05
1/25/91 (2) Jim

SANDIA REPORT

SAND91-1064 • TTC-1071 • UC-722

Unlimited Release

Printed September 1991

Certification Testing of the Los Alamos National Laboratory Heat Source/Radioisotopic Thermoelectric Generator Shipping Container

D. R. Bronowski, M. M. Madsen

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
under Contract DE-ACC1-76DP00789

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

NOTICE: This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government, any agency thereof or any of their contractors or subcontractors. The views and opinions expressed herein do not necessarily state or reflect those of the United States Government, any agency thereof or any of their contractors.

Printed in the United States of America. This report has been reproduced directly from the best available copy.

Available to DOE and DOE contractors from
Office of Scientific and Technical Information
PO Box 62
Oak Ridge, TN 37831

Prices available from (615) 576-8401, FTS 626-8401

Available to the public from
National Technical Information Service
US Department of Commerce
5285 Port Royal Rd
Springfield, VA 22161

NTIS price codes
Printed copy: A06
Microfiche copy: A01

SAND--91-1064

DE92 003340

SAND91-1064

TTC-1071

Unlimited Distribution

Printed September 1991

CERTIFICATION TESTING OF THE
LOS ALAMOS NATIONAL LABORATORY
HEAT SOURCE/RADIOISOTOPIC THERMOELECTRIC GENERATOR
SHIPPING CONTAINER*

D. R. Bronowski and M. M. Madsen
Transportation System Development Department
Sandia National Laboratories**
Albuquerque, NM 87185

ABSTRACT

The Heat Source/Radioisotopic Thermoelectric Generator shipping container is a Type B packaging currently under development by Los Alamos National Laboratory. Type B packaging for transporting radioactive material is required to maintain containment and shielding after being exposed to the normal and hypothetical accident environments defined in Title 10 of the Code of Federal Regulations Part 71. A combination of testing and analysis is used to verify the adequacy of this package design. This report documents the testing portion of the design verification. Six tests were conducted on a prototype package: a water spray test, a 4-foot normal conditions drop test, a 30-foot drop test, a 40-inch puncture test, a 30-minute thermal test, and an 8-hour immersion test.

* This work performed at Sandia National Laboratories, Albuquerque, New Mexico, supported by the U.S. Department of Energy under Contract DE-AC04-76DP00789.

** A United States Department of Energy Facility

MASTER

ACKNOWLEDGMENTS

The authors are indebted to a large group of individuals who have contributed to this test program. The cooperation and work of the following individuals are greatly appreciated: H. Kovaschetz and E. Barreras of Mechanical Measurements Division 7485-3; D. Cotter, K. Babb, and L. Abeyta of Dynamic Loads and Facilities Development Division 7531; T. Miller, Jr., of Track and Cables Division 7535; K. Sobolik, D. Schulze, and J. Bonner of Thermal Test and Analysis Division 7537; D. Helgesen and M. Apodaca of Photometrics and Optical Development Division 7556; C. Edwards and the staff of Welding and Plasma Spray Section 7473-4; and the staff of Secondary Standards Division 7414, especially W. Leisher and J. LaMarr. Special thanks are due to W. Uncapher and D. Stenberg of Transportation Systems Development Division 6323 for their technical expertise. The technical editing and document-production services of Creative Computer Services of Albuquerque, NM, are gratefully acknowledged.

CONTENTS

<u>Section</u>	<u>Page</u>
1.0 Introduction.....	1
2.0 Package Description.....	3
3.0 Test Program Description.....	9
3.1 Normal-Conditions-of-Transport Tests.....	9
3.2 30-Foot Drop Test.....	9
3.3 Puncture Test.....	9
3.4 Thermal Test.....	10
3.5 Immersion Test.....	10
3.6 Documentation/Quality Assurance.....	12
4.0 Test Facility Description.....	13
4.1 185-Foot Drop Tower	13
4.2 Thermal Test Facility.....	13
4.3 Pool Facility.....	13
5.0 Thermal Response Instrumentation.....	17
5.1 Temperature Labels.....	17
5.2 Thermocouples.....	17
5.3 Data Acquisition and Reduction System.....	17
6.0 Normal-Conditions-of-Transport Tests.....	27
6.1 Test Unit Preparation.....	27
6.2 Test Setup: Water Spray Test.....	27
6.3 Water Spray Test.....	29
6.4 Test Setup: 4-Foot Drop Test.....	29
6.5 4-Foot Drop Test.....	29
6.6 Exterior Deformations.....	29
6.7 Disassembly.....	35
6.8 Results: Nondestructive Examination.....	35
6.8.1 Leak Test.....	35
6.8.2 Inspection.....	36
7.0 Center-of-Gravity-Over-Corner Drop Test.....	37
7.1 Test Unit Preparation.....	37
7.2 Test Setup.....	37
7.3 Drop Test Event.....	37
7.4 Exterior Deformations.....	43

CONTENTS
(Concluded)

<u>Section</u>	<u>Page</u>
8.0 40-Inch Puncture Test.....	47
8.1 Test Setup.....	47
8.2 Test Event.....	47
8.3 Posttest Observations.....	47
9.0 Thermal and Immersion Tests.....	51
9.1 Test Unit Preparation.....	51
9.2 Test Setup.....	51
9.3 Thermal Test.....	56
9.4 Immersion Test.....	56
9.5 Disassembly.....	57
9.6 Test Results.....	66
9.6.1 Thermal Environment.....	66
9.6.2 Test Unit Thermal Response: Thermocouples.....	66
9.6.3 Test Unit Thermal Response: Temperature Labels.....	81
9.7 Results: Nondestructive Evaluation.....	81
9.7.1 Leak Test.....	81
9.7.2 Dimensional Inspection.....	82
10.0 Summary.....	83
Appendix A.....	A-1
Appendix B.....	B-1
References.....	R-1

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
2-1 Outer Container (Drum).....	4
2-2 Inner Container Components.....	5
2-3 Inner Container Assembly	6
2-4 Payload Assembly.....	7
4-1 Drop Test Facility.....	14
4-2 Thermal Test Facility.....	15
5-1 Temperature Label Locations.....	19
5-2 Temperature Label Configuration.....	20
5-3 Thermocouple Locations: Test Unit.....	22
5-4 Thermocouple Attachment.....	23
5-5 Thermocouple Locations: Shroud.....	25
5-6 Data Acquisition System.....	26
6-1 Water Spray Test Configuration.....	28
6-2 Water Spray Test.....	30
6-3 4-Foot Drop Test Setup.....	31
6-4 4-Foot Drop Test Sequence.....	32
6-5 Drum Deformations.....	33
6-6 Deformation Sketch.....	34
7-1 Test Unit Assembly.....	38
7-2 Thermocouples Attached to Drum Bottom.....	39
7-3 Test Unit in Cradle.....	40
7-4 30-Foot Drop Test Setup.....	41
7-5 30-Foot Drop Test Sequence.....	42
7-6 Outer Drum Deformations.....	44
7-7 Drum Deformation Sketch.....	45
8-1 Puncture Test Setup.....	48
8-2 Puncture Test Sequence.....	49
8-3 Drum Deformation Sketch.....	50
9-1 External Thermocouple Installation.....	52
9-2 Thermal Test Configuration.....	53
9-3 Test Unit in Array Before Shroud Installation.....	54
9-4 Shroud Installation.....	55
9-5 Array Ready for Test.....	55
9-6 Immersion Test Configuration.....	58
9-7 Test Unit Removed from Pool.....	58
9-8 Lid Removal.....	59
9-9 Celotex Removal.....	59
9-10 Thermocouples TCU1 and TCU3.....	61
9-11 Posttest Disassembly.....	62
9-12 Resinlike Substance on Exterior of Inner Container.....	63
9-13 Cross Section of Celotex Insulation.....	64

LIST OF FIGURES
(Concluded)

<u>Figure</u>		<u>Page</u>
9-14	Discoloration Pattern in Celotex.....	65
9-15	Body Seal Area.....	67
9-16	Lid Seal Area.....	67
9-17	Shroud Thermocouples STC8 Through STC11.....	68
9-18	Variations in Shroud Temperatures.....	69
9-19	Shroud Thermocouples STC2 Through STC5.....	70
9-20	Shroud Thermocouples STC14 Through STC17.....	71
9-21	Shroud Thermocouples STC6, STC7, STC12, and STC19.....	72
9-22	Test Unit Thermocouples TCU11 Through TCU14.....	73
9-23	Test Unit Thermocouples TCU15 and TCU16.....	74
9-24	Test Unit Thermocouples TCU7 Through TCU10.....	76
9-25	Cool-Down: Thermocouples TCU7 Through TCU10.....	77
9-26	Test Unit Thermocouples TCU1 Through TCU4.....	78
9-27	Test unit Thermocouples TCU5 and TCU6.....	79
9-28	Cool-Down: Thermocouples TCU3 Through TCU6.....	80
A-1	Leak Test Configuration.....	A-3
A-2	Leak Test Setup.....	A-4
A-3	Helium Permeation of Container O-Rings.....	A-5
B-1	Inspection Points: Body.....	B-3
B-2	Inspection Points: Lid.....	B-4
B-3	Inspection Setup: Inner Container Body.....	B-11

LIST OF TABLES

<u>Table</u>		<u>Page</u>
3-1	Test Sequence	10
3-2	Heat Source/Radiothermal-Generator Shipping Container Test Matrix.....	11
5-1	Temperature Label Locations.....	18
5-2	Thermocouple Locations.....	21
5-3	Thermocouple Locations: Shroud.....	23
9-1	Temperature Label Readings.....	82
B-1	Normal-Conditions Tests: Body.....	B-5
B-2	Normal-Conditions Tests: Lid.....	B-6
B-3	Regulatory Series Tests: Body.....	B-7
B-4	Regulatory Series Tests: Lid.....	B-8
B-5	All Tests: Body.....	B-9
B-6	All Tests: Lid.....	B-10

1.0 INTRODUCTION

This report describes testing performed on the Heat Source/Radioisotopic Thermoelectric Generator (HS/RTG) shipping container designed and fabricated by Los Alamos National Laboratory (LANL) to transport HS or RTG components. Sandia National Laboratories (SNL), Albuquerque, was asked to perform a series of tests on a certification test unit.

These tests provided data to verify container design adequacy under normal conditions of transport and following a hypothetical accident, and secondarily provided thermal data that will verify analytic predictions. This data will support LANL's Safety Analysis Report for Packaging (SARP) for the container.

The test series consisted of a water spray test, a 4-foot drop test, a 30-foot drop test, a 40-inch puncture test, a 30-minute thermal test, and an 8-hour immersion test on a single test container. All tests were conducted in accordance with 10 CFR 71.1

Data obtained from the test series include leakage test results, dimensional inspection data, thermal response data, and photometric documentation.

2.0 PACKAGE DESCRIPTION

The HS/RTG package is a Type B shipping container consisting of an inner and an outer container. The outer container is a 12-gallon military specification drum (MIL-D-6054) with a modified locking ring (Figure 2-1) measuring 14.75 inches in diameter and 21.1 inches high. The test unit weighed 69.5 pounds.

Filling the area between the inner and outer containers is layered Celotex® mineral board, which acts as a thermal insulator and shock absorber. Celotex layers are bonded into a body section and a lid section (Figure 2-1).

Inner container components are shown in Figure 2-2. The inner container body (Figure 2-3) is a flow-turned stainless steel payload container 4 inches in diameter and 12 inches long. A machined stainless steel lid incorporates a double O-ring seal, which serves as the required level of leak tightness and serves as a test cavity for leak testing. Closure of the inner container is made by a bolted V-clamp produced commercially by Aeroquip® Corporation. The RTG configuration payload (Figure 2-4) was employed for test unit assembly because it provided the highest weight contents.

Specific component orientation was maintained at each assembly to align the most vulnerable area of each component with the actual location of impact. The welded drum seam, the bolt lug of the drum-lid locking ring, and the bolt of the inner container V-clamp were oriented at the 180-degree side of the drum, the same side attacked in the center-of-gravity-over-corner test. Orientation of the V-clamp dictated orientation of the body Celotex, aligning the area of minimum insulation with the 180-degree side.

Figure 2-1. Outer Container (Drum)

Figure 2-2. Inner Container Components

Figure 2-3. Inner Container Assembly

Figure 2-4. Payload Assembly

3.0 TEST PROGRAM DESCRIPTION

The test series shown in Table 3-1 was performed to verify the structural integrity of the HS/RTG shipping container design. This series was defined by LANL in the HS/RTG Shipping Container Test Specification² and conducted on a single container. The series contained tests for both normal conditions of transport and hypothetical accidents, as defined in 10 CFR 71.1. The 30-foot drop, puncture, thermal, and immersion tests were performed as a sequence, with no disassemblies, modifications, or repairs being made between any of the tests. All tests (with the exception of the thermal test) were performed at ambient temperature.

Baseline data for the inner container of the package were established through pretest dimensional inspections and leakage-rate measurements. These nondestructive evaluation (NDE) procedures were repeated after the normal-conditions tests and again after the immersion test. Table 3-2 illustrates the application of NDE, assembly, and disassembly procedures. Results of NDE and disassembly tasks are presented in sections devoted to individual tests.

3.1 Normal-Conditions-of-Transport Tests

Normal-conditions-of-transport tests consisted of a water spray test followed by a 4-foot free-fall drop test. The water spray test simulated exposure to a rainfall of at least 2 inches per hour for a minimum period of 1 hour. The 4-foot drop test was conducted aligning the center of gravity of the test unit over the drum lid locking-ring bolt, an orientation for which maximum drum deformation was expected.

3.2 30-Foot Drop Test

A drop test was performed in a center-of-gravity (CG)-over-corner orientation. This orientation was determined by prior testing of structural test units dropped and punched in several orientations, which showed that the CG-over-corner orientation caused the most severe deformations. The test was a guided free-fall drop impacting an essentially unyielding target at 44 feet per second. An additional 2.3 feet of drop height (total 32.2 feet) was required to compensate for friction in the guidance system. The test facility and guidance system are described in detail in Section 4.2.

3.3 Puncture Test

A puncture test was performed on the test unit after the 30-foot drop test. The test was a 40-inch free-fall onto a 6-inch-diameter puncture bar defined in 10 CFR 71. The punch was directed at the area damaged by the drop test.

TABLE 3-1
Test Sequence

<u>Test</u>	<u>Test Description</u>	<u>Drop Height</u>	<u>Impact Angle</u>
1	Water Spray	NA	0°
2	Normal-Conditions Drop	4 ft	54°
3	Center-of-Gravity-Over-Corner Drop	32.3 ft	54°
4	Center-of-Gravity-Over-Corner Punch	40 in.	54°
5	Thermal	NA	90°
6	Immersion	NA	0°

NA = Not applicable.

3.4 Thermal Test

A 30-minute thermal test was performed on the package after the puncture test. The test consisted of exposure of the package to a 1475°F thermal environment for a period of 30 minutes. A circular radiant heat facility provided the controlled environment defined in 10 CFR 71.

Thermocouples were installed in and on the package prior to the test to measure thermal response at various locations. Thermocouple information is described in detail in Section 5.0. Temperature data is presented with information relating to the thermal test in Section 9.0.

3.5 Immersion Test

An immersion test was the final test performed on the package. This test consisted of an 8-hour immersion under 36 inches of water. Disassembly, leak check, and dimensional inspection evaluations were performed after completion of the test.

TABLE 3-2

HS/RTG Shipping Container Test Matrix

<u>Test</u>	<u>Description</u>	<u>Inspect</u>	<u>Instru-</u> <u>ment</u>	<u>Leak</u> <u>Test</u>	<u>Assembly</u>	<u>Test</u> <u>Procedure</u>	<u>Dis-</u> <u>Assembly</u>	<u>Leak</u> <u>Test</u>	<u>Inspect</u>
1	Norm Cond	X		X	X	LANL-1 (Ref. 3)	X	X	X
2	30-Ft Drop		X	X	X	LANL-C2 (Ref. 4)			
3	Puncture					LANL-C5 (Ref. 5)			
4	Thermal		X			LANL-C6 (Ref. 6)			
5	Immersion					LANL-C7 (Ref. 7)	X	X	X

3.6 Documentation/Quality Assurance

All testing and related activities were conducted under the SNL Transportation System Development Department 6320 Quality Assurance Program Plan.⁸ Project-specific program plans for testing⁹ and quality assurance¹⁰ were prepared. Detailed written test procedures with quality assurance (QA) hold points controlled testing and recording of all data. Additional procedures directed the assembly, disassembly, leak testing, and inspections of the package and provided directions for recording related data. Before use, all procedures were approved by SNL and LANL project and QA personnel. Documentation included test hardware identification, transducer calibrations, laboratory instrument identification and calibration, assembly and disassembly torque values and notes, deformation sketches with dimensions, NDE results and notes, and high-speed and still photographic records.

For each test, the applicable test procedures and all related data were organized into test books maintained as permanent records in the SNL Department 6320 Quality Assurance Records Storage Facility.

Photometric documentation data consisted of 400-frames-per-second photographs of all dynamic tests. An additional 2,000-frames-per-second camera was used for the 30-foot drop test. The test facility employed grid boards and a test unit striped with contrasting colors to aid in photometric analysis.

4.0 TEST FACILITY DESCRIPTION

4.1 185-Foot Drop Tower

Drop and puncture tests were conducted at the SNL 185-foot drop tower located in Technical Area III. The target at this facility meets the International Atomic Energy Agency (IAEA) essentially unyielding target criteria¹¹. This target consists of a block of reinforced concrete covered by a steel plate 4 feet by 6 feet by 8 inches thick. Total target weight of this facility is more than 55,000 pounds.

The test facility is illustrated in Figure 4-1. For the 4-foot drop and 40-inch puncture tests, the test unit was attached to an adjustable cradle using wire rope. Release was made using an explosive cable cutter, allowing the test unit to free-fall onto the target or puncture bar.

Because of the light weight of the test package, a guidance system was used for the 30-foot drop tests, enabling the impact angle to be controlled accurately. Actual drop height for the guided tests was 32 feet, 4 inches. Additional height (above the regulatory 30-foot free-fall test) was required to compensate for friction in the guidance system to achieve the required 44-feet-per-second impact velocity.

For the 44-feet-per-second tests the package was attached to the adjustable cradle with wire rope. The cradle was attached to a sliding beam, which guided the assembly through the first part of the fall. At approximately 8 feet above the target, the wire rope was cut using an explosive cable cutter, allowing the package to free-fall the remaining distance. The sliding beam and cradle assembly was stopped approximately 1 foot after package release using a water braking system.

4.2 Thermal Test Facility

The thermal test was performed at the SNL Radiant Heat Facility located in Technical Area III. Arrays of quartz lamps provided the thermal environment. The test unit was placed in a cylindrical steel shroud, around which was assembled an octagonal array of lamps (Figure 4-2). Environmental temperature was monitored by thermocouples located on interior surfaces of the shroud, with control made by computer. Readings from shroud and test-unit thermocouples were recorded by the facility's data acquisition system.

4.3 Pool Facility

Both the water spray normal-conditions test and immersion test were performed at the SNL Water Impact Facility located in Technical Area III. This facility consists of a large freshwater pool equipped with a crane and floating dock facilities.

Figure 4-1. Drop Test Facility

Figure 4-2. Thermal Test Facility

5.0 THERMAL RESPONSE INSTRUMENTATION

Temperature-sensing devices used to measure the thermal response of the package in the thermal test consisted of both passive and active transducers.

5.1 Temperature Labels

Passive indicators consisted of Walh Tem-Plate temperature labels affixed to various surfaces of the inner container assembly (Table 5-1 and Figure 5-1). Labels employed were chemical-change thermometers, which provided a nonreversible record of the maximum temperature attained at label locations. Each label location consisted of three individual labels covering a temperature range from 110 to 340°F in 10 or 20°F increments (Figure 5-2). Labels were read by visual observation after test-unit disassembly by noting the highest-value sensor of those that had turned from light grey to black in color.

5.2 Thermocouples

Active transducers consisted of Gordon type K thermocouples mounted on the exterior surfaces of both the inner container and outer drum, and embedded in the Celotex insulation (Table 5-2 and Figure 5-3). Each thermocouple channel was assigned a unique designation to maintain identification throughout the test series. Thermocouple channels are identified by the letters STC (shroud) or TCU (test unit) followed by a numeric designation.

Thermocouples were attached to inner container components by covering their tips with a small strip of nychrome wire, which was spot welded to the component, holding the tip of the thermocouple in contact with the component's surface. Thermocouples were routed towards the container bottom, attaching them with additional strips of nychrome wire (Figure 5-4). Thermocouples mounted on the inner container were routed out of the bottom of the drum through Swagelok tube fittings (which provided an air-tight seal) passing through a small hole in the Celotex.

Additional thermocouples were installed on the interior surfaces of the shroud at various locations to monitor and control the thermal environment (Table 5-3 and Figure 5-5).

5.3 Data Acquisition and Reduction System

Output from the transducers was recorded on a data acquisition system (Figure 5-6). This system--with calibration, scanning, and recording capabilities--supplied input voltages.

TABLE 5-1
Temperature Label Locations

<u>Designation</u>	<u>Component</u>	<u>Location</u>
TL1	Body	0°/top
TL2	Body	90°/top
TL3	Body	180°/top
TL4	Body	270°/top
TL5	Body	0°/bottom
TL6	Body	90°/bottom
TL7	Body	180°/bottom
TL8	Body	270°/bottom
TL9	Lid	Center/top
TL10	Body	Center/bottom
TL11	Payload	0°/top
TL12	Payload	180°/top
TL13	Payload	0°/bottom
TL14	Payload	180°/bottom
TL15	RTG	0°/top
TL16	RTG	180°/top
TL17	RTG	0°/bottom
TL18	RTG	180°/bottom

Data were recorded at 5-second intervals during the 30-minute test and for 10 minutes after test completion. The sampling rate was then reset to 2 minutes and the data recorded until all measurements had peaked and returned to approximately 100°F.

Data from the tests were processed and displayed in the form of plots (temperature versus time). A systematic review of data was performed, which included a comparison of data to other transducers on the test unit. Conclusions concerning accuracy were drawn, and each data channel was assigned a confidence level. Data plots are presented in the thermal test section.

Note: Designations in parentheses indicate label locations on the far side of the container.

Figure 5-1. Temperature Label Locations

Figure 5-2. Temperature Label Configuration (Example exposed to 220°F)

TABLE 5-2
Thermocouple Locations

<u>Designation</u>	<u>Component</u>	<u>Location</u>
TCU1	Lid	0°/flange
TCU2	Lid	180°/flange
TCU3	Body	0°/flange
TCU4	Body	180°/flange
TCU5	Body	0°/bottom
TCU6	Body	180°/bottom
TCU7	Celotex	0°/11.5 in.
TCU8	Celotex	180°/11.5 in.
TCU9	Celotex	0°/7.4 in.
TCU10	Celotex	180°/7.4 in.
TCU11	Drum	0°/11.5 in.
TCU12	Drum	180°/11.5 in.
TCU13	Drum	0°/7.4 in.
TCU14	Drum	180°/7.4 in.
TCU15	Drum	Center of top
TCU16	Drum	Center of bottom

Figure 5-3. Thermocouple Locations: Test Unit

Figure 5-4. Thermocouple Attachment

TABLE 5-3

Thermocouple Locations: Shroud

<u>Designation</u>	<u>Angular Location</u>	<u>Height (in.)</u>
STC2	0°	6
STC3	90°	6
STC4	180°	6
STC5	270°	6
STC6	0°	12
STC7	0°	18
STC8*	0°	24
STC9*	90°	24
STC10*	180°	24
STC11*	270°	24
STC12	0°	30
STC14	0°	42
STC15	90°	42
STC17	270°	42
STC19	Center	46

* Thermocouple monitored for temperature control

Note: Designations in parentheses indicate thermocouples attached to the far side of the shroud.

Figure 5-5. Thermocouple Locations: Shroud

Figure 5-6. Data Acquisition System

6.0 NORMAL-CONDITIONS-OF-TRANSPORT TESTS

Two tests were performed on the structural test unit to evaluate the package under normal conditions of transport. The tests consisted of a water spray test and a 4-foot free-fall drop test, performed in series, as defined in 10 CFR 71.71. Both tests were conducted following the HS/RTG Normal Conditions Test Procedure (LANL-1).³

The first test performed was a water spray test, subjecting the test unit to a simulated rainfall of a minimum of 2 inches of rain per hour for a period of at least 1 hour. The second test performed was a 4-foot free-fall drop test of the unit onto a flat, essentially unyielding target. The drop test was required to be performed between 1.5 and 2.5 hours after the conclusion of the water spray test.

6.1 Test Unit Preparation

A new (previously untested) inner container body and lid were inspected before the test for baseline data using a written inspection procedure.¹² The payload assembly and inner container were assembled following the Instrumentation and Assembly Procedure.¹³ The V-clamp bolt was tightened to 100 inch-pounds.

Helium leak testing was performed on the assembly in accordance with a project-specific leak test procedure¹⁴ and ANSI N14.5.¹⁵ The leakage rate measured 2.0×10^{-10} atm cm³/sec. This small rate was a result of cavity background (outgassing). Appendix A contains a detailed description of the leak testing.

The inner container assembly was installed in a previously untested outer drum with new Celotex. Then the drum lid and lid locking ring were installed. The locking-ring bolt was torqued to 180 inch-pounds. One-inch-diameter disks of vinyl-covered adhesive tape were affixed over each of the four vent holes in the outer drum.

The weight of the assembled test unit was 69.5 pounds.

6.2 Test Setup: Water Spray Test

Figure 6-1 illustrates the water spray test configuration. This configuration conformed to IAEA advisory material¹¹ for water delivery, providing maximum wetting of the package. The test unit was suspended horizontally from a crane hook with a swivel feature, which permitted rotation of the package.

Figure 6-1. Water Spray Test Configuration

The spray nozzle was adjusted to deliver an even coverage in a 30-inch-diameter pattern at a distance of 10.5 feet. This pattern was sufficient to envelop the entire test unit. Water consumption was measured at 3 gallons per minute. This consumption equated to a delivery of 58 inches per hour in the area of the spray at the 10-foot distance. This was far in excess of the required 2 inches per hour, but necessary in order to meet the 10-foot distance recommendation.

6.3 Water Spray Test

The water spray nozzle was directed at the test unit using the nozzle adjustments made during test setup. The water was then turned on and the starting time recorded (Figure 6-2). During this test, the ambient air temperature was 40°F, with winds of 1 to 2 mph. After 15 minutes of spray, the test unit was spun clockwise 90 degrees, with the water spray continued. Two additional 90-degree clockwise rotations were made at 15- to 17-minute intervals. After spraying 15 minutes at the fourth position, the water was stopped. The total test time was 1 hour, 2 minutes, with each position being sprayed for a minimum of 15 minutes. The unit was then removed from the crane and immediately transported to the drop test facility.

6.4 Test Setup: 4-Foot Drop Test

For this test, the unit was installed in the cradle at an angle of 54 degrees with respect to horizontal. This aligned the center of gravity of the unit over the lid locking ring and the bolt lug (Figure 6-3). The cradle and test unit were raised so that the lowest point of the unit, the edge of the bolt lug, was 48-1/16 inches above the target surface.

6.5 4-Foot Drop Test

The 4-foot drop test is shown in Figure 6-4. The test unit impacted at a velocity of 16.0 feet per second and an angle of 58 degrees. Photographs A and B show the unit at decreasing heights above the target. Photograph D shows the unit just after impact. The unit rotated slightly during rebound (maximum height approximately 3 inches, Photograph E), but remained on the target, coming to rest on its lid. Environmental conditions at test time were 44°F and winds of approximately 3 mph.

6.6 Exterior Deformations

Damage to the outer drum is shown in Figures 6-5 and 6-6. The outer drum deformed in the area of impact, shortening the drum approximately 0.25 inch. All damage was limited to the side of the drum in the area of impact.

Figure 6-2. Water Spray Test

Figure 6-3. 4-Foot Drop Test Setup

A -50 ms

B -10 ms

C 0 ms

D 5 ms

E +100 ms

F +260 ms

Figure 6-4. 4-Foot Drop Test Sequence

Figure 6-5. Drum Deformations

Figure 6-6. Deformation Sketch

6.7 Disassembly

Before disassembly, the test unit was weighed. The posttest weight of 69.5 pounds indicated no measurable change from pretest weight. A complete disassembly was performed after the normal-conditions test series. Posttest torque on the locking-ring bolt was measured at 60 inch-pounds, a decrease of 120 inch-pounds from the assembly torque of 180 inch-pounds. The locking ring was easily removed. The edge of the lid was rolled under the drum lip in the impact area. This was removed by lifting the opposite (0-degree) side of the lid first and then rotating the lid up and over the impact (180-degree) side. The welds on the locking-ring bolt lugs were intact. The lid section of Celotex was tight in the drum because of inward deformations, but was removed intact. There was no indication of water inleakage; all Celotex was dry to the touch.

The inner container assembly was easily removed. The body section of Celotex was retained in the drum by the indentation at the 180-degree side.

After visual inspection and leak testing of the inner container, the inner container was disassembled. Posttest torque on the V-clamp bolt was measured at 95 inch-pounds, a decrease of 5 inch-pounds from the assembly torque.

Upon removal of the inner container lid, the payload was noted to have rotated approximately 5 degrees counterclockwise in the container. Posttest torques on the RTG mounting bolts were as follows:

<u>Bolt</u>	<u>Location</u>	<u>Approximate Disassembly Torque (inch-pounds)</u>	<u>Approximate Net Change in Torque (inch-pounds)</u>
B1	0° upper RTG	30	0
B2	180° upper RTG	30	0
B5	0° lower RTG	30	0
B6	180° lower RTG	25	-5

6.8 Results: Nondestructive Examination

6.8.1 Leak Test

A posttest leak test of the inner container seal showed no detectable leak above the existing background of the leak-test cavity (1.8×10^{-9} atm cm³/sec). Appendix A contains a discussion on leak-test cavity background.

6.8.2 Inspection

A posttest dimensional inspection was performed on the inner container body and lid. No dimensional changes were detected within the accuracy of the inspection process for the inner container lid. The only measured changes to the inner container body were approximately 0.1-degree angular changes to the flange at 0 degrees and to the container bottom at 90 degrees. Angular changes in the flange may be the result of forces exerted by the V-clamp during assembly rather than caused by the tests themselves. Changes up to 0.14° were seen at the bottom of the inner container body. These observed changes may be the result of residual stresses inherent in a spun structure, i.e. minor forces induced by the tests caused the item to relieve residual stress by moving. Complete inspection data and a discussion of accuracy are contained in Appendix B.

7.0 CENTER-OF-GRAVITY-OVER-CORNER DROP TEST

7.1 Test Unit Preparation

Before assembly, temperature labels (described in Section 5.0) were affixed to inner container and payload components. RTG bolts were installed and torqued to specified values. The bolt on the V-clamp was torqued to 100 inch-pounds.

Helium leak testing of the lid seal showed no detectable leak ($< 2 \times 10^{-10}$ atm cm³/sec, the minimum quantity measurable by the detector).

Thermocouples TCU1 through TCU6 (see Section 5.0) were attached to the inner container assembly and routed to exit the bottom of the drum (Figure 7-1). Orientation of the inner container aligned the V-clamp bolt at 180 degrees, the target impact location of the drum. The welded seam of the drum was oriented at the 180-degree impact side. Lengths of thermocouples exiting the bottom of the drum were coiled and attached to the drum bottom inside the bottom lip for protection during the test (Figure 7-2).

7.2 Test Setup

This test was set up and performed following the CG-Over-Corner Drop Test Procedure.⁴ The test unit was installed in the cradle at an angle of 57 degrees with the 180-degree side facedown. This aligned the center of gravity of the unit over the lid locking ring nearest the bolt lug (Figure 7-3). Figure 7-4 shows the cradle and sliding beam assembly raised to a drop height of 32 feet, 4-1/2 inches.

7.3 Drop Test Event

Figure 7-5 shows the drop test event. The test unit impacted at a velocity of 44.8 feet per second and an angle of 54 degrees. Photographs A and B show the unit at decreasing heights above the target. Photograph D shows the unit at its maximum crush position. Maximum rebound height was approximately 5 inches (Photograph F). The unit remained on the elevated target, coming to rest on its lid. The lack of rotation of the package after impact indicated that the center of gravity of the test unit was accurately aligned over the impacting corner.

Figure 7-1. Test Unit Assembly

Figure 7-2. Thermocouples Attached to Drum Bottom

Figure 7-3. Test Unit in Cradle

Figure 7-4. 30-Foot Drop Test Setup

Figure 7-6. Outer Drum Deformations

Figure 7-7. Drum Deformation Sketch

8.0 40-INCH PUNCTURE TEST

No assembly of the package was required for this test; the puncture test was performed in sequence after the 44-feet-per-second drop test. This test impacted the package onto a mild steel bar from a distance of 40 inches. The 6-inch-diameter, 8-inch-long spike conformed to 10 CFR 71.73 requirements. Package orientation directed the bar to attack the area of damage produced in the previous test.

8.1 Test Setup

This test was set up and performed following the 40 Inch Puncture Test Procedure⁵. An 8-inch-long spike on its integral base was welded to the unyielding target described in Section 4.1. The test unit was rigged to the adjustable cradle and set at 54 degrees from horizontal (Figure 8-1). This aligned the center of gravity of the package over the corner damaged in the previous drop test. The drop height was set at 40-5/8 inches from the top of the spike to the impact location of the locking ring.

8.2 Test Event

The test sequence is shown in Figure 8-2. Photographs A and B show the test unit at decreasing heights above the puncture bar. The test unit impacted the spike (Photo C) as intended, with the locking ring and lug impacting the center of the puncture bar. Maximum rebound measured approximately 6 inches (Photo E), during which time the package rotated counterclockwise to a near vertical orientation. The package (center of lid) reimpacted the bar (Photo F), rotated counterclockwise, and fell to the target surface.

8.3 Posttest Observations

Deformation caused by the spike is shown in Figure 8-3. Damage was limited to the immediate impact area, which showed approximately 0.05 to 0.10 inch of additional crush at the outer edge of the drum.

There was no apparent damage to the thermocouples attached to the bottom of the drum.

Neither a disassembly nor a leak test was performed after the puncture test. The test sequence proceeded with the thermal test on the package.

Figure 8-1. Puncture Test Setup

A -50 ms

B -10 ms

C 0 ms

D +5.0 ms

E +150 ms

F +315 ms

Figure 8-2. Puncture Test Sequence

Figure 8-3. Drum Deformation Sketch

9.0 THERMAL AND IMMERSION TESTS

Thermal and immersion tests were conducted as part of the regulatory sequence defined in 10 CFR 71. This code requires subjecting a damaged package to a 1475°F thermal environment with an emissivity of at least 0.9 for a minimum period of 30 minutes. This environment was produced by the SNL Radiant Heat Facility located in Technical Area III. A written procedure detailed performance of this test.⁶ The thermal test was followed by a 3-foot immersion test.

9.1 Test Unit Preparation

Because the thermal test was performed in sequence with the puncture test, the only preparation the test unit required was the installation of additional thermocouples.

The coiled lengths of the previously installed thermocouples (TCU1 through TCU6) were removed from the bottom of the drum. Thermocouples TCU7 through TCU16 were installed at the locations defined in Section 5.0. Four of these thermocouples (TCU7 through TCU10) were inserted into the Celotex insulation by drilling 1/16-inch-diameter holes in the drum and inserting the thermocouples to a depth of 2.5 inches (Figure 9-1). The remaining six thermocouples (TCU11 through TCU16) were attached to the exterior surfaces of the drum by spot welding.

Electrical resistance measurements were taken for each of the thermocouples to verify continuity and to check for potential damage.

The pretest weight of the unit was measured at 71 pounds (including all thermocouples).

9.2 Test Setup

The test unit was placed on a stand in the center of the circular array of quartz lamps described in Section 4.2 (Figures 9-2 and 9-3). The shroud and plates were then installed (Figure 9-4) and the array closed for testing (Figure 9-5).

Temperatures inside the shroud were monitored by the shroud thermocouples described in Section 5.2. Heat was controlled by a computer which monitored thermocouples STC8 through STC11, located around the center plane of the shroud.

Prior tests performed at this facility showed a temperature gradient inside the shroud, with the bottom being naturally lower than the top. To assure that the average environment met the 1475°F requirement, the target temperature was increased to 1500°F. Additionally, the test unit was

Figure 9-1. External Thermocouple Installation

Figure 9-2. Thermal Test Configuration

Figure 9-3. Test Unit in Array Before Shroud Installation

Figure 9-4. Shroud Installation

Figure 9-5. Array Ready for Test

oriented with the lid end facing up. This positioned the damaged area of the drum as well as the seal area of the inner container above the center plane of the shroud, assuring higher average temperatures. A minimum thermal emissivity of 0.9 was assured by painting all surfaces of the shrouds with Pyromark® high-emissivity coating.

Shroud and test unit thermocouples were calibrated prior to installation. Calibration of the facility data acquisition system was made before the test using a calibrated thermocouple simulator that provided known signals to each channel. All shroud and test unit thermocouples were then connected to the recording system for the test. Data from each channel was recorded at 5-second intervals for the 30-minute test. This scan rate was also used while internal temperature continued to rise. After all temperature readings had peaked, the scanning rate was changed to 2 minutes. This rate was maintained until all temperatures had decreased to 100°F.

9.3 Thermal Test

The thermal array was turned on and the control thermocouples monitored. The official starting time for the test was marked by all four of the control thermocouples reaching a minimum temperature of 1475°F, which occurred 3.5 minutes after the array was turned on. Shroud temperatures (around the center plane) overshoot the target temperature during the initial warm-up, but settled in on the target temperature within 5 minutes. Temperatures then remained between 1495 and 1500°F for the balance of the test. Thirty-one minutes after the official start time, the array was turned off. Twenty minutes after the end of the test, the top plate and cylindrical shroud were removed from around the test unit. No artificial cooling was applied to the unit.

After all test unit temperatures had decreased to approximately 100°F (18 hours after the start of test) the thermocouples were disconnected from the recording system and the unit removed from the array. The test unit was then transported to the Water Impact Facility for the immersion test. Thermocouples were not cut or detached from the unit at this time; they were coiled and tied to the unit to protect them for later evaluation.

Posttest weight of the package was measured at 68 pounds, a 3-pound decrease. Test unit thermal data and leak test results are presented in later sections.

9.4 Immersion Test

An immersion test was performed following the Immersion Test Procedure⁷, which requires a 36-inch head of water immersion for a period of 8 hours.

Figure 9-6 illustrates the test configuration. The package was positioned horizontally using two slings. This orientation allowed maximum inleakage of water through vents. To sink the buoyant package, a lead weight was suspended from the unit with two additional slings. The damaged, 180-degree side of the unit was oriented facedown. A tape measure was attached to the lid locking ring at the highest point (0 degrees).

The submersion time was recorded. During submersion, the rigging slings slid on the drum, causing the unit to tilt. With the lid (measurement) end of the unit tilted lower, the submersion depth was exaggerated. For this reason, the submersion depth was increased to 44 inches, 8 inches greater than regulation. Rough measurements to the bottom end of the drum showed the unit to be tilted approximately 4 inches along its length. The test unit remained in this orientation for a total time of 8 hours, 2 minutes before it was removed from the pool (Figure 9-7).

Posttest weight measurements indicated an increase of 32 pounds from the pre-immersion test weight.

9.5 Disassembly

Prior to disassembly, an extensive check was made of two thermocouples (TCU2 and TCU7) that did not correlate with other thermocouples at similar locations. Data from these thermocouples indicated possible false junctions. A false junction is a connection between the two wires inside a thermocouple sheath, which causes that new connection location to provide data. To locate suspected false junctions, heat was applied along the lengths of the thermocouples with a torch while outputs were monitored. No false junctions were located.

Disassembly started by removing the lid locking-ring bolt. Neither the bolt head nor nut were accessible for a torque measurement because of drum deformations. The nut was found to be finger tight (~5 inch-pounds), and was removed by hand. Although deformed, the lid locking ring was easily removed. The bolt lug and welds were intact. Two depressions were present in the drum wall under the bolt lugs.

The edge of the lid was rolled around the drum lid in the impact area. The lid was removed by lifting its 0-degree side first and rotating off (Figure 9-8).

The top surface of Celotex was charred and brittle. In order to remove the lid section of Celotex without destroying it, a cut was made through the section. The less-deformed piece (away from the impact side) was removed first (Figure 9-9). Removal of the remaining piece allowed access to the inner container lid.

Figure 9-7. Test Unit Removed from Pool

Figure 9-6. Immersion Test Configuration

Figure 9-8. Lid Removal

Figure 9-9. Celotex Removal

A visual inspection of the thermocouples mounted to the lid revealed that TCU2 had pulled loose from its strip of retaining wire and was not in contact with the lid surface (Figure 9-10). TCU1 was still attached to the lid surface, but a loop indicated inner container movement of approximately 1/2 inch.

To check the attachments of the other thermocouples, the inner container was removed without cutting or detaching the thermocouples. This was accomplished by cutting a 3-inch by 3-inch square in the drum bottom and in the Celotex around the thermocouple exit location. The 3-inch by 3-inch section was then free to slide through the drum bottom toward the cavity, allowing it to be removed with the inner container (Figure 9-11). Thermocouples TCU3, TCU5, and TCU6 were found to be attached to the component surfaces. The tip of TCU4 had pulled loose from its attachment strip, but appeared to have remained in contact with the container surface.

Upon removal, a coating of varnish- or resin-like material was noted on the exterior surfaces of the inner container at the lid end (Figure 9-12). This coating, presumed to be a by-product of the binding material of the Celotex, required an alcohol-based solvent for removal.

As a final evaluation, the outer drum and body section of Celotex was sectioned through the 0- to 180-degree plane. Celotex surfaces near the drum were charred (loose and brittle) to a depth of 0.1 inch. Depths of discolored Celotex varied with the area: approximately 1.5 inches on the sides, and 1.0 inch on the bottom (Figure 9-13). Discolored areas were thicker in the lid section of Celotex.

Discoloration thickness was greatest at the 0-degree side adjacent to the lid area of the inner container. This pattern was also evident when observing various Celotex layers prior to sectioning. These views showed the discolored thicknesses as bands. The width of the band was thickest at the 0-degree side. Figure 9-14 shows an inner surface of a layer separated from the body section of Celotex.

These patterns indicate that a gap, opposite the impact corner, existed between two layers of Celotex on this side. The impact crushed the Celotex at the 180-degree side. Because they were rigid, the Celotex layers tried to rotate rather than bend. Rotation was allowed by a preexisting gap of approximately 0.4 inch (the difference in heights of the Celotex versus the drum cavity). A similar gap between Celotex layers was noted after a CG-over-corner drop test on a HS/RTG structural test unit.¹⁶

Figure 9-10. Thermocouples TCU1 and TCU3

Figure 9-11. Posttest Disassembly

Figure 9-12. Resin-like Substance on Exterior of Inner Container

Figure 9-13. Cross Section of Celotex Insulation

Figure 9-14. Discoloration Pattern in Celotex

After leak testing (for results, see Section 9.6), the inner container was disassembled. The posttest torque on the V-clamp bolt was measured at 80 inch-pounds, a decrease of 20 inch-pounds from the assembly torque. Upon removal of the lid, the resinlike substance was noted on the outer edges of both the body and lid flange (Figure 9-15). This substance was also found on the outside diameter of the outer O-ring groove and outer edge of the O-ring itself (Figure 9-16).

The payload assembly had rotated clockwise in the body 2 degrees. No discolorations or residue were observed on the payload assembly. Posttest torques on the RTG mounting bolts were as follows:

<u>Bolt</u>	<u>Location</u>	<u>Approximate Disassembly Torque (inch-pounds)</u>	<u>Approximate Net Change in Torque (inch-pounds)</u>
B1	0° upper RTG	20	-10
B2	180° upper RTG	20	-10
B5	0° lower RTG	25	-5
B6	180° lower RTG	20	-10

9.6 Test Results

9.6.1 Thermal Environment

Data were recorded at the 5-second rate for approximately 1-1/2 hours after the end of the test. At this point, all thermocouples had peaked and had started to decline.

Temperatures were measured by the control thermocouples located around the center plane of the shroud, as shown in Figure 9-17. As mentioned earlier, this area was very stable. Variations in temperatures at other locations in the shroud are illustrated in Figure 9-18. Temperatures indicated at the various heights are average temperatures at that plane over the duration of the test. Data from shroud thermocouples, which mapped the environment, are shown in Figures 9-19 through 9-21. Refer to Figure 5-5 for shroud thermocouple locations.

9.6.2 Test Unit Thermal Response: Thermocouples

Outer drum temperatures are shown in Figure 9-22 (drum sides) and Figure 9-23 (top and bottom). Thermocouples TCU11 and TCU12, located on the sides near the top, showed temperatures 40 to 50°F higher than TCU13 and TCU14 near the bottom of the drum. This correlated well with the variation in shroud temperatures versus height discussed in Section 9.6.1.

Figure 9-15. Body Seal Area

Figure 9-16. Lid Seal Area

Figure 9-17. Shroud Thermocouples STC8 Through STC11

Figure 9-18. Variations in Shroud Temperatures

Figure 9-19. Shroud Thermocouples STC2 Through STC5

Figure 9-20. Shroud Thermocouples STC14 Through STC17

Figure 9-21. Shroud Thermocouples STC6, STC7, STC12, and STC19

Figure 9-22. Test Unit Thermocouples TCU11 Through TCU14

Figure 9-23. Test Unit Thermocouples TCU15 and TCU16

Drum lid temperature (TCU15) leveled off at 1410°F 10 minutes into the test. The drum bottom (TCU16) was the coolest area, reaching only 1080°F by the end of the test. All exterior temperature readings dropped rapidly after the end of the test, cooling to 150°F within 1 hour of the test.

Thermocouples TCU7 through TCU10 provided temperatures at midthickness locations of the Celotex (Figure 9-24). These TCs provided data for LANL to verify heat transfer coefficients of the Celotex material. Thermocouples TCU8 through TCU10 reached peaks between 430 and 540°F approximately 52 minutes after the start of test. Again, the thermocouple located higher in the drum (TCU8) read higher than the lower ones. Cool-down data for this group of thermocouples are shown in Figure 9-25.

There was no correlation of the data from TCU7 with the other Celotex thermocouples. This channel showed rapid warming, which started immediately after initial heat input, peaking at 1000°F. Temperatures then decreased rapidly after the array was turned off, behaving much like a thermocouple on or near an exterior surface. Because of this behavior, a false junction in the thermocouple was first suspected. As noted in Section 9.5, no false junctions were found during specific checks for that problem. The high values are considered accurate and are attributed to high temperatures caused by the gap noted between the layers of Celotex.

Inner container temperatures were measured by six thermocouples: TCU1 through TCU4 near the lid end, and TCU5 and TCU6 near the bottom. Three of the four thermocouples on the lid end correlated well (Figure 9-26). Data from TCU2 correlated poorly and was checked for false junctions as discussed in Section 9.5. No false junctions were identified, but this was the thermocouple found detached from the surface of the inner container lid. It is believed that although this thermocouple operated properly, it measured air temperature near the inner container rather than the container surface.

Temperatures recorded by TCU5 and TCU6 near the bottom of the inner container were consistent with each other (Figure 9-27). These data showed an initial peak approximately 65 minutes after the start of the test, a decline, and then a second peak, of 210 °F, 4 hours after the start of the test. These second peaks are attributed to thermal conduction from the warmer lid end of the inner container. The second peaks and subsequent cool-down area are shown in Figure 9-28. Cool-down data from TCU3 and TCU4 are included for comparison.

Figure 9-24. Test Unit Thermocouples TCU7 Through TCU10

Figure 9-25. Cool-Down: Thermocouples TCU7 Through TCU10

Figure 9-26. Test Unit Thermocouples TCU1 Through TCU4

Figure 9-27. Test Unit Thermocouples TCU5 and TCU6

Figure 9-28. Cool-Down: Thermocouples TCU3 Through TCU6

9.6.3 Test Unit Thermal Response: Temperature Labels

Data obtained from the temperature labels is listed in Table 9-1. Each reading consists of two numbers. The upper number is a definitive temperature reached, as indicated by a blackened sensor. The bottom value is a temperature that was not reached, as indicated by a conclusive light-colored sensor. For most label locations, the two values are consecutive sensor locations on the label; i.e., 220/240, defining a small temperature range at that location. Other label locations were inconclusive as to a small temperature range. These labels displayed a particular sensor that was blackened and a definite nonblackened sensor that was two or more sensor locations higher, leading to a wide range of possible temperatures at that location. Physical damage to labels caused by contact with the Celotex during testing was the main cause of the inability to read several individual sensors.

Three of the four labels (TL1, TL2, and TL4) around the lid end of the inner container read >220 and <240. This reading was slightly below the average peak temperature of 260°F read by TCU1, TCU2, and TCU4. The fourth lid-end label (TL3), because of physical damage, indicated an inconclusive reading between 180 and 280°F. The label on top of the lid was unreadable because of an accumulation of resinlike material.

All of the labels (TL5 through TL8, and TL10) at the bottom end indicated a minimum temperature of 200°F. Upper-end temperatures varied from 220°F to 300°F because of damaged labels. These numbers correlate with thermocouple data that showed peaks of 210°F.

Labels attached to internal components were free from any damage and were more conclusive. Temperatures between 220°F and 240°F were recorded on all of the labels located near the lid end. Near the bottom end, all labels showed a temperature between 200°F and 220°F.

9.7 Results: Nondestructive Evaluation

9.7.1 Leak Test

Before disassembly of the inner container, helium leak testing was performed on the container seal. Measurements from this test demonstrated no detectable leak above the test cavity background (2.2×10^{-8} atm cm³/sec). This background was significantly higher than previous measurements, which may be because of outgassing of the seal material caused by the elevated temperatures during the thermal test. Vacuum pumping on the test cavity was continued for approximately 24 hours in an attempt to remove the excessive background. The unit was

TABLE 9-1

Temperature Label Readings

<u>Designation</u>	<u>Component</u>	<u>Location</u>	<u>Temperature (°F)</u>
TL1	Body	0°/top	>220 / <240
TL2	Body	90°/top	>220 / <240
TL3	Body	180°/top	>180 / <280
TL4	Body	270°/top	>220 / <240
TL5	Body	0°/bottom	>200 / <300
TL6	Body	90°/bottom	>200 / <260
TL7	Body	180°/bottom	>200 / <240
TL8	Body	270°/bottom	>200 / <220
TL9	Lid	Center/top	Unreadable
TL10	Body	Center/bottom	>200 / <220
TL11	Payload	0°/top	>220 / <240
TL12	Payload	180°/top	>220 / <240
TL13	Payload	0°/bottom	>200 / <220
TL14	Payload	180°/bottom	>200 / <220
TL15	RTG	0°/top	>220 / <240
TL16	RTG	180°/top	>220 / <240
TL17	RTG	0°/bottom	>200 / <220
TL18	RTG	180°/bottom	>200 / <220

then retested, the results showing no detectable leak above an improved background of 1.6×10^{-9} atm cm³/sec. Appendix A contains a detailed description of leak testing performed and a discussion on leak-test cavity background.

9.7.2 Dimensional Inspection

A posttest dimensional inspection was performed on the inner container body and lid after leak testing and subsequent disassembly. No dimensional changes were detected within the accuracy of the inspection process for the inner container lid. A small change was noted in the body flange at 0°. This change was in the opposite direction as seen after the normal conditions drop test. These changes are believed to be caused by clamping forces induced by the V-clamp during assembly.

A change of 0.16° was measured at the inner container bottom near 90°. This change may be the result of residual stresses inherent in a spun structure, i.e. minor forces induced by the tests caused the item to relieve residual stress by moving. Changes were smaller than those seen after the 4 foot normal conditions drop test even though this was a more severe test. Appendix B contains complete inspection data and a discussion of its accuracy.

10.0 SUMMARY

The inner container assembly met the primary design criteria of no leakage rate greater than 1.0×10^{-7} atm cm^3/sec following the regulatory test sequence. Leakage rate measurements were conducted a total of three times during the test series.

The inner container body and lid received no damage as a result of the tests. Slight dimensional changes were noted on the body flange and angled bottom. Angular changes in the flange appeared to be a flexing of the flange resulting from forces exerted by the V-clamp during assembly rather than caused by the tests themselves. Changes up to 0.15° were observed at the bottom of the inner container body. These changes may be the result of residual stresses inherent in a spun structure, i.e. minor forces induced by the tests caused the item to relieve residual stress by moving. This is indicated by the fact less changes were observed after the 30 foot drop test (test #2) than after the 4 foot drop test (test #1) even though the 30 foot test was more severe. There were no measurable changes to the inner container lid.

The outer drum satisfactorily performed its function of containing and protecting the Celotex insulation. There were no tears or cracked welds which would expose the insulation in a fire scenario. The drum deformed at the immediate impact location, cushioning the inner container assembly; however, these deformations were not excessive in that they did not significantly decrease the thickness of insulation at any location around the inner container. The change in insulation thickness after the test series was a decrease of approximately 0.5 inch from the original 3.5 inches in an angular direction of impact.

The tests did result in a gap between Celotex layers that provided a heat path to the inner container. This gap resulted in higher than expected temperatures at the lid end of the inner container during the thermal test. Maximum temperatures at the lid were 270°F , versus 190°F near the bottom end. Although the inner container seals were still leak tight after the test, temperatures would be reduced by eliminating the posttest gap at the seal area. This gap could be reduced or eliminated by more closely matching the total Celotex height to the interior cavity height of the outer drum. Additional thermal protection could be provided for the lid end of the inner container by moving the inner container assembly lower (toward the drum bottom) in the Celotex by $1/2$ to 1 inch.

REFERENCES

1. "Packaging and Transportation of Radioactive Material," Code of Federal Regulations, Title 10, Part 71, Nuclear Regulatory Commission, Washington D.C., 1989.
2. "Test Specification: HS/RTG Shipping Container," Hazpact-HS/RTG-03, Los Alamos National Laboratory, Los Alamos, NM, November 1989.
3. "Normal Conditions Test Procedure: HS/RTG Shipping Container," LANL-1, Sandia National Laboratories, Albuquerque, NM, 1990.
4. "CG Over Corner Drop Test Procedure: HS/RTG Shipping Container," LANL-C2, Sandia National Laboratories, Albuquerque, NM, 1990.
5. "40 Inch Puncture Test Procedure: HS/RTG Shipping Container," LANL-C5, Sandia National Laboratories, Albuquerque, NM, 1990.
6. "Thermal Test Procedure: HS/RTG Shipping Container," LANL-6, Sandia National Laboratories, Albuquerque, NM, 1990.
7. "Immersion Test Procedure: HS/RTG Shipping Container," LANL-7, Sandia National Laboratories, Albuquerque, NM, 1990.
8. "Transportation Systems Development Quality Assurance Program Plan," Department 6320, Sandia National Laboratories, Albuquerque, NM, 1988.
9. "Test Program Plan: HS/RTG Shipping Container," LANL-TPP, Sandia National Laboratories, Albuquerque, NM, 1990.
10. "Quality Assurance Program Plan: HS/RTG Shipping Container," LANL-QAPP, Sandia National Laboratories, Albuquerque, NM, 1990.
11. "Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material," Safety Series No. 37, International Atomic Energy Agency, Vienna, Austria, 1985.
14. "Inspection Procedure: HS/RTG Shipping Container," LANL-10, Sandia National Laboratories, Albuquerque, NM, 1990.
13. "Instrumentation and Assembly Procedure: HS/RTG Shipping Container," LANL-8, Sandia National Laboratories, Albuquerque, NM, 1990.

REFERENCES
(Concluded)

14. "Leak Test Procedure: HS/RTG Shipping Container," LANL-9, Sandia National Laboratories, Albuquerque, NM, 1990.
15. "American National Standards for Radioactive Materials Leakage Tests on Packages for Shipment," Standard N14.5, American National Standards Institute, New York, NY, January 16, 1987.
16. "Structural Testing of the Los Alamos National Laboratory Heat Source/Radioisotopic Thermoelectric Generator Shipping Container," D. Bronowski and M. Madsen, SAND 91-0244, Sandia National Laboratories, Albuquerque, NM, 1991.

APPENDIX A

LEAK TESTING

Leak testing is a form of nondestructive evaluation used for detecting and measuring leaks in a pressurized or evacuated system. The method of leak testing used for the evaluation of the HS/RTG inner container seal was a mass-spectrometer envelope technique using helium as a tracer gas. The leak tests were performed following ANSI N14.5 guidelines¹⁵ and a project-specific procedure.¹⁴

Inner container and leak test configurations are shown in Figures A-1 and A-2. The mass spectrometer leak detector was connected to a test cavity formed by two concentric O-rings. The payload cavity was evacuated and backfilled with helium tracer gas. The leak detector measured the amount of tracer gas leaking across the inner O-ring. (The function of the outer O-ring is to form the test cavity. The O-ring is not itself tested in this configuration.)

The maximum allowable leakage rate for the container was 1.0×10^{-7} atm cm³/sec. In accordance with ANSI N14.5, the minimum sensitivity of the detector was established as 5.0×10^{-8} . Leak test sensitivity refers to how small a physical leak can be detected. The mass spectrometer leak detector used is capable of detecting a leak of 2.0×10^{-10} atm cm³/sec. Actual test sensitivity was dependent on cavity background, which varied somewhat from test to test. High backgrounds, resulting from both outgassing and permeation, decreased sensitivity to the 10^{-9} range for several tests.

The majority of higher backgrounds were the result of permeation and subsequent release of helium from the O-rings. Helium, because of its small molecular size, readily permeates Viton seal material. Helium also requires a significant period of time to diffuse from the seal, leading to a high background for any tests performed in rapid succession; i.e., on a daily basis. A graph illustrating helium permeation is shown in Figure A-3.

The leak detector was calibrated using a leak standard in the 10^{-8} cm³/sec range before and after each test, assuring the required detector sensitivity and establishing the scale for quantitative measurements.

The payload cavity was evacuated to 0.01 atm and backfilled to 1 atm with high-purity helium, assuring a high (near 100 percent) concentration of tracer gas. Each leak test was monitored for a minimum of 3 minutes; sufficient time to ensure detector response. Helium was then removed to avoid severe permeation of the O-rings.

Each leak test was repeated as an assurance measure immediately following a posttest calibration check of the initial leak test. Helium permeation was evident during each of the repeated tests.

Figure A-1. Leak Test Configuration

Figure A-2. Leak Test Setup

Figure A-3. Helium Permeation of Container O-Rings

The background reading after the regulatory series was high because of the elevated temperature of the seals during the thermal test. As the temperature of seal material rose, various gases in the material were released (outgas). These gases elevated the background reading of the leak detector, decreasing the minimum detectable leakage rate.

APPENDIX B

DIMENSIONAL INSPECTION

Dimensional inspections were performed on the inner container lid and body components before, during, and after the test sequence. These inspections were made to detect any dimensional changes as a result of the tests.

Inspection points used for all inspections are shown in Figure B-1 for the inner container body and Figure B-2 for the lid. All inspections were performed by Sandia National Laboratories Mechanical Measurements Department 7485 using calibrated equipment. All inspection data and calculated changes are presented on a test-by-test basis in Tables B-1 through B-6.

The measuring equipment employed could accurately reproduce measurements within 0.0005 inch. Overall inspection accuracy is dependent on this equipment as well as the repeatability of the inspection setup. The lid setup was easily repeated with a high degree of accuracy. Overall inspection accuracies for lid dimensions are ± 0.001 inch for linear dimensions and 0.015 degrees for angular dimensions.

Accuracies relating to inner container body measurements varied with the location of the measurement. The setup from which radial measurements were made is shown in Figure B-3. The open end of the body was used as the datum as well as a mounting surface. Measurements in this immediate area (R5 and R6 inspection points) were quite accurate, typically ± 0.001 inch. However, this surface was not perfectly square with the centerline, requiring the use of shims at various locations. A small change in shim thickness made a larger change in a radial measurement at the far, closed end. For example, a 0.001 inch shim under the flange affects radial measurements at the far end by over 0.002 inch as a result of geometry. Difficulty in reproducing this setup was magnified by slight angular movements of the flange. Centerline offsets at the far end were generally 0.002 to 0.003 inch. Because these offsets were in random directions, the errors were additive in many cases, making the total inaccuracy 0.004 to 0.006 inch at the far end of the body. Inspection accuracies for other inner container body locations are as follows: length measurements to ± 0.001 inch and angular measurements to $\pm 0.020^\circ$.

INSPECT POINT	MEASURE TYPE	LOCATION OF MEASUREMENT			INSPECT POINT	MEASURE TYPE	LOCATION OF MEASUREMENT		
		LENGTH	REF	ANGLE			LENGTH	REF	ANGLE
1	RADIUS	R1	2.04	0°	25	RADIUS	R4	2.04	0°
2	RADIUS	R1	2.04	45°	26	RADIUS	R4	2.04	45°
3	RADIUS	R1	2.04	90°	27	RADIUS	R4	2.04	90°
4	RADIUS	R1	2.04	135°	28	RADIUS	R4	2.04	135°
5	RADIUS	R1	2.04	180°	29	RADIUS	R4	2.04	180°
6	RADIUS	R1	2.04	225°	30	RADIUS	R4	2.04	225°
7	RADIUS	R1	2.04	270°	31	RADIUS	R4	2.04	270°
8	RADIUS	R1	2.04	315°	32	RADIUS	R4	2.04	315°
9	RADIUS	R2	2.04	0°	33	RADIUS	R5	2.07	0°
10	RADIUS	R2	2.04	45°	34	RADIUS	R5	2.07	45°
11	RADIUS	R2	2.04	90°	35	RADIUS	R5	2.07	90°
12	RADIUS	R2	2.04	135°	36	RADIUS	R5	2.07	135°
13	RADIUS	R2	2.04	180°	37	RADIUS	R5	2.07	180°
14	RADIUS	R2	2.04	225°	38	RADIUS	R5	2.07	225°
15	RADIUS	R2	2.04	270°	39	RADIUS	R5	2.07	270°
16	RADIUS	R2	2.04	315°	40	RADIUS	R5	2.07	315°
17	RADIUS	R3	2.04	0°	41	RADIUS	R6	2.61	0°
18	RADIUS	R3	2.04	45°	42	RADIUS	R6	2.61	45°
19	RADIUS	R3	2.04	90°	43	RADIUS	R6	2.61	90°
20	RADIUS	R3	2.04	135°	44	RADIUS	R6	2.61	135°
21	RADIUS	R3	2.04	180°	45	RADIUS	R6	2.61	180°
22	RADIUS	R3	2.04	225°	46	RADIUS	R6	2.61	225°
23	RADIUS	R3	2.04	270°	47	RADIUS	R6	2.61	270°
24	RADIUS	R3	2.04	315°	48	RADIUS	R6	2.61	315°

INSPECT POINT	MEASURE TYPE	LOCATION OF MEASUREMENT			INSPECT POINT	MEASURE TYPE	LOCATION OF MEASUREMENT		
		LENGTH	REF	ANGLE			LENGTH	REF	ANGLE
49	LENGTH	L1	11.87	0°	57	LENGTH	L1	11.87	0°
50	LENGTH	L1	11.87	45°	58	LENGTH	L1	11.87	45°
51	LENGTH	L1	11.87	90°	59	LENGTH	L1	11.87	90°
52	LENGTH	L1	11.87	135°	60	LENGTH	L1	11.87	135°
53	LENGTH	L1	11.87	180°	61	LENGTH	L1	11.87	180°
54	LENGTH	L1	11.87	225°	62	LENGTH	L1	11.87	225°
55	LENGTH	L1	11.87	270°	63	LENGTH	L1	11.87	270°
56	LENGTH	L1	11.87	315°	64	LENGTH	L1	11.87	315°
57	ANGULAR	A1	70°	0°	65	ANGULAR	A1	70°	0°
58	ANGULAR	A1	70°	45°	66	ANGULAR	A1	70°	45°
59	ANGULAR	A1	70°	90°	67	ANGULAR	A1	70°	90°
60	ANGULAR	A1	70°	135°	68	ANGULAR	A1	70°	135°
61	ANGULAR	A1	70°	180°	69	ANGULAR	A1	70°	180°
62	ANGULAR	A1	70°	225°	70	ANGULAR	A1	70°	225°
63	ANGULAR	A1	70°	270°	71	ANGULAR	A1	70°	270°
64	ANGULAR	A1	70°	315°	72	ANGULAR	A1	70°	315°

Figure B-1. Inspection Points: Body

INSPECT POINT	MEASURE TYPE	LOCATION OF MEASUREMENT		
		LENGTH	REF DIM	REF ANGLE
1	RADIUS	R1	2.61	0°
2	RADIUS	R1	2.61	45°
3	RADIUS	R1	2.61	90°
4	RADIUS	R1	2.61	135°
5	RADIUS	R1	2.61	180°
6	RADIUS	R1	2.61	225°
7	RADIUS	R1	2.61	270°
8	RADIUS	R1	2.61	315°
9	ANGLE	A1	20°	0°
10	ANGLE	A1	20°	45°
11	ANGLE	A1	20°	90°
12	ANGLE	A1	20°	135°
13	ANGLE	A1	20°	180°
14	ANGLE	A1	20°	225°
15	ANGLE	A1	20°	270°
16	ANGLE	A1	20°	315°
17	LENGTH	L1	1.25	0°
18	LENGTH	L1	1.25	45°
19	LENGTH	L1	1.25	90°
20	LENGTH	L1	1.25	135°
21	LENGTH	L1	1.25	180°
22	LENGTH	L1	1.25	225°
23	LENGTH	L1	1.25	270°
24	LENGTH	L1	1.25	315°
25	LENGTH	L2	1.25	0°
26	LENGTH	L2	1.25	90°
27	LENGTH	L2	1.25	180°
28	LENGTH	L2	1.25	270°

Figure B-2. Inspection Points: Lid

TABLE B-1

Normal-Conditions Tests: Body

Radial Measurements							
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R1-000	2.034	2.035	0.001	R2-000	2.041	2.042	0.001
R1-045	2.036	2.039	0.003	R2-045	2.041	2.043	0.002
R1-090	2.041	2.045	0.004	R2-090	2.043	2.046	0.003
R1-135	2.048	2.051	0.003	R2-135	2.044	2.048	0.004
R1-180	2.048	2.053	0.005	R2-180	2.044	2.049	0.005
R1-225	2.045	2.050	0.005	R2-225	2.042	2.046	0.004
R1-270	2.040	2.043	0.003	R2-270	2.041	2.043	0.002
R1-315	2.036	2.038	0.002	R2-315	2.040	2.042	0.002
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R3-000	2.044	2.045	0.001	R4-000	2.049	2.049	0.000
R3-045	2.043	2.045	0.002	R4-045	2.047	2.048	0.001
R3-090	2.044	2.046	0.002	R4-090	2.044	2.046	0.002
R3-135	2.043	2.047	0.004	R4-135	2.043	2.045	0.002
R3-180	2.042	2.047	0.005	R4-180	2.042	2.046	0.004
R3-225	2.042	2.046	0.004	R4-225	2.043	2.046	0.003
R3-270	2.043	2.045	0.002	R4-270	2.045	2.047	0.002
R3-315	2.043	2.044	0.001	R4-315	2.049	2.048	-0.001
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R5-000	2.075	2.078	0.003	R6-000	2.609	2.609	0.000
R5-045	2.075	2.077	0.002	R6-045	2.609	2.609	0.000
R5-090	2.071	2.073	0.002	R6-090	2.608	2.609	0.001
R5-135	2.067	2.071	0.004	R6-135	2.607	2.609	0.002
R5-180	2.067	2.070	0.003	R6-180	2.606	2.609	0.003
R5-225	2.071	2.073	0.002	R6-225	2.605	2.608	0.003
R5-270	2.073	2.076	0.003	R6-270	2.606	2.608	0.002
R5-315	2.075	2.077	0.002	R6-315	2.608	2.608	0.000
Angular Measurements							
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
A1-000	69.954	69.816	-0.138	A2-000	3.625	3.593	-0.032
A1-045	70.005	69.979	-0.026	A2-045	3.576	3.574	-0.002
A1-090	69.905	70.896	-0.009	A2-090	3.729	3.584	-0.145
A1-135	69.999	70.018	0.019	A2-135	3.855	3.759	-0.096
A1-180	70.016	70.014	0.002	A2-180	3.945	3.890	-0.055
A1-225	69.912	69.892	-0.020	A2-225	3.979	3.901	-0.078
A1-270	69.997	69.994	-0.003	A2-270	3.894	3.859	-0.035
A1-315	69.871	69.817	-0.054	A2-315	3.663	3.666	0.003

TABLE B-1
(Concluded)

Length Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
L1-000	11.880	11.881	0.001
L1-045	11.877	11.878	0.001
L1-090	11.875	11.875	0.000
L1-135	11.872	11.871	-0.001
L1-180	11.872	11.870	-0.002
L1-225	11.875	11.874	-0.001
L1-270	11.877	11.877	0.000
L1-315	11.880	11.881	0.001

TABLE B-2

Normal-Conditions Tests: Lid

Radial Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R1-000	2.609	2.610	0.001
R1-045	2.609	2.610	0.001
R1-090	2.609	2.610	0.001
R1-135	2.609	2.611	0.002
R1-180	2.609	2.611	0.002
R1-225	2.609	2.611	0.002
R1-270	2.609	2.611	0.002
R1-315	2.609	2.611	0.002

Angular Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
A1-000	19.902	19.914	0.012
A1-045	19.895	19.892	-0.003
A1-090	19.962	19.954	-0.008
A1-135	19.963	19.956	-0.007
A1-180	19.936	19.942	0.006
A1-225	19.950	19.952	0.002
A1-270	19.869	19.877	0.008
A1-315	19.869	19.881	0.012

Length Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
L1-000	1.245	1.247	0.002	L2-000	1.244	1.244	0.000
L1-045	1.248	1.248	0.002	L2-045	1.246	1.246	0.000
L1-090	1.248	1.248	0.002	L2-090	1.246	1.246	0.000
L1-135	1.248	1.248	0.002	L2-135	1.246	1.246	0.000
L1-180	1.248	1.248	0.001	L2-180	1.246	1.246	0.000
L1-225	1.248	1.248	0.000	L2-225	1.246	1.245	-0.001
L1-270	1.247	1.247	0.000	L2-270	1.244	1.244	0.000
L1-315	1.244	1.245	0.001	L2-315	1.242	1.242	0.000

TABLE B-3

Regulatory Series Tests: Body

Radial Measurements							
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R1-000	2.035	2.039	0.004	R2-000	2.042	2.044	0.002
R1-045	2.039	2.037	-0.002	R2-045	2.043	2.042	-0.001
R1-090	2.045	2.039	-0.006	R2-090	2.046	2.042	-0.004
R1-135	2.051	2.045	-0.006	R2-135	2.048	2.044	-0.004
R1-180	2.053	2.048	-0.005	R2-180	2.049	2.045	-0.004
R1-225	2.050	2.048	-0.002	R2-225	2.046	2.047	0.001
R1-270	2.043	2.048	0.005	R2-270	2.043	2.047	0.004
R1-315	2.038	2.044	0.006	R2-315	2.042	2.046	0.004
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R3-000	2.045	2.046	0.001	R4-000	2.049	2.050	0.001
R3-045	2.045	2.044	-0.001	R4-045	2.048	2.047	-0.001
R3-090	2.046	2.043	-0.003	R4-090	2.046	2.045	-0.001
R3-135	2.047	2.044	-0.003	R4-135	2.045	2.044	-0.001
R3-180	2.047	2.045	-0.002	R4-180	2.046	2.044	-0.002
R3-225	2.046	2.047	0.001	R4-225	2.046	2.047	0.001
R3-270	2.045	2.048	0.003	R4-270	2.047	2.049	0.002
R3-315	2.044	2.048	0.004	R4-315	2.048	2.051	0.003
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R5-000	2.078	2.075	-0.003	R6-000	2.609	2.609	0.000
R5-045	2.077	2.075	-0.002	R6-045	2.609	2.608	-0.001
R5-090	2.073	2.071	-0.002	R6-090	2.609	2.607	-0.002
R5-135	2.071	2.069	-0.002	R6-135	2.609	2.608	-0.001
R5-180	2.070	2.069	-0.001	R6-180	2.609	2.609	0.000
R5-225	2.073	2.073	0.000	R6-225	2.608	2.607	-0.001
R5-270	2.076	2.077	0.001	R6-270	2.608	2.609	0.001
R5-315	2.077	2.079	0.002	R6-315	2.608	2.609	0.001
Angular Measurements							
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
A1-000	69.816	69.875	0.059	A2-000	3.593	3.585	-0.008
A1-045	69.979	69.957	-0.022	A2-045	3.574	3.578	0.004
A1-090	69.896	69.891	-0.005	A2-090	3.584	3.565	-0.019
A1-135	70.018	70.005	-0.013	A2-135	3.759	3.782	0.023
A1-180	70.014	69.997	-0.017	A2-180	3.890	3.867	-0.023
A1-225	69.892	69.895	0.003	A2-225	3.901	3.902	0.001
A1-270	69.994	69.984	-0.010	A2-270	3.859	3.855	-0.004
A1-315	69.817	69.831	0.014	A2-315	3.666	3.530	-0.136

Table B-3
(Concluded)

Length Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
L1-000	11.881	11.880	-0.001
L1-045	11.878	11.878	0.000
L1-090	11.875	11.875	0.000
L1-135	11.871	11.872	0.001
L1-180	11.870	11.872	0.002
L1-225	11.874	11.875	0.001
L1-270	11.877	11.877	0.000
L1-315	11.881	11.880	-0.001

TABLE B-4

Regulatory Series Tests: Lid

Radial Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R1-000	2.610	2.609	-0.001
R1-045	2.610	2.609	-0.001
R1-090	2.610	2.609	-0.001
R1-135	2.611	2.609	-0.002
R1-180	2.611	2.609	-0.002
R1-225	2.611	2.609	-0.002
R1-270	2.611	2.609	-0.002
R1-315	2.611	2.609	-0.002

Angular Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
A1-000	19.914	19.911	-0.003
A1-045	19.892	19.886	-0.006
A1-090	19.954	19.914	-0.005
A1-135	19.956	19.953	-0.003
A1-180	19.942	19.939	-0.003
A1-225	19.952	19.955	0.003
A1-270	19.877	19.876	-0.001
A1-315	19.881	19.882	0.001

Length Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
L1-000	1.247	1.247	0.000	L2-000	1.244	1.244	0.000
L1-045	1.248	1.248	0.000	L2-045	1.246	1.246	0.000
L1-090	1.248	1.248	0.000	L2-090	1.246	1.246	0.000
L1-135	1.248	1.248	0.000	L2-135	1.246	1.246	0.000
L1-180	1.248	1.248	0.000	L2-180	1.246	1.246	0.000
L1-225	1.248	1.248	0.000	L2-225	1.245	1.245	0.000
L1-270	1.247	1.247	0.000	L2-270	1.244	1.244	0.000
L1-315	1.245	1.246	0.001	L2-315	1.242	1.242	0.000

TABLE B-5

All Tests: Body

Radial Measurements							
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R1-000	2.034	2.039	0.005	R2-000	2.041	2.044	0.003
R1-045	2.036	2.037	0.001	R2-045	2.041	2.042	0.001
R1-090	2.041	2.039	-0.002	R2-090	2.043	2.042	-0.001
R1-135	2.048	2.045	-0.003	R2-135	2.044	2.044	0.000
R1-180	2.048	2.048	0.000	R2-180	2.044	2.045	0.001
R1-225	2.045	2.048	0.003	R2-225	2.042	2.047	0.005
R1-270	2.040	2.048	0.008	R2-270	2.041	2.047	0.006
R1-315	2.036	2.044	0.008	R2-315	2.040	2.046	0.006
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R3-000	2.044	2.046	0.002	R4-000	2.049	2.050	0.001
R3-045	2.043	2.044	0.001	R4-045	2.047	2.047	0.000
R3-090	2.044	2.043	-0.001	R4-090	2.044	2.045	0.001
R3-135	2.043	2.044	0.001	R4-135	2.043	2.044	0.001
R3-180	2.042	2.045	0.003	R4-180	2.042	2.044	0.002
R3-225	2.042	2.047	0.005	R4-225	2.043	2.047	0.004
R3-270	2.043	2.048	0.005	R4-270	2.045	2.049	0.004
R3-315	2.043	2.048	0.005	R4-315	2.049	2.051	0.002
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R5-000	2.075	2.075	0.000	R6-000	2.609	2.609	0.000
R5-045	2.075	2.075	0.000	R6-045	2.609	2.608	-0.001
R5-090	2.071	2.071	0.000	R6-090	2.608	2.607	-0.001
R5-135	2.067	2.069	0.002	R6-135	2.607	2.608	0.001
R5-180	2.067	2.069	0.002	R6-180	2.606	2.609	0.003
R5-225	2.071	2.073	0.002	R6-225	2.605	2.607	0.002
R5-270	2.073	2.077	0.004	R6-270	2.606	2.609	0.003
R5-315	2.075	2.079	0.004	R6-315	2.608	2.609	0.001
Angular Measurements							
<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
A1-000	69.954	69.875	-0.079	A2-000	3.625	3.585	-0.040
A1-045	70.005	69.957	-0.048	A2-045	3.576	3.578	0.002
A1-090	69.905	69.891	-0.014	A2-090	3.729	3.565	-0.164
A1-135	69.999	70.005	0.006	A2-135	3.855	3.782	-0.073
A1-180	70.016	69.997	-0.019	A2-180	3.945	3.867	-0.078
A1-225	69.912	69.895	-0.017	A2-225	3.979	3.902	-0.077
A1-270	69.997	69.984	-0.013	A2-270	3.894	3.855	-0.039
A1-315	69.871	69.831	-0.040	A2-315	3.663	3.530	-0.133

Table B-5
(Concluded)

Length Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
L1-000	11.880	11.880	0.000
L1-045	11.877	11.878	0.001
L1-090	11.875	11.875	0.000
L1-135	11.872	11.872	0.000
L1-180	11.872	11.872	0.000
L1-225	11.875	11.875	0.000
L1-270	11.877	11.877	0.000
L1-315	11.880	11.880	0.000

TABLE B-6

All Tests: Lid

Radial Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
R1-000	2.609	2.609	0.000
R1-045	2.609	2.609	0.000
R1-090	2.609	2.609	0.000
R1-135	2.609	2.609	0.000
R1-180	2.609	2.609	0.000
R1-225	2.609	2.609	0.000
R1-270	2.609	2.609	0.000
R1-315	2.609	2.609	0.000

Angular Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
A1-000	19.902	19.911	0.009
A1-045	19.895	19.886	-0.009
A1-090	19.962	19.914	-0.048
A1-135	19.963	19.953	-0.010
A1-180	19.936	19.939	0.003
A1-225	19.950	19.955	0.005
A1-270	19.869	19.876	0.007
A1-315	19.869	19.882	0.013

Length Measurements

<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>	<u>Location</u>	<u>Pretest</u>	<u>Posttest</u>	<u>Change</u>
L1-000	1.245	1.247	0.002	L2-000	1.244	1.244	0.000
L1-045	1.248	1.248	0.000	L2-045	1.246	1.246	0.000
L1-090	1.248	1.248	0.000	L2-090	1.246	1.246	0.000
L1-135	1.248	1.248	0.000	L2-135	1.246	1.246	0.000
L1-180	1.248	1.248	0.000	L2-180	1.246	1.246	0.000
L1-225	1.248	1.248	0.000	L2-225	1.246	1.245	-0.001
L1-270	1.247	1.247	0.000	L2-270	1.244	1.244	0.000
L1-315	1.244	1.246	0.002	L2-315	1.242	1.242	0.000

Figure B-3. Inspection Setup: Inner Container Body

DISTRIBUTION LIST

U.S. Department of Energy (205)
Office of Scientific and
Technical Information
Attn: DOE/OSTI-4500-R74 UC-722
Oak Ridge, TN 37830

U.S. Department of Energy
Office of Security Regulations
Washington, DC 20545
Attn: J. Read, EH-321

U.S. Department of Energy (2)
Albuquerque Operations Office
P.O. Box 5400
Albuquerque, NM 87115
Attn: D. Bandy
K. Golliher

Los Alamos Nat'l Laboratory (21)
Los Alamos, NM 87845
Attn: A. Guthrie
R. Sharp (15)
N. King
Group HSE3 M.S. G726
G. Rinehart
Group NMT9 M.S. E502
M. Lewis
D. Trujillo
Group MME4 M.S. G787
D. Summers
Group Q00 M.S. G736

3141 S. A. Landenberger (5)
3145 Document Processing (8)
for DOE/OSTI
3151 G. C. Claycomb (3)
9522 M. M. Madsen (5)
6000 D. L. Hartley
6300 T. O. Hunter
6320 R. E. Luna, Actg.
Attn: TTC Master File
6320 TTC Library (25)
6321 M. G. Vannoni, Actg.
6322 G. F. Hohnstreiter
6323 T. L. Sanders
6323 D. R. Bronowski (5)
6323 W. L. Uncapher
8523-2 Central Technical Files

U.S. Department of Energy (4)
Washington, DC 20545
Attn: S. Denny, EM-50.1
L. Harmon, EM-53
F. Falchi, EM-50.1
C. Miller, EM-50.1

U.S. Department of Energy (3)
1000 Independence SW
Washington, DC 20585
Attn: J. Williams, RW-321
W. Lake, RW-323
C. Kouts, RW-323

U.S. Department of Energy
Chicago Operations Office
9800 S. Cass Ave, Bldg. 350
Argonne, IL 60439
Attn: R. Rothman

U.S. Department of Energy (2)
Idaho Operations Office
550 Second Street
Idaho Falls, ID 83401
Attn: M. Fisher
K. Svinicki

END

**DATE
FILMED**

01 / 23 / 92.