak testing (Appendix E) indicated that a helium leak rate of less that 10^{-7} std cc/sec was achieved. Note that the U.S. NRC recognizes leak rates of this magnitude to reflect a leaktight containment system.

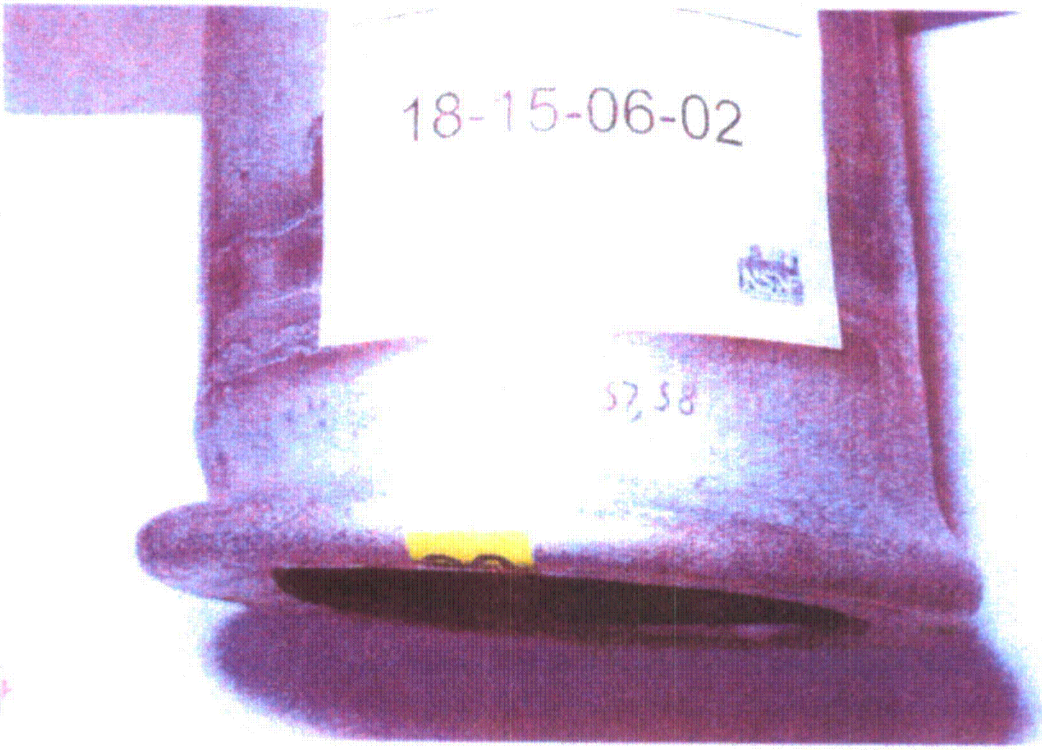

Figure 24. CG-Over-Corner Drop (6 degree) – Canister 18-15-06-02

Figure 25. Pulling a Vacuum on a Test Canister During Helium Leak Test Activities

Figure 26. Helium Leak Test In Progress

After the post-drop measurements and the helium leak testing were completed, the test canisters were cut open (Figure 27) in order to examine the condition of the internals, the rebar, and the interior surfaces of the test canisters.

After the canisters were cut apart, the two final closure welds previously UT examined and "mapped" (canister 18-15-80-05 was accepted and canister 18-10-90-06 was rejected) were UT examined again by the same person. No changes in the results of the UT examinations were noted. These welds were then RT examined in order to gain more insights on UT versus RT capabilities. The results indicate (Appendix E) that both of the final closure welds (including canister 18-10-90-06) were acceptable per TPR-4970 (Reference 12) criteria. A phone conversation with the examiner clarified that, although canister 18-15-80-05 was difficult to interpret due to the backing ring and that "info only" was indicated for weld acceptance, the examiner could see not any indications in the radiograph. This suggests that the UT methodology used for these closure welds needs improvement. The longitudinal weld seam that was previously RT examined during canister fabrication (Section 5 of this report) was RT examined after the drop test. Appendix E contains that examination record and no changes were observed. Finally, the butt weld adjacent to the longitudinal weld was also RT examined after the drop test. This butt weld had been previously RT examined during canister fabrication and had obviously passed. With this most recent RT examination, the weld was still acceptable. From this small amount of data, it would appear that the drop tests had little degradation effects on the stainless steel welds.

Additional material testing was performed after the test canisters returned to the INEEL. Material used for the vessel heads was not previously tested and the only material available was obtained from one of the heads used in the test canisters. The material from the bottom head in canister 18-15-PW-08 was used since it was not significantly strained during its drop test. This material testing (as previously discussed in Section 6) was performed using a calibrated tensile testing machine. Although material certifications were obtained for the head materials, the actual stress-strain relationship was not accurately known. Therefore, once again, limited material testing was completed to more fully define appropriate strain behavior for the head material utilized. The material testing data report is contained in Appendix D.

Figure 27. Cutting Apart A Test Canister

The subsections below provide highlights of the post-drop condition of each test canister. Additional details can be found in Appendix E. However, it is important to differentiate between damage to the canister skirt and damage to the canister pressure boundary (or containment system). The skirt was incorporated into the canister design to act as an energy-absorption device and significant deformation is expected. Yet skirt deformation does not necessarily affect the containment function of the canister. More important is deformation of the canister pressure boundary. This directly affects the containment system function of the canister.

8.1. Canister 18-15-00-01

This test canister was dropped from a vertical orientation 30 feet onto the essentially unyielding surface. Figures 28 and 29 show the bottom portion of the canister, especially the deformed skirt. The skirt protected the canister pressure boundary as expected. The top portion of this canister was not damaged since the test canister remained standing vertical after the drop test. The internals showed no recognizable damage.

Figure 28. Bottom End View of Canister 18-15-00-01

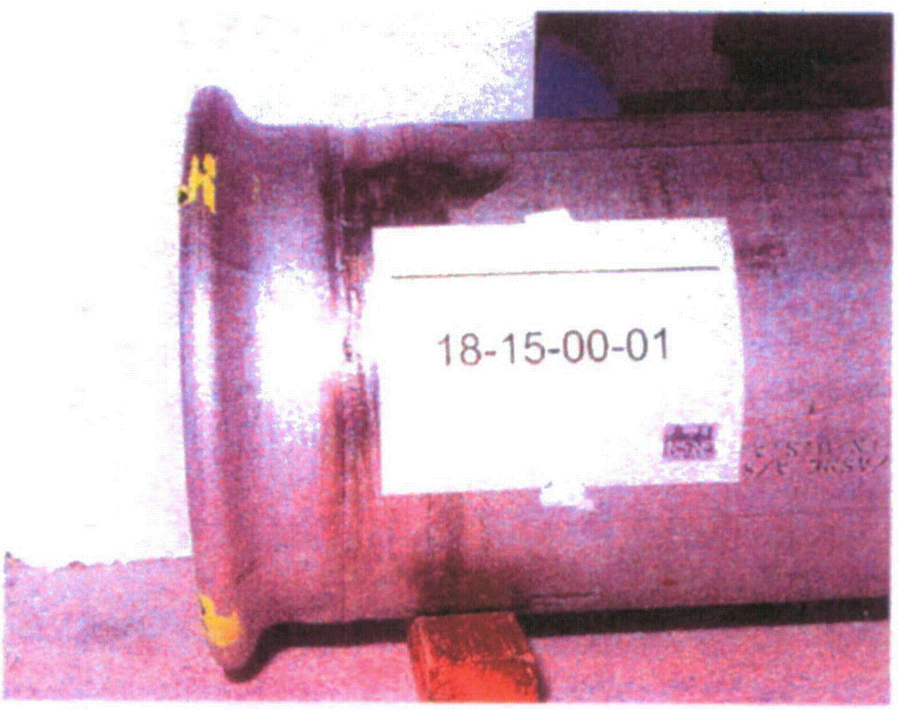

Figure 29. Bottom Side View of Canister 18-15-00-01

8.2. Canister 18-15-06-02

This test canister was dropped from a "center-of-gravity-over-the-corner" orientation (approximately 6 degrees from vertical) 30 feet onto the essentially unyielding surface. Figures 30 and 31 show the bottom portion of the canister, especially the deformed skirt. The skirt protected the pressure boundary of the test canister as expected. The top portion of the canister was only slightly deformed (Figure 32) as it fell over after the initial impact. The internals showed no recognizable damage.

Figure 30. Bottom End View of Canister 18-15-06-02

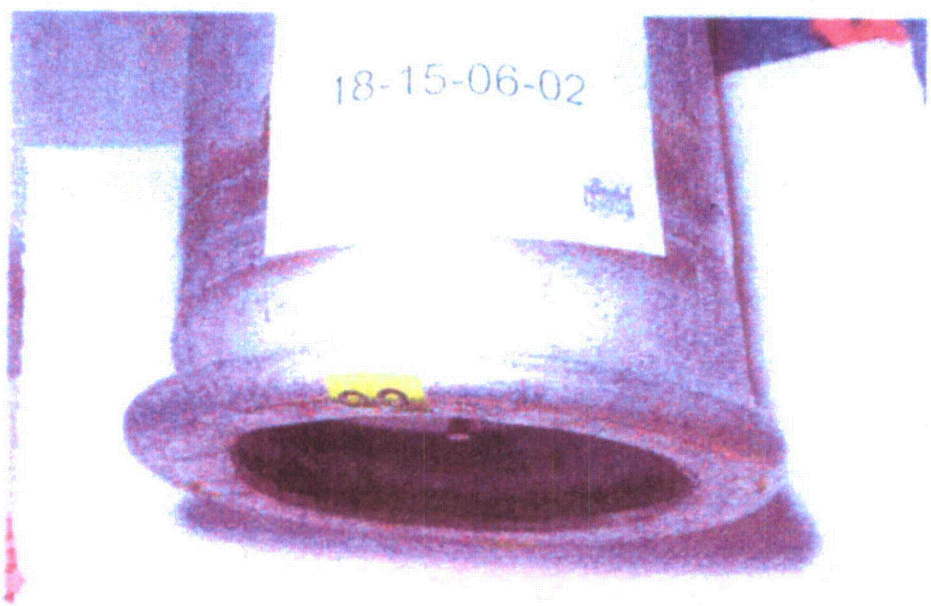

Figure 31. Side View of Canister Bottom 18-15-06-02

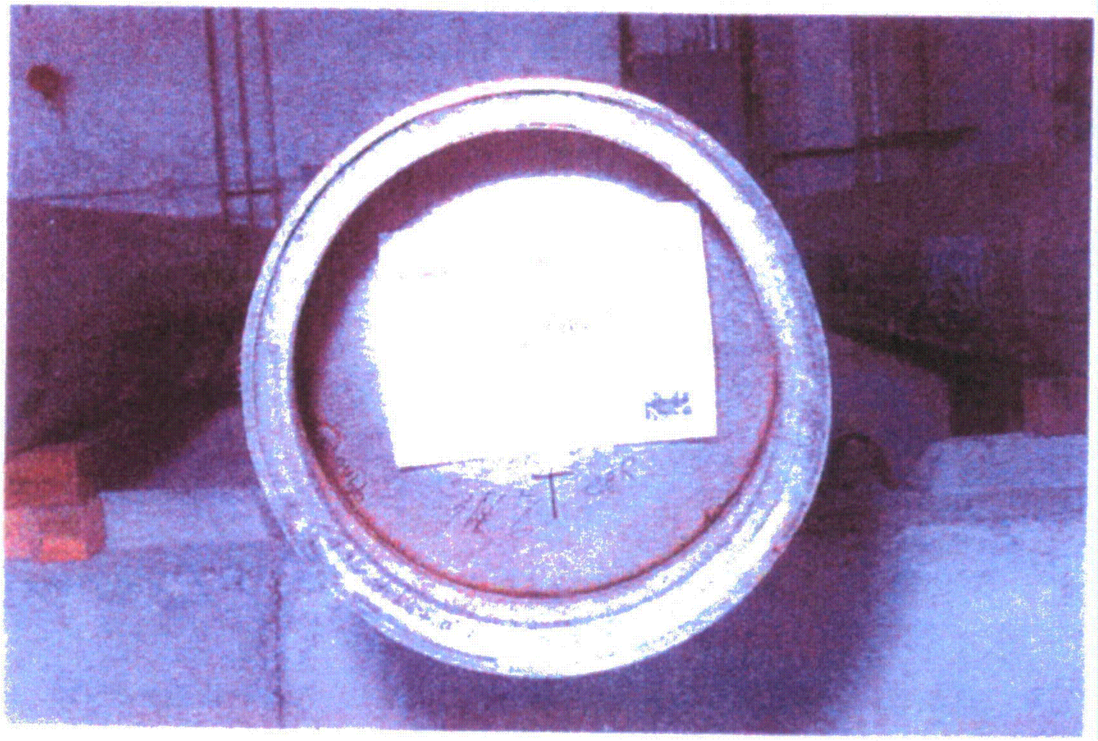

Figure 32. Top End View of Canister 18-15-06-02

8.3. Canister 18-15-90-03

This test canister was dropped from a horizontal orientation 30 feet onto the essentially unyielding surface. Figure 33 shows the bottom portion of the canister end while Figure 34 shows the top end portion of the test canister. The skirt ends deformed very little. Most of the deformation occurred in the mid-section where the canister body flattened along the point of impact and the body ovalized to a maximum diameter of slightly less than 19 inches. The internals were somewhat deformed but could easily still carry out their intended function of separating the SNF and keeping it adequately positioned. Figure 35 is a cut-away view of the internals without the rebar. The drop test missed impacting the longitudinal weld seam on the test canister body.

8.4. Canister 18-15-45-04

This test canister was dropped from a 45-degree orientation 30 feet onto the essentially unyielding surface. Figures 36 and 37 show the bottom portion of the canister while Figures 38 and 39 show the top portion of the canister. Both the top and bottom skirts deformed, especially the bottom skirt. However, the skirt still absorbed much of the impact energy and significantly reduced the damage that could have potentially occurred to the canister pressure boundary. The test canister had a noticeable bow over the entire canister length after the drop test. The internals showed no recognizable damage with the exception of the 2-inch thick impact plates that were slightly deformed (Figure 40) in the local area of the impact point. However, they could still perform their intended function.

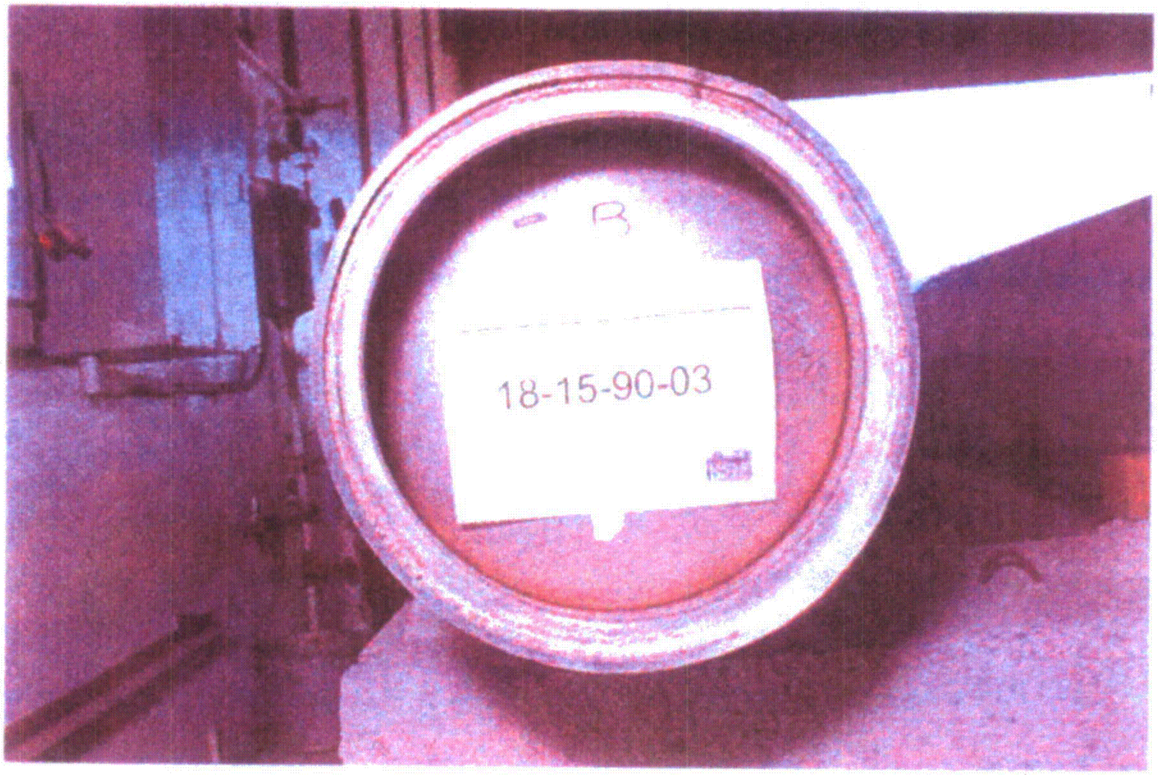

Figure 33. Bottom End View of Canister 18-15-90-03

Figure 34. Top End View of Canister 18-15-90-03

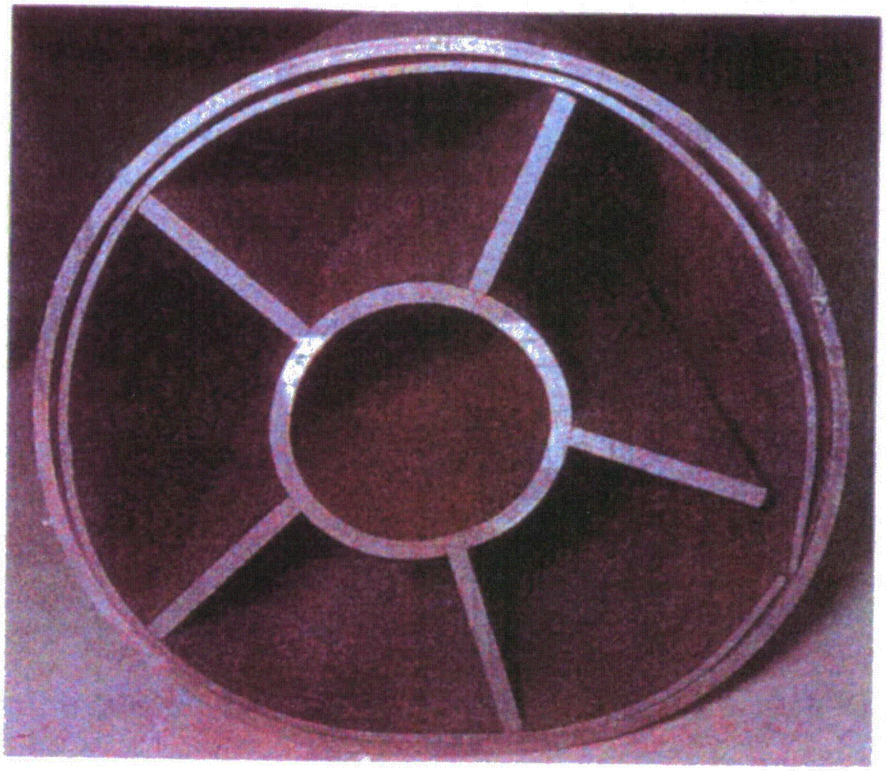

Figure 35. Cut-Away of Internals Without Rebar for Canister 18-15-90-03

Figure 36. Bottom of Canister 18-15-45-04

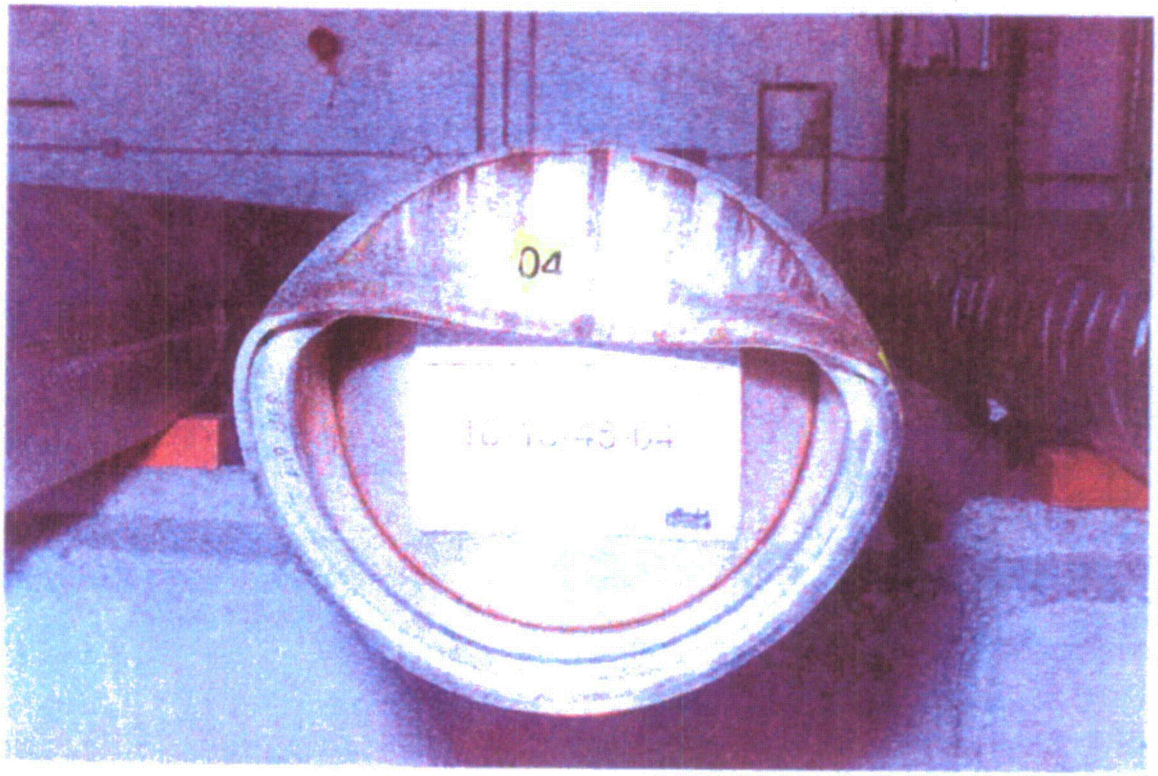

Figure 37. Bottom End View of Canister 18-15-45-04

Figure 38. Top End View of Canister 18-15-45-04

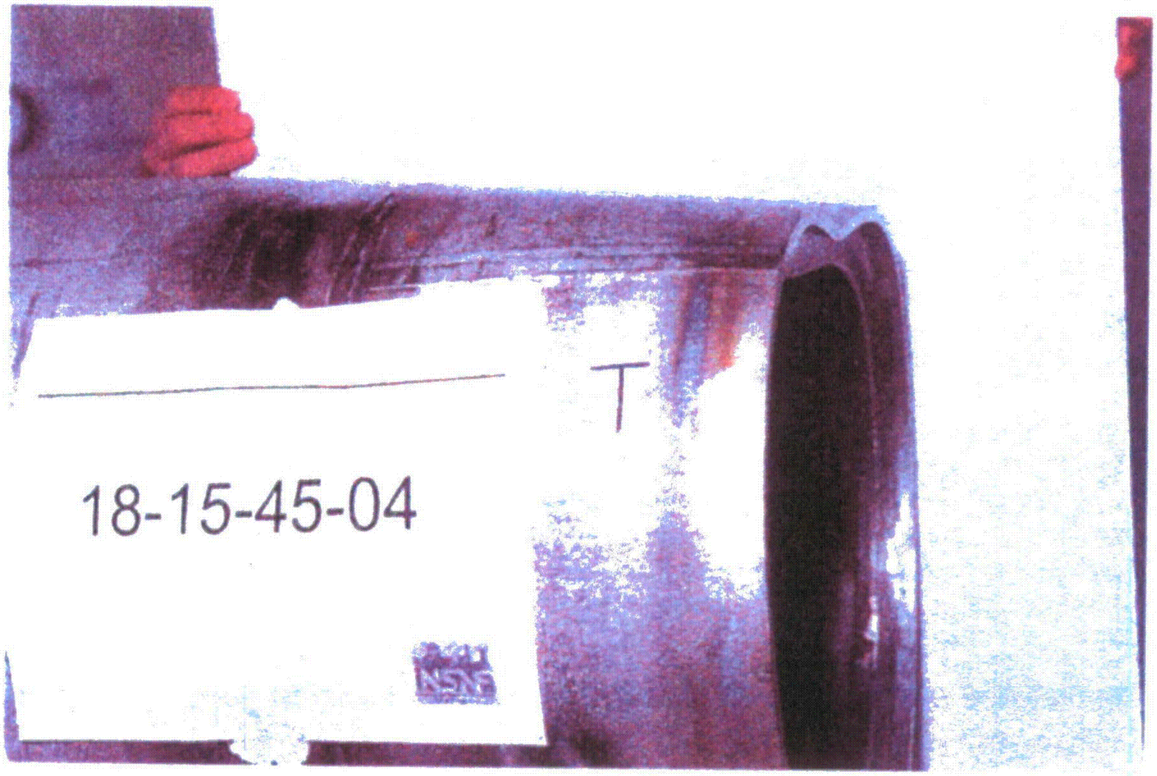

Figure 39. Top Side View of Canister 18-15-45-04

Figure 40. Impact Plate Showing Slight Deformation

8.5. Canister 18-15-80-05

This test canister was dropped from an 80-degree (near horizontal) orientation 30 feet onto the essentially unyielding surface. Figures 41 and 42 show the bottom portion of the canister while Figures 43 and 44 show the top portion of the test canister. Since the slapdown effect was achieved, the top portion of the canister pressure boundary was more damaged than the bottom. This test canister experienced the most damage to the canister pressure boundary, especially for the welds made at the INEEL. The top head to canister body weld was significantly flattened during slapdown (Figures 45 and 46) and the dished portion of the head had a noticeable bulge at the slapdown impact location near where the skirt was welded onto the head. The spoked-wheel basket internal for this test canister showed the most significant damage of all of the test canisters. However, that damage was not that significant. Three of the spokes showed some deformation due to the rebar impacting the spokes. Figure 47 shows the spoke most damaged. Some slight deformation of the spoke is noticeable. Along that same spoke, two of the intermittent welds (near the top end) cracked. Figure 48 shows those two welds and Figure 49 shows a close-up of one of the cracked welds. The 2-inch thick impact plates were slightly deformed at the point of impact but were still able to perform their intended function.

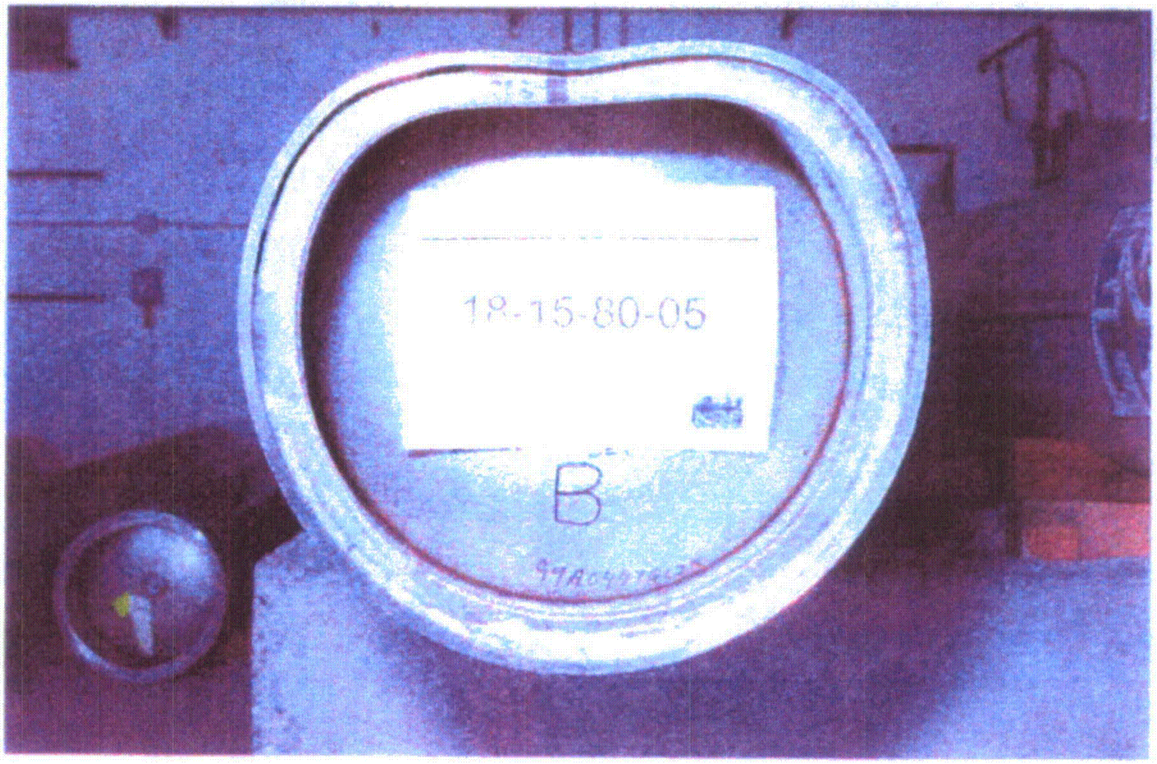

Figure 41. Bottom End View of Canister 18-15-80-05

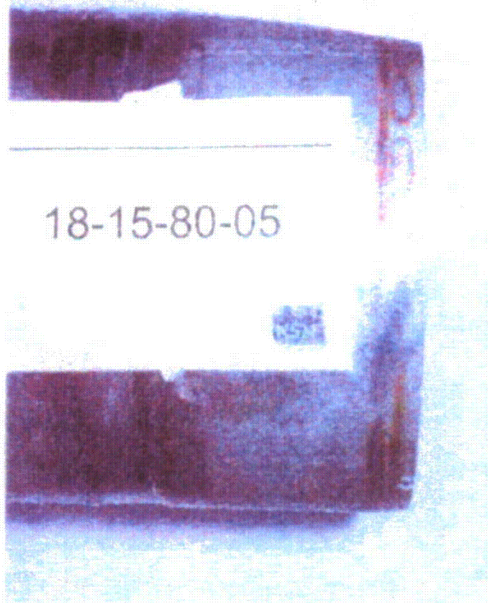

Figure 42. Bottom Side View of Canister 18-15-80-05

Figure 43. Top End View of Canister 18-15-80-05

Figure 44. Top Side View of Canister 18-15-80-05

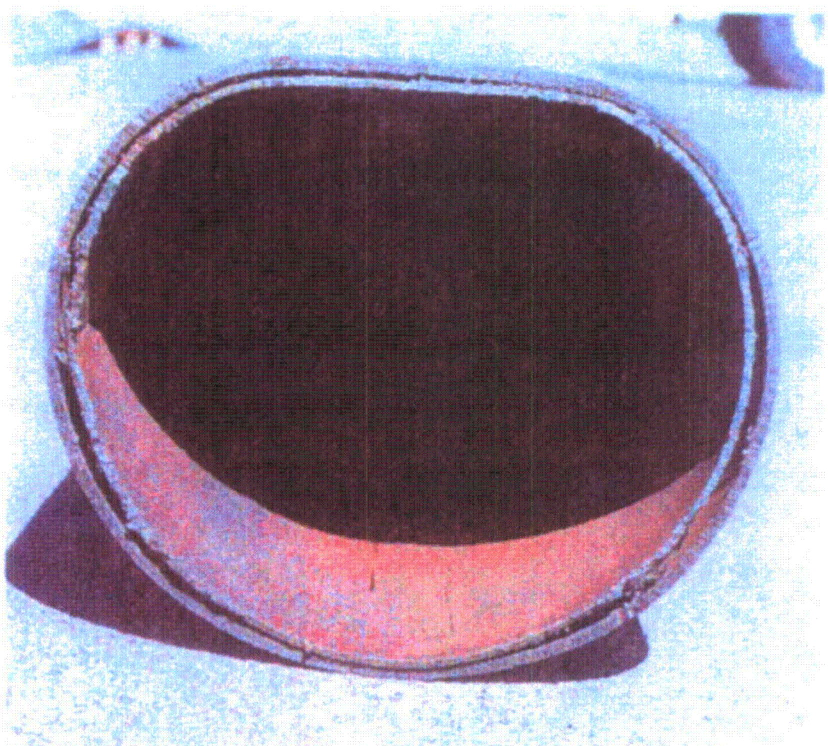

Figure 45. Cross-Section of Canister 18-15-80-05 at Flattened Region

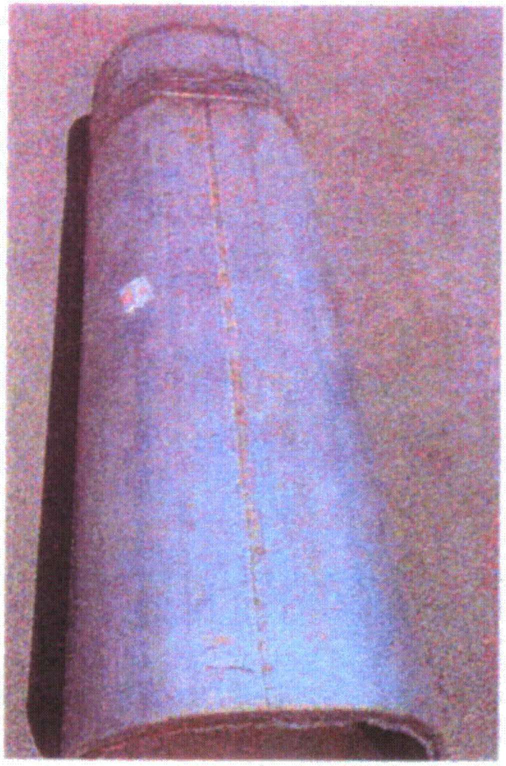

Figure 46. Top Third of Canister 18-15-80-05

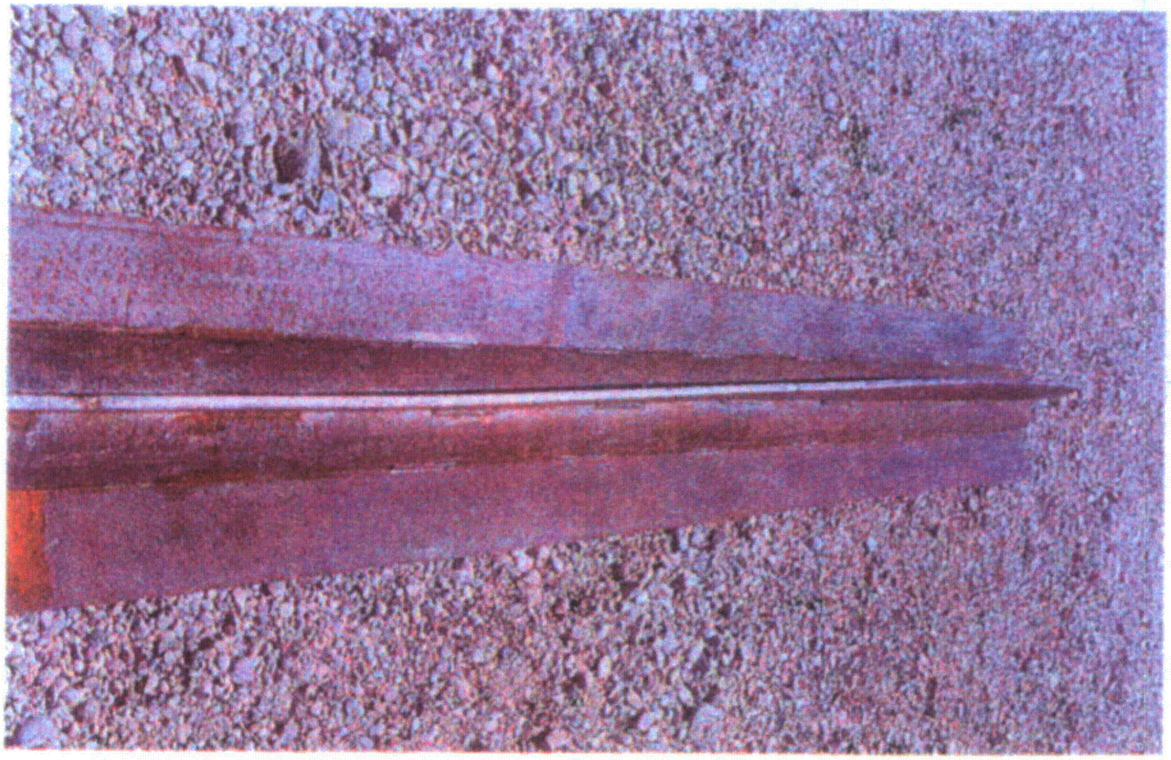

Figure 47. Spoked-Wheel Basket of Canister 18-15-80-05

Figure 48. Spoked-Wheel Cracked Welds

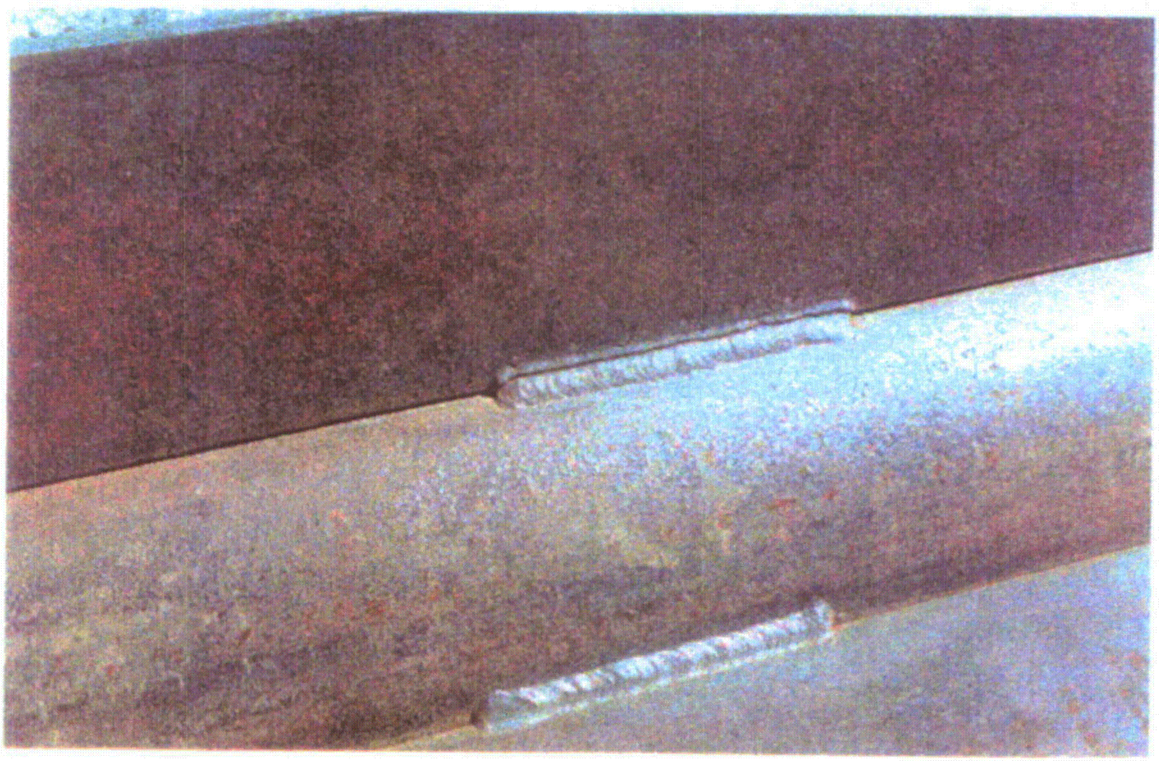

Figure 49. Close-up of Cracked Weld

8.6. Canister 18-10-90-06

This test canister was dropped from a horizontal orientation 30 feet onto the essentially unyielding surface. Figure 50 shows a representative end view of the canister, highlighting the slightly deformed skirt. The most damage occurred in the middle section of the canister where the canister body flattened along the point of impact and the body ovalized to a maximum diameter of approximately 18-5/8 inches. The drop test missed impacting the longitudinal weld seam on the test canister body. The simulated HICs were inside this test canister. All of the simulated HICs had a slight bow over their entire length due to the 90-degree impact. The one simulated HIC that was left empty was indeed flattened and is shown in Figure 51. The mid-section maximum measured diameter on this empty simulated HIC was 6-11/16 inches and the minimum diameter was measured as 3-15/16 inches.

8.7. Canister 18-10-90-07

This test canister was dropped from a horizontal orientation 30 feet onto the essentially unyielding surface. Figure 52 shows a representative end view of the canister, highlighting the slightly deformed skirt. This test canister experienced even less apparent damage than 18-10-90-06. The most damage occurred in the middle section of the canister where the canister body flattened along the point of impact and the body ovalized to a maximum diameter of approximately 18-1/2 inches. This canister deformed a smaller amount than 18-10-90-06 due to the different internals configuration and the lighter total weight of the test canister. The drop test missed impacting the longitudinal weld seam on the test canister body. The internals for this test canister were the simulated Shippingport fuel bundles. Figure 53 shows the resulting deformation of these pieces. Note that the corners were ground down during canister loading to allow the backing ring on the top head assembly to properly fit. Since these internals represented a specific fuel bundle and not a basket design, the deformations were not a major concern to this drop test effort.

Figure 50. End View of Canister 18-10-90-06

Figure 51. Flattened Empty HIC

Figure 52. End View of Canister 18-10-90-07

Figure 53. Simulated Shippingport Fuel Bundles After Drop

8.8. Canister 18-15-PW-08

This test canister was dropped from a vertical orientation 2 feet onto a rigid and vertically oriented 2-inch thick plate (representing an edge of a repository waste package or other similar component). The test canister was then allowed to tip over onto another essentially rigid and vertically oriented 2-inch thick plate (representing the other edge of the waste package or other component). Figure 54 shows the results of the initial impact on the skirt. The skirt was indented approximately ½-inch. Figure 55 shows the damage done to the test canister body due to the secondary impact. This damage was noticeable but not very significant. The minimal diameter at this secondary impact point was measured as approximately 16-5/8 inches, resulting in an indent of approximately 1-3/8 inches. The edges on both of the 2-inch thick plates were relatively sharp since these edges were not ground down or rounded but were "as-received". The top portion of this test canister impacted the essentially unyielding surface at the position where a welded-on lifting lug had been placed. This third main impact resulted in the localized deformation of the top skirt shown in Figure 56. The uniqueness of this deformation was due to a "pad eye" (welded-on lifting lug) attached to the skirt at the point of the third impact. This test canister had loaded into it a spoked-wheel basket without a sleeve and rebar was not placed adjacent to the desired impact location. The spoked-wheel basket received only minor localized deformation (Figure 57) to one of the spokes adjacent to the impact location.

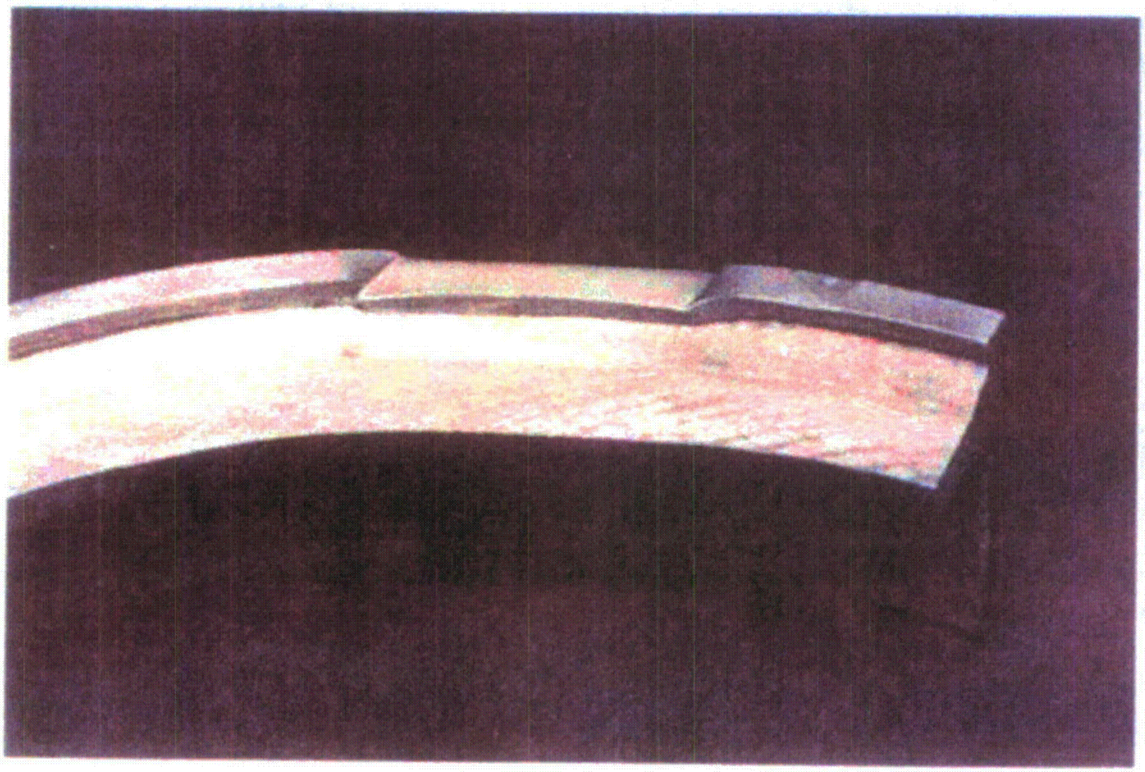

Figure 54. Deformation on Canister 18-15-PW-08 Skirt Due to Initial Impact

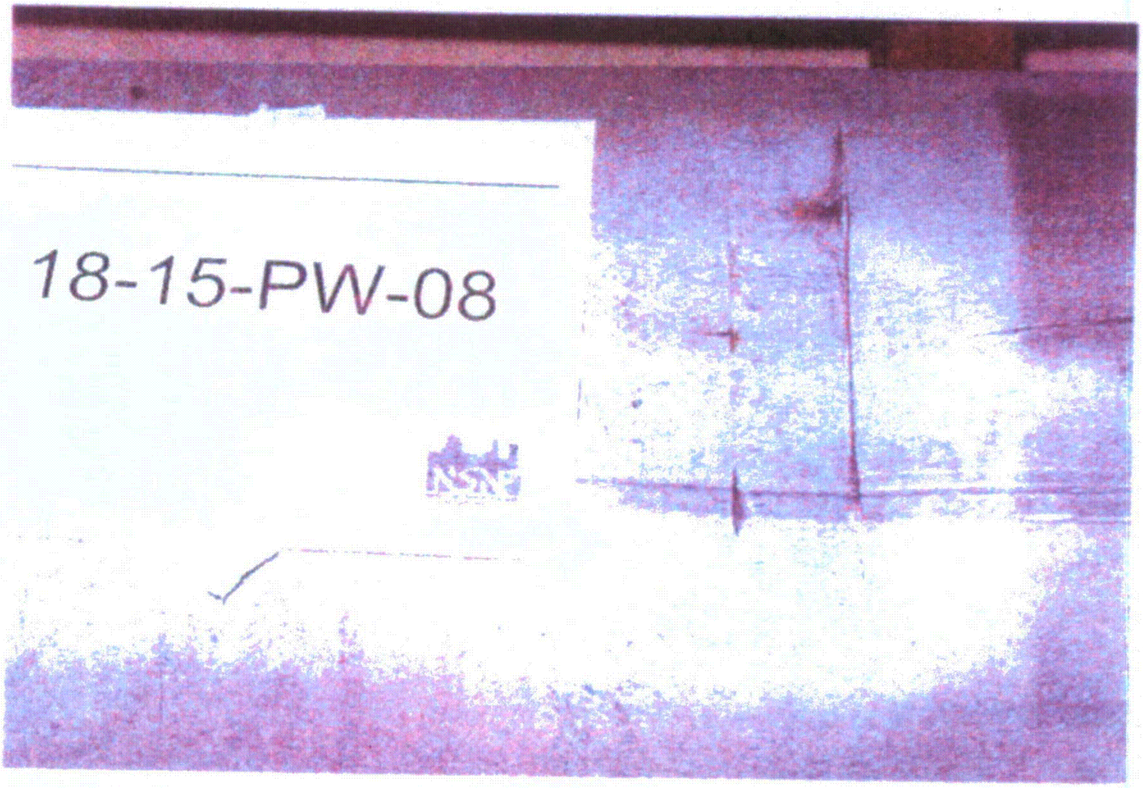

Figure 55. Secondary Impact Damage to Canister 18-15-PW-08

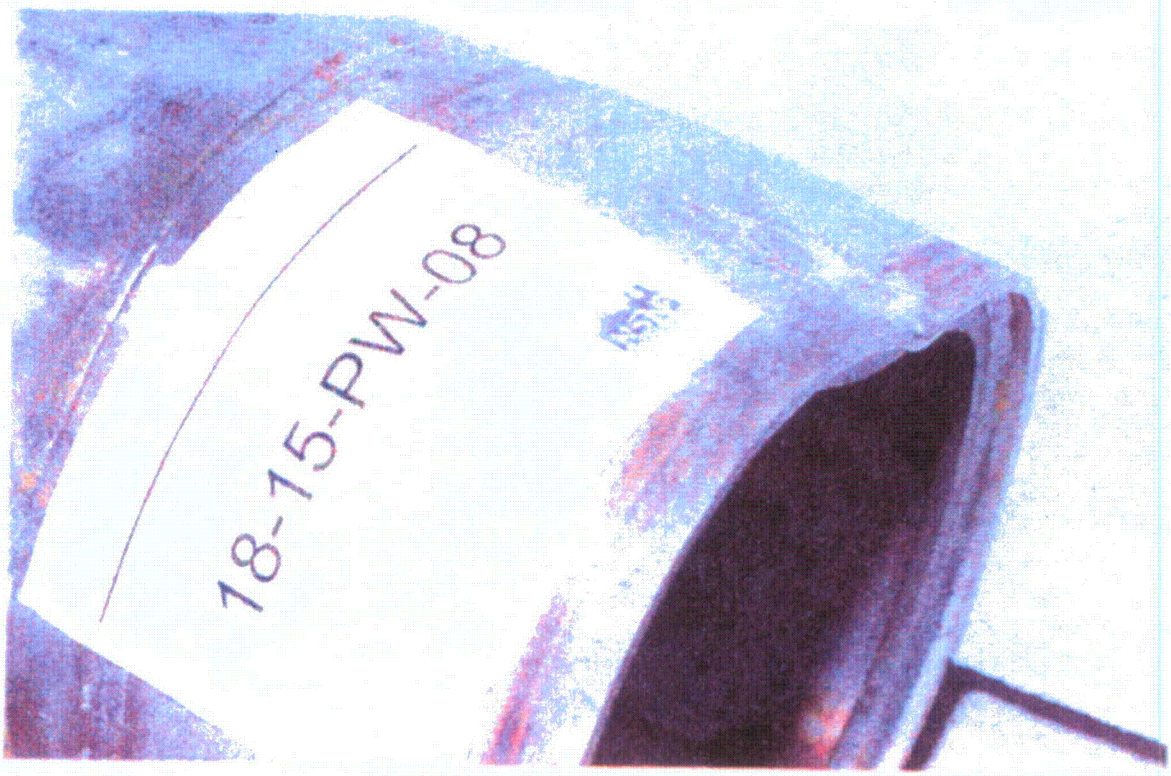

Figure 56. Top Skirt Deformation of Canister 18-15-PW-08

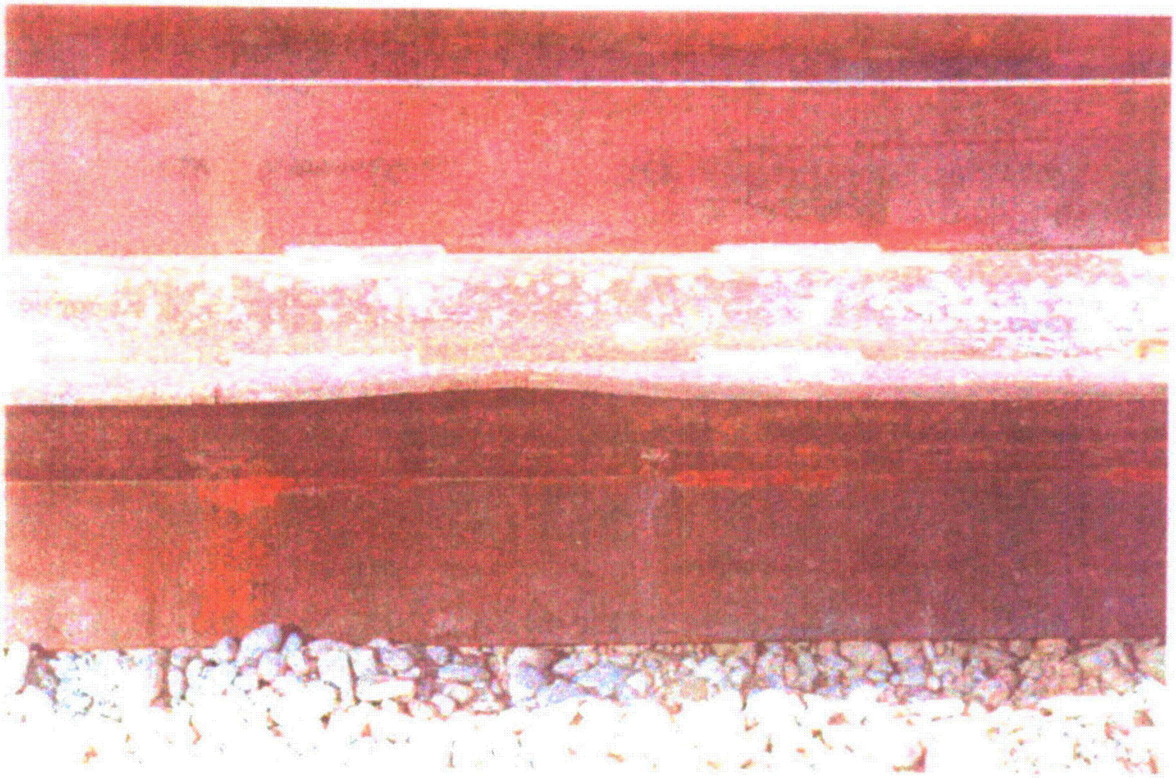

Figure 57. Localized Deformation of Spoked-Wheel Basket From Canister 18-15-PW-08

8.9. Canister 18-15-PP-09

This test canister was dropped from 40 inches onto a six-inch diameter puncture bar. This test duplicated that specified in 10 CFR 71.73 (c) (3). The impact target was the center-of-gravity of the test canister. This orientation would produce the most deformation to the canister body. However, the drop test actually impacted about ½-inch more toward the lower head and about 1-1/4-inch off of the longitudinal weld seam. Figures 58 and 59 show the results of this puncture test. Damage to the test canister body was significant. The post-drop measurements indicated that the resulting puncture deformation was approximately 2-3/4 inches into the canister. Both the top and bottom portions of the canister were virtually undamaged due to the short fall to the essentially flat unyielding surface of the drop pad. However, after impact, the test canister rolled off the puncture bar, impacting an eye bolt used to lift the puncture bar assembly. As indicated earlier in Section 6, this test canister was loaded with a spoked-wheel basket only (no sleeve) and with no rebar adjacent to the impact point (Figure 60). The resulting damage to the spoked-wheel basket was very minimal. The edge of the one spoke in the vicinity of the puncture impact had a slight mark that resembled a rub mark. The damage was so slight that it was very hard see. The interior surface of the canister where the puncture occurred also shows little if any noticeable damage, except in the immediate area of the puncture bar deformation.

Figure 58. Damage at Point of Impact on Canister 18-15-PP-09

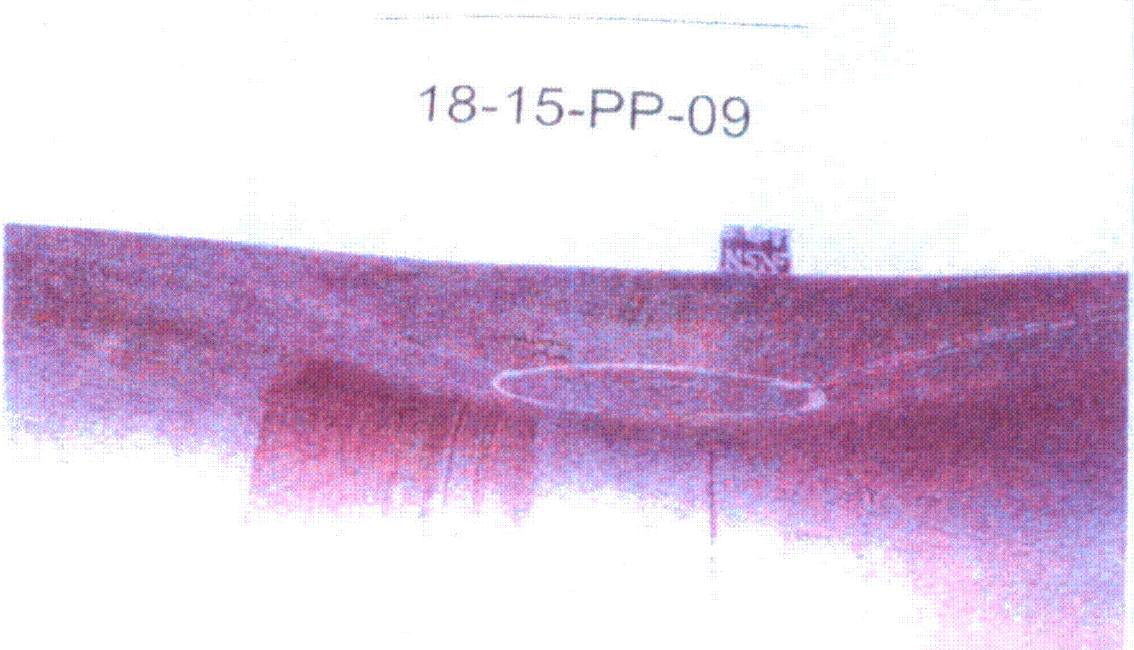

Figure 59. Side View of Damaged Canister 18-15-PP-09

Figure 60. Internals Arrangement of Canisters 18-15-PW-08 and 18-15-PP-09

9. PHASE VI – FINAL REPORT AND DOCUMENTATION PACKAGES

The last phase of the FY99 effort included: (1) the generation of a final report (this report) by NSNFP qualified personnel that addresses all of the associated activities, especially the computer prediction efforts, (2) submitting the three INEEL work order packages to the NSNFP, and (3) submitting the documentation generated by SNL, reporting on all of their associated efforts to physically perform the drop tests, the pressure tests, and the pre- and post-drop measurement activities at the SNL.

The computer code ABAQUS/Explicit Release 5.8-1 (Reference 28) was used for the finite element modeling. However, this computer code already existed at the INEEL. Therefore, the validation and verification process, described in NSNFP PMP 19.01 Computer Software Management, (Reference 29) started at step 5 of the "Acquired Software" section for ABAQUS/Explicit. The associated plan and actual validation reports for ABAQUS/Explicit are References 30 and 31.

10. CONCLUSIONS

Nine test canisters were fabricated using "best practices possible" and using the ASME B&PV Code, Section III, Division 3 as guidance. These nine test canisters were drop tested at SNL onto an essentially unyielding flat surface. Seven of the test canisters were dropped from a 30-foot drop height. The remaining two canisters were puncture drop tested from shorter drop heights. After the tests, all nine canisters were able to hold 50 psig of air steady for one hour without loss of pressure. Four of the most heavily damaged canisters were also helium leak tested and demonstrated to have leak rates less that 10^{-7} std cc/sec. These results clearly show that the design of the standardized DOE SNF canister is robust and that its containment system remains functional even after an accidental drop event. In addition, these nine test results provide adequate validation of the capability of computer analyses to predict the structural response of these canisters under a wide variety of situations not necessarily tested.

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31. *Software Qualification Report For HKS ABAQUS/Explicit, Version 5.8-1*, DOE/SNF/DSN-015, Revision 0, February 2000.