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AEC RESEARCH AND DEVELOPMENT REPORT

MASTER

DEMONSTRATION FUEL ELEMENT SHIPPING CASK
FROM
LAMINATED URANIUM METAL
PART III
TESTS AND DEMONSTRATIONS

C. B. CLIFFORD

**UNION CARBIDE CORPORATION
NUCLEAR DIVISION
PADUCAH GASEOUS DIFFUSION PLANT**

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AND PROGRESS REPORTS
(TID-4500, 53rd EDITION)

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C. B. Clifford

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UNION CARBIDE CORPORATION
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Author:

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ABSTRACT

A demonstration fuel element shipping cask that uses laminated uranium metal as the shielding material was designed, fabricated, tested, and evaluated by the Paducah Gaseous Diffusion Plant, operated by Union Carbide Corporation, Nuclear Division, for the U. S. Atomic Energy Commission. This report describes destructive and nondestructive test programs designed to demonstrate the capability of the cask for successfully meeting the applicable AEC Chapter 0529, 10 CFR 71, and IAEA Safety Series 6 normal transit design criteria and passing the hypothetical accident series described therein. Described in this report are (1) the test facilities and equipment utilized at the Paducah Gaseous Diffusion Plant, (2) the scope of general test work prior to the destructive and nondestructive test programs, and (3) details of the destructive and nondestructive test programs.

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INTRODUCTION

A demonstration fuel element shipping cask utilizing laminated uranium metal as the shielding material was designed, fabricated, tested, and evaluated by the Paducah Gaseous Diffusion Plant, operated by Union Carbide Corporation, Nuclear Division, for the U. S. Atomic Energy Commission. The project was authorized by the AEC Division of Reactor Development and Technology.¹ This report, describing the tests and demonstrations performed on the cask, is the third in a series covering the overall project. Other reports in this series cover (a) the general information, background, and design of the demonstration cask,² and (b) the fabrication and costs of the demonstration cask.³

The demonstration cask shown in figure 1 was subjected to an extensive series of nondestructive and destructive tests by using experimentally verified procedures and instrument systems developed during the testing of the quarter-scale model of this cask.⁴

The cask testing program was designed to meet the following objectives:

- (a) Demonstrate the ability of the cask to pass the normal transit and hypothetical accident series as outlined in applicable regulations in AEC Chapter 0529, 10 CFR 71, and IAEA Safety Series 6.
- (b) Demonstrate the adequacy of the cask design criteria for producing large fuel element shipping casks based on engineering studies and the quarter-scale model testing program.
- (c) Provide limited amounts of engineering data for the design, fabrication, and evaluation of full-size stainless steel clad uranium metal fuel element shipping casks.
- (d) Provide information for studies being conducted by the Oak Ridge National Laboratory for their "Reactor Fuel Transportation Safety Studies," project 04 60 80 03-1.

SECTIONAL DRAWING OF THE DEMONSTRATION FUEL ELEMENT SHIPPING CASK FROM LAMINATED URANIUM METAL

Figure 1

SUMMARY

A demonstration fuel element shipping cask that uses laminated uranium metal as the shielding material has been designed, fabricated, tested, and evaluated by the Paducah Gaseous Diffusion Plant.

The demonstration cask was instrumented with electrical accelerometers and strain gauges, mechanical accelerometers, mechanical compressometers, pressure transducers, and thermocouples during various phases of the testing program to determine the ability of the cask to withstand normal transportation and hypothetical accident conditions. Existing penetrations were used for instrumenting the cask to avoid violating the integrity of the cask by installing special penetrations through the cask walls. Limited amounts of quantitative data were obtained during each phase of the testing program, and motion-picture and still photography were used to document the tests. Extensive physical measurements, cladding pressure tests, and dye-penetrant weld tests were made throughout the testing program to determine the extent of the damage to the cask.

The maximum cask deceleration rates for the 30-foot free fall closure edge drop test were 445 g's on the bottom of the lid and 281 g's on the bottom of the cask. The maximum deceleration rate for the 40-inch free fall puncture test was 78 g's. The largest permanent changes in the cask cavity diameter for the closure edge drop test and the puncture test were -0.053 and -0.119 inch, respectively.

The cask outside cladding reached a maximum temperature of 1520°F during the thermal exposure test, and the largest permanent change in the cask cavity diameter was +0.116 inch.

The cask damage resulting from the transportation and hypothetical accident testing programs was superficial, being limited to the deformation of fins and other sacrificial members near the points of impact. There was no leakage of liquid to the outside of the cask during any hypothetical accident test, and all of the dimensional changes were small except for those in the impact areas. No dimensional change experienced during the testing program would prevent the cask from being used safely for shipping spent fuel elements.

The cask successfully met the applicable AEC Chapter 0529, 10 CFR 71, and IAEA Safety Series 6 normal transit design criteria, and it passed the hypothetical accident series for shipping radioactive materials.

This project has proven the technical feasibility of using laminated uranium metal for structural and shielding materials in large radioactive material shipping casks.

TEST FACILITIES AND EQUIPMENT

DEVICE FOR LIFTING DEMONSTRATION CASK

Figure 2 is an engineering drawing of the lifting yoke used for loading and unloading the cask shipping skid and for moving the cask in the vertical position.

EQUIPMENT FOR HEAT DISSIPATION TEST

A heat dissipation test was conducted on the cask by spot welding sixty 22-gauge chromel-alumel thermocouples to the inside and outside stainless steel cladding and by installing a three-phase electrical heater and a 6-1/2-in-thick heat-insulating lid in the closure end of the cask cavity. Two thermocouples were also spot welded to the top and bottom sections of the 15-in-dia electrical heater mounting fixture. The heat-insulating lid was installed between the lid gasket shoulder and the lid stud flange. The lid was made up of a 2-in-thick layer of 1800°F insulating material next to the heater and three 1-1/2-in-thick layers of 1200°F insulating material on the outside of the high temperature insulation. Figure 3 is a drawing of the electrical heater used in the cask cavity.

The power supply to each phase of the electrical heater was individually controlled by a 0-480 volt Powerstat, and the power input variables were measured on four industrial analyzers. The total power was metered on one of the analyzers and the other three analyzers were used to meter the power to each phase of the heater. This power system was protected by a local breaker equipped with an overcurrent tripping device.

The cask temperatures were read on an 80-point temperature indicator calibrated to read 0 to 750°F and a 20-point temperature recorder calibrated to read 0 to 2000°F. The forty-two lowest test temperatures were read on the indicator, and the twenty highest temperatures were recorded.

EQUIPMENT FOR THERMAL SHOCK TEST

An existing cold-water rinse tank was used during the cask thermal shock test. The tank was 45-ft 8-in long by 7-ft 8-in wide by 10-ft 2-in deep and contained 25,380 gallons of water. The tank was equipped with a 3-in-dia continuous water-feed system and an overflow weir box.

The cask temperatures were obtained during the test by using nine of the thermocouples installed for the heat dissipation test. These thermocouples were located on the top, middle, and bottom sections of the inside cladding, outside cladding, and heat transfer fin areas. The cask and water bath temperatures were taken on a recorder calibrated to print a temperature point every 1-1/2 seconds.

EQUIPMENT FOR LOW TEMPERATURE EXPOSURE TEST

The cask low temperature exposure test was made in a 54-in-dia by 8-ft-high open-top steel tank, spray coated on the outside with a 1-in-thick layer of

Figure 2

Figure 3

polyurethane foam insulating material. The tank was mounted on a 6-in-thick wooden pallet to provide a layer of thermal insulating material under the tank.

Seven copper-constantan thermocouples were used to measure the cask and cooling bath temperatures during the test. These thermocouples were peened into the top, middle, and bottom sections of the stainless steel cladding on the inside and outside of the cask. The test temperatures were read on a potentiometer.

RAILCAR TIE-DOWN AND TESTING EQUIPMENT FOR NORMAL TRANSIT TEST

Figure 4 is a drawing of the modified railcar and cask tie-down system showing the location of the normal transit test instrumentation. Figure 5 is a drawing of the cask tie-down fixtures and parts used during the railroad transit test. Figure 6 shows the sling used for loading and unloading the cask during the normal transit tests.

The electrical accelerometer, cask load cell, pressure transducer, and strain gauge voltage outputs were recorded on two battery-powered portable environmental samplers designed and built by the Sandia Corporation of Albuquerque, New Mexico. The samplers are 14-channel analog magnetic tape recording systems designated ELI 31 and 32. Each of the fourteen channels was equipped with a system of three amplification circuits designed to receive signals from either strain gauge, piezoelectric, or linear voltage sensors. Each channel was independent of the others and any combination of pickup systems could be sampled at one time. The units were designed to be calibrated, adjusted, or to monitor source sensors without the use of ancillary test equipment; and the overall system frequency response was flat from DC to 2500 cps when the units were operating at 15 ips. Each recording system was equipped with a power-on, recorder-on, recorder-out-of-tape indicating light system during the railroad transit test, and the recorders were operated through a battery-powered radio receiver systems control unit. Each recorder held 650 feet of tape which provided for 8.7 minutes of recording at a tape speed of 15 ips.

TRACTOR TRAILER TIE-DOWN AND TESTING EQUIPMENT FOR NORMAL TRANSIT TEST

Figure 7 is a drawing of the modified trailer, cask tie-down system, and the normal transit test instrument locations.

The ELI 31 portable environmental sampler used during the tractor trailer normal transit test was operated through a direct wire remote control unit. This unit was manually operated from the tractor cab when a portable acceleration indicating meter showed the desired road conditions existed. The control unit contained the required push buttons and indicating lights to operate the environmental sampler, and the data recordings were identified by placing a voice record on a magnetic tape.

SIMULATED FUEL ELEMENT ASSEMBLY

A 2500-lb simulated fuel element assembly was installed in the cask during the normal transit tests and the 30-ft free fall drop test. Figures 8, 9, and 10

Figure 4

Figure 5

LIFTING BEAM

1/4" = 1"

SLING LEG

1/4" = 1" 4 REQ'D.

SECT. 1-1

1/4" = 1"

SECT. 2-2

1:1

ASSEMBLY

N.T.S.

ENGINEERING INFORMATION

1. MAXIMUM DESIGN CAPACITY: 36,000 LBS.
2. DESIGN SAFETY FACTORS (BASED ON U.T.S.):
WIRE ROPE 8 MIN.
FITTINGS 5 "
STRUCTURAL 5 "
3. WEIGHT OF SLING: 280 LBS.
4. TEMPERATURE RANGE: 0° TO 160° F.

GENERAL NOTES

1. USE ASTM A-36 STEEL THROUGH-OUT UNLESS OTHERWISE SHOWN.
2. USE E-70 ELECTRODES AND WELD IN ACCORD WITH E.S.P. 4.3-1A.
3. BREAK ALL SHARP EDGES.
4. PAINT BEAM ALUMINUM. DO NOT PAINT WIRE ROPE OR FITTINGS.

DEMONSTRATION CASK SLING FOR NORMAL TRANSIT TEST

FROM DWG. NO. E-S-12345 D

Figure 6

Figure 7

are drawings of the assembly and the mechanical accelerometers mounted on this unit. The spring constant for the leaf spring bolted to the closure end of the unit was 4000 lbs/in. Figure 11 is a photograph of the simulated fuel element assembly being lowered into the cask.

DROP TEST PAD

Figure 12 shows the design of the drop test impact pad. This pad, constructed for a previous drop test program,⁵ is made up of a reinforced concrete block 18-ft long by 14-ft wide by 6-3/4-ft thick supported on soil having a bearing capacity of 5400 lbs/sq ft. The surface of the pad is covered with a 4-1/2-in-thick steel plate made from two 8-by-12-ft sections of plate welded together and anchored into concrete. Each section of the steel plate was made up of 1-1/2 in. of armor plate backed with 3 in. of boiler plate. The total weight of the pad is approximately 151 tons. This weight is made up of 268,000 lbs of concrete and 34,700 lbs of steel.

A sheet metal backdrop, painted with 6 in. red and yellow squares, is located on one side of the drop test pad to provide a means for measuring the relative movement of the test object during and after impact. The 10-ft-high by 14-ft-wide backdrop is adjustable for alignment with a high-speed camera.

DROP TEST PISTON

An 8-in-dia by 6-in-high mild steel piston was used for the 40-in free fall puncture test. The piston was welded to a 1/2-by-24-by-24-in mild steel plate which was bolted securely to the steel plate installed on top of the drop test pad. Figure 13 is a photograph of the drop test piston used in the 40-in free fall puncture test.

DROP TEST CRANE

A 65-ton crawler crane with an 80-ft boom was used for dropping the cask during the free fall drop tests. No abnormal boom recoil effects were experienced when the maximum test load was dropped. The total weight of this load was 28,190 lbs.

DROP TEST SLINGS

Figure 14 is a drawing of the drop test slings used for orienting the cask for both free fall tests. The slings were designed to clear the electrical accelerometers mounted on the cask, and they were positioned on the cask to place the vertical axis of the electrical accelerometers and the cask center of gravity over the point of impact.

18-TON DROP TEST RELEASE MECHANISM

Figure 15 is a drawing of the release mechanism used during both free fall tests. The drop beam in this mechanism is held in place with a solenoid-operated safety pin and an explosive nut until an electrically controlled timing circuit disengages the safety pin and energizes the explosive nut firing circuit.

Figure 8

ITEM 3
2 REQD. MATL. 1" R H.S.
SCALE: 1/2" = 1"

ITEM	NO	REQD	L" ± 1/8	W" ± 1/8
4	1	14 1/2	12	
5	1	16 1/2	12	
6	2	14 1/2	5 1/2	
7	2	16 1/2	5 1/2	
8	4	14 1/2	6 1/2	
9	4	16 1/2	6 1/2	

ITEM 4 5 6 7 8 9
MATL. 1/2" R H.S. SCALE - NONE

ITEM 10
1 REQD. MATL. 1" R C.R.S.
SCALE: 1/2" = 1"

ITEM 11
4 REQD. MATL. 1 1/2" HEX BAR 316 S.S.
FULL SCALE

NOTE: BREAK SHARP EDGES

ITEM 13
MATL. URANIUM DERBY
SCALE: 1/2" = 1"

ITEM	NO	REQD	L" ± 1/8	W" ± 1/8
13-A	1	6"		
13-B	1	5 1/2		
13-C	1	4		

SIMULATED FUEL ELEMENT DETAILS

FROM DWG. NO. E-M-123418 REV.1

Figure 9

Figure 10

LOADING SIMULATED FUEL ELEMENT INTO DEMONSTRATION CASK

Figure 12

DROP TEST PISTON

Figure 13

3457-41 (U)

Figure 14

Figure 15

FROM DWG. NO. E-5-12262A REV. 3

Figure 16 is a drawing of the explosive nut and the cap screw assembly that was used in the drop test release mechanism.

CAMERAS AND TIMERS

One rotating-prism, 16-mm, high-speed motion picture camera and two 16-mm normal-speed motion picture cameras were used to photograph the action of the 30-ft free fall drop test and the 40-in free fall puncture test. The high-speed camera was placed 87.9 ft from the center of the cask impact area, and the elevation of the camera was essentially at the same elevation as the drop test pad. This camera was operated at 1000 frames per second with high-speed black and white film and at 2000 frames per second with color film. High-speed black and white film was used in the high-speed camera to photograph the 30-ft free fall drop test due to subnormal lighting conditions; color film was used during all of the other motion picture photography associated with the cask testing programs. A 50 frame-per-second motion picture camera was used to photograph the overall drop test areas, and a 64 frame-per-second motion picture camera was used to obtain closeup photographs of the drop tests. A normal-speed motion picture was also made of the cask thermal exposure test, and 35-mm photographs were made of all the nondestructive and destructive cask tests.

A 3600-rpm timing clock was used in conjunction with the high-speed camera to assist in making time-sequence analysis. The oscillograph recorder, cask release mechanism, high-speed camera start circuit, and the impact time signals were operated by a timer control circuit. Figure 17 is a drawing of the timer control circuit and the time-sequence schedule used during the drop test programs.

DROP TEST INSTRUMENTATION

The cask cavity accelerometers and strain gauges were waterproofed with a compound which showed no visible deterioration or change in dielectric strength when it was tested for 74 hours in the water-soluble fluorescent leak detection oil used in the cask cavity during the free fall drop tests. Tables 1, 2, and 3 show the accelerometer and strain gauge data for the drop test programs, and figure 18 shows a one-line schematic diagram of the drop test instrumentation.

MECHANICAL ACCELEROMETERS

Figure 19 is a drawing of the mechanical accelerometer that was designed and fabricated for use during the 30-ft free fall closure edge drop test. The range of this instrument is 200 to 800 g's.

The cantilever beam for each instrument was spray coated on its top surface with a thin film of Stresscoat brittle lacquer, and a test beam was loaded in a special jig to determine the threshold cracking stress for the lacquer.

One mechanical accelerometer was installed in a holding bracket welded to the outside surface of the skirt on the bottom of the cask. This accelerometer was positioned adjacent to the electrical accelerometer on the bottom of the cask for comparison purposes, and the accelerometer cantilever beam was installed

NOTES:

1. FIRING CHARACTERISTICS

NO FIRE CURRENT - 0.5 AMPS
100 % FIRE CURRENT - 2.5 AMPS
BRIDGE WIRE RESISTANCE - 0.37 ± 0.04 OHM THRU LEADS

2. MATERIAL DATA

NUT - E4T30 STL PER MIL-S-6758 HT TREAT TO RC 46-51
CARTRIDGE BODY - B1113/C1213 STL TIN PLT PER MIL-T-10727
PINS - C1010 STL - TIN PLT PER MIL-T-10727
CLOSURE - .003 SST
PINS ENTER BODY THRU FUSED CERAMIC SEAL

3 .0655 DIM. IS FROM END OF BOLT TO TOP OF HEX

SCHEMATIC

EXPLOSIVE NUT AND CAP SCREW FOR DROP TEST RELEASE MECHANISM

Figure 16

NOTE:
Circuit Change For 40-Inch Free Puncture Test:
45-Circuit Open
1.5 V Battery
2.5 K

DEVICE

30' DROP TEST TIME SEQUENCE

DEVICE

40" DROP TEST TIME SEQUENCE

DROP TEST TIMER CONTROL CIRCUIT AND TIMING SCHEDULES

Figure 17

STRAIN GAUGE DATA

STRAIN GAUGE	COMPENSATING GAUGE	TYPE	ALLOY MATERIAL	BACKING MATERIAL	LENGTH	WIDTH	RESISTANCE, OHMS	GAUGE FACTOR	TEMP. COMP. FOR	MAX. ELONGATION
1,2,3,5,6 & 7		FOIL-60°ROSETTE	CONSTANTAN	EPOXY RESIN	0.250"	0.250"	120 $\pm$ 0.2	2.02 $\pm$ 1/2%	NONE	15 %
4 & 17		" " "	"	" "	"	"	" "	206 " "	ST. STEEL	5 "
11,12 & 16		" " "	"	" "	"	0.125"	" "	209 " 1%	" "	3 TO 5 "
13,14 & 15		" " "	"	" "	0.50" DIA.		" "	2.02 " "	" "	2 "
21,22,23 & 24		FOIL SINGLE	"	" "	0.500"	0.175"	" 0.15	2.11 " 1/2%	" "	1 "
	A & B	FOIL-60°ROSETTE	"	" "	0.250"	0.250"	" 0.2	2.06 " "	" "	5 "
	C	" " "	"	" "	0.50" DIA.		" "	2.02 " "	" "	" "
	D & E	" " "	"	" "	0.250"	0.125"	" "	2.05 " 1%	" "	15 "
	F	FOIL SINGLE	"	" "	0.495"	0.180"	" "	2.02 " "	" "	" "

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STRAIN GAUGE CEMENT DATA						STRAIN GAUGE WATERPROOF DATA					STRAIN GAUGE INSTALLATION DATA		
CEMENT NO.	°F TEMP. RANGE	MAX. ELONGATION	CURE TIME	CURE TEMP.	CURE PRESS.	WATERPROOF NO.	°F TEMP. RANGE	CURE TIME	CURE TEMP.	CURE PRESS.	GAUGE NO.	CEMENT NO.	WATERPROOF NO.
I	-65°TO+150°F	10	1-5MIN	75°F	1-15PSI	I	-90°TO+300°F	30 MIN	75°F	0-PSI	A	I	I
II	-100 TO+150°	10	16-72HRS	75°F	5-15PSI	II	-90°TO+250°F	6 HRS	75°F	0-PSI	11,12,13,14,15, 16,17,21,22, 23,24 & D	I	II
						III	-90°TO+250°F	6 HRS	75°F	0-PSI	1,2,3,4,5, 6,7 & F	I	III
											E	II	II
											B & C	II	III

STRAIN GAUGE MATERIALS USED DURING THE 30-FOOT FREE FALL CLOSURE EDGE DROP TEST

Table 1

INPUT DEVICE	COMPENSATING STRAIN GAUGE NO.	BALANCING UNIT CHANNEL NO.	AMPLIFIER NO.	AMPLIFIER CHANNEL NO.	AMPLIFIER CALIBRATION SETTING	RECORDER CHANNEL NO.	RECORDER GALVANOMETER TYPE	GALVANOMETER SERIES RESISTANCE	RECORDER CALIBRATION
1000 CYCLE PER SECOND	—	—	—	—	—	T-1	M-5000	NONE	1000 ~ SIGNAL
RELEASE & IMPACT SIGNAL	—	—	—	—	—	T-2	M-1000	8200	ON-OFF SIGNAL
STRAIN GAUGE NO. 21	E-1	1	1	1	ATTENUATION: 15	1	M-5000	15 ~	1" = 6000 ~
NO. 22	E-2	2	1	2	" 15	2	"	"	" "
NO. 23	E-3	3	1	3	" 15	3	"	"	" "
NO. 24	D-1	4	1	4	" 15	4	"	"	" "
NO. 17-1	B-1	5	2	1	" 1	5	M-1650	22 ~	" 3320
NO. 17-2	B-2	6	2	2	" 1	6	"	"	1" 1710
NO. 17-3	B-3	7	2	3	" 1	7	"	"	" "
NO. 7-1	A-1	8	2	4	" 1	8	"	"	" "
NO. 7-2	A-2	9	3	1	GAIN: 0.9	9	M-5000	15 ~	" "
NO. 7-3	A-3	10	3	2	" 0.9	10	"	"	" "
ACCELEROMETER NO. 1	—	—	4	2	740 PC/g 3000G	11	M-8000	"	1" = 3000 G
NO. 2	—	—	4	2	765 PC/g 3000G	12	"	"	" "

ACTIVE GAUGE NO.	COMPENSATING GAUGE NO.	BALANCING UNIT	BALANCING UNIT CHANNEL NO.	ACTIVE GAUGE NO.	COMPENSATING GAUGE NO.	BALANCING UNIT	BALANCING UNIT CHANNEL NO.	ACTIVE GAUGE NO.	COMPENSATING GAUGE NO.	BALANCING UNIT	BALANCING UNIT CHANNEL NO.
1-1	C-2	1	1	5-1	C-2	2	4	13-1	F	3	7
1-2	"	1	2	5-2	"	2	5	13-2	"	3	8
1-3	"	1	3	5-3	"	2	6	13-3	"	3	9
2-1	"	1	4	6-1	"	2	7	14-1	"	3	10
2-2	"	1	5	6-2	"	2	8	14-2	"	3	11
2-3	"	1	6	6-3	"	2	9	14-3	"	3	12
3-1	"	1	7	—	—	2	10	15-1	"	3	13
3-2	"	1	8	11-1	F	3	1	15-2	"	3	14
3-3	"	1	9	11-2	"	3	2	15-3	"	3	15
—	—	1	10	11-3	"	3	3	16-1	"	3	16
4-1	C-2	2	1	12-1	"	3	4	16-2	"	3	17
4-2	"	2	2	12-2	"	3	5	16-3	"	3	18
4-3	"	2	3	12-3	"	3	6				

ACCELEROMETER, STRAIN GAUGE AND TIMING DATA FOR THE 30-FOOT
FREE FALL CLOSURE EDGE DROP TEST

Table 2

INPUT DEVICE	COMPENSATING STRAIN GAUGE NO.	BALANCING STRAIN GAUGE NO.	AMPLIFIER NO.	AMPLIFIER CHANNEL NO.	AMPLIFIER CALIBRATION SETTING	RECORDER CHANNEL NO.	RECORDER GALVANOMETER TYPE	GALVANOMETER SERIES RESISTANCE	RECORDER CALIBRATION
1000 CYCLE SIGNAL	—	—	—	—	—	T 1	M-5000	NONE	1000 SIGNAL
RELEASE & IMPACT SIGNAL	—	—	—	—	—	T 2	M-1000	8200 —	ON-OFF SIGNAL
STRAIN GAUGE 40-1	A-1	1	1	1	ATTENUATION: 2	1	M-5000	15	1"=800
40-2	A-2	2	1	2	2	2	" "	" "	" "
40-3	A-3	3	1	3	2	3	" "	" "	" "
41-1	B-1	4	1	4	2	4	" "	" "	" "
—	—	5	2	1	—	5	M-1650	22 "	—
—	—	6	2	2	—	6	" "	" "	—
—	—	7	2	3	—	7	" "	" "	—
—	—	8	2	4	—	8	" "	" "	—
41-2	B-2	9	3	1	GAIN: 2.85	9	" 5000	15 "	1"=800
41-3	B-3	10	3	2	" 2.85	10	" "	" "	" "
ACCELEROMETER #1	—	—	4	1	745PC/g300g	11	" 8000	" "	" "

ACTIVE GAUGE NO.	COMPENSATING GAUGE NO.	TYPE	ALLOY MATERIAL	BACKING MATERIAL	LENGTH	WIDTH	RESISTANCE OHMS	GAUGE FACTOR	TEMP. COMP. FOR	MAX. ELONGATION
40 & 41	A & B	FOIL-60°ROSETTE	CONSTANTAN	EPOXY RESIN	0.250"	0.250"	120 ⁺ 0.2	2.06	S. STEEL	15

STRAIN GAUGE CEMENT DATA						STRAIN GAUGE WATERPROOF DATA					STRAIN GAUGE INSTALLATION DATA		
CEMENT NO.	°F TEMP. RANGE	MAX. ELONGATION	CURE TIME	CURE TEMP.	CURE PRESS.	WATERPOOF NO.	°F TEMP. RANGE	CURE TIME	CURE TEMP.	CURE PRESS.	GAUGE NO.	CEMENT NO.	WATERPOOF NO.
I	-65° TO +150°F	10	1-5 MIN	75°F	1 TO 15 PSI	I	-90 TO +300°F	30 MIN.	75°F	0-PSI	40, 41 & A	I	I
II	-100° TO +150°F	10	16-72 HRS	75°F	5 TO 15 PSI	III	-90 TO +250°F	6 HRS	75°F	0-PSI	B & C	II	III

**ACCELEROMETER, STRAIN GAUGE AND TIMING DATA FOR THE 40-INCH
FREE FALL PUNCTURE TEST**

Table 3

DROP TEST INSTRUMENTATION SCHEMATIC DIAGRAM

Figure 18

Figure 19

normal to a line through the center of gravity of the cask and the point of impact. Two mechanical accelerometers on the closure end of the simulated fuel element assembly were positioned with one cantilever beam normal to the center line of the cask and the other beam normal to a line through the center of gravity of the cask and the point of impact.

The following method of analysis was used for calculating the maximum g forces experienced by the mechanical accelerometers during the 30-ft drop test. Figure 20 shows the cantilever beam dimension symbols used in analyzing the results obtained from the mechanical accelerometers.

$$\sigma = \frac{Mc}{I} \quad (1)$$

$$M = \frac{wx^2}{2} \quad (2)$$

$$I = \frac{bh^3}{12} \quad (3)$$

where σ = the stress in the beam at any distance x from the movable end of the beam,

M = the bending moment of the beam at any distance x from the movable end of the beam in in-lbs,

I = the moment of cross-sectional area of the beam in lbs-in²,

c = the distance from the neutral fiber to the surface of the beam, or $h/2$,

w = uniform beam load in pounds force per inch,

x = distance in inches from the movable end of the beam,

b, h, ℓ = dimensions in inches as shown in figure 20.

Substituting equations (2) and (3) into equation (1) gives:

$$\sigma = \frac{3wx^2}{bh^2} \quad (4)$$

The static loading on the beam in a normal gravitational field is:

$$w = \frac{\rho b h \ell}{\ell} = \rho b h \quad (5)$$

where ρ = the density of the beam in lbs/in³.

In an artificially induced gravitational field:

$$w = n \rho b h \quad (6)$$

where n = the number of g's induced.

Substituting equation (6) into equation (4) gives:

$$\sigma = \frac{3n \rho b h x^2}{bh^2} = \frac{3n \rho x^2}{h} \quad (7)$$

Solving equation (7) for n gives:

$$n = \frac{h}{3 \rho x^2}$$

MECHANICAL ACCELEROMETER CANTILEVER BEAM
DIMENSIONS

Figure 20

The Stresscoat brittle lacquer applied to each accelerometer beam develops parallel transverse cracking when the beam is loaded. This cracking starts at the fixed end of the beam and progresses along the beams until the beam stresses are equal to the threshold cracking stress for the stresscoat material.

In the above analysis, x equals the experimentally determined distance from the movable end of the beam to the line where the threshold cracking starts.

MECHANICAL COMPRESSOMETERS

Figure 21 is a photograph of one of the compressometers used in the cask cavity during the 40-in free fall puncture test. The outer sleeves for these instruments were made from 1/4-in-dia sections of stainless steel tubing, and the plungers were fabricated by machining longitudinal slots through the walls of 1/8-in-dia sections of stainless steel tubing to allow the diameter of the plungers to be adjusted for friction control purposes. Solid brass knobs were soldered to each end of the instruments.

FIRE TEST FACILITY

The fire test facility consisted of a 20-ft-square by 2-ft-deep unlined fire pit containing two reinforced concrete columns to support the cask. Figure 22 is a drawing of the cask support columns.

The cask thermal exposure test was instrumented with 18 external cladding thermocouples and 18 fire zone thermocouples. All of the thermocouples were fabricated from 3/16-in-dia magnesium oxide and stainless steel-sheathed 22-gauge chromel-alumel thermocouple wire. The internal cask cladding was instrumented with ten 28-gauge chromel-alumel high temperature glass-insulated thermocouples. The fire zone thermocouples were mounted on a 1-1/4-in-dia stainless steel tubing rack, and the thermocouple lead wires were wrapped with asbestos tape and cloth. The insulated wires were run through the fire zone in stainless steel tubing. Figure 23 is a photograph of the instrumented cask and fire pit area before the fire test was made. Three 8-by-15-ft sheet metal wind deflectors were used to control the fire temperatures around the cask, and the test temperatures were recorded on two recorders calibrated to print a temperature point every 1-1/2 seconds. The temperature recording system was paralleled with a secondary temperature indicator, capable of reading all of the test temperatures. A standby motor generator set, capable of furnishing the test power requirements in the event of a power failure, was available at the test site.

LIFTING BRACKET FOR THE DEMONSTRATION CASK LID

Figure 24 is a drawing of the lifting bracket that was used to stabilize the cask lid when it was installed in the cask or removed from the cask during the radiation attenuation test remote control operations.

⁶⁰Co LINE SOURCE LOADING FIXTURE

Figure 25 shows a drawing of the fixture that was used to transfer the ⁶⁰Co line source into and out of the cask during the radiation attenuation test. The

MECHANICAL COMPRESSOMETER

Figure 21

FIRE PIT SUPPORT COLUMNS FOR THE DEMONSTRATION CASK

Figure 22

FIRE PIT AREA BEFORE THERMAL EXPOSURE TEST

Figure 23

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Figure 24

aluminum-clad ^{60}Co capsules were equally spaced in the fixture by alternately loading coil springs and capsules into the fixture with a hot cell crane and a mechanical manipulator. The source was removed from the fixture by lowering the source tube over a ram rod and removing the springs and capsules from the top of the tube with a mechanical manipulator.

⁶⁰
Co CAPSULE LOADING FIXTURE
FOR THE DEMONSTRATION CASK

SCOPE OF PRELIMINARY TEST WORK PERFORMED PRIOR TO THE DESTRUCTIVE AND NONDESTRUCTIVE TESTING PROGRAMS

DROP TEST LEAK-DETECTION TEST

A method was developed for detecting and measuring small leaks that might develop across the cask closure systems during the drop tests. This method of leak detection utilizes a 10% solution of a highly fluorescent water-soluble oil in the cask cavity, and the test is capable of detecting leaks as small as 0.0001 ml when ultraviolet light is used to detect the fluorescent solution on metal surfaces.

18-TON DROP TEST RELEASE MECHANISM AND HIGH-SPEED CAMERA TEST

A preoperational drop test was made with the timer control circuit, 18-ton drop test release mechanism, and the high-speed camera by dropping a 21,000-lb weight. The release mechanism and test load were photographed at 2000 frames per second by using color film in the high-speed camera.

The film was processed and reviewed to determine if improved photographic procedures needed to be considered for the cask drop test programs. Satisfactory photography was obtained during this test, but the test showed that a sheet metal deflector was needed between the explosive actuated nut and the release mechanism to protect the device from flying shrapnel. It was also necessary to shorten the explosive nut cap screw 7/32 of an inch to position the release bar and the explosive nut properly.

PRELIMINARY RAILCAR SHOCK LOADING TEST

Arrangements were made with Mr. J. T. Foley of the Sandia Corporation, Albuquerque, New Mexico, for Sandia personnel to participate in a demonstration cask transportation testing program. This program included shipping the cask from Paducah, Kentucky, to Oak Ridge, Tennessee, by railcar and returning the cask to Paducah by a tractor trailer shipment.

The Paducah Plant designed and furnished the cask tie-down systems and the modified railcar and tractor trailer units for the testing program, and the Sandia Corporation utilized their experienced technical personnel and proven test equipment to obtain environmental transit data that would be beneficial to the program.

Arrangements were made with the Illinois Central and Louisville and Nashville Railroads to allow a Sandia engineer to make a preliminary shock loading survey of a railcar in transit between Paducah, Kentucky, and Knoxville, Tennessee. The test data were obtained by installing a longitudinal, transverse, and vertical accelerometer mounting system on a centrally located structural member in the framework of the cabooses used during the survey and by using a portable acceleration meter to monitor the shock and vibration acceleration rates. Acceleration readings were obtained for essentially all of the railroad curve, grade, run-in and run-out, roadbed, and train speeds experienced. The data obtained from this test were used to develop the environmental sampling program used during the cask railcar normal transit test. The preliminary test data showed that longitudinal, transverse, and vertical acceleration rates as high as 3.5, 2.0, and 2.5 g's, respectively, could be expected during the cask railcar transit test.

DEMONSTRATION CASK ACCELEROMETER, STRAIN GAUGE, AND THERMOCOUPLE INSTALLATION TESTS

A series of tests was made to determine the number of internal accelerometer and strain gauge cables and thermocouple wires that could be installed through the cask vent and drain lines. Tests were also made to develop a cable seal capable of withstanding a 375 psig hydrostatic pressure test without leaking. These tests showed that the accelerometer and strain gauge cables would have to be installed through the drain line and that the cables could be sealed in a silicone elastomer stuffing box to withstand a 500 psig hydrostatic pressure test. The elastomer was allowed to cure under room temperature conditions before pressure was applied to the seal.

The thermocouple installation tests showed that a maximum of five high temperature glass-insulated 28-gauge chromel-alumel thermocouples could be installed through the cask vent line and that ten of the same type thermocouples could be installed through the cask drain line. Larger diameter thermocouple wire could not be threaded through the bends in the cask penetrations due to the stiffness of the wire.

DEMONSTRATION CASK CLOSURE EDGE DROP TEST ANGLE

A test was made on the cask equipped with the simulated fuel element assembly and the adjustable closure edge drop test sling to determine the cask drop test angle required to position the center of gravity of the cask and the vertical axis of the electrical accelerometers over the point of impact for the 30-ft free fall drop test. The longitudinal center line of the cask was positioned $18^{\circ}45'$ from the vertical to meet the above testing conditions and to fulfill the 10 CFR 71 requirements for drop testing the cask "onto a flat essentially unyielding horizontal surface, striking the surface in a position for which maximum damage is expected."

DROP TEST INSTRUMENT CALIBRATION AND PRETESTING OPERATIONS

Instrumentation was developed and fabricated to photograph a thousand cycle per second light pulse and the cask drop test pad contact light history. These light pulses were photographed along the edges of the high-speed camera film. This system was pretested in conjunction with a high-speed camera operation, and the thousand cycle per second light pulse was photographed. The drop test pad contact light was not photographed due to the failure of a neon bulb in the camera. New neon bulbs were installed in the pulse photography section of the camera and the instrumentation functioned properly on the second test run.

The spring constant for the simulated fuel element leaf spring was measured, and the spring was modified to provide a spring constant of 4000-lbs/in. The simulated fuel element was modified to accommodate two mechanical accelerometers and the other instrumentation in the cask cavity. A guide rail was installed in the cask cavity to prevent the simulated fuel element from rotating and damaging the electrical accelerometer and strain gauge wiring.

The simulated fuel element was placed in the instrumented cask, and the drop test trailer electrical accelerometer and strain gauge instrumentation were

pretested as a system. The cask was bump-tested five times, from a height of two inches, to adjust the accelerometer and strain gauge amplifier sensitivities and check the cask drop test pad contact light and recording circuits.

MECHANICAL COMPRESSOMETER CALIBRATION TEST

The cask cavity compressometers for the 40-in free fall puncture test were test loaded in the vertical position, and the friction between each compressometer plunger and shaft was adjusted to prevent the plungers from being driven into the shafts by the forces associated with the cask deceleration.

PRELIMINARY KEROSENE FIRE TEST

The quarter-scale model of the cask was fire tested in the 20-ft square by 2-ft deep fire pit by burning 2000 gallons of kerosene having a gross heat value of 19,780 to 19,980 Btu/lb. This test was made to pretest the thermocouple systems that were being considered for the demonstration cask thermal exposure test and to determine the atmospheric conditions and quantity of kerosene required for this test.

The fire zone temperatures were measured by installing six asbestos-insulated 22-gauge chromel-alumel thermocouples 30, 45, and 60 inches above the initial fuel level in the pit. The thermocouple junctions were made by spot welding the thermocouple wires to 2-by-2-by-1/4-in stainless steel coupons.

The model was instrumented with nine 28-gauge chromel-alumel high temperature glass-insulated thermocouples spot welded to the inside stainless steel cladding and with nine 22-gauge chromel-alumel high temperature glass-insulated thermocouples spot welded to the outside stainless steel cladding. Two additional 3/16-in-dia magnesium oxide and stainless steel sheathed 22-gauge thermocouples were installed near each other on the outside stainless steel cladding of the model. These thermocouples were installed by welding the wires from one of the thermocouples to the outside cladding and by peening the wires from the other thermocouple into small diameter holes drilled into the cladding.

The fire test lasted 45 minutes. The average wind velocity was approximately 6 miles per hour. The maximum and minimum wind velocities experienced were 11.4 and 2.3 miles per hour, respectively. The fire temperature reached 1475°F approximately one minute after the kerosene was ignited, and the average fire temperature was above the required 1475°F thermal exposure test temperature for 22 consecutive minutes.

This test confirmed that wind velocities of less than 5 miles per hour are desirable for a fire test and, also, that the peened thermocouple temperature readings were 3 to 20°F lower than similar temperature readings obtained from the spot welded thermocouples. The kerosene burning rate indicated that 2500 gallons of kerosene would be needed for the cask thermal exposure test and that wind defectors should be available for use during the test.

This was the second fire test made on the model without a failure of any type developing in the stainless steel cladding surrounding the uranium shielding.

STANDARD DEMONSTRATION CASK INSPECTION TESTS

The following tests were made on the cask after fabrication was completed:

- (a) The stainless steel cladding volume was vacuum leak rated for 24 hours at a leak-up rate of less than 2 microns per hour. This pressure rise was considered to be due to metal outgassing.
- (b) The stainless steel cladding was soap tested by pressuring the cladding volume to 5 psig with helium, and all of the accessible cladding welds were tested with dye penetrant. No cladding leaks were found.
- (c) The cask cavity was hydrostatically tested at a pressure of 375 psig without a leak developing.
- (d) An as-built set of precision measurements was made on the cask so that the extent of future cask testing damage could be determined.

NONDESTRUCTIVE TEST PROGRAM

INTRODUCTION

The nondestructive test program consisted of a heat dissipation test, a thermal shock test, a low temperature exposure test, a normal transit test, and a radiation attenuation test. This test series was made according to the above sequence except for the radiation attenuation test which was made after the destructive testing program was completed. The detailed test procedures for the nondestructive test program are presented in the appendix.

HEAT DISSIPATION TEST

A heat dissipation test was conducted on the demonstration cask to establish the ability of a full-size cask of this type to dissipate the heat load generated by four Indian Point core A spent fuel elements without exceeding the cask design specifications. Figure 26 is a photograph of the test assembly, and table 4 shows the equilibrium heat dissipation test data.

The cask design specifications are as follows:

Internal temperature	375°F
Fin temperature	250°F
Maximum pressure	250 psig
Operating pressure	170 psig
Minimum ambient temperature	-40°F
Maximum ambient temperature	130°F

A 43,500 Btu/hr electrical heat load was generated inside the dry cavity while the cask was in the horizontal and vertical positions and exposed to ambient temperature conditions. The test heat load was approximately 1.8 times the maximum effective solar heat load for the cask plus the nominal decay heat load from four Indian Point core A fuel element sections having an active fuel-to-cavity length ratio equivalent to the ratio used in the Indian Point fuel element shipping casks. The maximum effective solar heat load was calculated by using the ORNL graphical method for determining the incident solar energy,⁶ and the total decay heat load was based on the nominal decay heat load per linear foot of fuel published in table 2 of KY-550 covering the general information, background, and design section of this report series.

Calculations have shown that the cask would meet the design temperature data if it were tested in a 130°F temperature in sunlight with the expected decay heat load generated inside the cask.

The cask design specifications were chosen to develop a uranium shielded fuel element shipping cask capable of handling twice the payload of the existing Indian Point fuel element casks without reaching internal temperatures capable of damaging the cask or a fuel element shipment. A cask of this type would have to be enclosed in a heat shield to prevent contact burns to personnel.

HEAT DISSIPATION TEST ASSEMBLY

Figure 26

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DATE	CASK TEST POS.	AMPS	VOLTS	AMB. TEMP	BTU / HR
2/16/68	HOR.	16.5	463	76	43,500
2/25/68	VER.	16.7	458	86	43,500

OUTSIDE BOTTOM											
1	2	3	4	5	6	7	8	9	10	11	12
213	205	204	210	212	206	208	215	218	215	220	222
215	209	210	213	213	207	205	211	210	209	217	221

TOP OF LID								
13	14	15	16	17	18	19		
128	132	135	136	131	125	385		
131	127	125	125	123	122	349		

BOLT FLANGE	TOP RING	TOP O.D.
20 21 22	23	24
235 235 223	148	260
224 224 215	140	236

TOP RING	TOP O.D.
23	24
148	260
140	236

BOTTOM OF LID					
25	26	27	28	29	30
1025	1032	1032	1020	976	853
1000	1000	1000	985	927	795

INSIDE BOTTOM		
31	32	33
303	292	273
331	308	200

INSIDE WALL								
BOTTOM			MIDDLE			TOP		
34	35	36	37	38	39	40	41	42
295	312	294	432	436	433	438	435	460
336	320	312	423	410	402	413	378	391

OUTSIDE WALL								
BOTTOM			MIDDLE			TOP		
43	44	45	46	47	48	49	50	51
233	232	207	314	316	310	287	290	279
248	223	225	307	273	275	278	250	249

FIN EDGE								
BOTTOM			MIDDLE			TOP		
52	53	54	55	56	57	58	59	60
183	187	129	262	235	210	223	237	216
206	158	158	252	182	185	238	178	171

HTR. WALL	
61	62
982	950
957	947

TEMPERATURE DATA IN °F

EQUILIBRIUM HEAT DISSIPATION TEST DATA

Table 4

THERMAL SHOCK TEST

A thermal shock test was conducted on the demonstration cask to determine the ability of the cask to withstand immersion in cold water when the cask was near its normal operating temperature. This test was made since it closely represents normal service conditions.

Immediately following the heat dissipation test, the cask was submerged in a 25,000 gallon tank of water equipped with a 3-in-dia water supply line and an overflow wier. Figure 27 shows the cask being immersed in the cooling water. The average inside cladding temperature was 310°F when the test was started. The water temperature near the cask was 45°F at the start of the test and 48°F at the time the test was terminated. The cask was immersed at 0.35 ft/sec, and the average internal cask temperature decreased at a rate of $2.2^{\circ}\text{F}/\text{min}$ until the test was terminated, when the average internal cask temperature reached 100°F .

The following standard inspection tests were made on the cask, after each phase of the nondestructive and destructive testing program, to determine the extent of the cask damage:

- (a) A vacuum leak rate test was made on the cask cladding volume.
- (b) The cask cladding was soap tested by pressuring the cladding volume to 5 psig with helium, and all accessible cladding welds were tested with dye penetrant.
- (c) The cask cavity was hydrostatically tested at 375 psig.
- (d) Precision measurements were made on the cask.

The standard inspection tests made after the heat dissipation and thermal shock tests showed no cladding failures or dimensional changes which could affect the performance of the cask.

LOW TEMPERATURE EXPOSURE TEST

A low temperature exposure test was conducted on the demonstration cask to establish the ability of the cask to withstand a -40°F environment without sustaining structural failures.

A 4.5-ft-dia by 8-ft-high open-top steel tank was insulated with polyurethane foam and mounted on a 6-in-thick wooden pallet. Copper-constantan thermocouples were installed on the inside and outside walls of the cask and on the inside of the tank to measure the test temperatures.

The cask was placed in the tank, and the tank was filled to near the top of the cask with a 45% methanol-water solution containing dry ice. The cask was cooled until all of the test temperatures were below -40°F . The cask cavity was hydrostatically tested at a pressure of 375 psig by using -45°F methanol solution for the test fluid without a leak developing in the cask. The average temperature of the cask was below -40°F for 6 hours prior to the time that the hydrostatic test was conducted. Figure 28 shows the demonstration cask being removed from the low temperature exposure bath.

THERMAL SHOCK TEST

Figure 27

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LOW TEMPERATURE EXPOSURE TEST

Figure 28

The standard inspection tests made after the low temperature exposure test showed no cladding failures or dimensional changes which could affect the performance of the cask.

NORMAL TRANSIT TEST

The cask was shipped from Paducah, Kentucky, to Oak Ridge, Tennessee, by railcar and was returned to Paducah by a tractor trailer shipment. This test was made to demonstrate the ability of the cask and tie-down systems to withstand normal transit conditions and a series of severe railroad switching operations.

A 2500-lb simulated fuel element assembly was installed inside of the cask to represent the weight of four full-length Indian Point core A fuel elements securely positioned against the cask lid. The cask cavity was filled 90% full with a water-soluble fluorescent leak detection oil, and it was pressurized to 200 psig with nitrogen.

The railcar and tractor trailer were modified to accommodate the horizontal cask, and the tie-down systems were designed to meet applicable regulations for shipping radioactive materials although no materials of this type were shipped during the tests.

The cask was shipped from Paducah to Oak Ridge on railcar USAX-38655 by using regularly scheduled Illinois Central and Louisville and Nashville railroad freight shipments. An extra caboose was installed ahead of the test car, and two Sandia engineers familiar with the environmental sampling equipment and the test road beds rode in the extra caboose through the cooperation of the Illinois Central and Louisville and Nashville Railroads. The test car was positioned between the extra caboose and the regular caboose that was located at the end of the train. The environmental sampling equipment indicator lights were positioned so they could be seen from the extra caboose.

The environmental recordings were taken at predetermined locations where typical railroad curve, grade, roadbed, run-in and run-out, and train speed shock-loading conditions existed. These recordings were made by operating the radio-controlled environmental recording equipment from the extra caboose and by monitoring each operation through the use of a portable acceleration meter and the environmental sampling equipment indicating lights. Figures 29, 30, and 31 are photographs of the railcar shipment, cask tie-down system and environmental sampling system, and the accelerometer cluster mounting system used on the end of the railcar.

The instrumented cask was returned to the Paducah Plant by a special tractor trailer shipment incorporating a reinforced trailer frame. The ELI-31 environmental sampling equipment used during this test was operated by a direct wire control system located in the tractor cab. Figures 32, 33, and 34 are photographs of the tractor trailer shipment, cask tie-down system and environmental sampling equipment, and the direct wire instrument control system.

The electrical accelerometer, cavity pressure, shipping skid load cell, and tie-down strain gauge data presented in this report were obtained through the cooperation of the Environmental Data Analysis Group of the Sandia Corporation of Albuquerque, New Mexico. A preliminary analysis of this data has shown that the maximum steady state rail and truck acceleration rates were as shown in table 5. A computerized systems analysis of the normal transit test data is

RAILCAR EQUIPPED FOR NORMAL TRANSIT TEST

Figure 29

ENVIRONMENTAL SAMPLING SYSTEM FOR THE RAILCAR NORMAL TRANSIT TEST

Figure 30

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RAILCAR ACCELEROMETER MOUNT

Figure 31

3457-17 (U)

DIRECT WIRE CONTROL SYSTEM FOR THE
TRACTOR TRAILER ENVIRONMENTAL SAMPLING SYSTEM

Figure 34

3457-22 (U)

being prepared by the Sandia Corporation for publication in the near future. This report will present a dynamic environmental analysis of the railroad and tractor trailer transport tests.

Table 5

MAXIMUM ACCELERATION RATES
FOR THE NORMAL TRANSIT TESTS

<u>Operation and Instrument Location</u>	<u>Acceleration Rates (g)</u>		
	<u>Longitudinal</u>	<u>Transverse</u>	<u>Vertical</u>
Railcar switching - tie-down pedestal	5.75	4.50	6.00
Railcar switching - shipping skid	4.70	2.30	4.50
Railcar at 50 mph - shipping skid	0.75	0.75	0.75
Railcar run-in, run-out at 40 mph - near coupling	4.50	2.00	2.00
Railcar run-in, run-out at 40 mph - shipping skid	2.00	1.00	1.00
Truck on concrete road at 50 mph - tie-down pedestal	<1.00	<1.00	1.50
Truck on concrete road at 50 mph - shipping skid			1.50
Truck into dip and railroad tracks at 40 mph - tie-down pedestal	<1.00	<1.00	3.00
Truck into dip and railroad tracks at 40 mph - shipping skid			2.00

The maximum longitudinal loading conditions for the tie-down bars between the railcar anchor studs and the ends of the shipping skid were as follows:

Railcar switching operations	8000 lbs
Railcar running at 50 mph	3000 lbs
Railcar run-in, run-out impact conditions	3000 lbs

The shipping skid load cells were loaded to 2000 lbs when the skid accelerometers experienced a 2 g vertical acceleration.

The nitrogen pressure was monitored throughout both trips, and no indications of a cavity leak developed. The tie-down systems performed as designed, and

no damage was sustained by the cask or tie-down systems when the railcar was switched under heavy impact loading conditions.

The standard inspection tests made after the normal transit tests showed no cladding failures or dimensional changes which could affect the performance of the cask.

DESTRUCTIVE TEST PROGRAM

INTRODUCTION

The destructive test program consisted of a 30-ft free fall drop test, a 40-in free fall drop puncture test, and a thermal exposure test. This test series was made according to the above sequence, and it was followed by the radiation attenuation test. The detailed test procedures for the destructive test program are presented in the appendix.

30-FOOT FREE FALL CLOSURE EDGE DROP TEST

The cask containing the simulated fuel element was drop tested on its closure edge on an essentially immovable surface to demonstrate the ability of the cask to withstand physical damage and prevent radioactive material from escaping to the outside of the cask when it was dropped in a position for which maximum damage was expected. Limited amounts of quantitative data were obtained to measure the cask and fuel element assembly deceleration rates, the stresses generated in critical cladding areas near the point of impact, and the time that the cask was on and off of the drop test pad.

The cask was equipped with two electrical accelerometers and 18 strain gauge assemblies as shown in figure 35, and a mechanical accelerometer was mounted on the bottom outside surface of the cask. Two mechanical accelerometers were also mounted on the impact end of the simulated fuel element assembly, and the assembly was positioned securely against the cask lid through a spring loading device. The cask cavity was filled 90% full with a water-soluble fluorescent leak detection oil, and it was pressurized to 200 psig with nitrogen.

The cask was rigged to drop at an angle of $18^{\circ}45'$ from the vertical to place the center of gravity of the cask directly over the point of impact. The cask and simulated fuel element weighed 28,190 lbs which gave a drop test pad-to-cask weight ratio of 10.7 to 1. Normal-speed and high-speed motion picture photography was used to document all phases of the drop test. Figures 36 and 37 are photographs of the drop test area and the inside of the drop test instrument trailer.

Continuity tests were made on the strain gauges installed on the cask prior to the drop tests. These tests showed that the 15-3 static strain gauge developed an open circuit while the simulated fuel element was being placed in the cask and that the 17-2 dynamic strain gauge developed a grounded circuit when the cask was inverted for the drop test.

The dynamic drop test instrument recordings are shown in figures 38 and 39. This data and the results from the mechanical accelerometer tests showed the following maximum deceleration rates for:

The bottom of the lid (electrical accelerometer)	445 g
The bottom of the cask (electrical accelerometer)	281 g
The bottom of the cask (mechanical accelerometer)	230 g
The simulated fuel element (mechanical accelerometer)	200 g

NOTES

- Four longitudinal lid stud strain gauges spaced equally from the point of impact
- Six 60° static strain gauge rosettes spaced evenly around the outside stainless steel cladding.
- Six 60° static strain gauge rosettes spaced evenly around the inside stainless steel cladding
- ▲ 60° dynamic strain gauge rosettes

30-FOOT FREE FALL DROP TEST ELECTRICAL ACCELEROMETER AND STRAIN GAUGE LOCATIONS

Figure 35

30 - FOOT FREE FALL DROP TEST AREA

Figure 36

DROP TEST INSTRUMENT TRAILER

Figure 37

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30-FOOT FREE FALL DROP TEST INSTRUMENT RECORDING
FOR THE FIRST CASK IMPACT WITH THE DROP TEST PAD

Figure 38

30-FOOT FREE FALL DROP TEST INSTRUMENT RECORDING
FOR THE SECOND CASK IMPACT WITH THE DROP TEST PAD

Figure 39

Calculations have shown that the body of the cask came in contact with the drop test pad approximately 0.007 of a second after the sacrificial fins made contact with the pad, and evidences of these conditions can be seen on the dynamic drop test instrument recordings. The No. 1 electrical accelerometer on the bottom of the cask showed a maximum deceleration rate of 281 g's after the body of the cask made contact with the pad. This deceleration rate is 16.7% higher than the maximum deceleration rate experienced while the impact fins were being distorted. The No. 2 electrical accelerometer on the bottom of the lid showed a maximum deceleration rate of 445 g's shortly after the time of impact. The remainder of this acceleration recording was affected by a capacitance bleed off from a damaged section of the accelerometer charge amplifier cable which was crushed by the simulated fuel element.

The high strain indications associated with the discontinuities in the No. 21 and No. 24 lid stud strain gauge recordings are probably due to a combination of lateral and tensile forces on the studs. The impact displacement of the lid produced lateral stud forces that were large enough to distort the stud flange around nine of the lid studs.

The strain gauge tests made after the drop showed that the 7-1 and 7-2 dynamic gauges had also developed open circuits. An analysis of the strain recordings for these gauges has shown that the gauges failed in 0.004 to 0.005 of a second after the initial time of impact.

Stress values in excess of the stainless steel cladding yield point were indicated for localized areas on the inside and outside of the cask, but there were no indications of a cladding failure. Table 6 shows the calculated stress values for the 30-ft drop test. The following equations from "The Strain Gage Primer"⁷ were used for making the stress analysis.

$$\sigma_{\max} = E \left[\frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3(1 - \mu)} + \frac{1}{1 + \mu} \sqrt{\left(\epsilon_1 - \frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3} \right)^2 + \left(\frac{\epsilon_2 - \epsilon_3}{\sqrt{3}} \right)^2} \right]$$

$$\sigma_{\min} = E \left[\frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3(1 - \mu)} - \frac{1}{1 + \mu} \sqrt{\left(\epsilon_1 - \frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3} \right)^2 + \left(\frac{\epsilon_2 - \epsilon_3}{\sqrt{3}} \right)^2} \right]$$

$$\tau_{\max} = \frac{E}{1 + \mu} \sqrt{\left(\epsilon_1 - \frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3} \right)^2 + \left(\frac{\epsilon_2 - \epsilon_3}{\sqrt{3}} \right)^2}$$

$$\psi_p = \frac{1}{2} \tan^{-1} \left[\frac{\frac{1}{\sqrt{3}}(\epsilon_2 - \epsilon_3)}{\epsilon_1 - \frac{\epsilon_1 + \epsilon_2 + \epsilon_3}{3}} \right]$$

Definitions:

- $\sigma_{\max}$ = Maximum normal stress
- $\sigma_{\min}$ = Minimum normal stress
- $\tau_{\max}$ = Maximum shearing stress
- ψ_p = Angle from gauge 1 axis to maximum normal stress
- $\epsilon_1, \epsilon_2, \epsilon_3$ = Strain readings in microinches per inch
- μ = Poisson's ratio for 304 L stainless steel
- E = Young's modulus of elasticity for 304 L stainless steel

STRAIN GAUGE NUMBERS		MICROINCHES PER INCH	P.S.I. σ max.	P.S.I. σ min.	P.S.I. τ max.	φ_p
1	1	+ 14,350	*			
	2	+ 1,255				
	3	+ 110				
2	1	+ 290	*			
	2	+ 5,715				
	3	- 560				
3	1	+ 65	+ 6,720	+ 12	+ 3,345	132.36°
	2	- 40				
	3	+ 210				
4	1	+ 20	+ 5,298	+ 1,415	+ 1,941	113.05°
	2	+ 55				
	3	+ 160				
5	1	+ 65	+ 11,061	+ 1,795	+ 4,632	57.53°
	2	+ 350				
	3	+ 35				
6	1	+ 450	*			
	2	- 375				
	3	+ 3,120				
7	1	- 294	+ 22,713	- 4,142	+ 13,427	89.18°
	2	+ 187				
	3	+ 160				

11	1	+ 65	+ 30,932	+ 9,068	+ 10,932	73.99°
	2	+ 885				
	3	+ 450				
12	1	+ 570	*			
	2	+ 430				
	3	+ 1,340				
13	1	+ 250	+ 12,832	+ 8,025	+ 2,403	136.83°
	2	+ 150				
	3	+ 330				
14	1	+ 50	+ 3,786	- 1,072	+ 2,429	109.56°
	2	+ 15				
	3	+ 130				
15	1	+ 530	—	—	—	—
	2	+ 560				
	3	OPEN				
16	1	+ 1,925	*			
	2	+ 510				
	3	+ 270				
17	1	+ 1,149	—	—	—	—
	2	GROUNDING				
	3	+ 401				

21			- 30,930			
22			- 39,390			
23			+ 39,390			
24			- 25,320			

* INDICATED STRESS WAS ABOVE THE YIELD POINT.

7 DYNAMIC STRAIN GAUGE FOR OUTSIDE CLADDING.

17 DYNAMIC STRAIN GAUGE FOR INSIDE CLADDING.

21 THRU 24 DYNAMIC STRAIN GAUGE FOR LID STUDS.

1 THRU 6 STATIC STRAIN GAUGES FOR OUTSIDE CLADDING.

11 THRU 16 STATIC STRAIN GAUGES FOR INSIDE CLADDING.

**CALCULATED STRESS VALUES FOR THE 30-FOOT
FREE FALL CLOSURE EDGE DROP TEST**

Table 6

The cask was on the drop test pad for 20 milliseconds before it rebounded approximately 9 inches, and it was off the pad 120 milliseconds before pad contact was re-established. An elevation survey before and after the drop test showed no permanent pad displacement.

The 250 psig cavity rupture disk was blown to a pressure relief volume designed to prevent the fluorescent oil from escaping to the outside of the cask. This relief system allowed precise measurements to be made on the amount of oil which leaked across the lid gasket after the time of impact.

The generation of high-pressure hydraulic systems in a shipping cask, under impact loading conditions, is obviously not restricted to uranium shielded casks. Accordingly, the design and testing of an optimum pressure relief system never were intended to be within the scope of this project.

An ultraviolet light inspection of the lid, cask surfaces, drop test pad, and the absorbent paper between the lid and cavity wall showed that 0.1 to 0.2 ml of fluorescent leak detection oil leaked across the lid seal, but none of the oil reached the outside surfaces of the cask. This type of inspection can detect the presence of 0.0001 ml of the leak detection oil used. The cask cavity contained approximately 108 liters of oil.

The cask cavity pressure was 165 psig 5 hours after the drop test was completed; however, there was no additional pressure drop during the next 24 hours. The pressure drop was due to nitrogen absorbed into the fluorescent oil in the cask cavity. Cask pressure tests have confirmed that the oil will absorb the required amount of nitrogen to account for the pressure drop experienced during the drop test.

An inspection of the cask showed that the impact damage was isolated to approximately half of the closure end impact fins and to a small section of the stud flange that the fins were welded to. Figure 40 is a photograph of the cask closure end damage. Seven of the lid stud nuts, near the point of impact, were finger tight after the test due to the deformation of the stud flange. The remaining stud nuts were still torqued to between 50 and 480 ft-lbs. The original torque was 500 ft-lbs. Figure 41 is a drawing of the loose nut positions, and figure 42 is a drawing of the distorted holes in the lid flange.

The damaged impact fins were removed from the cask with an air blast cutting torch. It was necessary to remove all of the undamaged lid studs and free two jammed studs before the lid could be removed without difficulty. The jammed studs were freed by scarfing away a small amount of the lid flange around each of the jammed studs. The steps required to remove the lid could have been performed safely if the cask had contained a spent fuel element assembly.

The standard inspection tests made after the 30-ft free fall test showed no cladding failures or dimensional changes which could affect the performance of the cask. The precision measurements made on the cask showed that the maximum change in cavity diameter was located near the top of the cavity. This dimensional change was -0.053 in. Figure 43 shows the location of the precision measurements made on the cask. Tables 7 through 10 show the precision measurements made before and after the drop test.

The results of the 30-ft drop test demonstrated the ability of the cask to pass the hypothetical-accident free fall test specifications in the applicable regulations.

DEMONSTRATION CASK 30-FOOT FREE FALL CLOSURE END DAMAGE

Figure 40

3457-25 (U)

LEGEND

- BOLTS WITH NO TORQUE AFTER 30'-0" DROP TEST
- (No.) BOLT TORQUE IN Ft-Lbs AFTER 30'-0" DROP TEST

LOCATION OF LOOSE STUD NUTS
ON LID

Figure 41

LEGEND

- STUD HOLES WITH APPRECIABLE VISUAL DISTORTION
- STUD HOLES WITH NO VISUAL DISTORTION

LOCATION OF DISTORTED HOLES IN STUD FLANGE

Figure 42

DEMONSTRATION CASK PRECISION MEASUREMENT LOCATIONS
FOR THE 30-FOOT FREE FALL DROP TEST

Figure 43

POSITION NUMBER	0° TO 180°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST	26.996	26.996	20.939	20.900	20.833	17.036	16.969	16.979	16.975	16.972	16.969	16.960	16.978	16.965
AFTER TEST	26.986	27.009	20.953	20.905	20.829	17.025	17.032	16.945	16.963	16.965	16.954	16.968	16.982	16.992
DIFF. (+ or -)	-.010	+.013	+.014	+.005	-.004	-.011	+.063	-.034	-.012	-.007	-.015	+.008	+.004	+.027

POSITION NUMBER	45° TO 225°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST	26.996	26.996	20.940	20.900	20.834	17.033	16.970	16.970	16.964	16.964	16.956	16.966	16.957	16.990
AFTER TEST	26.965	26.983	20.930	20.890	20.829	17.050	16.985	16.970	16.985	16.984	16.972	16.980	16.972	16.960
DIFF. (+ or -)	-.031	-.013	-.010	-.010	-.005	+.017	+.015	.000	+.021	+.020	+.016	+.014	+.015	+.030

POSITION NUMBER	90° TO 270°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST	26.996	26.996	20.939	20.900	20.835	17.034	16.970	16.982	16.969	16.977	16.963	16.969	16.965	16.938
AFTER TEST	26.984	26.992	20.936	20.894	20.825	17.000	16.975	16.978	16.956	16.988	16.970	16.973	16.975	16.924
DIFF. (+ or -)	-.012	-.004	-.003	-.006	-.010	-.034	+.005	-.004	-.013	+.011	+.007	+.004	+.010	-.014

POSITION NUMBER	135° TO 315°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST	26.996	26.996	20.940	20.900	20.835	17.040	16.970	16.975	16.968	16.970	16.946	16.958	16.960	17.000
AFTER TEST		26.954	20.951	20.908	20.828	17.000	16.942	16.940	16.940	16.943	16.925	16.942	16.950	16.944
DIFF. (+ or -)		-.042	+.011	+.008	-.007	-.040	-.028	-.035	-.028	-.027	-.021	-.016	-.010	-.056

NOTE: POINT OF IMPACT WAS AT 0° ALL DIMENSIONS SHOWN ARE IN INCHES

PRECISION MEASUREMENTS 1 THROUGH 14 FOR THE
30-FOOT FREE FALL CLOSURE EDGE DROP TEST

Table 7

POSITION NUMBER	0° TO 180°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	31.018	31.046	30.998	29.958	29.953	29.945	30.021	29.902	35.945	35.916	35.916	35.917	35.917	35.914
AFTER TEST	31.056	31.103	31.047	29.945	29.948	29.909	30.027	29.898	35.920	35.897	35.894	35.889	35.893	35.898
DIFF. (+ or -)	-.038	+.057	+.049	-.013	-.005	-.036	+.006	-.004	-.025	-.019	-.022	-.028	-.024	-.016

POSITION NUMBER	45° TO 225°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	31.000	31.000	31.011	29.915	29.927	29.929	30.034	29.917	35.971	35.913	35.900	35.916	35.902	35.914
AFTER TEST	31.092	31.070	31.028	29.915	29.910	29.917	30.031	29.877	35.945	35.904	35.874	35.884	35.882	35.898
DIFF. (+ or -)	+.092	+.070	+.017	.000	-.017	-.012	-.003	-.040	-.026	-.009	-.026	-.032	-.020	-.016

POSITION NUMBER	90° TO 270°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	31.092	31.036	31.047	29.950	29.944	29.951	30.019	29.877	35.963	35.909	35.903	35.900	35.900	35.932
AFTER TEST	30.972	31.039	31.039	29.968	29.977	29.935	30.028	29.921	35.982	35.909	35.912	35.911	35.902	35.943
DIFF. (+ or -)	-.120	+.003	-.008	+.018	+.027	-.016	+.009	+.044	+.019	.000	+.008	+.011	+.002	+.011

POSITION NUMBER	135° TO 315°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	30.998	31.037	31.037	29.959	29.930	29.928	30.053	29.885	35.958	35.907	35.906	35.918	35.892	35.928
AFTER TEST	30.952	31.039	31.061	29.961	29.944	29.942	30.073	29.921	35.982	35.909	35.925	35.938	35.906	35.907
DIFF. (+ or -)	-.046	+.002	+.024	+.002	+.014	+.014	+.020	+.036	+.024	+.002	+.019	+.020	+.014	-.021

NOTE: POINT OF IMPACT WAS AT 0°. ALL DIMENSIONS SHOWN ARE IN INCHES.

PRECISION MEASUREMENTS 15 THROUGH 28 FOR THE
30-FOOT FREE FALL CLOSURE EDGE DROP TEST

Table 8

POSITION NUMBER	"29"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	4.000	4.000	4.000	3.938	3.938	4.000	4.000	3.969
AFTER TEST	4.000	4.000	4.000	3.935	3.937	3.995	4.000	3.969
DIFF. (+ or -)	.000	.000	.000	-.003	-.001	-.005	.000	.000

POSITION NUMBER	"30"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	4.313	4.313	4.375	4.344	4.344	4.313	4.281	4.281
AFTER TEST	4.165	4.270	4.320	4.333	4.263	4.306	4.338	4.319
DIFF. (+ or -)	-0.148	-.043	-.055	-.011	-.081	-.007	+.057	+.038

POSITION NUMBER	"31"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	6.993	6.993	6.993	6.993	6.993	6.992	6.992	6.993
AFTER TEST	7.001	6.998	7.000	6.996	6.995	6.992	6.996	6.993
DIFF. (+ or -)	+.008	+.005	+.007	+.003	+.002	.000	+.004	.000

POSITION NUMBER	"32"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	60.531	60.533	60.469	60.500	60.531	60.531	60.563	60.563
AFTER TEST	60.562	60.500	60.562	60.562	60.562	60.562	60.562	60.562
DIFF. (+ or -)	+.031	-.033	+.093	+.062	+.031	+.031	+.001	+.001

POSITION NUMBER	"33"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	80.315	80.315	80.315	80.315	80.344	80.344	80.315	80.315
AFTER TEST	80.062	80.187	80.250	80.406	80.406	80.343	80.406	80.375
DIFF. (+ or -)	-.253	-.128	-.065	+.091	+.062	-.001	+.091	+.060

NOTE: POINT OF IMPACT WAS AT 0°. ALL DIMENSIONS SHOWN ARE IN INCHES.

PRECISION MEASUREMENTS 29 THROUGH 33 FOR THE
30-FOOT FREE FALL CLOSURE EDGE DROP TEST

Table 9

POSITION NUMBER	"34"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	15.063	15.125	15.315	15.250	15.063	15.188	15.125	15.000
AFTER TEST	15.063	15.125	15.315	15.250	15.063	15.188	15.125	15.000
DIFF. (+ or -)	.000	.000	.000	.000	.000	.000	.000	.000

POSITION NUMBER	"35"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	51.250	51.125	50.750	50.938	51.250	51.125	51.188	51.438
AFTER TEST	50.812	50.812	50.687	51.062	51.312	51.123	51.250	51.375
DIFF. (+ or -)	-.438	-.313	-.063	+.124	+.062	-.002	+.062	-.063

POSITION NUMBER	"36"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	7.028	7.026	7.033	7.026	7.028	7.029	7.029	7.031
AFTER TEST	7.024	7.030	7.033	7.033	7.033	7.031	7.031	7.028
DIFF. (+ or -)	-.004	+.004	.000	+.007	+.005	+.002	+.002	-.003

POSITION NUMBER	"37"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	2.874	2.875	2.874	2.876	2.874	2.875	2.874	2.875
AFTER TEST	2.875	2.878	2.877	2.878	2.877	2.873	2.875	2.877
DIFF. (+ or -)	+.001	+.003	+.003	+.002	+.003	-.002	+.001	+.002

POSITION NUMBER	"38"	"39"	"40"	"41"	"42"	"43"	"44"
BEFORE TEST	26.715	20.910	20.837	20.670	16.871	8.719	4.125
AFTER TEST	26.725	20.906	20.836	20.668	16.868	8.708	4.156
DIFF. (+ or -)	+.010	-.004	-.001	-.002	-.003	-.011	+.031

NOTE: POINT OF IMPACT WAS 0°. ALL DIMENSIONS SHOWN ARE IN INCHES.

PRECISION MEASUREMENTS 34 THROUGH 44 FOR THE 30-FOOT FREE FALL CLOSURE EDGE DROP TEST

Table 10

40-INCH FREE FALL PUNCTURE TEST

The cask was drop tested from a height of 40 inches onto an essentially immovable 6-in-dia by 8-in-high mild steel piston to demonstrate the ability of the cask to withstand puncture damage and prevent the release of radioactive material to the outside of the cask. Limited amounts of quantitative data were obtained at the time of impact to measure the cask impact loading conditions, cladding stresses, vertical diameter profile along the length of the cavity, and the time that the cask was on and off of the pad.

The cask was equipped with an electrical accelerometer, two electrical strain gauges, and nine mechanical compressometers as shown in figure 44. The cavity free volume was filled 90% full with a water-soluble fluorescent leak detection oil, and it was pressurized to 200 psig with nitrogen.

The cask was dropped in the horizontal position with its center of gravity directly over the drop test piston. The cask, without the simulated fuel element assembly, weighed 25,480 lbs which gave a drop test pad-to-cask weight ratio of 11.9 to 1.

Normal-speed and high-speed color motion picture photography was used to document all phases of the drop test. Figure 45 is a photograph of the drop test area, figure 46 is a photograph of the cask balanced on the drop test piston following the drop, and figure 47 shows a view of the heat transfer fin damage produced by the piston.

The drop test instrument recordings are shown on figures 48 and 49. The accelerometer mounted directly above the point of impact showed a maximum deceleration of 78 g, and the calculated stress values at the strain gauge locations were below the yield point for the cladding material. Table 11 shows the calculated stress values for the 40-in free fall puncture test.

Table 11

CALCULATED STRESS VALUES FOR THE
40-INCH FREE FALL PUNCTURE TEST

Strain Gauge Numbers	Microinches Per Inch	PSI $\sigma_{\max}$	PSI $\sigma_{\min}$	PSI $\tau_{\max}$	ψ_{ρ}
40-1	-6				
40-2	-44	-793	-2,064	+636	3.63°
40-3	-50				
41-1	+275				
41-2	+162	+9,987	+4,642	+2,272	12.86°
41-3	+75				
$\sigma_{\max}$ = Maximum normal stress					
$\sigma_{\min}$ = Minimum normal stress					
$\tau_{\max}$ = Maximum shearing stress					
ψ_{ρ} = Angle from gauge 1 axis to maximum normal stress

NOTE:

- ▲ 60° Dynamic Strain Gauge Rosettes

INSTRUMENT LOCATION FOR THE
40-INCH FREE FALL PUNCTURE TEST

Figure 44

40-INCH FREE FALL DROP TEST AREA

Figure 45

3457-39 (U)

DEMONSTRATION CASK BALANCED ON THE DROP TEST PISTON

Figure 46

DEMONSTRATION CASK HEAT TRANSFER FIN DAMAGE
DUE TO THE 40-INCH FREE FALL PUNCTURE TEST

Figure 47

3457-35 (U)

40-INCH FREE FALL PUNCTURE TEST INSTRUMENT RECORDING FOR THE FIRST CASK IMPACT

Figure 48

40-INCH FREE FALL PUNCTURE TEST INSTRUMENT RECORDING FOR THE SECOND CASK IMPACT

Figure 49

The cask was on the drop test piston 42 milliseconds before it rebounded approximately 5 inches, and it was off the pad for 221 milliseconds before piston contact was re-established.

The mechanical compressometers indicated that the maximum nonpermanent change in the cavity diameter was -0.47 inch and that this change took place above the point of impact. The cavity diameter profile, measured by the compressometers, changed from -0.25 inch near the top of the cavity through the maximum diameter deflection to a -0.025 inch change near the bottom of the cavity. Figure 50 is a graph of the reduction in the length of the compressometers versus the instrument locations.

The 200 psig cavity pressure decreased to 182 psig within 24 hours after the cask was pressurized with nitrogen. Therefore, the cavity was repressurized to 200 psig immediately before the drop test was made. The cask pressure was 190 psig after the test was completed. There were no signs of a lid gasket leak, and the pressure loss was probably due to nitrogen absorbed into the leak detection oil used in the cask cavity.

An ultraviolet light inspection of the lid, cask surfaces, drop test pad, and the absorbent paper between the lid and the cavity wall showed that there was no loss of fluorescent leak detection oil from the cask cavity during the drop test. The 250 psig cavity rupture disk was blown to the pressure relief volume designed to prevent the leak detection oil from escaping to the outside of the cask.

There was no loosening of the lid studs or other indications of unsatisfactory cask performance during this test, and no difficulties were encountered in removing the lid from the cask.

The standard cask tests made after the 40-in free fall test showed no cladding failures or dimensional changes which could affect the performance of the cask. The precision measurements made on the cask showed that the maximum permanent change in the cask cavity diameter was located near the point of impact. This change in diameter was -0.119 inch. Figure 51 shows the location of the precision measurements made on the cask. Tables 12 through 15 show the precision measurements made before and after the drop test.

The results of this test demonstrated the ability of the cask to pass the hypothetical accident puncture test conditions specified in applicable regulations.

THERMAL EXPOSURE TEST

The demonstration cask was fire tested for 45 minutes with a dry cavity in a 20-ft-square by 2-ft-deep fire pit to demonstrate the ability of the cask to withstand the effects of a 1475°F thermal exposure test as defined in the applicable regulations.

The cask was instrumented with 10 internal cladding, 18 external cladding, and 18 flame chromel-alumel thermocouples. The locations of the cask and fire zone thermocouples are shown in figures 52 and 53, respectively. The fire test temperatures were recorded on two recorders which were calibrated to print a temperature point every 1.5 seconds. The thermocouples were mounted on the cask and in the fire zone as shown in figures 54 and 55, respectively. The temperature

REDUCTION IN LENGTH OF COMPRESSOMETER
(Inches)

0.50
0.40
0.30
0.20
0.10
0

1 2 3 4 5 6 7 8 9

COMPRESSOMETER STATION

COMPRESSOMETER GRAPH FOR 40-INCH FREE FALL PUNCTURE TEST

Figure 50

DEMONSTRATION CASK PRECISION MEASUREMENT LOCATIONS
40-INCH FREE FALL PUNCTURE TEST

Figure 51

POSITION NUMBER	0° TO 180°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST	26.986	27.009	20.953	20.905	20.829	17.025	17.032	16.945	16.963	16.965	16.954	16.968	16.982	16.992
AFTER TEST		26.989	20.931	20.895	20.813	17.024	16.968	16.972	16.990	17.003	16.968	16.898	16.926	16.956
DIFF. (+ or -)		-.022	-.022	-.010	-.016	-.001	-.064	+.027	+.021	+.038	+.014	+.030	-.056	-.036

POSITION NUMBER	45° TO 225°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST	26.965	26.983	20.930	20.890	20.829	17.050	16.985	16.970	16.985	16.984	16.972	16.980	16.972	16.960
AFTER TEST	26.961	26.981	20.925	20.893	20.831	17.074	17.027	17.002	17.022	16.968	17.002	17.019	16.996	16.963
DIFF. (+ or -)	-.004	-.002	-.005	+.003	+.002	+.024	+.042	+.032	+.037	-.016	+.030	+.039	+.024	+.003

POSITION NUMBER	90° TO 270°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST	26.984	26.992	20.936	20.894	20.825	17.000	16.975	16.978	16.956	16.988	16.970	16.973	16.975	16.924
AFTER TEST	26.966	26.994	20.928	20.891	20.822	17.036	16.972	16.973	16.984	17.024	16.994	16.966	16.974	16.898
DIFF. (+ or -)	-.018	+.002	+.008	-.003	+.003	+.036	-.003	-.00	+.028	+.036	+.024	-.007	-.001	-.026

POSITION NUMBER	135° TO 315°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST		26.954	20.951	20.908	20.828	17.000	16.942	16.940	16.940	16.943	16.925	16.942	16.950	16.944
AFTER TEST			20.930	20.896	20.817	17.018	16.943	16.924	16.874	16.824	16.864	16.870	16.902	16.932
DIFF. (+ or -)			-.021	+.012	+.011	+.018	+.001	-.016	-.066	-.119	-.061	-.072	-.048	-.012

NOTE: POINT OF IMPACT WAS AT 0° ALL DIMENSIONS SHOWN ARE IN INCHES.

**PRECISION MEASUREMENTS 1 THROUGH 14 FOR THE
40-INCH FREE FALL PUNCTURE TEST**

Table 12

POSITION NUMBER	0° TO 180°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	31.056	31.103	31.047	29.945	29.948	29.909	30.027	29.898	35.920	35.897	35.894	35.889	35.893	35.898
AFTER TEST	31.078	31.122	31.055	29.954	29.943	29.900	30.023	29.930	35.936	35.895	35.921	35.906	35.874	35.896
DIFF. (+ or -)	+ .022	+ .019	+ .008	- .009	+ .005	- .009	- .004	+ .032	+ .016	- .002	+ .027	+ .017	- .019	- .002

POSITION NUMBER	45° TO 225°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	31.092	31.070	31.028	29.915	29.910	29.917	30.031	29.877	35.945	35.904	35.874	35.884	35.882	35.898
AFTER TEST	31.000	31.040	31.105	30.014	29.940	29.947	30.058	29.926	36.017	35.955	35.948	35.958	35.929	35.936
DIFF. (+ or -)	-.092	-.030	+ .077	+ .099	+ .030	+ .030	+ .027	+ .049	+ .072	+ .051	+ .074	+ .074	+ .047	+ .038

POSITION NUMBER	90° TO 270°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	30.972	31.039	31.039	29.968	29.917	29.935	30.028	29.921	35.982	35.909	35.912	35.911	35.902	35.943
AFTER TEST	31.000	31.035	31.038	29.973	29.972	29.942	30.034	29.890	35.990	35.929	35.944	35.925	35.915	35.929
DIFF. (+ or -)	+ .028	-.004	-.001	+ .005	+ .055	+ .007	+ .006	- .031	+ .008	+ .020	+ .032	+ .014	+ .013	-.014

POSITION NUMBER	135° TO 315°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	30.952	31.039	31.061	29.961	29.944	29.942	30.073	29.921	35.982	35.909	35.925	35.938	35.906	35.907
AFTER TEST	31.084	31.068	31.048	29.883		29.898		29.837	35.929	35.851		35.850	35.845	35.780
DIFF. (+ or -)	+ .132	+ .029	+ .013	- .078		- .044		- .084	+ .053	- .058		- .088	- .061	- .127

NOTE: POINT OF IMPACT WAS AT 0° ALL DIMENSIONS SHOWN ARE IN INCHES.

PRECISION MEASUREMENTS 15 THROUGH 28 FOR THE
40-INCH FREE FALL PUNCTURE TEST

POSITION NUMBER	"29"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	4.000	4.000	4.000	3.935	3.937	3.995	4.000	3.969
AFTER TEST	4.000	4.000	4.000	3.935	3.937	3.995	4.000	3.969
DIFF. (+ or -)	.000	.000	.000	.000	.000	.000	.000	.000

POSITION NUMBER	"30"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	4.165	4.270	4.320	4.333	4.263	4.306	4.338	4.319
AFTER TEST	4.165	4.320	4.314	4.320	4.342	4.332	4.335	4.319
DIFF. (+ or -)	.000	+.050	-.006	-.013	+.079	+.026	-.003	.000

POSITION NUMBER	"31"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	7.001	6.998	7.000	6.996	6.995	6.992	6.996	6.993
AFTER TEST	7.009	7.004	6.997	7.000	7.001	6.995	7.002	7.004
DIFF. (+ or -)	+.008	+.006	-.003	+.004	+.006	+.003	+.006	+.011

POSITION NUMBER	"32"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	60.562	60.500	60.562	60.562	60.562	60.562	60.562	60.562
AFTER TEST	60.562	60.500	60.562	60.500	60.500	60.562	60.562	60.562
DIFF. (+ or -)	.000	.000	.000	-.062	-.062	.000	.000	.000

POSITION NUMBER	"33"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	80.062	80.187	80.250	80.406	80.406	80.343	80.406	80.375
AFTER TEST	80.062	80.180	80.245	80.400	80.395	80.339	80.400	80.370
DIFF. (+ or -)	.000	-.007	-.005	-.006	.011	-.004	-.006	-.005

NOTE: POINT OF IMPACT WAS AT 0°. ALL DIMENSIONS SHOWN ARE IN INCHES.

PRECISION MEASUREMENTS 29 THROUGH 33 FOR THE
40-INCH FREE FALL PUNCTURE TEST

Table 14

POSITION NUMBER	"34"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	15.063	15.125	15.315	15.250	15.063	15.188	15.125	15.000
AFTER TEST	15.188	15.250	15.438	15.500	15.500	15.125	15.188	15.125
DIFF. (+ or -)	+.123	+.125	+.123	+.250	+.000	-.063	+.063	+.125

POSITION NUMBER	"35"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	50.812	50.812	50.687	51.062	51.312	51.123	51.250	51.375
AFTER TEST	51.250	50.875	50.937	50.875	51.188	51.375	51.250	51.063
DIFF. (+ or -)	+.338	+.063	+.250	-.187	-.124	+.252	.000	-.312

POSITION NUMBER	"36"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	7.024	7.030	7.033	7.033	7.033	7.031	7.031	7.028
AFTER TEST	7.026	7.030	7.033	7.033	7.031	7.031	7.031	7.029
DIFF. (+ or -)	+.002	.000	.000	.000	-.002	.000	.000	.001

POSITION NUMBER	"37"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	2.875	2.878	2.877	2.878	2.877	2.873	2.875	2.877
AFTER TEST	2.875	2.877	2.876	2.878	2.872	2.872	2.876	2.876
DIFF. (+ or -)	.000	-.001	-.001	.000	-.005	-.001	+.001	-.001

POSITION NUMBER	"38"	"39"	"40"	"41"	"42"	"43"	"44"
BEFORE TEST	26.725	20.906	20.836	20.668	16.868	8.708	4.156
AFTER TEST	26.720	20.905	20.830	20.660	16.868	8.708	4.156
DIFF. (+ or -)	-.00	-.001	-.006	-.008	-.000	.000	.000

NOTE: POINT OF IMPACT WAS AT 0°. ALL DIMENSIONS SHOWN ARE IN INCHES.

PRECISION MEASUREMENTS 34 THROUGH 44 FOR THE 40-INCH FREE FALL PUNCTURE TEST

Table 15

NOTES:

- Four thermocouples spaced evenly around the outside stainless steel cladding.
- Four thermocouples spaced evenly around the inside stainless steel cladding. These thermocouples will be opposite thermocouples on the outside cladding.
- ▲ Single thermocouples.

DEMONSTRATION CASK THERMOCOUPLE LOCATIONS
FOR THE THERMAL EXPOSURE TEST

Figure 52

NOTE

This location 30," 45," and 60" above initial fire pit Fuel level.

FIRE ZONE THERMOCOUPLE LOCATIONS
FOR THE THERMAL EXPOSURE TEST

Figure 53

$\frac{3}{16}$ inch diameter magnesium oxide and stainless steel sheathed, 22 gauge chromel-alumel thermocouple mount used

on the outside of the demonstration fuel element cask. The stainless steel sheath was tack welded to the cask to limit thermocouple motion, and the thermocouple wires were heliarc welded individually to the cask.

28 gauge, high temperature glass insulated thermocouples were mounted on the inside of the cask. The glass insulation was stripped from the fused end of the thermocouple wire to a point

near the hole through the $\frac{1}{2} \times \frac{1}{2} \times \frac{1}{16}$ stainless steel thermocouple mounting plate, and the plate was tack welded to the inside cladding of the cask to produce a pressed fit between the fused thermocouple joint and the cladding.

DEMONSTRATION CASK THERMOCOUPLE MOUNTING SYSTEM

Figure 54

The Above Thermocouple Is Typical Of Those Used In The Fire Zone By Heliarc Welding The Stainless Steel Sheath And The Thermocouple Wires To Stainless Steel Coupon As Shown.

FIRE ZONE THERMOCOUPLE MOUNTING SYSTEM

Figure 55

recording system was paralleled with a secondary temperature indicator capable of reading all the test temperatures and a standby motor generator set capable of furnishing the test power requirements in the event of a power failure.

The cask was placed in a horizontal position in the fire pit by supporting its ends on reinforced cast refractory columns. The longitudinal center line of the cask was located 30 inches above the initial fuel level in the pit, and 2500 gallons of kerosene were burned during the test. The kerosene burned during this test had a gross heat content of between 19,780 and 19,980 Btu/lb. A 6.5- to 8.5-ft fire wall was maintained around the cask during this test, and three 8-by-15-ft sheet metal wind deflectors were used to provide some control over the flame temperatures around the cask. An analysis of the fire test data showed that the following temperature conditions existed for over 30 consecutive minutes during the test.

Average fire temperature at center line of cask	1500°F
Average fire temperature at top of cask	1536°F
Average fire temperature 15 inches above cask	1400°F
Maximum outside cladding temperature	1520°F

Figures 56 and 57 show photographs of the test area during and after the fire test.

The cask was allowed to cool under ambient temperature conditions for 3 hours before it was cooled to an average temperature of 150°F with water from a 2-1/2-inch fire hose.

The standard inspection tests made after the thermal exposure test showed that there was no loosening of lid studs during the fire and no cladding failures. The precision measurements made on the cask showed that the maximum permanent change in the cask cavity diameter was +0.116 inch. The lid gaskets were inspected for fire damage, but no significant damage was found. The fire damage to the fluoro-elastomer ring gasket was of a minor nature and the gasket was reusable. Figure 58 shows the location of the precision measurements made on the cask. Tables 16 through 19 show the precision measurements made before and after the thermal exposure test.

The results of the demonstration cask fire test program demonstrated the ability of the cask to withstand the hypothetical accident thermal exposure conditions specified in the applicable regulations.

Attempts to measure internal cladding temperatures were not successful due to the failure of the high temperature glass insulation on the cavity thermocouples. The type of thermocouple used inside the cask was pretested satisfactorily at 2000°F, but it failed to perform properly during the fire test. This failure was probably caused by the thermocouple wire conduit bending in the fire zone and causing the wires to short out where the insulation failed.

THERMAL EXPOSURE TEST
FIRE ZONE

Figure 56

3457-48 (U)

THERMAL EXPOSURE TEST AREA AFTER FIRE

Figure 57

3457-49 (U)

DEMONSTRATION CASK PRECISION MEASUREMENT LOCATIONS FOR THE THERMAL EXPOSURE TEST

Figure 58

POSITION NUMBER	0° TO 180°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST		26.989	20.931	20.895	20.813	17.024	16.968	16.972	16.990	17.003	16.968	16.898	16.926	16.956
AFTER TEST		26.993	20.886	20.760	20.788	17.004	16.992	16.921	16.943	16.913	16.908	16.933	16.922	16.984
DIFF. (+ or -)		+ .004	-.045	-.135	-.025	-.024	+ .024	-.051	-.047	-.090	-.060	+ .035	-.004	+ .028

POSITION NUMBER	45° TO 225°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST	26.961	26.981	20.925	20.893	20.831	17.074	17.027	17.002	17.022	16.968	17.002	17.019	16.996	16.963
AFTER TEST	27.012	27.008	20.902	20.882	20.818	17.079		17.011	16.999	16.983	17.003	17.003	16.989	
DIFF. (+ or -)	+ .051	+ .027	-.023	-.011	-.013	+ .005		+ .009	-.023	+ .015	+ .001	-.016	-.007	

POSITION NUMBER	90° TO 270°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST	26.966	26.994	20.928	20.891	20.822	17.036	16.972	16.973	16.984	17.024	16.994	16.966	16.974	16.898
AFTER TEST	27.025	27.038	20.940	20.920	20.848	17.103		17.089	17.091	17.059	17.037	17.035	17.010	16.943
DIFF. (+ or -)	+ .059	+ .044	+ .012	+ .029	-.026	+ .067		+ .116	+ .105	-.035	+ .043	+ .069	+ .036	+ .045

POSITION NUMBER	135° TO 315°													
	"1"	"2"	"3"	"4"	"5"	"6"	"7"	"8"	"9"	"10"	"11"	"12"	"13"	"14"
BEFORE TEST			20.930	20.896	20.817	17.018	16.943	16.924	16.874	16.824	16.864	16.870	16.902	16.932
AFTER TEST			20.908	20.886	20.817	17.035	16.965	16.942	16.843	16.898		16.933	16.995	16.953
DIFF. (+ or -)			-.022	-.010	.000	+ .017	+ .022	+ .018	-.031	+ .074		-.063	+ .093	+ .021

NOTE: POINT OF IMPACT WAS AT 0°. ALL DIMENSIONS SHOWN ARE IN INCHES.

PRECISION MEASUREMENTS 1 THROUGH 14 FOR THE
THERMAL EXPOSURE TEST

Table 16

POSITION NUMBER	0° TO 180°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	31.078	31.122	31.055	29.954	29.943	29.900	30.023	29.930	35.936	35.895	35.921	35.906	35.874	35.896
AFTER TEST	31.075	31.084	31.025	29.900	29.890	29.883	30.117	29.939	35.880	35.823	35.840	35.835	35.845	35.873
DIFF. (+ or -)	-.003	-.038	-.030	-.054	-.053	-.017	-.094	-.009	-.056	-.072	-.081	-.071	-.029	-.023

POSITION NUMBER	45° TO 225°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	31.000	31.040	31.105	30.014	29.940	29.947	30.058	29.926	36.017	35.955	35.948	35.958	35.929	35.936
AFTER TEST	31.010	31.026	31.045	29.962	29.930	29.920	30.073	29.880	35.973	35.898	35.898	35.910	35.872	35.870
DIFF. (+ or -)	+.010	-.014	-.060	-.052	-.010	-.027	+.015	-.046	-.044	-.057	-.050	-.048	-.057	-.066

POSITION NUMBER	90° TO 270°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	31.000	31.035	31.035	29.973	29.972	29.942	30.034	29.890	35.990	35.929	35.944	35.925	35.915	35.929
AFTER TEST	31.025	31.057	31.075	29.990	29.995	29.958	30.025	29.867	35.995	35.969	35.969	35.947	35.915	35.905
DIFF. (+ or -)	+.025	+.022	+.040	+.017	+.023	+.016	-.009	-.023	+.005	+.040	-.025	+.022	.000	-.024

POSITION NUMBER	135° TO 315°													
	"15"	"16"	"17"	"18"	"19"	"20"	"21"	"22"	"23"	"24"	"25"	"26"	"27"	"28"
BEFORE TEST	31.084	31.068	31.048	29.883		29.898		29.837	35.929	35.851		35.850	35.845	35.780
AFTER TEST	31.135	31.083	31.045	29.860		29.888			35.911			35.824	35.831	35.861
DIFF. (+ or -)	+.051	+.015	-.003	-.023		-.010			-.018			-.026	-.014	-.019

NOTE: POINT OF IMPACT WAS AT 0°. ALL DIMENSIONS SHOWN ARE IN INCHES.

PRECISION MEASUREMENTS 15 THROUGH 28 FOR THE
THERMAL EXPOSURE TEST

Table 17

POSITION NUMBER	"29"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	4.000	4.000	4.000	3.935	3.937	3.995	4.000	3.969
AFTER TEST	4.000	4.000	4.000	3.935	3.937	3.995	4.000	3.969
DIFF. (+ or -)	.000	.000	.000	.000	.000	.000	.000	.000

POSITION NUMBER	"30"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	4.165	4.320	4.314	4.320	4.342	4.332	4.335	4.319
AFTER TEST	4.170	4.305	4.297	4.305	4.290	4.321	4.329	4.325
DIFF. (+ or -)	+.005	-.015	-.017	-.015	-.052	-.011	-.00	+.00

POSITION NUMBER	"31"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	7.009	7.004	6.997	7.000	7.001	6.995	7.002	7.004
AFTER TEST	7.020	7.017	7.023	7.020	7.023	7.022	7.019	7.022
DIFF. (+ or -)	+.011	+.013	+.026	+.020	+.022	+.027	+.017	+.018

POSITION NUMBER	"32"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	60.562	60.500	60.562	60.500	60.500	60.562	60.562	60.562
AFTER TEST	60.562	60.562	60.562	60.562	60.562	60.562	60.562	60.562
DIFF. (+ or -)	.000	+.062	.000	+.062	+.062	.000	.000	.000

POSITION NUMBER	"33"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	80.062	80.180	80.245	80.400	80.395	80.339	80.400	80.370
AFTER TEST	80.062	80.180	80.245	80.400	80.395	80.339	80.400	80.370
DIFF. (+ or -)	.000	.000	.000	.000	.000	.000	.000	.000

NOTE: POINT OF IMPACT WAS AT 0°. ALL DIMENSIONS SHOWN ARE IN INCHES

PRECISION MEASUREMENTS 29 THROUGH 33 FOR THE THERMAL EXPOSURE TEST

Table 18

POSITION NUMBER	"34"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	15.188	15.250	15.438	15.500	15.063	15.125	15.188	15.125
AFTER TEST	15.188	15.225	15.438	15.500	15.063	15.125	15.188	15.125
DIFF. (+ or -)	.000	.000	.000	.000	.000	.000	.000	.000

POSITION NUMBER	"35"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	51.250	50.875	50.937	50.875	51.188	51.375	51.250	51.063
AFTER TEST	51.250	50.875	50.937	50.875	51.188	51.375	51.250	51.063
DIFF. (+ or -)	.000	.000	.000	.000	.000	.000	.000	.000

POSITION NUMBER	"36"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	7.026	7.030	7.033	7.033	7.031	7.031	7.031	7.029
AFTER TEST	7.024	7.030	7.033	7.033	7.033	7.031	7.031	7.028
DIFF. (+ or -)	-.002	.000	.000	.000	+.002	.000	.000	.001

POSITION NUMBER	"37"							
	0°	45°	90°	135°	180°	225°	270°	315°
BEFORE TEST	2.875	2.877	2.876	2.878	2.872	2.872	2.876	2.876
AFTER TEST	2.875	2.878	2.871	2.878	2.877	2.873	2.875	2.877
DIFF. (+ or -)	.000	+.001	+.001	.000	+.00	+.001	-.001	+.001

POSITION NUMBER	"38"	"39"	"40"	"41"	"42"	"43"	"44"
BEFORE TEST	26.720	20.905	20.830	20.660	16.868	8.708	4.156
AFTER TEST	26.727	20.906	20.836	20.668	16.868	8.708	4.156
DIFF. (+ or -)	.000	+.001	+.006	+.008	.000	.000	.000

NOTE: POINT OF IMPACT WAS AT 0° ALL DIMENSIONS SHOWN ARE IN INCHES

PRECISION MEASUREMENTS 34 THROUGH 44 FOR THE THERMAL EXPOSURE TEST

Table 19

RADIATION ATTENUATION TEST

Although the radiation attenuation test is a part of the nondestructive testing program, it was conducted after the completion of the destructive testing sequence. A 90,000 curie ^{60}Co source was used in this test to demonstrate the ability of this type of cask to transport four Indian Point core A spent fuel elements without exceeding 200 mr/hr at any point on the external surface of the cask and 10 mr/hr one meter from the center of the cask.

The test was performed in the Los Alamos Scientific Laboratory CMB-14 hot cell area by loading five 0.94-in-dia by 8.5-in-long aluminum jacketed ^{60}Co capsules spaced equally throughout the length of the cask cavity. Each capsule contained approximately 18,000 curies of activity. This method of installing the test source was selected to approximate the radiation attenuation requirements that would be required if four cavity-length Indian Point core A spent fuel element sections were loaded in the cask. Figure 59 is a photograph of a ^{60}Co capsule being loaded into the cask in the hot cell test area.

Background radiation measurements were made on all of the accessible external surfaces of the cask and one meter from the center of the cask cavity. None of these measurements exceeded a dose rate of 1.25 mr/hr. Similar measurements were made after the test source and the lid were installed in the cask cavity. The average dose rate measured on the external cylindrical surfaces of the cask was 16.6 mr/hr, with the dose rates ranging from 9.9 to 19.3 mr/hr. The average dose rate one meter from the center of the cavity was 3.3 mr/hr, with the dose rates ranging from 1.0 to 6.7 mr/hr. The dose rate measurements made on the external surface of the lid and the bottom of the cask were 1.3 and 3.0 mr/hr, respectively. No abnormal radiation dose rates were found around the lid joint or the drain and vent line penetrations in the top and bottom sections of the cask.

LOADING ^{60}Co CAPSULE INTO THE DEMONSTRATION CASK

APPENDIX

DEMONSTRATION FUEL ELEMENT SHIPPING CASK
FROM LAMINATED URANIUM METAL - TESTING PROGRAM

The following tests prescribed under the normal conditions of transport in 10 CFR 71 were performed on the demonstration cask: (1) heat, (2) cold, and (3) vibration. The tests to determine the container performance relative to (1) pressure, (2) water spray, (3) free drop, and (4) penetration were not performed since the cask was subjected to more rigorous tests than were required by these normal conditions of transport. The corner drop and compression tests were not applicable for the demonstration cask. All of the hypothetical accident condition tests except the water immersion test were conducted. Under the postulated cask operating conditions, water leakage would be out of the cask rather than into the cask. Two additional tests were made on the cask to demonstrate the ability of the cask to withstand normal operating conditions. A thermal shock test was made by immersing the cask in cold water when it was at its normal operating temperature, and a radiation attenuation test was made to demonstrate that the cask design would provide the necessary radiation attenuation to meet the radiation dose rate requirements specified in 49 CFR 73.

The following testing procedures were developed early in the project to determine the sequential steps that would be required for the testing program. A few minor changes were made in the procedures as the project progressed; these have been described in the preceding descriptions of the actual tests.

- A. Heat Dissipation Test
- B. Thermal Shock Test
- C. Low Temperature Exposure Test
- D. Normal Transit Test
- E. 30-Foot Free Fall Drop Test
- F. 40-Inch Free Fall Drop Puncture Test
- G. Thermal Exposure Test
- H. Radiation Attenuation Test

A.

DEMONSTRATION FUEL ELEMENT SHIPPING CASK
FROM LAMINATED URANIUM METAL - TESTING PROGRAM

TEST TITLE

Heat Dissipation Test.

TEST SEQUENCE NUMBER

One.

OBJECTIVES OF TEST

1. To demonstrate the ability of this cask to dissipate the amount of heat which would be generated by four Indian Point core A spent fuel assemblies without exceeding the internal pressure calculated for the ambient temperature at the time of the test.
2. To obtain data with which coefficients of heat transfer, both through the cask shielding and from the external cladding to the ambient air, can be calculated.

CONDITIONS OF TEST

1. 43,500 Btu/hour of electrical heat will be dissipated from inside the cask cavity.
2. Cask will be dry.
3. Cask will be in horizontal attitude.
4. Ambient will be still air, in shade, at the highest available temperature (an attempt to surround the cask with 130°F air will not be made).
5. Test will be continued until thermal equilibrium conditions are assured.

DATA TO BE OBTAINED DURING TEST

1. Heat input.
2. Average temperature of cavity wall, outer cladding, fins, and ambient.

DATA TO BE OBTAINED AFTER TEST

None. Test will be followed immediately by the thermal shock test.

TESTS TO BE MADE TO CASK AFTER HEAT DISSIPATION TEST

Thermal Shock Test first; others to follow.

Heat Dissipation Test (continued)

DOCUMENTATION TO BE PROVIDED

1. Power input and thermal data will be determined by using recently calibrated test equipment with all data logged periodically by Paducah operating personnel.
2. Test setup will be photographed.

TIME REQUIRED TO PREPARE FOR TEST

Two days.

TIME REQUIRED TO EXAMINE CASK AFTER TEST

None.

PERTINENT INFORMATION

1. Heat load is equal to 8000 Btu/hr/linear foot of cask cavity plus an allowance for solar energy with the cask in the horizontal attitude. The 8000 Btu figure is about 1-1/2 times the calculated decay heat rate based on estimated service conditions and a 120-day cooling period.
2. Test will not be made in the sun due to the inherent difficulty of setting up the test out of doors.
3. There is no need to surround the cask with 130°F air since all calculations are based on temperature differentials and the effect of the lower temperature is not significant.

B.

DEMONSTRATION FUEL ELEMENT SHIPPING CASK
FROM LAMINATED URANIUM METAL - TESTING PROGRAM

TEST TITLE

Thermal Shock Test.

TEST SEQUENCE NUMBER

Two.

OBJECTIVES OF TEST

To demonstrate the ability of the cask to withstand immersion into cold water while at its normal operating temperature.

CONDITIONS OF TEST

1. Cask will be submersed into a tank of cold (approximately 75°F) water immediately following the heat dissipation test.
2. Cask will be in a vertical attitude with its end closure in place.

DATA TO BE OBTAINED DURING TEST

1. Temperature of water.
2. Cask outer wall temperature before, during, and after immersion.
3. Rate of immersion.

DATA TO BE OBTAINED AFTER TEST

Physical measurements of cask cavity.

TESTS TO BE MADE TO CASK AFTER SUBMERSION TEST

1. Hydrostat test of cask cavity at 375 psig.
2. Soap test of space within cask cladding at 5 psig.
3. Dye check of all accessible welds.

DOCUMENTATION TO BE PROVIDED

1. Test data will be recorded by Paducah operating personnel.
2. Physical measurements and the hydrostat, soap, and dye penetrant tests will be made and results recorded by the Paducah Mechanical Inspection Department.

Thermal Shock Test (continued)

DOCUMENTATION TO BE PROVIDED (continued)

3. The actual cask immersion will be photographed.
4. Any defects resulting from the test will be photographed.

TIME REQUIRED TO PREPARE FOR TEST

None.

TIME REQUIRED TO CONDUCT TEST

One day.

TIME REQUIRED TO EXAMINE CASK AFTER TEST

Two days.

PERTINENT INFORMATION

A demonstration of the integrity of the cask cladding following thermal shock is especially important for uranium casks due to the possibility of subsequent uranium-water reactions resulting from cladding failure which could result in physical distortion of the cask cladding.

C.

DEMONSTRATION FUEL ELEMENT SHIPPING CASK
FROM LAMINATED URANIUM METAL - TESTING PROGRAM

TEST TITLE

Low Temperature Exposure Test.

TEST SEQUENCE NUMBER

Three.

OBJECTIVES OF TEST

1. To demonstrate the ability of the cask to withstand exposure to a -40°F environment without structural failure.
2. To obtain a limited amount of quantitative data relative to cask cooling rate.

CONDITIONS OF TEST

1. Cask will be placed into a -40°F methanol-water-dry ice bath for 4 hours.
2. Cask will be in its horizontal attitude with its end closure in place.
3. Cask will be at ambient temperature at start of test.

DATA TO BE OBTAINED DURING TEST

1. Time of exposure and bath temperature.
2. Cask inner wall and outer wall temperatures during cooling.

DATA TO BE OBTAINED AFTER TEST

Physical measurements of cask cavity.

TESTS TO BE MADE TO CASK AFTER TEST

1. Hydrostat of cask cavity at 375 psig using methanol-water solution as a test fluid while cask is still cold.
2. Soap test of space within cask cladding at 5 psig after cask reaches ambient temperature.
3. Dye check of all accessible welds.

Low Temperature Exposure Test (continued)

DOCUMENTATION TO BE PROVIDED

1. Test data will be recorded by Paducah operating personnel.
2. Physical measurements and the hydrostat, soap, and dye penetrant checks will be made and results recorded by the Paducah Mechanical Inspection Department
3. The test setup will be photographed.
4. Any defects resulting from the test will be photographed.

TIME REQUIRED TO PREPARE FOR TEST

One day.

TIME REQUIRED TO CONDUCT TEST

One day.

TIME REQUIRED TO EXAMINE CASK AFTER TEST

Two days.

D.

DEMONSTRATION FUEL ELEMENT SHIPPING CASK
FROM LAMINATED URANIUM METAL - TESTING PROGRAM

TEST TITLE

Normal Transit Test.

TEST SEQUENCE NUMBER

Four.

OBJECTIVES OF TEST

1. To demonstrate the ability of the cask, shipping supports, and attachments to the tie-down system to withstand normal transit conditions.
2. To obtain a limited amount of quantitative data relative to the conditions experienced by the cask in normal rail and truck transit.

CONDITIONS OF TEST

1. Cask will travel from Paducah to Oak Ridge for the radiation attenuation test and be returned to Paducah. Transportation will be by rail in one direction and by truck in the other.
2. Cask will be 90% full of water at approximately 200 psig.
3. Cask will be in its horizontal attitude and attached to the vehicle in a suitable manner to withstand the anticipated transit conditions.
4. Cask will be at ambient temperature.
5. A mass which simulates the weight of four full-length Indian Point core A fuel assemblies will be secured within the cask.

DATA TO BE OBTAINED DURING TEST

1. Shock recorders on the vehicle and accelerometers on the cask will provide a record of the conditions experienced in transit.
2. Pressure within the cask cavity will be recorded continuously.

DATA TO BE OBTAINED AFTER TEST

1. Physical measurements of the cask cavity.
2. Physical measurements at any location where damage is found.

TESTS TO BE MADE TO CASK AFTER TEST

1. Hydrostat of cask cavity at 375 psig.

Normal Transit Test (continued)

2. Soap test of space within the cask cladding at 5 psig.
3. Dye check of all accessible welds.

DOCUMENTATION TO BE PROVIDED

1. Test data will be recorded by Paducah operating personnel.
2. Physical measurements and the hydrostat, soap, and dye checks will be made and results recorded by the Paducah Mechanical Inspection Department.
3. The cask, shipping supports and tie-down arrangements will be photographed during both modes of travel.
4. Any failures of the tie-down equipment, cask supports, etc., will be photographed.

TIME REQUIRED TO PREPARE FOR TEST

One day.

TIME REQUIRED TO CONDUCT TEST

Two weeks.

TIME REQUIRED TO EXAMINE CASK AFTER TEST

Two days.

PERTINENT INFORMATION

1. Since cask will be empty during transport, the tie-down system may not be comparable to that normally used for this type shipment.
2. The specified data, tests, and documentation will be obtained both at ORNL after the first leg of the trip and again after cask is returned to Paducah.

E.

DEMONSTRATION FUEL ELEMENT SHIPPING CASK
FROM LAMINATED URANIUM METAL - TESTING PROGRAM

TEST TITLE

30-Foot Free Fall Drop Test.

TEST SEQUENCE NUMBER

Five.

OBJECTIVES OF TEST

1. To demonstrate the ability of the cask to fall freely for 30 feet and strike its most vulnerable area against an essentially immovable surface without suffering significant physical damage or permitting the escape of radioactive materials.
2. To obtain some quantitative data relative to the shock experienced by fuel assemblies within a uranium cask during this hypothetical accident.
3. To determine some quantitative data relative to stresses generated in certain areas of the cask at impact.
4. To determine some quantitative data relative to the general behavior of a uranium cask during this hypothetical accident.

CONDITIONS OF TEST

1. Cask will be dropped 30 feet onto an essentially unyielding surface.
2. Cask will strike on its end closure with its center of gravity above the point of impact.
3. Cask will be in an approximate 45° angle to the horizontal at time of impact.
4. Cask will be 90% full of water at approximately 200 psig.
5. Cask will be at ambient temperature.
6. Cask will have a mass equal to the weight of four full-length Indian Point core A fuel assemblies securely positioned against its end closure.

DATA TO BE OBTAINED DURING TEST

1. Shock data will be obtained by using mechanical accelerometers within the cask cavity.
2. Stress data will be obtained on the cask exterior by using brittle lacquer and strain gauges.

30-Foot Free Fall Drop Test (continued)

3. Photographic data will be obtained by using high-speed cameras throughout the time of free fall and until cask comes to rest.

DATA TO BE OBTAINED AFTER THE TEST

1. Extensive physical measurements will be made of both interior and exterior cask surfaces to determine the extent of any damage resulting from the drop.
2. Cask pressure will be determined.
3. The quantity of water within the cask will be measured to determine whether or not water was lost at the moment of impact.

TESTS TO BE MADE TO CASK AFTER THE TEST

1. Hydrostat test of cask cavity at 375 psig.
2. Soap test of space within cask cladding at 5 psig.
3. Dye penetrant test of all accessible welds.
4. Dye penetrant test of cladding in the impact area.

DOCUMENTATION TO BE PROVIDED

1. Data will be recorded by Paducah operating personnel.
2. Physical measurements and the hydrostat, soap, and dye penetrant checks will be made and the results recorded by the Paducah Mechanical Inspection Department.
3. Test setup and actual drop will be photographed.
4. Cask will be photographed from several views after test.
5. Drop test pad will be surveyed for any change in elevation or attitude resulting from the impact.

TIME REQUIRED TO PREPARE FOR TEST

Two days.

TIME REQUIRED TO CONDUCT TEST

One day.

TIME REQUIRED TO EXAMINE CASK AFTER TEST

Three days.

30-Foot Free Fall Drop Test (continued)

PERTINENT INFORMATION

1. Drop pad has a pad-to-cask mass ratio of 12.6:1.
2. A backdrop marked with 6-inch red and yellow squares will be used to provide a means of measuring relative motion during and after impact.
3. The dropping harness will be restrained from striking the cask after impact.
4. Cask will be raised above pad by a 20-ton mobile crane.
5. An electrically operated timer will synchronize the time of the drop with the high-speed cameras.
6. High-speed camera will operate, using color film if possible, at 2000 frames per second.
7. The quick release device will be operated by a single explosive device activated by an electrical signal from a program timer.
8. A microphone on the pad surface will indicate the precise times of impact.
9. A timing disc rotating at 3600 rpm (synchronous speed) will be used in conjunction with the high-speed camera to obtain precise data relating time to motion.

F.

DEMONSTRATION FUEL ELEMENT SHIPPING CASK
FROM LAMINATED URANIUM METAL - TESTING PROGRAM

TEST TITLE

40-Inch Free Fall Drop Puncture Test.

TEST SEQUENCE NUMBER

Six.

OBJECTIVES OF TEST

1. To demonstrate the ability of the cask to fall freely for 40 inches and strike its most vulnerable area against an essentially immovable piston without suffering significant physical damage or permitting the escape of radioactive materials.
2. To obtain some quantitative data relative to the shock experienced by fuel assemblies within a uranium cask during this hypothetical accident.
3. To determine some quantitative data relative to stresses generated in certain areas of the cask at impact.
4. To determine some quantitative data relative to the general behavior of a uranium cask during this hypothetical accident.

CONDITIONS OF TEST

1. Cask will be dropped 40 inches onto an essentially unyielding 6-inch diameter by 8-inch high piston.
2. Cask will strike on its side with its center of gravity above the point of impact in an area along the longitudinal cladding weld.
3. Cask will be in a horizontal attitude at time of impact.
4. Cask will be 90% full of water at approximately 200 psig.
5. Cask will be at ambient temperature.
6. Cask will have a mass equal to the weight of four full-length Indian Point core A fuel assemblies secured within the cask cavity.

DATA TO BE OBTAINED DURING TEST

1. Shock data will be obtained by using mechanical accelerometers within the cask cavity.
2. Stress data will be obtained on the cask exterior by using brittle lacquer and strain gauges.

40-Inch Free Fall Drop Puncture Test (continued)

3. Photographic data will be obtained by using high-speed cameras throughout the time of free fall and until the cask comes to rest.
4. Mechanical compressometers will be installed to indicate the maximum distortion experienced within the cask cavity.

DATA TO BE OBTAINED AFTER TEST

1. Extensive physical measurements will be made of both interior and exterior cask surfaces to determine the extent of any damage resulting from the drop.
2. Cask pressure will be determined.
3. The quantity of water within the cask will be measured to determine whether or not water was lost at the moment of impact.

TESTS TO BE MADE TO CASK AFTER TEST

1. Hydrostat test of cask cavity at 375 psig.
2. Soap test of space within cask cladding at 5 psig.
3. Dye penetrant test of all accessible welds.

DOCUMENTATION TO BE PROVIDED

1. Test data will be obtained and recorded by Paducah operating personnel.
2. Physical measurements and hydrostat, soap, and dye penetrant checks will be made and results recorded by the Paducah Mechanical Inspection Department.
3. Test setup and actual drop will be photographed.
4. Cask will be photographed from several views after test.

TIME REQUIRED TO PREPARE FOR TEST

Two days.

TIME REQUIRED TO CONDUCT TEST

One day.

TIME REQUIRED TO EXAMINE CASK AFTER TEST

Three days.

40-Inch Free Fall Drop Puncture Test (continued)

PERTINENT INFORMATION

1. Drop pad has a pad-to-cask mass ratio of 12.6:1.
2. A backdrop marked with 6-inch red and yellow squares will be used to provide a means of measuring relative motion during and after impact.
3. The dropping harness will be restrained from striking the cask after impact.
4. Cask will be raised above pad by a 20-ton mobile crane.
5. An electrically operated timer will synchronize the time of the drop with the high-speed cameras.
6. High-speed camera will operate, using color film if possible, at 2000 frames per second.
7. The quick release device will be operated by a single explosive device activated by an electrical signal from a program timer.
8. A microphone on the pad surface will indicate the precise time of impact.
9. A timing disc rotating at 3600 rpm (synchronous speed) will be used in conjunction with the high-speed camera to obtain precise data relating time to motion.

G.

DEMONSTRATION FUEL ELEMENT SHIPPING CASK
FROM LAMINATED URANIUM METAL - TESTING PROGRAM

TEST TITLE

Thermal Exposure Test.

TEST SEQUENCE NUMBER

Seven.

OBJECTIVES OF TEST

1. To demonstrate the ability of the cask to withstand the effects of the hypothetical fire as defined in 10 CFR 71 and AEC Chapter 0529.
2. To obtain a limited amount of quantitative data relative to the rate of heat absorption by the cask from which an estimate of actual cask internal temperature and pressure during this hypothetical accident can be made.

CONDITIONS OF TEST

1. Cask will be exposed to a petroleum fire having temperatures ranging between 1500°F and 1850°F for 30 minutes.
2. Cask will be in a horizontal attitude supported approximately 30 inches above the surface of an oil fire.
3. Fire will extend beyond the outline of the cask by at least 3 feet in all directions.
4. No water will be inside the cask.
5. Cask will be cooled in air, after the 30-minute test period has ended, until the internal cask temperatures start to drop. At this time, the cask will be removed from the fire test area and cooled with water from a 2-1/2-inch fire hose until the average temperature of the cask is 150°F.

DATA TO BE OBTAINED DURING TEST

Internal and external cask cladding temperatures and extensive flame temperatures will be recorded by a high-speed recorder throughout the test.

DATA TO BE OBTAINED AFTER TEST

Extensive physical measurements will be made of both interior and exterior cask surfaces to determine the extent of any damage resulting from the fire exposure.

Thermal Exposure Test (continued)

TESTS TO BE MADE TO CASK AFTER TEST

1. Hydrostat test of cask cavity at 375 psig.
2. Soap test of space within cladding at 5 psig.
3. Dye penetrant test of all accessible welds.

DOCUMENTATION TO BE PROVIDED

1. Test data will be determined and recorded by Paducah operating personnel.
2. Physical measurements and the hydrostat, soap, and dye penetrant checks will be made and the results will be recorded by the Paducah Mechanical Inspection Department.
3. Any failure of the cask will be photographed.
4. Photographs will be made of the test setup.
5. Photographs will be made during the actual fire test.

TIME REQUIRED TO PREPARE FOR TEST

Two weeks.

TIME REQUIRED TO CONDUCT TEST

Two days.

TIME REQUIRED TO EXAMINE CASK AFTER TEST

Two days.

PERTINENT INFORMATION

1. Fire will utilize No. 2 diesel oil as fuel.
2. Oil will be contained in a 9-foot by 13-foot pan.
3. Backdrops will be provided to assure that the cask will be completely enveloped with fire at all times.

H.

DEMONSTRATION FUEL ELEMENT SHIPPING CASK
FROM LAMINATED URANIUM METAL - TESTING PROGRAM

TEST TITLE

Radiation Attenuation Test.

TEST SEQUENCE NUMBER

Eight.

OBJECTIVES OF TEST

1. To demonstrate the ability to design and fabricate a uranium shipping cask which will provide the required amount of radiation attenuation to permit shipment of four Indian Point core A spent fuel assemblies without exceeding the specified limits for radiation levels outside the cask.
2. To demonstrate uniformity of radiation attenuation over all cask surfaces with no high radiation areas such as at the closure or drain penetrations.

CONDITIONS OF TEST

1. Cask will be loaded with a radiation source at Oak Ridge National Laboratory. The source will simulate the activity of four Indian Point core A spent fuel assemblies.
2. Cask will be dry during this test.

DATA TO BE OBTAINED DURING TEST

1. Background radiation level before cask is loaded.
2. Radiation levels at all areas around the cask surface.
3. Average temperature of outer wall, fins, and ambient.

DATA TO BE OBTAINED AFTER TEST

None.

TESTS TO BE MADE TO CASK AFTER TEST

None.

Radiation Attenuation Test (continued)

DOCUMENTATION TO BE PROVIDED

Information relative to source strength and radiation levels will be logged on appropriate data sheets and certified by Oak Ridge National Laboratory.

TIME REQUIRED TO PREPARE FOR TEST

One day.

TIME REQUIRED TO CONDUCT TEST

One day.

TIME REQUIRED TO EXAMINE CASK AFTER TEST

None.

PERTINENT INFORMATION

Cask was designed for 5-3/4 inches of uranium shielding or equivalent. This amount of shielding should provide the same level of radiation at the cask surface when loaded with four Indian Point core A assemblies as is provided by the G. E. 15 x 140 cask when loaded with two Indian Point core A assemblies.

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