6.8 *TEST #5.2.8 - 30-FT FREE DROP TEST: TOP END DROP ORIENTATION*

Test # 6	**Step 5.2.8 - MDS Nordion Test Plan IN/QA 1368 F-294 (1)** **Hypothetical Accident Condition 30-ft Free Drop** (Ref: MDS Nordion Dwg. F629401-011, see Figure 2.10.12-F124)
Date test conducted:	February 25, 1998

Conditions

- Drop height = 30 feet
- Orientation: Inverted (top end drop). Puncture pin is removed from drop test pad.
- Temperature: 9.4° C
- Time of drop: 4:40 p.m.

Photographic Record (Figures 2.10.12-F125 through 2.10.12- F132)

9802-23308-77	F-294, pre-drop
9802-23308-78 to 9802-23308-84	F-294, post-drop

Observations

- Crush shield as per photographs.
- Crush shield top retaining bolts still in place. Crush shield retained (jammed) on top of the container.
- Part of crush shield top ring missing.
- Most severe deformation on half of circumference.
- Most crush shield fins attached. Some crush shield fins with broken pieces. Some fins flattened.
- Fireshield intact. Slight outward bowing along top circumference.
- **Set-up:** Puncture pin removed.
- **Set-up:** 30-foot drop height verified with plumb line.
- **Additional damage as per photographic records.**

Figure 2.10.12-F124
Test #6 - 30-Ft. Free Drop Test: Top End (inverted) Drop Orientation

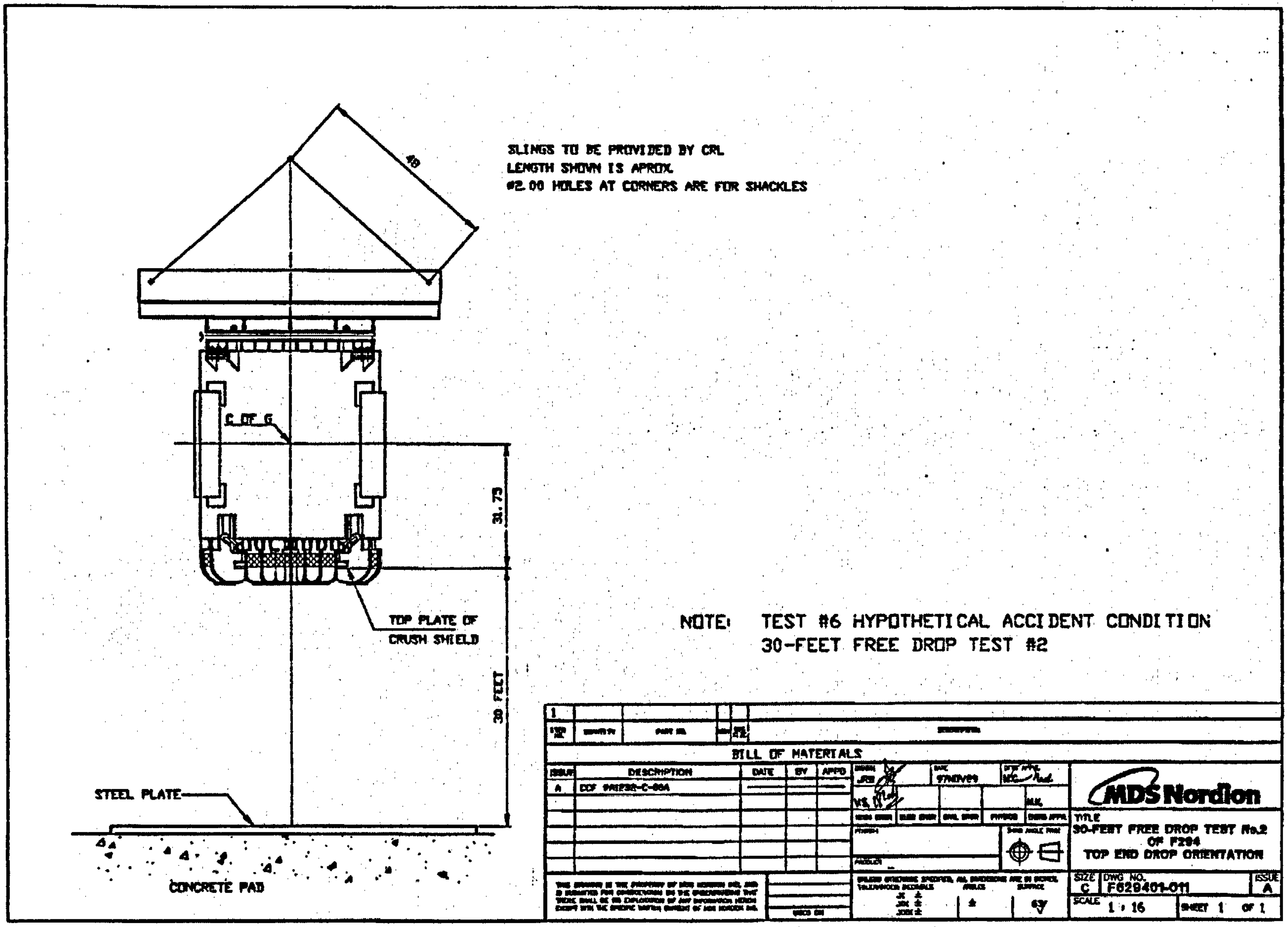
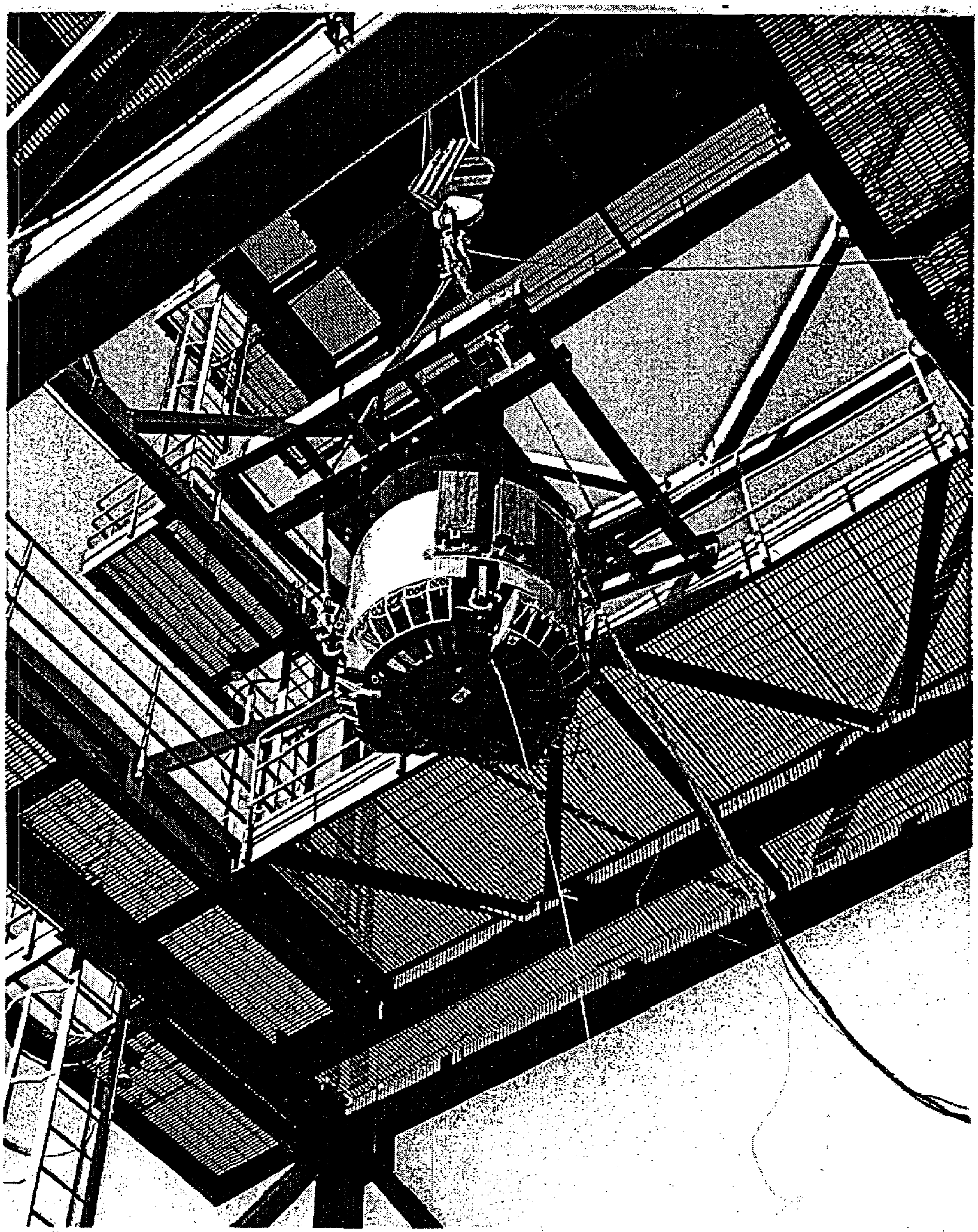


Figure 2.10.12-F125
Photograph 9802-23308-77



ATOMIC ENERGY OF CANADA LTD

9802-23308-77

Figure 2.10.12-F126
Photograph 9802-23308-78

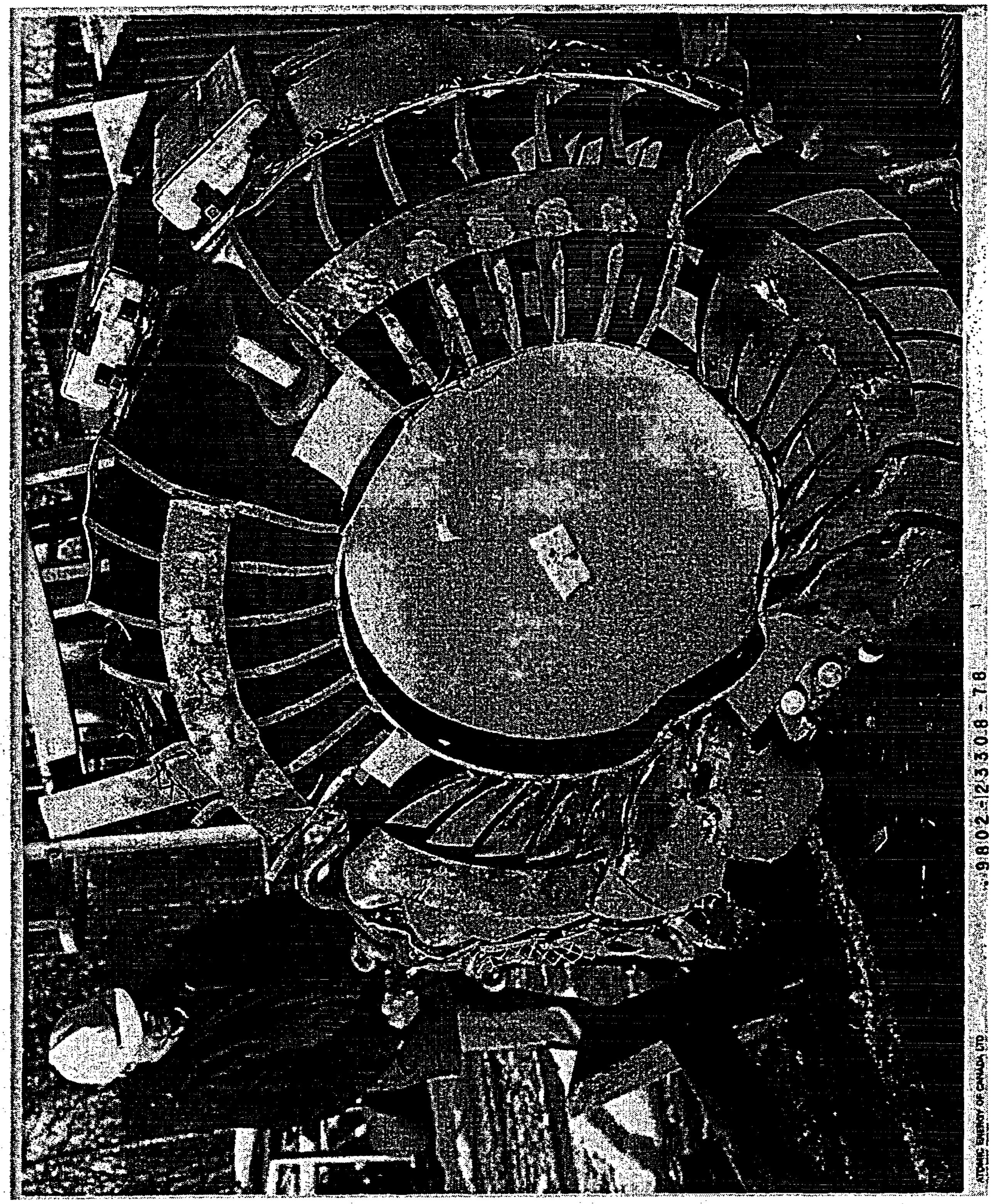
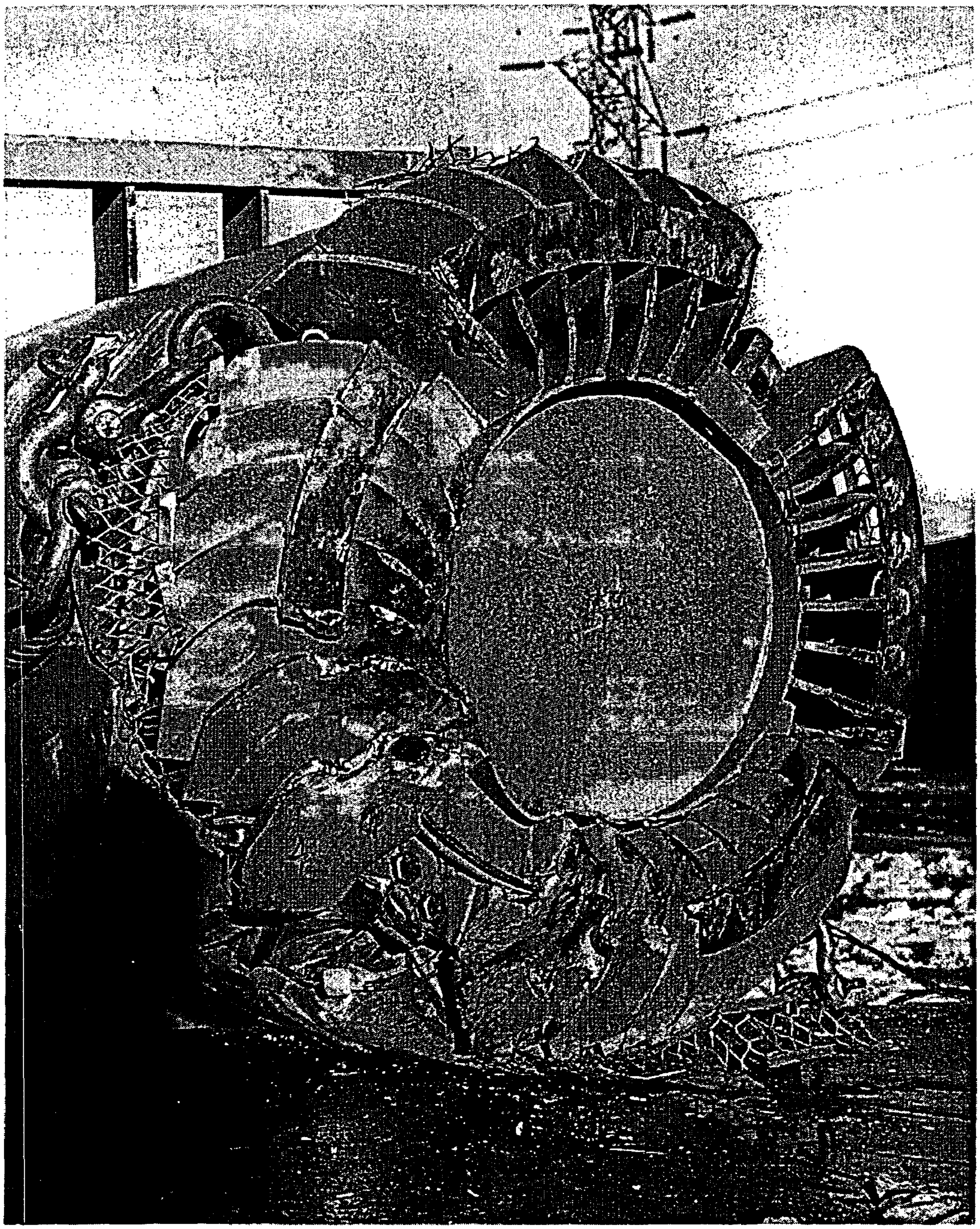


Figure 2.10.12-F127
Photograph 9802-23308-79



ATOMIC ENERGY OF CANADA LTD

9802-23308-79

Figure 2.10.12-F128
Photograph 9802-23308-80

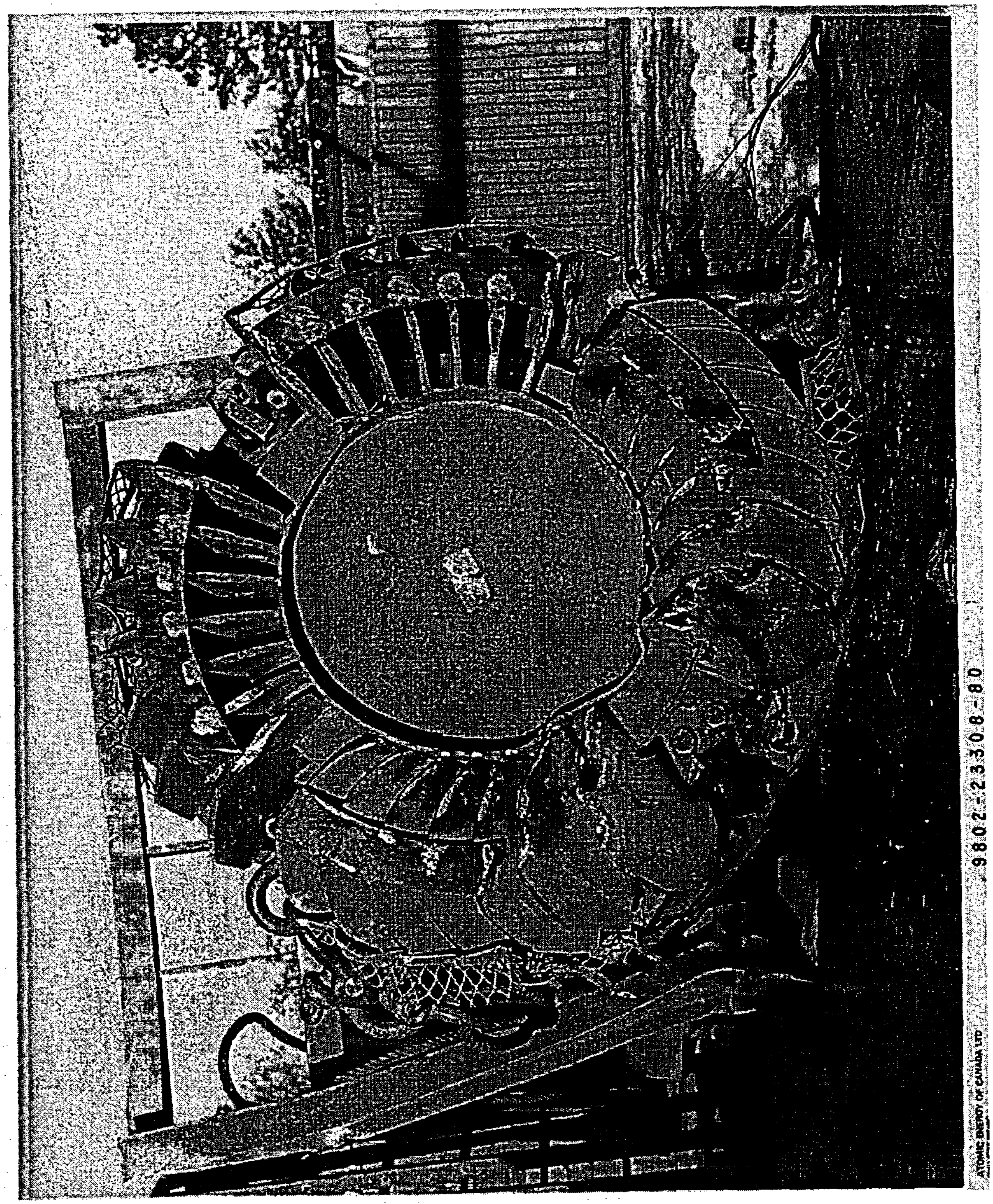
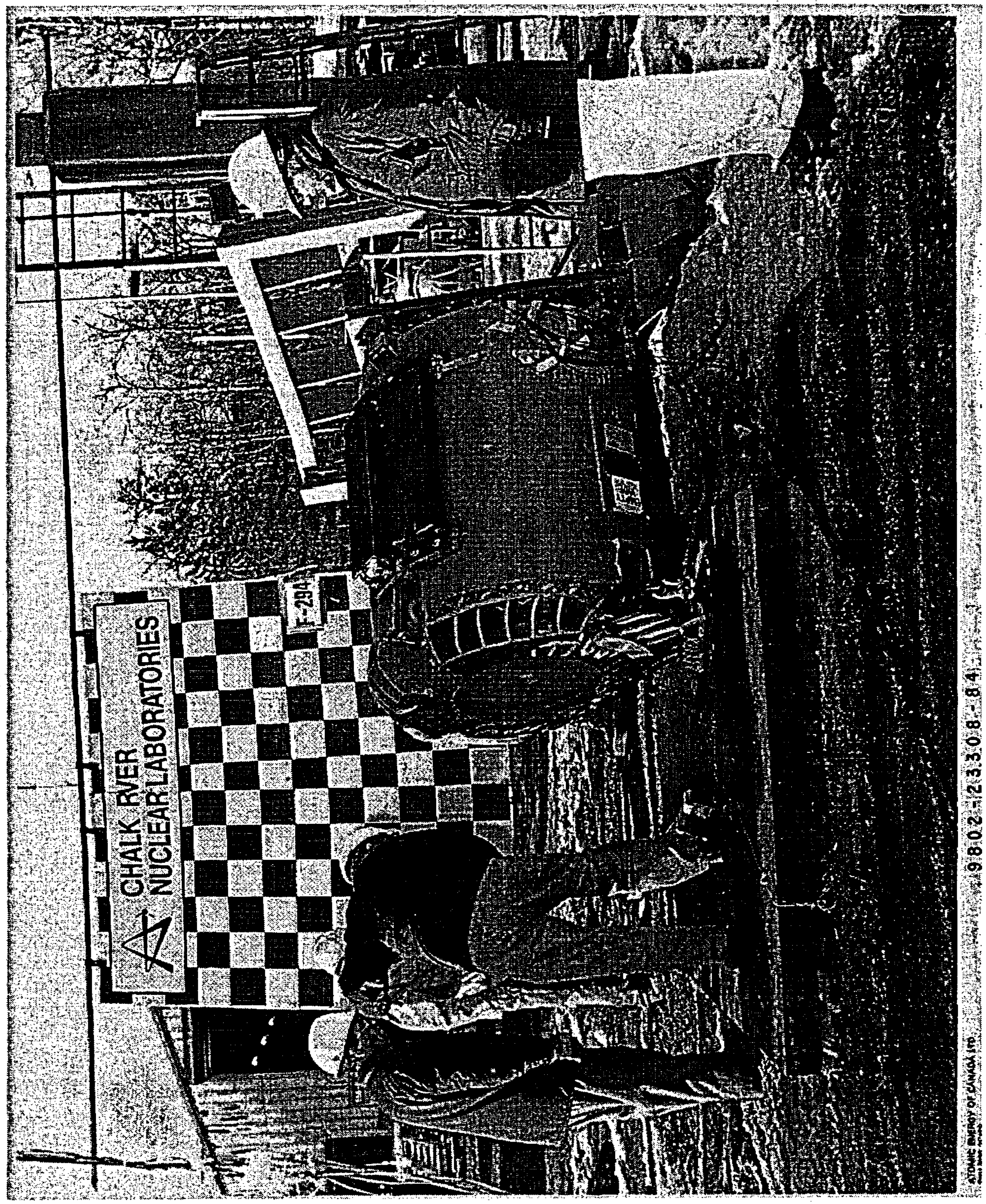


Figure 2.10.12-F129
Photograph 9802-23308-81

Figure 2.10.12-F130
Photograph 9802-23308-82

Figure 2.10.12-F131
Photograph 9802-23308-83

Figure 2.10.12-F132
Photograph 9802-23308-84



6.9 TEST #5.2.9 - PUNCTURE TEST: IMPACT ON THE CRUSH SHIELD UPPER PLATE

Test # 7	**Step 5.2.9 - MDS Nordion Test Plan IN/QA 1368 F-294 (1)** **Hypothetical Accident Condition Puncture Test** (Ref: MDS Nordion Dwg. F629401-012, see Figure 2.10.12-F133)
Date test conducted:	February 25, 1998

Conditions

- Drop height = 40 inches from top of 26-inch high puncture pin (67 inches from plate)
- Orientation: Inverted (top end drop). 26-inch puncture pin is reinstalled on drop test pad.
- Impact target: Top of crush shield
- Temperature: 8.9°C
- Time of drop: 5:00 p.m.

Photographic Record (Figures 2.10.12-F134 through 2.10.12-F138)

9802-23308-85	Verification of 40-inch drop height, using measured steel rod
9802-23308-86 to 9802-23308-89	F-294, post-drop

Observations

- 6-inch diameter main deformation, 16-inch diameter gradual deformation.
- No penetration. However, footprint of the pin on the upper plate of the crush shield.
- Approximately 2 inches vertical deformation.
- 26-inch high puncture pin (second pin) was used.
- The puncture pin fastening to the steel pad was checked before and after the test. The puncture pin did not move during the test.
- The puncture pin face was not damaged after the test.
- Set-up: 401/2 inches over puncture pin height, verified visually with bar.
- Additional damage as per photographic records.

Figure 2.10.12-F133
Test #7 - Puncture Test: Impact on the Crush Shield Upper Plate

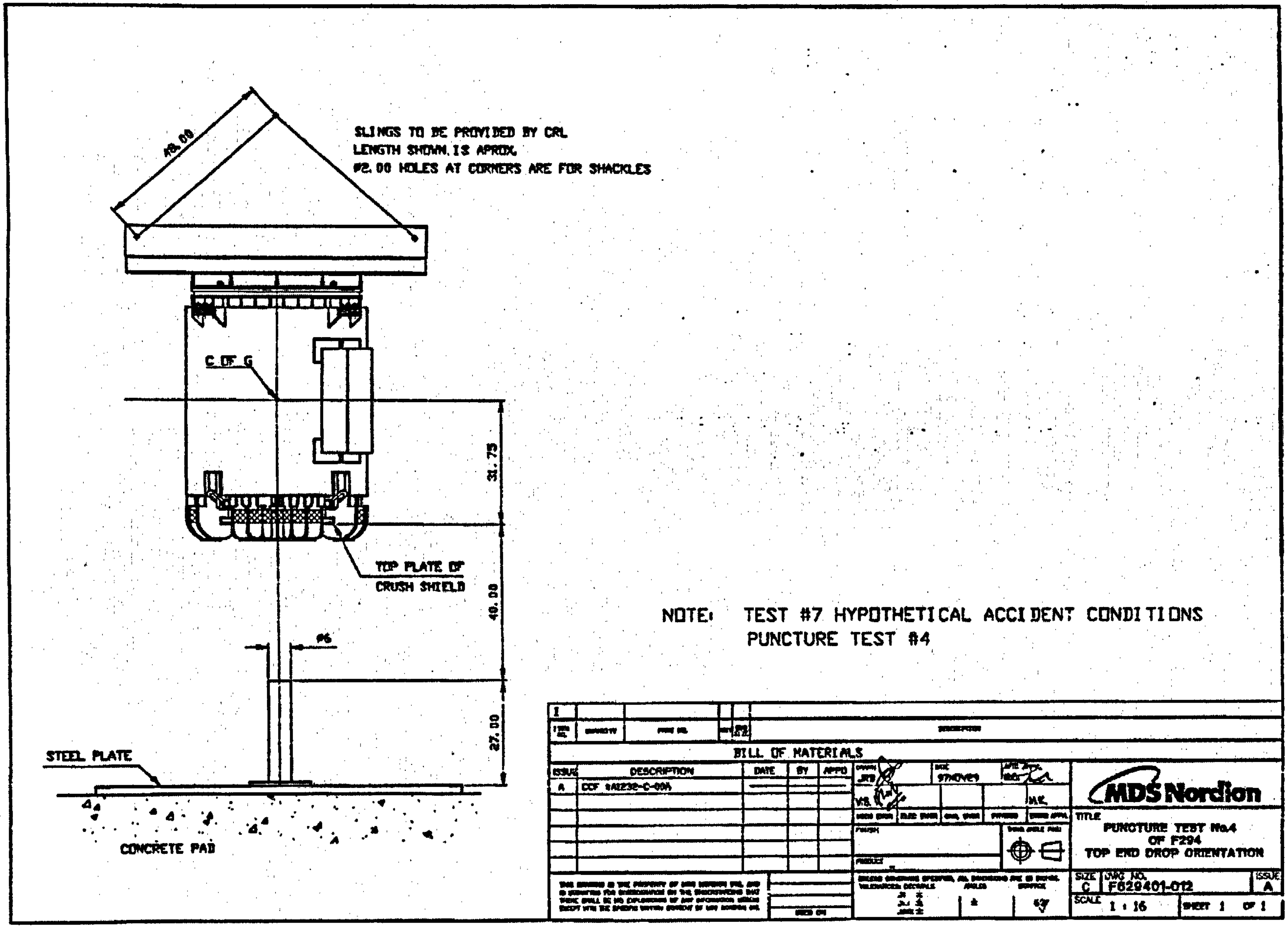


Figure 2.10.12-F134
Photograph 9802-23308-85

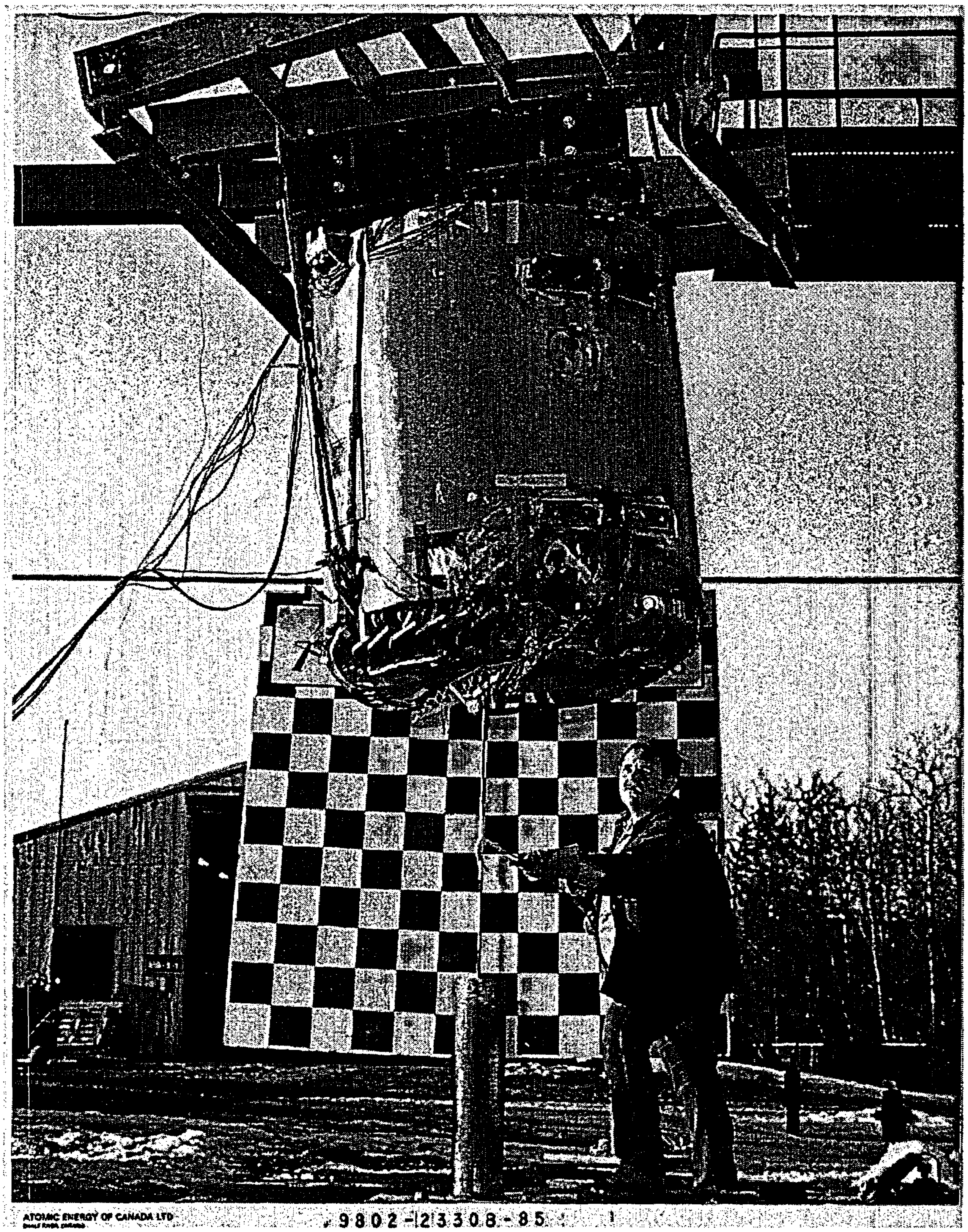


Figure 2.10.12-F135
Photograph 9802-23308-86

Figure 2.10.12-F136
Photograph 9802-23308-87

Figure 2.10.12-F137
Photograph 9802-23308-88

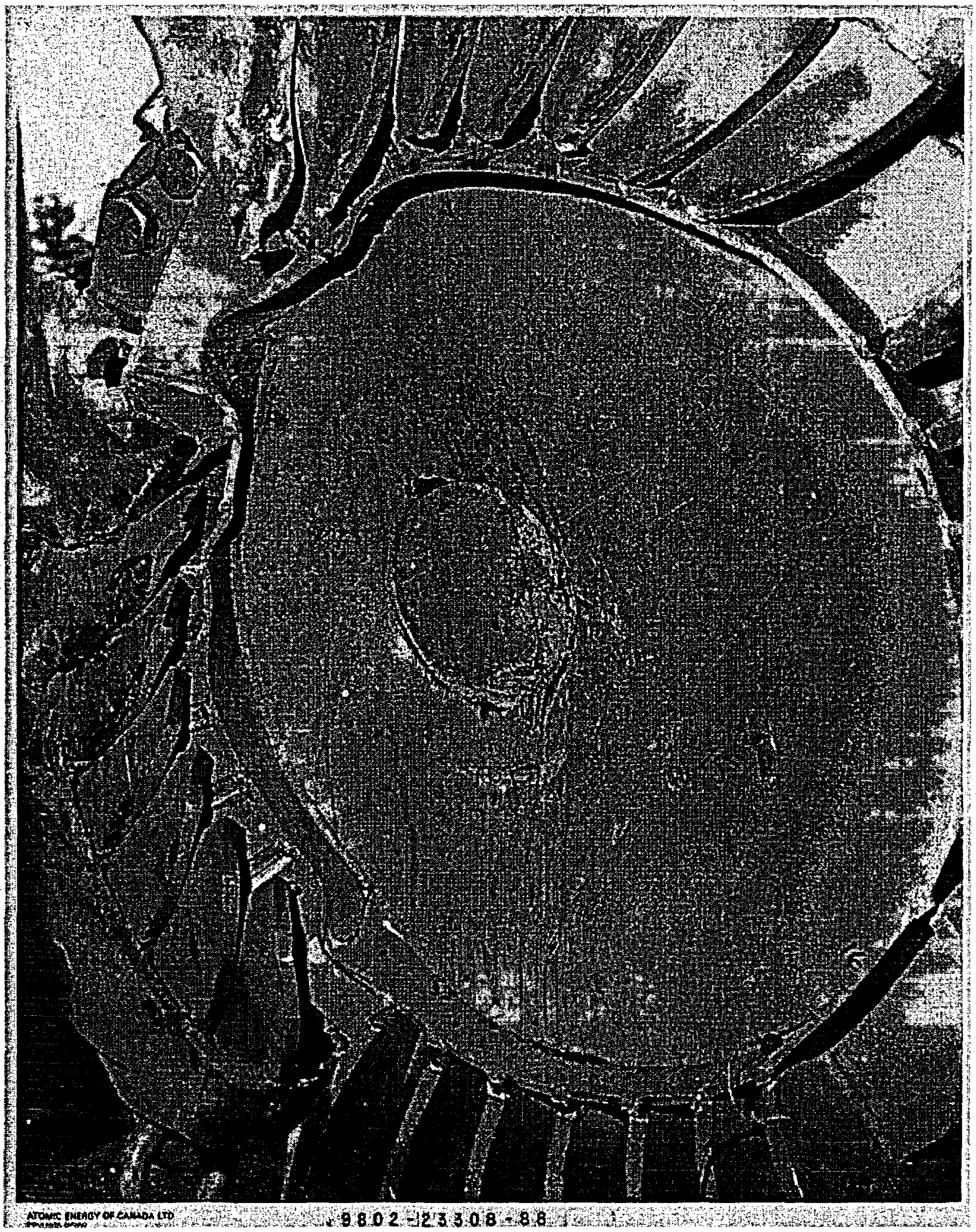
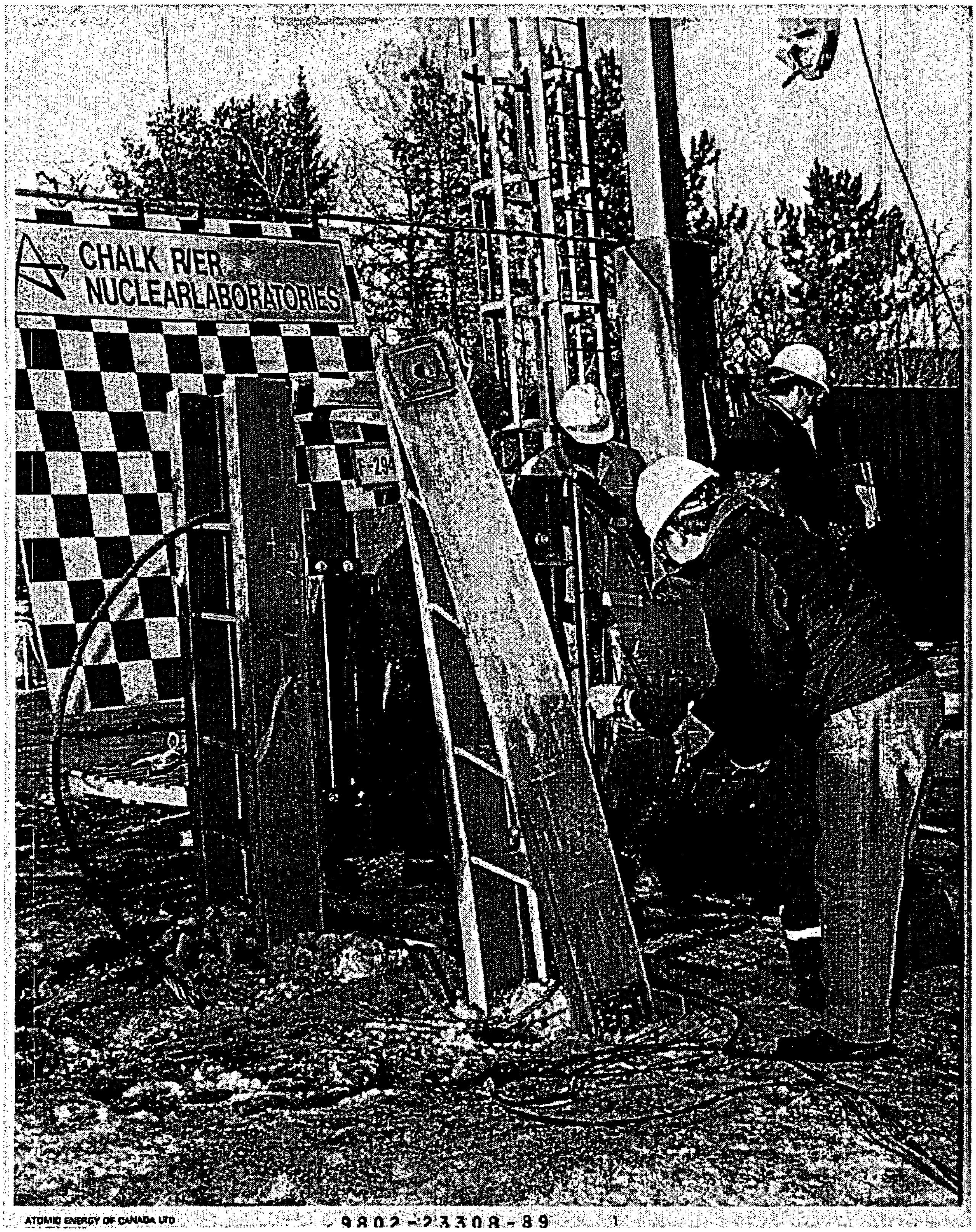


Figure 2.10.12-F138
Photograph 9802-23308-89



6.10 TEST #5.2.10 - PUNCTURE TEST: IMPACT ON SIDE FIRESHIELD: NAME PLATE ZONE

Test # 8	**(Additional test, not listed in the Test Plan, to assess effect of reinforced area of the outer fireshield shell.)**
	Hypothetical Accident Condition Puncture Test
	(Similar to Ref: MDS Nordion Dwg. F629401-024, see Figure 2.10.12-F139)
Date test conducted:	February 25, 1998

Conditions

- Drop height = 40 inches from top of 26-inch high puncture pin (67 inches from plate)
- Orientation: Side puncture on nameplate (Centre-of-gravity on fireshield.)
- Temperature: 7.2°C
- Time of drop: 5:28 p.m.

Photographic Record (Figures 2.10.12-F140 through 2.10.12-F144)

9802-23308-90	Target area, showing removal of nameplate
9802-23308-91	F-294, pre-drop
9802-23308-92 to 9802-23308-94	F-294, post-drop

Observations

- Shipping skid cleared the steel pad (impact plate).
- Packaging remained balanced on pin (pin penetrated fireshield).
- 1-foot diameter deformation by 1-1/2 inch deep.
- 2/3 circumference (of 6-inch diameter indent) penetrated.
- 26-inch high puncture pin (second pin) used.
- The puncture pin fastening to the steel pad was checked before and after the test. The puncture pin did not move during the test.
- The puncture pin top face was not damaged after the drop test.
- The shipping skid landed on the reinforced concrete pad just outside the steel pad. The shipping skid did not bottom out first.
- **Set-up:** 40 inches over puncture pin drop height, verified visually with bar.
- **Set-up:** Nameplates removed on impact target.
- **Additional damage as per photographic records.**

Figure 2.10.12-F139
Test #8 - Puncture Test: Impact on the Nameplate Zone (reinforced) of the Cylindrical Fireshield

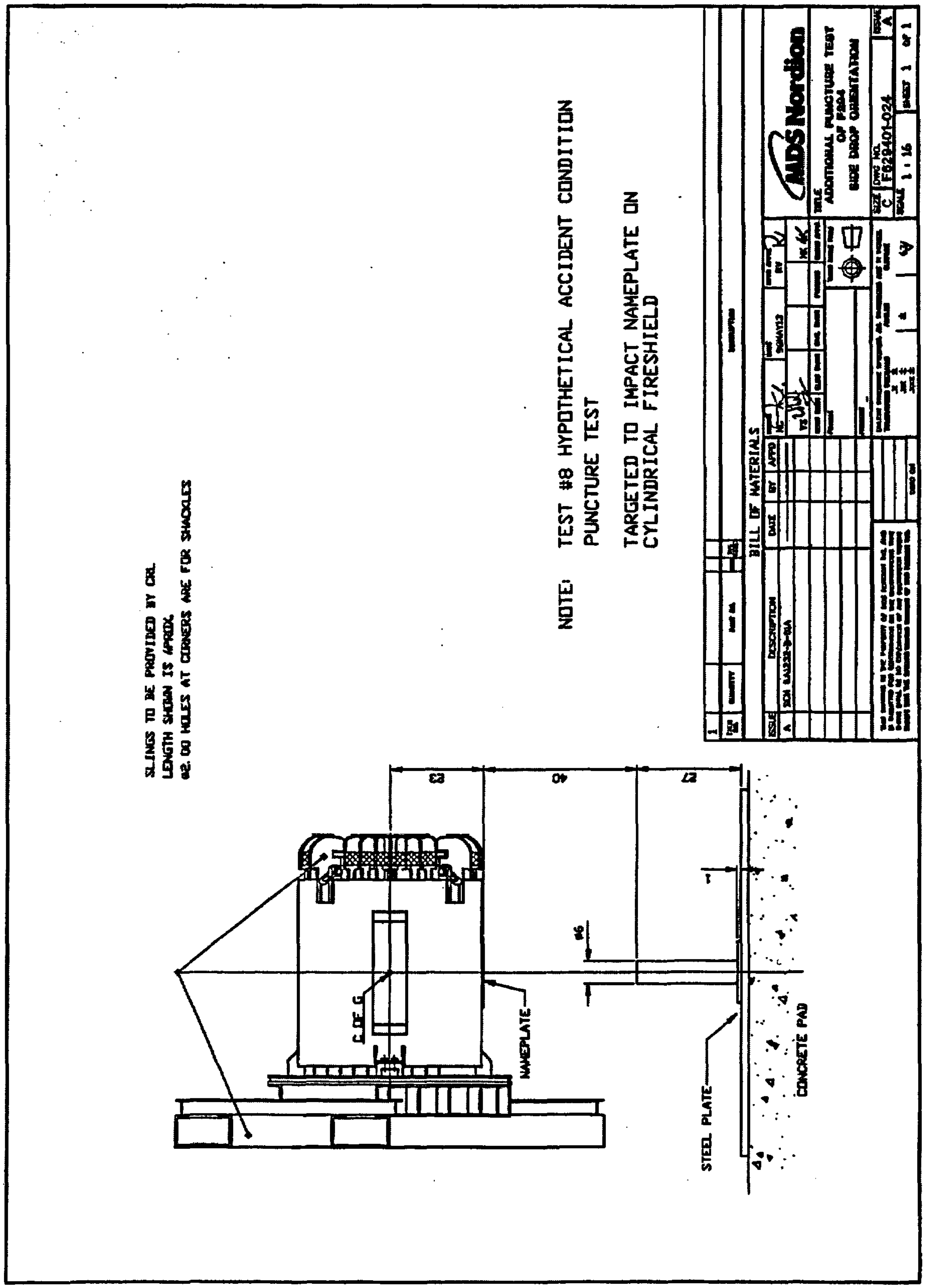


Figure 2.10.12-F140
Photograph 9802-23308-90

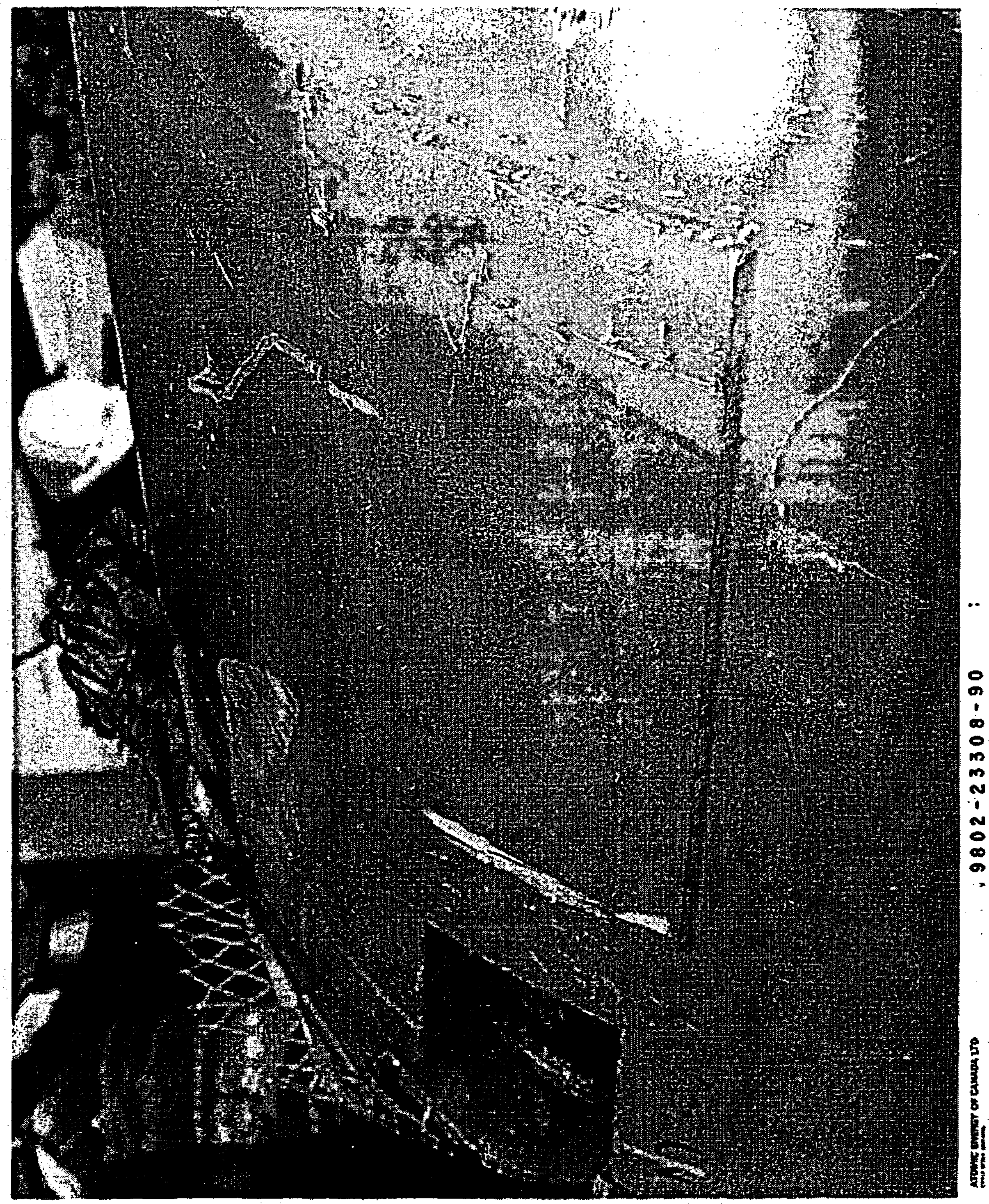


Figure 2.10.12-F141
Photograph 9802-23308-91

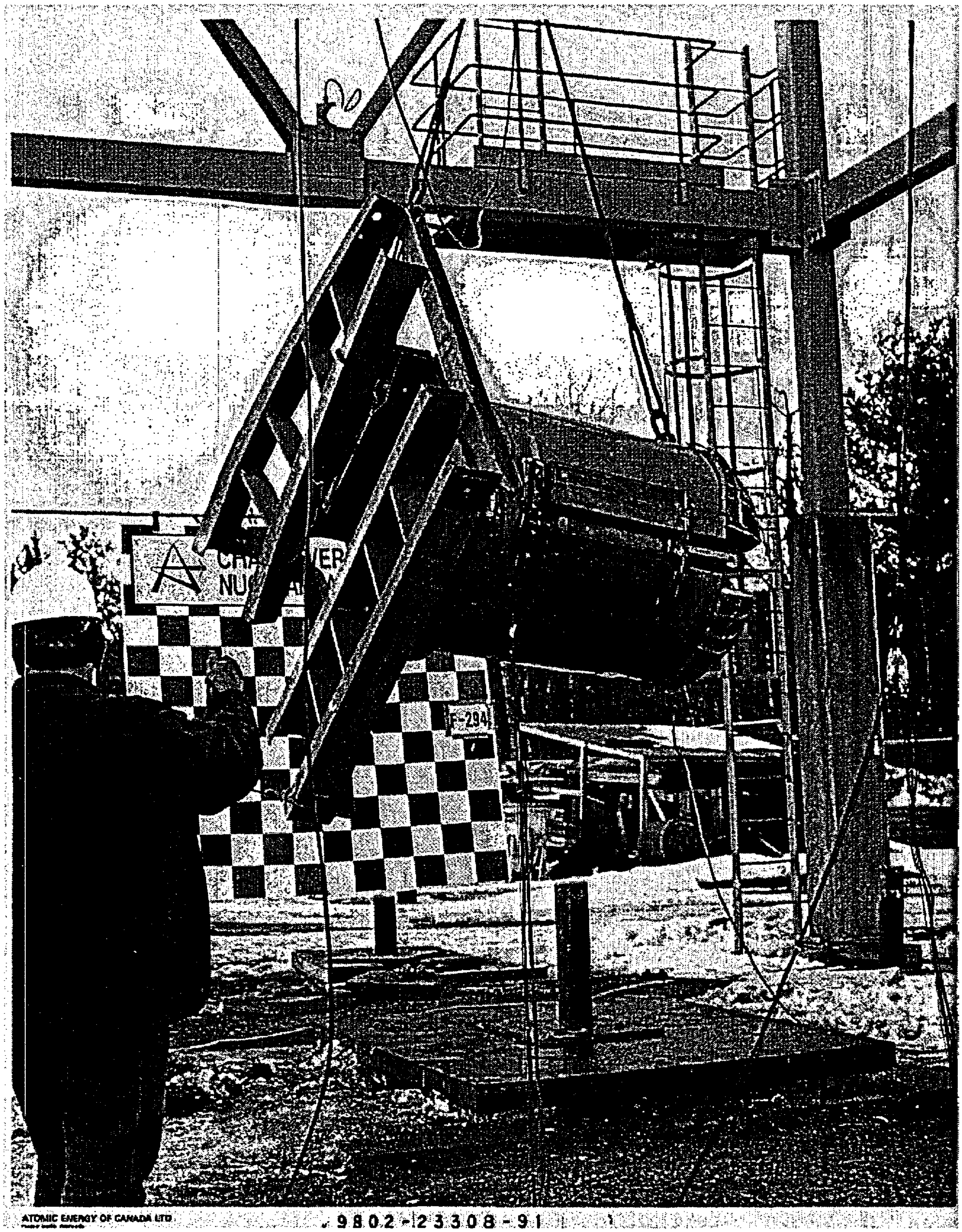


Figure 2.10.12-F142
Photograph 9802-23308-92

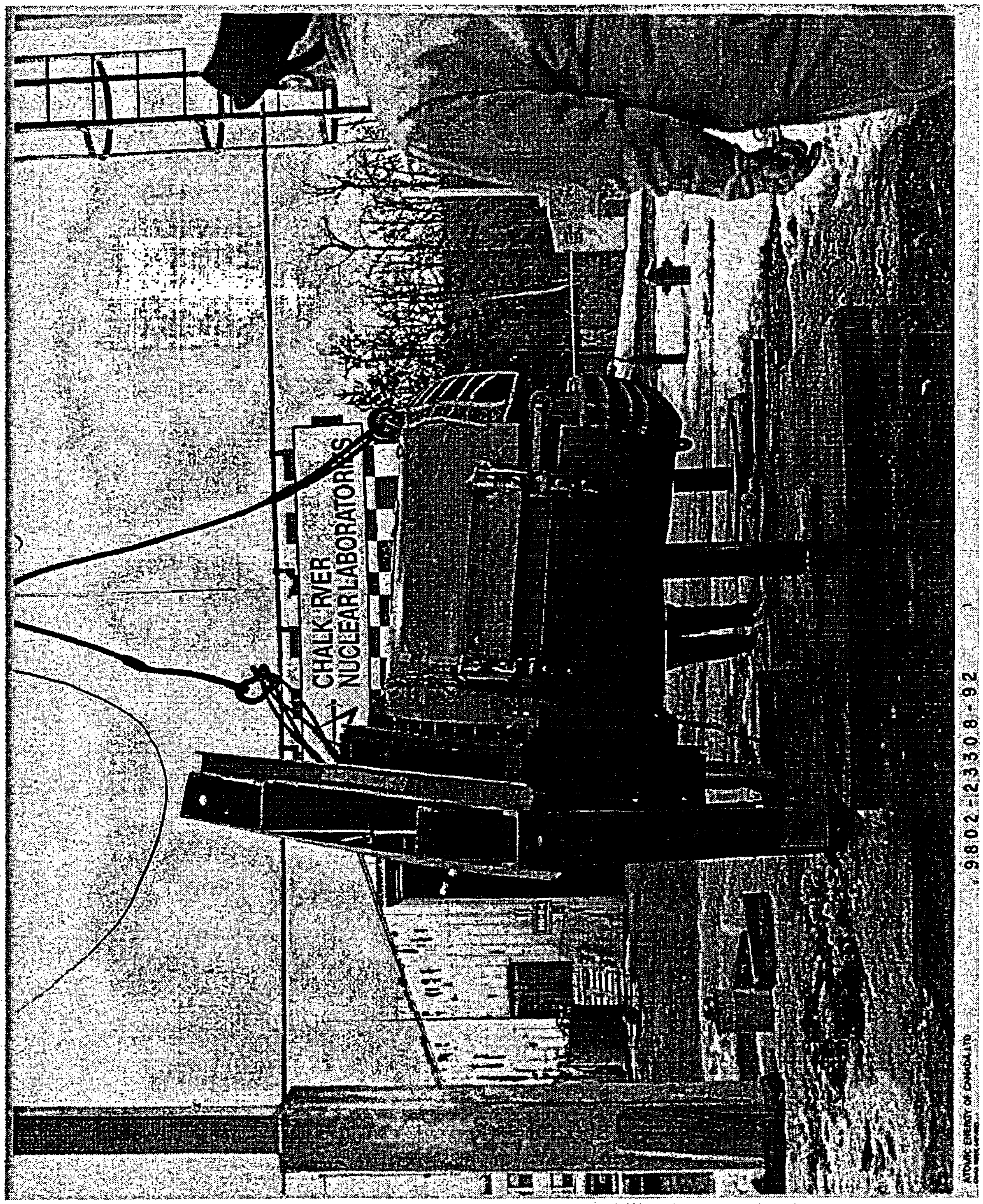


Figure 2.10.12-F143
Photograph 9802-23308-93

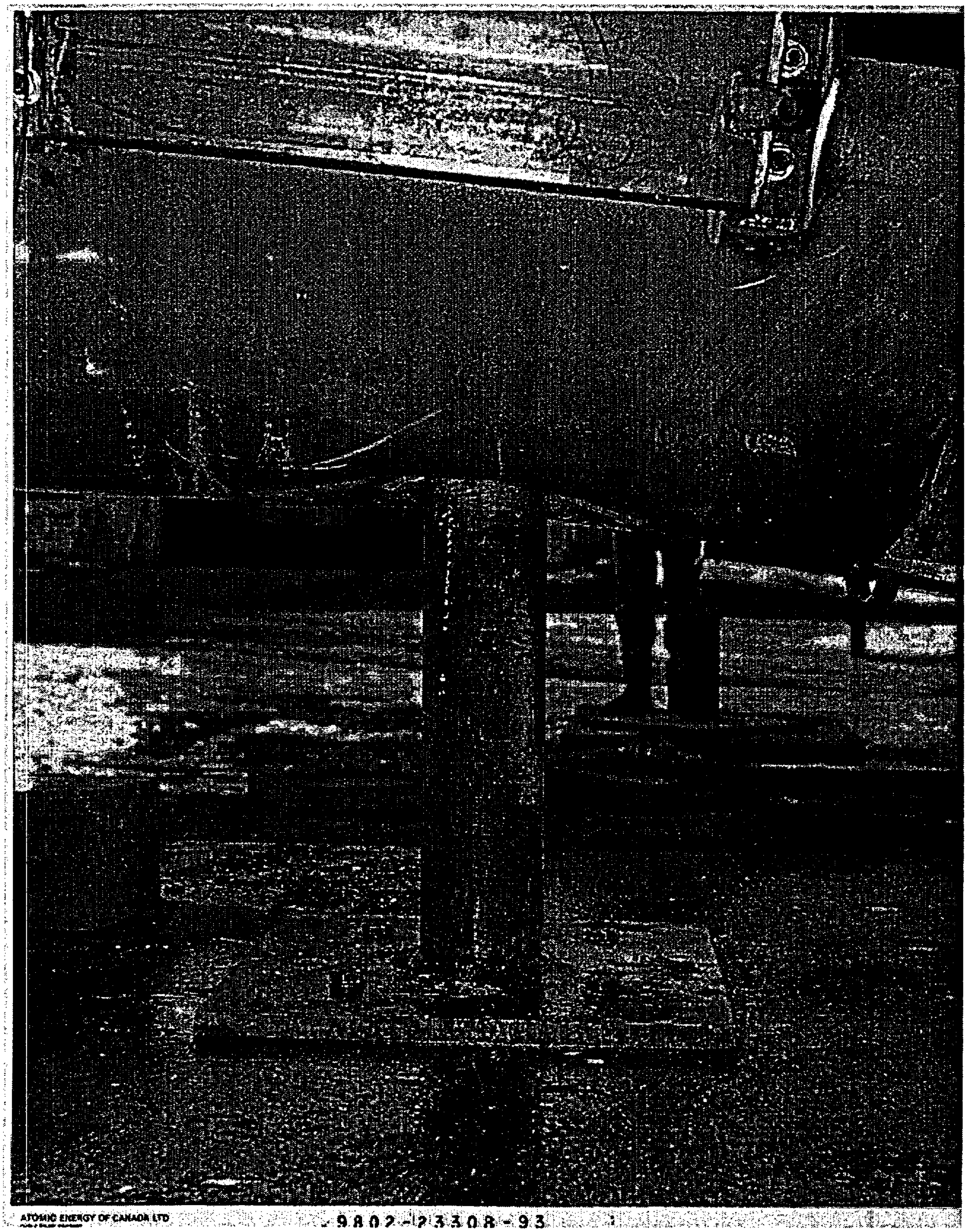


Figure 2.10.12-F144
Photograph 9802-23308-94

6.11 TEST 5.2.11 - SHIP THE DROP TESTED F-294 TEST PACKAGING TO MDS NORDION, OTTAWA

The drop-tested F-294 test packaging was shipped to MDS Nordion from CRL (Chalk River Laboratory) AECL, Chalk River, Ontario on 3rd March, 1998. See section 7.1 for details.

7. POST-DROP TESTS ON F-294 TEST SPECIMEN

7.1 TEST #5.3.1 - RECEIPT OF TESTED F-294 SPECIMEN

#1. Test # 5.3.1 as per test plan document IN/QA 1368 F294 (1)
Receipt of tested F-294 specimen.

Date of the test: March 3 1998 - March 5 1998

#2 Test Observations

#1. The drop tested F-294 specimen came in at MDS Nordion, Ottawa premises at 5.15 PM on 3rd March 1998 (Tuesday) from CRL, AECL-Research Co., Chalk River, Ontario on the cobalt waste trailer (see Figure 2.10.12-F145).

#2. The tested F-294 specimen was tied down on the cobalt waste trailer at three (3) points. However, it was fully secured on the trailer bed (see Figures 2.10.12-146 and 2.10.12-F148).

#3. The tested F-294 specimen was propped up (raised) on the wooden blocks, placed underneath the shipping (removable) skid to secure the container onto the trailer bed (see Figures 2.10.12-F147 and 2.10.12-F149).

#4. On March #4 1998, the tested F-294 specimen was unloaded from the trailer bed onto a staging area, receiving bay, Industrial Operations building.

#5. Plans to disassemble tested F-294 specimen were discussed with QA. (See memo from V. Shah to D. Sidney: 98-March-05.)

#6. A box came with the tested F-294 specimen. The box contained: drainline cap; vent cap; F-313 carrier handle.

#2.3 Photos

Five photographs are attached (Figures 2.10.12-F145 through 2.10.12-F149).

#3. Notes

Video pictures of the skid and tested F-294 specimen were taken.

#4. Personnel

	Name	Title
Test conducted by:	G.Chupick	Senior Decontamination Operator
Test Conducted by:	D. Whitby	Industrial Q.C.
Reviewed by:	V. Shah	Package Engineer

Figure 2.10.12-F145
The Drop Tested F-294 Specimen Arriving at MDS Nordion, Ottawa

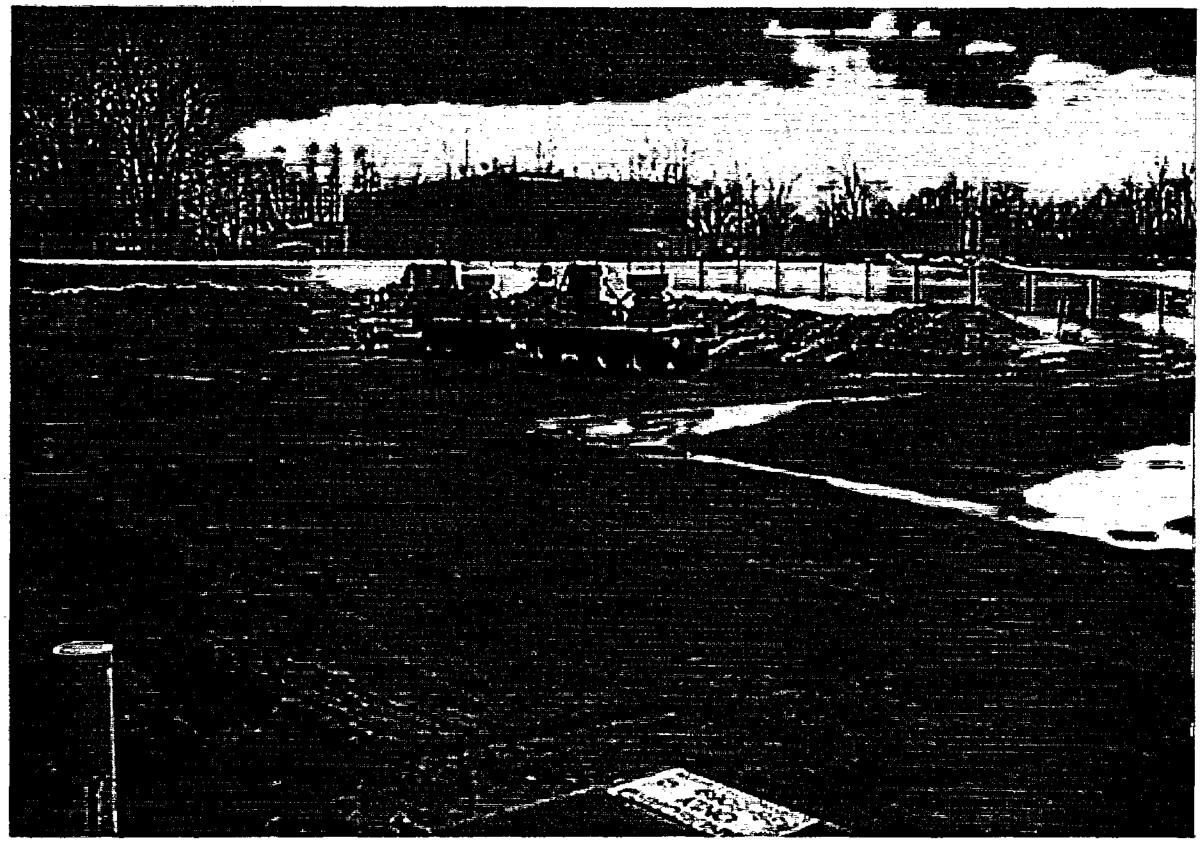


Figure 2.10.12-F146
The Drop Tested F-294 Specimen on the Trailer

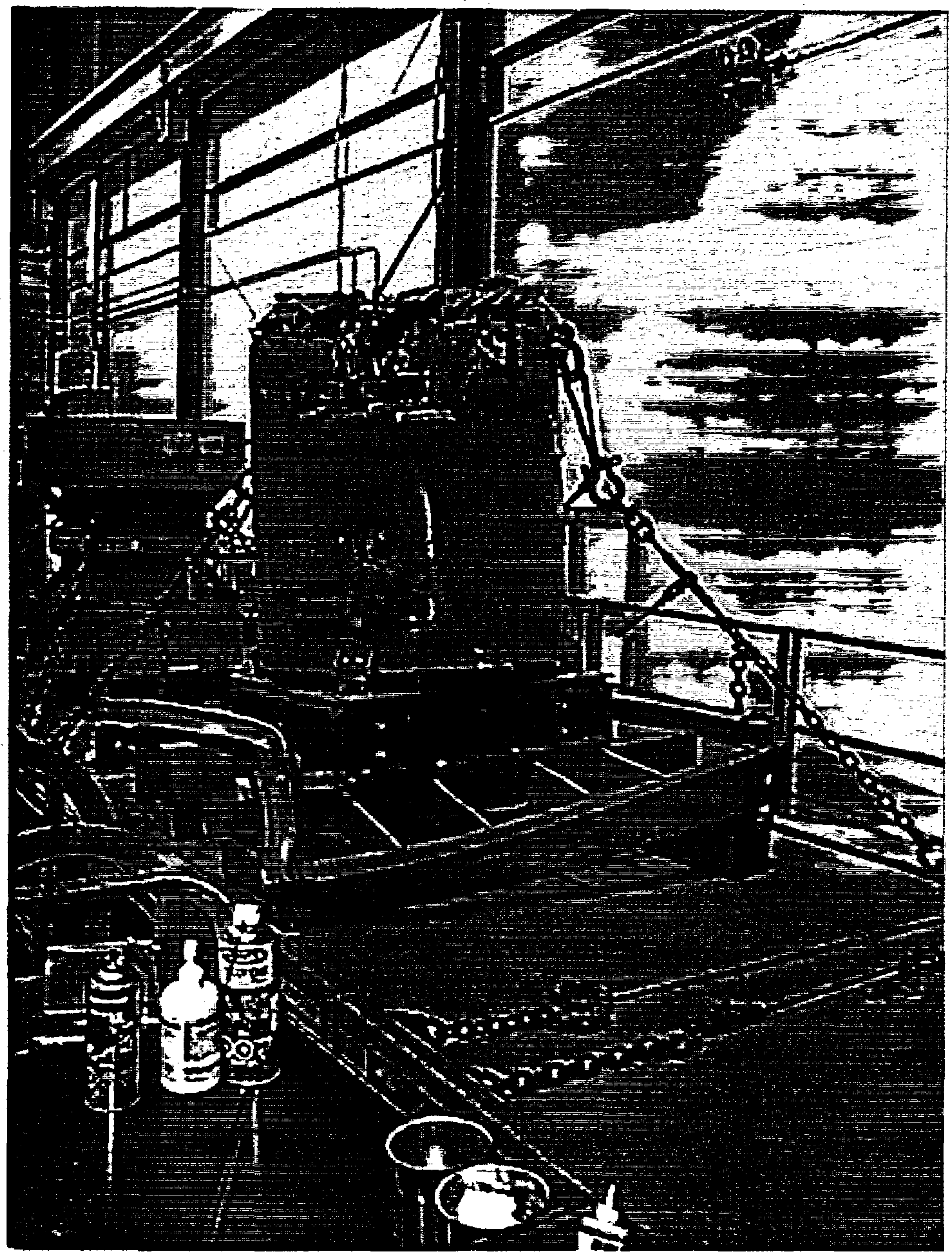


Figure 2.10.12-F147
The Drop Tested F-294 Specimen Chocked on the Trailer

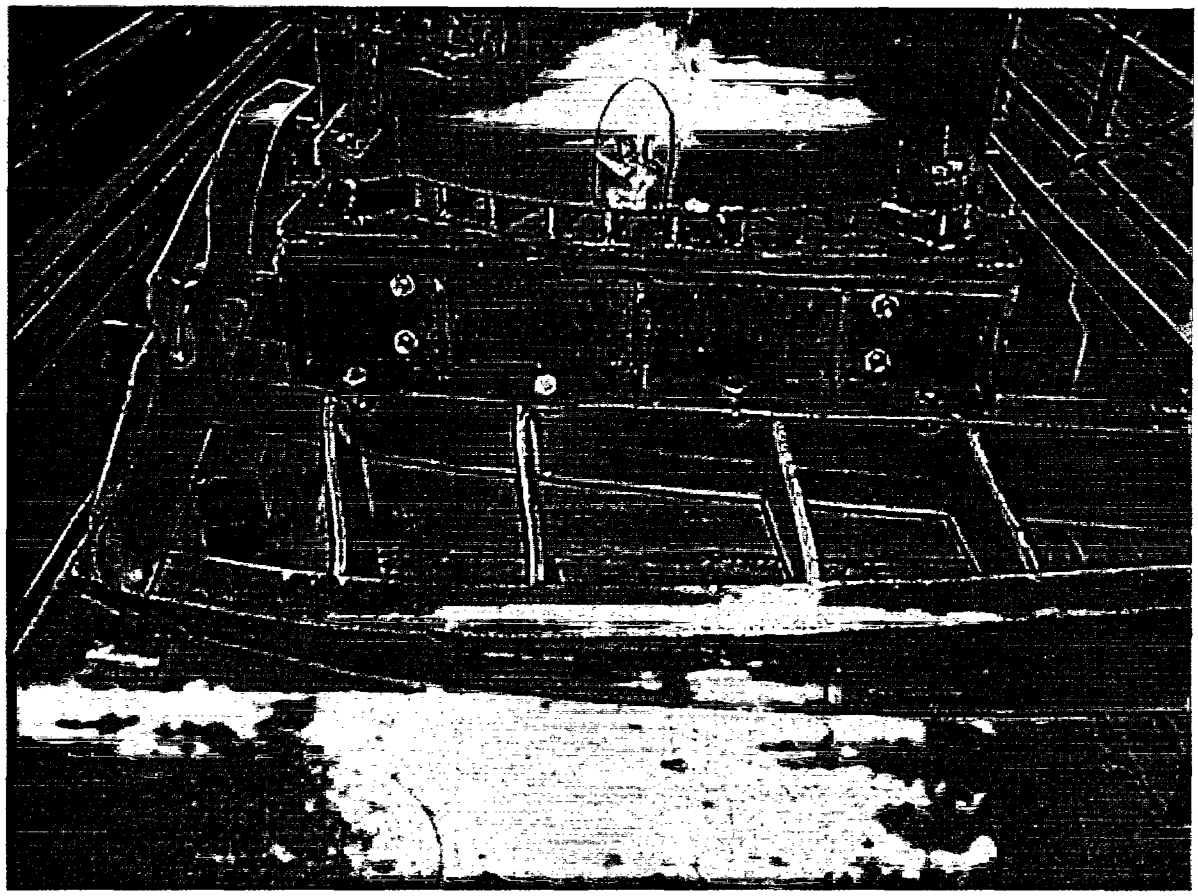


Figure 2.10.12-F148
The Drop Tested F-294 Specimen Tie Downs

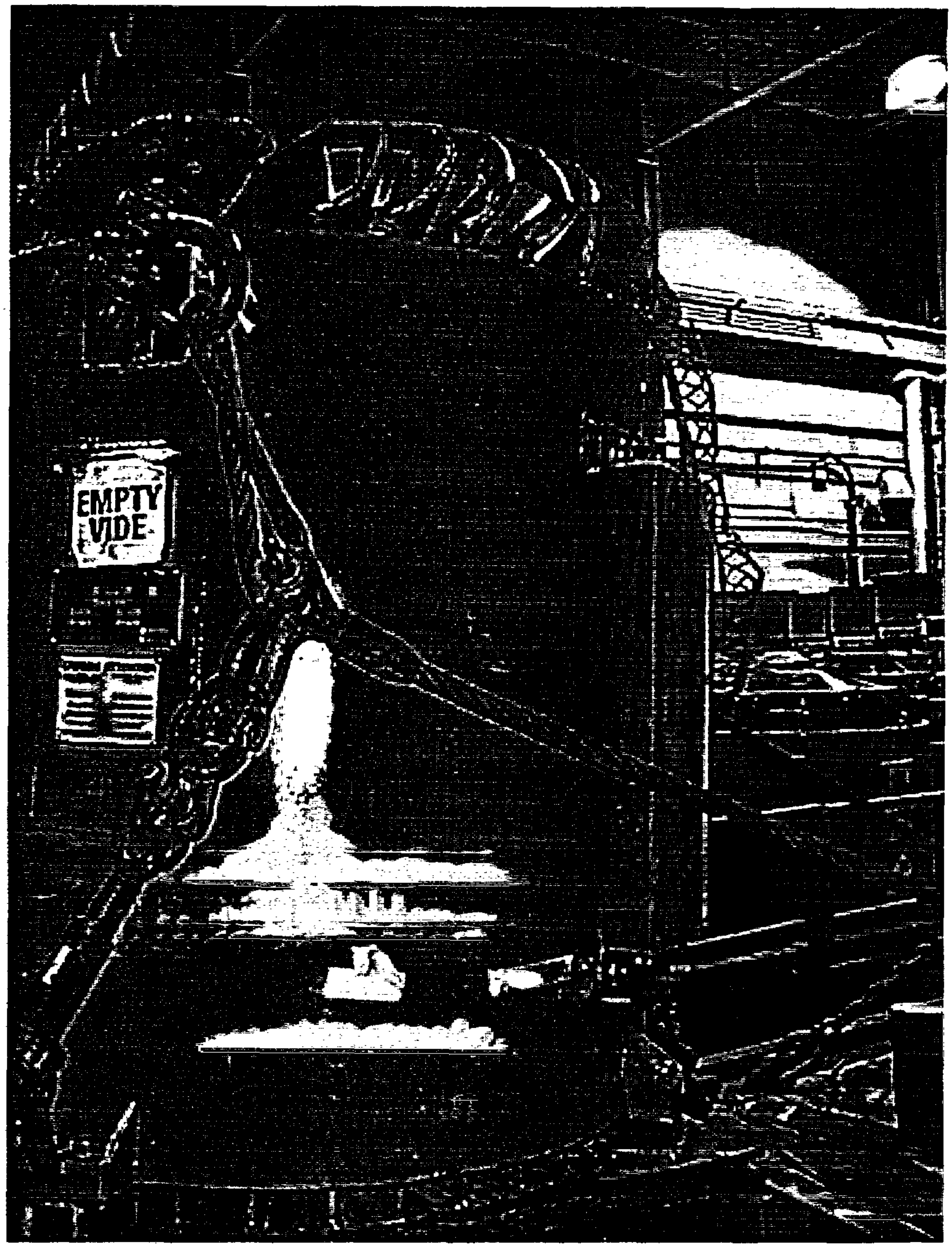
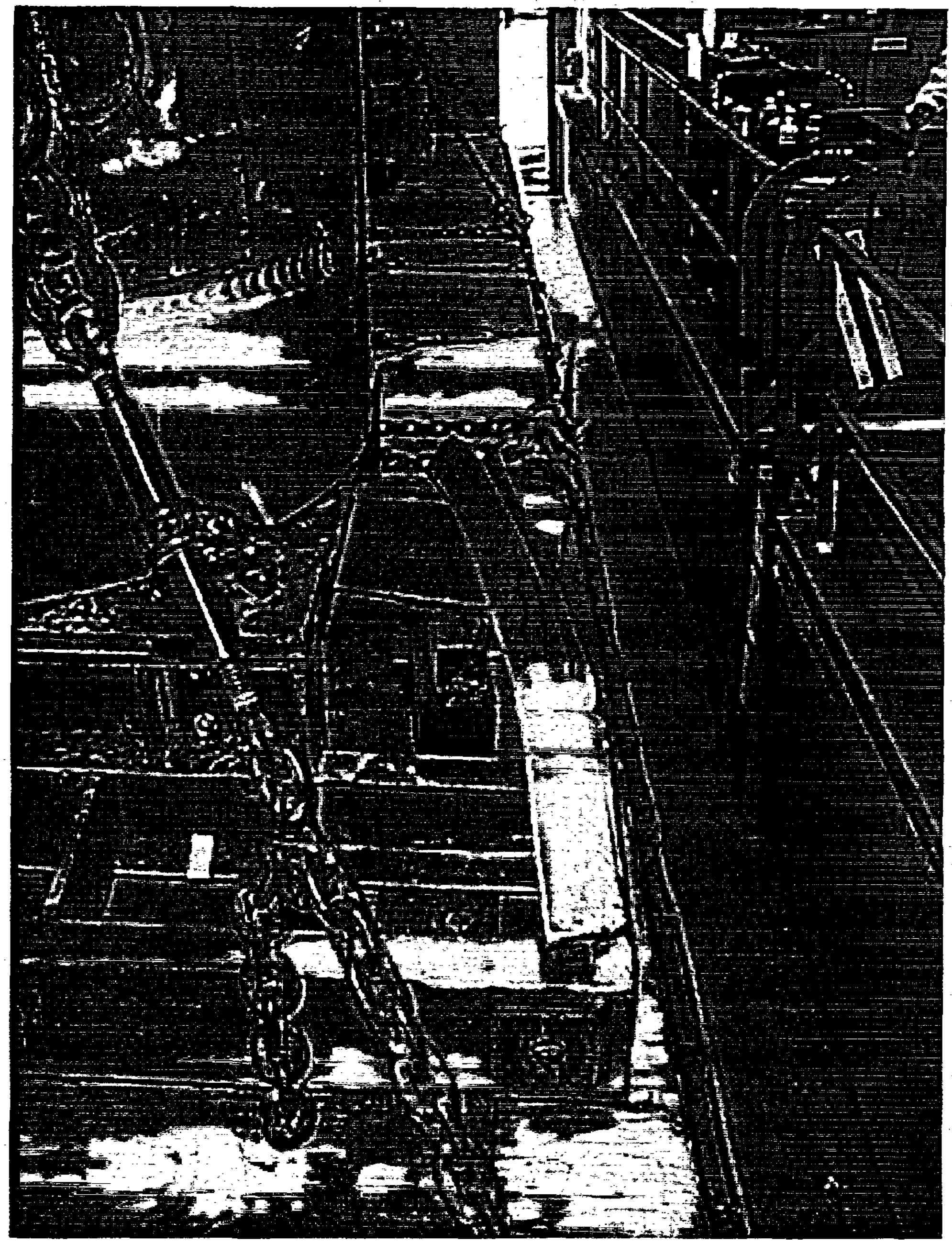


Figure 2.10.12-F149
The Drop Tested F-294 Specimen Chocked on the Waste Trailer



7.2 TEST #5.3.2 - DIMENSIONAL MEASUREMENTS OF THE F-294 AFTER THE DROP

#1 Test # **5.3.2,** as per test plan document IN/QA 1368 F294 (1) Dimensional Measurements of the F-294 After the Drop

Date test conducted: April 3, 1998

#2 Person conducting test/procedure

Dave Whitby, Industrial Quality Control.

#3 Test details

The same features that were dimensionally measured on the F-294 container before the drop were repeated after the drop as specified by Package Engineering.

The measurements were again performed by Dave Whitby of Industrial QC using the same instrumentation. All instruments were calibrated and traceable to a national standard with the exception of the 24 in. vernier caliper and the inside micrometer. In these cases, the measurement on the caliper or micrometer was transferred to a surface plate and height gauge to check the measurement setting on calibrated equipment.

Instrument	Serial Number	Calibration Date	Accuracy
12 in. Digital Caliper	7040843	97/06/26	± 0.001 in.
Height Gauge	9000141	97/07/03	± 0.0002 in.
Dial Indicator	6C0271	97/07/02	± 0.0005 in.
Inside Micrometer	G94R	n/a	n/a
24 in. Vernier Caliper	V-24-2	n/a	n/a

Measurements after the drop were conducted and recorded on 1998 April 03.

Some diameters were measured in two planes. Plane 'X' is a vertical plane through the center of the container and the drainline. Plane 'Y' is through the center of the container, 90° to plane 'X'. All single measurements were taken through plane 'X'. See Figures 2.10.12-F150 and 2.10.12-F151.

#4 Plug Assembly F029402-002

Feature	Dimension No.	Dimension on Drawing	Actual	Comments
Shielding plug O.D.	1	14.705 in./14.695 in. diameter	X - 14.703 in. Y - 14.713 in.	3 in. from end.
Flange O.D.	2	21-1/2 in. diameter.	21.484 in.	
Plug shield height	3	11.990 in./12.000 in.	11.991 in.	
Plug height	4	14 in.	14.010 in.	
Lift lug height	5	2-1/2 in. (dwg F029402-010)	1.843 in.	

#5 Crack Shield Assembly F029402-018

Feature	Dimension No.	Dimension on Drawing	Actual	Comments
O.D.	6	17-5/8 in. diameter	17.614 in.	
I.D.	7	n/a	11.966 in.	
Height	8	1-15/16 in. Ref.	1.898 in.	

#6 Container F029402-024

Feature	Dimension No.	Dimension on Drawing.	Actual	Comments
Upper Cavity I.D.	9	14.785 in./14.795 in. diameter	X - 14.823 in. Y - 14.813 in.	Near top only
Upper height	10	not dimensioned	11.896 in.	Fig. 2.10.12-F152 EF
Gasket seating zone height	11	not dimensioned	0.156 in.	Fig. 2.10.12-F152 CD
Gasket seating zone I.D.	12	16-3/4 in. diameter	16.975 in.	Fig. 2.10.12-F152 diameter at C
Lower cavity I.D.	13	11.500 in./11.510 in. diameter	X - 11.501 in. Y - 11.516 in.	
Lower cavity height (edge)	14	20.0 in. Ref	20.254	Fig. 2.10.12-F152 GH
Lower cavity height (center)	15	n/a	n/a	Fig. 2.10.12-F152 GI

#7 Observations

- All diameters were taken in the X plane unless otherwise specified.
- The variation of some diameters/dimensions (e.g., crack shield assembly, or plug flange O.D.) was significant due to roughness and waviness, and replicating the exact original measurement position proved difficult; the differences in the before and after measurements could therefore be attributed to both deformation and/or the inability to repeat the exact measurement location.
- The cavity heights (depth) were measured adjacent to the cavity wall only.
- Some additional measurements were taken at different heights in the upper cavity, see Figure 2.10.12-F153
- There was no visual damage evident within the cavity; there were no cracks evident within the cavity (see Figure 2.10.12-F154).

#8 Personnel

	Name	Title
Test prepared by	D. Whitby	Industrial Quality Control.
Approved by:	V. Shah	Package Engineering

Figure 2.10.12-F150
Plan View of the F-294 Indicating the Location of Planes X and Y

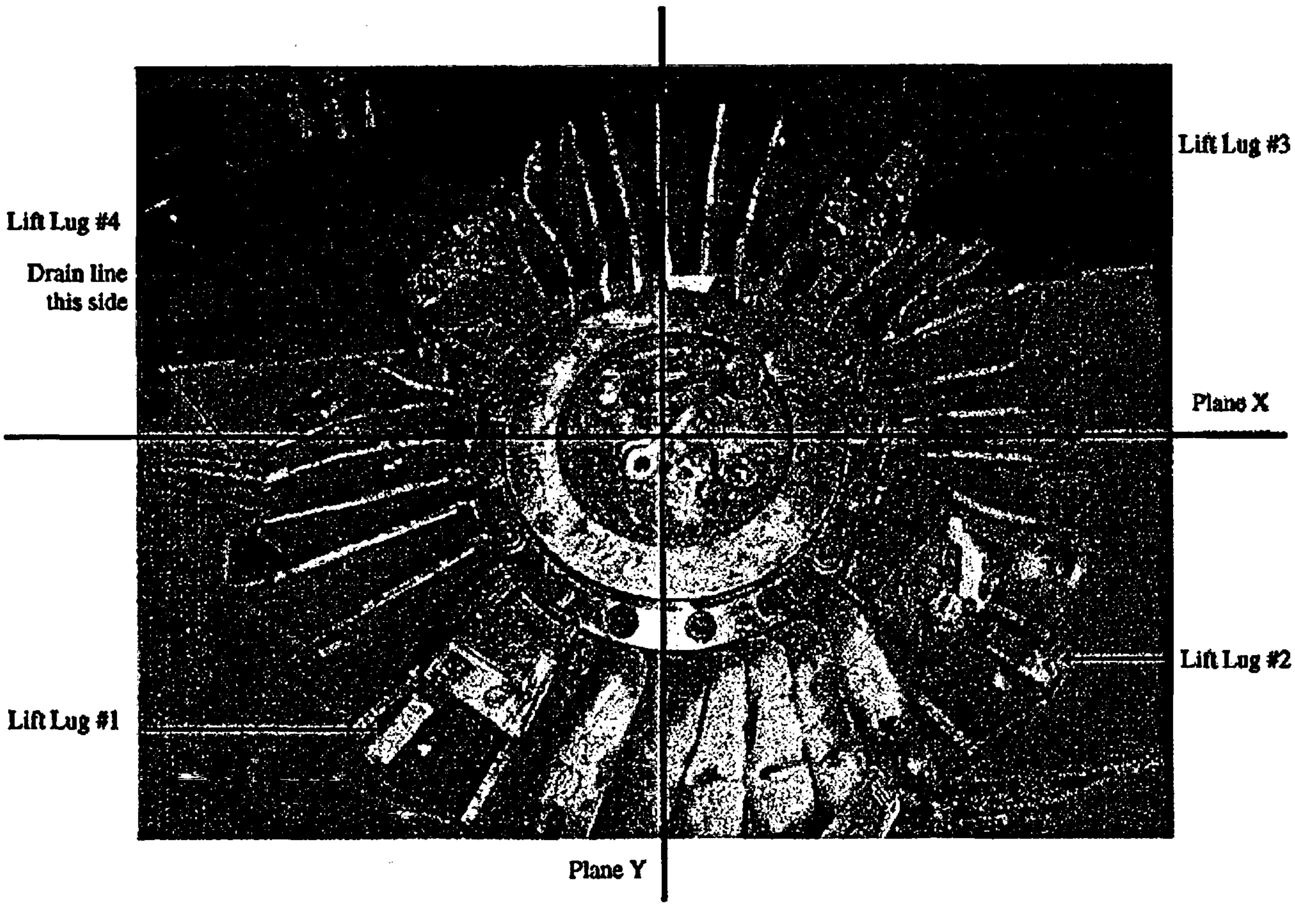


Figure 2.10.12-F151
F-294 Measurement Locations Through Plane X

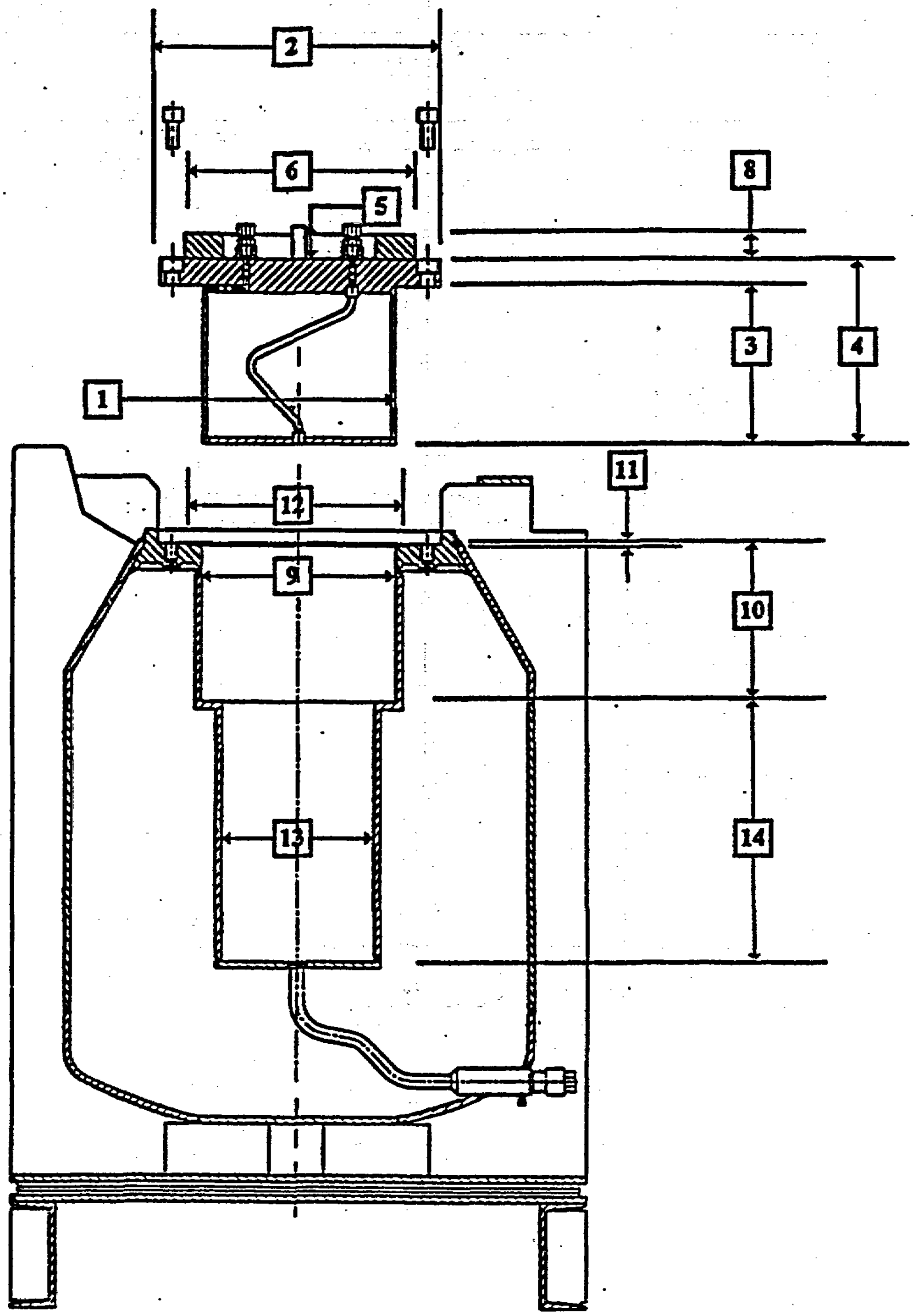


Figure 2.10.12-F152
F-294 Cavity

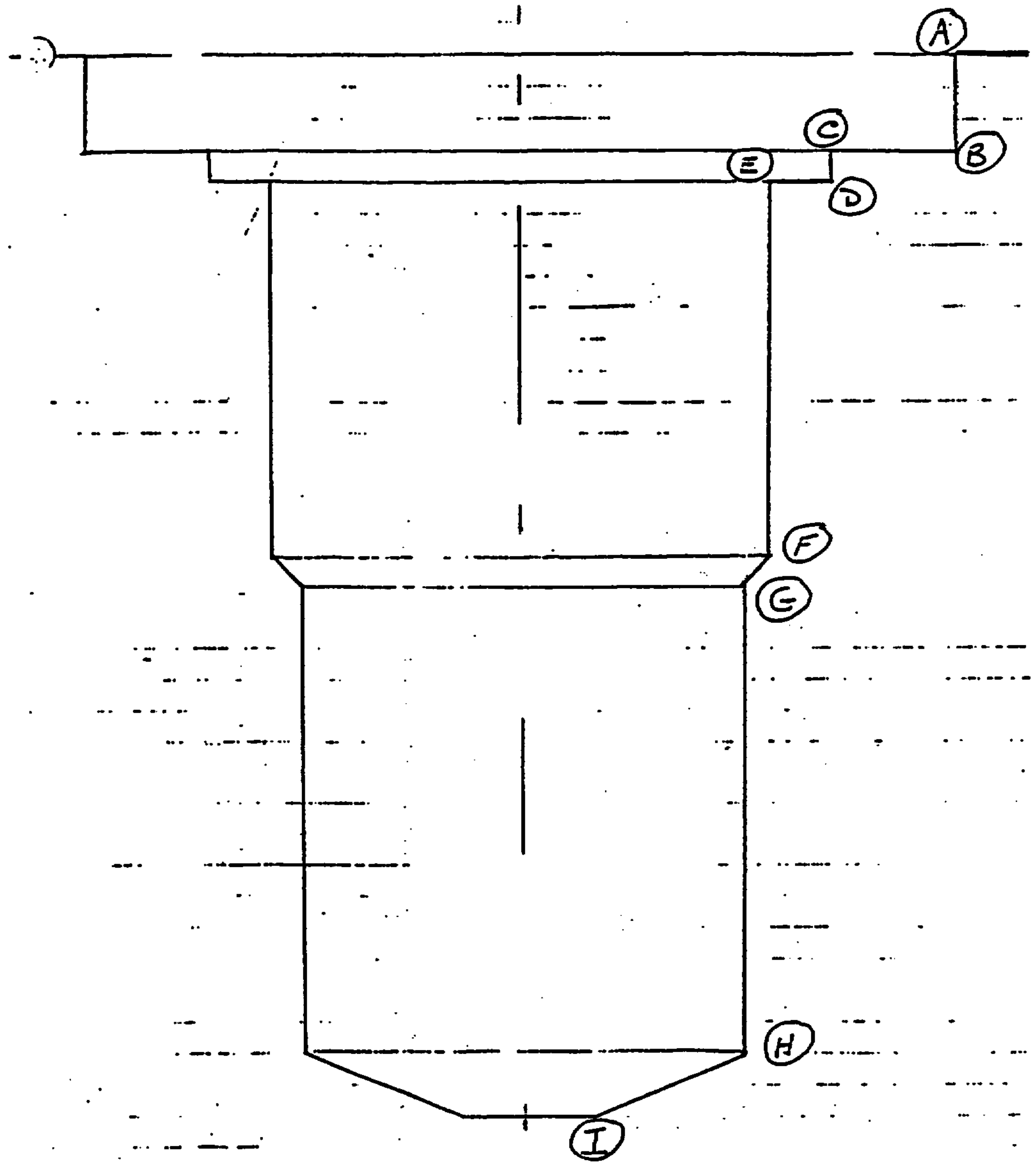


Figure 2.10.12-F153
F-294 Upper Cavity I.D. Measurements After the Drop

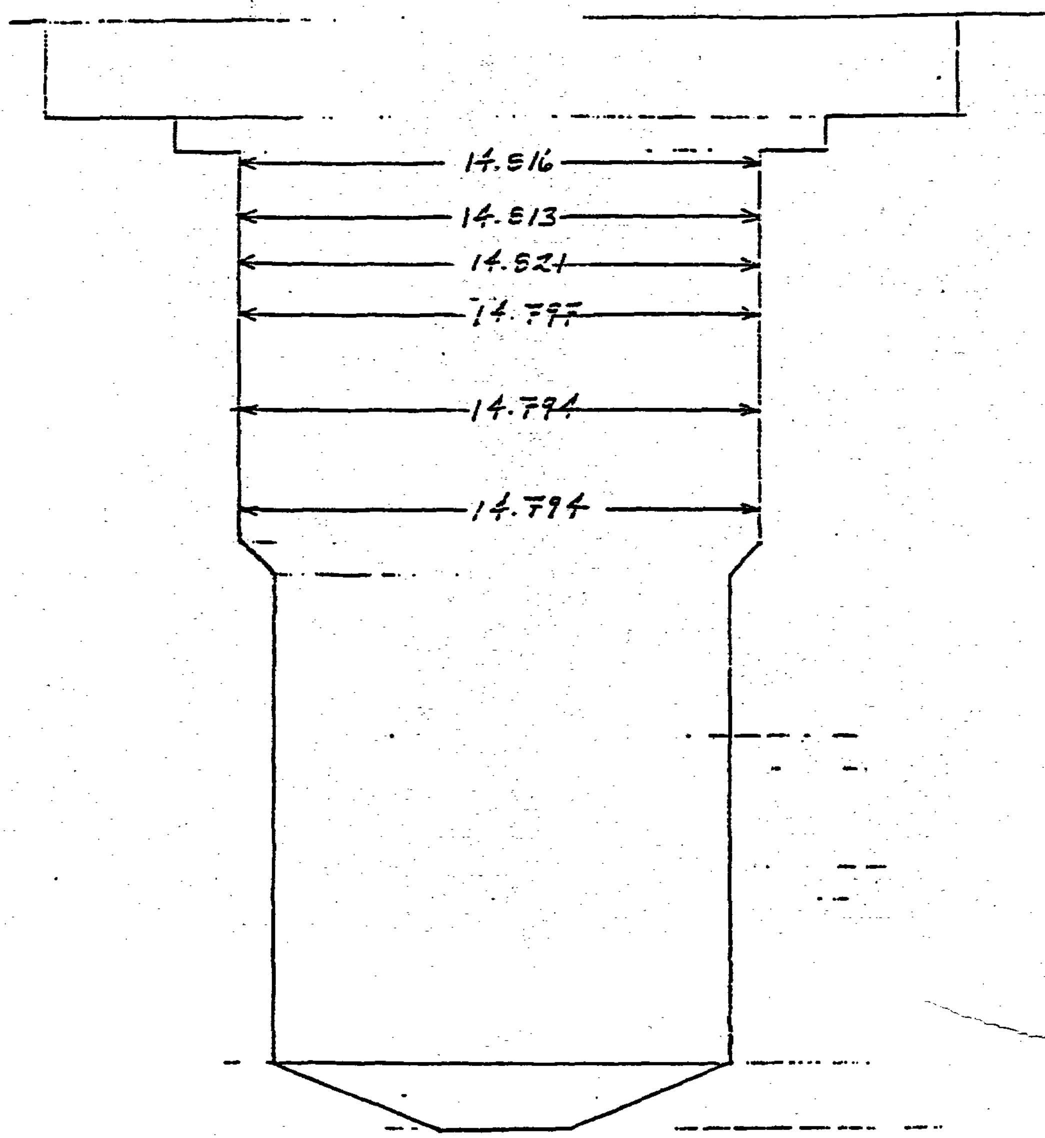
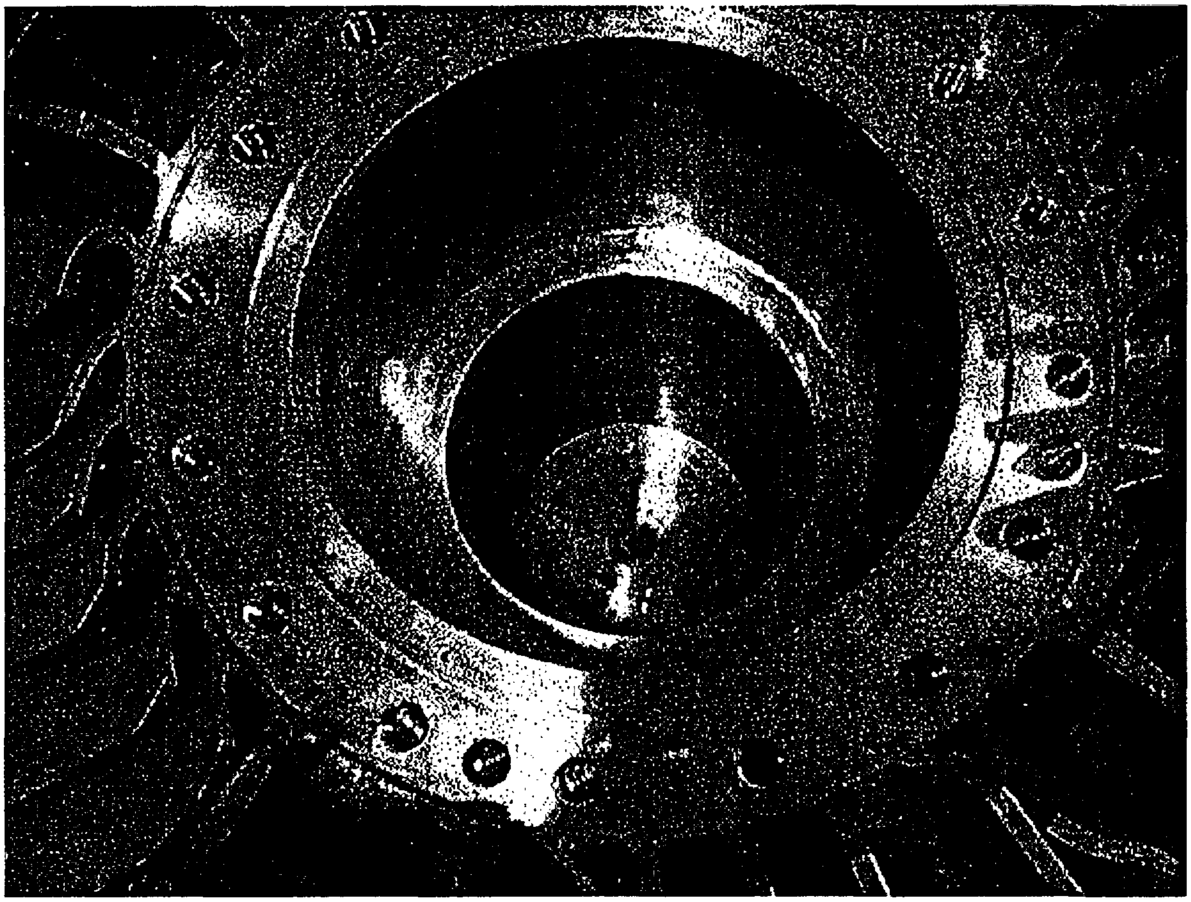


Figure 2.10.12-F154
F-294 Cavity After the Drop (no visible damage)



7.3 TEST #5.3.3 - AIR PRESSURE TEST OF THE DROP TESTED F-294 CAVITY

#1. Test #

5.3.3 as per test plan document IN/QA 1368 F294 (1): Air pressure test of the F-294 cavity (post-drop).

Test with "neoprene" gasket.

Date test conducted: March 13, 1998

#2. Person conducting the test/procedure

Greg Chupick conducted the air pressure leak test of F-294 cavity as per procedure IN/MP 0019 Z000 Issue G, Appendix 1 with following noted exceptions.

#2.1 Test details

The Joint configuration is as follows:

- drainline cap: 50 ft-lb. ± 10%
- "UNBRAKO" bolts: 16 out of 16 in place.
- Gasket: "neoprene" gasket: 16-3/8 in. OD x 15-1/8 in. ID x 3/16 in. thick. "Neoprene" material: MDS Nordion Stores stock: 2R039201

The torques provided on the bolts or other closures (i.e., caps) were not touched or disturbed after the drop test.

The cavity was not filled with water. The cavity was pressurized with 45 psig. air.

#2.2 Observations

When the F-294 plug closure joint was subjected to soap bubble (leak tek) leak test, no soap bubbles were observed around the gasket area. Also no soap bubbles were observed around the drain line cap area.

The pressure gauge readings:

At start 11.30 am	45 psig
At finish 1.30 pm	45 psig

#2.3 Photographs

Three photographs are attached (Figures 2.10.12-F155 through 2.10.12-F157).

#2.4 Conclusions

With the "neoprene" gasket in the joint, the drop-tested F-294 cavity air pressure leak test passed.

#3. Notes

#3.1 The torque wrench used is No. 1296500071

Calibration Date: 98/02/18

Calibration Due Date: 99/02/18

#4. Personnel

	Name	Title
Test conducted by:	G. Chupick	Senior Decontamination Monitor
Reviewed by:	V. Shah	Package Engineer
Reviewed by:	D. Whitby	Industrial Q. C.

Figure 2.10.12-F155
Air Pressure Test of the Cavity of the Drop-Tested F-294 Packaging

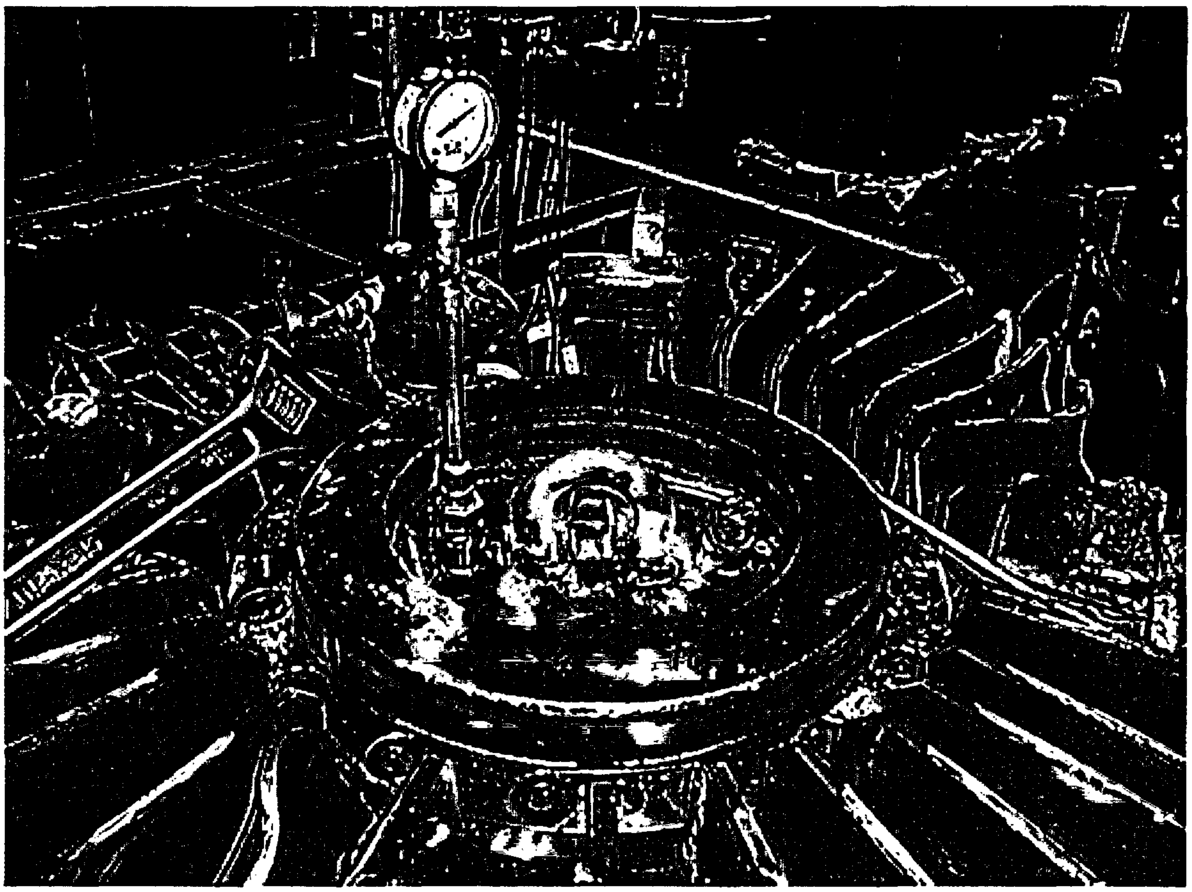
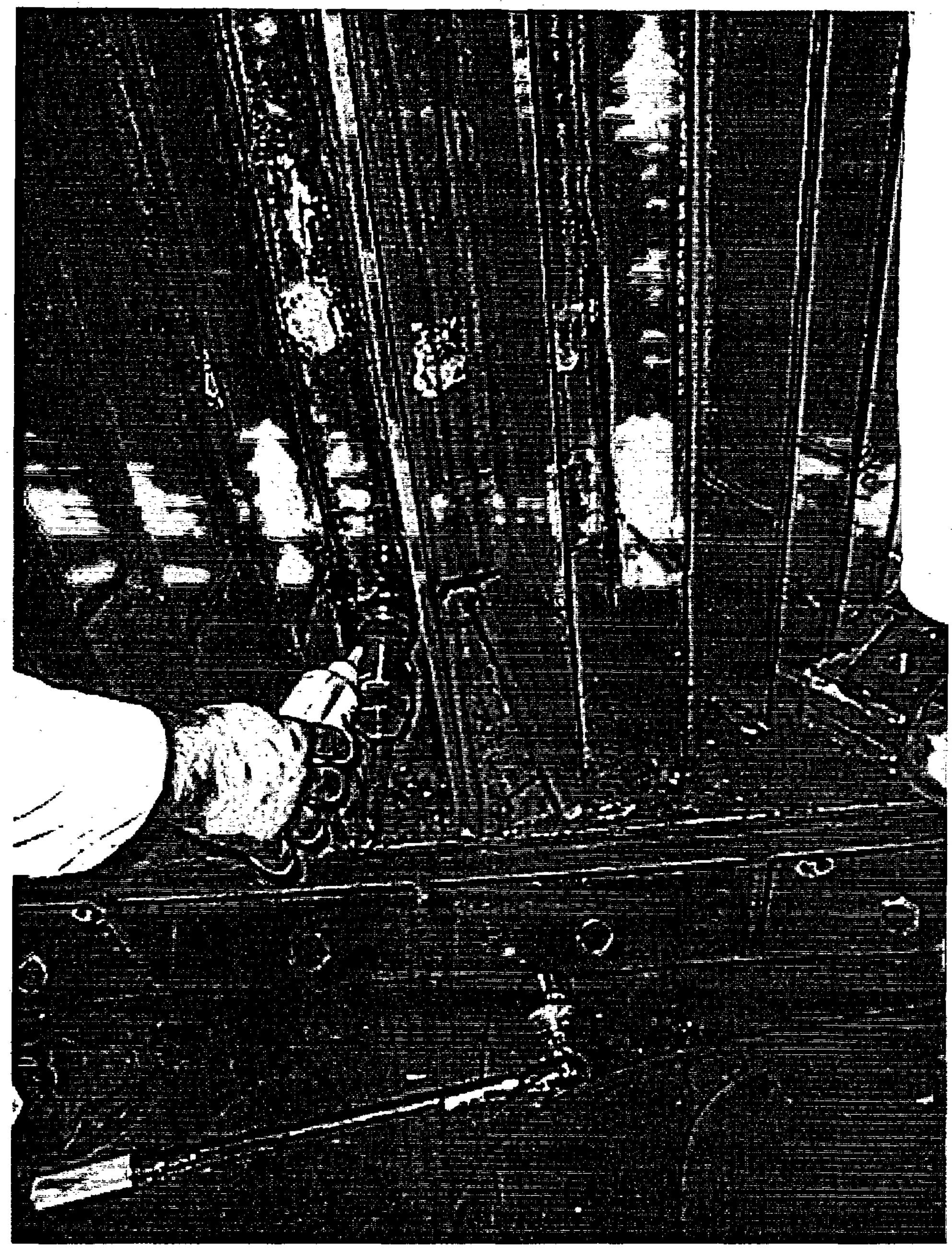


Figure 2.10.12-F156
Air Pressure Test of the Cavity of the Drop-Tested F-294 Packaging
Applying "Leak-Tek" (soap) Solution on Top Closure Plug

Figure 2.10.12-F157
Air Pressure Test of the Cavity of the Drop-Tested F-294 Packaging
Applying "Leak Tek" (soap) Solution on the Drainline Cap



7.4 TEST #5.3.4 - HELIUM LEAK TEST OF THE F-294 CAVITY

#1. Test # 5.3.4 as per test plan document IN/QA 1368 F294 (1): Helium Leak Test of the F-294 cavity.

Date test conducted: March 13, 1998

#2 Person who conducted the test/procedure

Chris Nicholson, Greg Chupick and V. Shah conducted the helium leak test of F-294 cavity as per procedure IN/OP 0598 F294 Issue A with following noted exceptions.

#2.1 Test details

The Joint configuration is as follows:

1) UNBRAKO bolts: 16 out of 16 in place.
2) Gasket: Neoprene gasket.
   Size: 16-3/8 in. OD x 15-1/8 in. ID x 3/16 in. thick. "Neoprene" material: MDS Nordion Stores stock: 2R039201

The torques provided on the bolts or other closures (i.e., caps) were not disturbed or adjusted after the drop tests conducted at AECL, CRL, Chalk River Ontario, Canada on February 25, 1998.

There was no water in the cavity. The cavity was pressurized with 14 psig. helium.

The ambient temperature was 21°C.

#2.2 Observations

The container was "sniffed" around the top plug closure, ventline caps and drainline cap.

When the F-294 plug closure joint was subjected to sniffer helium leak test, it met leaktightness level of 4×10^{-7} atm cc sec.

When the F-294 drainline joint was subjected to sniffer helium leak test, it met leaktightness level of 6×10^{-6} atm cc/sec.

When the F-294 vent line joint was subjected to sniffer helium leak test, it met leaktightness level of 4×10^{-7} atm cc/sec.

#2.3 Photographs

Three photographs are attached (Figures 2.10.12-F158 through 2.10.12-F160).

#2.4 Conclusions

With "neoprene" gasketed plug joint, the F-294 cavity passed the helium leak test as the leaktightness level of 6×10^{-6} atm cc/sec, which exceeds the required leaktightness level of 1×10^{-4} atm cc/sec as stated in procedure IN/OP 0598 F294 Issue A.

#3. Notes

#3.2 Helium Leak Testing Equipment:

Varian 947 Helium Leak Detector # 10487/6-809-416

Calibration information:

- The machine has a built-in calibration standard. This is traceable to national standard as per certificate provided by the manufacturer.
- The machine is verified to the built-in calibrated standard at the start of every leak test.

#4. Personnel

	Name	Title
Test conducted by:	C. Nicholson	Development Technician
Test conducted by:	G. Chupick	Senior Decontamination Monitor
Test conducted by:	V. Shah	Package Engineer
Reviewed by:	D. Whitby	Industrial Q.C.

Figure 2.10.12-F158
Helium Leak Test of the Cavity of the Drop-Tested F-294 Packaging

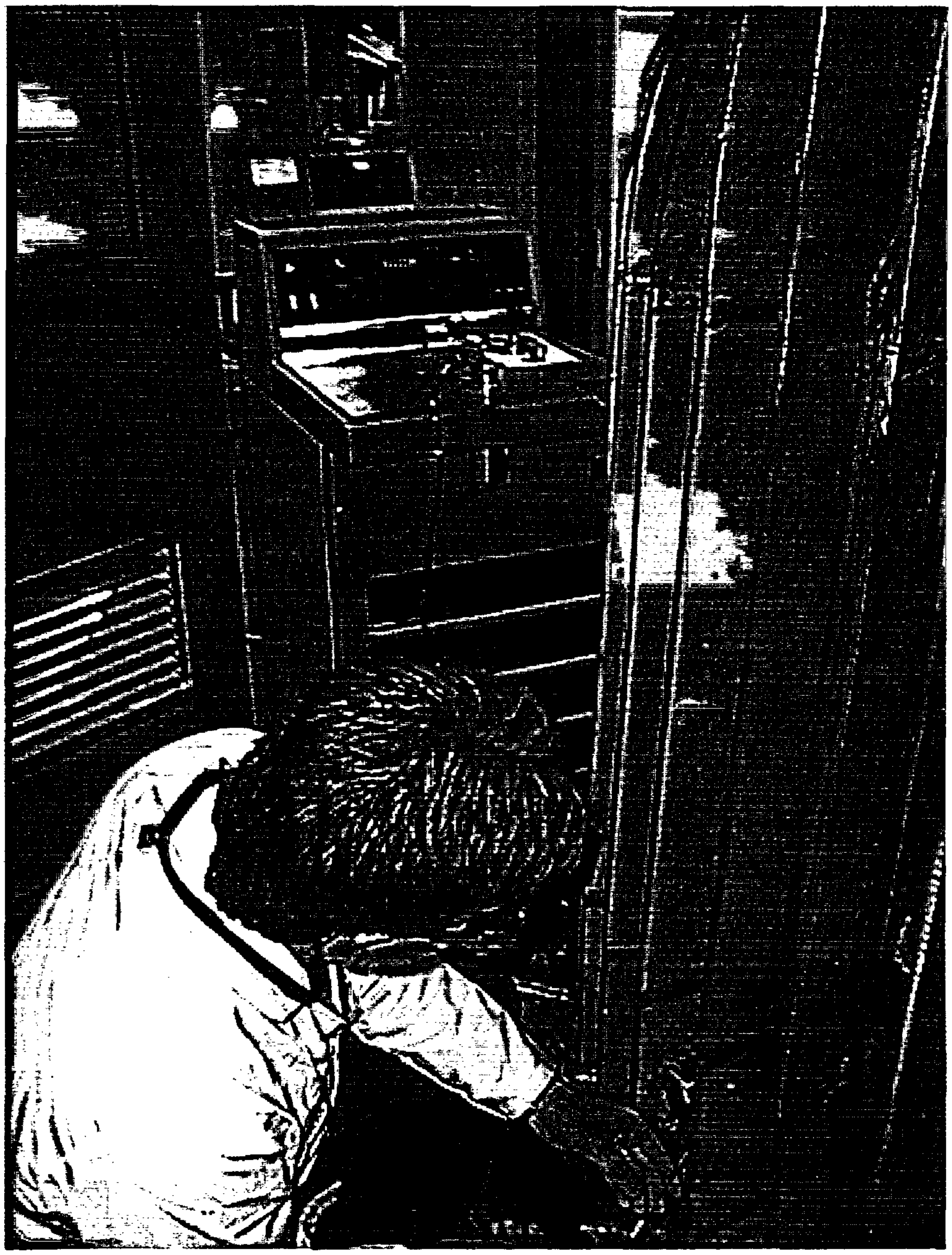


Figure 2.10.12-F159
Helium Leak Test of the Cavity of the Drop-Tested F-294 Packaging
Sniffing for Leaks at Top Closure Plug Joint

Figure 2.10.12-F160
Helium Leak Test of the Cavity of the Drop-Tested F-294 Packaging
Sniffing for Leaks at the Drainline Cap

7.5 TEST #5.3.5 - Damage Assessment of the Tested F-294 Specimen

MDS Nordion Test Plan IN/QA-1368 F294 (1)

Damage Assessment of the Tested F-294 Specimen

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2	Deformed Area on the F-294 Packaging Assembly (c:\droptest\photos\114a.doc)
3	The Cutting of the Fireshield (c:\droptest\photos\fs.doc)
4	The F-294 Crush Shield (c:\droptest\photos\cshield.doc)
5	Standard J-shape Crush Shield Fin (h:\files\pckengrg\fin#2.doc)
6	Standard I-shape Crush Shield Fin (c:\droptest\photos\fin#13.doc)
7	Standard S-shape Fin (c\:droptest\photos6\fin8.doc)
8	Standard U-shape Fin (c:\droptest\photos6\fin12.doc)
9	Standard J-shape Fin (c:\droptest\jfin.doc)
10	Standard I-shape Fin(c:\droptest\photos\ifin.doc)
11	Deformation on Lift Lug #4 (no code on photo)
12	Deformation on Lift Lug #4, Top (c:\droptest\photos\114.doc)
13	Fin #29 (c:\droptest\photos\fin29.doc)
14	Puncture Pin Damage Zone from Drop Test #8 (c:\droptest\photos\tear.doc)
15	Fireshield Segment #1 (c:\droptest\photos\seg1.doc)
16	Fireshield Segment #2 (c:\droptest\photos\seg2c.doc)
17	Fireshield Segment #2 Lower Puncture Zone (c:\droptest\photos\seg2.doc)
18	Fireshield Segment #2 Upper Puncture Zone (c:\droptest\photos\seg2a.doc)
20	Fireshield Segment #2, Inboard View (c:\droptest\photos\seg2b.doc)
21	Fireshield Segment #3 (c:\droptest\photos\seg3.doc)
22	Fireshield Segment #3, Inboard View (c:\droptest\photos\seg3a.doc)
23	Fireshield Segment #3, Inboard View (c:\droptest\photos\seg3b.doc)
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30	Shipping Skid, View 4 (c:\droptest\skid4.doc)
31	Shipping Skid, View 5 (c:\droptest\skid5.doc)
32	F-294 Container Fins (c:\droptest\photos\crack.doc)

#1 Introduction

The F-294 test packaging was subjected to eight (8) drop tests conducted on 1998 February 25 at Chalk River Laboratory, AECL, Chalk River, Ontario, Canada.

Drop Test	Description
#1	Normal free drop test, top end orientation (3-ft drop).
#2	30-ft free drop. Side oblique drop orientation (on lift lug #4).
#3C	Puncture test: impact on the zone near lift lug fin #4 (40-inch drop).
#4	Puncture test: impact cylindrical fireshield (40-inch drop at midheight of fireshield, on lift lug #4 axis).
#5	Puncture test: impact on fixed skid lower plate (40-inch drop).
#6	30-ft free drop test: top end drop orientation.
#7	Puncture test: impact on the crushshield upper plate (40-inch drop at center zone of crushshield).
#8	Puncture test: impact cylindrical fireshield (40-inch drop at midheight on name plate zone).

The drop tested F-294 assembly was returned to MDS Nordion, Ottawa for assessment after the above drop tests.

The drop tested crushshield had to have several fins flame cut to enable its removal from the container. All cut fins were saved for assessment.

Leak tests were performed to determine the cavity leak tightness.

The damage assessments were performed by Vinod Shah and Dave Whitby on the drop tested F-294 packaging. Unless otherwise specified, the damage assessments were conducted on the dates between 1998 April 03 and 1998 April 14.

The following tests were performed and the results recorded.

#2 Plug Removal and Assessment

The plug fasteners were numbered as shown in Figure 2.10.12-F161. The torque required to loosen each fastener is as specified in Table 2.10.12-T12.

There was no obvious damage on any of the closure plug fasteners. The closure plug was easily lifted out of the cavity with no evidence of binding or jamming. The operation of removing the plug was just the same as during the pre-drop condition. The gasket had no visible damage, was still pliable and performed well after the drop as was evidenced with the leak test results.

The cavity had appeared clean and undamaged as documented in the Test Report #5.3.2 Dimensional Measurements of the F-294 after the Drop. There were light ridges in the upper cavity that could be felt by hand (approximately 0.005 in. proud). There was no evidence of cracking on the surfaces of the cavity wall.

There was no visible damage to the plug, other than the crushed lifting eye and light marks on some of the bolt holes left by the threaded fasteners. All welds appeared sound with no cracking. The dimensional results were recorded in Test Report #5.3.2.

#3 **Crush Shield Fin Damage Assessment**

The fins were numbered as in Figure 2.10.12-F162, and the deformation of the outer edge on each fin was quantified in the planes shown in Digital Photos 5 and 6.

Graduated rules and/or a tape measure were used for measuring the fins. The deformation for each fin had two characteristic shapes as shown in Digital Photos 5 and 6; these shapes and the measured deformations are referred to in Tables 2.10.12-T13 and 2.10.12-T14.

#4 **Crush Shield Puncture Zone**

The deformation caused by Drop Test #7 was a 2-1/4 in. impression on the top of the crushshield and a 2-13/16 in. proud deflection on the underside. See Digital Photo 4.

The deformation profile of the crush shield is given in Figure 1.10.12-F166.

#5 **Container Fin Damage Assessment**

The container fins were numbered as shown in Figure 2.10.12-F162 and the fin deformation was measured as was done with the crush shield.

Graduated rules and/or a tape measure were used for measuring the fins. The deformation for each fin had four characteristic shapes as shown in Digital Photos 7, 8, 9 and 10; these shapes and the measured deformations are shown in Tables 2.10.12-T15 and 2.10.12-T16.

#6 **Puncture Pin Damage Zones**

See Table 2.10.12-T17

#6.1 Observations

1. The fin deformation for each of the puncture pin locations indicates that the pin did not come in direct contact with the container wall.
2. The estimated closest proximity to the container wall was the torn fin #29, which was 1/2 in. from the reinforcing plate, and 1-1/4 in. from the container wall (shell).

#7 **Fireshield Damaged Areas**

After the drop tests, the cylindrical fireshield was cut in to three (3) segments, see Digital Photo 3.

Segment No.	Position on F-294 Container	Deformation
1	around Lift Lug # 1	slight deformation around lower mounting bracket only.
2	around Lift Lug #4	the most deformed - from Drop Tests #2, #3 and #4.
3	around Lift Lugs #2 and #3	puncture pin zone from Drop Test #8

#7.1 Fireshield Segment #1

Only slight deformation - the lower mounting bracket was recessed approximately 1/8 in. from its normal position, Photo 15.

#7.2 Fireshield Segment #2

Significant deformation at the top due to Drop Tests #2 and #3, and a puncture pin damage zone at midheight due to Drop Test #4.

The puncture pin partially tore through the fireshield wall as shown in Digital Photos 16 and 17. The deformation profile and approximate area of the opening are shown in Figure 2.10.12-F163.

The upper damage zone due to Drop Tests #2 and #3 was deformed as shown in Digital Photos 18 and 19.

#7.3 Fireshield Segment #3

Due to Drop Test #8, the puncture area included the ID plate mounting plaque on the fireshield wall. The puncture pin partially tore through the fireshield wall as shown in Digital Photos 21 and 22. The deformation profile and the approximate area of opening are shown in Figure 2.10.12-164.

#8. Fixed Skid Puncture Zone

A puncture zone impression was as shown in Digital Photo 26 due to Drop Test #5.

Other fixed skid deformation is shown in Digital Photo 24. The deformation profile is shown in Figure 2.10.12-F165.

#9 Removable Shipping Skid

For assessment, the deformed shipping skid was oriented with the lowest corner touching the floor and the three remaining corners set on blocks such that the undamaged portion of the skid was horizontal to the floor. All measurements were taken in the planes parallel or normal to the floor as shown in Digital Photos 27 to 31.

#10 Conclusions

1. Integrity of stainless steel shell surrounding the lead shielding in the container assembly.
   - 1.1 There were no cracks in the external primary shell (inclusive of welds) of the container of F-294 test packaging.
   - 1.2 There were no cracks in the shell (inclusive of welds) of the closure plug of the F-294 test packaging.
   - 1.3 There were no cracks in the cavity of the container of the F-294 test packaging.
   - 1.4 All the container/fin root welds were intact and not cracked, with the exception of few root welds located at the top container zone near the closure plug.
2. The shapes of the impacted fins followed the standard deformation profiles (S- or J-curves). An extensive photographic record as well as a deformation measurement record of the impacted fins has been compiled.

3. Integrity of Thermal Protection

3.1 As a result of the puncture pin tests, there were very small openings in the cylindrical fireshield. (27 in^2 out of 9,257 in^2).

3.2 As a result of the puncture pin test, there were no openings in the thermal protection integral with the crush shield.

3.3 As a result of the puncture pin test, there were no openings in the thermal protection integral within the fixed skid plate assembly.

#11 Personnel

	Name	Title
Prepared by	D. Whitby	Industrial Quality Control
Approved by	V. Shah	Package Engineering

Table 2.10.12-T12
Opening Torques for the Closure Plug

Bolt No.	Opening Torque (ft.-lb.)
1	30
2	70
3	90
4	90
5	20
6	30
7	5
8	30
9	40
10	0
11	140+
12	140+...220 (binding)
13	120 (binding)
14	140+...180
15	140+...220
16	140+...210 (2nd torque wrench)

Table 2.10.12-T13
Crush Shield Fin Shapes

Dimension	Description	Shape Characteristic
A	maximum horizontal deformation from the plane normal to upper donut ring.	J shape - Photo 5.
B	maximum deformed vertical height from the upper donut ring.	J shape - Photo 5.
C	maximum horizontal deformation from the plane normal to upper donut ring.	Straight - Photo 6.
D	maximum deformed vertical height from the upper donut ring.	Straight - Photo 6.

Table 2.10.12-T14
Deformation Measurements on the Crushshield Fins

Fin No.	Fin Shape	Dim. A	Dim. B	Dim. C	Dim. D	Comments
1	J- Photo 5	6 in.	7 - 7/8 in.			cracked weld
2	J- Photo 5	4 in.	8 in.			cracked weld
3	J- Photo 5	7 - 7/8 in.	3 - 7/8 in.			
4	J- Photo 5	7 - 3/4 in.	3 - 3/4 in.			
5	J- Photo 5	7 - 7/8 in.	3 - 1/4 in.			
6	J- Photo 5	7 - 1/2 in.	cut			
7	J- Photo 5	7 - 7/8 in.	cut			
8	J- Photo 5			cut	7 - 5/8 in.	cracked weld
9	J- Photo 5			cut	8 in.	cracked weld
10	J- Photo 5	7 - 7/8 in.	1/2 in.			cracked weld
11	J- Photo 5	8 in.	1/4 in.			cracked weld
12	J- Photo 5	7 - 1/8 in.	3 - 1/4 in.			cracked weld
13	J- Photo 5	7 - 1/2 in.	3 - 1/4 in.			cracked weld
14	J- Photo 5	7 - 3/4 in.	3 in.			cracked weld
15	I- Photo 6			6 - 3/8 in.	6 in.	cracked weld
16	I- Photo 6			6 - 1/2 in.	5 - 1/2 in.	1 in. detached
17	I- Photo 6			6 in.	6 in.	1 - 1/4 in.
18	I- Photo 6			7 in.	5 - 1/4 in.	1 - 1/4 in.
19	I- Photo 6			7 in.	4 - 1/4 in.	broken weld
20	I- Photo 6			6 in.	4 in.	broken ring
21	I- Photo 6			7 in.	4 - 1/4 in.	broken ring
22	I- Photo 6			4 - 1/4 in.	3 - 1/2 in.	cracked weld
23	I- Photo 6			5 - 1/2 in.	4 in.	cracked weld
24	I- Photo 6			5 - 1/2 in.	4 in.	cracked weld
25	I- Photo 6			6 in.	4 in.	cracked weld
26	I- Photo 6			6 in.	4 in.	cracked weld
27	I- Photo 6			6 - 1/2 in.	5 in.	cracked weld
28	I- Photo 6			6 in.	4 in.	cracked weld

Table 2.10.12-T15
Fin Shape Definition

Dimension	Description	Photo
J-Shape Deformed Fin		
A	Overall height, from upper weld to highest point of the fin.	9
B	Distance, from upper weld to center of curved portion of fin.	9
C	Horizontal deformation of curved portion, from normal plane.	9
D	Horizontal deformation of top edge, from normal plane.	9
S-Shape Deformed Fin		
A	Overall height, from upper weld to highest point of the fin.	7
B	Height from upper weld to upper most S section.	7
C	Horizontal deformation of upper most S section.	7
D	Horizontal deformation of the middle S section.	7
E	Horizontal deformation of the lower S section.	7
F	Height from upper weld to the middle S section.	7
G	Height from upper weld to the lower S section.	7
Straight (I) Bent Fin		
A	Overall height, from upper weld to highest point of the fin.	10
B	Height from upper weld to the bend.	10
C	Horizontal deformation at top of fin.	10
U-Shape Deformed Fin		
A	Overall height, from upper weld to highest point of the fin.	8
B	Height from upper weld to the bend.	8
C	Horizontal deformation at top of fin.	8
D	Horizontal deformation of the middle section.	8
Lower Section Bow		
H	Maximum horizontal deformation of lower section bow.	n/a
J	Height from top of skid plate to maximum bow.	n/a

Table 2.10.12-T16
Container Fin Deformation Measurements

Fin No.	Shape	Dim A	Dim B	Dim C	Dim D	Dim E	Dim F	Dim G	Dim H	Dim J	Comments
1	no damage										LL #1
2	I Photo 10			3/4 in.					5/32 in.	4 in.	
3	J Photo 9	14-5/8 in.	10-3/4 in.	1-1/2 in.	2-5/16 in.						
4	J Photo 9	14-7/8 in.	10-1/2 in.	1-3/4 in.	1-1/2 in.						cracked top weld
5	J Photo 9	14-27/32 in.	10-5/16 in.	1-7/8 in.	1-3/4 in.				9/32 in.	16 in.	
6	J Photo 9	15 in.	10-7/8 in.	1-1/4 in.	2-1/4 in.						cracked top weld
7	J Photo 9	15-5/32 in.	11-17/32 in.	1-15/16 in.	1-7/32 in.						cracked top weld
8	S Photo 7	15-29/32 in.	14-11/16 in.	5/16 in.	1/8 in.	3/8 in.	12-3/4 in.	10-13/16 in.	13/16 in.		cracked top weld
9	I Photo 10			15/16 in.							support
10	no damage										LL # 2
11	I Photo 10			1-1/16 in.							
12	U Photo 8	14-22/32 in.	10 in.	1-13/32 in.	2-1/2 in.						broken top weld
13	no damage										
14	no damage										
15	no damage										
16	I Photo 10			13/32 in.					3/16 in.	18 in.	
17	J Photo 9	15 in.	10-25/32 in.	3-13/16 in.	5/32 in.						broken top weld
18	see Photo 14										
19	see Photo 14										LL #3
20	I Photo 10			15/32 in.							
21	no damage										
22	no damage										
23	no damage										
24	no damage										
25	I Photo 10			1-23/32 in.							
26	U Photo 8	15-12/32 in.	12-9/16 in.	3-13/16 in.	3-1/2 in.						
27	see Photo 11										
28	see Photo 11										LL #4
29	see Photo 13										
30	U Photo 8	15-1/4 in.	13-1/8 in.	4-1/4 in.	4-5/8 in.						
31	J Photo 9	15-5/8 in.	13-1/2 in.	4-5/8 in.	3-7/8 in.						
32	J Photo 9	16 in.	15 in.	2-1/16 in.	2 in.						slight J shape
33	J Photo 9	16 in.	15 in.	7/8 in.	1-1/16 in.						slight J shape
34	J Photo 9	16 in.	15 in.	1/8 in.	3/16 in.						slight J shape
35	J Photo 9	16 in.	15 in.	5/16 in.	3/8 in.						slight J shape
36	J Photo 9	15-1/2 in.	12 in.	3/8 in.	1-1/4 in.						slight J shape

Table 2.10.12-T17
Puncture Pin Damage Zones

Drop Test No.	Location of Impact	Fin No.	Photo No.
3	container, lift lug #4	LL #4 and #29	11
4	cylindrical fireshield midpoint	#28 and #29	11
5	bottom plate of fixed skid	fixed skid	26
7	upper plate of crushshield	crushshield	4
8	cylindrical fireshield - nameplate	#18 & #19	14

Figure 2.10.12-F161
Closure Plug Fastener Numbers

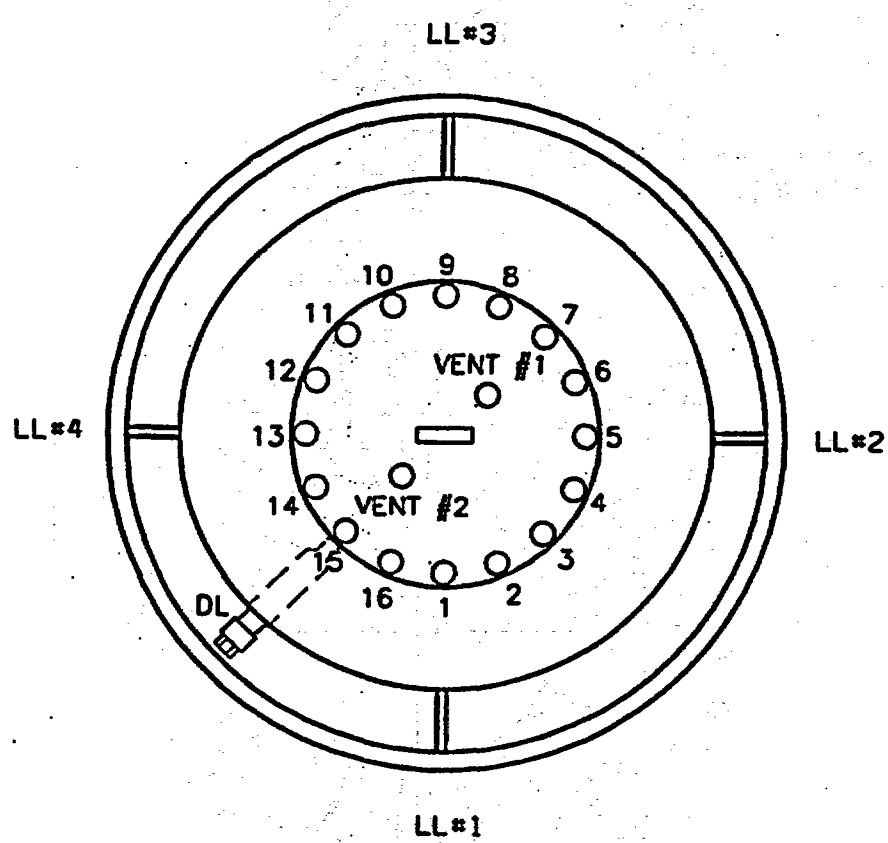


Figure 2.10.12-F162
Fin Numbering for the Crush Shield and the Container

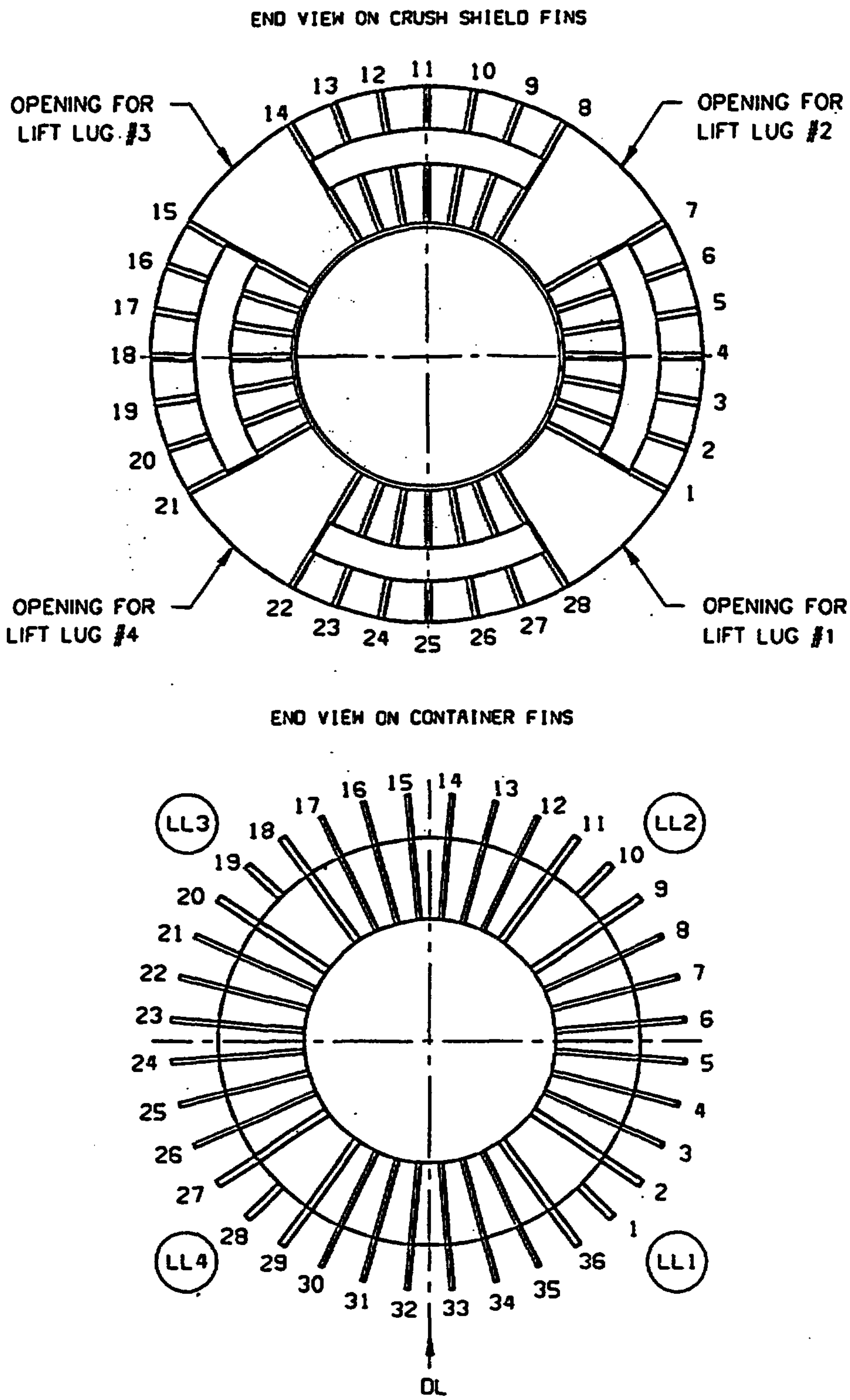


Figure 2.10.12-F163
Deformation of Fireshield during Puncture Pin Drop Test #4

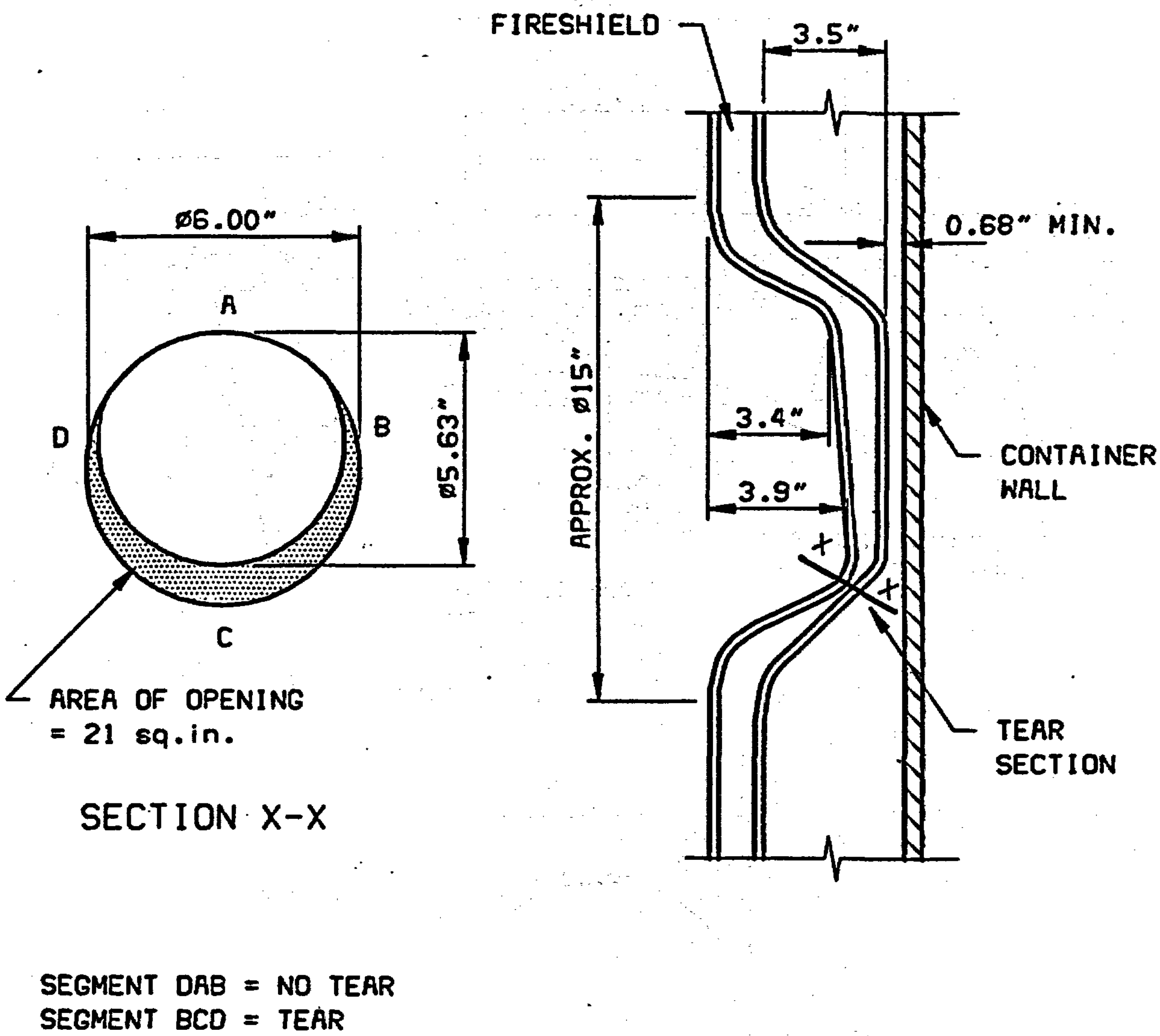
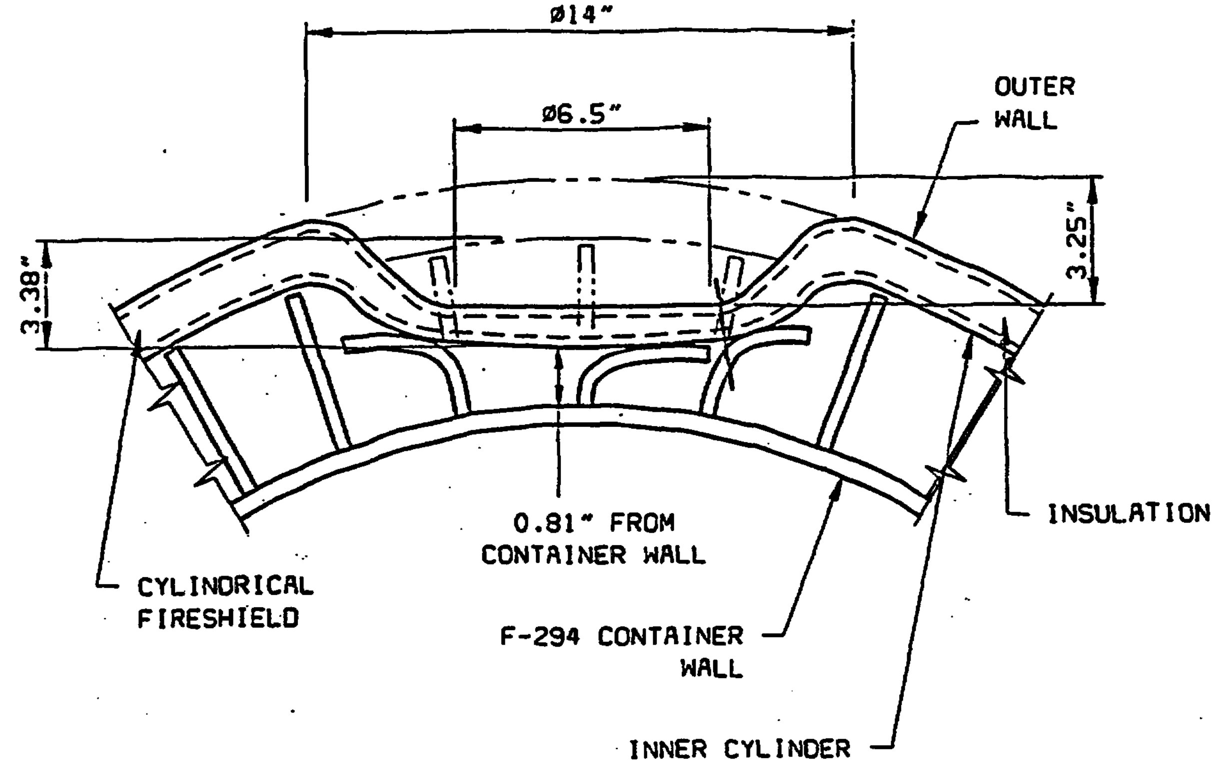


Figure 2.10.12-F164
Deformation of Fireshield (nameplate zone) during Puncture Pin Drop Test #8



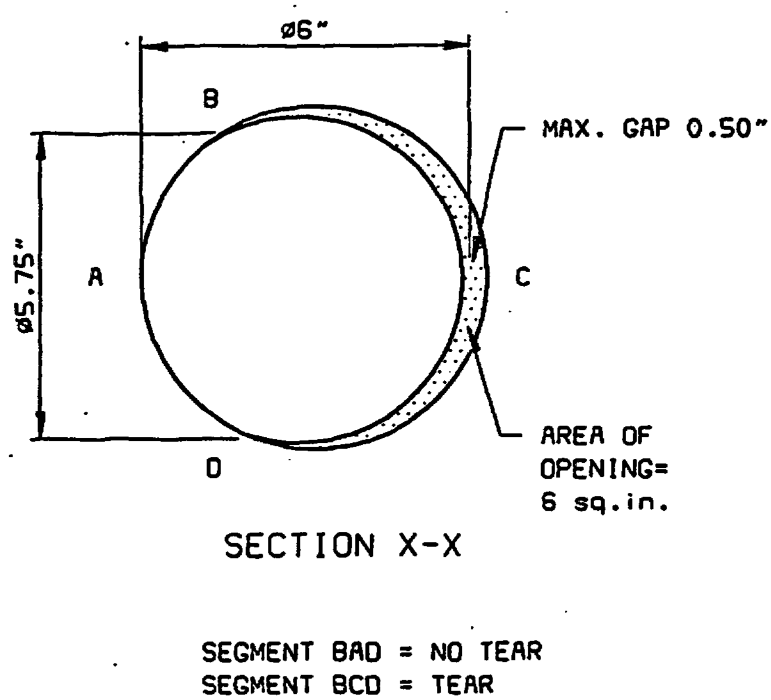


Figure 2.10.12-F165
Deformation on the Bottom of Fixed Skid due to Puncture Pin Drop Test #5

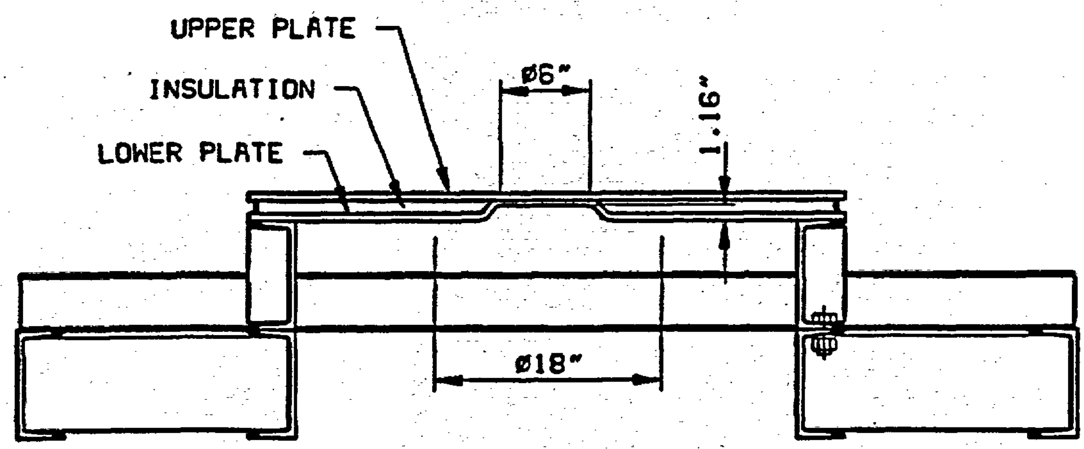
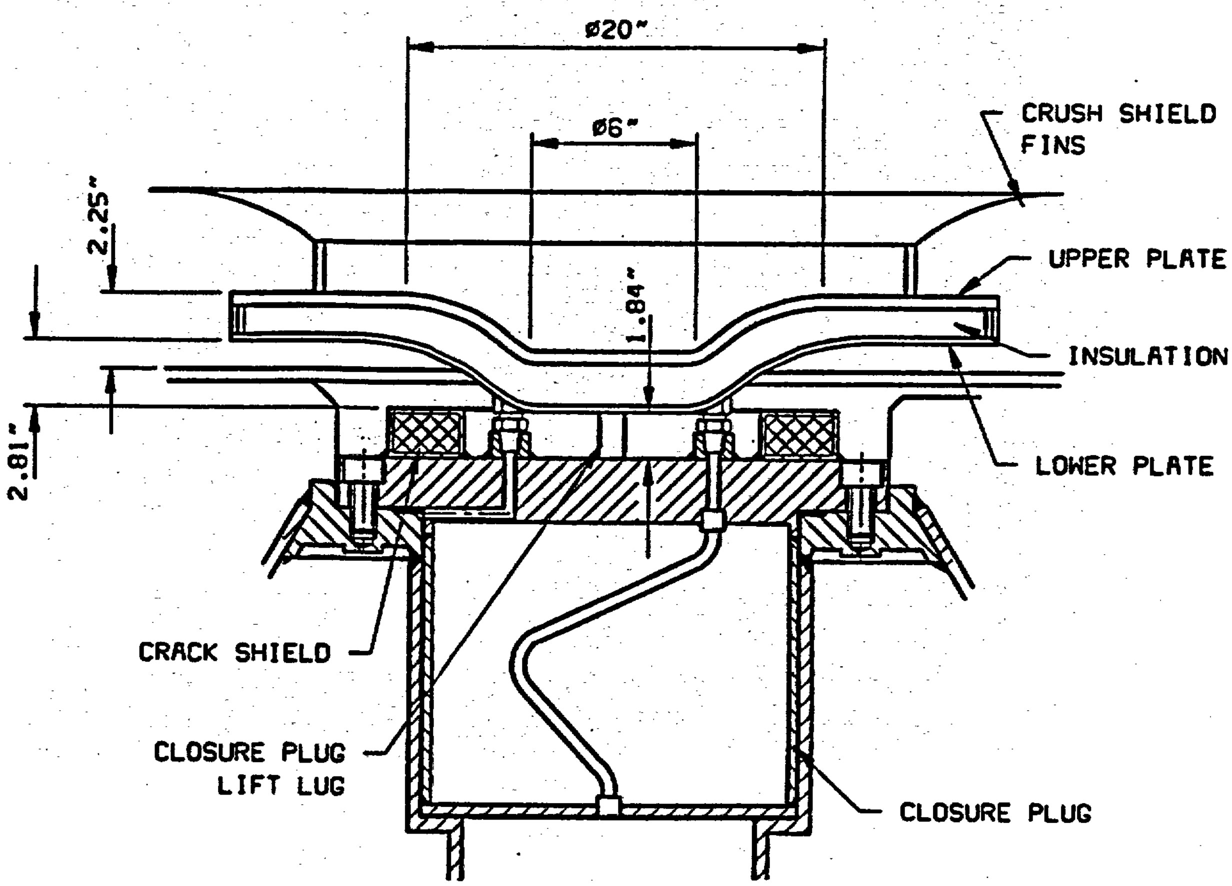
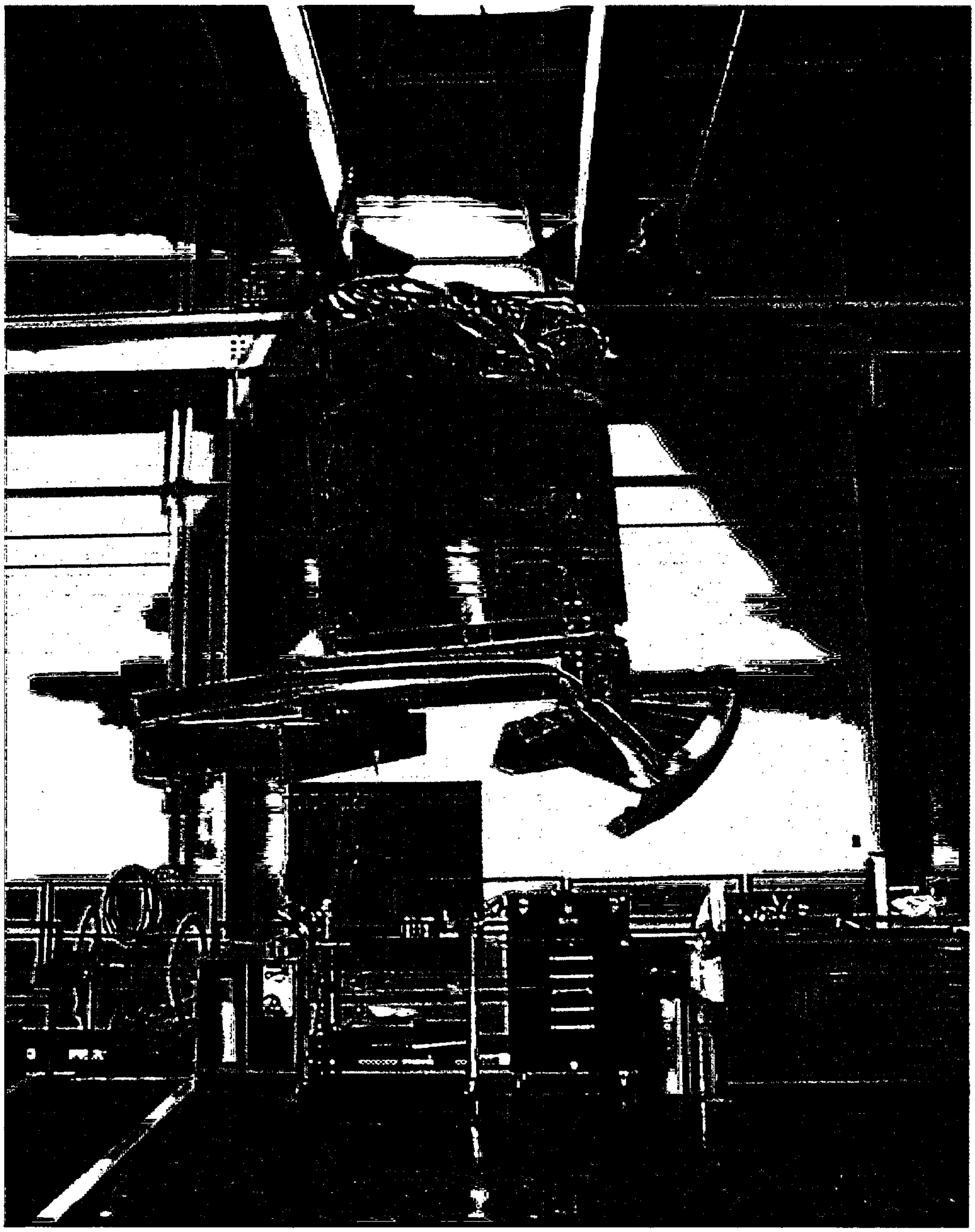


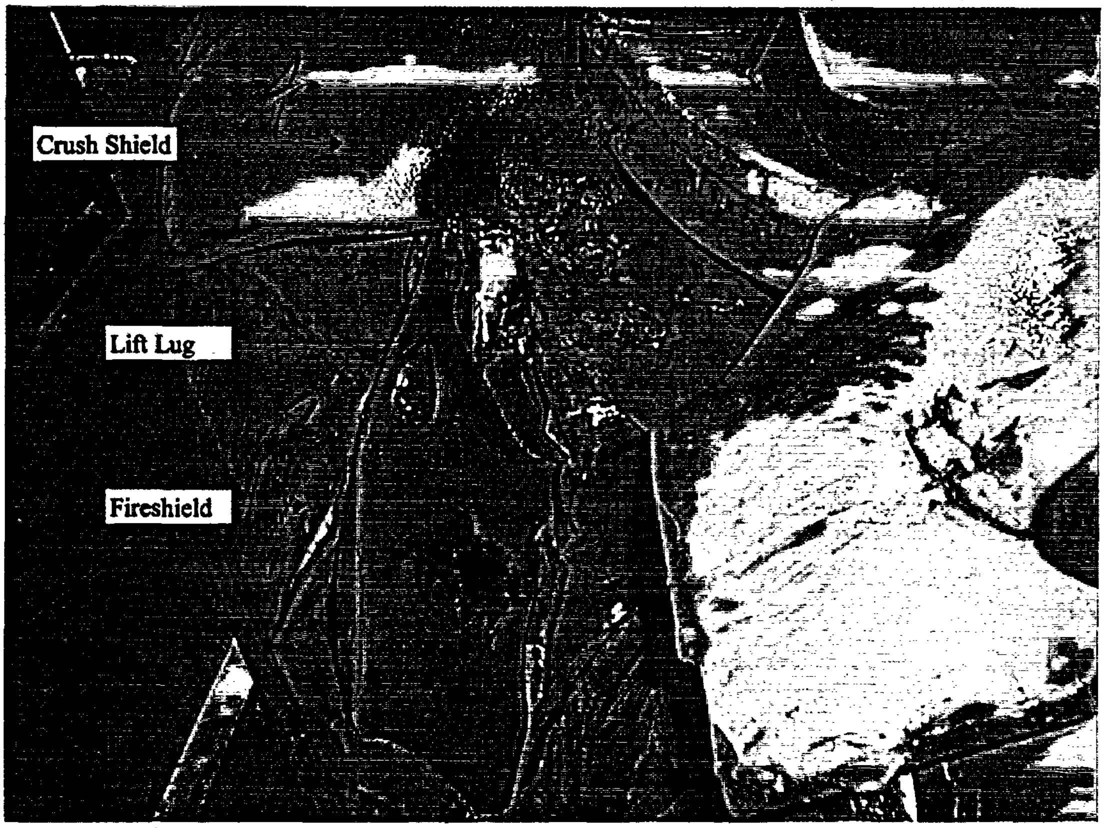
Figure 2.10.12-F166
Deformation Profile on Crush Shield due to Puncture Pin Drop Test #7



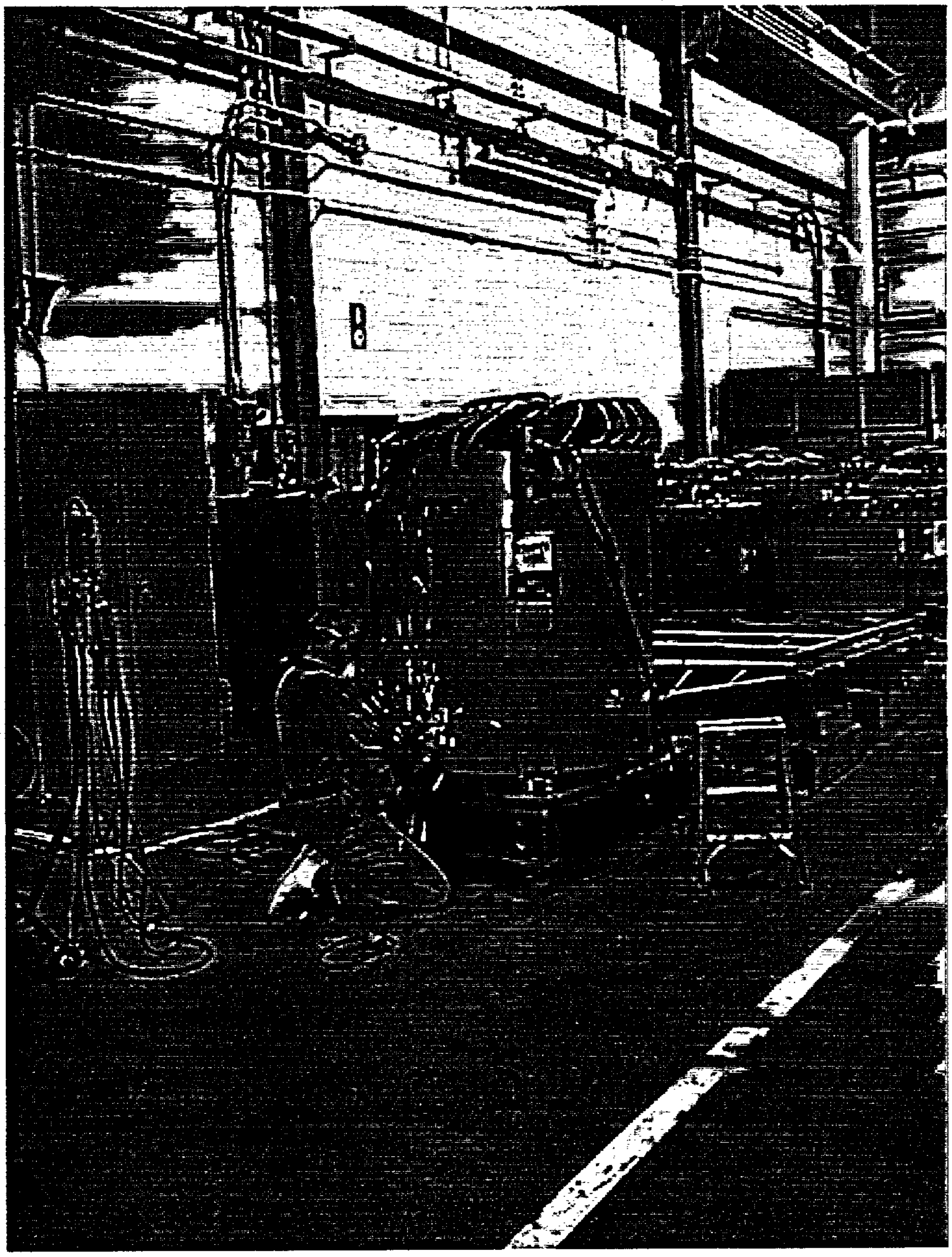
Digital Photo No. 1 (c:\droptest\249a.doc)
Unloading of the F-294 Packaging



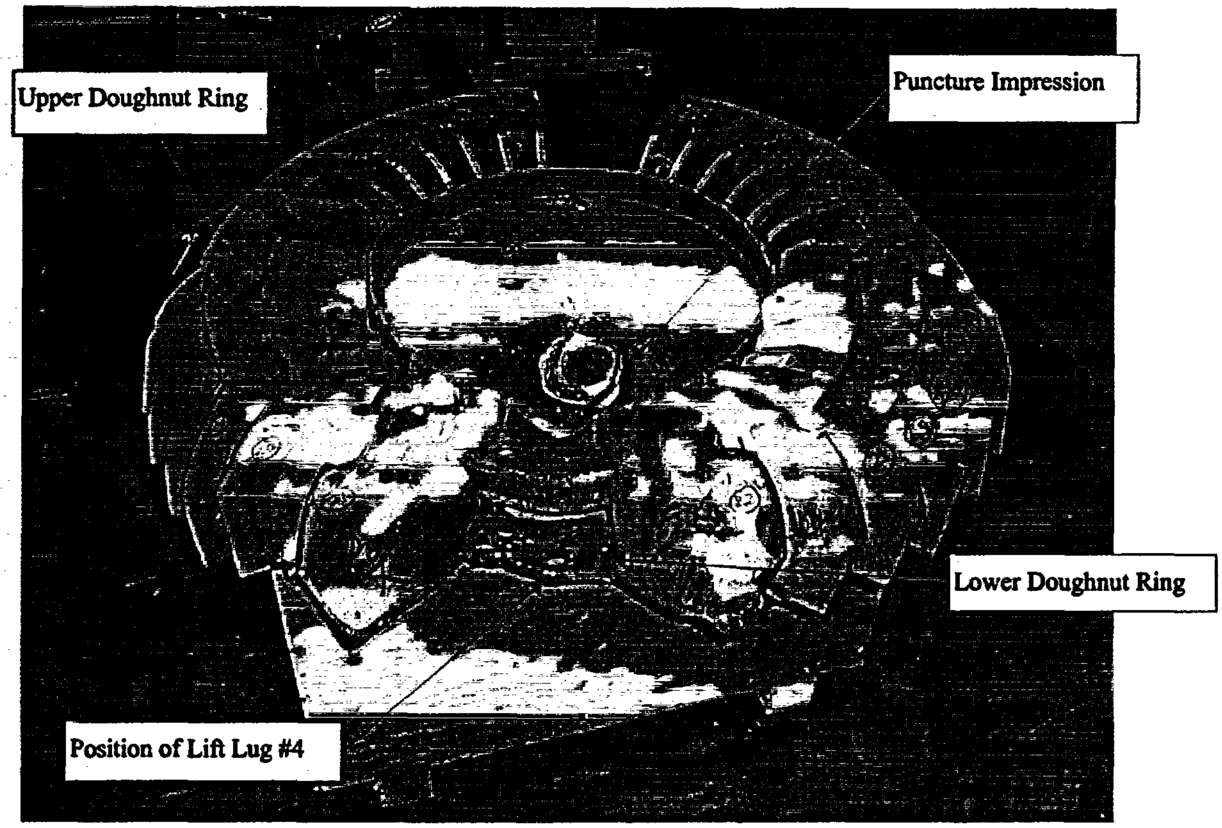
Digital Photo No. 2 (c:\droptest\photos\114a.doc)
Deformed Area on the F-294 Packaging Assembly



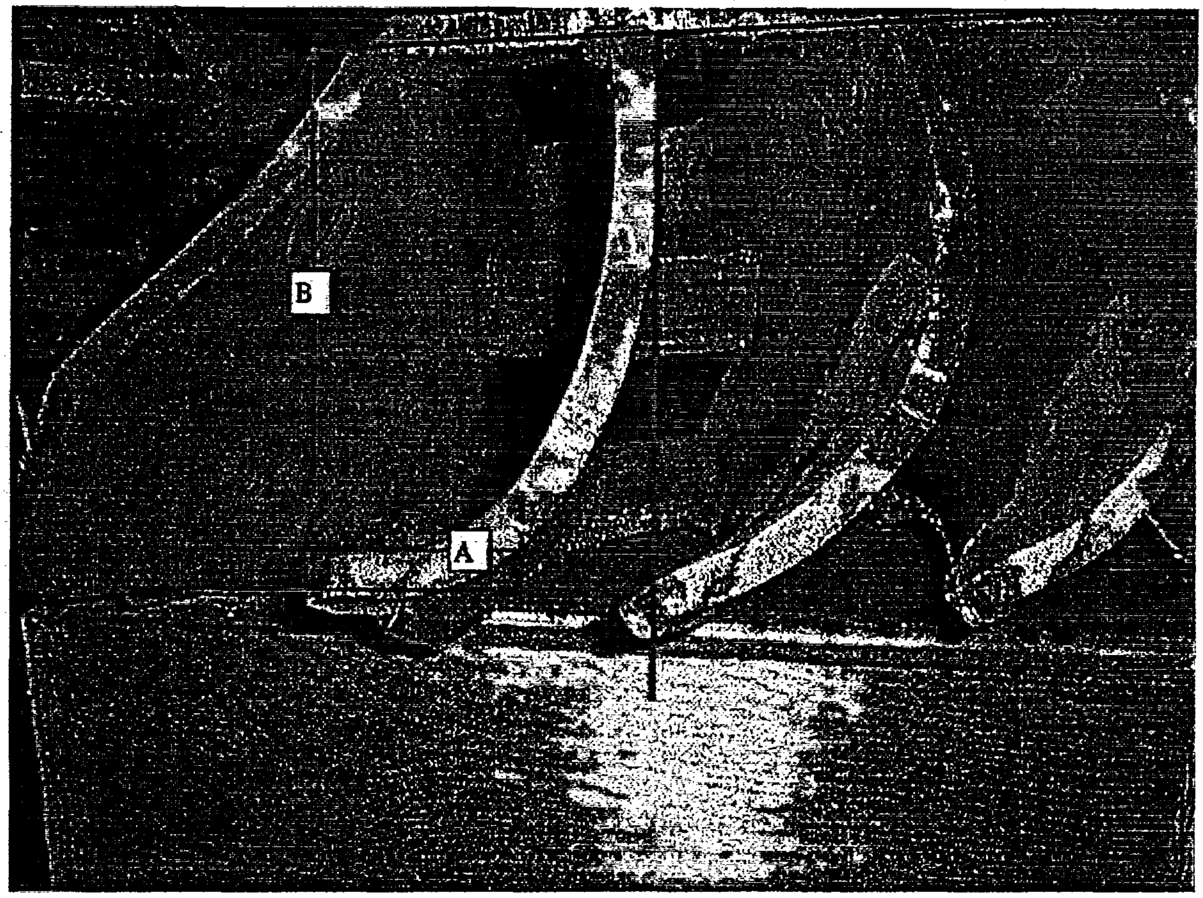
Digital Photo No. 3 (c:\droptest\photos\fs.doc)
The Cutting of the Fireshield



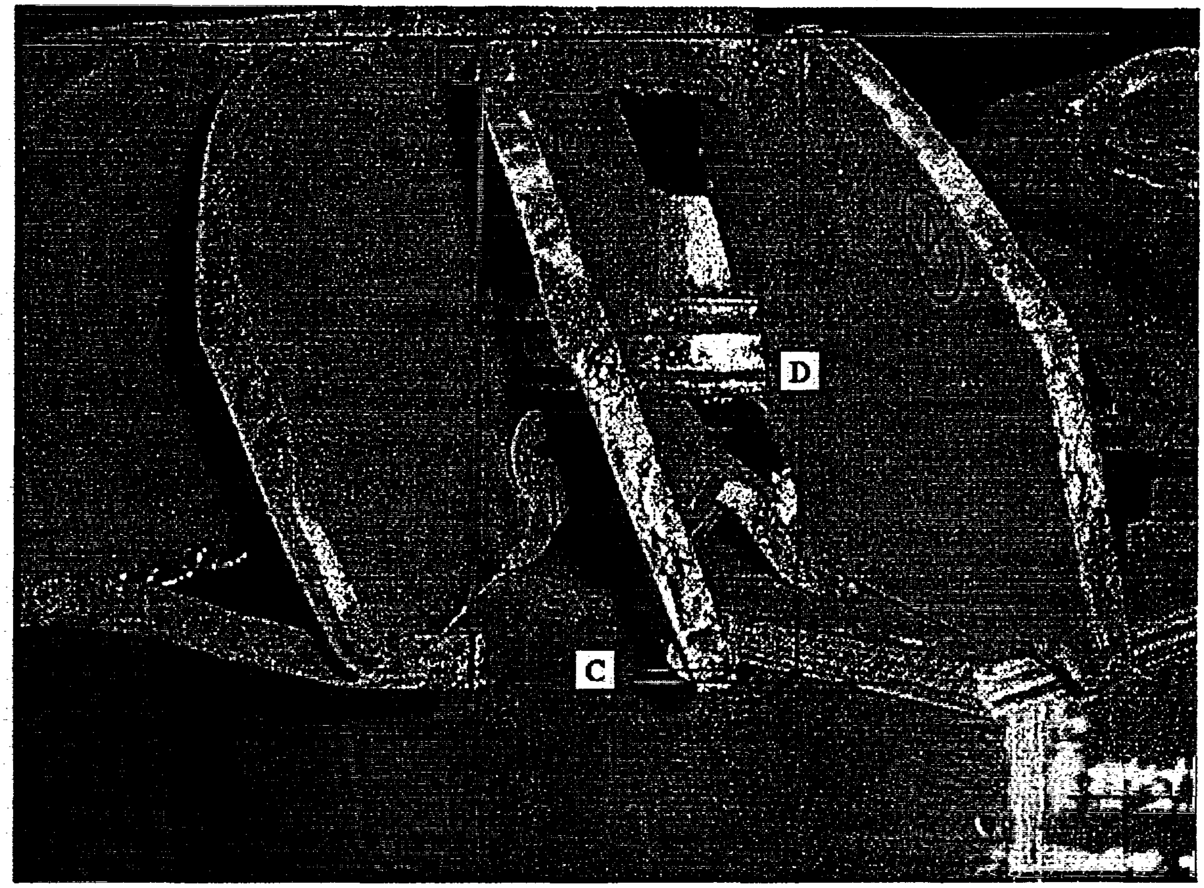
Digital Photo No. 4 (c:\droptest\photos\cshield.doc)
The F-294 Crush Shield



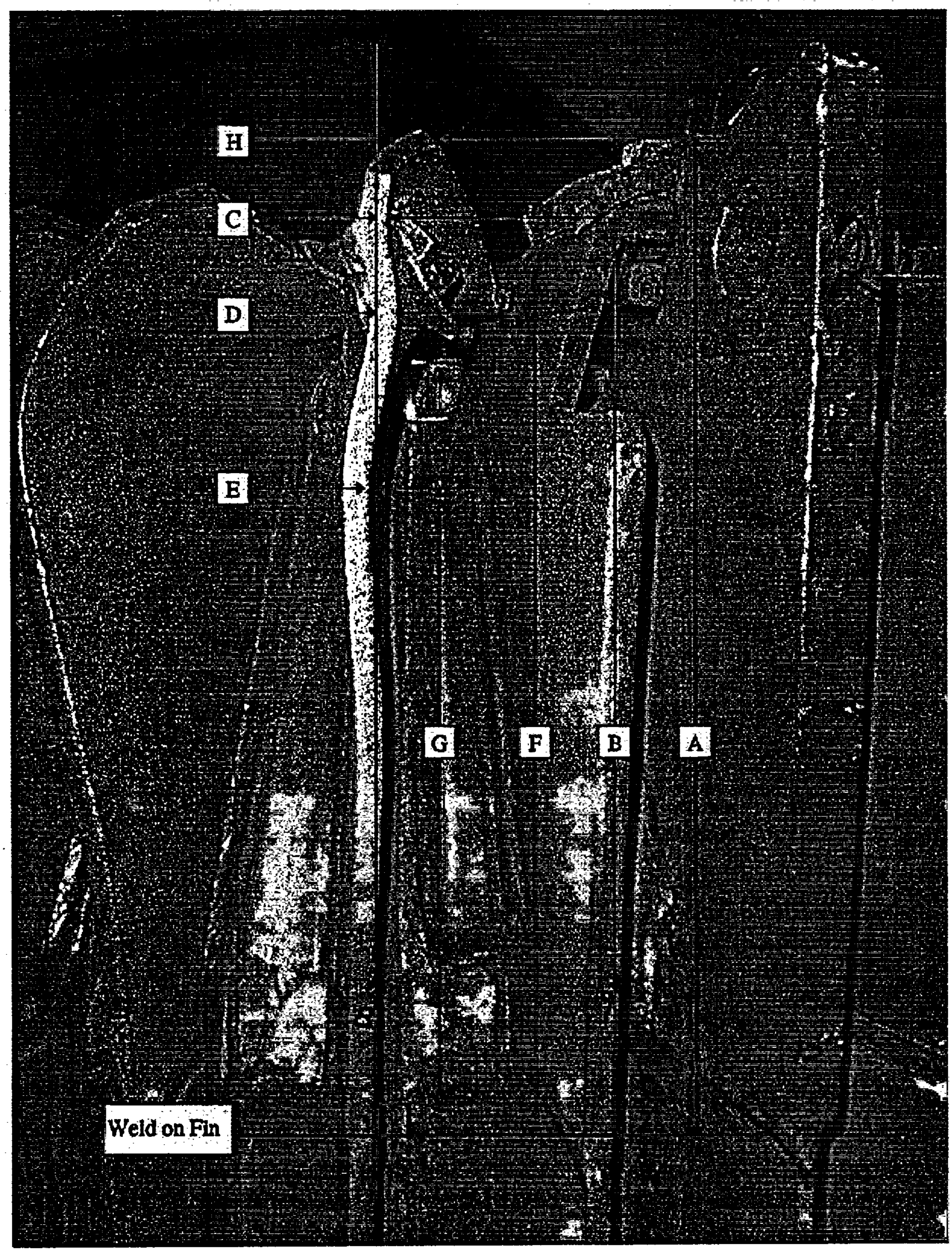
Digital Photo No. 5 (h:\files\pckengrg\fin#2.doc)
Standard J-shape Crush Shield Fin



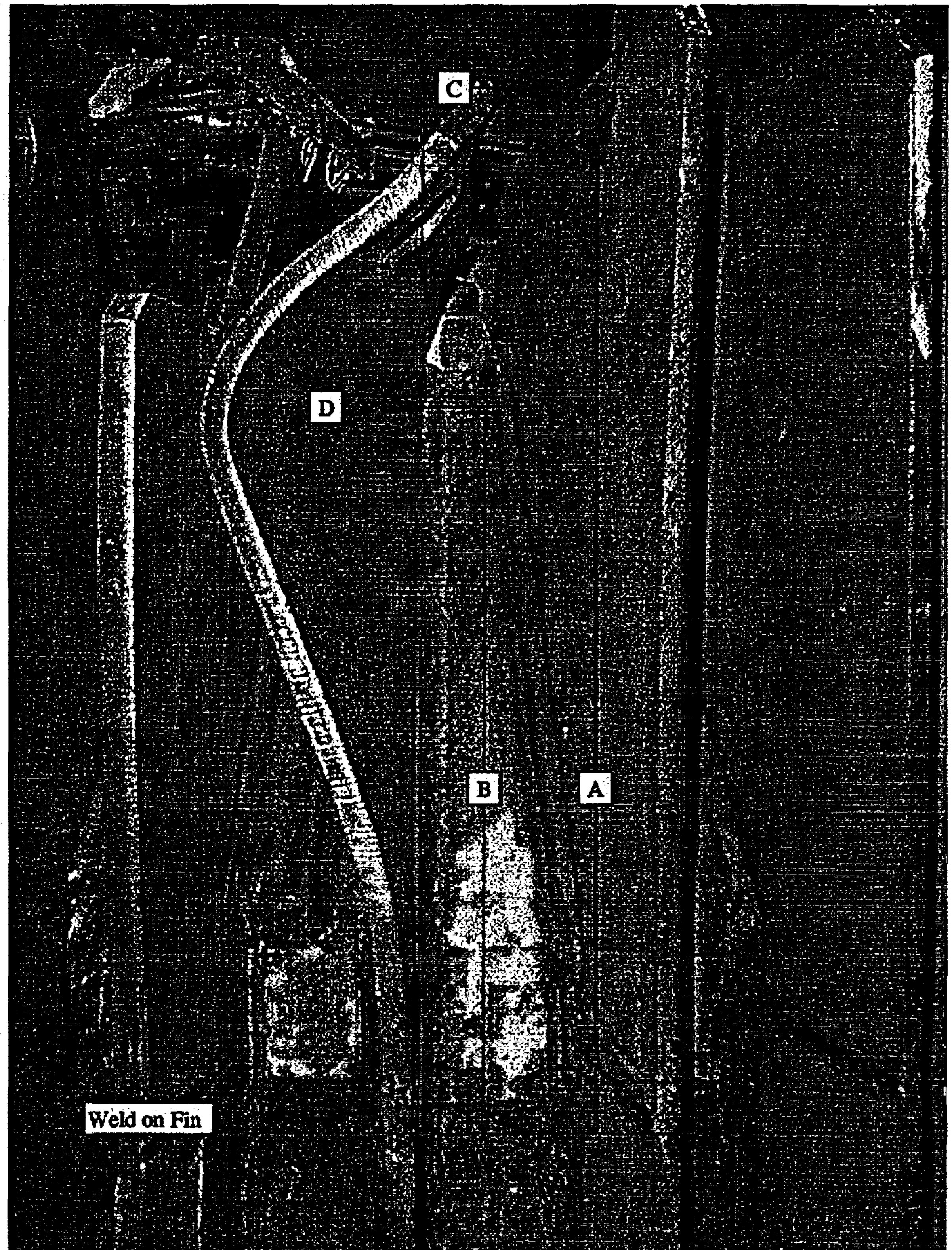
Digital Photo No. 6 (c:\droptest\photos\fin#13.doc)
Standard I-shape Crush Shield Fin



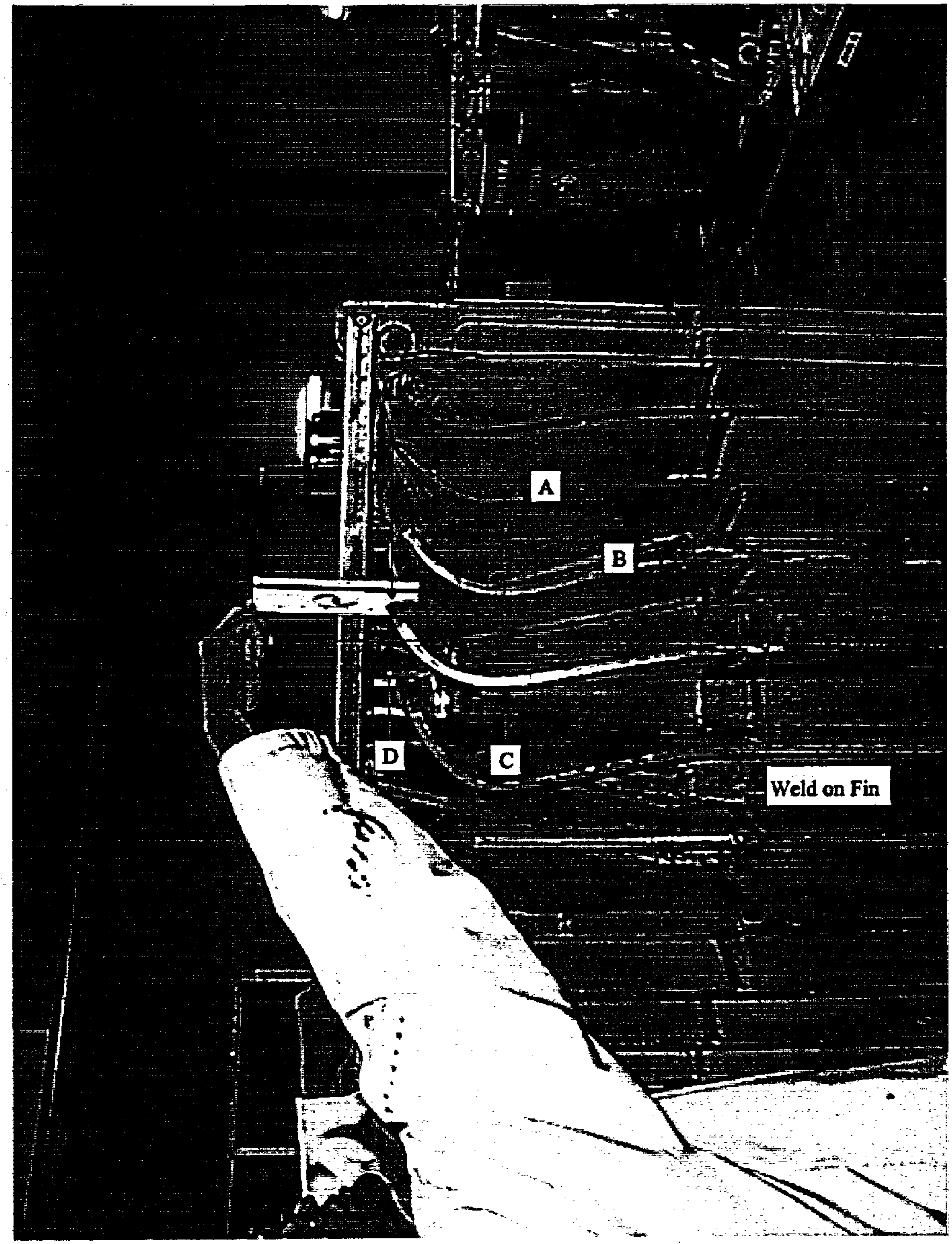
Digital Photo No. 7 (c\:droptest\photos6\fin8.doc)
Standard S-shape Fin



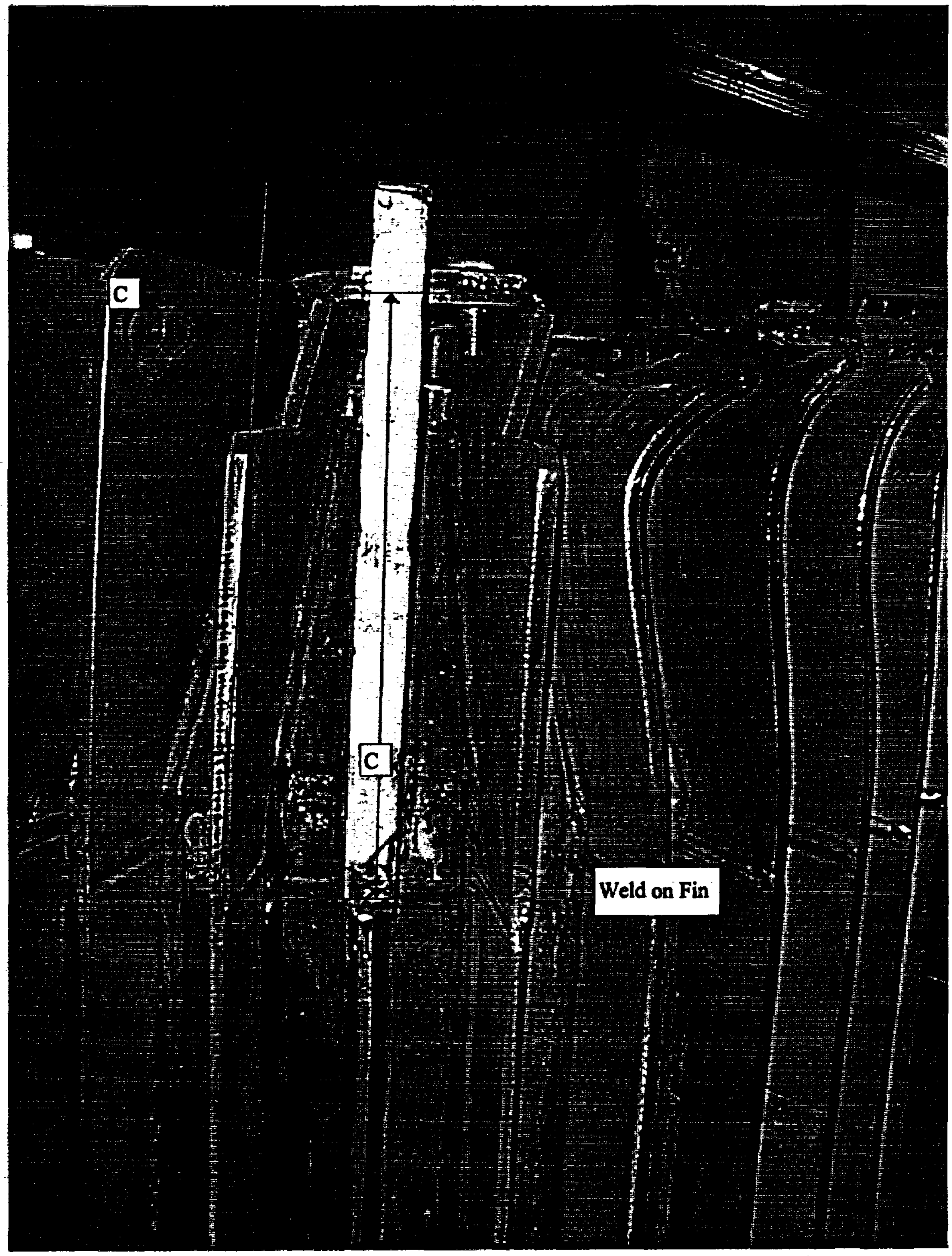
Digital Photo No. 8 (c:\droptest\photos6\fin12.doc)
Standard U-shape Fin



Digital Photo No. 9 (c:\droptest\jfin.doc)
Standard J-shape Fin



Digital Photo No. 10 (c:\droptest\photos\ifin.doc)
Standard I-shape Fin



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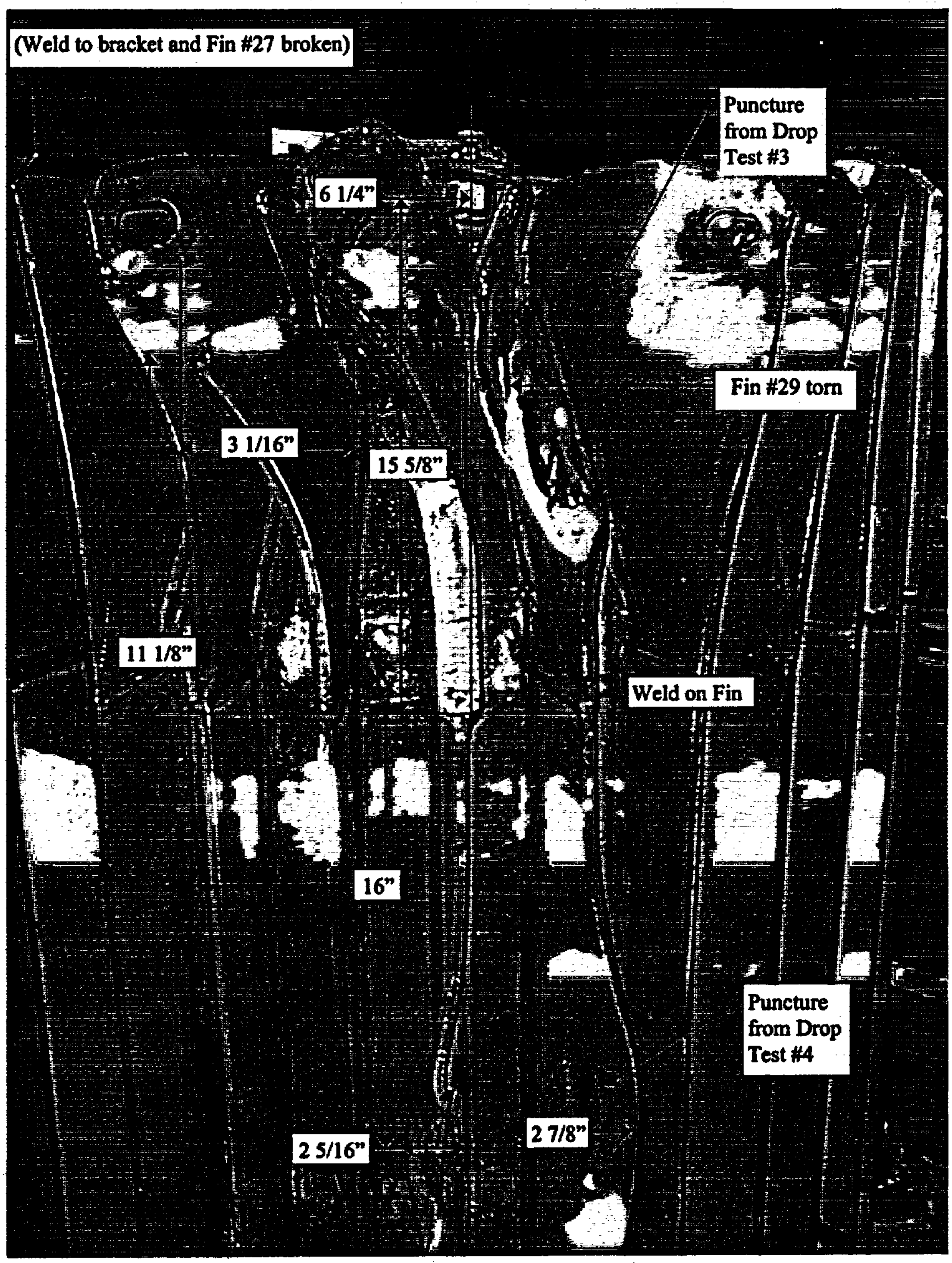
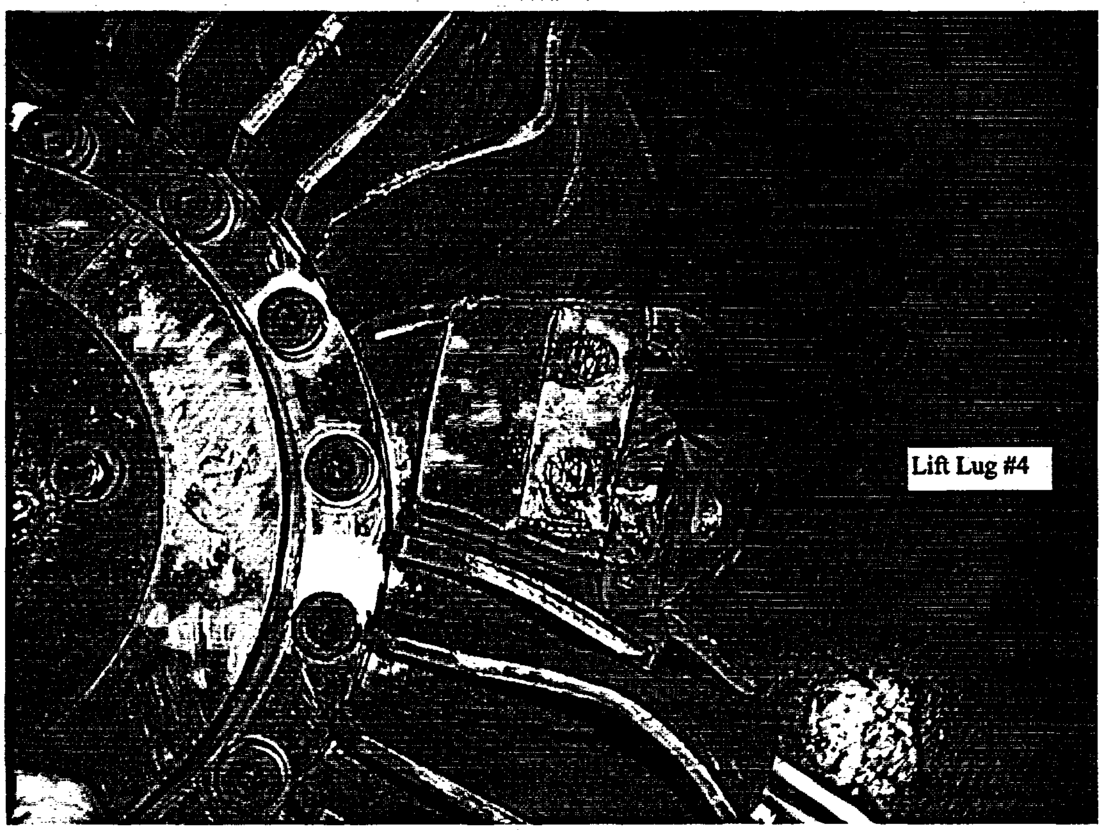
Deformation on Lift Lug #4



Digital Photo No. 12 (c:\droptest\photos\114.doc)
Deformation on Lift Lug #4, Top



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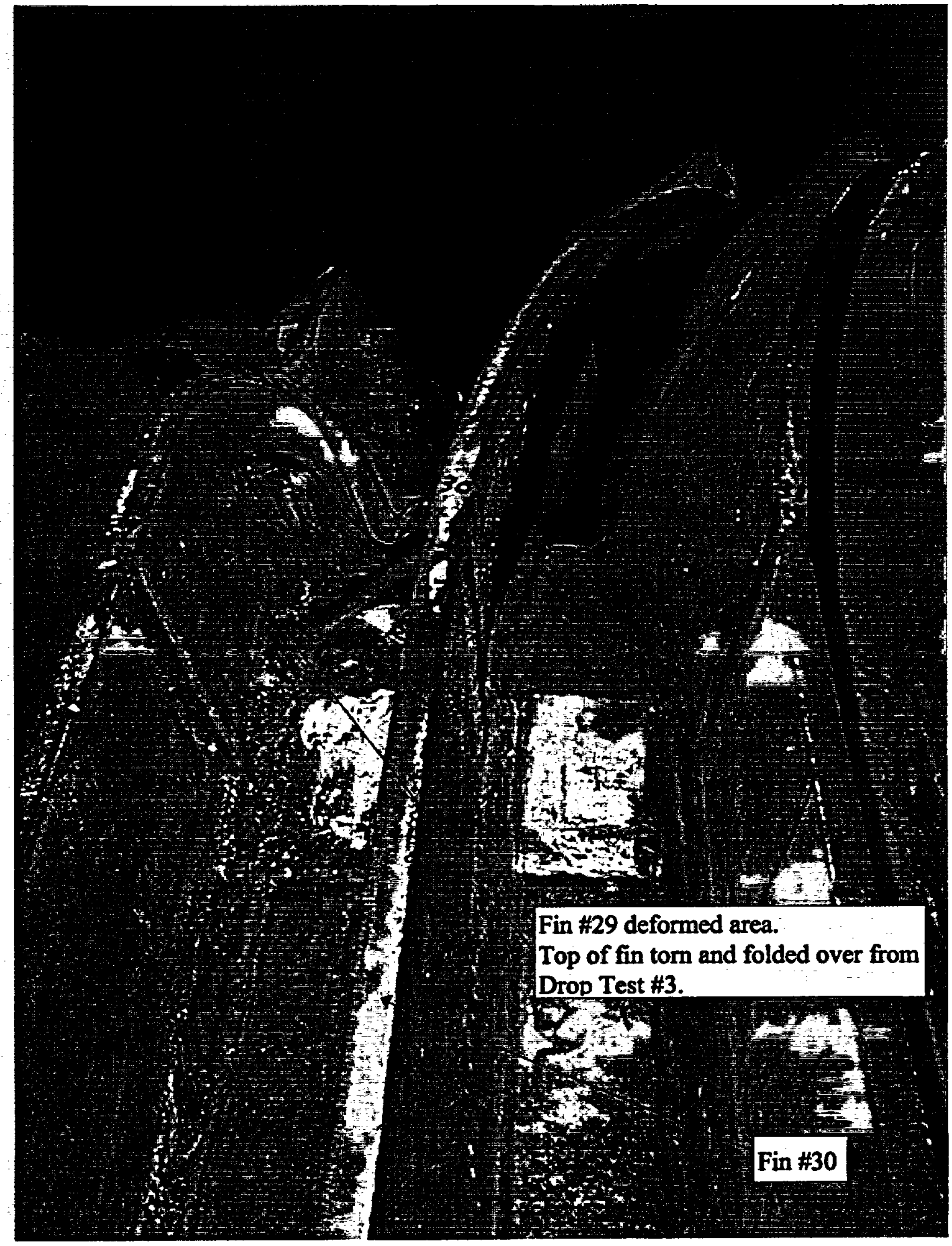
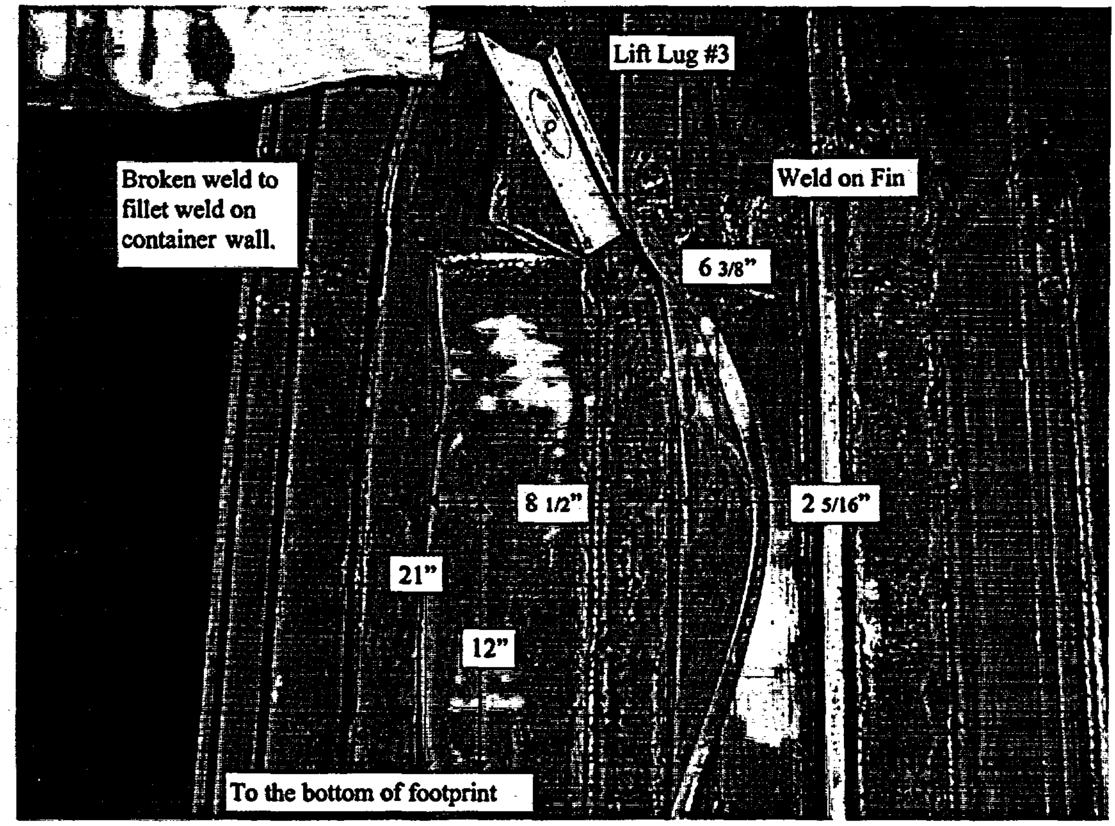
Fin #29



Digital Photo No. 14 (c:\droptest\photos\tear.doc)
Puncture Pin Damage Zone from Drop Test #8



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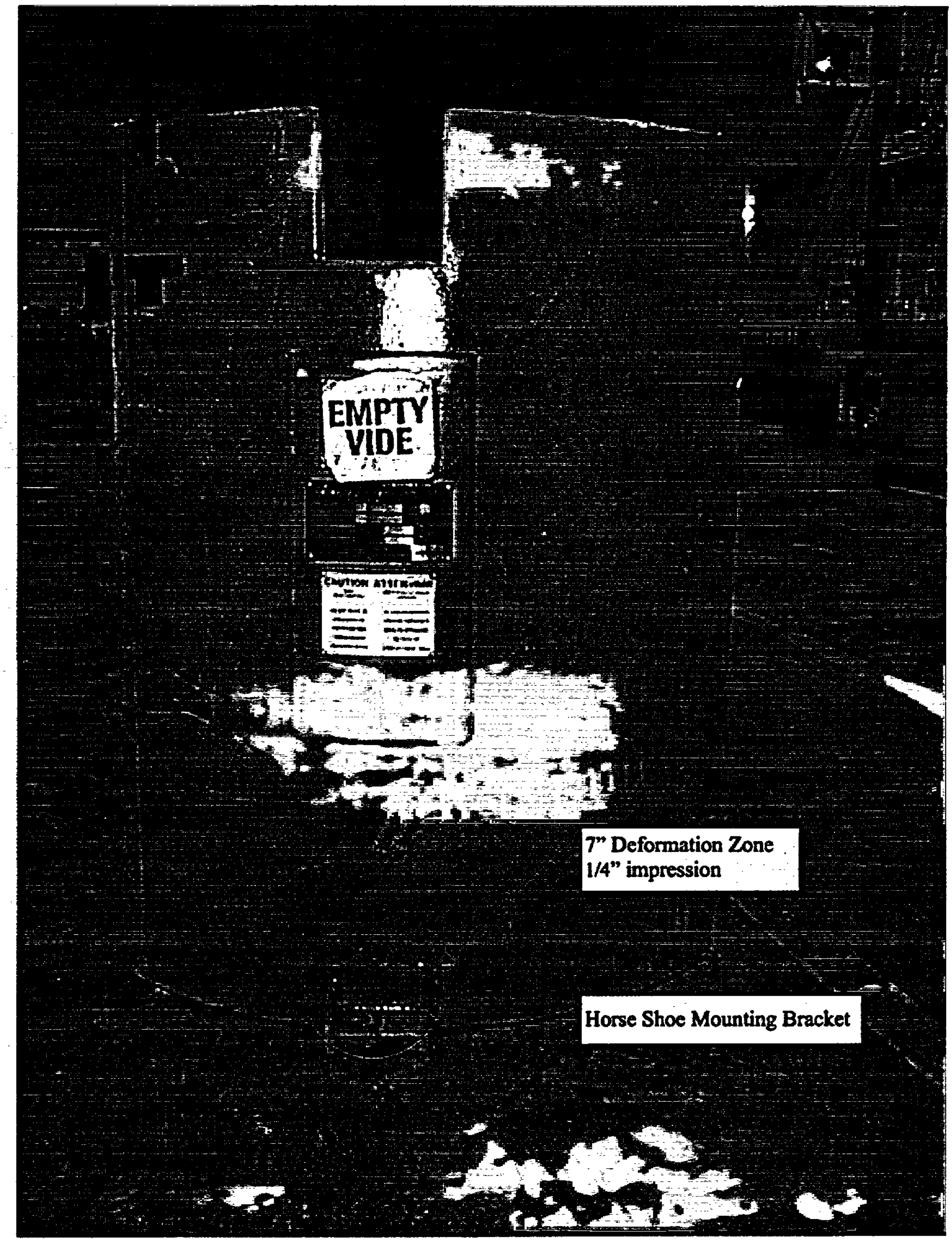
Fireshield Segment #1



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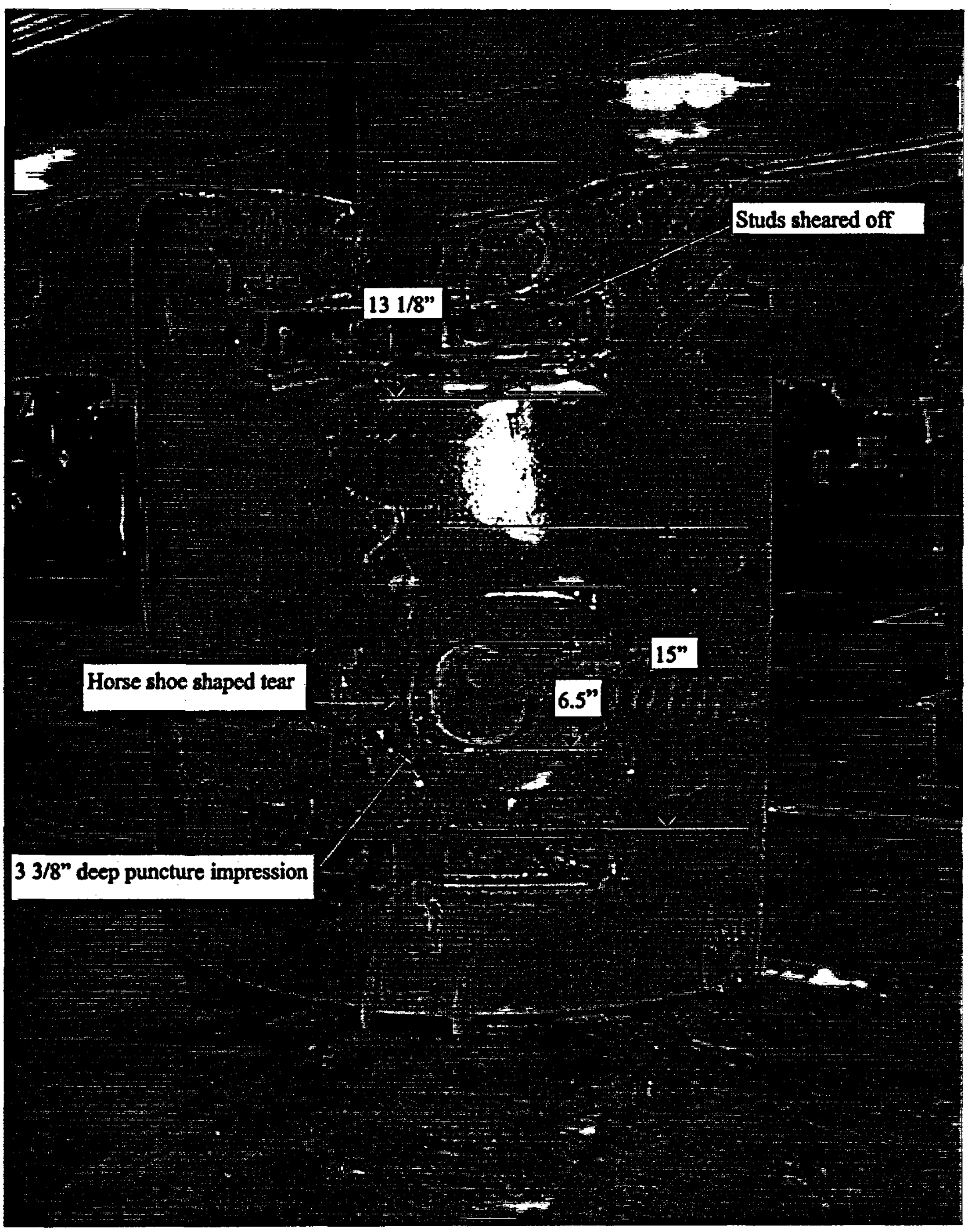
Fireshield Segment #2



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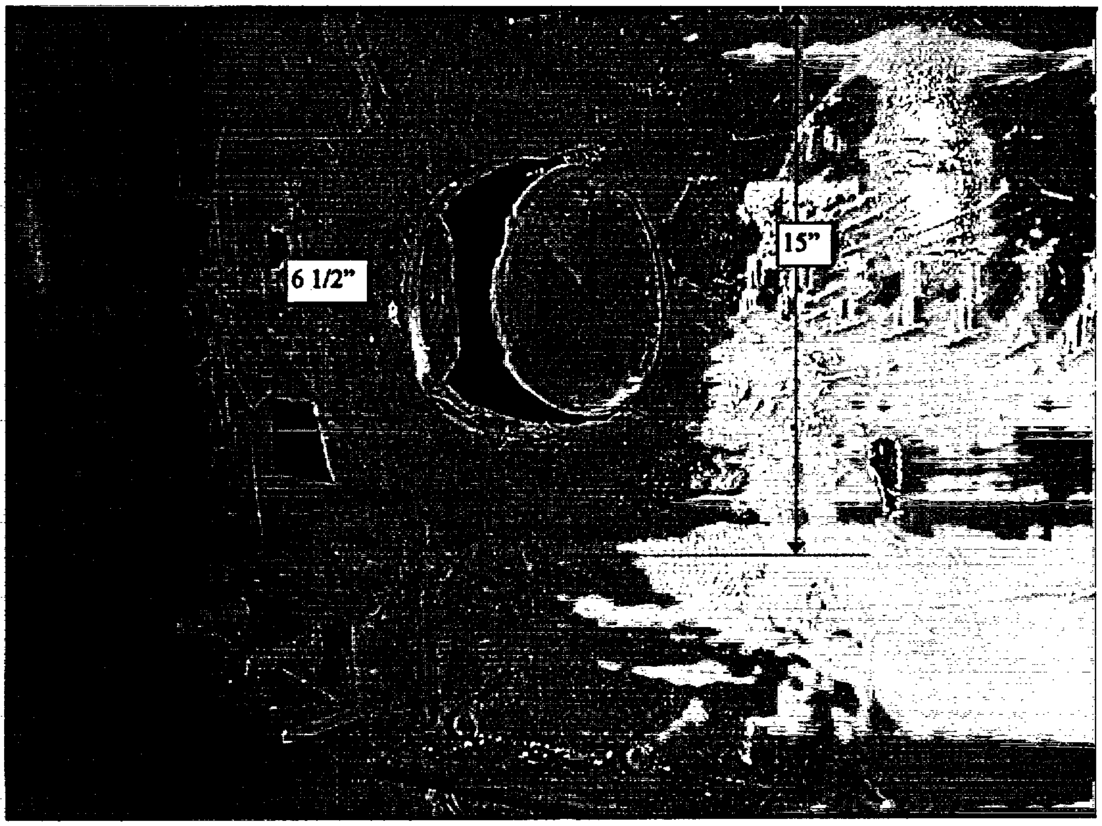
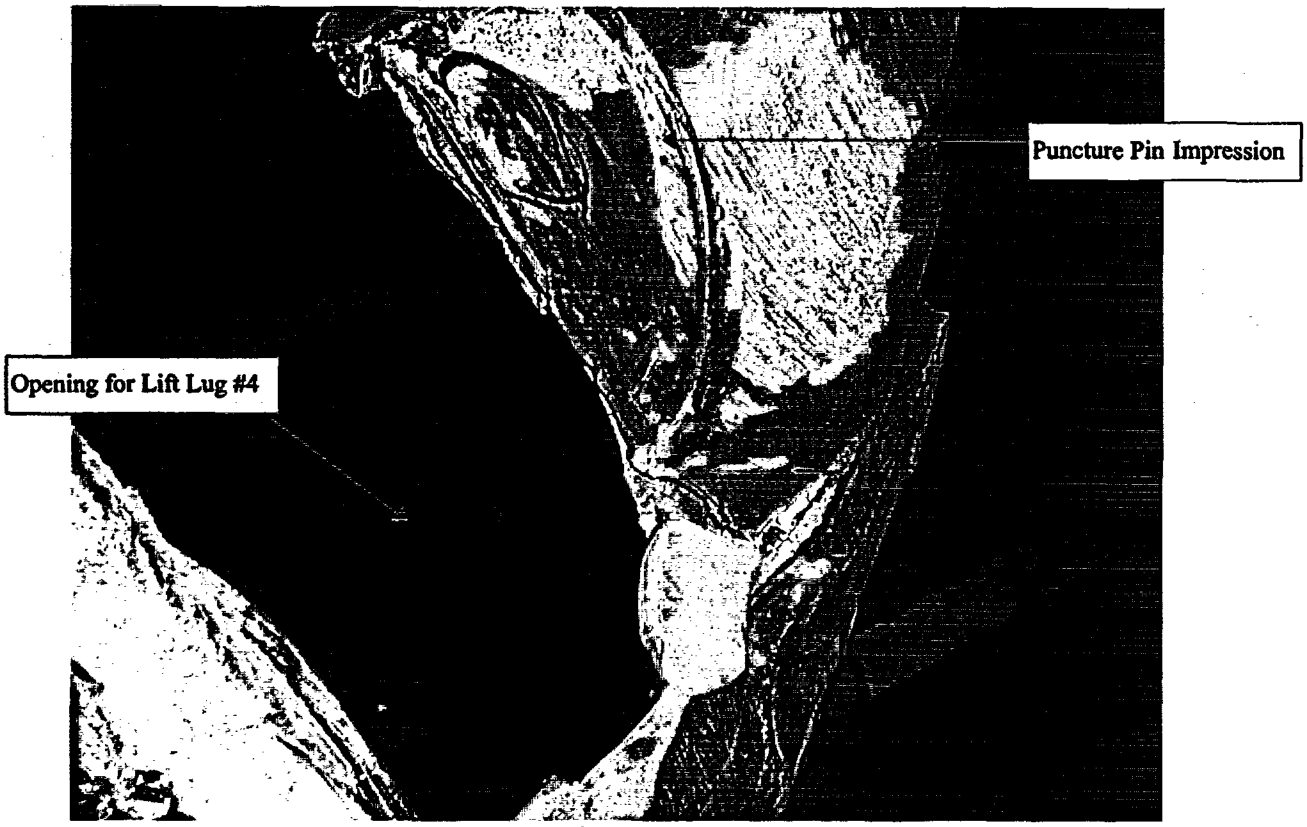
Fireshield Segment #2 Lower Puncture Zone



Digital Photo No. 18 (c:\droptest\photos\seg2a.doc)
Fireshield Segment #2 Upper Puncture Zone



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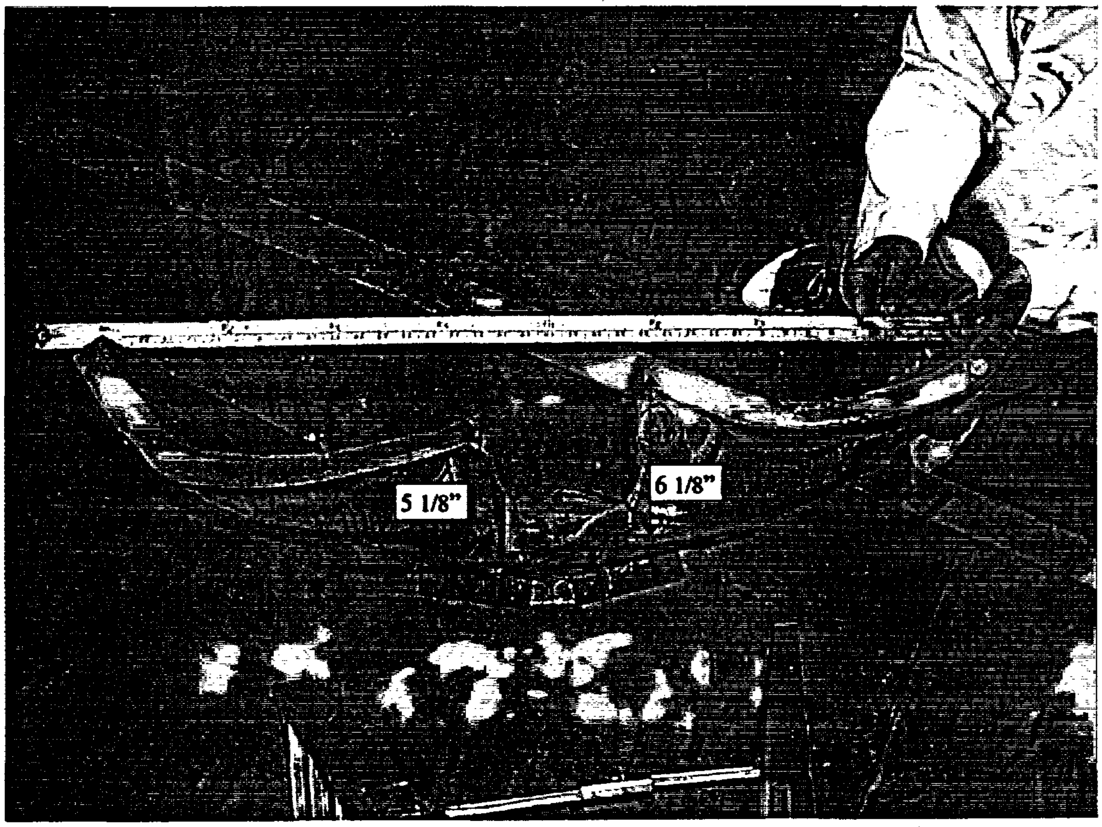
Fireshield Segment #2, Top View



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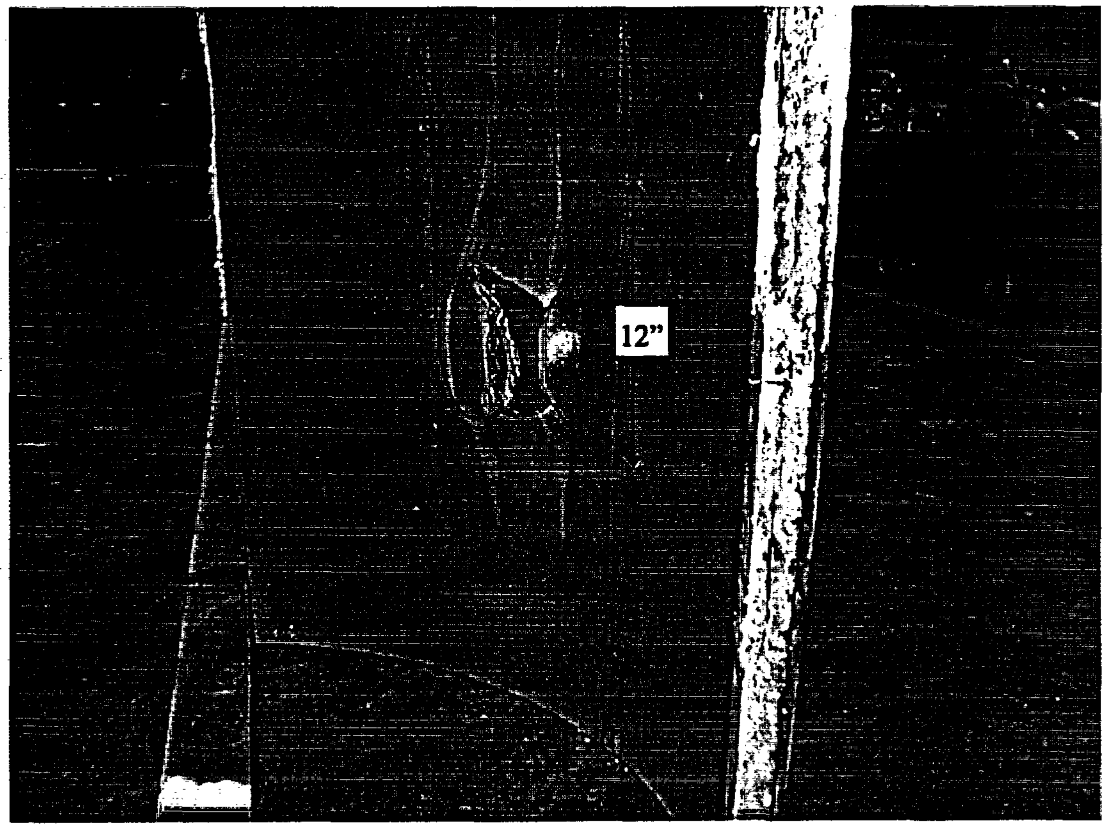
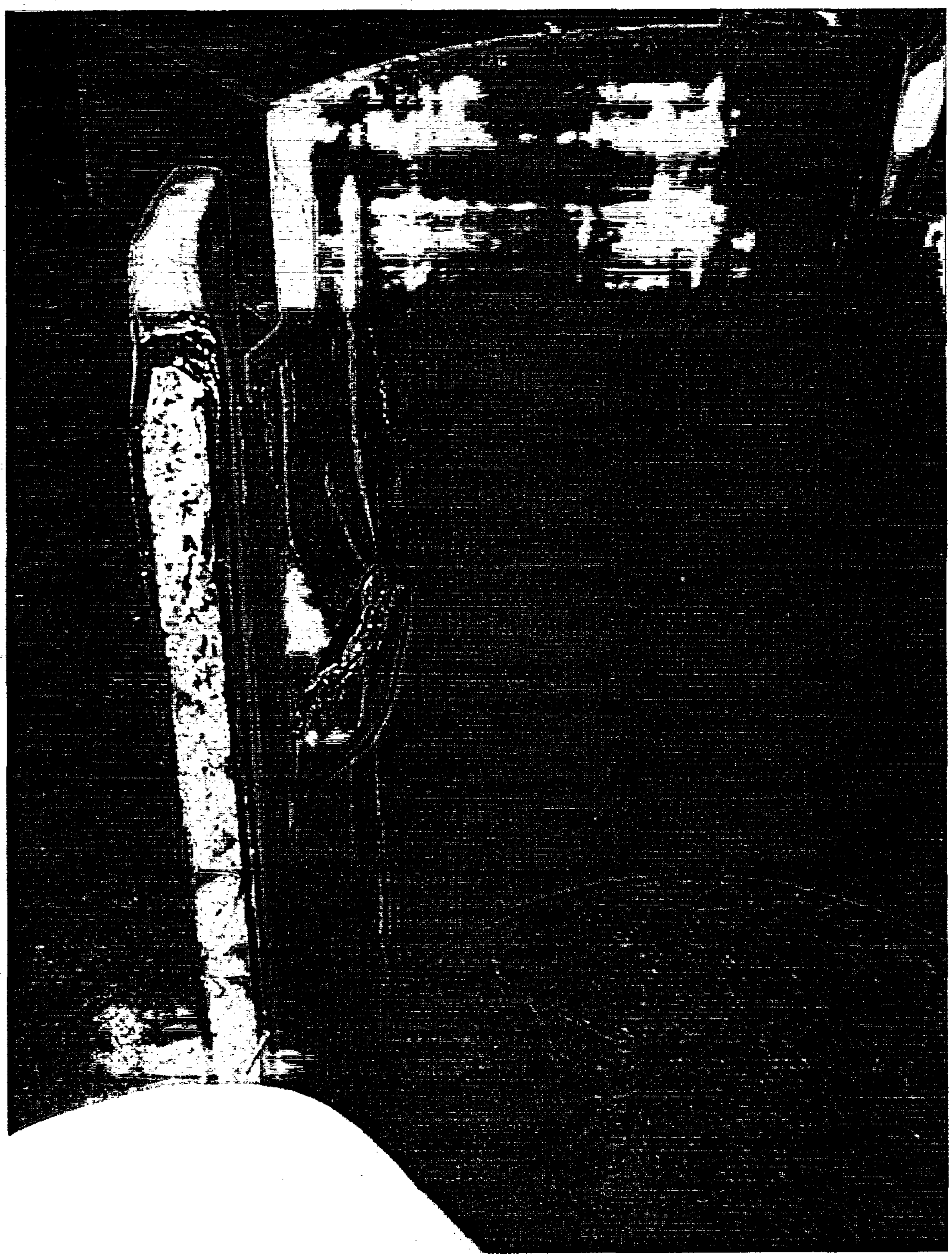
Fireshield Segment #2, Inboard View



Digital Photo No. 21 (c:\droptest\photos\seg3.doc)
Fireshield Segment #3

Digital Photo No. 22 (c:\droptest\photos\seg3a.doc)
Fireshield Segment #3, Inboard View (c:\droptest\photos\seg3a.doc)



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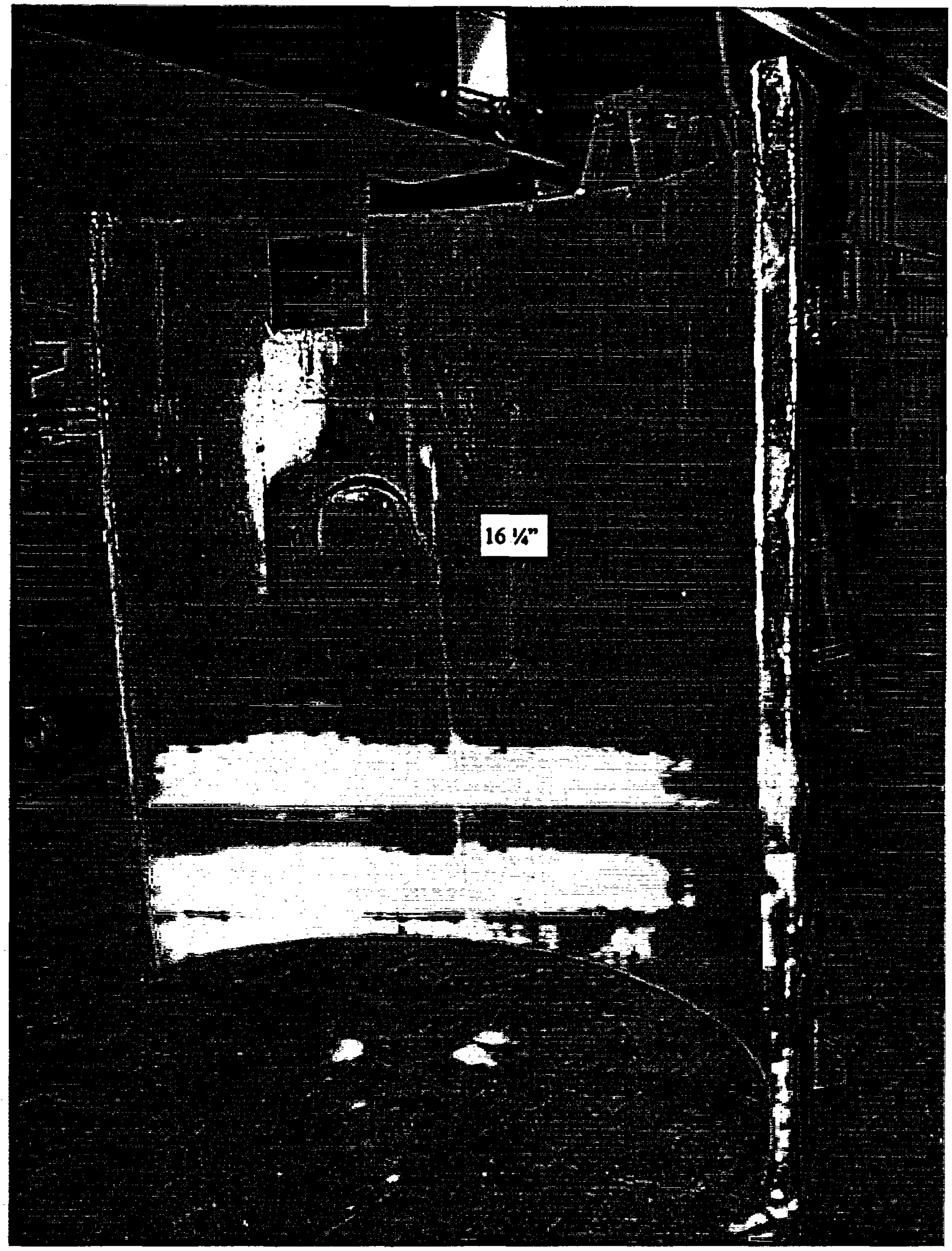
Fireshield Segment #3, Inboard View



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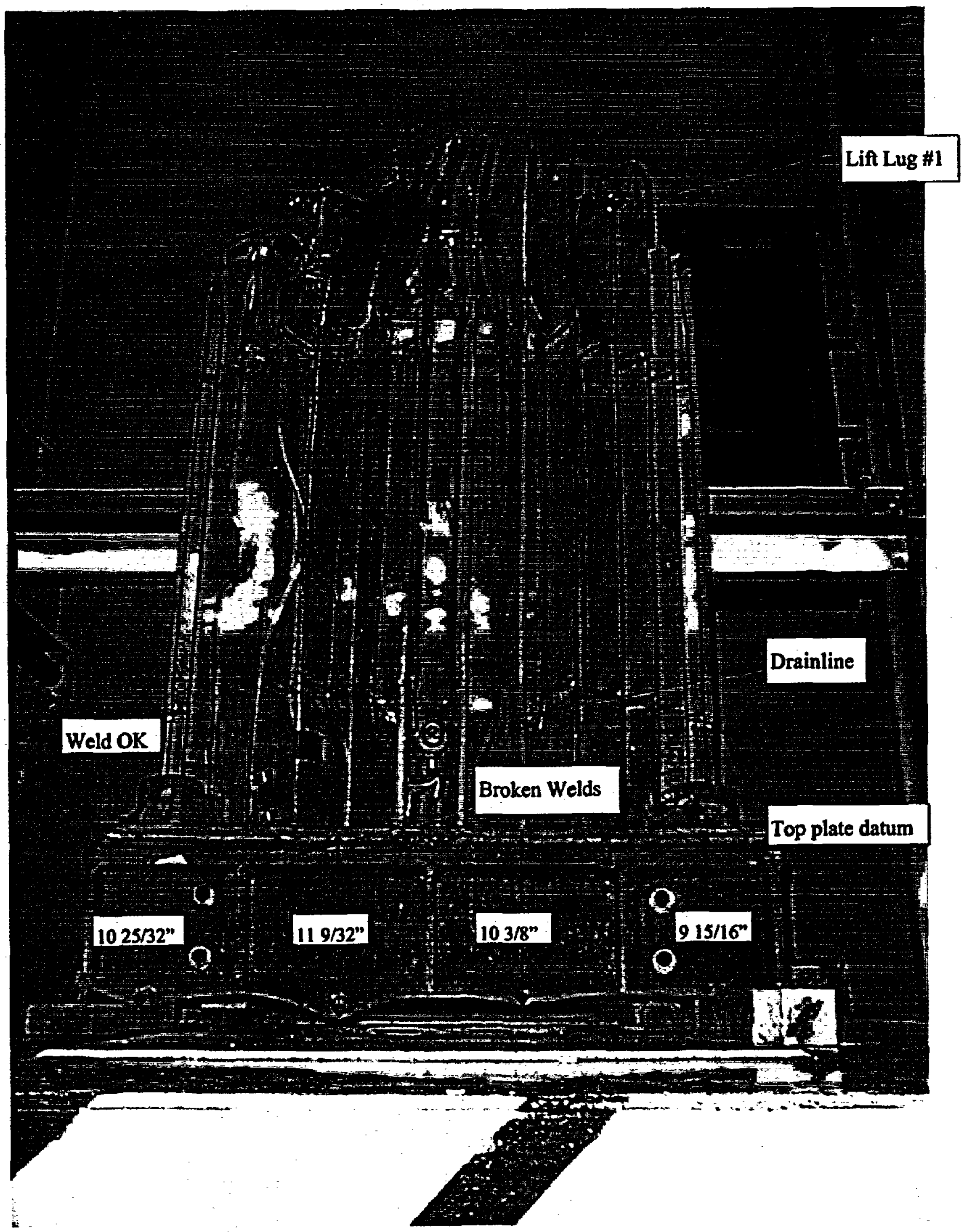
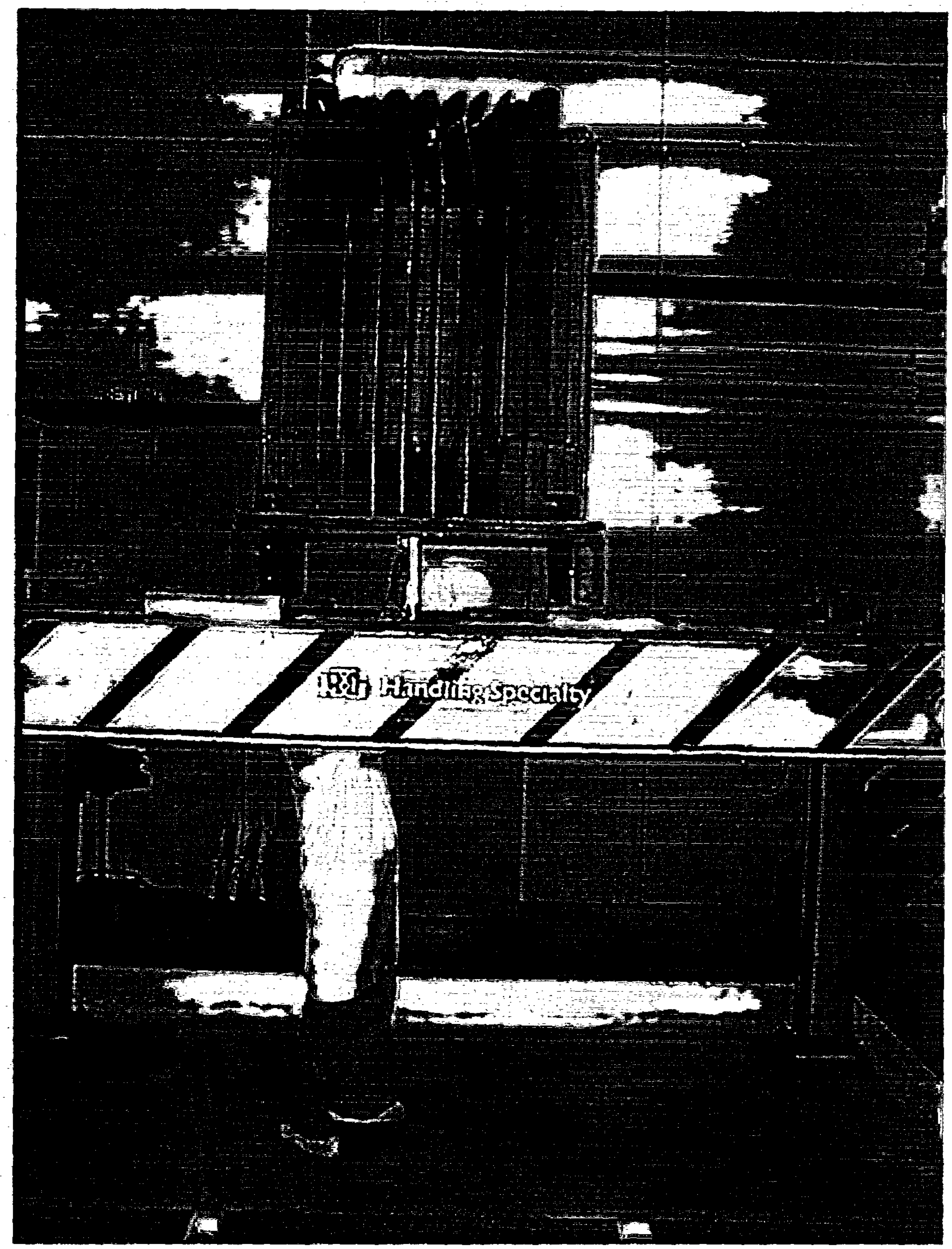
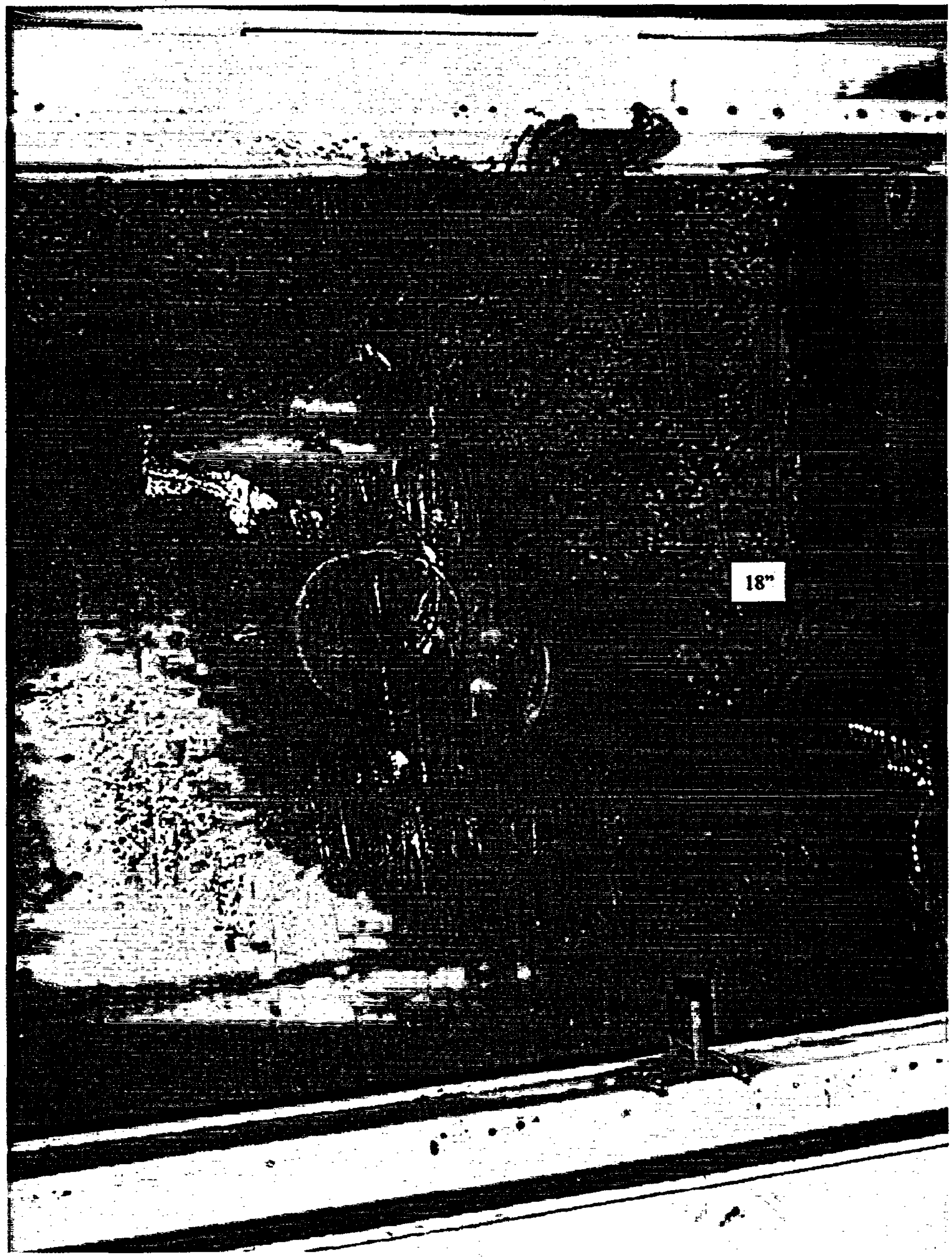
F-294 Fixed Skid



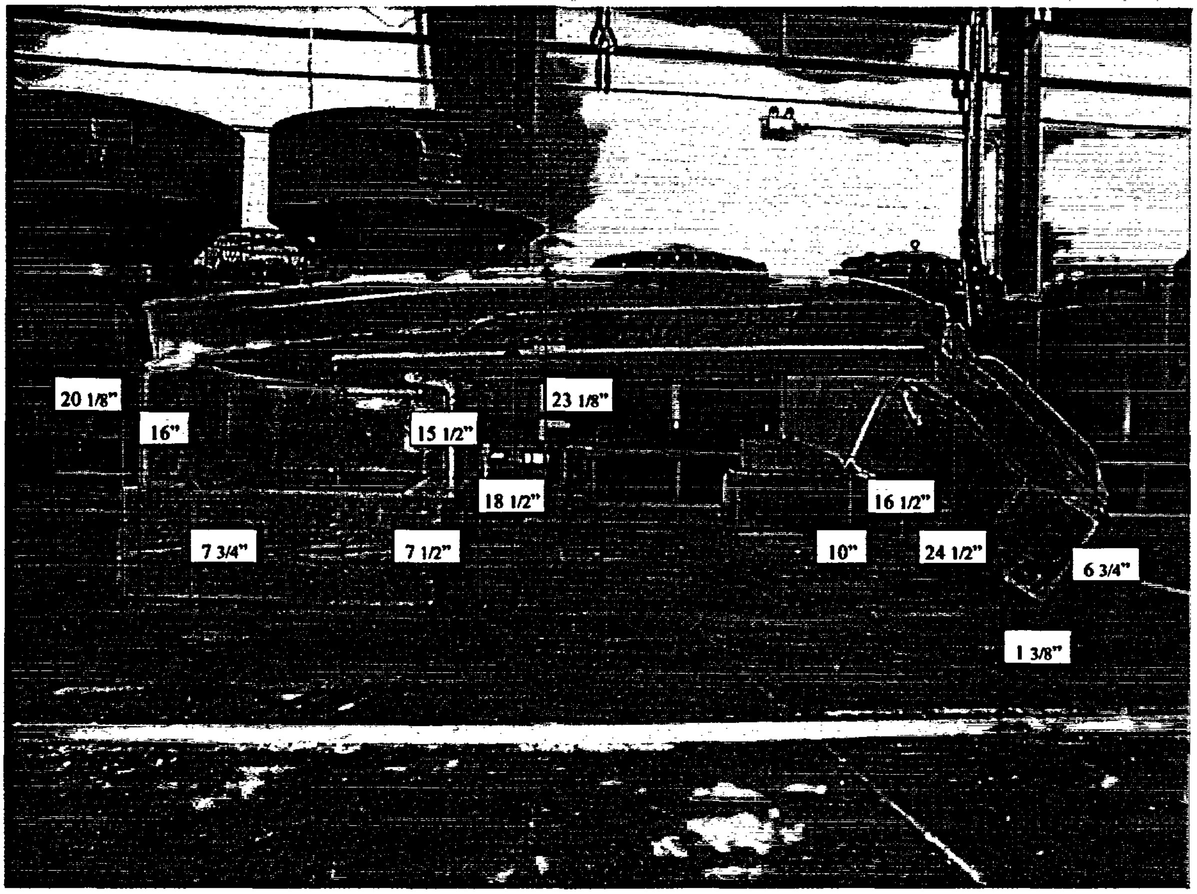
Digital Photo No. 25 (c:\droptest\photos\skid.doc)
Measuring the Puncture Zone



Digital Photo No. 26 (c:\droptest\photos\skid1.doc)
Puncture Impression from Drop Test #5



Digital Photo No. 27 (c:\droptest\photos4\skid.doc)
Shipping Skid, View 1



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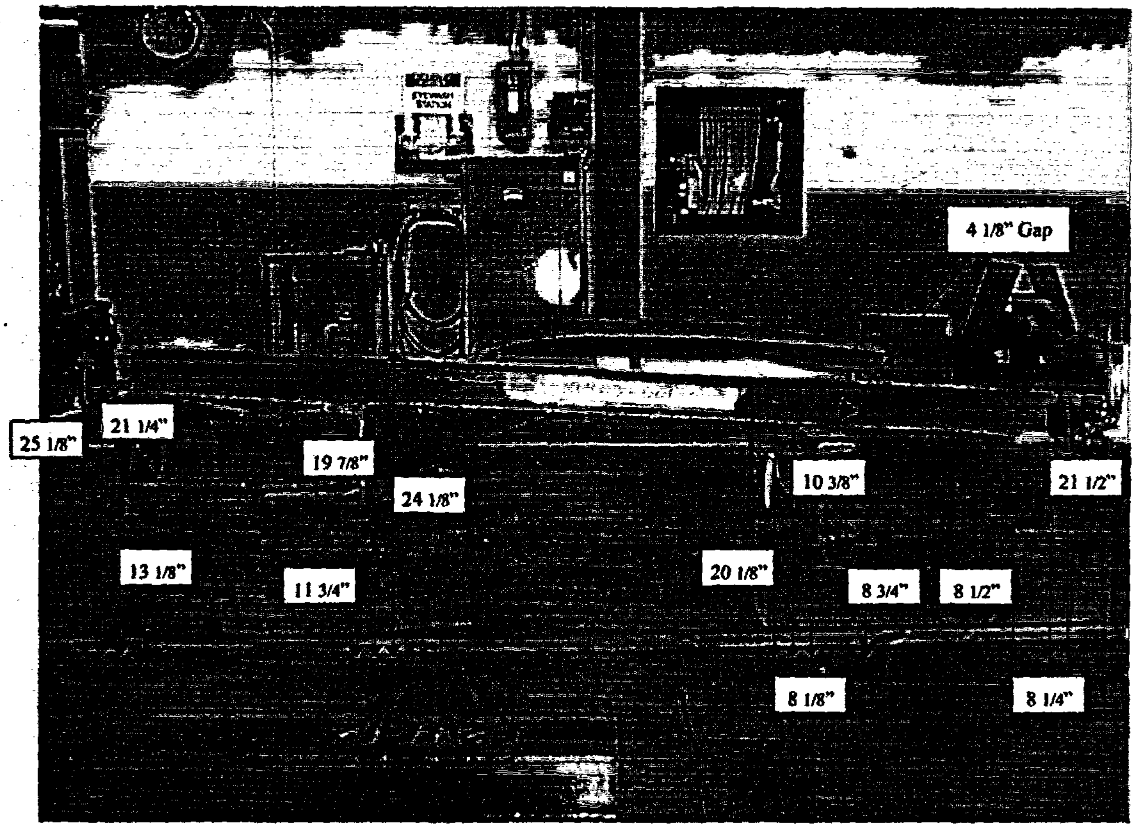
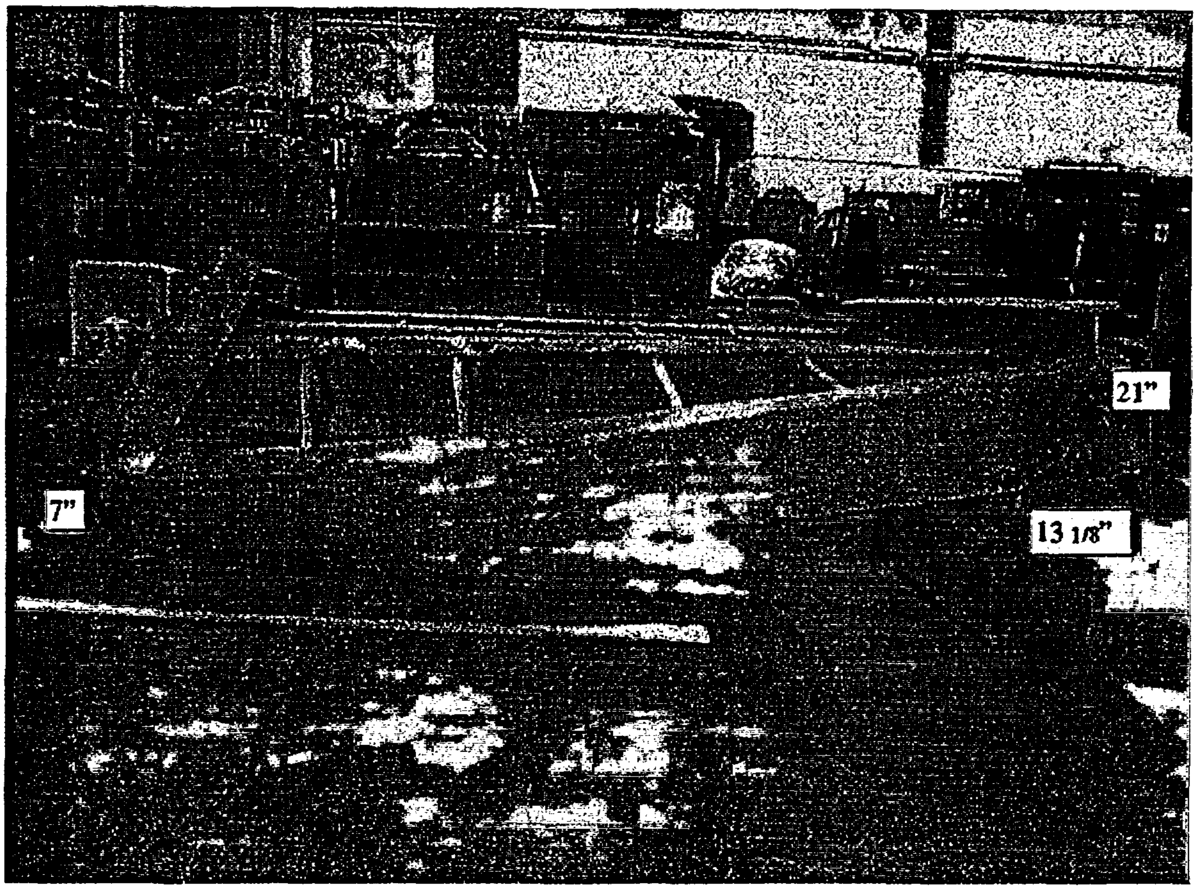
Shipping Skid, View 2

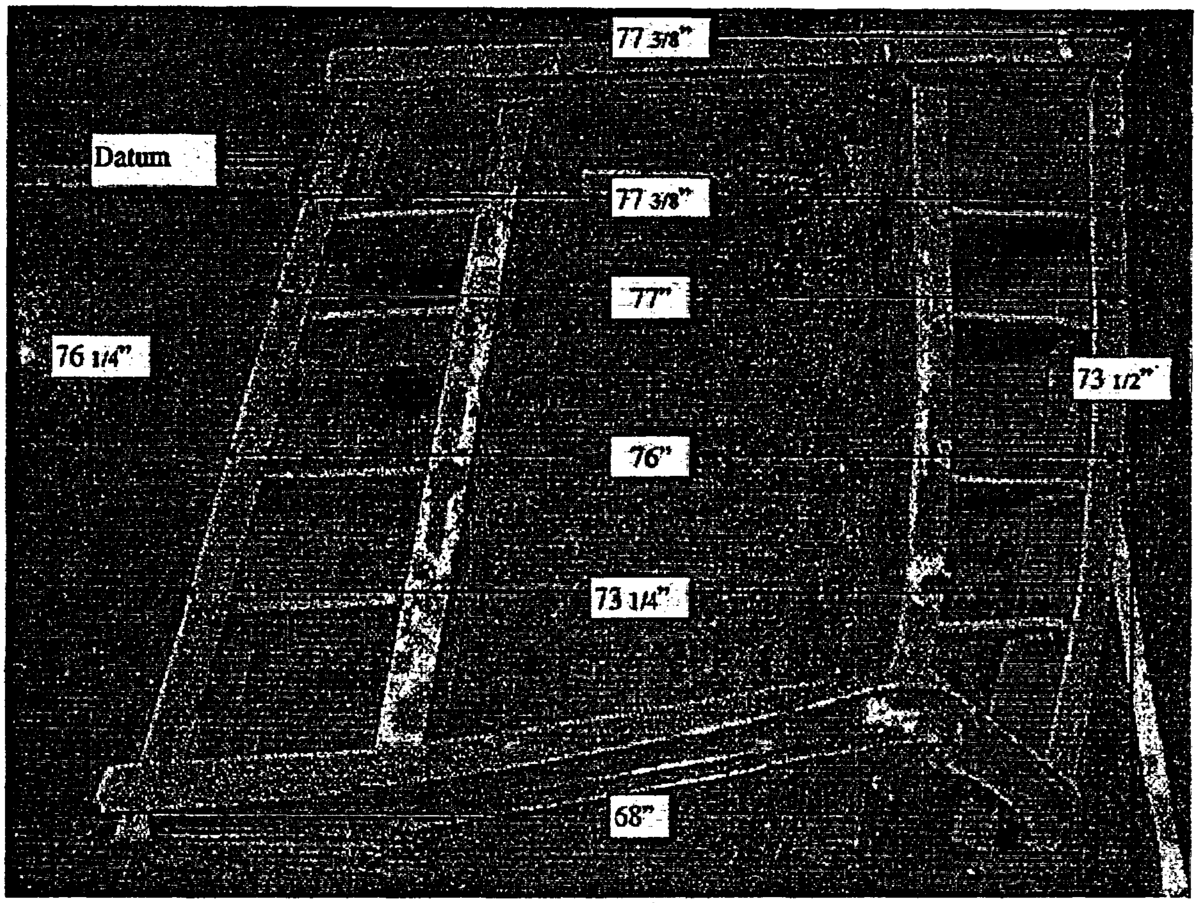


Digital Photo No. 29 (c:\droptest\skid3.doc)
Shipping Skid, View 3 (c:\droptest\skid3.doc)

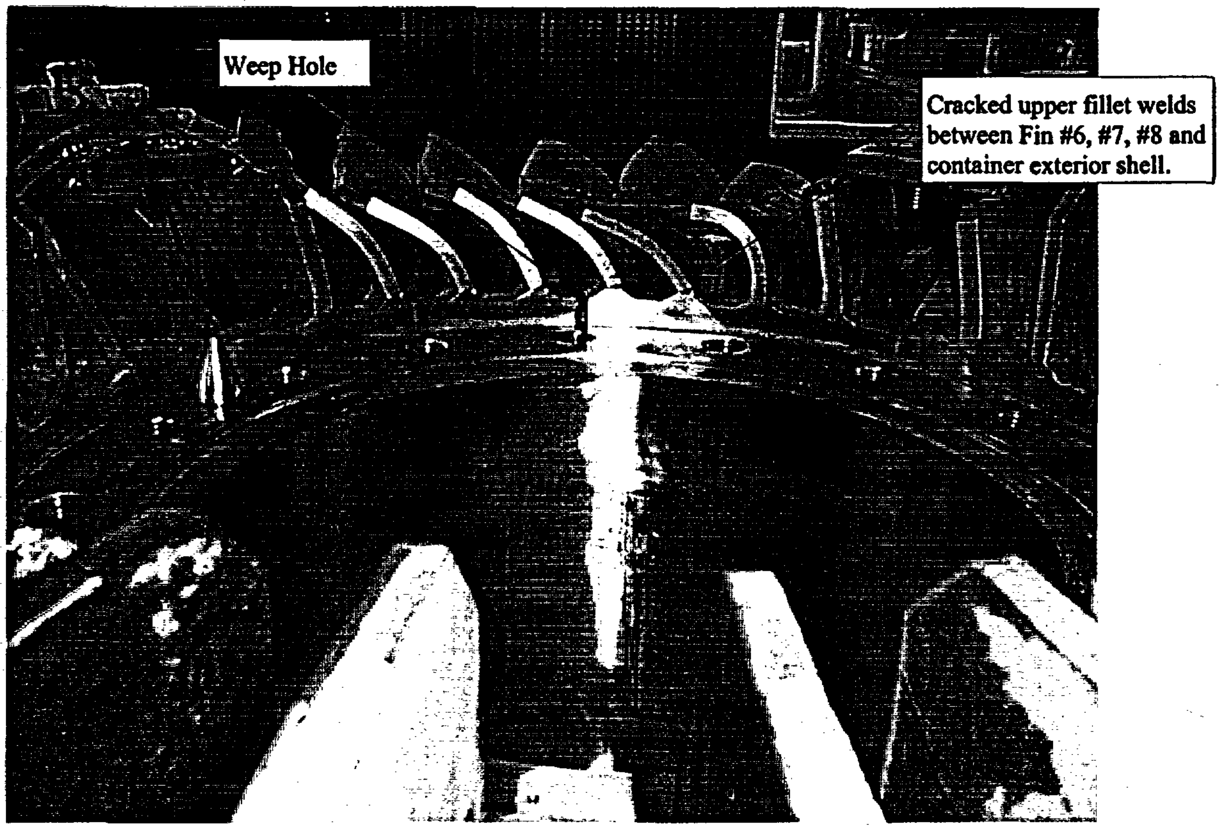


Digital Photo No. 30 (c:\droptest\skid4.doc)
Shipping Skid, View 4

Digital Photo No. 31 (c:\droptest\skid5.doc)
Shipping Skid, View 5



Digital Photo No. 32 (c:\droptest\photos\crack.doc)
F-294 Container Fins



7.6 TEST #5.3.6 - INSPECTION AND DIMENSIONAL MEASUREMENT OF C-188 DUMMY CAPSULES

#1. Test # **5.3.6** as per test plan document IN/QA 1368 F294 (1): Inspection and dimensional measurement of C-188 dummy capsules.

Date test conducted: March 16, 1998

#2. Person who conducted the test/procedure

Helen Sheehan conducted the inspection and dimensional measurement of C-188 dummy capsules as per guidelines of standard capsule inspection procedure CO-QC/IT-0001 and as per requirements stated by V. Shah.

#2.1 Test details

The following dimensions were measured on C-188 dummy capsules.

- Overall Dimensions: (at cap end, at tube center and at cap-to-tube junction)
- Overall length
- Straightness

The dimensional data is given in Table 2.10.12-T18.

#2.2 Observations

#2.2.1 F-313 carrier/buffers

After the drop, when the F-294 closure plug was opened, it was discovered that the F-313 carrier was restrained in two locations at the top. It was restrained, using wood and plastic foam buffers as per (see Figure 2.10.12-F167). In addition, the carrier handle was not on the F-313 carrier. Also, the C-188 dummy capsules were located as per Figure 2.10.12-F168.

This is further addressed in Chapter 2, Appendix 2.10.13.

These modifications were carried out by the Test Operator (CRL, AECL) to protect the G-gage accelerometer.

#2.2.2 All C-188 dummy capsules

There were no gouge marks on the C-188 dummy capsules.

Table 2.10.12-T18
Recorded Dimensions of C-188 Dummy Capsules

Dummy C-188 Serial Numbers	Overall Length (inches)	T.I.R.	O.D. Serial Number End (inches)	O.D. at Cap End (inches)	O.D. at Tube Centre (inches)	O.D. at Cap to Tube Junction (inches)	O.D. at Other End (inches)
60200	17.776	0.003	.382	.379	.379	.379	.382
60201	17.777	0.002	.382	.379	.379	.379	.381
60202	17.776	0.003	.382	.380	.380	.380	.382
60203	17.777	0.004	.382	.378	.378	.378	.382
60204	17.771	n/a	.383	.380	.38-	.380	.383
60205	17.775	0.003	.383	.380	.380	.380	.383
60206	17.775	0.004	.382	.380	.380	.380	.382
60207	17.778	0.003	.382	.379	.379	.379	.382

#2.3 Photographs

Photographs will be provided, if available.

#2.4 Conclusions

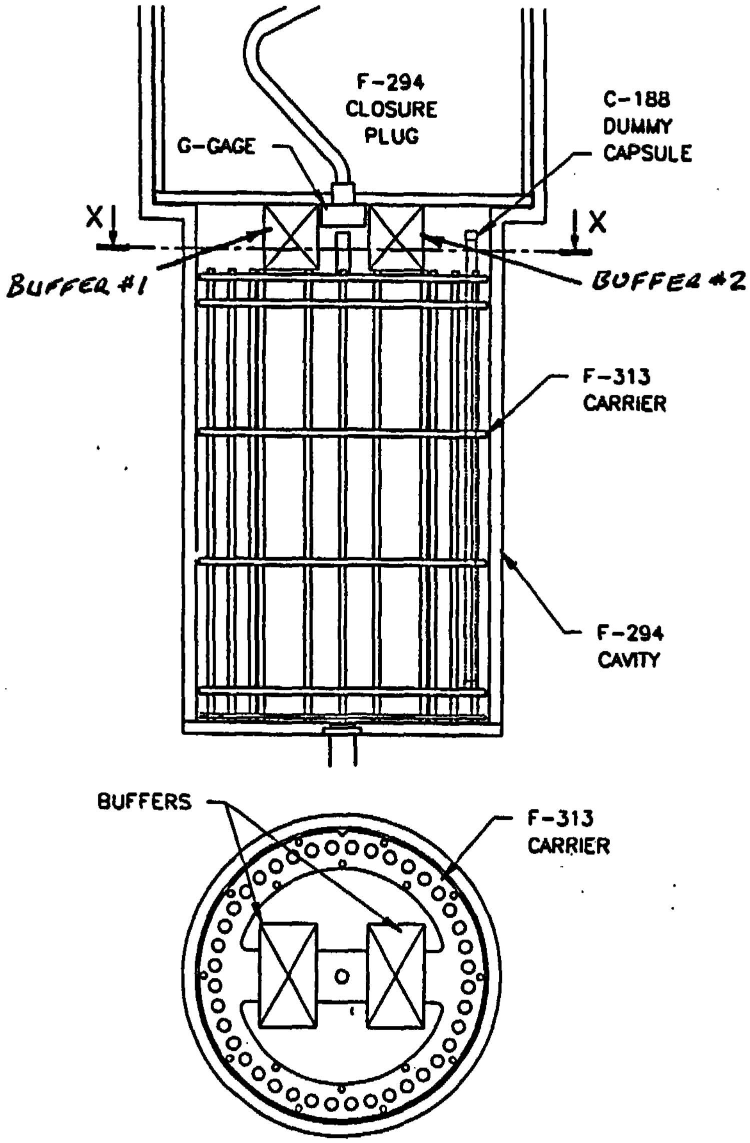
1. When we compare the dimensions of C-188 dummy capsules before and after the F-294 drop tests, there is no significant change in the C-188 dimensional.
2. There were no gouges on the C-188 dummy capsules after the drop tests.

#3. Notes

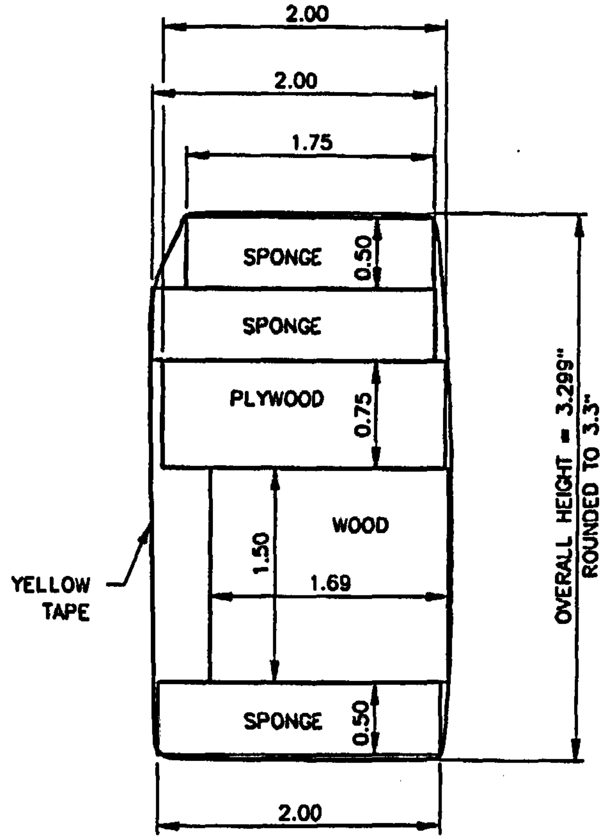
#4. Personnel

	Name	Title
Test conducted by:	H. Sheehan	Quality Control Technician
Reviewed by:	V. Shah	Package Engineer
Reviewed by:	D. Whitby	Industrial Quality Control

Figure 2.10.12-F167
Buffer #1 and Buffer #2 between F-313 Carrier and Underside of Closure Plug



SECTION X–X



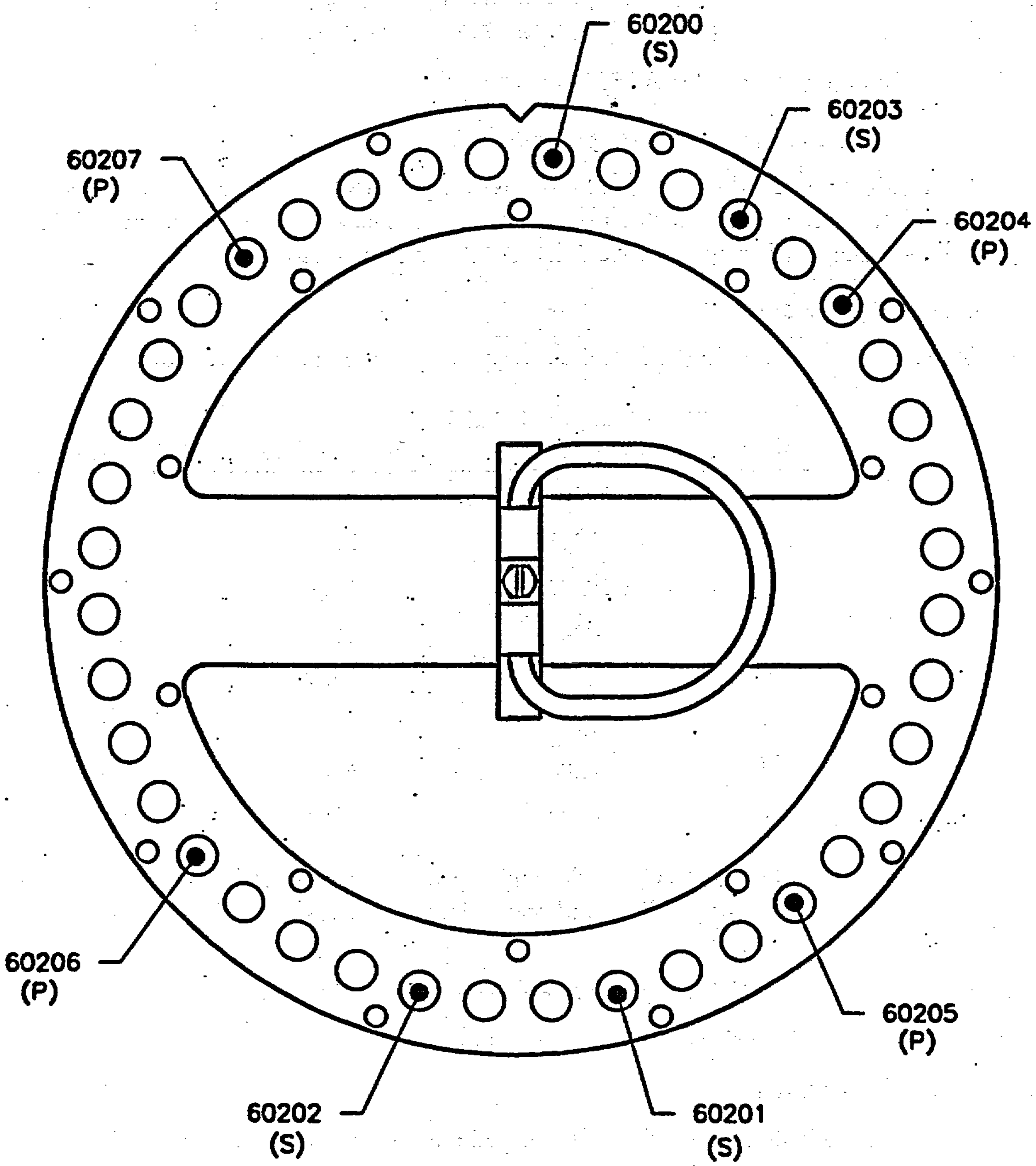
BUFFER #1

SPONGE = 4.5" DEPTH
PLYWOOD = 4.0" DEPTH
WOOD = 3.88" DEPTH

BUFFER #2

SIMILAR TO BUFFER #1
EXCEPT OVERLENGTH = 3.285"
(ROUNDED TO 3.3")

Figure 2.10.12-F168
Location of C-188 Dummy Capsules within F-313 Carrier during the Drop Test



7.7 *TEST #5.3.7 - HELIUM LEAK TEST OF THE C-188 DUMMY CAPSULES*

#1. Test # 5.3.7 as per test plan document IN/QA 1368 F294 (1): Helium Leak Test of the C-188 dummy capsules.

Date test conducted: March 25, 1998

#2.0 Person who conducted the test/procedure

John Culbertson conducted the helium leak test of C-188 dummy capsules as per manufacturer's operating instructions for the helium leak testing equipment and ANS N542-77 Standard: Appendix A2.2.6.1, A2.2.6.2, and A2.2.6.3.

#2.1 Test details

Step #1: The eight (8) C-188 dummy capsules are numbered as follows:

Item	Serial Number of C-188 Dummy Capsule	Pellet or Slug	Weight in grams
1	60200	Slug	230.
2	60201	Slug	229.
3	60202	Slug	232.
4	60203	Slug	229.5
5	60204	Pellet	194
6	60205	Pellet	194.5
7	60206	Pellet	193.5
8	60207	Pellet	193.

Step #2: All eight (8) C-188 dummy capsules were inserted in a pressure vessel containing helium and pressurized with helium to 350 psig for two (2) hours.

Step # 3: Each C-188 dummy capsule was individually helium leak tested.

Step # 4: The ambient temperature was 21°C.

#2.2 Observations

All eight C-188s that were helium leak tested met leaktightness level of 2×10^{-9} atm cc/sec.

#2.3 Photos

Photographs were not taken. There was no visible damage on dummy C-188 capsules.

#2.4 Conclusions

After the drop test of F-294 prototype container, the dummy C-188s passed the helium leak test, as the leaktightness level of 2×10^{-9} atm cc/sec exceeds the required leaktightness level of 1×10^{-8} std cc/sec as stated in procedure ANS N542-77 standard (Appendix A2.2.6.4).

#3. Notes

#3.1 Helium Leak Testing Equipment:

Varian 947 Helium Leak Detector # 10487/6-809-416

Calibration information:

- The machine has a built-in calibration standard.
- The machine is verified to the built-in calibrated standard at the start of every leak test.

#4. Personnel

	Name	Title
Test Conducted by:	J. Culbertson	Materials Specialist
Reviewed by:	V. Shah	Package Engineer
Reviewed by:	D. Whitby	Industrial Q.C.

Figure 2.10.12-F169

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7.8 TEST #5.3.8 - INSPECTION AND DIMENSIONAL MEASUREMENT OF F-313 SOURCE CARRIER

#1. **Test #** **5.3.8** as per test plan document IN/QA 1368 F294 (1): Inspection and dimensional measurement of F-313 source carrier.

Date test conducted: March 16, 1998

#2. **Person who conducted the test/procedure**

Helen Sheehan conducted the inspection and dimensional measurement of F-313 source carrier (Figure 2.10.12-F170) as per incoming inspection procedure and as per requirements stated by V. Shah.

#2.1 Test details

The following dimensions were measured on F-313 source carrier.

- Overall diameter
- Overall length
- Height from top elevation of support rod to bottom elevation of support rod.
- Height of center post assembly.

#2.2 Test Results

See Figure 2.10.12-F171 for legend:

1. Overall Length (A) = 19.794 in. (see Note)
2. Height from bottom feet of support rod to top plate. (measurement at center of hole pattern).

Dimension B1	17.459 in.
Dimension B2	17.454 in.
Dimension B3	17.486 in.
Dimension B4	17.500 in.

3. Height of each plate from the bottom of feet of support rod.

Dimension C	0.359 in.
Dimension D	1.407 in.
Dimension E	6.429 in.
Dimension F	11.497 in.
Dimension G	16.560 in.
Dimension H	17.486 in.

#2.3 Photographs

Photographs, if available, will be provided.

#2.4 Conclusions

#3. Notes

#3.1 F-313 drawing

The F-313 source carrier was fabricated to Drawing F31301-001 Issue B.

#3.2 Configuration of F-294 cavity:

After the drop, when the F-294 closure plug was opened, it was discovered that the F-313 carrier was restrained in two locations at the top. It was restrained, using wood and plastic foam buffers as per Figure 2.10.12-F172. In addition, the carrier handle was not on the F-313 carrier. Also, the dummy C-188 capsules were located as per Figure 2.10.12-F173.

#3.3 Calibrated measuring instruments were used to measure dimensions.

#3.4 The handle of the F-313 carrier had been removed. Consequently the mounting screw for the handle to the post was not located as per pre-drop configuration.

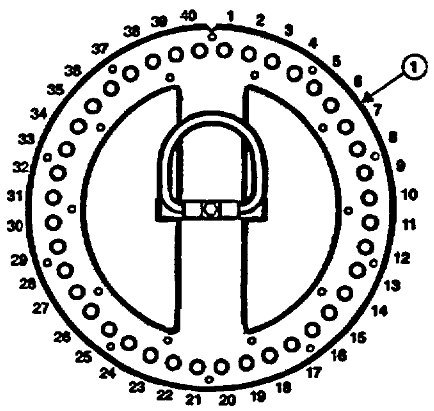
#4. Personnel

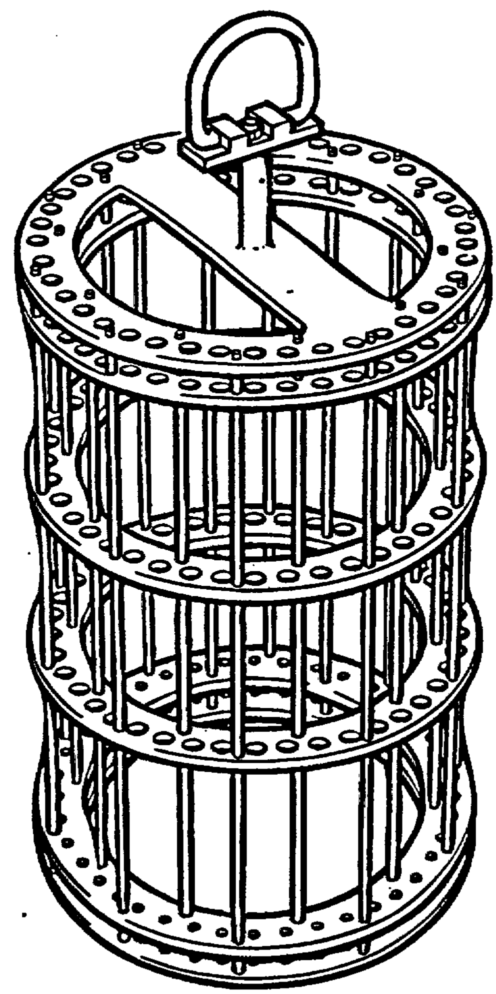
	Name	Title
Conducted by:	H. Sheehan	Quality Control Technician
Reviewed by:	D. Whitby	Industrial Quality Control
Reviewed by:	V. Shah	Package Engineer

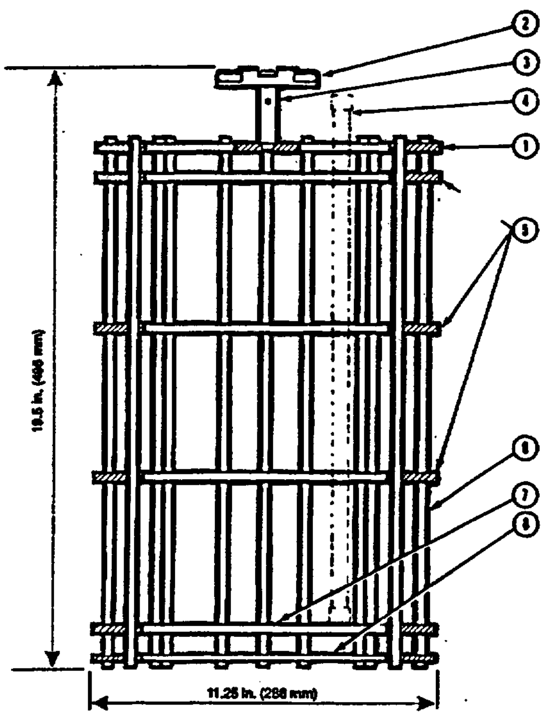
Figure 2.10.12-F170
F-313 Source Carrier

Notes

1. Material - Stainless Steel AISI SS 316
2. Welded Construction
3. Capacity: 40 C-188 Sealed Sources
4. Used with the F-294 Transport Packaging
5. Total Weight - 23 lbs (10.5 kg)







Parts

1. Top Plate: 40 Locating Holes
2. Swivel Type Lifting Handle
3. Centre post
4. C-188 Sealed Source
5. Spacer Plates (3)
6. Support Rods (20)
7. Support Plate
8. Bottom Plate

MDS Nordion 447 March Road, P.O. Box 13500 Kanata, Ontario, Canada, K2K 1X8 Tel: (613) 592-2790 · Fax. (613) 592-6937	TITLE **F-313 Source Carrier**		
	REF. F131301-001 IN/SS 1403 F313	REVISED JUN 98	DCN A1232-D-02A
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Figure 2.10.12-F171
F-313 Source Carrier - Legend for Dimensional Measurements

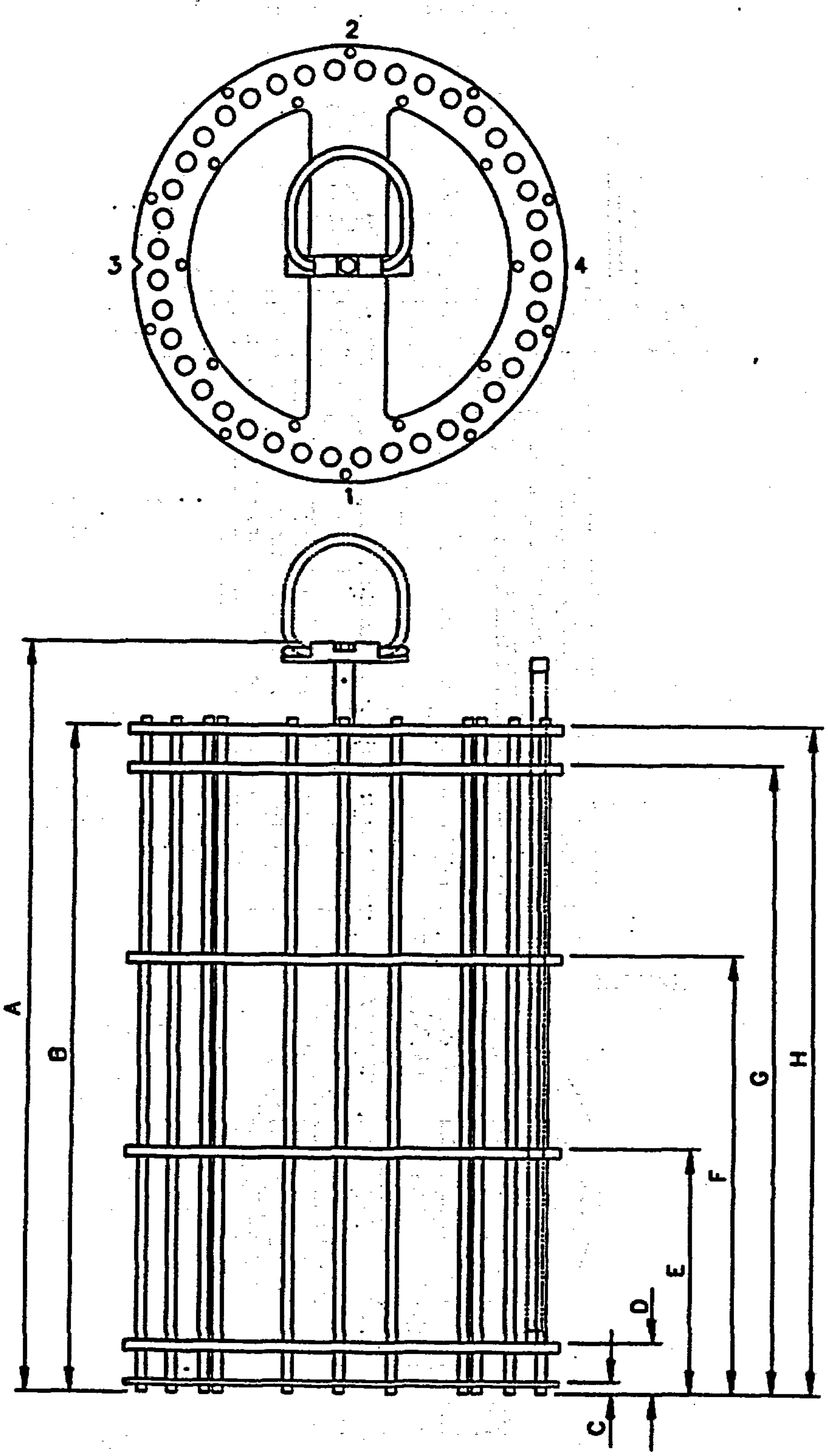


Figure 2.10.12-F172
Location of "Buffers" and C-188 Dummy Capsules in F-313 Carrier during F-294 Drop Tests

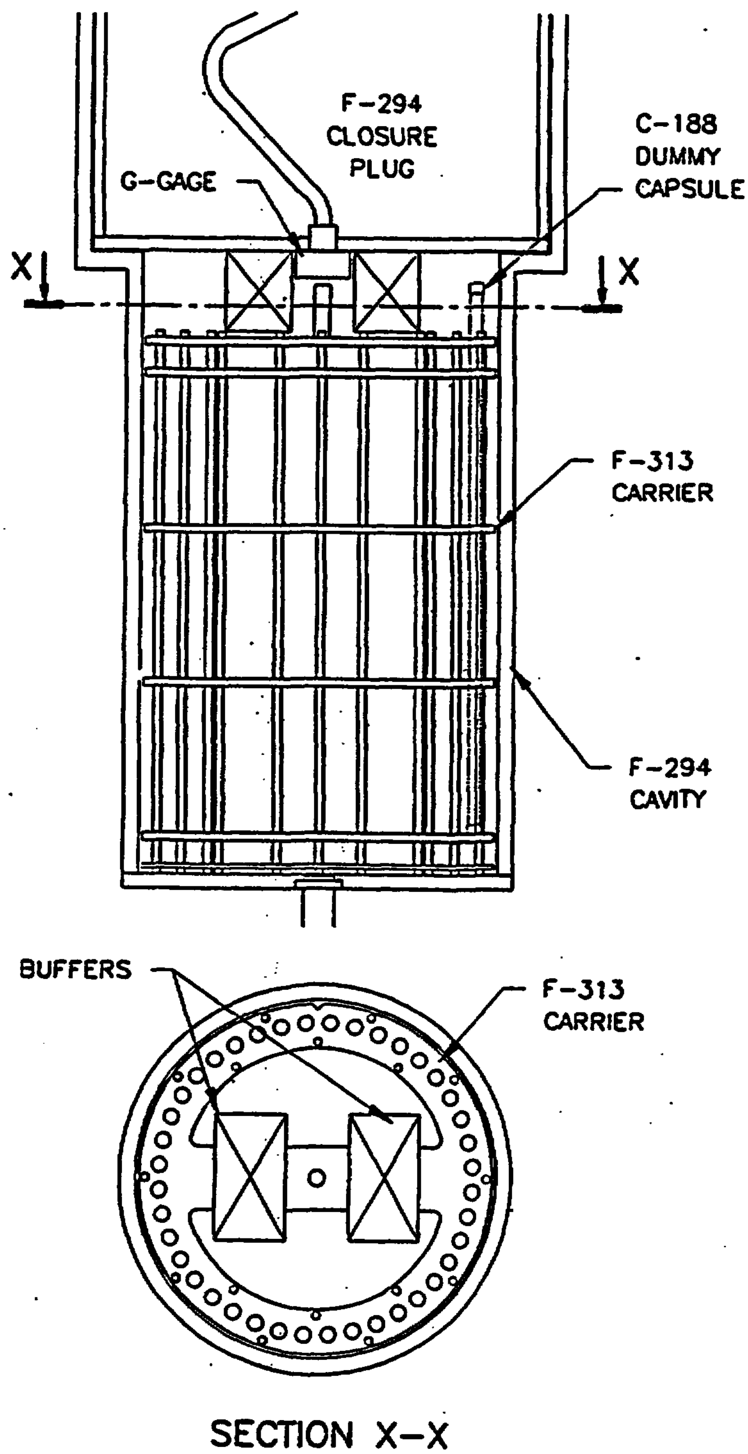
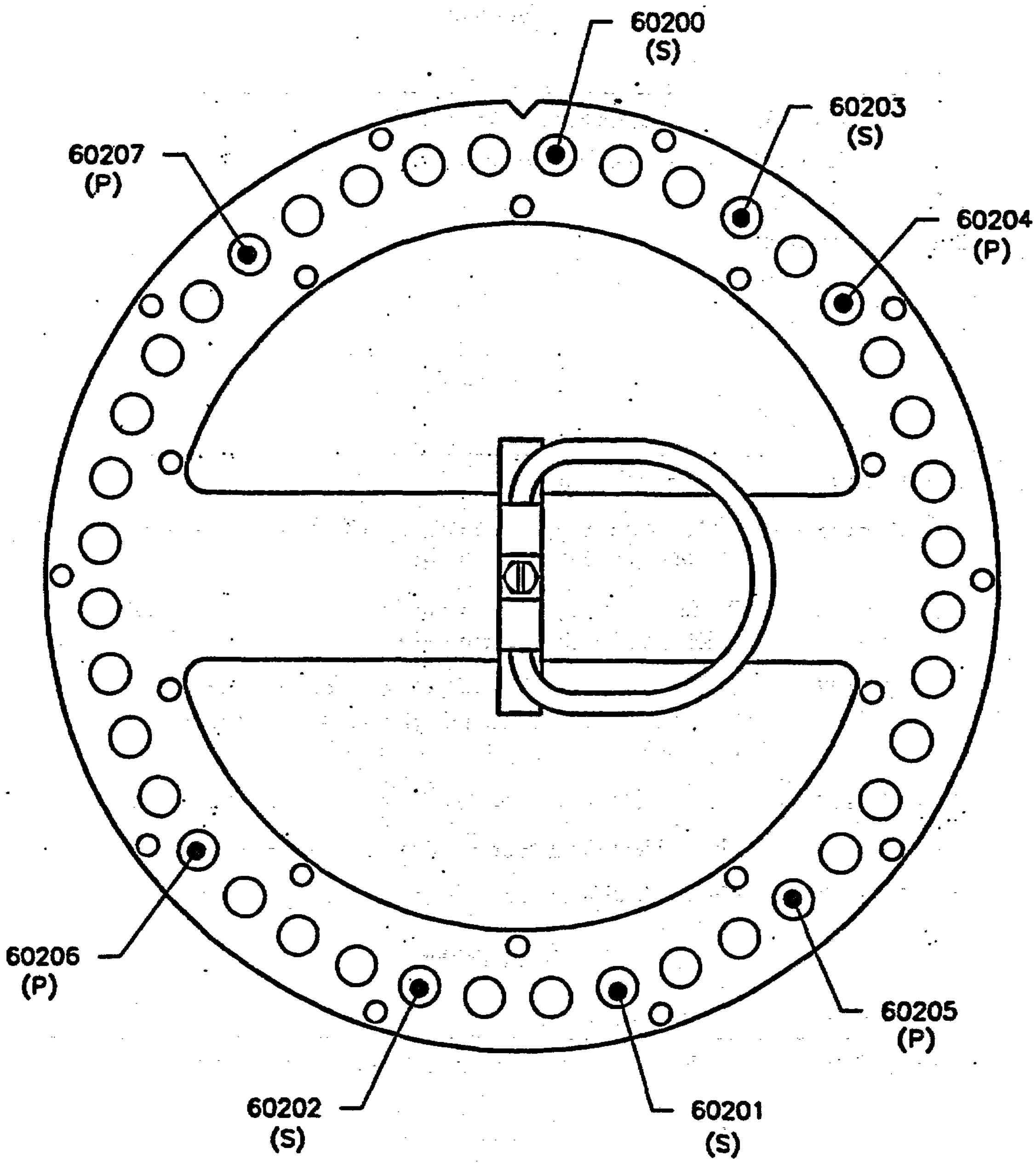


Figure 2.10.12-F173
Location of C-188 Dummy Capsules in F-313 Carrier during F-294 Drop Tests



7.9 TEST #5.3.9 - RADIATION SURVEY AFTER THE DROP

Contents

Section	*Title*
1.	Test # 5.3.9 - Radiation Survey After the Drop
2.	Person Conducting the Test/Procedure
2.1	Test Details
2.2	Observations
2.3	Conclusions
3	Personnel

List of Figures

Figure	*Description*
2.10.12-F174	Loading Diagram for F-294
2.10.12-F175	Radiation Survey: F-294 Package Configuration (Crush Shield and Fireshield in Place)
2.10.12-F176	Radiation Survey: F-294 Container Configuration (Crush Shield and Fireshield Removed)
2.10.12-F177	Radiation Survey: F-294 Container Configuration (Crush Shield and Fireshield Removed, Placement of meter as if Fins were not Damaged)
2.10.12-F178	Photo: Identification of Position of Damaged Zones 1 and 3
2.10.12-F179	Photo: Identification of Position of Damaged Zone 2
2.10.12-F 180	Photo: Identification of Position of Damaged Zone 4

List of Tables

Table Number	*Description*
2.10.12-T19	Radiation Survey at the F-294 Damaged Zones

#1 **Test # 5.3.9** as per test plan document IN/QA 1386 F294 (1)
Radiation Survey After the Drop

Date test conducted: March 17, 1998

#2 Person conducting the test/procedure

D. Whitby conducted the radiation surveys.

#2.1 Test details

The F-294 was loaded in the same manner as the pre-drop survey; with the same forty (40) C-188 sources decayed to 366,160 curies Cobalt-60 on March 17, 1998 as per the loading diagram attached (see Figure 2.10.12-F174). The loading was again done as any typical preparation for shipment, complete with a cavity argon purge and all fasteners appropriately torqued in Cell 06 within Industrial Operations, MDS Nordion, Ottawa.

After the thermal testing, the upper crushshield was set in place as close as it could be to its proper damaged position. The three segments of the cylindrical sectioned fireshield were assembled and secured in place. The loaded flask was then moved on to the levelator for access to the underside (position #8 on the survey report), which is also an area of low background activity levels, providing for accurate survey results. The second and third survey were performed with the fireshield and crush shield removed.

The F-294 shipping package was surveyed with the same two calibrated instruments as the pre-drop survey as outlined in the Radiation Integrity for New Transport Packaging Procedure CO-QC/TP-0001 (2). The highest reading for each elevation/location on the F-294 was recorded on the attached forms CO-QC/TPF4-0001 (2).

The first post-drop survey was completed with the upper crush shield and the sectioned fireshield in place on 1998 March 24 (see Figure 2.10.12-F175).

The second survey was completed on the container with both the fireshield and the crush shield removed on 1998 March 26 (see Figure 2.10.12-F176). Both the first and second survey included contact readings within the damaged zones.

A varied third survey was completed on 1998 March 26 (see Figure 2.10.12-F177). The damaged fins of the F-294 permitted a more intimate contact reading with the survey meter on the container wall. Therefore, the readings gathered on the first two surveys are the highest readings attained per CO-QC/TP-0001, but are not necessarily good for before and after comparison readings, as the proximity of the meter to the sources is closer on the damaged F-294. Therefore, the third survey was to attain readings as if the fins were not damaged; the contact readings were taken at approximately the same distance from the container wall as the pre-drop survey. Readings were recorded, only if different from the second post-drop survey.

There were no unusually high localized readings with either instrument for all configurations.

Configuration	Max. Reading on Contact	Max. Reading @ 1 Meter	Figure
F-294 Package	30 mR/h	1.9 mR/h	2.10.12-F175
F-294 Container	30 mR/h	3.5 mR/h	2.10.12-F176
F-294 Container (varied)	26 mR/h	n/a	2.10.12-F177

Special additional measurements were taken around the F-294 damaged zones. These are recorded in Table 2.10.12-T19.

2.2 Observations

There was a moderate increase in the fields around all areas, with a considerable increase at the bottom center of the container:

(post-drop reading)/(pre-drop reading) = % increase

30/14 = 2.14 or approximately 100% increase

#2.3 Conclusions

All configurations meet the acceptance criteria of 1 rem/h at one meter from the external surface of the package. [10CFR 71.51 (a) (2)]

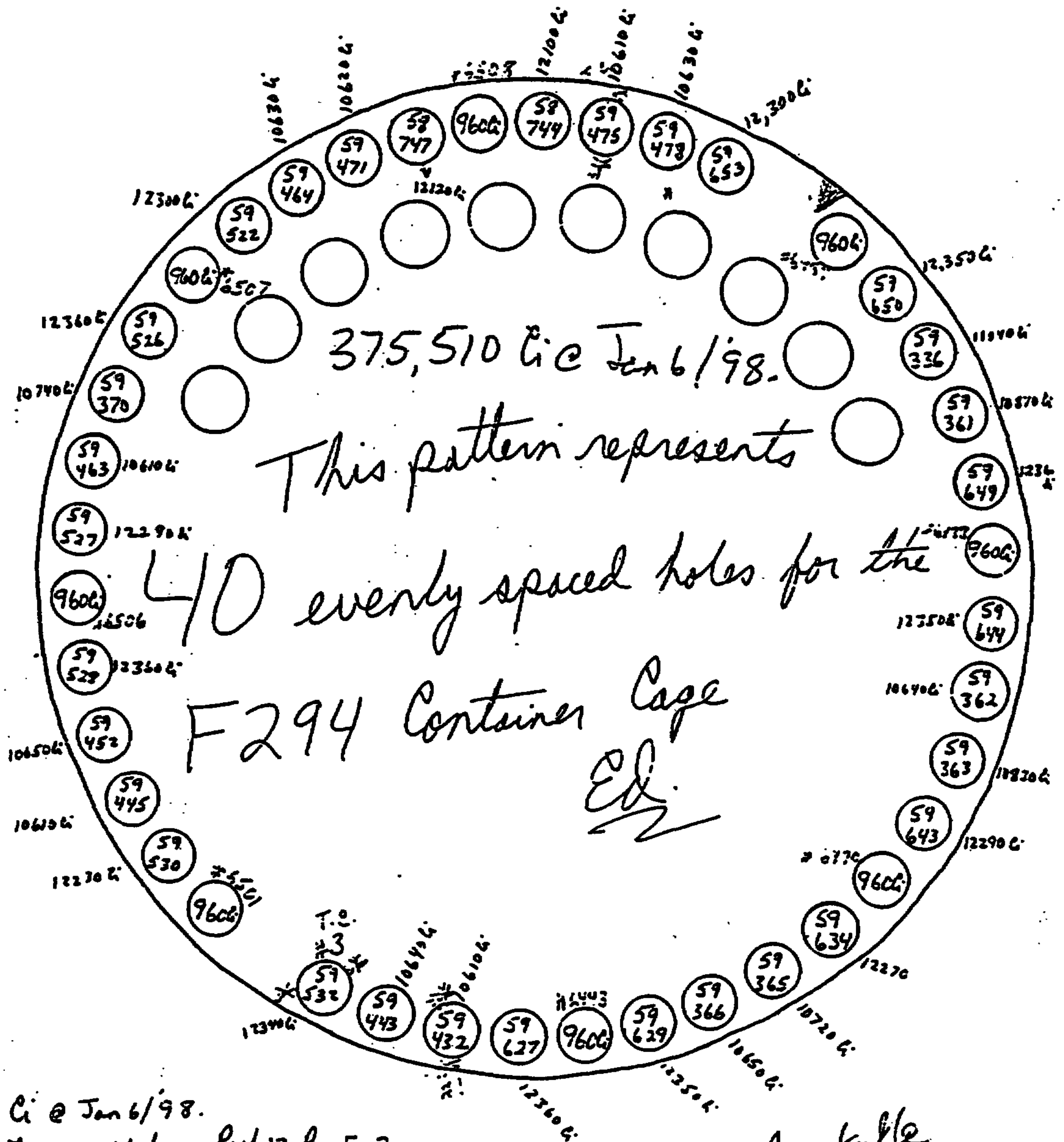
#3 Personnel

	Name	Title
Test prepared by:	D. Whitby	Industrial Quality Control
Reviewed by:	K. O'Hara	Industrial Engineering, Physics
Approved by:	V. Shah	Package Engineering

Table 2.10.12-T19
Radiation Survey at the F-294 Damaged Zones (Additional Readings)

	Location	Contact Reading (mR/h)	1 Meter Reading (mR/h)	Opposite Position	Contact Reading (mR/h)	1 Meter Reading (mR/h)
Fig. 2.10.12-F178 Position #1	Upper damaged zone at lift lug #4	8.5	1.4	Upper section, at lift lug #2	3.0	1.0
Fig. 2.10.12-F179 Position #2	Puncture pin damage zone near lift lug #3	26	3.5	Mid section, at lift lug #1	12	2.0
Fig. 2.10.12-F178 Position #3	Puncture pin midsection lift lug #4	26	2.4	Mid-section near lift lug #2	10.4	2.2
Fig. 2.10.12-F180 Position #4	Top of fins of damaged zone, 16 in. from center	4.0	1.4	Top of fins, between lift lugs #2 and #3	3.0	1.4
	Highest reading on top of plug (over bolt hole pattern)	22	1.6	Over bolt holes on opposite side (nr. lift lug #1)	10	1.4
	Over vent line	10				

Figure 2.10.12-F174
Loading Diagram for F-294



Ci @ Jan 6/98.
Low pencils from Pool 13 Pos E-2.
[illegible]

Acceptable 98/01/06

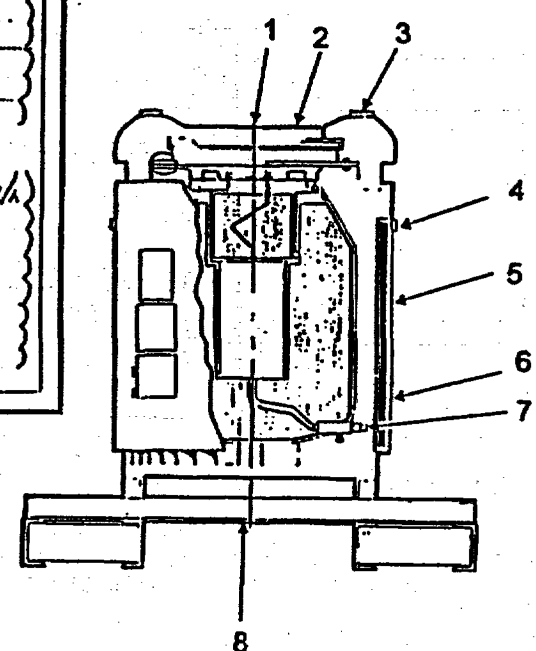
Figure 2.10.12-F175
Radiation Survey: F-294 Package Configuration (Crush Shield and Fireshield in Place)

RADIATION SURVEY
READINGS IN MILLIROENTGENS PER HOUR

POSITION	SURVEY METER: GM Tube (S/N 2000)	SURVEY METER: Ion Chamber (S/N 200)
	Make: BERTHOLD	Make: NUCLEAR ENTERPRISES
	Model: RATO/F	Model: PDM-1
	Calibration Date: 98-03-05	Calibration Date: 98-03-03
AT 1 METRE FROM SURFACE		
1	0.8 mR/h	9 µSv/h (0.9 mR/h)
2	0.8	8 (0.8)
3	0.8	8 (0.8)
4	1.4	13 (1.3)
5	1.8	19 (1.9)
6	1.6	13 (1.3)
7	1.0	10 (1.0)
8	1.8	13 (1.3)
METER IN CONTACT WITH SURFACE		
1	4.0 mR/h [PUNCTURE ZONE DEPRESSION]	40 µSv/h (4.0 mR/h)
2	2.6 mR/h	20 (2.0)
3	1.6	10 (1.0)
4	5.0 [DEPRESSION NEAR L.L. #4]	24 (2.4)
5	16 [" " "]	100 (10.0)
6	5.5	40 (4.0)
7	0.6	5 (0.5)
8	30 [PUNCTURE ZONE DEPRESSION]	210 (21)

SURVEYED BY: [signature]

NOTE: Measurements on contact and at 100 cm from contact are made with the GM Tube and Ion Chamber instruments.



CONTAINER F-294 # .... PROTOTYPE {POST DROP}
SURVEY AND ACTIVITY DATE: 98 MARCH 24
SOURCE DESCRIPTION: C-188's
CURIES: 365,221 Ci
REMARKS: CRUSHSHIELD + FIRESHIELD ARE IN PLACE.

APPROVED BY: [signature] Senior Radiation Physicist and [signature] Package & Facility Engineering

CO-QC/TPF4-0001 Rev 2

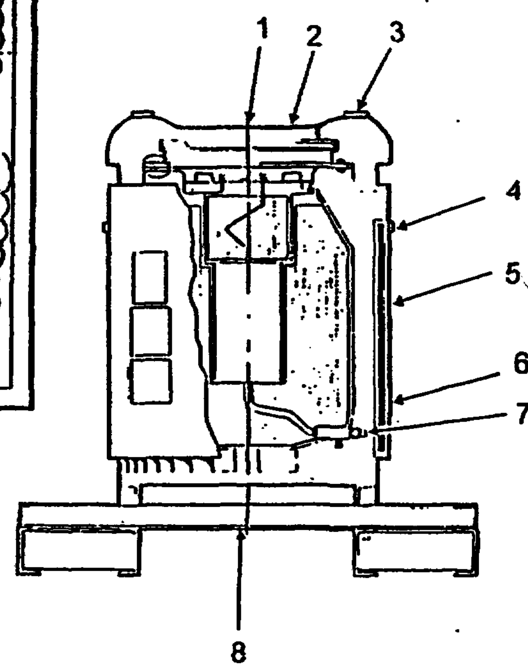
Figure 2.10.12-F176
Radiation Survey: F-294 Container Configuration (Crush Shield and Fireshield Removed)

RADIATION SURVEY
READINGS IN MILLIROENTGENS PER HOUR

POSITION	SURVEY METER S/N 2000 — GM Tube: Make: BERTHOLD; Model: RATO/F; Calibration Date: 98-03-05	SURVEY METER S/N 200 — Ion Chamber: Make: NUCLEAR ENTERPRISES; Model: PDM-1; Calibration Date: 98-03-03
AT 1 METRE FROM SURFACE		
1	1.2 mR/h	6 μSv/h (0.6 mR/h)
2	1.4	6 (0.6)
3	1.6	9 (0.9)
4	1.4	14 (1.4)
5	3.5	25 (2.5)
6	3.0	20 (2.0)
7	1.2	9 (0.9)
8	1.6	13 (1.3)
METER IN CONTACT WITH SURFACE		
1	9.0 mR/h [BESIDE WELDED SHACKLE]	90 μSv/h (9.0 mR/h)
2	14 [NR. L.L. #1]	90 (9.0)
3	22 [HOLE BETWEEN NR. L.L. #1]	110 (11)
4	8.5 [BETWEEN FINS @ [illegible]]	50 (5.0)
5	26 [BETWEEN DAMAGED FINS	140 (14)
6	0.7	50 (5.0)
7	0.7	5 (0.5)
8	30	200 (20)

SURVEYED BY: [signature]

NOTE: Measurements on contact and at 100 cm from contact are made with the GM Tube and Ion Chamber instruments.



CONTAINER F-294 # .... PROTOTYPE – POST DROP
SURVEY AND ACTIVITY DATE: 98-03-26
SOURCE DESCRIPTION: C-198's
CURIES: 364,958 C
REMARKS: CRUSHSHIELD + FIRESHIELD REMOVED.

APPROVED BY: [signature] Senior Radiation Physicist and [signature] Package & Facility Engineering

CO-QC/TPF4-0001 Rev. 2

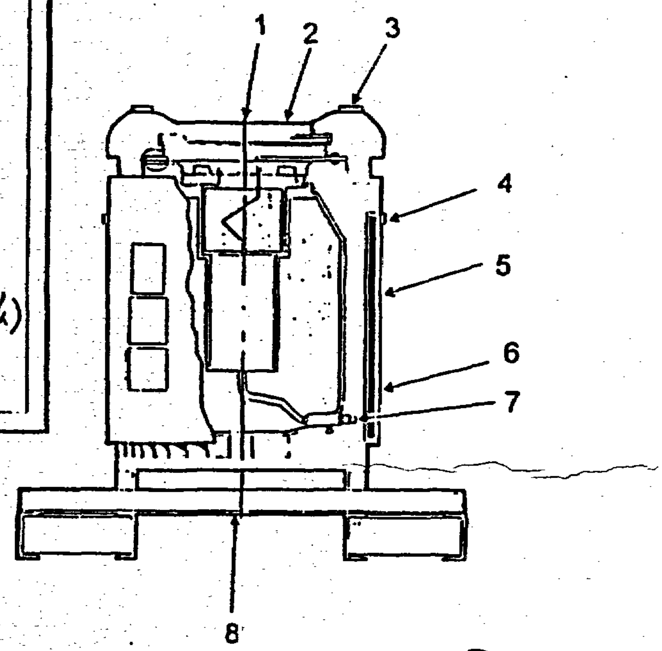
Figure 2.10.12-F177
Radiation Survey: F-294 Container Configuration (Crush Shield and fireshield Removed, Placement of Meter as if Fins were not Damaged)

RADIATION SURVEY
READINGS IN MILLIROENTGENS PER HOUR

POSITION	SURVEY METER s/n 2000 — GM Tube	SURVEY METER s/n 200 — Ion Chamber
	Make: BERTHOLD	Make: NUCLEAR ENTERPRISES
	Model: RATE/F	Model: PDM-1
	Calibration Date: 98-03-05	Calibration Date: 98-03-03
AT 1 METRE FROM SURFACE		
1		
2		
3		
4		
5		
6		
7		
8		
METER IN CONTACT WITH SURFACE *		
1		
2		
3		
4	5.5 mR/h NR LL#3	
5	24 NR LL#3	130 µSv/h (13 mR/h)
6		
7		
8	26	

SURVEYED BY: [signature]

NOTE: Measurements on contact and at 100 cm from contact are made with the GM Tube and Ion Chamber instruments.



CONTAINER F-294 # .... PROTOTYPE POST DROP
SURVEY AND ACTIVITY DATE: 98-03-26
SOURCE DESCRIPTION: C-188's
CURIES: 364,958 Ci
REMARKS: CRUSHSHIELD + FIRESHIELD REMOVED.
* PLACEMENT OF METER AS IF FINS WERE NOT DAMAGED.

APPROVED BY: [signature] Senior Radiation Physicist and [signature] Package & Facility Engineer

CO-QC/TPF4-0001 Rev 2

Figure 2.10.12-F178
Digital Photo: Identification of Position of Damaged Zones 1 and 3

(G:\QA\QC\PHOTOS\1F294.BMP)

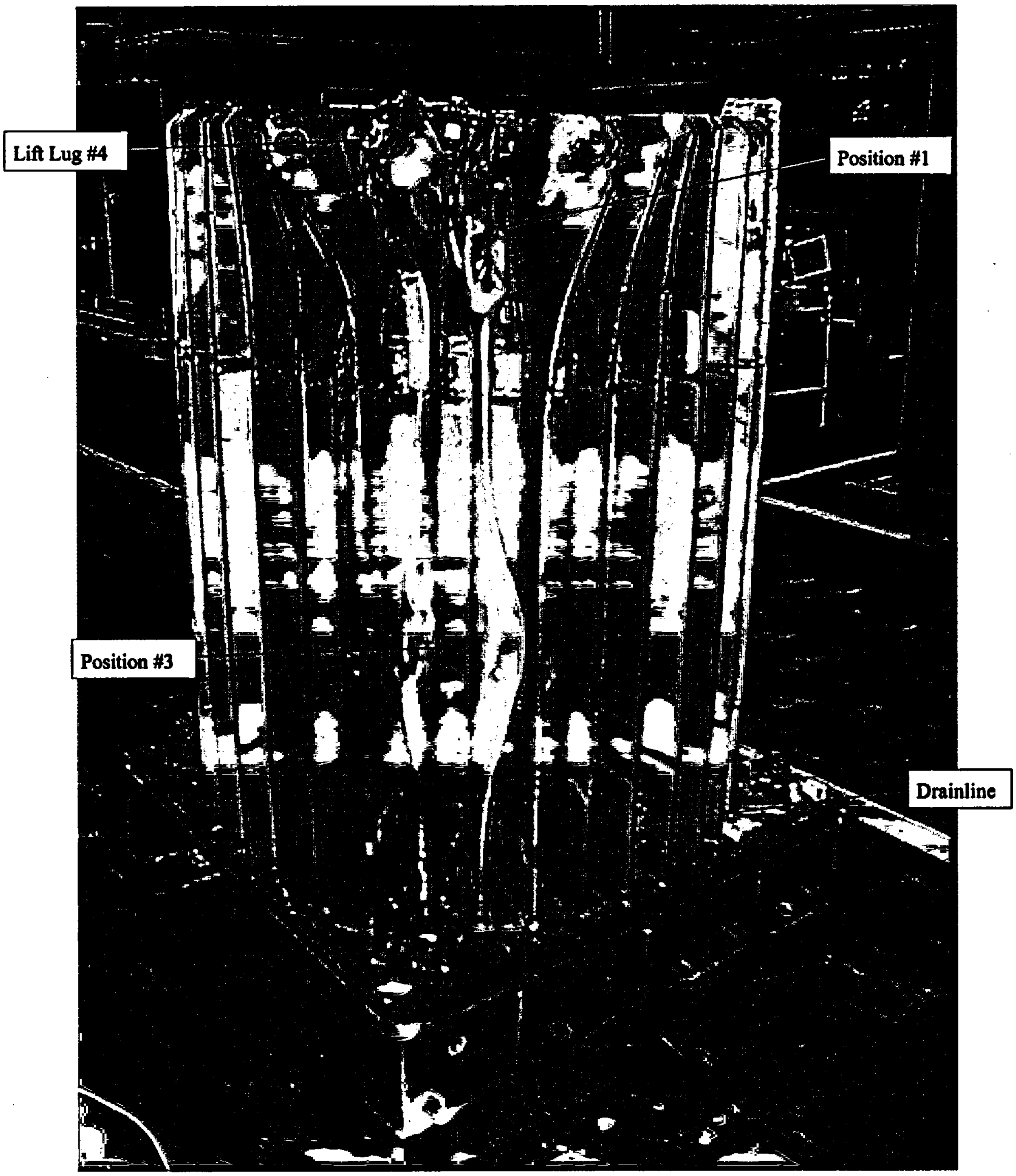


Figure 2.10.12-F179
Digital Photo: Identification of Position of Damaged Zone 2

(G:\QA\QC\PHOTOS\2F294.BMP)

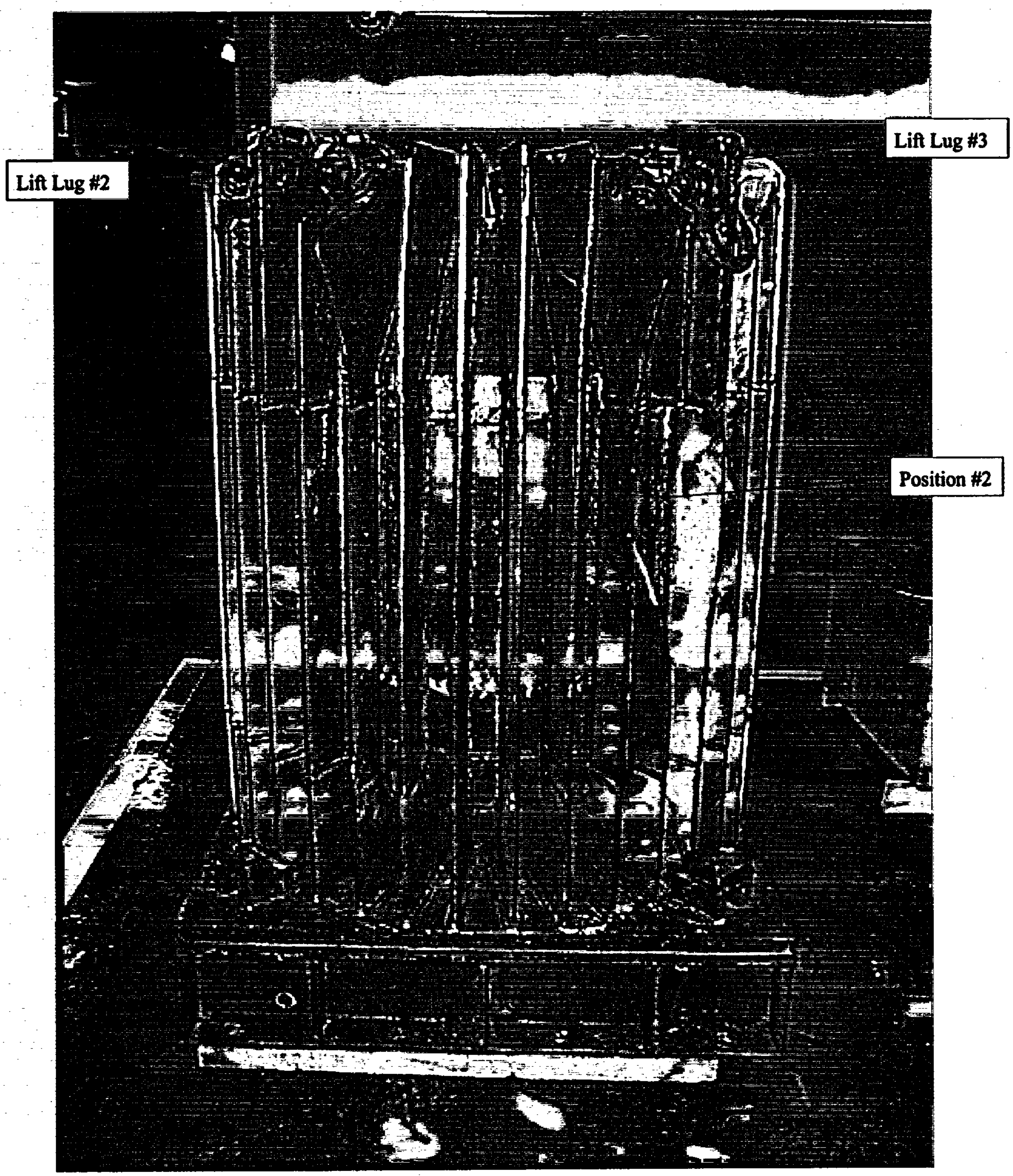
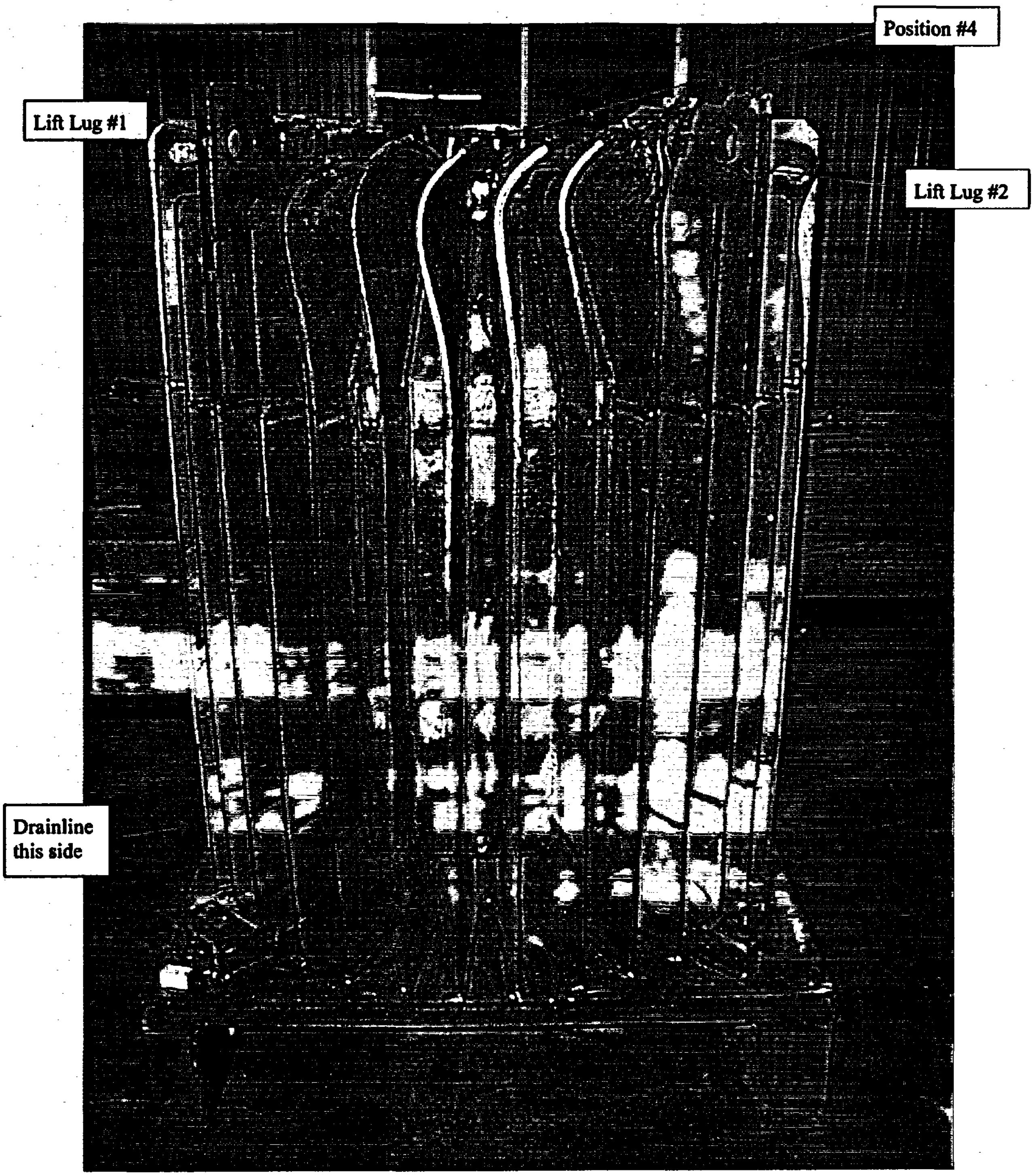


Figure 2.10.12-F180
Photo: Identification of Position 4 of Damaged Zone

(G:\QA\QC\PHOTOS\3F294.BMP)



7.10 TEST #5.3.10 - NORMAL THERMAL TEST AFTER THE DROP

Contents

Section	Description
1.	Test #5.3.10 - Normal Thermal Test After the Drop
2	Person(s) Who Conducted the Test/Procedure
3	Test Details
3.1	Instrumentation
3.2	Source Loading in Cell 06
4	Actual Termal Tests
4.1	Test #1 - Fireshield and Crush Shield Removed
4.2	Test #2 - Firesheild and Crush Shield in Place
4.3	Test #3 - Fireshield and Crush Shield Removed: Insulated
4.4	Test #4 - Firesheild and Crush Shield in Place: Insulated
5	Observations
6	Conclusions
7	Personnel

List of Figures

Figure No.	Description
2.10.12-F181	Photo: Locations and Identifications of Damaged Zones
2.10.12-F182	Photo: Locations and Identifications of Damaged Zones
2.10.12-F183	Loading Diagram of F-294 and Locations of Thermocouples in the F-294 Cavity
2.10.12-F184	Thermocouple Locations (plane through drainline)
2.10.12-F185	Thermocouple Locations (other planes)
2.10.12-F186	Test #1 Temp vs. Time - Plot of Selective Thermocouples

List of Tables

Table No.	Description
2.10.12-T20	Identification of Thermocouples shown in Figures 4 and 5
2.10.12-T21	Test #1 Temperature Data
2.10.12-T22	Test #2 Temperature Data
2.10.12-T23	Test #3 Temperature Data
2.10.12-T24	Test #4 Temperature Data
2.10.12-T25	Thermocouple Location with Highest Temperature Readings

#1 **Test #** **5.3.10** as per test plan document IN/QA 1368 F294 (1)
Normal Thermal Test After the Drop

Date test conducted: March 17 - 24, 1998

#2 **Person(s) who conducted the test/procedure**

Ed Psutka, Industrial Operations
Greg Chupick, Industrial Operations Monitor
Dave Whitby, Industrial Quality Control

#3 **Test Details**

The F-294 test packaging was subjected to eight (8) drop tests conducted on February 25, 1998 at Chalk River Laboratory, AECL, Chalk River, Ontario, Canada. After the drop tests, the F-294 Shipping Package was subjected to the same normal thermal testing after the drop test as was performed prior to the drop test when loaded with Co-60 as outlined in The Procedure for Steady State Thermal Test IN/OP 0597. The drop-tested F-294 was loaded by the same technician, Ed Psutka of Industrial Operations, and the thermal testing was carried out by Greg Chupick, the Industrial Operations Monitor, and Dave Whitby of Industrial Quality Control. The same four tests were again carried out on the four different configurations.

1. with fireshield and crush shield, no added insulation
2. without fireshield or crush shield, no added insulation
3. without fireshield or crush shield, with added insulation
4. with fireshield and crush shield, with added insulation

#3.1 Instrumentation

All the instrumentation used on the pre-drop thermal test was also used on the post-drop test. A third temperature reader was used due to the higher number of thermocouple locations on the drop-tested F-294. The following instrumentation was used.

Instrument	Make	Model	Cal. Date	Accuracy	Nordion No.
Temperature Logger	Omega	OM-302	1997 Sept.	± 2°C	6-810-021
Temperature Reader	Fluke	2166A	1997 Oct.	± 0.5%	6-810-022
Temperature Reader	Omega	650	1998 Feb.	± 1°C	6-810-013
Thermocouple wire Type K	Omega	HH-K-20	1998 Jan.	± 2.2°C or ± 0.75%	n/a

The thermocouples each had a flame fusion junction that could be mounted on the container wall. The method of affixing the thermocouples onto the container was improved over the pre-drop thermal test. Each thermocouple junction was fusion welded onto a stainless steel flat plate, approximately ½ in. square and approximately 0.030 inch thick which, in turn, was tack welded directly on to the container wall.

The F-294 flask was prepared for thermal tests prior to loading just as the pre-drop test, except with an additional thermocouple located in the cavity. Two thermocouples were mounted on the cavity wall, in line with the drainline, radially opposed to each other and axially on the cavity center line. A third thermocouple was mounted in line with the most damaged area of the F-294, near lift lug #4 (see Figure 2.10.12-F181). A fourth thermocouple was mounted on the underside of the container plug, adjacent to the vent line exit hole. The wire for the four thermocouples was routed out the F-294 plug vent line to Type K connectors.

Thermocouples were also mounted actively onto the same three C-188 sources, using hose clamps for a secure contact. The thermocouples were positioned at approximately the center of the sources; the Source Technician then placed these sources (s/n's 59475, 59432, 59532) within the F-313 cage assembly as shown on the Loading Diagram attached (see Figure 2.10.12-F183). The thermocouple wire was routed through the drainline to Type K connectors.

#3.2 Source Loading in Cell 06

The F-294 was loaded 1998 March 17 with the same sources in the same loading configuration as the pre-drop thermal test. The activity for that date was 366,160 curies Cobalt-60, as per the loading diagram attached (see Figure 2.10.12-F183). The loading was done as any typical preparation for shipment, complete with a cavity argon purge and the plug fasteners torqued to 100 ft-lb. in Cell 06 within Industrial Operations, MDS Nordion, Ottawa.

The loaded container was removed from Cell 06 and placed in the shipping bay. The thermocouples were mounted on the container as listed in Table 2.10.12-T20 and shown in Figure 2.10.12-F184. Some additional thermocouples were mounted onto the damaged areas of the container (see Figures 2.10.12-F181 and 2.10.12-F182).

#4 Actual Thermal Tests

#4.1 Test #1 - Fireshield and Crush Shield Removed

The F-294 was loaded at approximately 13:00 on 1998 March 17; after preparation, temperature readings were acquired at 14:20 and successive readings were taken to demonstrate a thermal steady state condition up to 1998 March 19 (see Test #1, Table 2.10.12-T21 and Figure 2.10.12-F185).

#4.2 Test #2 - Fireshield and Crush Shield in Place

The fireshield and the upper crush shield, which had been damaged during the drop test, had to be cut from the container assembly prior to loading. The fireshield was cut into three segments and the more damaged crush shield had to have some fins flame cut for removal.

To re-assemble the fireshield in place, the lower edge was fastened normally while the upper area was strapped together. The seams were taped to prevent air flow between the segments. The puncture holes on the fireshield were also taped to prevent air flow bypass. The crushshield was set in place on top of the container, although it could not be fastened down. As the crushshield was propped up by the lifting eye welded on top of the plug, we had to cut out an elliptical hole approximately 4 in. x 6 in. so that the crush shield would seat as close as possible to the top of the container. This hole was taped so that there

would not be any bypass of air flow. Temperature readings were taken on March 19 through to March 20 (see Test #2, Table 2.10.12-T22).

#4.3 **Test #3 - Fireshield and Crush Shield Removed - Insulated**

One-half-inch Kaowool insulation strips were cut and taped on to the upper and lower sections, as per instructions from V. Shah on March 20. Temperature readings were then recorded from March 20 and again on March 23 (see Test #3, Table 2.10.12-T23).

Test #4 - Fireshield and Crush Shield in Place - Insulated

The fireshield and upper crush shield were assembled into place as in Test #2 and the appropriate additional thermocouples were tacked into position after Test #3 on March 23. Temperature readings were recorded through to March 24 (see Test #4, Table 2.10.12-T24).

#5 **Observations**

The thermocouple mounted on C-188 s/n 59432 must have broken during the loading procedure as it was not operating properly afterward; therefore this thermocouple was not allocated to a channel during the testing.

Position 5 on the Omega 650 temperature reader, which corresponds with channel 25, was inoperative and was not used for these tests.

Based on Test #1, it appears that temperature equilibrium is reached in approximately 24 hours from the start of the test.

The highest temperature readings are shown in Table 2.10.12-T25.

#6 **Conclusions**

1. Four cases (tests) were carried out as follows:
   - without fireshield and crush shield, no added insulation
   - with fireshield and crush shield, no added insulation
   - without fireshield and crush shield, with added insulation
   - with fireshield and crush shield, with added insulation
2. The decay heat load was simulated using quantity forty (40), full-scale active C-188 cobalt-60 sources. The C-188 capsules were loaded in a single ring within the F-313 source carrier. These C-188 sources were the same ones used in the pre-drop thermal test. The curies used at the start and finish of the post-drop thermal test are as follows:
   - at the start: 1998 Mar 17 - 366,160 curies (5.638 kW)
   - at the finish: 1998 Mar 24 - 365,237 curies (5.624 kW)
3. The F-294 cavity was purged with argon. Therefore the F-294 cavity environment was argon.
4. It is estimated that the time required for the temperature to reach equilibrium is 24 hours, based on Case 1.
5. The highest temperatures of the following designated location/components are based on Case 4 (F-294 with fireshield and crushshield, with added insulation) are as per table below.

Item	Location	Temperature (°C)
1	C-188	413
2	Cavity wall	193
3	Underside of the F-294 closure plug	222
4	Top of the F-294 closure plug	111
5	Mid height of the F-294 external container wall	110
6	Top of lift lug fin (most accessible surface)	56
7	Ambient	23

6. The lowest temperatures of the following designated location/components are based on Case 1 (F-294 without fireshield and crushshield, without added insulation) are as per table below.

Item	Location	Temperature (°C)
1	C-188	368
2	Cavity wall	167
3	Underside of the F-294 closure plug	206
4	Top of the F-294 closure plug	87
5	Mid height of the F-294 external container wall	91
6	Ambient	25

#7 Personnel

	Name	Title
Test prepared by:	D. Whitby	Industrial Quality Control
Reviewed by:	G. Chupick	Industrial Monitor, Decontamination Services
Approved by:	V. Shah	Package Engineering

Table 2.10.12-T20
Thermocouple Locations

Channel	Location
1	C-188 source, midpoint of s/n 59532
2	C-188 source, midpoint of s/n 59475
3	Underside of shielding plug, adjacent to ventline exit hole
4	Cavity wall midheight, in line with damaged lift lug #4
5	Cavity wall midheight on the side opposite the drainline
6	Cavity wall midheight on the same side as the drainline
7	Container wall between the fins, middle section, in line with drainline
8	Ambient, at elevation even with cavity midpoint
9	Top center of shielding plug
10	Ambient, approximately one meter above top of container
11	Top of lift lug #2
12	Container wall, lower section, adjacent to the drainline
13	Underside of container, center; middle of indentation from puncture pin
14	Container wall, upper section, under damaged fins, mid-way between lift lugs #1 and #2 (damage zone #2)
15	Container wall, middle section, mid-way between lift lugs #1 and #2 (damage zone #2)
16	Container wall, lower section, mid-way between lift lugs #1 and #2 (damage zone #2)
17	Air temperature, top edge of fireshield, in line with drainline
18	Air temperature, lower edge of fireshield, in line with drainline
19	Air temperature, upper section, between damaged fins near lift lug #4
20	Container wall, middle section; under fin folded over from puncture pin, near lift lug #4
21	Container wall, upper section, in line with drainline.
22	Top of damaged lift lug #4
23	Top of insulation, over t/c #21
24	Top of insulation, over t/c #12
25	Inoperative
26	Container wall, upper section, adjacent to damaged lift lug #4 (on reinforcing pad)
27	Air temperature, lower section, between damaged fins, near lift lug #4
28	Container wall, upper section, adjacent to damaged lift lug #4 (other side of fin from t/c #26)
29	Top of insulation, over t/c #26
30	Top of insulation, lower section, next to lift lug #4
31	Top center of crush shield
32	Top of crush shield, equidistant between center and outside edge of plate, in line with lift lug #2
33	Top of crush shield, outside edge of plate, in line with lift lug #2
34	Top edge of fireshield, in line with drainline
35	Mid-height of fireshield, in line with drainline
36	Bottom edge of fire shield, in line with drainline
37	Air temperature, between damaged fins of crush shield, in line with drainline
38	Top of upper donut ring on crush shield, in line with lift lug #2
39	Top of lower donut ring on crush shield, in line with lift lug #2
40	Top of fireshield, puncture pin damaged zone #1, near lift lug #4
41	Top of fireshield, near lift lug #2
42	Top of insulation, upper section, between fins of damage zone #2
43	Top of insulation, lower section, between fins of damage zone #2

Table 2.10.12-T21
Test #1 - Recorded Temperatures
(No Added Insulation; Crush Shield and Fireshield Removed)

Channel	98/03/17										98/02/18							98/03/19	
	14:20	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	8:30	10:00	11:00	12:00	13:00	14:00	15:45	8:45	10:50
1		357	358	359	359	359	360	360	359	360	368	367	367	368	368	368	368	368	368
2		398	400	400	400	400	399	399	399	398	404	404	404	405	405	405	405	405	405
3		167	171	174	178	181	183	186	188	189	204	205	206	204	206	204	206	206	206
4		128	132	136	139	143	146	148	150	152	167	167	167	167	168	168	168	167	167
5		144	149	151	153	155	157	158	159	161	173	173	173	173	174	174	174	174	174
6		138	142	146	149	152	155	157	159	161	174	174	175	175	175	175	175	175	175
7		48	53	57	61	64	67	71	73	76	90	90	90	91	91	91	91	91	91
8		24	24	24	25	25	24	25	25	24	25	24	24	25	25	25	25	23	25
9		42	46	49	53	56	62	63	67	69	83	87	88	88	86	85	83	85	87
10		26	27	27	29	28	28	32	30	31	33	31	29	28	31	33	32	30	29
11	25	26	27	29	30	31	32	33	34	35	41	41	41	41	42	41	41	41	41
12	33	40	45	48	52	55	58	60	62	64	77	77	77	77	77	77	78	77	77
13	22	22	23	23	24	24	25	26	26	27	32	32	33	33	33	33	33	33	33
14	37	43	48	52	55	58	62	64	66	68	83	84	84	84	85	85	84	84	84
15	41	50	54	59	62	66	69	72	73	75	91	91	91	92	92	92	91	91	91
16	31	38	42	45	48	51	54	57	58	60	74	75	75	75	76	75	76	74	75
17	24	26	26	27	27	28	28	28	28	29	31	31	31	31	31	32	31	31	31
18	22	22	22	22	23	23	23	23	23	23	24	23	23	24	24	24	28	28	28
19	24	28	29	30	31	31	32	32	33	34	36	38	38	38	37	38	39	38	39
20	41	49	54	58	62	65	68	71	73	75	88	88	89	89	89	89	89	89	88
21		42	46	50	53	56	59	61	62	64	77	78	78	78	78	78	77	77	77
22		27	29	30	32	34	35	36	37	38	44	44	45	45	-	45	45	44	45
23		42																	
24		22																	
25		43																	
26		42	46	49	53	56	59	62	63	65	80	80	80	82	81	81	80	80	80
27		22	26	27	27	28	29	30	31	31	25	25	25	25	25	26	26	26	26
28		43	48	52	55	58	61	63	65	67	82	82	82	80	83	83	83	82	83

Table 2.10.12-T22
Test #2, Recorded Temperatures
(No Added Insulation, with Crush Shield and Fireshield in Place)

Channel	98/03/19		98/03/20			
	16:00	17:00	8:45	9:45	11:00	11:50
1	371	371	373	373	372	372
2	406	406	407	407	407	407
3	209	209	212	212	212	212
4	169	170	172	172	172	172
5	173	174	176	176	176	175
6	178	178	181	180	180	179
7	94	95	97	97	97	97
8	24	24	24	23	24	23
9	98	98	103	102	103	102
10	28	27	28	26	25	25
11	51	52	53	53	53	53
12	68	67	68	69	68	68
13	32	32	32	31	31	31
14	91	92	94	94	94	94
15	95	95	97	97	97	96
16	61	59	63	63	65	61
17	51	51	52	51	51	51
18	33	33	36	34	34	36
19	50	50	50	50	50	50
20	87	88	89	89	89	88
21	86	86	88	87	88	88
22	57	56	57	56	57	57

Channel	98/03/19		98/03/20			
	16:00	17:00	8:45	9:45	11:00	11:50
23	–	–	–	–	–	
24	–	–	–	–	–	
25	–	–	–	–	–	
26	89	90	92	92	92	92
27	24	24	24	18	24	23
28	91	92	94	94	94	94
29	–	–	–	–	–	–
30	–	–	–	–	–	–
31	42	42	43	43	43	43
32	39	39	40	40	40	40
33	40	40	41	41	41	41
34	34	34	34	34	34	34
35	29	29	29	29	29	29
36	28	29	28	27	28	28
37	46	46	47	45	47	47
38	43	44	44	44	44	44
39	57	58	59	58	58	58
40	38	39	39	39	39	39
41	37	37	37	37	37	37
42	–	–	–	–	–	–
43	–	–	–	–	–	–

Table 2.10.12-T23
Test #3, Recorded Temperatures
(With Added Insulation, no Crush Shield or Fireshield in Place)

Channel	98/03/20		98/03/23	Channel	98/03/20		98/03/23
	15:30	16:30	9:30		15:30	16:30	9:30
1	373	374	377	23	66	66	64
2	408	408	411	24	70	72	75
3	211	211	213	25			
4	174	175	179	26	93	94	97
5	181	182	187	27	27	27	28
6	182	183	187	28	95	96	99
7	96	97	102	29	71	72	71
8	24	24	24	30	67	73	78
9	92	91	93	31			
10	27	28	26	32			
11	45	45	46	33			
12	89	91	96	34			
13	33	34	37	35			
14	96	97	100	36			
15	97	99	103	37			
16	90	92	98	38			
17	32	33	33	39	40	40	40
18	28	29	28	40			
19	41	42	43	41			
20	96	98	102	42	65	66	66
21	96	97	100	43	65	67	73
22	48	48	n/r				

Table 2.10.12-T24
Test #4, Recorded Temperatures
(With Added Insulation, Crush Shield and Fireshield in Place)

Channel	98/03/23				98/03/24	
	11:15	13:05	15:10	16:50	8:20	9:15
1	378	379	379	379	381	381
2	411	411	412	412	413	413
3	213	215	218	218	221	222
4	181	182	183	184	186	186
5	187	187	188	189	191	191
6	188	189	191	191	193	193
7	104	105	106	107	109	108
8	24	23	23	23	23	23
9	99	103	106	108	110	111
10	28	28	28	31	27	29
11	50	53	55	56	56	56
12	94	94	94	95	96	96
13	37	36	35	35	36	35
14	102	105	108	109	111	111
15	105	107	108	109	111	110
16	97	97	97	98	99	99
17	49	51	52	53	53	52
18	32	33	32	33	33	32
19	52	53	53	54	54	54
20	101	101	102	103	104	104
21	102	106	108	109	111	111
22	57	61	62		63	64

Channel	98/03/23				98/03/24	
	11:15	13:05	15:10	16:50	8:20	9:15
23	73	75	76	78	79	79
24	72	71	70	71	70	71
25						
26	100	103	105	106	109	109
27	24	24	24	25	24	23
28	102	106	108	109	111	111
29	82	84	80	86	87	87
30	63	61	61	63	64	64
31	31	42	44	45	45	45
32	30	41	42	43	43	43
33	31	39	40	41	41	40
34	31	34	34	35	34	35
35	27	29	29	29	29	29
36	27	27	27	28	27	27
37	44	46	47	47	48	47
38	35	44	45	46	46	46
39	50	54	56	56	56	57
40	38	41	41	42	42	42
41	32	36	36	37	37	37
42	72	75	76	77	78	79
43	74	72	73	70	74	65

Table 2.10.12-T25
Thermocouple Location with Highest Temperature Readings

Channel	Location	Final Temperature (°C)			
		Test #1	Test #2	Test #3	Test #4
1	C-188 source, midpoint of s/n 59532	368	372	377	381
2	C-188 source, midpoint of s/n 59475	405	407	411'	413
3	Underside of shielding plug, adjacent to ventline exit hole	206	212	213	222
4	Cavity wall midheight, in line with damaged lift lug #4	167	172	179	186
5	Cavity wall midheight on the side opposite the drainline	174	175	187	191
6	Cavity wall midheight on the same side as the drainline	175	179	187	193
7	Container wall between the fins, middle section, in line with drainline	91	97	102	108
8	Ambient, at elevation even with cavity midpoint	25	23	24	23
9	Top center of shielding plug	87	102	93	111
10	Ambient, approximately one meter above top of container	29	25	26	29
11	Top of lift lug #2	41	53	46	56
12	Container wall, lower section, adjacent to the drainline	77	68	96	96
13	Underside of container, center; middle of indentation from puncture pin	33	31	37	35
14	Container wall, upper section, under damaged fins, mid-way between lift lugs #1 and #2 (damage zone #2)	84	94	100	111
15	Container wall, middle section, mid-way between lift lugs #1 and #2 (damage zone #2)	91	96	103	110
16	Container wall, lower section, mid-way between lift lugs #1 and #2 (damage zone #2)	75	61	98	99
17	Air temperature, top edge of fireshield, in line with drainline	31	51	33	52
18	Air temperature, lower edge of fireshield, in line with drainline	28	36	28	32
19	Air temperature, upper section, between damaged fins near lift lug #4	39	50	43	54
20	Container wall, middle section; under fin folded over from puncture pin, near lift lug #4	88	88	102	104
21	Container wall, upper section, in line with drainline.	77	88	100	111
22	Top of damaged lift lug #4	45	57	n/r	64
23	Top of insulation, over t/c #21	n/a	n/a	64	79
24	Top of insulation, over t/c #12	n/a	n/a	75	71
25	Inoperative	n/a	n/a	n/a	n/a
26	Container wall, upper section, adjacent to damaged lift lug #4 (on reinforcing pad)	80	92	97	109
27	Air temperature, lower section, between damaged fins, near lift lug #4	26	23	28	23
28	Container wall, upper section, adjacent to damaged lift lug #4 (other side of fin from t/c #26)	83	94	99	111
29	Top of insulation, over t/c #26	n/a	n/a	71	87
30	Top of insulation, lower section, next to lift lug #4	n/a	n/a	78	64
31	Top center of crush shield	n/a	43	n/a	45
32	Top of crush shield, equidistant between center and outside edge of plate, in line with lift lug #2	n/a	40	n/a	43
33	Top of crush shield, outside edge of plate, in line with lift lug #2	n/a	41	n/a	40
34	Top edge of fireshield, in line with drainline	n/a	34	n/a	35
35	Mid-height of fireshield, in line with drainline	n/a	29	n/a	29
36	Bottom edge of fire shield, in line with drainline	n/a	28	n/a	27
37	Air temperature, between damaged fins of crush shield, in line with drainline	n/a	47	n/a	47
38	Top of upper donut ring on crush shield, in line with lift lug #2	n/a	44	n/a	46
39	Top of lower donut ring on crush shield, in line with lift lug #2	n/a	58	40	57
40	Top of fireshield, puncture pin damaged zone #1, near lift lug #4	n/a	39	n/a	42
41	Top of fireshield, near lift lug #2	n/a	37	n/a	37
42	Top of insulation, upper section, between fins of damage zone #2	n/a	n/a	66	79
43	Top of insulation, lower section, between fins of damaged zone #2	n/a	n/a	73	65

Figure 2.10.12-F181
Digital Photo: Locations and Identifications of Damaged Zone #1

(G:\QA\QC\PHOTOS\4F294.BMP)

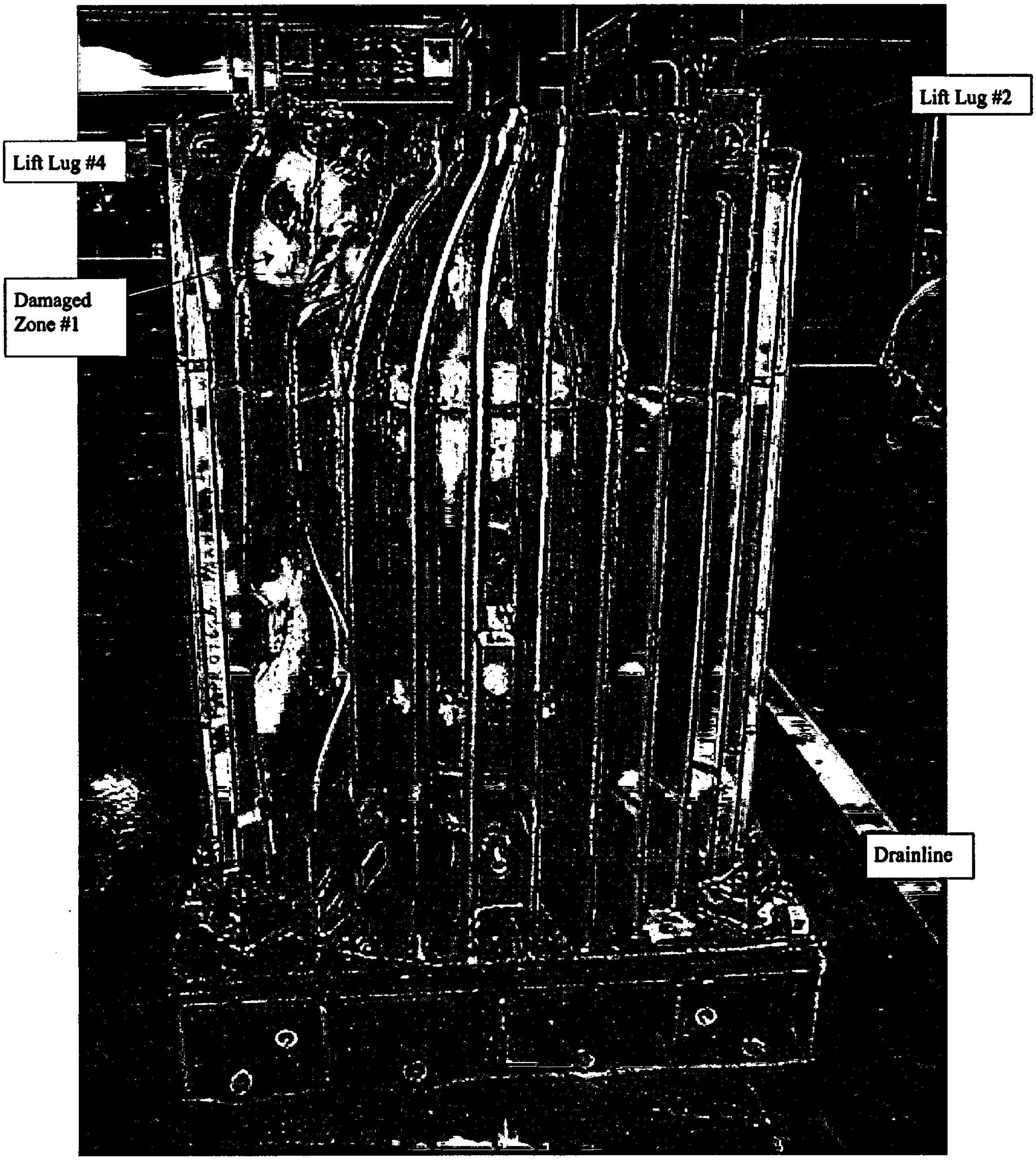


Figure 2.10.12-F182
Digital Photo: Locations and Identifications of Damaged Zone #2
(G:\QA\QC\PHOTOS\3F294.BMP

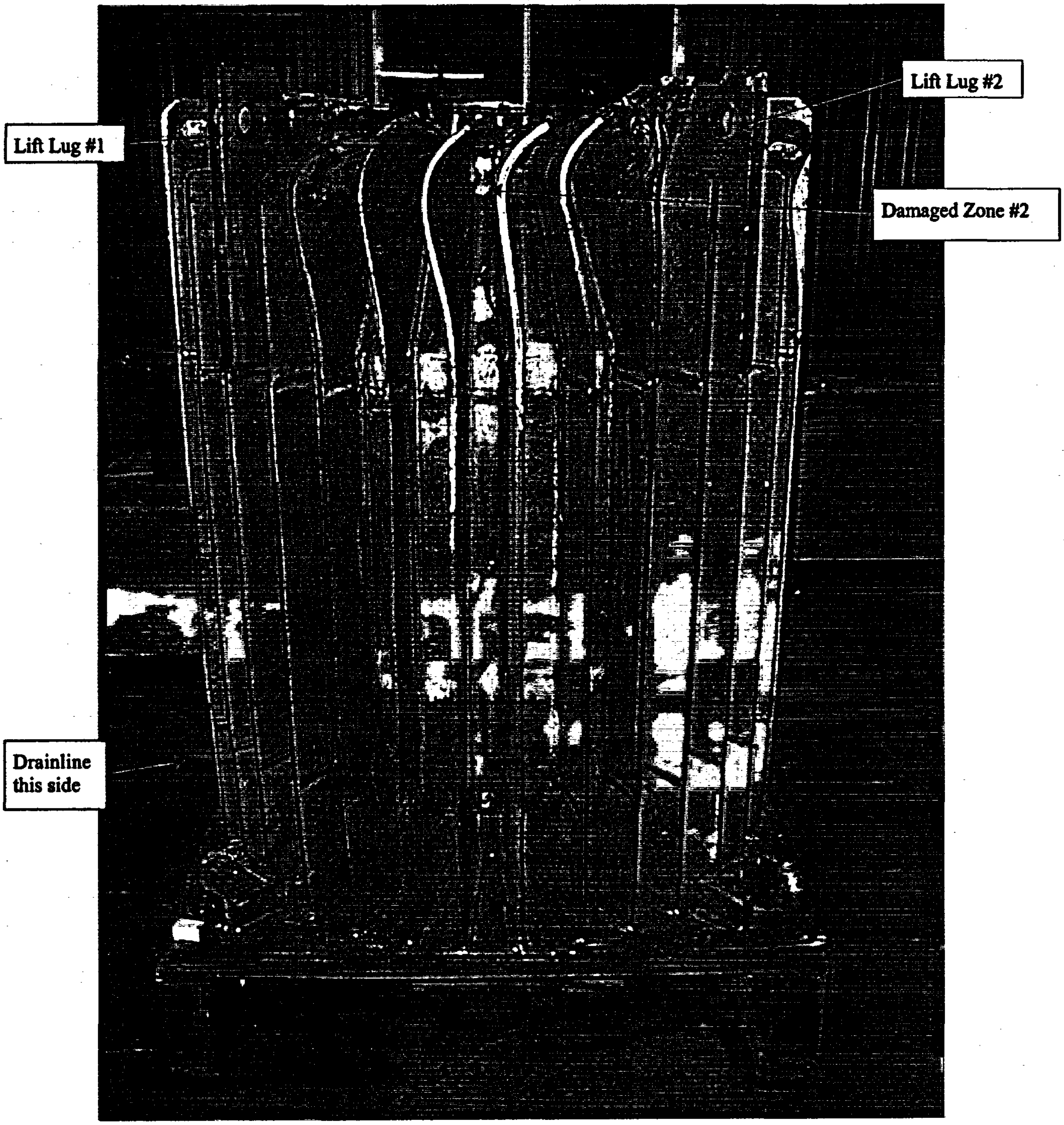


Figure 2.10.12-F183
Loading Diagram of F-294 and Locations of Thermocouples in the F-294 Cavity

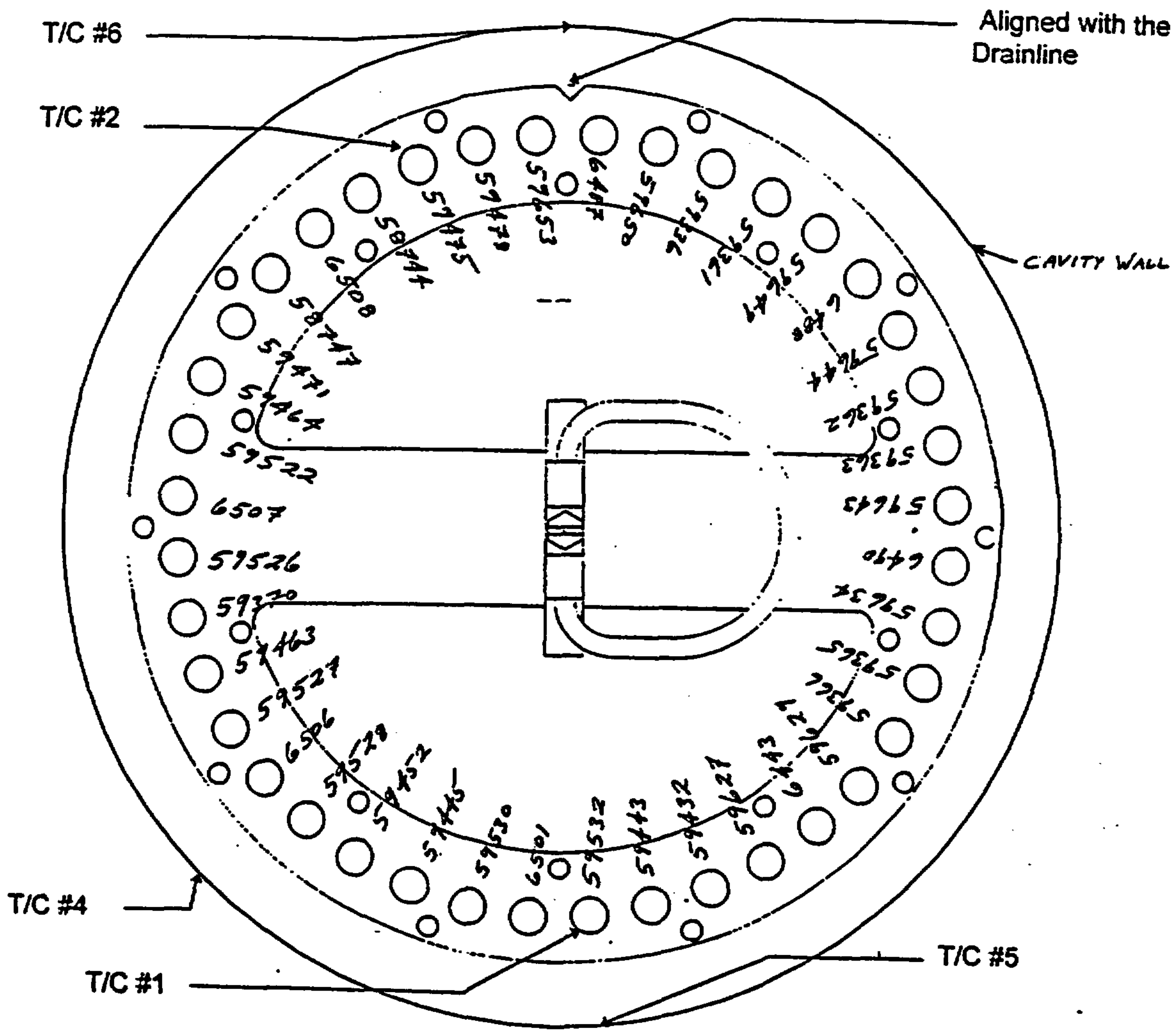


Figure 2.10.12-F184
Thermocouple Locations (plane through drainline)

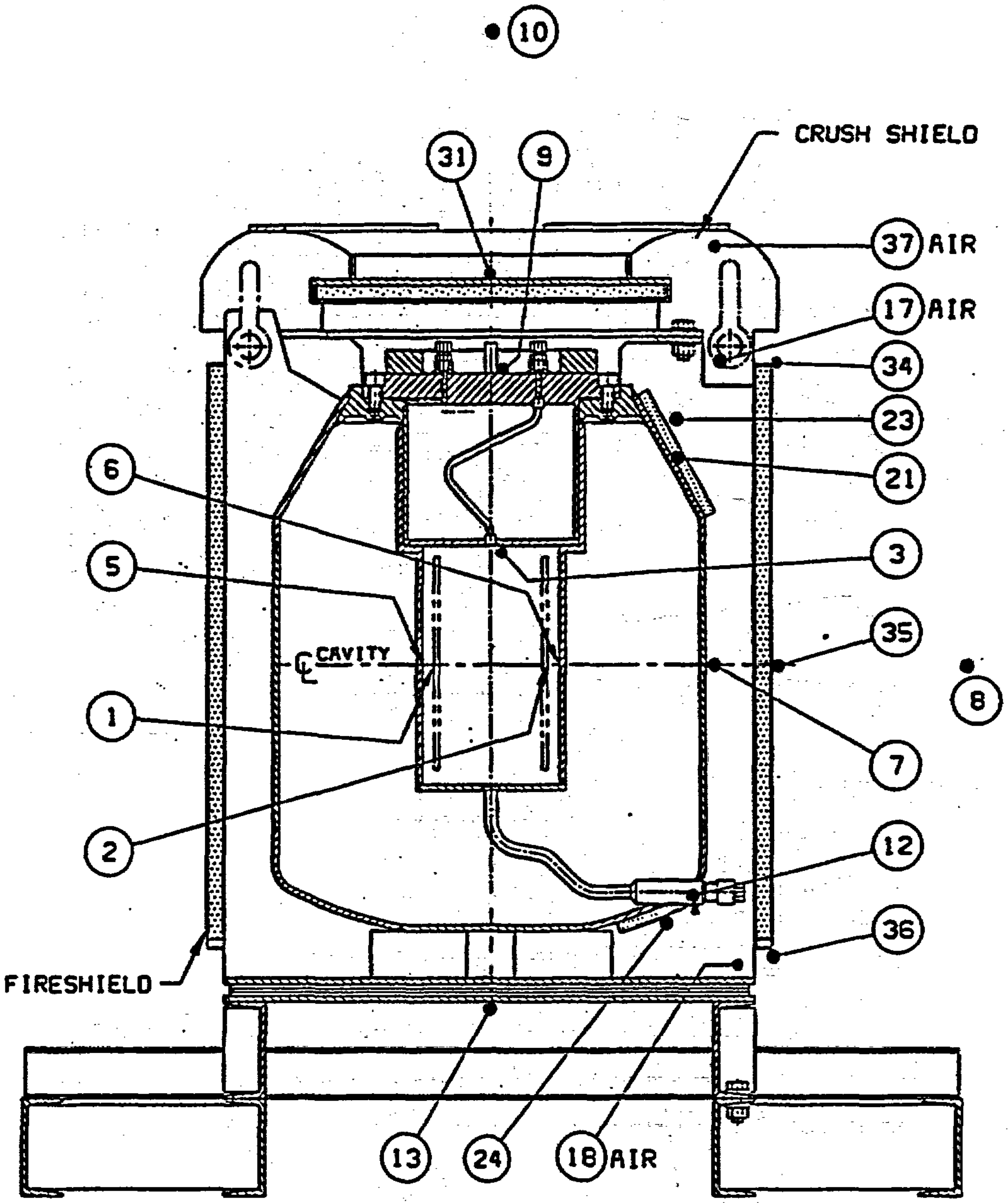


Figure 2.10.12-F185
Thermocouple Locations (other planes)

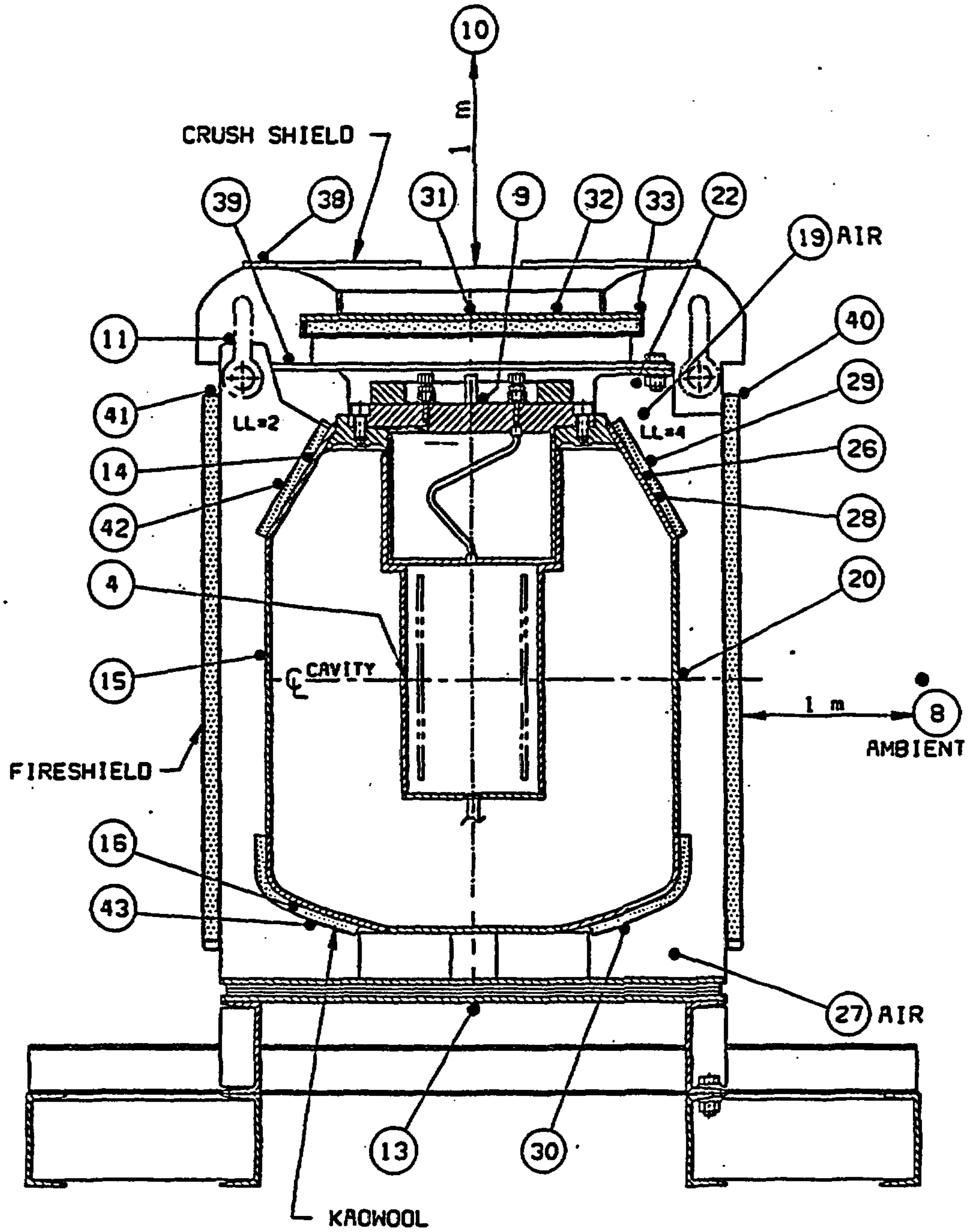
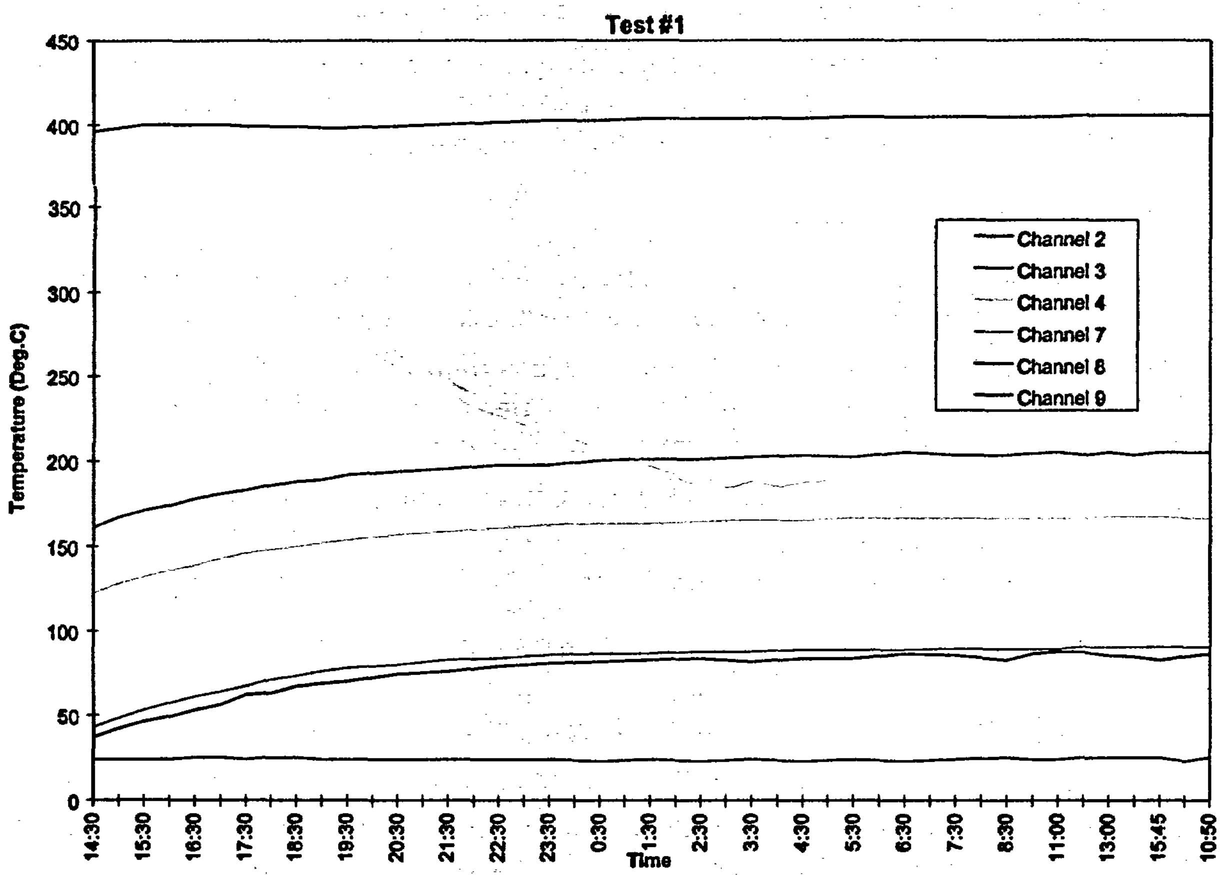


Figure 2.10.12-F186
Test #1 Temperature vs. Time - Plot of Selective Thermocouples



8. DISCUSSION OF TEST RESULTS

8.1 F-294 TEST PACKAGING CLOSURE PLUG BOLTED JOINT GASKET

As the F-294 closure joint with the flexitallic gasket failed the air pressure test, it was decided to change the gasket design from "flexiltallic" to "neoprene" material.

The air pressure tests for the F-294 container cavity, using neoprene gasket were successful. Hence a change was made in the design of the F-294 closure plug bolted joint to use "neoprene" gasket. "Neoprene" gasket was used on the F-294 test packaging plug bolted closure joint.

8.2 NORMAL DROP TEST

The F-294 test packaging was subjected to the Normal drop test. As the packaging weight is between 5,000 kg and 10,000 kg, the required drop test distance is 3 feet (36 inches).

The F-294 was drop tested in top end drop orientation from a distance of 3 feet. (36 inches). The significant deformation was in the lower donut ring of the crush shield. The lower donut ring suffered about 0.5 in. of deformation of wave-like pattern.

Therefore, from the shielding standpoint, there are two significant implications:

1. the dose point moved closer towards the source (0.5 in.)
2. the sources moved to the underside of the closure plug (1.0 in.)

8.3 DEFORMED FLASK/PACKAGING PROFILE

8.3.1 F-294 Deformation Profile After Normal Drop Test

The F-294 was drop tested in top end drop orientation from a distance of 3 feet. (36 inches). The significant deformation was in the lower donut ring of the crush shield. The lower donut ring suffered about 0.5 in. of deformation of wave like pattern. See Figure 2.10.12-F187.

Therefore, from the shielding standpoint, there are two significant implications:

1. the dose point moved closer towards the source (0.5 in.)
2. the sources moved to the underside of the closure plug (1.0 in.)

8.3.2 F-294 Deformation Profile After Two Sets of 30-ft Drop Tests and Five Sets of Puncture Tests

The approximate deformation profile of the F-294 packaging is as per Figure 2.10.12-F188.

FIGURE WITHHELD UNDER 10 CFR 2.390

FIGURE WITHHELD UNDER 10 CFR 2.390

8.4 DECELERATION (G-LOAD) DATA

Four tri-axial accelerometers were mounted on F-294. See Figure 2.10.12-F189 for location (position) of accelerometers. The data for deceleration is given in Table 2.10.12-T26 (Ref. [56]).

Table 2.10.12-T26
Maximum Absolute Decelerations for F-294 Transport Packaging (g's)

Test #	1	2	3	4	5	6	7	8
Accelerometer Location G1	116	136[2]	LOS	20	46	132[3]	60	22
Accelerometer Location G2	113	LOS	LOS	LOS	LOS	LOS	LOS	LOS
Accelerometer Location G3	130	66	LOS	26	58	118	32	14
Accelerometer Location G4	277[1]	73	23	35	0	0	50	15

Notes:

1. The very high G4 value for Test No. 1 is not valid. G4 is mounted on the bottom of container fixed skid, a thin plate supported around the perimeter of the skid acting as a diaphragm. As per Figure 6 of A-16485-TN-1, page 9, (Ref. [55]) the maximum level attained by G4 does not occur until after the initial impact.

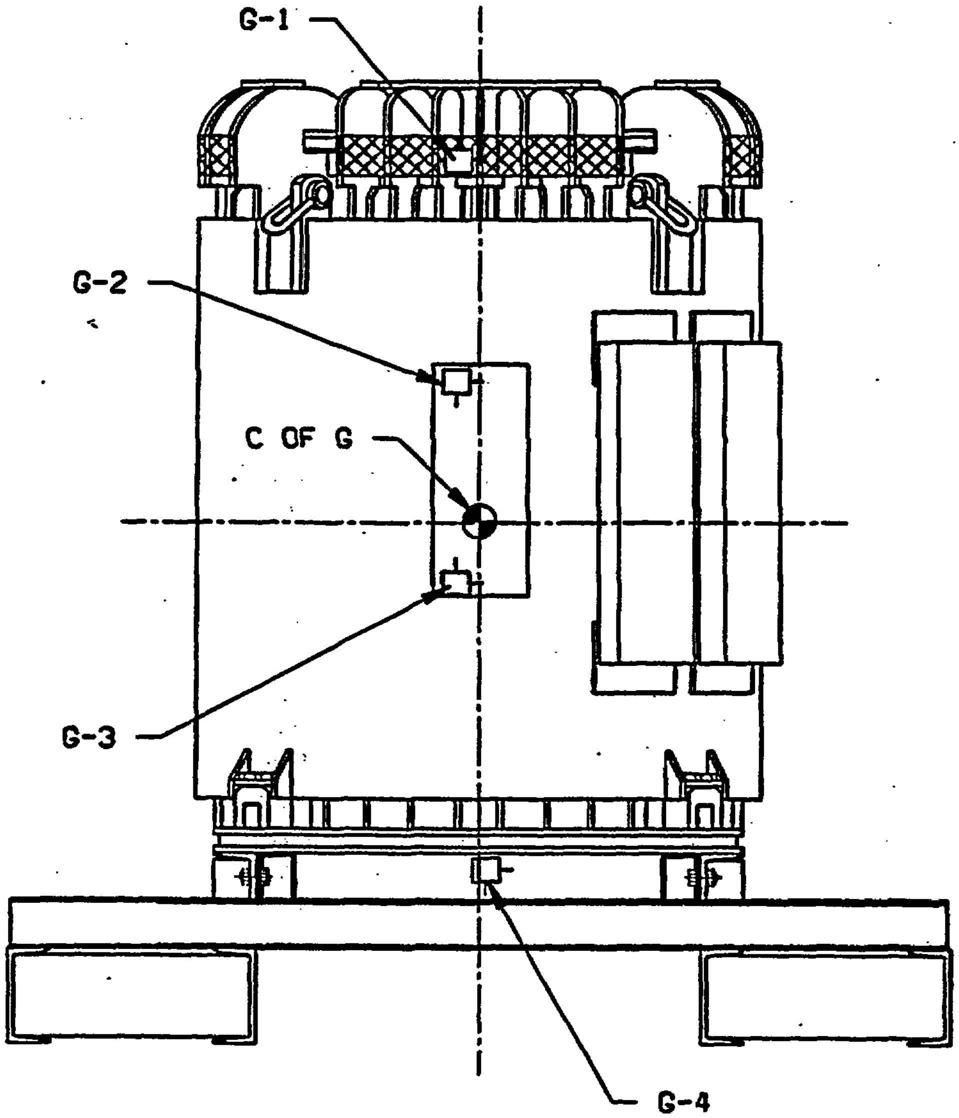
   The crush shield does not significantly deform during this test. The rigidity of the F-294 package in this orientation and drop speed is a possible cause for the high deceleration value observed.

2. Test No. 2 is the first 30-ft drop. G1 is very near the impact point for Test No. 2. It is observed to measure the highest deceleration value. G3 and G4 are located further away from the impact point, and are subject to "pivoting" effect on impact. The crush shield fins on the impact target are greatly deformed, helping to reduce the maximum deceleration value.

3. Test No. 6 is the second 30-ft drop. The maximum value attained by G1 for Test No. 6 is similar to that maximum attained for the first 30-ft drop, Test No. 2. Again, the crush shield fins on the impact target are greatly deformed, helping to reduce the maximum deceleration value.

4. LOS = Loss of signal.

Figure 2.10.12-F189
Location of Accelerometers on F-294 Test Packaging



8.5 INTEGRITY OF THERMAL PROTECTION

The issue of integrity of thermal protection is divided in two classes:

1) Loss of thermal protection.

   When there is loss of thermal protection, the thermal protection devices have been completely and fully removed due to impact of drop tests. For example, as a result of the drop test impact, the detachment of the crush shield (which has an integral fireshield) from the flask, would constitute such a loss of thermal protection.

2) Damage to the thermal protection.

   When there is damage of thermal protection, the protection devices have been not been completely and fully removed due to impact of drop tests. For example, as a result of the drop test impact, the cylindrical fireshield is deformed. The thermal insulation is still present but its configuration may be altered, i.e., compressed or displaced.

8.5.1 Loss of Thermal Protection

On the F-294 test packaging, prior to the drop tests, the thermal protection consists of:

- Side: (cylindrical fireshield – 6786 in^2 area)
- Top: (fireshield integral with crush shield – 707 in^2 area)
- Bottom: (fireshield integral with fixed skid – 1,764 in^2 area)

Prior to the drop tests, the total thermal protection area is 9,257 in^2 (i.e., 6,786 + 707 + 1,764).

After the drop test program, the status of the thermal protection is as follows:

When the cylindrical fireshield was subject to puncture tests, the fireshield was damaged due to the impact of 6 in. diameter puncture pin. There was no clean full through puncture hole opening; rather, the damage can be best described a tear of the shell (i.e., as partial puncture and not clean full though hole opening).

1) Due to Test #4: the opening area on the fireshield = 21 in^2

   Due to Test # 8: the opening area on the fireshield = 6 in^2

2) Due to Test # 7: on the top fireshield, integral with the crush shield, the pin puncture damage is confined to indentation of the upper plate of the crush shield and not a full through puncture hole opening. Therefore, there was no loss of thermal protection in the top.

3) Due to Test #5: on the bottom fireshield (integral with the fixed skid), the pin puncture damage is confined to indentation of the lower plate of the fixed skid and not a full through puncture hole opening. Therefore, there was no loss of thermal protection at the bottom.

After the eight drop tests, the total loss of thermal protection is 27 in^2.

After seven planned drop tests, the total loss of thermal protection is 21 in^2.

In percentage terms, the loss of thermal protection is 21/9257 = 0.2% of the original thermal protection.

In actual terms, the loss of protection is 21 in^2, from a total of 9257 in^2 of original thermal protection.

To summarize:

1) There is no loss of crush shield. There is no loss of cylindrical fireshield. There is no loss of fixed skid. Therefore, there is no loss of gross thermal protection devices. However, due to a number of puncture drops, there are partial openings in the cylindrical fireshield amounting to 0.2% loss of localized thermal protection. After the F-294 is subjected to eight (8) drop tests, 97.8% of the thermal protection remains intact.

8.5.2 Damage to the Thermal Protection

Due to Test #2 and #3:
the deformed area on the cylindrical fireshield = 301 in^2 (top corner)
Due to Test #4:
the deformed area on the fireshield = 176 in^2 (side, mid-height)
Due to Test #5:
the deformed area on the fixed skid = 28 in^2 (bottom, center)
Due to Test #7:
the deformed area on the crush shield = 113 in^2 (top, center)
Due to Test #8:
the deformed area on the fireshield = 220 in^2 (side, name plate)

After the eight drop tests, the total damaged thermal protection area is 838 in^2.

Based on eight drop tests, the damage to the thermal protection is

$$838 \text{ in}^2 / 9{,}257 \text{ in}^2 = 9\ \%$$ of the original thermal protection

After the seven planned drop tests, the total damaged thermal protection area is 618 in^2.

Based on seven planned drop tests, the damage to the thermal protection is

$$618 \text{ in}^2/9{,}257 \text{ in}^2 = 6.67\%$$

8.6 CONTAINMENT SYSTEM INTEGRITY: LEAKTIGHTNESS OF CAVITY

8.6.1 Integrity of the Cavity of F-294

Prior to the drop test, the cavity of F-294 was air pressure tested at internal pressure of 45 psig. at 20°C for a period of two (2) hours. No loss of pressure was observed. Subsequently, the cavity was subjected to helium leak test, the cavity was leak tight to 4. x 10^{-7} atm cc/sec.

The F-294 was then subjected to a series of eight drop tests. After the drop tests, before opening the plug, the container was subjected to air pressure test and helium leak test. To conduct these tests the drainline cap was fastened and torqued to 50-ft-lb. torque. No other torques were disturbed.

The cavity was pressure tested at 45 psig at 20°C for a period of 2 hours and there was no loss of pressure.

Subsequently, the cavity was pressurized to 15 psig and subjected to sniffer helium leak test. The cavity was leaktight to 1 x 10^{-6}.atm cc/sec.

Therefore it is concluded that the integrity of the F-294 cavity is sound before the drop tests and after the drop tests.

8.6.2 The Closure Plug Bolt Torques

Prior to the drop tests, the torques on the fasteners were as follows:

1. Bolts: 100 ft-lb ± 10%
2. Vent #1: open (to permit accelerometer cables to go through)
   Vent #2: 20 ft-lb ± 10%
3. Drainline cap: open (to permit accelerometer cables to go through)

After the drop tests, the torques on the fasteners were as follows. The fasteners are numbered as per Figure 2.10.12-F190.

1. Bolt: Opening torques of the bolts are recorded as per Table 2.10.12-T27.

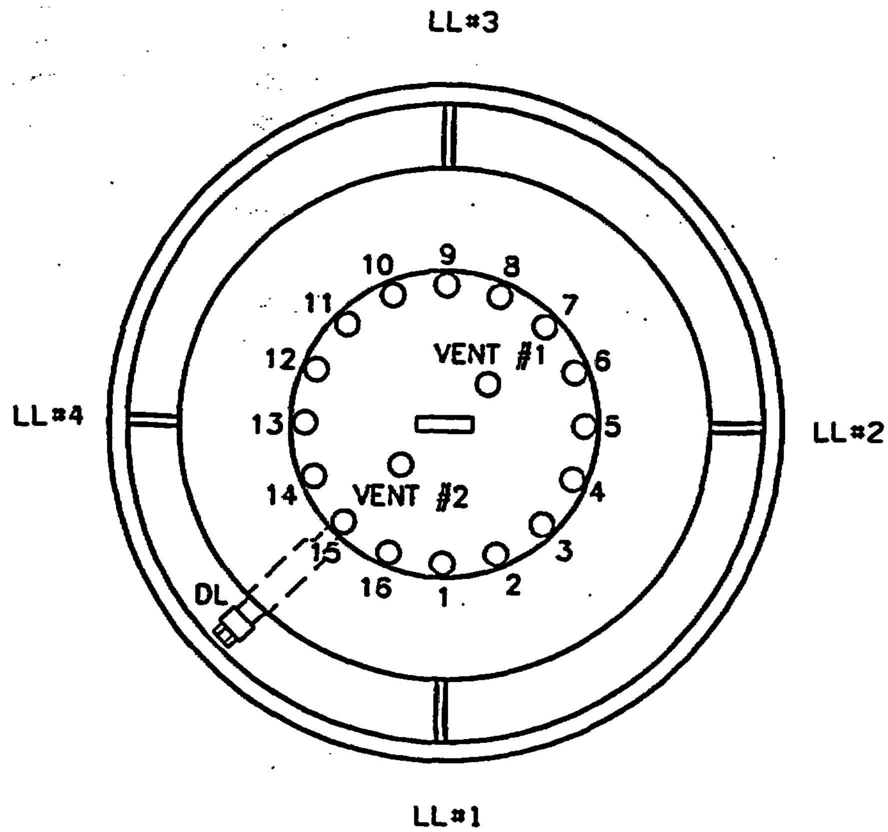
Table 2.10.12-T27
Post-Drop: Opening Torques for F-294 Closure Plug

Bolt No.	Opening Torque (ft.-lb.)
#1	30
#2	70
#3	90
#4	90
#5	20
#6	30
#7	5
#8	30
#9	40
#10	0
#11	140+
#12	140+ ---- 220 - binding
#13	120 ------binding
#14	140+ ---- 180
#15	140+ ----- 220
#16	140+ -----210 (2nd torque wrench)

2 Vent #1: open (to permit accelerometer cables to go through)
  Vent #2: 20 ft-lb. ± 10%

3. Drainline cap: open (to permit accelerometer cables to go through)

Figure 2.10.12-F190
The Numbering of Closure Plug Bolts



8.7 C-188 DUMMY CAPSULES/F-313 SOURCE CARRIER (SUBSTITUTED RADIOACTIVE CONTENTS)

8.7.1 The integrity of c-188 Dummy Capsules

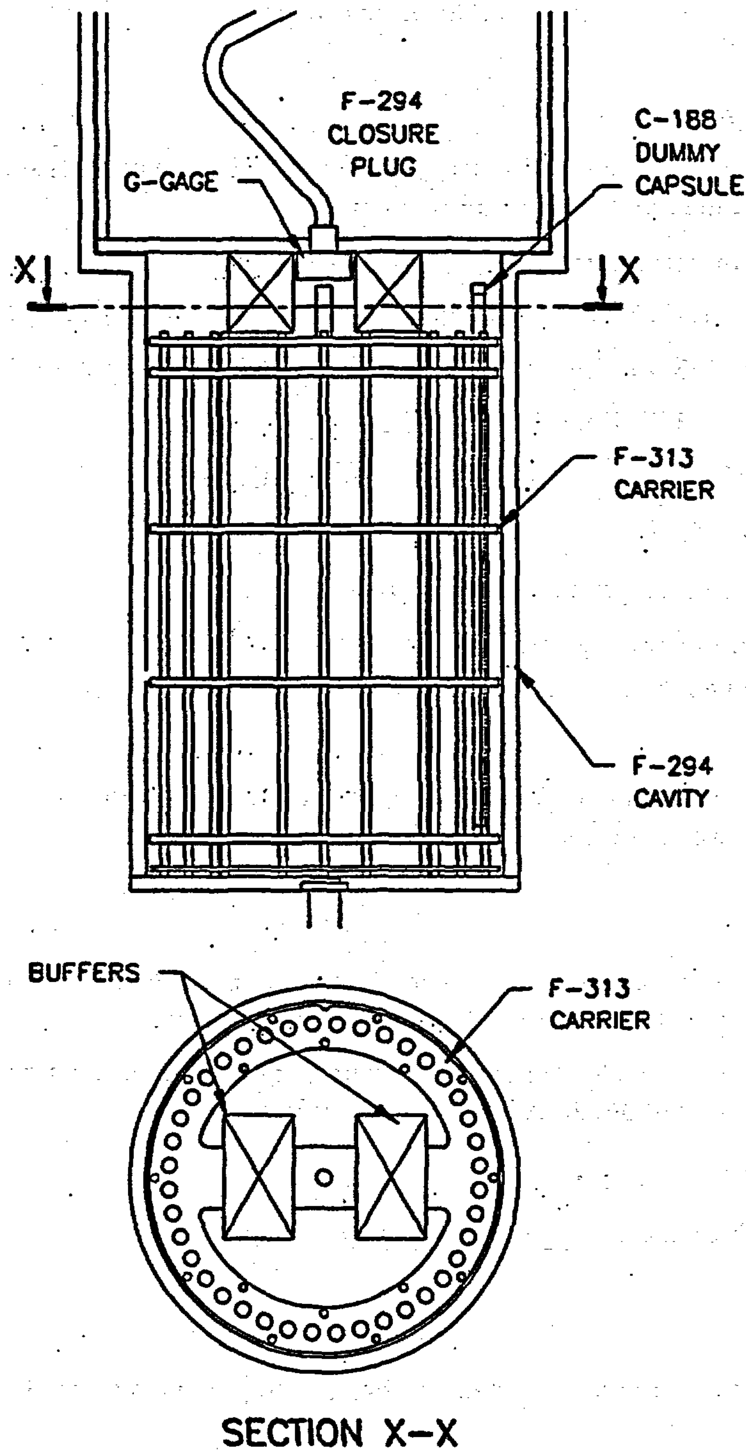
Eight (8) full-scale C-188 dummy capsules were helium leak tested prior to the drop test of F-294.

The same eight (8) C-188 dummy capsules were located in a F-313 carrier and installed in the cavity of F-294. Figure 2.10.12-F191 shows that the F-313 carrier was buffered between the top of the carrier and the bottom of the plug to protect the accelerometer cables during the drop tests. The C-188 dummy capsules were not restrained and were free to bounce up or down and sideways. However, the F-313 carrier was restrained.

The C-188 dummy capsules were helium leak tested after the drop tests. They were leaktight to a level of 2 x 10^{-9} atm cc/sec.

Therefore it is concluded that the integrity of the C-188 capsules is sound.

Figure 2.10.12-F191
Location of Dummy C-188s in F-313 Carrier during F-294 Drop Tests



8.8 RADIATION SURVEYS BEFORE AND AFTER THE DROP TEST PROGRAM

Table 2.10.12-T28 provides the radiation readings on the F-294 test packaging before the drop tests and after the drop tests. The locations for radiation readings are identified in Figure 2.10.12-F192.

8.8.1 Acceptance/Rejection

The design acceptance criteria is 80% of 1,000 mrem/h at 1.0 meter from surface of tested F-294 packaging, based on maximum radioactive contents.

Step 1 Radioactive Content

Prior to drop test, Radioactive content = 375,510 (January 6, 1998)

After drop test, Radioactive content = 364,958 (March 26, 1998)

Step 2 Licensed Radioactive Content

Licensed radioactive content = 360,000 Ci

Extra curies = 4,958 ÷ 360,000 = 1.38%

Step 3 Design Acceptance Criteria (DAC)

DAC = 80% of 1,000 mrem/h

= 800 mrem/h at 1 m from the drop tested package surface

Step 4

After the drop tests, the highest reading of 1.8 mrem/h at 1 m from the drop tested package surface is at location 5 (side mid-height of package) and at location 8 (bottom of package)

Step 5

As radiation reading of 1.8 mrem/h at 1.0 m from the surface of drop tested package is less than the 800 mem/h allowable, the F-294 package meets the acceptance criteria.

Additional credit, due to radiation survey source of 364,958 being greater than maximum licensed capacity of 360,000, has been ignored.

8.8.2 Estimate of Lead Slump

When we examine the before and after drop radiation readings for the package, we make the following observations:

Step 1

At bottom of container, on contact, before the drop, the reading = 14 mrem/h.

Step 2

At bottom of container, on contact, after the drop, the reading = 30 mrem/hr.

Step 3

Therefore, increase in radiation reading = 30 ÷ 14 = 2.143

The decrease in radiation reading = 14 ÷ 30 = 0.47

Step 4

Estimate n, half value layer (HVL) for lead (Pb) (where n = number of HVL)

$(0.5)^n$ = 0.47
n log 0.5 = log 0.47
therefore n = 1.1

Step 5

It appears that 1.1 HVL of Pb "slump" has taken place after the drop tests. Assuming 0.4 in. of Pb = HVL, it is estimated that 0.44 in of Pb "slump" has taken place, at the bottom of fixed skid (location). This amount of Pb "slump" would have taken place in F-294 due to three (3) F-294 drop tests in top end drop orientation.

Test #1: Normal 3-ft. drop in top end

Test #6: 30-ft. drop in top end

Test #7: Puncture Pin in top end

8.8.3 Special Cases

Selective radiation readings at various locations of F-294 damaged zones were also recorded. The observations are:

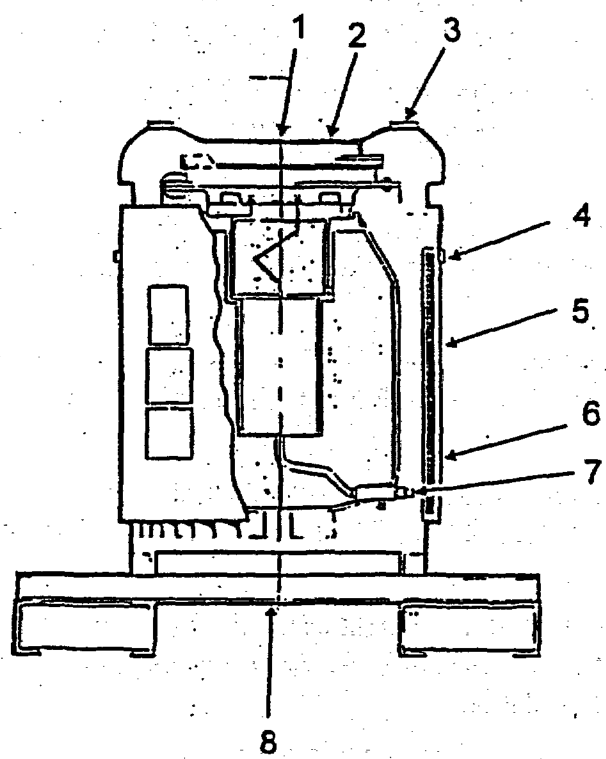
1. The highest contact reading of 26 mrem/h was at the puncture pin zone of mid-section of fireshield.
2. The highest 1.0 m reading of 3.5 mrem/h was at puncture pin damage zone near lift lug #3.

As the highest reading of 3.5 mrem is less than the design acceptance criteria of 800 mrem/h, it is clear that the F-294 has met the shielding criteria.

Table 2.10.12-T28
F-294 Radiation Surveys: Before and After the Drop Test

	Before the Drop mrem/h	After the Drop mrem/h
1.0 m from Surface Location		
1	0.4	0.8
2	0.4	0.8
3	0.35	0.8
4	0.95	1.4
5	1.8	1.8
6	1.2	1.6
7	0.8	1.0
8	1.4	1.8
Contact with Surface		
1	2.2	4.0
2	2.0	2.6
3	1.0	1.6
4	2.8	5.0
5	12.0	16.0
6	6.5	5.5
7	0.3	0.6
8	14.0	30.0

Figure 2.10.12-F192
Identification of Locations on F-294 Container for Radiation Survey



8.9 *STEADY STATE THERMAL TEST: PRE-DROP AND POST-DROP*

8.9.1 Pre-Drop Steady State Thermal Test

#1. Four thermal tests (cases) were carried out as follows:

Test 1 - with fireshield and crush shield, no added insulation
Test 2 - without fireshield and crush shield, no added insulation
Test 3 - without fireshield and crush shield, with added insulation
Test 4 - with fireshield and crush shield, with added insulation

#2. The decay heat load was simulated using quantity forty (40), full-scale active C-188 cobalt-60 sources. The C-188s were loaded in F-313 source carrier. The curies used at the start and finish of the pre-drop thermal test are as follows:

at the start – January 6, 1998 – 375,510 curies (5.782 kW)
at the finish – January 14, 1998 – 374,428 curies (5.766 kW)

#3. The F-294 cavity was purged with argon. Therefore the F-294 cavity environment was argon.

#4. The highest temperature of C-188 in the F-294 cavity is 417°C, at an ambient of 20°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, with added insulation).

The lowest temperature of C-188 in the F-294 cavity is 386°C at an ambient of 23°C. This was attributed to Test 2 (i.e., F-294 without fireshield and crush shield, no added insulation).

#5. The highest cavity wall temperature of F-294 is 175°C at an ambient of 20°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, **with** added insulation).

The lowest temperature of cavity wall of F-294 is 158°C at an ambient of 23°C. This was attributed to Test 2 (i.e., F-294 without fireshield and crush shield, **no** added insulation).

#6. The highest temperature of underside of the F-294 closure plug is 200°C at an ambient of 20°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, **with** added insulation).

The lowest temperature of underside of the F-294 closure plug is 179°C at an ambient of 23°C. This was attributed to Test 2 (i.e., F-294 without fireshield and crush shield, **no** added insulation).

#7. The highest temperature of top of the F-294 closure plug is 112°C at an ambient of 20°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, **with** added insulation).

The lowest temperature of top of the F-294 closure plug is 101°C at an ambient of 23°C. This was attributed to Test 2 (i.e., F-294 without fireshield and crush shield, **no** added insulation).

#8. The highest temperature of mid height of the F-294 external container wall is 107°C at an ambient of 20°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, **with** added insulation).

The lowest temperature of mid height of the F-294 external container wall is 90°C at an ambient of 23°C. This was attributed to Test 2 (i.e., F-294 without fireshield and crush shield, **no** added insulation).

#9. The highest temperature of most accessible surface of the F-294 (considered to be top of lift lug fin) is 53°C at an ambient of 20°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, **with** added insulation).

#10. It is estimated that the time required for the temperature to reach equilibrium is 24 hours, based on Test 1.

8.9.2 Post Drop Steady State Thermal Test

#1. Four cases were carried out as follows:

Test 1 - without fireshield and crush shield, no added insulation
Test 2 - with fireshield and crush shield, no added insulation
Test 3 - without fireshield and crush shield, with added insulation
Test 4 - with fireshield and crush shield, with added insulation

#2. The decay heat load was simulated using quantity forty (40), full scale active C-188 cobalt-60 sources. The C-188 capsules were loaded in a single ring within an F-313 source carrier. These C-188 sources were the same ones that were used in the pre-drop thermal test. The curies used at the start and finish of the pre-drop thermal test are as follows:

at the start – March 17, 1998 – 366,160 curies (5.638 kW)
at the finish – March 24, 1998 – 365,237 curies (5.624 kW)

#3. The F-294 cavity was purged with argon. Therefore the F-294 cavity environment was argon.

#4. The highest temperatures of C-188 in the F-294 cavity is 413°C, at an ambient of 23°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, with added insulation).

The lowest temperature of C-188 in the F-294 cavity is 368°C at an ambient of 25°C. This was attributed to Test 1 (i.e., F-294 without fireshield and crush shield, no added insulation).

#5. The highest cavity wall temperature of F-294 is 193°C at an ambient of 23°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, with added insulation).

The lowest temperature of cavity wall of F-294 is 167°C at an ambient of 25°C. This was attributed to Test 1 (i.e., F-294 without fireshield and crush shield, no added insulation).

#6. The highest temperature of underside of the F-294 closure plug is 222°C at an ambient of 23°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, with added insulation).

The lowest temperature of underside of the F-294 closure plug is 206°C at an ambient of 25°C. This was attributed to Test 2 (i.e., F-294 without fireshield and crush shield, no added insulation).

#7. The highest temperature of top of the F-294 closure plug is 111°C at an ambient of 23°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, with added insulation).

The lowest temperature of top of the F-294 closure plug is 87°C at an ambient of 25°C. This was attributed to Test 1 (i.e., F-294 without fireshield and crush shield, no added insulation).

#8. The highest temperature of mid-height of the F-294 external container wall is 110°C at an ambient of 23°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, with added insulation).

The lowest temperature of mid height of the F-294 external container wall is 91°C at an ambient of 25°C. This was attributed to Test 2 (i.e., F-294 without fireshield and crush shield, no added insulation).

#9. The highest temperature of most accessible surface of the F-294 (considered to be top of lift lug fin) is 56°C at an ambient of 23°C. This was attributed to Test 4 (i.e., F-294 with fireshield and crush shield, with added insulation).

#10. It is estimated that the time required for the temperature to reach equilibrium is 24 hours, based on Test 1.

9. SUMMARY OF TEST OBSERVATIONS, RESULTS AND KEY FINDINGS

On February 25, 1998, a single full-scale prototype F-294 was subjected to a series of eight (8) drop tests as listed below:

Test #1:	Normal Free Drop Test: top end drop orientation
Test #2:	30-ft Free Drop: side oblique drop orientation
Test #3C:	Puncture Test: impact on the zone near lift lug fin #4
Test #4:	Puncture Test: impact cylindrical fireshield
Test #5:	Puncture Test: impact on fixed skid lower plate
Test #6:	30-ft Free Drop Test: top end drop orientation.
Test #7:	Puncture Test: impact on the crush shield upper plate
Test #8:	Puncture Test: impact cylindrical fireshield (nameplate zone)

In this section, the key findings of the drop test program, are listed.

9.1 F-294 PROTOTYPE CONTAINER

The F-294 prototype container was fabricated to a quality program. A history file to support this claim is available for audit purposes. The F-294 prototype container was modified to F-294 test packaging.

9.2 GASKET

Prior to the drop test, there was a change in design of the closure plug bolted joint of F-294 test packaging. The flexitallic gasket was replaced by a "Neoprene" gasket. With the "Neoprene" gasket, both the cavity air pressure test and the cavity helium leak test passed successfully.

9.3 WEIGHT

The weight of the test packaging is 21,482 lb. The design weight of the F-294 transport package is 21,000 lb. max. Therefore, the F-294 drop test results, using F-294 test packaging weight, are conservative.

9.4 F-294 DROP TEST PROJECT

The F-294 drop tests were carried out at CRL, AECL-Research Co., Chalk River, Ontario, Canada on February 25, 1998. Seven planned drop tests, as per Ref. [48], were carried out. One unplanned drop test was also carried out. The drop test was observed by representatives from USNRC, AECB, MDS Nordion and AECL Research Co.

CRL has provided the following deliverables for the F-294 drop tests project:

- Black and white photographs
- Video film
- High-speed film
- Preliminary Drop test report A-16485-TN-2 (Ref. [56])
- Measured Accelerations for F-294 during the drop tests: A-16485-TN-1 (Ref. [55])

9.5 C-188 DUMMY CAPSULES

Eight (8) C-188 dummy capsules were used. Four (4) were slug type and four (4) were pellet type.

Prior to the drop tests, the eight (8) C-188 dummy capsules were helium leak tested and were leak tight to 2 x 10^{-9} atm. cc/sec. After the drop tests, the same eight (8) C-188 dummy capsules were helium leak tested and were leak tight to 2 x 10^{-9} atm. cc/sec.

9.6 DAMAGE TO F-294 TEST PACKAGING

After the drop, the following observations are summarized:

1. There were no cracks in the F-294 cavity wall or the external primary shell of the container (flask). There were no cracks in the closure plug.
2. Some fin-to-fin welds had fractured. Some fins had deformed significantly.
3. Fin/container welds had not cracked.
4. The closure plug was in place and had not come loose. Fifteen (15) out of sixteen (16) fasteners of the closure plug were tight. The "neoprene" gasket was not damaged. The lift lug of the closure plug was compressed by 0.66 in. primarily due to puncture pin impact.
5. In the normal drop test (3-ft free drop in top end drop orientation), the crush shield lower donut plate deformed 0.5 in.
6. In the 30-ft free drop tests, the fins of the crush shield and the container have buckled in the standard J shape or S- shape.
7. In the puncture pin tests on top of the crush shield, only pin foot print was left on the upper plate. The sandwich plates had deformed; however, the pin did not tear through the plates.

In the puncture pin tests on bottom of the fixed skid, only pin foot print was left on the lower plate. The sandwich plates had deformed; however, the pin did not tear through the lower plate.

In the puncture pin tests on the cylindrical fireshield, the pin tore the sandwich shell of the fireshield. The total opening area is approximately 21 sq. in. for Test #4 and 6 sq. in. for Test #8 (an unplanned puncture test on the nameplate zone of the cylindrical fireshield).

9.7 INTEGRITY OF THERMAL PROTECTION

1. Prior to the drop tests, the total area of the thermal protection on the F-294 test packaging is 9,257 sq. in.
2. After the drop tests, there is an opening of 21 sq. in.
3. There is no loss of gross thermal protection; i.e., the crush shield with top integral fireshield did not fly off. The cylindrical fireshield was fully retained. The thermal protection within the fixed skid was not lost.
4. There is local loss of thermal protection, which amounts to 21/9257 = 0.2% of total thermal protection. After the F-294 is subjected to eight (8) drop tests, 99.8% of the thermal protection remains intact.

9.8 INTEGRITY OF THE CONTAINMENT SYSTEM

After the drop test, the closure plug stayed in place.

Before the drop tests, the cavity of the F-294 was pressure tested and helium leak tested and was found to be leaktight.

After the drop tests, the cavity of the F-294 was pressure tested and helium leak tested and was found to be leaktight.

9.9 MEASURED ACCELERATIONS (G-LOAD)

1) In the normal 3-ft free drop test in the top end drop orientation, the maximum deceleration measured was 130 g's at bottom of the cavity. At the top of the plug the measured acceleration was 116 g's.
2) In the 30-ft free drop test, in the top end drop orientation, the measured maximum deceleration was 132 g's on top of the plug.
2) In the 30-ft free drop test, in the side oblique drop orientation, the measured maximum deceleration was 136 g's on top of the plug.

9.10 RADIATION SURVEY BEFORE AND AFTER THE DROP TESTS

9.10.1 Before The Drop Radiation Survey

Before the drop tests, the radiation survey data are as follows:

1. The survey source was 375,374 Ci. of cobalt-60 (January 7, 1998).
2. On contact, the maximum reading is 14 mrem/h at bottom of the fixed skid.
3. At one meter from the surface of the package, the maximum reading is 1.8 mrem/hr at mid-height of the container.

This data meets the standard regulatory requirements of 200 mrem/h on contact and 10 mrem/h at one meter from the surface of the package.

9.10.2 After the Drop Radiation Survey

After the drop tests, the radiation survey data are as follows:

1. The survey source was 365,221 Ci. of cobalt-60 (March 24, 1998).
2. On contact, the maximum reading is 30 mrem/hr at the bottom of the fixed skid.
3. At one meter from the surface of the package, the maximum reading is 1.8 mrem/hr at bottom of the fixed skid and at mid-height on the side of the container.

This data meets the standard regulatory requirements of 1000 mrem/h at one meter from the surface of the package.

9.10.3 Special Cases

Selective radiation readings at various locations of F-294 damaged zones were also recorded. The observations are:

1. The highest contact reading of 26 mrem/h was at the puncture pin zone of mid-section of fireshield.
2. The highest 1.0 m reading of 3.5 mrem/h was at puncture pin damage zone at the mid-section of the container, along the lift lug #3 axis.

As the highest reading of 3.5 mrem/hr is less than the design acceptance criteria (DAC) of 800 mrem/h, it is clear that the F-294 has met the shielding criteria.

9.10.4 Lead Slump

As a result of eight drop tests, the total cumulative lead slump is of the order of 0.44 in. at the bottom of the container. There is also some lead slump on the side of the container, based on radiation survey data.

Based on the thermal test data, it is also inferred that there is lead slump at the bottom of the closure plug.

9.11 THERMAL TESTS DATA

9.11.1 Before the Drop Thermal Test Data

1. The decay heat was simulated using 40, C-188s. At the start, January 6, 1998, the curies were 375,510 Ci. of cobalt-60; at the finish, January 14, 1998, the curies were 374,428 Ci. of cobalt-60. F-294 cavity had an argon environment.
2. The maximum temperatures are as follows:
    1. 417°C
    2. Top of plug: 112°C
    3. Bottom of plug: 200°C
    4. Cavity wall: 175°C
    5. Container external wall (mid-height): 107°C
    6. Top of lift lug (accessible surface): 53°C
    7. Ambient: 20°C

9.11.2 After the Drop Thermal Test Data

1. The decay heat was simulated using 40, C-188s. At the start, March 17, 1998, the curies were 366,160 Ci. of cobalt-60; at the finish, March 24, 1998, the curies were 365,237 Ci. of cobalt-60. The F-294 cavity had an argon environment.
2. The maximum temperatures are as follows:
    1. C-188: 413°C
    2. Top of plug: 111°C
    3. Bottom of plug: 222°C
    4. Cavity wall: 193°C
    5. Container external wall (mid-height): 110°C
    6. Top of lift lug (accessible surface): 56°C
    7. Ambient: 23°C

10 COMPARISON OF TEST RESULTS TO ACCEPTANCE CRITERIA STATED IN REF. [48]

10.1 ACCEPTANCE CRITERIA

1. The test packaging shall be radiation surveyed prior to drop tests and after the drop tests. The Design Acceptance Criteria (DAC) shall be 80% of the regulatory allowable 1000 mrem/h radiation at 1.0 m. from the surface of the drop tested packaging, based on maximum radioactive contents in the package (Para 71.51 (a) (2) of Ref. [1]).
2. There shall be no weld fractures or fractures in the primary stainless steel shell that envelopes the lead shielding in the plug and in the container assembly. Fractures in the fillet weld between the fin and container shell or fractures in the fin shall not be a cause of rejection.
3. There shall be no loss of thermal protection (i.e., no through puncture holes in the fireshields such that the container wall is directly exposed to the flame of fire in the hypothetical thermal test or loss of crush shield). The damage and displacement of the thermal protection is to be less than 10% of the total insulated area (9,260 in^2).
4. After the drop tests, dummy C-188s to meet the leaktightness of 1 x 10^{-7} std. cc/sec of air.

10.2 RADIATION SURVEY AFTER THE DROP TESTS

Using a radiation survey source of was 365,221 Ci. of cobalt-60 (March 24, 1998), at one (1) meter from the surface of the drop tested package, the maximum reading is 1.8 mrem/hr at bottom of the fixed skid and at mid-height on the side of the container.

Also, in a damaged zone, at one (1) meter from the surface of the package, the maximum reading is 3.5 mrem/hr at mid-height on the side of the container (near the puncture pin impact zone), along the axis of lift lug #3.

As the highest reading of 3.5 mrem/hr is less than the Design Acceptance Criteria of 800 mrem/h, it is clear that the F-294 has met the shielding criteria.

This demonstrates that the F-294 test packaging has met the acceptance criteria per Item 1 of Section 10.1.

10.3 PRIMARY SHELL OF CONTAINER AND CLOSURE PLUG

Before the drop tests, the cavity of the F-294 was pressure tested and helium leak tested and was found to be leaktight.

After the drop tests, the cavity of the F-294 was pressure tested and helium leak tested and was found to be leaktight.

Therefore, the integrity of the cavity is sound (i.e., no cracks).

The external shell of the drop tested container was visually examined and found to be free of cracks. The fin-to-container welds were also examined visually and found to be free of cracks.

The external shell of the closure plug was visually examined and found to be free of cracks.

This demonstrates that the F-294 test packaging has met the acceptance criteria per Item 2 of Section 10.1.

10.4 INTEGRITY OF THERMAL PROTECTION

1. Prior to the drop tests, the total area of the thermal protection on the F-294 test packaging is 9,257 sq. in. (rounded up to 9,260 sq. in.)

2. After the drop tests, there is an opening of 21 sq. in. in the cylindrical fireshield.

   2.1 There is no loss of gross thermal protection; i.e., the crush shield with top integral fireshield did not fly off. The cylindrical fireshield was fully retained. The thermal protection within the fixed skid was not lost.

   2.2 There is local loss of thermal protection, which amounts to 21/9260 = 0.2 % of total thermal protection. As the puncture pin caused a partial tear of the cylindrical fireshield, a small area of the container wall can be exposed to flame of the fire. Therefore, acceptance criteria 3 of section 7 of Ref. [48] is considered satisfied. However, after the F-294 is subjected to eight (8) drop tests, 99.8% of the thermal protection area remains intact.

   2.3 After the seven planned drop tests, the total damaged thermal protection area is 618 in^2. Based on seven planned drop tests, the damage to the thermal protection is 618 in^2/9,257 in^2 = 6.67%, which is less than 10%. This meets the acceptance criteria stated in Item 3 of Section 10.1.

10.5 INTEGRITY OF C-188 DUMMY CAPSULES

Prior to the drop tests, eight (8) dummy C-188s were helium leak tested and were found to be leaktight to 2 x 10^{-9} atm cc/sec. After the drop tests, the same eight (8) dummy C-188s were helium leak tested and were found to be leaktight to 2 x 10^{-9} atm cc /sec.

This demonstrates that the dummy C-188s have met the acceptance criteria (the leaktightness of 1 x 10^{-7} std. cc/sec of air) per Item 4 of Section 10.1.

11 CONCLUSIONS

1. The F-294 drop test program was carried out as per Test Plan Ref. [48] and Quality Plan Ref.[49].

2. On February 25, 1998, a single full-scale prototype F-294 was subjected to a series of eight (8) drop tests as listed below:

   Test #1: Normal Free Drop Test: top end drop orientation
   Test #2: 30-ft Free Drop: side oblique drop orientation
   Test #3C: Puncture Test: impact on the zone near lift lug fin #4
   Test #4: Puncture Test: impact on the cylindrical fireshield
   Test #5: Puncture Test: impact on the fixed skid lower plate
   Test #6: 30-ft Free Drop Test: top end drop orientation.
   Test #7: Puncture Test: impact on the crush shield upper plate
   Test #8: Puncture Test: impact on the cylindrical fireshield (nameplate zone).

   Tests 1 to 7 were stated in the test plan; test #8 was unplanned.

3. The F-294 drop test program has fully and amply demonstrated that the full-scale F-294 test packaging meets the regulatory requirements pertaining to the mechanical drop tests as per Ref. [1].

APPENDIX 2.10.13
IMPACT OF DIFFERENCES BETWEEN THE F-294 TRANSPORT PACKAGE AND THE F-294 TEST PACKAGING

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1. INTRODUCTION

A total of eight (8) drop tests were conducted on a single, full-scale F-294 test packaging, on February 25th 1998 at AECL-CRL, Chalk River, Ontario, Canada. Representatives from USNRC, AECB, MDS-Nordion and AECL-CRL were on hand to observe the drop tests.

The eight drop tests are designated as follows:

Test #1:	Normal Free Drop Test: top end drop orientation
Test #2:	30-ft Free Drop Test: side oblique drop orientation
Test #3C:	Puncture Test: impact on the zone near lift lug fin #4
Test #4:	Puncture Test: impact on the cylindrical fireshield
Test #5:	Puncture Test: impact on the fixed skid lower plate
Test #6:	30-ft Free Drop Test: top end drop orientation.
Test #7:	Puncture Test: impact on the crush shield upper plate
Test #8:	Puncture Test: impact on the cylindrical fireshield (nameplate zone)

The Engineering Information Drawings for the F-294 test packaging are provided in Chapter 2, Appendix 2.10.12 (also see Figure 2.10.13-F1).

The F-294 transport package is described in Chapter 1. The Engineering Information Drawings for the F-294 transport package are provided in Chapter 1, Appendix 1.4.2 (also see Figure 2.10.13-F2).

There are differences between the F-294 test packaging and the F-294 transport package. The differences are identified and the impact of these differences is assessed in this Appendix.

2. F-294 TEST PACKAGING

The F-294 prototype container has been fabricated as per DWG. F029401-001 Issue C and Technical Specification DS 0757 F294 Issue A. The F-294 prototype container has been demonstrated to meet the quality standard (CAN-CSA Z299.3-1979 and three elements of CAN-CSA Z299.2-1979) specified in the technical specification DS 0757 F294 Issue A (Ref. [3]). A history file is available to support that the F-294 prototype container is a qualified packaging. This F-294 prototype is designated the full-scale F-294 test packaging.

The full-scale F-294 test packaging consists of the assembly of the following components:

1) F-294 prototype container
   - A container (flask) assembly.
   - The cylindrical fireshield.
   - The top integral crush shield and fireshield
   - The removable shipping skid.
2) F-313 source cage, inclusive of eight (8) C-188 dummy capsules.
3) Quantity = four (4) dummy weights, evenly distributed.
4) Accelerometer instrumentation.

The drawings produced as a result of converting F-294 prototype container to F-294 test packaging are given in drawing list as per Table 2.10.13-T1. The Engineering Information Drawing of the F-294 test packaging is given in Chapter 2, Appendix 2.10.12.

Table 2.10.13-T1
Drawing List - F-294 Test Packaging

Drawing #	Title
F629401-002	Drop Test Modifications
F629401-003	Puncture Pin 6 in. Dia. X 16 in. High
F629401-004	Puncture Pin 6 in. dia. x 26 in. High
F629401-005	Normal free drop Test
F629401-006	30-ft free drop test
F629401-007	Puncture test No. 1A
F629401-008	Puncture Test No. 1B
F629401-009	Puncture Test NO. 2
F629401-010	Puncture Test No. 3
F629401-011	30-ft free drop test #2.
F629401-012	Puncture Test #4
F629401-013	Weight Assembly
F629401-014	Tube
F629401-015	End Plate
F629401-017	Mounting Plate
F629401-018	Mounting Plate Lower
F629401-019	F-294 Test Specimen
F629401-020	Flow Diagram

2.1. SIMILARITIES AND DIFFERENCES BETWEEN THE F-294 TRANSPORT PACKAGE AND F-294 TEST PACKAGING

The similarities and the differences between the current F-294 transport package and the full scale F-294 test packaging are listed in Table 2.10.13-T2. The differences are identified as *DEV*. Most of the differences are marginal dimensional changes and are considered insignificant. The differences that are considered significant are addressed below in section 2.2

2.2 DIFFERENCES

2.2.1 Overall Weight

The actual weight of the F-294 test packaging is 21,482 lb. The design weight of F-294 transport package (Dwg. F629401-001 Rev. C) is 21,000 lb. max. The difference is 482 lb.

2.2.2 Lift Lug

The lift lug region of the current F-294 transport package is different from the lift lug region of the F-294 test packaging (see Figure 2.10.13-F3).

2.2.3 Secondary Shell And Extra Thermal Insulation: Thermal Protection

In the F-294 transport package, the top and bottom corners of the container have a secondary shell enveloping the primary shell. The gap between the secondary and primary shells is filled with thermal insulation, which provides extra thermal protection in the top and bottom corner of the container. However, this additional thermal protection does not exist on the F-294 test packaging.

2.2.4 Fastening of the Crush Shield

In the F-294 test packaging, the crush shield was fastened with 16 fasteners (8 on the top and 8 on the side). Shim plates were added to four mounting pads to facilitate assembly of the crush shield and the container.

In the F-294 transport package, the crush shield is designed to be fastened with 16 fasteners (8 on the top and 8 on the side). The shim plates, if required shall be used to facilitate the assembly of the crush shield and the container. Some of the crush shield fins shall be modified at appropriate places to facilitate the assembly of the crush shield and the container using 8 side fasteners.

2.2.5 Closure Plug Joint Configuration

For the F-294 test packaging, the closure plug joint configuration and neoprene gasket are shown in Figure 2.10.13-F4.

For the F-294 transport package, the closure plug joint configuration and neoprene gasket is shown in Figure 2.10.13-F5.

The comparison of the plug/container closure of the F-294 transport package versus the F-294 test packaging is given in Table 2.10.13-T3. The elements that are different are identified as *DEV* (deviation).

The minor differences are:

- gasket size
- retention of gasket (groove design)
- mounting of gasket (i.e., tabs)

2.2.6 F-294 Cavity and F-313 or F-457 Source Carrier

The F-294 test packaging has a cavity of nominal size, 11.5 in. in diameter x 20 in. high. The lower cavity end cap is nominal 11.5 in. ID x 0.5 in. thick. The F-313 source carrier is loaded within this cavity. The F-313 source carrier has nominal dimensions of 11.25 in. diameter x 19.718 in. overall height.

The F-294 transport package has a cavity of nominal size 11.5 in. dia. x 19.75 in. high. The lower cavity end cap is nominal 11.5 in. ID x 0.75 in. thick. The F-313 or F-457 source carrier is loaded within this cavity. The F-313 source carrier has nominal dimensions of 11.25 in. diameter x 19.468 in. overall height. The F-457 source carrier has nominal dimensions of 11.25 in. diameter x 19.47 in. overall height.

2.2.7 Crack Shield

The F-294 test packaging has a donut-shaped crack shield, welded on top of the closure plug to shield any radiation streaming from the cavity. The crack shield is of nominal size: OD = 17.63 in., ID = 11.95 in., height = 1.94 in. The crack shield is made up of cast lead within stainless steel casing. Therefore, the shielding consists of materials: 1) lead and 2) stainless steel.

The F-294 transport package has a donut-shaped crack shield, welded on top of the closure plug to shield any radiation streaming from the cavity. The crack shield is of nominal size: OD = 17.63 in., ID = 11.63 in., height = 2.0 in. The crack shield is made up of solid stainless steel. Therefore, the shielding consists of stainless steel material only.

2.2.8 Drop Test Related Items

1) To facilitate drop testing in various attitudes, the lifting eye hooks are attached to the removable skid. The zones around the holes, where the lifting eye hooks are attached, are reinforced.
2) F-294 test packaging has attachment/mounting pads for the accelerometers and cables to be removed from the F-294 test specimen. Four (4) accelerometers are mounted on the F-294 test packaging.

3. IMPACT OF DIFFERENCES

3.1 OVERALL WEIGHT

The actual weight of the F-294 test packaging (used on Feb. 25 1998 drop test program) is 21,482 lb. The maximum design weight of F-294 transport package is 21,000. lb. Therefore the difference is 482 lb.; in other words, the F-294 test packaging is marginally heavier than the F-294 transport package. Therefore, the drop test results based on 21,482 lb. weight of F-294 test packaging, are marginally conservative.

3.2 LIFT LUG

See Figure 2.10.13-F3.

As the lift lug region of the current F-294 transport package design has additional reinforcements (double shell [primary and secondary] and 1-inch thick reinforcement plate) versus the lift lug region of the F-294 test packaging (single primary shell and 0.5-inch thick reinforcement plate), the lift lug region of the F-294 test packaging is considered weaker than the lift lug region of the current F-294 transport package design. The effects of these differences will be negligible as structurally the F-294 test packaging is marginally weaker than the current F-294 transport package design. Therefore, in the drop and puncture tests, the F-294 test packaging is likely to suffer more damage than a test specimen fabricated to F-294 transport package design.

3.3 SECONDARY SHELL AND EXTRA THERMAL INSULATION

The absence of the secondary shell at the top and bottom corner of the F-294 test packaging means that the primary shell is more vulnerable to fracture, rupture and tear during the F-294 drop tests. The presence of the secondary shell on the F-294 transport package provides additional protection to the primary shell. Therefore the drop test results, based on absence of secondary shell on the top and bottom corners of the F-294 test packaging, are marginally conservative.

3.4 FASTENING OF THE CRUSH SHIELD TO THE CONTAINER

The fasteners specified for connecting the crush shield to the container are identical for the F-294 test packaging configuration and for the F-294 transport package configuration. Therefore the same amount of applied bolting (connecting) force is available for both configurations.

In the F-294 transport package configuration, some of the fins of the crush shield are re-designed to permit easier access to fasten the eight (8) side bolts using standard tools. From the point of view of the retention of the crush shield during the F-294 drop tests, this design difference is insignificant as the applied bolting load to connect the crush shield to the container for both configurations is the same.

3.5 CLOSURE PLUG JOINT

Step #1

The closure joints for the F-294 test packaging and the F-294 transport package are depicted in Figure 2.10.13-F4 and Figure 2.10.13-F5 respectively. Table 2.10.13-T3 provides the comparison between two configurations.

Step #2

As the closure bolts are the same for both configuration and as the applied torque of 100 ft.-lb. per bolt are the same for both configuration, the bolting load available to make the closure plug joint is the same for both joint configurations.

Estimate applied load per bolt:

$T = 0.2 \times Dnom \times F_{bolt}$

$1200 = 0.2 \times 1.0 \times F_{bolt}$

$F_{bolt} = 6{,}000$ lb.

The total bolting load (F) available is:

$F_{joint} = F_{bolt}$ x number of bolts

$= 6{,}000 \times 16$

$= 96{,}000$ lb.

where

T = torque per bolt = 100 ft.-lb. = 1,200 in.-lb.

$Dnom$ = Nominal diameter of the bolt = 1 in.

F_{bolt} = Applied force per bolt.

F_{joint} = Applied force on the closure plug joint

Step #3 F-294 transport package gasket seating load, F_{SG}

$F_{SG} = \pi * b * G * y$

where

b = effective gasket seating width

G = gasket diameter

y = gasket seating stress = 200 psi

(Ref. [17] i.e., ASME VIII Div. I: Table UA-49-1)

Basic gasket seating width, b_O = actual width of gasket /2

$= (16.38 - 15.44) \times 0.5/2$

$= 0.235$ in.

When $b_O \leq 1/4$ in., the effective gasket seating width, $b = b_O = 0.235$ in.

When $b_O \leq 1/4$ in., diameter at location of gasket reaction, G

G = Mean diameter of gasket contact face

$= (16.38 + 15.44) \times 0.5$

$= 15.91$ in.

Gasket seating Load, F_{SG}

$F_{SG} = \pi * b * G * y$

$= \pi * 0.235 * 15.91 * 200$

$= 2{,}400$ lb.

The gasket seating load for the F-294 transport package is 2,400 lb.

As the gasket seating load for F-294 transport package is 2,400 lb. and as the applied bolt load for the closure joint is 96,000 lb., the balance of load 93,600 lb. is available to resist any operating loads due to internal pressure and maintain leaktight closure plug joint.

Step #4 F-294 test packaging: gasket seating Load, F_{SG}

$F_{SG} = \pi * b * G * y$

where

b = effective gasket seating width

G = gasket diameter

y = gasket seating stress = 200 psi

(Ref. [17] i.e., ASME VIII Div. I: Table UA-49-1)

Basic gasket seating width, b_O = actual width of gasket /2
= (16.38 – 15.13) x 0.5/2
= 0.313 in.

When b_O> 1/4 in, the effective gasket seating width, $b = (\sqrt{b_O})/2 = (\sqrt{(0.313)})/2 = 0.280$ in.

When b_O > 1/4 in., diameter at location of gasket reaction, G

G = Outside diameter of contact face - 2b
= 16.38 - 2 x 0.280
= 15.82 in.

Gasket seating Load, F_{SG}

$F_{SG} = \pi * b * G * y$
$= \pi * 0.280 * 15.82 * 200$
= 2,784 lb.

The gasket seating load for the F-294 test packaging is 2,784 lb.

As the gasket seating load for F-294 test packaging is 2,784 lb. and as the applied bolt load for the closure joint is 96,000 lb., the balance of load of 93,216 lb. is available to resist any operating loads due to internal pressure and maintain leaktight closure plug joint.

Step #5

The balance of load available for F-294 test packaging joint configuration is 93,216 lb. The balance of load available for the F-294 transport package is 93,600 lb.

As the balance of load available to provide a leaktight closure plug joint is almost same (i.e., 93,000 lb.) in both configurations, the leaktight closure plug joint shall be maintained in both joint configurations.

3.6 F-294 CAVITY AND F-313 SOURCE CARRIER

Step #1

The cavity end cap of F-294 test packaging is 0.5 in. thick.

The cavity end cap of F-294 transport package is 0.75 in. thick.

As the end cap of cavity of F-294 test packaging is marginally thinner than the end cap of the cavity of the F-294 transport package, during the drop tests, the F-294 test packaging configuration is more vulnerable to deformation and damage than the F-294 transport package configuration. After the drop test of the F-294 test packaging, the cavity was leak tested and found to be leaktight. Therefore it is concluded that after the drop test, the cavity of the F-294 transport package shall remain leaktight.

Step #2

The F-313 carrier.

In the F-294 test packaging, the F-313 carrier had the overall height of 19.718 in. nominal x 11.5 in. dia. nominal. In the F-294 transport package, the F-313 carrier overall height shall be 19.468 in. nominal x 11.25 in. dia. nominal. The F-457 source carrier has an overall height of 19.47 in. nominal x 11.25 in. diameter nominal. In other words, the F-313 carrier in F-294 test packaging configuration is 0.25 in. longer than the F-313 source carrier in the F-294 transport package configuration. Therefore, the longer F-313 carrier in the F-294 test packaging configuration is marginally more vulnerable to deformation than the shorter F-313 carrier in the F-294 transport package configuration. The C-188 dummy capsules were loaded within the F-313 carrier in the F-294 test packaging and subject to the drop test program. Subsequently, the C-188 dummy capsules were found to be leaktight. Therefore it is concluded that the C-188 dummy capsules will remain leaktight in the "shorter" F-313 carrier/F-294 and F-457 carrier/F-294 transport package configurations, subjected to the drop test program.

3.7 CRACK SHIELD

The F-294 test packaging uses a crack shield made of cast lead encased in stainless steel. The F-294 transport package uses a crack shield made of stainless steel only. The impact of the difference in shielding materials is assessed and calculations are presented in Chapter 5, Appendix 5.5.8.

For the F-294 test packaging, using a lead and stainless steel crack shield, for 360 kCi of cobalt-60, the surface dose is estimated to be 1.52 mrem/h and the dose at one (1) meter from the surface is estimated to be 1.2 mrem/h.

For the F-294 transport package, using a stainless steel crack shield, for 360 kCi of cobalt-60, the surface dose is estimated to be 4.56 mrem/h and the dose at one (1) meter from the surface is estimated to be 3.6 mrem/h.

These doses are well within the allowable of 200 mrem/h on contact and 10 mrem/h at one (1) meter from the surface of the F-294 package for normal conditions of transport.

3.8 DROP TEST RELATED ITEMS

#1. To facilitate drop testing, the lifting eye hooks are attached to the removable skid at four (4) corner locations. The local zones around the holes for the lifting eye hooks were reinforced.

#2. Four (4) tri-axial accelerometers were mounted on the F-294 test packaging.

#3. The modifications were carried out by the test operator (CRL, AECL) in the F-294 cavity. Two shock buffers were located between the F-313 source carrier and the underside of the F-294 closure plug. The purpose of the shock buffers was to prevent destruction of the G-gage accelerometers mounted under the closure plug during the F-294 drop testing. The G-load data was considered more important than other considerations like cushioning the impact of the F-313 carrier due to buffers. Despite the cushioning, the C-188 capsules were free to move axially and radially.

These three items are required on the test packaging to carry out drop tests. These items do not impact adversely the drop test results.

4. CONCLUSIONS

4.1 There are eight differences between the F-294 test packaging and the F-294 transport package. They are:

- Overall weight
- Lift lug
- Secondary shell and extra thermal protection.
- Fastening of the crush shield to container
- Closure Plug joint
- F-294 Cavity and source carrier
- Crack shield
- Drop test related items

4.2 In all cases, with the exception of "Drop test related items", where a difference exists between the F-294 test packaging and the F-294 transport package, the drop tested F-294 test packaging configuration is considered structurally weaker than the F-294 transport package configurations. Therefore, the results of the drop tests using F-294 test packaging are considered marginally conservative.

Table 2.10.13-T2
Parameters of Current F-294 Transport Package Design and F-294 Test Packaging

Item	Parameter	F-294 (SAR Rev. 3) (F629401-001 Issue C)	F-294 Test Packaging (F029401-001 Issue C)	Deviation (*DEV*)
1. Overall Package	height	80.5 in.	80.5 in.	
	width	78 in.	78 in	
	length	78 in.	78 in.	
	weight	21,000 lb. max.	21,482 lb.	*DEV*
2. Main Container	shell OD	36 in.	36 in.	
	shell material	ss304L	ss304L	
	shell thickness	0.5 in.	0.5 in.	
	shell top	Dished cone (60°)	Dished cone (60°)	
	shell bottom	Dished head	Dished head	
	welds (see drawing)	Dwg. F629401-001 Issue C	Dwg. F629401-001 Issue A	*DEV*
	lead shielding	11.25 in. at center	11.25 in. at center	
	double shell at top corner	yes: 0.5 in. /insulation 0.375 in./0.5 in.	no	*DEV*
	double shell at bottom corner	yes: 0.5 in. /insulation 0.375 in./0.5 in.	no	*DEV*
2.1 Cavity	overall size	11.5 in. dia. x 19.75 in. ht.	11.5 in. dia x 20 in. ht.	*DEV*
	shell material/thickness	ss304L/0.5 in.	ss304L/0.5 in.	
	bottom plate material/thickness	0.75 in./C-276 Hastelloy	0.5 in./C-276 Hastelloy	*DEV*
2.2 Cooling Fins	Fin #1 (top corner) number	16	16	
	overall size	16 in. ht. x 11.2 in. width at top, 4 in. width at bottom	16 in. ht. x 11.2 in. width at top, 4 in. width at bottom	
	thickness	0.375 in.	0.375 in.	
	cutout area	10 in. x 1.0 in. (approx.)	nil	*DEV*
	material	ss304L	ss304L	
	Fin #2 (top corner) number	8	8	
	overall size	16 in. ht. x 11.2 in. width at top, 4 in. width at bottom	16 in. ht. x 11.2 in. width at top, 4 in. width at bottom	
	thickness	0.375 in.	0.375 in.	
	cutout area	10 in. x 1.0 in. (approx.)	nil	
	material	ss304L	ss304L	*DEV*
	Fin #3 (top corner) number	8	8	
	overall size	15.5 in. ht. x 11.2 in. width at top, 4 in. width at bottom	15.5 in. ht. x 11.2 in. width at top, 4 in. width at bottom	
	thickness	0.5 in.	0.5 in.	
	cutout area	10 in. x 1.0 in. (approx.)	nil	
	material	ss304L	ss304L	*DEV*

Table 2.10.13-T2 (Cont'd.)

Item	Parameter	F-294 (SAR Rev. 3) (F629401-001 Issue C)	F-294 Test Packaging (F029401-001 Issue C)	Deviation (*DEV*)
2.2 Cooling Fins (Cont'd.)	Fin #5 (side fin) number	36	36	
	thickness	0.375 in.	0.375 in.	
	height	27 in.	27 in.	
	width	4 in.	4 in.	
	cutout area	3.75 in. x 1.0 in.	nil	*DEV*
	material	ss304L	ss304L	
	Fin #6 (bottom corner) number	36	36	
	overall size	10 in. ht. x 3 in. width at top 13.5 in. width at bottom	10 in. ht. x 4 in. width at top 13.5 in. width at bottom	
	thickness	0.375 in.	0.375 in.	
	cutout area	12 in. x 1.0 in. (approx.)	nil	*DEV*
	material	ss304L	ss304L	
	Fin #7 (bottom) number	8	8	
	overall size	4 in. ht. x 8 in. width	4 in. ht. x 8 in. width	
	thickness cutout area	0.375 in. nil	0.375 in. nil	
	material	ss304L	ss304L	
2.3 Lift Lug Fin (Fin #4)	number	4	4	
	size/shape	see F629401-001 Issue B sheet 4	1.25 in. thick x 17.625 ht.	*DEV*
	thickness	variable: 1.25 in. at top and 2.0 in. at base	uniform 1.25 in. thick	*DEV*
	fin material	ss304	ss304L	*DEV*
	at base of lift lug fin	ss304 pad; 1.0 in. thick x 8 in. average width x 7 in. length	ss304L pad 0.5 in. x 9 in. x 11 in.	*DEV*
	at base of lift lug fin	secondary shell	primary shell	*DEV*
3. Main Plug /Container Closure	type	recessed	recessed	
	gasket	neoprene	neoprene	
	flange thickness	2.5 in.	2.5 in.	
	bolts	"UNBRAKO" soc. hd.	"UNBRAKO" soc. hd.	
	number of bolts	16	16	
	length of bolts	2.0 in.	2.0 in.	
	depth of hole	1.25 in.	1.25 in.	
	size/type of thread	1-8-UNC	1-8-UNC (coarse thread)	
	bolt material	low alloy steel	low alloy steel	
4. Main Plug	shell thickness	uniform 0.5 in.	uniform 0.5 in.	
	height to top of lift lug	16.5 in.	16.5 in.	
	OD of shell	14.7 in.	14.7 in.	
	OD of flange shielding material	21.5 in. lead	21.5 in. lead	

Table 2.10.13-T2 (Cont'd.)

Item	Parameter	F-294 (SAR Rev. 3) (F629401-001 Issue C)	F-294 Test Packaging (F029401-001 Issue C)	Deviation (*DEV*)
5. Cylindrical Fireshield	height	48.5 in.	48.5 in.	
	OD	47.38 in.	47.38 in.	
	ID	44.38 in.	44.38 in.	
	outer wall	0.25 in.	0.25 in.	
	inner wall	0.25 in.	0.25 in.	
	insulation thickness	1.0 in.	1.0 in.	
	insulation type	Kaowool	Fibrefrax**	*DEV*
6. Crack Shield	OD	17.63 in.	17.63 in.	
	ID	11.63 in.	11.88 in.	*DEV*
	height	2.0 in.	1.94 in.	*DEV*
	shield material	ss304	lead, encased in ss304	*DEV*
	insulation type	Kaowool	Fibrefrax**	
7. Drainline	type	double pipe	double pipe	
	material	C-276 Hastelloy	C-276 Hastelloy	
	gasket	Neoprene	Neoprene	
	closure	threaded cap	threaded cap	
8. Fixed Skid	size	44 in. x 44 in. x 10.25 in.	44 in. x 44 in. x 10.25 in.	
	top plate	44 in. x 44 in. x 0.5 in. (ss304)	44 in. x 44 in. x 0.5 in. (ss304)	
	insulation	42 in. x 42 in. x 1.0 in. (Kaowool)	42 in. x 42 in. x 1.0 in. (Kaowool)	
	bottom plate	44 in. x 44 in. x 0.5 in. (A-36)	44 in. x 44 in. x 0.5 in. (A-36)	
	structural channel	8 in. x 3 in.	8 in. x 3 in.	
	material	ASTM A-36	ASTM A-36	
9 Removable Skid	size	78 in. x 78 in. x 8 in.	78 in. x 78 in. x 8 in.	
	channel	8 in. x 3 in.	8 in. x 3 in.	
	material	A-36	A-36	
10. Crush Shield with Integral Top Fireshield	number of fins	28	28	
	fin material	cold rolled AISI C1020	cold rolled AISI C1020	
	top plate size/material	0.5 in. thick x 30 in. dia. (A-36)	0.5 in. thick x 30 in. dia. (A-36)	
	bottom plate size/material	0.5 in. thick x 30 in. dia. (A-36)	0.5 in. thick x 30 in. dia. (A-36)	
	insulation size/material	1.0 in. thick x 28 in. dia. /Kaowool	1.0 in. thick x 28 in. dia. /Kaowool	

** Fibrefrax: Trademark of Union Carbide Corp. for high temperature ceramic fibre insulation
*** Transite: Trademark of Johns Manville Corp. insulation.

Table 2.10.13-T3
Closure Comparison: Current F-294 Transport Package Design versus the F-294 Test Packaging

Item	Description	F-294 Transport Package	F-294 Test Packaging	Deviation
1.0	Gasket			
	type	Neoprene	Neoprene	
	ID	15.44 in.	15.13 in.	*DEV*
	OD	16.38 in.	16.38 in.	
	thickness	0.188	0.188	
2.0	Bolts			
	type	UNBRAKO 1960	UNBRAKO 1960	
	number/size/type	1 in. dia. cap screws UNC	1 in. dia. cap screws UNC	
	material	Low alloy steel	Low alloy steel	
	UTS	180. ksi	180. ksi	
	YS	155. ksi	155. ksi	
	length	2.0 in.	2.0 in.	
3.0	Threaded Hole in Container Flange			
	Thread Type	1 in. dia. UNC	1 in. dia. UNC	
	Depth	1.25	1.25	
	Material of flange	ss304L	ss304L	
4.0	Torque			
	Specified	100 ft.-lb. per bolt	100 ft.-lb. per bolt	
5.0	Retention			
	Tabs	yes	no	*DEV*
	groove	yes	no	*DEV*

Figure 2.10.13-F1
F-294 Test Packaging - Information Drawing
(Dwg Number F629401-021: Sheet 3 of 5)

Figure 2.10.13-F2
F-294 Transport Package - Information Drawing
(Dwg Number F-629401-001: Sheet 3 of 5)

FIGURE WITHHELD UNDER 10 CFR 2.390

MDS Nordion

V.S.

TITLE

F-294
TRANSPORT PACKAGE
INFORMATION DRAWING

SIZE E

DWG NO. F829401-001

ISSUE D

SCALE 1:4

SHEET 3 OF 5

FIGURE WITHHELD UNDER 10 CFR 2.390

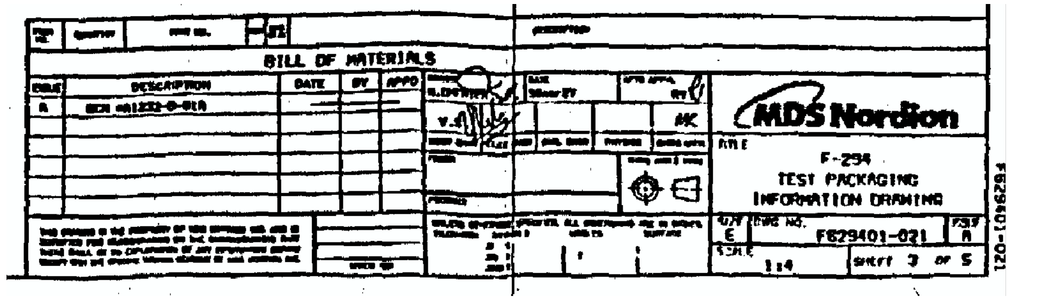


Figure 2.10.13-F3
Lift Lug Fin Region - Current F-294 Transport Package Design Versus F-294 Test Packaging

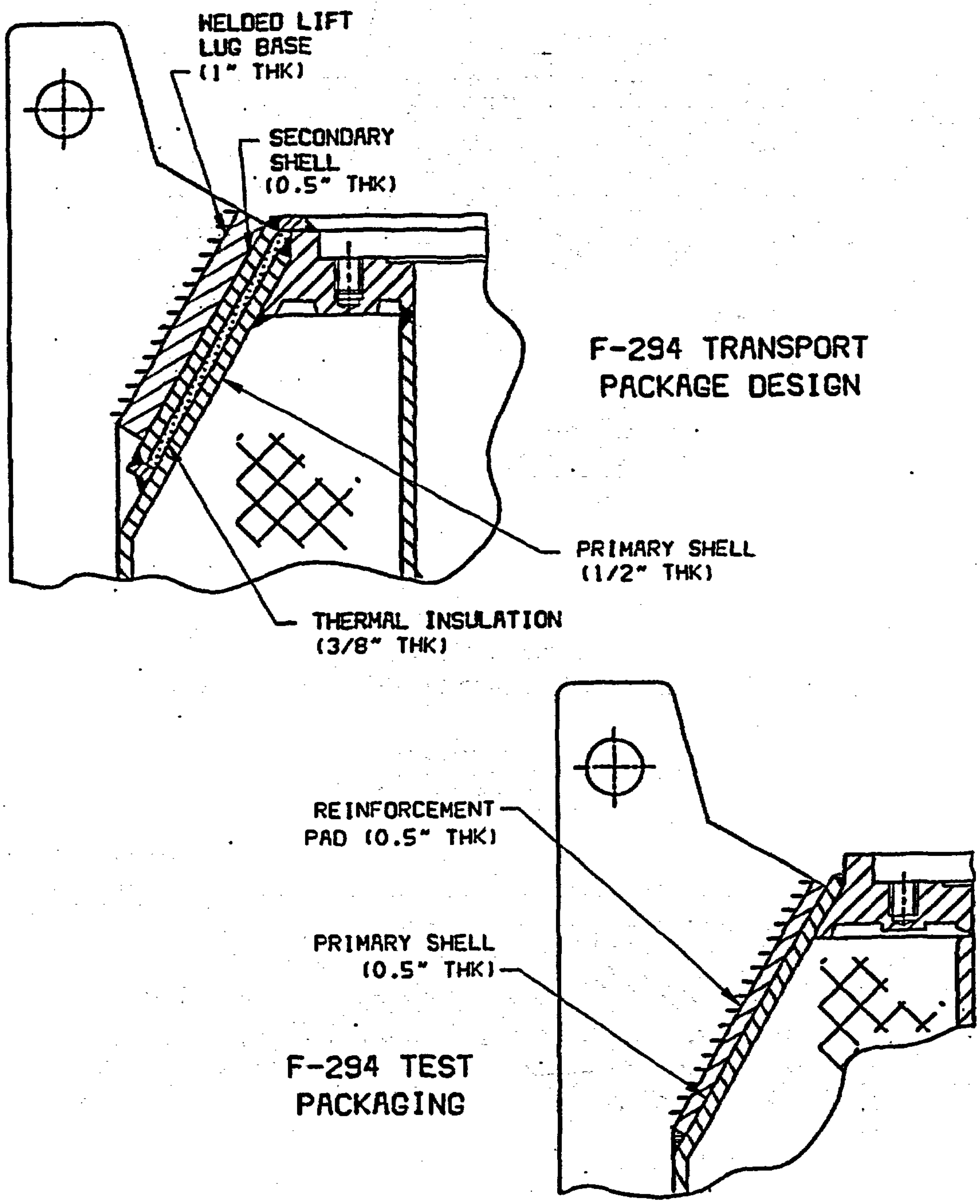


Figure 2.10.13-F4
Closure Plug Joint Configuration for F-294 Test Packaging

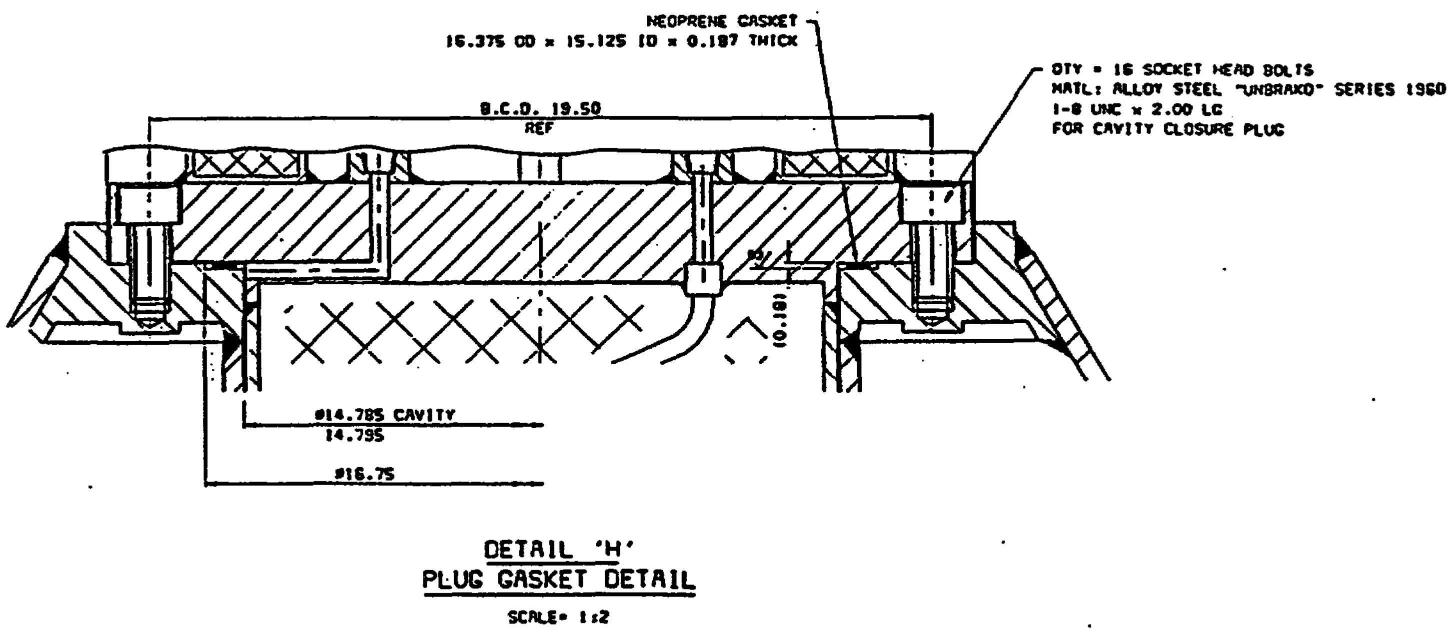
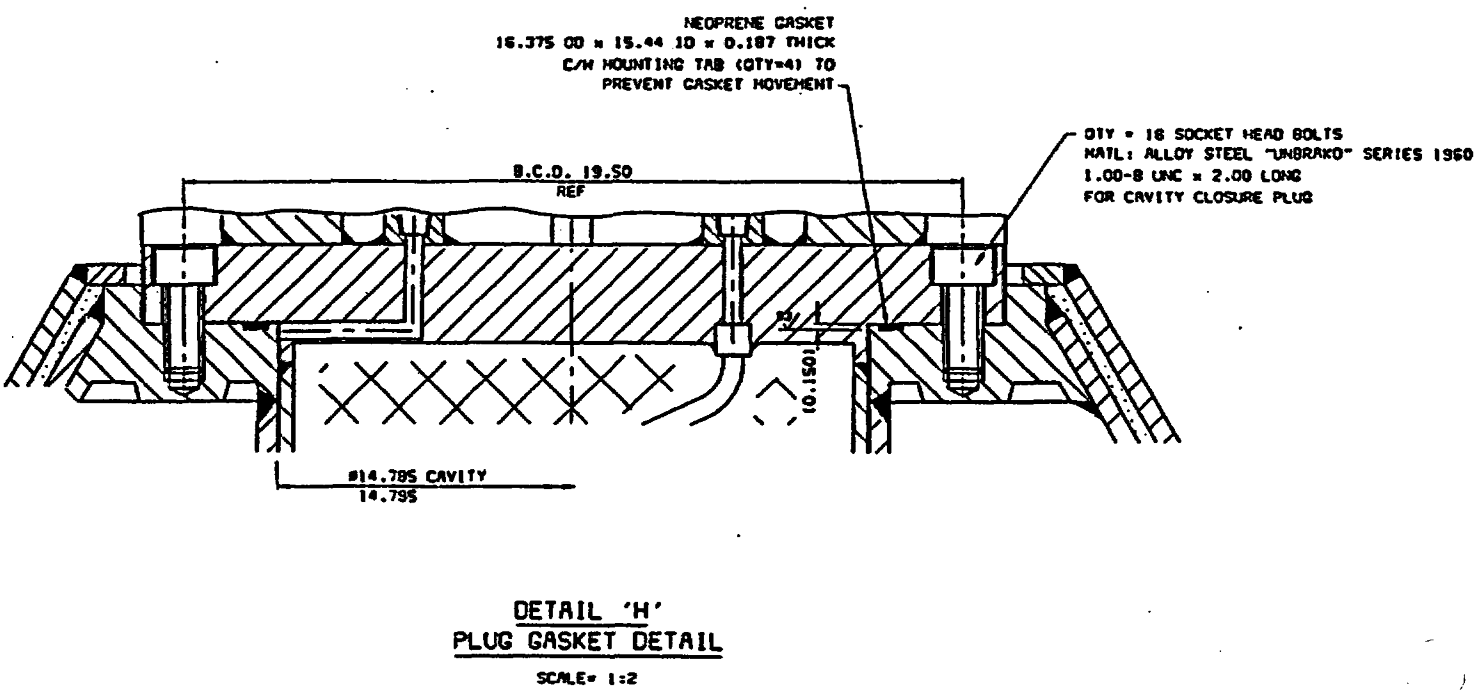


Figure 2.10.13-F5
Closure Plug Joint Configuration for F-294 Transport Package



APPENDIX 2.10.14
STRESS ANALYSIS OF F-294 COMPONENTS IN HYPOTHETICAL ACCIDENT CONDITIONS OF TRANSPORT

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1. INTRODUCTION

On February 25 1998, a single full-scale prototype F-294 was subjected to a series of eight (8) drop tests as listed below:

Test #1:	Normal Free Drop Test: top end drop orientation
Test #2:	30-ft Free Drop: side oblique drop orientation
Test #3C:	Puncture Test: impact on the zone near lift lug fin #4
Test #4:	Puncture Test: impact on the cylindrical fireshield
Test #5:	Puncture Test: impact on the fixed skid lower plate
Test #6:	30-ft Free Drop Test: top end drop orientation.
Test #7:	Puncture Test: impact on the crush shield upper plate
Test #8:	Puncture Test: impact on the cylindrical fireshield (nameplate zone)

The entire test program has been presented in Chapter 2, Appendix 2.10.12. By way of tests, it was demonstrated that

1. the integrity of the containment system is maintained
2. the integrity of the shielding is maintained.

The deceleration loads (g-loads) resulting from these eight (8) drop tests are recaptured in Table 2.10.14-T1. Four tri-axial accelerometers were mounted on F-294. See Figure 2.10.14-F1 for location (position) of accelerometers.

The performance of the F-294 Transport Package when subjected to the measured deceleration loads, in various drop orientations, is presented in this section by stress analysis and is shown to demonstrate that the integrity of containment system and the shielding shall be met. The stress analysis also serves to quantify the safety factors and the margin of safety available for the F-294 components.

Table 2.10.14-T1
Maximum Absolute Decelerations for F-294 Transport Packaging (g's)

Test #	1	2	3	4	5	6	7	8
Accelerometer Location G1	116	136[2]	LOS	20	46	132[3]	60	22
Accelerometer Location G2	113	LOS	LOS	LOS	LOS	LOS	LOS	LOS
Accelerometer Location G3	130	66	LOS	26	58	118	32	14
Accelerometer Location G4	277[1]	73	23	35	0	0	50	15

Notes:

1. The very high G4 value for Test No. 1 is not valid. G4 is mounted on the bottom of container fixed skid, a thin plate supported around the perimeter of the skid acting as a diaphragm. As per Figure 6 of A-16485-TN-1, page 9 (Ref. [55)]), the maximum level attained by G4 does not occur until after the initial impact.
   The crush shield does not significantly deform during this test. The rigidity of the F-294 package in this orientation and drop speed is a possible cause for the high deceleration value observed.
2. Test No. 2 is the first 30-ft drop. G1 is very near the impact point for Test No. 2. It is observed to measure the highest deceleration value. G3 and G4 are located further away from the impact point, and are subject to "pivoting" effect on impact. The crush shield fins on the impact target are greatly deformed, helping to reduce the maximum deceleration value.
3. Test No. 6 is the second 30-ft drop. The maximum value attained by G1 for Test No. 6 is similar to that maximum attained for the first 30-ft drop, Test No. 2. Again, the crush shield fins on the impact target are greatly deformed, helping to reduce the maximum deceleration value.
4. LOS = Loss of signal.

1.1 FREE DROP

The F-294 package can be dropped in any of the four designated free drop orientations shown in Figure 2.10.14- F2. The drop orientations are identified as

Orientation #1.1	-	End Drop - Top
Orientation #1.2	-	End Drop - Bottom
Orientation #2	-	Side Drop
Orientation #3.1	-	Corner Drop - Top
Orientation #3.2	-	Corner Drop - Bottom
Orientation #4	-	Oblique Drop

To cushion the impact during the 30-ft drop test, the F-294 package has a top crush shield. The crush shield assembly sits flush on the container top fins and is bolted at sixteen (16) locations to the container top fins. In addition to the above energy absorbing elements, the F-294 container has:

- the external cooling fins on the container
- the fixed skid
- the shipping skid

all of which serve as energy absorbing devices during the 30-ft drop test. Depending on the drop orientation, not all of the energy absorbing devices come into play.

The analytical assessment of the F-294 package subject to the 30-ft drop test is given in detail in Appendix 2.10.9. In the following sections, each drop orientation is discussed in detail.

Figure 2.10.14-F1
Location of Accelerometers on F-294 Test Packaging

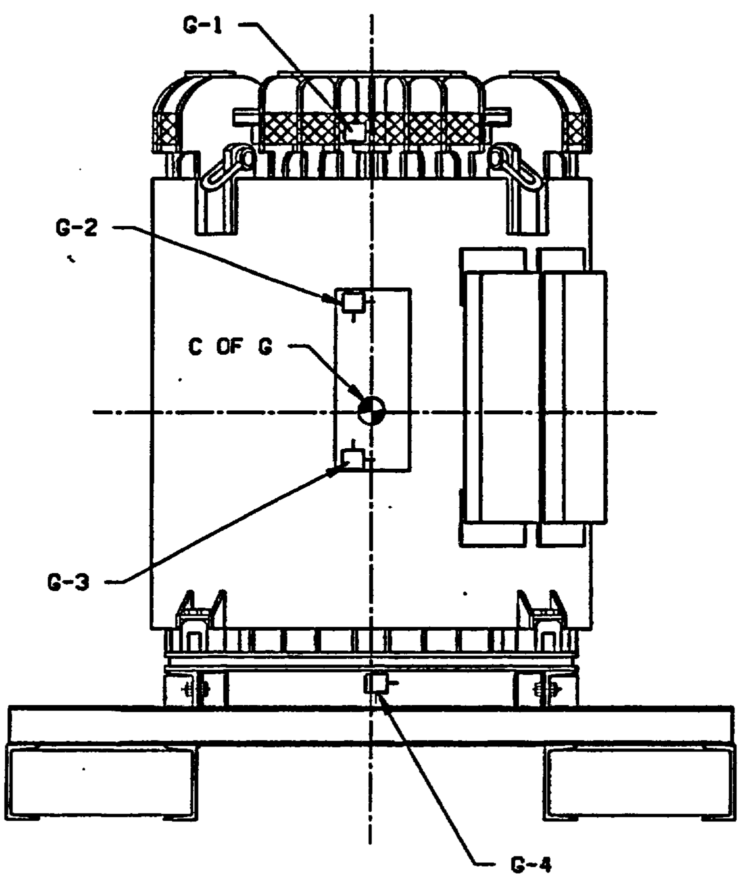
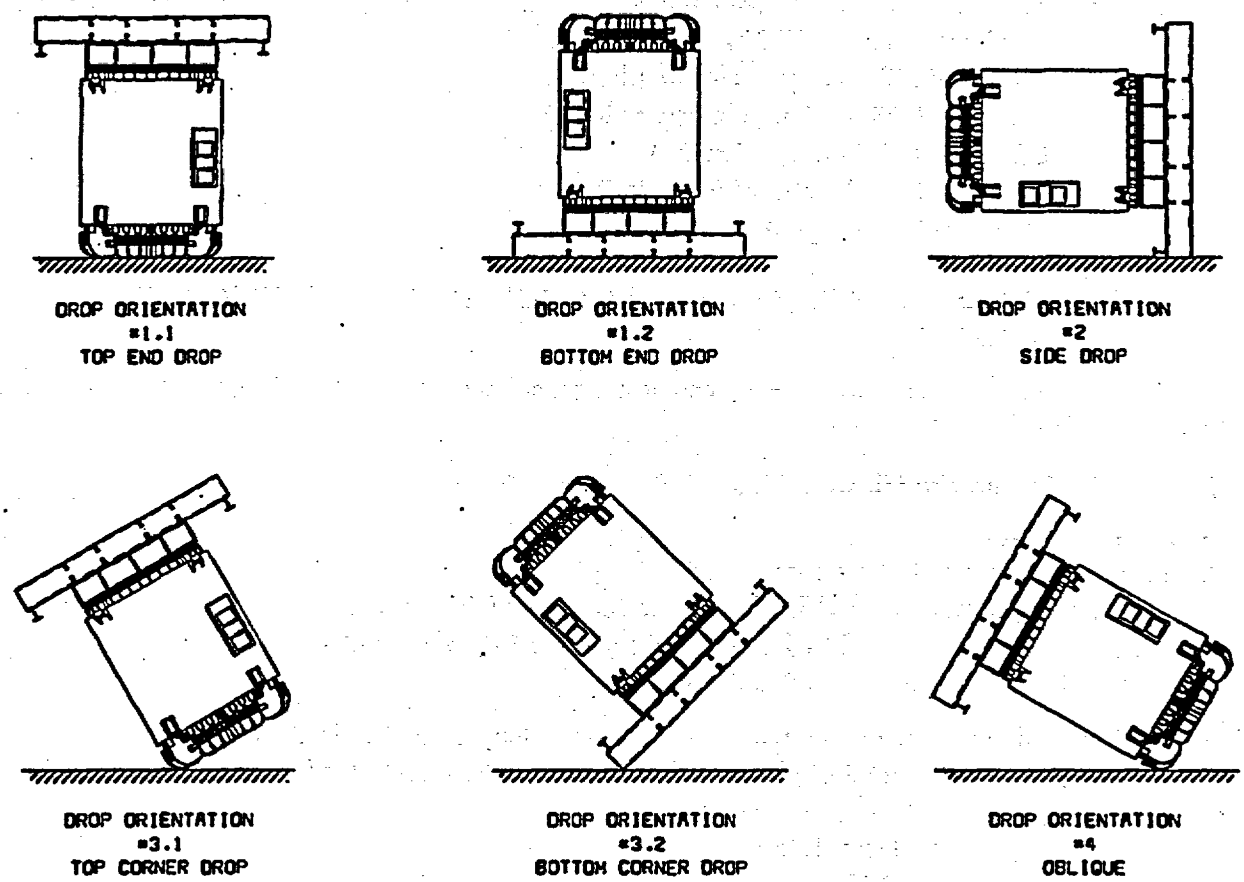


Figure 2.10.14-F2
Drop Test Orientations



2. F-294 STRESS ANALYSIS IN END DROP - TOP ORIENTATION

2.1 MAGNITUDE OF G-LOADS

1. Based on the 30-ft. free drop test of the full-scale F-294 packaging in the top end drop orientation, the measured deceleration of F-294 are as follows:

   G1 = 132 g's (top of closure plug)
   G2 = LOS (bottom of closure plug)
   G3 = 112 (bottom of cavity)
   G4 = LOS (bottom of fixed skid)
   LOS = loss of signal

2.2 EFFECT OF G-LOADS ON THE LEAD SHIELDED CONTAINER AND COMPONENTS

Using 132 g's as deceleration load in the top end drop orientation (Figure 2.10.14-F3), the stress analysis of components of F-294 is carried out.

2.2.1 Bolting on the Closure Plug

See Figure 2.10.14-F4.
Estimate bolt g-load (max) based on static UTS

Number of bolts = 16, 1 in. dia. UNBRAKO, UNC (coarse thread).
Total bolt area, $_{ABOLT}$ = 8.816 in^2 (i.e., 16 bolts x 0.551 in^2 per bolt)
Static UTS = 180,000 psi

Based on deceleration load of 132 g's in the top drop orientation, the applied load on the bolt,

P_{IMPACT} = weight of plug and contents x Deceleration G-load
= $W_{PLUG\ \&\ CONTENTS}$ x 132
= 1,115 x 132
= 147,180 lb.

Gasket seating load, $_{FSG}$ = 2,400 lb.

Pressure build-up load W_{plug} = 4,000 lb.

Therefore, total load on 16 bolts, P_{TOTAL}

P_{TOTAL} = $P_{IMPACT} + F_{SG} + W_{plug}$
= 147,180 + 2,400 + 4,000
= 153,580 lb.

What is the stress in the bolt?

Bolt stress, σ = P_{TOTAL}/A_{BOLT} = 153,580 lb./8.816 in^2
= 17,420 psi.

The allowable static UTS at 20°C is 180,000 psi in tension.
Safety Factor, $SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress
= static UTS/bolt tensile stress
= 180,000 psi/17,420 psi
= 10.33

Margin of Safety, $MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 10.33 - 1 = 9.33$

As the Margin of Safety (MS) > 0, the bolts as specified will maintain the plug closure/container joint.

The bolt stress (17,420 psi) is less than yield stress = 155,000 psi of the bolt material. Therefore the bolt material has not yielded in the 30-ft. free drop of F-294 in top end drop orientation (Test # 6).

2.2.2 Male Flange

At 132 g's deceleration load, what are the stress levels in the male and female flange of the bolted closure?

See Figure 2.10.14-F5.

It is assumed that the ligament area around the bolt holes is the critical area in terms of failure mode. Effective Ligament area is considered that area 1.5 Diameters from bolt hole center line.

Minimum ligament area in shear around the bolt holes AS

$$AS = 5/16 * 1 + 0.5 * 1$$
$$= 13/16 \text{ in}^2$$

Number of bolt holes = 16
Total ligament area = 16 x 13/16 = 13 in^2
Based on deceleration load of 132 g's in the top drop orientation, the applied load on the bolt,

$$P_{IMPACT} = \text{weight of plug and contents x Deceleration G-load}$$
$$= W_{PLUG \& CONTENTS} \times 132$$
$$= 1{,}115 \times 132$$
$$= 147{,}180 \text{ lb.}$$

Gasket seating load, $_{FSG}$ = 2,400 lb.

Pressure build-up load W_{plug} = 4,000 lb.

Therefore total load on 16 bolts, P_{TOTAL}

$$P_{TOTAL} = P_{IMPACT} + F_{SG} + W_{plug}$$
$$= 147{,}180 + 2{,}400 + 4{,}000$$
$$= 153{,}580 \text{ lb.}$$

Shear stress in the ligament zone, τ

$$\tau = P_{TOTAL}/A_{TOTAL\ LIGAMENT\ AREA}$$
$$= 153{,}580/[16 \times (AS)]$$
$$= 153{,}580/[13]$$
$$= 11{,}820 \text{ psi}$$

$$SF_{STRESS\text{-}BASED} = \text{allowable stress/applied stress}$$
$$= 0.6 \times UTS/\tau$$
$$= 0.6 \times 70{,}000/11{,}820$$
$$= 3.55$$

$$MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 3.55 - 1 = 2.55$$

As the Margin of Safety (MS) > 0, the male flange as specified is acceptable.

2.2.3 Female Flange

At 132 g's deceleration load, what are the stress levels in the female flange of the bolted closure?

See Figure 2.10.14-F6.

The weld joint WCC7 between the female flange to the cavity liner (location B as per Figure 2.7.1.1-i)-F3.3) is the critical area in terms of failure mode. It is assumed that the entire deceleration load of 132 g's is resisted by weld WCC7 only. This is conservative as the deceleration load is shared by components other than weld joint WCC7.

Area of the butt weld,

$A_{WELD} = \pi * D_m * t * 0.7$

$A_{WELD} = \pi * \{(2 * 7.392)+0.5\} * 0.5 * 0.7$

$A_{WELD} = 16.8 \text{ in}^2$

Based on deceleration load of 132 g's in the top drop orientation, the applied load on the bolt,

P_{IMPACT} = weight of plug and contents x Deceleration G-load

$= W_{PLUG \& CONTENTS} \times 132$

$= 1{,}115 \times 132$

= 147,180 lb.

Gasket seating load, $_{FSG}$ = 2,400 lb.

Pressure build-up load W_{plug} = 4,000 lb.

Therefore total load on 16 bolts, P_{TOTAL}

$P_{TOTAL} = P_{IMPACT} + F_{SG} + W_{plug}$

$= 147{,}180 + 2{,}400 + 4{,}000$

= 153,580 lb.

Stress in the weld, $_{sWELD}$

$\sigma_{WELD} = P_{TOTAL}/A_{WELD}$

$= 153{,}580 \text{ lb.}/16.8 \text{ in}^2$

= 9,150 psi

For weld with 100% joint efficiency (fully radiographed weld joint)'

$SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress in tension

$= UTS/\tau$

= 70,000/9,150

= 7.65

$MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 7.65 - 1 = 6.56$

As the Margin of Safety (MS) > 0, the female flange as specified is acceptable.

2.2.4 Stripping of Internal Threads of Bolt Hole Under Impact Load

See Figure 2.10.14-F7.

Note: The bolt hole thread depth is 1.25 in. The effective engagement length is 1.0 in.

What G loads can the internal threads of the bolt hole in the female flange of the bolted closure withstand without stripping?

Area of shear of the threads per bolt hole = 1.8 in^2

Effective area of thread to be stripped = 1.44 in^2

Number of bolts = 16

Min. compressive strength UCS = 70,000 psi

Based on deceleration load of 132 g's in the top drop orientation, the applied load on the bolt,

P_{IMPACT} = weight of plug and contents x deceleration G-load

$= W_{PLUG \& CONTENTS} \times 132$

$= 1{,}115 \times 132$

= 147,180 lb.

Gasket seating load, $_{FSG}$ = 2,400 lb.

Pressure build-up load W_{plug} = 4,000 lb.

Therefore total load on 16 bolts, P_{TOTAL}

$$P_{TOTAL} = P_{IMPACT} + F_{SG} + W_{plug}$$
$$= 147{,}180 + 2{,}400 + 4{,}000$$
$$= 153{,}580 \text{ lb.}$$

Shear stress in the bolt hole threads, τ

$$\tau = P_{TOTAL}/A_{BOLT\ HOLE\ THREADS}$$
$$= 153{,}580/[16 \times 1.44]$$
$$= 6{,}670 \text{ psi.}$$

For stripping of bolt hole threads, the safety factor and margin of safety are:

$SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress in shear

$$= 0.6 \times UTS/\tau$$
$$= 0.6 \times 70{,}000/6{,}670$$
$$= 42{,}000/6{,}670$$
$$= 6.29$$

$MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 6.29 - 1 = 5.29$

As the Margin of Safety (MS) > 0, the bolt hole threads as specified are acceptable.

2.2.5 Container Welds

In the top end drop, at the top of the container there are a number of welds that retain the shell structure for the lead shielding within the container or the plug. We shall examine these welds in their ability to withstand the deceleration load based on 132 g's.

See Figure 2.10.14-F8 for identification of welds and the dimensions.

- WCC1 = conical dished head to container top flange, external, fillet, circumferential
- WCC2 = conical dished head to container top flange, internal, fillet, circumferential
- WCC7 = container flange to cavity upper tube, butt, circumferential
- WCC3 = container outside shell to conical dished head, butt, circumferential
- WF = cooling fins to container shell, conical dished head, fillet, longitudinal

Weld designated WCC1: Area $A_{1,\ circumferential} = 2\pi \times 11.812 \times 0.5 \times 0.707 = 26.23\ in^2$

Weld designated WCC2: Area $A_{2,\ circumferential} = 2\pi \times 12.812 \times 0.5 \times 0.707 = 28.46\ in^2$

Weld designated WCC3: Area $A_{3,\ circumferential} = 2\pi \times 17.500 \times 0.5 \times 0.707 = 38.87\ in^2$

Weld designated WCC7: Area $A_{7,\ circumferential} = 2\pi \times 7.392 \times 0.5 \times 0.707 = 16.42\ in^2$

Weld designated WF: Area $A_{WF} = 229\ in^2$

A_{WF} = No. of fins x no. of fillet welds x thickness of weld x length of weld x 0.707

$= 36 \times 2 \times 0.375 \times 12 \times 0.707 = 229\ in^2$

Strength of weld in shear: 0.6 x UTS of weld S_{UTS}

= 70,000 psi, same as the parent material ss304L.

Assume for fillet welds, a weld joint efficiency of $\eta_1 = 80\%$ (as the welds are liquid penetrant inspected and radiographed) and for butt welds, a weld joint efficiency of $\eta_2 = 100\%$ (as the welds are liquid penetrant examined and fully radiographed). (Table UW-12 of ASME VIII Division 1).

Thus the maximum capacity of the weld joint is:

Weld WCC1: P_1 = Joint efficiency $\eta_1 \times 0.6 \times S_{UTS} \times A_{1,\ circumferential}$

(in shear) $= 0.8 \times 0.6 \times 70{,}000 \times 26.23$

$= 0.882 \times 10^6$ lb.

Weld WCC2: P_2 (in shear) $= \text{Joint efficiency } \eta_1 \times 0.6 \times S_{UTS} \times A_{2,\,circumferential}$
$= 0.8 \times 0.6 \times 70{,}000 \times 28.46$
$= 0.956 \times 10^6$ lb.

Weld WCC3: P_3 (in tension) $= \text{Joint efficiency } \eta_2 \times S_{UTS} \times A_{3,\,circumferential}$
$= 1.0 \times 70{,}000 \times 38.87$
$= 2.72 \times 10^6$ lb.

Weld WCC7: P_7 (in tension) $= \text{Joint efficiency } \eta_2 \times S_{UTS} \times A_{7,\,circumferential}$
$= 1.0 \times 70{,}000 \times 16.42$
$= 1.14 \times 10^6$ lb.

Weld WF: P_{WF} (in shear) $= \text{Joint efficiency } \eta_1 \times 0.6 \times S_{UTS} \times A_{WF}$
$= 0.8 \times 0.6 \times 70{,}000 \times 229$
$= 7.694 \times 10^6$ lb.

In the top drop orientation the weight of the lead shielding is segmented into four zones: W_1, W_2, W_3, W_4 respectively.

The weight W_1 acts directly on the lower cavity end plate and affects lower cavity buckling.

The weight W_2 acts directly on the off-set ring flange between upper and lower cavity and affects buckling of upper cavity.

The weight W_3 and W_4 is directly acting on the container female flange, the container conical head and welds WCC1, WCC2, WCC3, WCC7 and WF. Therefore the welds WCC1, WCC2, WCC3, WCC7 and WF collectively resist the impact of weight $W_3 + W_4$ in top end drop orientation.

The estimate of weights W_1, W_2, W_3, W_4 is given here:

W_1 = volume x density of lead
$= \pi \times 6.25^2 \times (11.25) \times 0.410$
= 566 lb.

W_2 = volume x density of lead
$= \pi \times (7.892^2 - 6.25^2) \times (31.75) \times 0.410$
= 950 lb.

W_3 = volume x density of lead
$= \pi \times (12.968^2 - 7.892^2 \times (41.75) \times 0.410$
= 5,695 lb.

W_{31} = volume x density of lead
$= \pi \times (10.5^2 - 7.892^2 \times (41.75) \times 0.410$
= 2,580 lb.

W_4 = volume x density of lead
$= \pi \times (17.5^2 - 12.968^2) \times (31.) \times 0.410$
= 5,514 lb.

Therefore, the g-load capability of welds WCC1, WCC2, WCC3, WCC7, and WF collectively is:

G-load = allowable impact load/relevant weight

$= [P_1 + P_2 + P_3 + P_7 + P_{WF}]/[W_3 + W_4]$

$= [(0.882 + 0.956 + 2.72 + 1.14 + 7.694) \times 10^6]/[5{,}695 + 5{,}514]$

$= [13.392 \times 10^6]/[11{,}209]$

= 1,194 g's

Safety Factor (SF) = G-load capability/applied G-loads = 1,194/132 = 9.04

Margin of Safety g-load based, $M_{FG\text{-}LOAD\ BASED}$ = SF – 1 = 9.04 – 1 = 8.04

The cumulative impact load on welds WCC1, WCC2, WCC3, WCC7 and WF due to deceleration load of 132 g's is

$P_{IMPACT} = [W_3 + W_4] \times 132$ g's

$= [5{,}695 + 5{,}514] \times 132$

$= 1.479 \times 10^6$ lb.

The collective effective area of welds, inclusive of joint efficiency, is

$A = \eta_1 \times A_{1,circumferential} + \eta_1 \times A_{2,circumferential} + \eta_2 \times A_{7,circumferential} + \eta_2 \times A_{3,circumferential} + \eta_1 \times A_{WF}$

$A = 0.8 \times 26.23 + 0.8 \times 28.46 + 1.0 \times 16.42 + 1.0 \times 38.87 + 0.8 \times 229.$

$A = 282.2\ in^2$

The average stress on the welds WCC1, WCC2, WCC3, WCC7 and WF is

$\sigma_{AVG.} = P_{IMPACT}/A$

$= 1.479 \times 10^6$ lb./282.2 in^2

= 5,243 psi.

The average stress in the welds is above the Yield stress of 25,000 psi for ss 304L parent metal and far below static UTS of 70,000 psi.

Safety Factor, $SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress in shear

$= 0.6 \times 70{,}000/5{,}243$

= 8.01

Margin of Safety, $MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 8.01 - 1 = 7.01$

As the Margin of Safety (MS) > 0, the container welds as specified are acceptable.

2.2.6 Closure Plug Welds

There are two welds in the plug assembly that resist the deceleration loads based on 800 g's. These welds are identified as WPC1 and WPC2 respectively (see Figure 2.10.14-F8).

Weld designated WPC1: Area $A_{1,circumferential} = 2\pi \times 6.358 \times 0.5 \times 0.707 = 14.1\ in^2$

Weld designated WPC2: Area $A_{2,circumferential} = 2\pi \times 6.858 \times 0.5 \times 0.707 = 15.23\ in^2$

Strength of weld in tension: UTS of weld S_{UTS} = 70,000 psi, same as the parent material ss304L.

For butt weld, a weld joint efficiency η_2 = 100% (as the welds are liquid penetrant inspected and radiographed).

Thus the maximum capacity of the weld joint is:

Weld WPC1: P_1 = Joint efficiency $\eta_2 \times S_{UTS} \times A_{1,circumferential}$

(in tension) $= 1.0 \times 70{,}000 \times 14.1$

$= 0.987 \times 10^6$ lb.

Weld WPC2: P_2 = Joint efficiency $\eta_2 \times S_{UTS} \times A_{2,circumferential}$

(in tension) $= 1.0 \times 70{,}000 \times 15.23$

$= 1.066 \times 10^6$ lb.

The weight of the shield plug (1,070 lb.) + contents (F-313 source carrier (25 lb.) + C-188 sources (20 lb. approximately)) = 1,115 lb.
The impact load on weld WPC1 due to deceleration load of 132 g's is

$$P_{IMPACT} = W_{PLUG + CONTENTS} \times 132 \text{ g's} = 1{,}115 \times 132 = 147{,}180 \text{ lb.}$$

The load sharing by weld WPC2 is ignored.
The effective area of weld WPC1 inclusive of joint efficiency, is

$$A = \eta_2 \times A_{1, circumferential}$$
$$A = 1.0 \times 14.1$$
$$A = 14.1 \text{ in}^2$$

The average stress on the welds WPC1 (in tension under the top end drop) and ignoring any load sharing by weld WPC2,

$$\sigma_{AVG.} = P_{IMPACT}/A$$
$$= 147{,}180 \text{ lb.}/14.1 \text{ in}^2$$
$$= 10{,}438 \text{ psi.}$$

The average stress in the weld is below the yield stress of 25,000 psi for ss 304L parent metal and far below static UTS of 70,000 psi.
Safety Factor, $SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress

$$= 70{,}000/10{,}438$$
$$= 6.7$$

Margin of Safety, $MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 6.7 - 1 = 5.7$
As the Margin of Safety > 0, the closure plug welds as specified are acceptable.

2.2.7 Buckling of Lower Cavity Tube

See Figures 2.10.14-F9 and 2.10.14-F10.
The weight of lead borne by the steel tube + cap

$$W_1 = \pi \times 6.25^2 \times 11.25 \times 0.41$$
$$W_1 = 566 \text{ lb.}$$

Assume the load is applied at the centre of the tube. Then the collapse pressure load, using Euler's formula is

$$P_C = \pi^2 EI/L_e$$

where

$$E = 28 \times 10^6 \text{ psi}$$
$$L_e = 20 \text{ in.}$$
$$I = \text{2nd moment of area} = 340 \text{ in}^4$$
$$P_C = 234.8 \times 10^6 \text{ lb. (collapse load).}$$

Applied impact load = 132 g's x weight of lead borne by tube
= 132 x 566
= 74,712 lb.

Safety Factor (SF) = collapse load to buckle cavity tube/applied load
$= 234.8 \times 10^6/[\ 74{,}712 \text{ lb.}]$
= 3,130

Margin of Safety, $MS_{LOAD\ BASED} = SF - 1 = 3{,}130 - 1 = 3{,}129$

As the Margin of Safety > 0, it is concluded that the lower cavity tube will not buckle under a G-load of 132 g's.

2.2.8 Bending of Lower Cavity End Plate

See Figure 2.10.14-F11.
In this model, the cavity end plate is under external applied pressure as a result of impact. The applied pressure acts on the cavity tube end cap.

$G\text{-load}_{cavity\ end\ plate} = 132$ g's.

The applied pressure on the cavity tube cap is

$$\begin{aligned} p &= \text{weight of lead} \times 132\ \text{g's}/A_{CAP} \\ &= 566 \times 132/[\pi \times 6.25^2] \\ &= 74{,}712/122.73 \\ &= 610\ \text{psi} \end{aligned}$$

The thickness of the end cap is 0.75 in. thick. Is 0.75 in. thick Hastelloy C-276 tube cap strong enough to resist 610 psi maximum applied pressure?

For Hastelloy C-276, the material properties are:
Yield Stress (YS) = 41,000 psi.
Ultimate Tensile Strength (UTS) = 100,000 psi.

Using ASME VIII, Division 1 (Ref[17])

$$s = cp/[t/d]^2$$

where

c = constant depending on end tube to cap joint configuration
= 0.2 (ASME VIII, Division 1, Figure UG-34(i)).
p = applied pressure = 610 psi
t = thickness of cap = 0.75 in.
d = 11.5 in. inside diameter

$$s = cp/[t/d]^2$$
$$s = 0.2 \times 610/[0.75/11.5]^2$$
$$s = 28{,}683\ \text{psi.}$$

$$\begin{aligned} \text{Safety Factor, } SF_{STRESS\text{-}BASED} &= \text{allowable stress/applied stress} \\ &= \text{static UTS}/28{,}683 \\ &= 100{,}000\ \text{psi}/28{,}683\ \text{psi} \\ &= 3.48 \end{aligned}$$

Margin of Safety, $MS_{STRESS\text{-}BASED} = SF - 1 = 3.48 - 1 = 2.48$

The maximum stress in the end cap s = 28,683 psi is below the YS of 41,000 psi and the UTS of 100,000 psi. As the Margin of Safety (MS) > 0, the end cap material will not yield.

2.2.9 Buckling of Upper Cavity Tube

See Figure 2.10.14-F12.
The weight of lead borne by the steel tube + flange = $\pi \times [7.892^2 - 6.25^2] \times 31.75 \times 0.41$
W2 = 950 lb.

The loads (W1 + W2) are applied at the centre of the tube. The line of action of deceleration force is in line with the centre of gravity of the upper tube. Therefore this is the case of compressive stress leading to buckling. Then the collapse load, using Euler's formula is

$$P_C = \pi^2\, EI/L_e$$

where

E $= 28 \times 10^6$ psi
L_e $= 11$ in.
I $=$ 2nd moment of area $= \pi/4\ [7.892^4 - 6.25^4] = 1,848\ in^4$
P_C $= 46,438 \times 10^6$ lb. (collapse load).

Applied impact load on the lower cavity tube:
= weight of lead borne by tube x G-load
= 1,516 x 132
= 200,112

Safety Factor, SF = collapse load required to buckle cavity tube/applied load
$= 46.4 \times 10^9/[0.2 \times 10^6$ lb.]
= 232, 000

Margin of Safety, $MS_{LOAD\ BASED} = SF - 1 = 232,000 - 1 = 231,999$
As the Margin of Safety > 0, it is concluded that the upper cavity tube will not buckle.

2.2.10 Bending of Upper Cavity Ring Flange

See Figure 2.10.14-F13.
In this model, the cavity ring flange plate is under external applied pressure as a result of impact. The applied pressure acts on the upper cavity tube and the upper cavity ring flange. The g-load on the upper cavity tube is = 132 g's.

Based on 132 g's deceleration load, the applied pressure on the cavity ring flange is

p = weight of lead x 132 g's/$A_{RING\ FLANGE}$
$= 950 \times 132/[\pi \times (7.892^2 - 6.25^2)]$
= 125,400/73
= 1,718 psi.

Is 0.5 in. thick stainless steel forging (ring flange) strong enough to resist 1,718 psi maximum applied pressure?

For stainless steel (ss304L) A-182, the material properties are:
Yield Stress (YS) = 25,000 psi.
Ultimate Tensile Strength (UTS) = 70,000 psi.

Case 77, Table X of Ref. [4].

$s_r = \beta\,\omega\,a^2/t^2$

where

s_r = maximum radial stress
β = constant depending upon a/b = 7.892/6.25 = 1.262, $\beta = 0.0195$
ω = p = applied pressure = 1,718 psi
t = thickness of ring flange = 0.5 in.
a = 7.892 in. ring flange outside radius
b = 6.25 in. ring flange inside radius
$s_r = \beta\,\omega\,a^2/t^2$
$s_r = 0.0195 \times 1,718 \times 7.892^2/0.5^2$
$s_r = 8,346$ psi

Safety Factor, $SF_{STRESS-BASED}$ = allowable stress/applied stress
= static UTS/ 8,346
= 70,000 psi/ 8,346 psi
= 8.38

Margin of Safety, $MS_{STRESS-BASED}$ = SF − 1 = 8.38 − 1 = 7.38

The maximum stress in the ring flange s_r = 8,346 psi is above static YS of 25,000 psi. but less than UTS of 70,000 psi. As the Margin of Safety >0, the ring flange will deform but will not rupture.

2.2.11 Container Top Flange

See Figure 2.10.14-F14.
In this model, the container top flange plate is under external applied pressure as a result of impact. The applied pressure acts on the container top flange and the conical shell. The container ring flange has 1.5 in. min. thickness up to 10.5 in. radius; and 2.75 in. thickness for radius greater than 10.5 in.

Based on 132 g's deceleration load, the applied pressure on the container top flange is

p = weight of lead x 132 g's/$A_{RING\ FLANGE}$
= $(W_1 + W_2 + W_{31})$ x 132/[π x $(10.5^2 - 7.892^2)$]
= (566 + 950 + 2580) x 132 / 150.7
= 4096 x 132 /150.7
= 3,588 psi

Is 1.5 in. thick stainless steel plate (ring flange) strong enough to resist 3,588 psi applied pressure?

For stainless steel (ss304L) A-240, the material properties are:
Yield Stress (YS) = 25,000 psi.
Ultimate Tensile Strength (UTS) = 70,000 psi.

Case 77, Roark, 4th Edition.

s_r = $\beta\,\omega\,a^2/t^2$
s_r = 0.03 x 3,588 x $10.5^2/1.5^2$
s_r = 5,280 psi.

where

s_r = maximum radial stress
β = constant depending upon a/b = 10.5/7.892 = 1.33, β = 0.03
ω = p = applied pressure = 3,588 psi
t = thickness of ring flange = 1.5 in.
a = 10.5 in. ring flange outside radius
b = 7.892 in. ring flange inside radius

Safety Factor, $SF_{STRESS-BASED}$ = allowable stress/applied stress
= static UTS/ 5,280
= 70,000 psi/ 5,280 psi
= 13.2

Margin of Safety, $MS_{STRESS-BASED}$ = SF − 1 = 13.2 − 1 = 12.2

The maximum stress in the ring flange s_r = 5,280 psi is below YS of 25,000 psi and UTS of 70,000 psi. As the Margin of Safety (MS) > 0, the ring flange material will not yield.

2.2.12 Effect of Peak Force on the Stainless Steel Shell Directly Under the Base of the Lift Lug Fin

See Figure 2.10.14-F15.

The lift lug region around the top conical shell of the container has been modified to allow for

1. Inclusion of 0.375 in. thermal insulation around the container primary conical shell.
2. Inclusion of 0.5 in. thick ss304 secondary conical shell all around the container primary conical shell, resulting in double conical shell construction; the void space is sandwiched with 0.375 in thick thermal insulation.
3. One (1) inch thick reinforcing base plate (ss304) welded to the secondary conical shell.
4. The modified lift lug is welded at the base to the 1 in. thick reinforcing base plate.
5. The modified lift lug material changed from ss304L to ss304.
6. The hole of the lift lug is welded with a bearing sleeve of material ss304 ASTM A-666.
7. The lift lug is changed from uniform thickness of 1.25 in. to variable thickness of 2 in. at the base and 1.25 in. in the balance of the fin.

There are four (4) lift lug fins on the F-294. At the base of each of the lift lug fins, the 0.5 in. thick ss secondary conical shell is reinforced with a pad approximately 1.0 in. thick x 6.75 in. wide at top x 9.5 in. wide at bottom x 7 in. height. After the top end drop, the crush shield displaces (moves) down by 3.8 in. but the lift lug tip which is not only recessed but is located between the fins of the crush shield and consequently the lift lug fin is not impacted. However the 0.5 in thick container fins (qty = 2) adjacent to the lift lug fin are impacted. The (bearing) compressive load on the shell wall at the base of the lift lug fin is computed as follows:

The impact load, W_{impact} = W_{F294} x G-load
= 21,000 lb. x 132
= 2.772×10^6 lb.

The bearing stress, σ_C

σ_C = W_{impact} /area under compression
= W_{impact} /effective area per pad x 4 pads
= $[2.772 \times 10^6]/\{(7 \times (9.5 + 6.75) \times 0.5) \times 4\}$
= $[2.772 \times 10^6]/227.5$
= 12,184 psi.

Safety Factor, $SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress
= static UTS/12,184
= 70,000 psi/12,184 psi
= 5.74

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = SF – 1 = 5.74 – 1 = 4.74

Since the maximum stress σ_1 = 12,184 psi in the container wall is less than the static ultimate compressive stress and yield stress of the secondary conical dished head (material ss304 UTS = 75,000 psi and YS = 30,000 psi), the container reinforced secondary conical shell wall will not yield. The safety factor = 5.74 implies that the container secondary conical shell under the base of the lift lug fin will not fail (fracture). The primary conical shell is not affected as most of the stress is taken up by the secondary conical shell. As the Margin of Safety > 0, the reinforcement design feature at the base of the lift lug fin as specified is acceptable.

2.2.13 C-188 Sealed Source Under Top End Impact

The case of C-188 sealed source capsule under top impact is presented here. The model chosen to represent this case is given in Figure 2.10.14-F16. Measured G-load in the cavity of F-294 is 118 g's; at the plug G= 132 g's, therefore G = 132 g's is used in the following analysis.

Therefore the stress developed in the capsule outer shell only will be due to the mass of the entire C-188 at 132 g's. The weight of C-188 is $W_{C\text{-}188}$ = 230 g = 0.51 lb.

The support reaction P due to 132-g level is:

$$P = -W_{C\text{-}188} \times \text{G-load} = -0.51 \times 132 = 67.32 \text{ lb.}$$

The axial stress for this condition is given by:

$$\sigma_{comp.} = P/A_{outer\ shell,\ min.\ wall}$$
$$= 67.32/(\pi/4\ (0.376^2 - 0.338^2))$$
$$= 67.32/0.0213$$
$$= 3{,}160 \text{ psi.}$$

Safety Factor = allowable stress/applied stress
= UTS for ss316L at 836°F/applied stress
= 60,000 psi/3,160 psi
= 19.0

Margin of Safety = SF – 1 = 19.0 – 1 = 18.0

The yield stress of ss316L at 836 °F = 16,000 psi. (Ref. [26])

As the $\sigma_{comp.}$ (3,160) < Yield Stress (16,000 psi), the tube shall not yield in the top end drop.

Let us examine C-188 sealed source capsule under end impact for buckling. The model chosen to represent this case is shown in Figure 2.10.14-F16. The ends of the capsule are free to rotate, translation is fixed because the ends of the C-188 are trapped between the bottom plate of F-313 or F-457 source carrier and the shield plug. Any restraining of C-188 sealed source capsule by intermediate spacer plates of the source holder has been ignored. The restraint offered by the inner capsule of C-188 is ignored.

The critical buckling load (Euler load) is given by

$$P_{cr} = \pi^2 EI/[kl]^2$$

where

- E = modulus of elasticity = 24×10^6 psi at 950°F
- I = 2nd moment of area = $\pi/64\ (0.376^4 - 0.326^4) = 4.267 \times 10^{-4}$ in^4
- l = length of the column = 17.777 – 0.9 = 16.877 in.
- k = effective length factor, dependent of the conditions of fixity of the column.

In this case the column is free to rotate i.e., hinge i.e., zero moment reaction, but translation is zero. Therefore the column end condition code is "pin-jointed and fixed end". In this case K = 1.2 (Ref.[24] CISC Handbook 1967).

Therefore

$$P_{cr} = \pi^2\ 24 \times 10^6 \times 4.267 \times 10^{-4}/(1.2\times 16.877)^2$$
$$= 246.5 \text{ lb.}$$

The weight of the C-188, $W_{C\text{-}188}$ = 0.51 lb.
The applied impact load on C-188, $P_{APPLIED}$ = 0.51 x 132 g's = 67.3 lb.
Is buckling initiated?

As $P_{APPLIED}$ (67.3 lb.) < P_{cr} (246.5 lb.), buckling is not initiated.

$SF_{G\text{-}LOAD\ BASED}$ = critical buckling load/applied g-load at impact point
= 246.5/67.3
= 3.66

$MS_{G\text{-}LOAD\ BASED}$ = SF – 1 = 3.66 – 1 = 2.66

Assuming no credit of the restraint offered by the inner capsule of the C-188, as the Margin of Safety (MS) > 0, the C-188 sealed source will not exhibit onset of buckling in a F-294 subject to 30-ft free drop test in the top end (inverted) drop orientation. It must be noted that the C-188 source is a Special Form source and meets 10 CFR Para. 71.77. The URNRC source registration number is NR-222-S-103-S (see Chapter 4, Appendix 4.4.2).

2.2.14 Lead Slump in the Top End Impact

An end drop of a cask in which lead is not bonded to the steel shell will cause the lead to settle, thus creating a void in the end opposite the point of impact (see Figure 2.10.14-F17). An analysis of such an impact, based on the energy absorbed by the lead (as a result of its deformation) and by the outer steel shell (as a result of its circumferential strain from internal lead pressure) has been made (Ref. [25]).

The change in the lead volume in an impact may be estimated from equation:

$$\Delta V = RWH/(t_S\sigma_S + R\sigma_{Pb}) \quad \text{Equation 1}$$

For negligible changes in the outer radius, R, and the inner radius of lead, r, the change in the height of the lead column, ΔH is

$$\Delta H = \Delta V/[\pi(R^2 - r^2)] \quad \text{Equation 2}$$

combining equations 1 & 2 yields

$$\Delta H = RWH/[\pi((R^2 - r^2)(t_S\sigma_S - R\sigma_{Pb})] \quad \text{Equation 3}$$

where

ΔH = amount of lead slump, in.
R = outer radius of lead cylinder = 17.5 in.
r = inner radius of lead cylinder = 6.25 in.
t_S = thickness of ss304 shell = 0.5 in.
H = drop test height = 30-ft = 360 in.
$W_{F\text{-}294}$ = weight of the F-294 container = 21,000 lb.
σ_S = dynamic flow stress of steel = 50,000 psi
σ_{Pb} = dynamic flow stress of lead = 5,000 psi

As noted, equation 3 is based on an unbonded lead condition since neither the support provided by steel shells nor the possibility of collapse of the inner shell by buckling is taken into account. For an end impact of a cylindrical cask having non-buffered ends (without any shock absorbers), the amount of lead slump is:

$$\begin{aligned}\Delta H &= RWH/[\pi((R^2 - r^2)(t_S\sigma_S - R\sigma_{Pb})] \\ &= 17.5 \times 21{,}000 \times 360/[\pi\,(17.5^2 - 6.25^2)\,(0.5 \times 50{,}000 + 17.5 \times 5{,}000)] \\ &= 17.5 \times 21{,}000 \times 360/839.5 \times 112{,}500 \\ &= 1.4 \text{ in.}\end{aligned}$$

In the end impact, all (100%) of the potential energy attributed to 30-ft drop height of the package has been shown to be absorbed by 1) the crush shield and 2) the fins on the container (see Appendix 2.10.9). Consequently there is no unabsorbed energy remaining; therefore neither the container lead shielding nor the container shells are called upon to absorb impact energy.

Therefore, the estimate of lead slump ΔH = 1.4 in. based on the cask without shock absorbers, absorbing all the PE due to 30-ft drop height as impact energy, is conservative. In addition, the lead shielding is normally bonded to the steel shell which further mitigates the lead slump. For purposes of shielding calculations in the post hypothetical accident conditions situation, the effect of lead slump of 1.4 in. has been taken into consideration and the radiation doses calculated in Chapter 5, Section 5.4.

2.3 SUMMARY OF TOP END DROP ANALYSIS

1. The highest measured G-load for the F-294 subjected to 30-ft. free drop test in the top end (inverted) drop orientation, is 132 g's.
2. Using 132 g's deceleration load at the crush shield/container impact point, the following components of the F-294 package were stress analyzed; the corresponding stresses or loads, Safety Factors (SF) and Margins of Safety (MS) are listed here:

Closure Plug

	Stress (psi)	SF	MS
- bolts: avg. bolt stress	17,420	10.33	9.33
- male flange shear stress	11,820	3.55	2.55
- female flange - WCC7 weld	9,150	7.65	6.65
- stripping bolt hole, shear	6,670	6.29	5.29
- welds WPC1	10,438	6.7	5.7

Container

	Stress (psi)	SF	MS
- weld group WCC1, WCC2, WCC7 WCC3 and WF1	5,243	8.01	7.01
- lower cavity tube (buckling)		3,130	3,129
- lower cavity tube end cap	28,683	3.48	2.48
- upper cavity tube (buckling)		232,000	231,999
- upper cavity tube ring flange	8,346	8.38	7.38
- container top flange	5,280	13.2	12.2
- ext. reinforced secondary conical shell, local region under lift lug	12,184	5.74	4.74

The major changes are:

1. Lower cavity end plate thickness from 0.5 in. to 0.75 in. thick.
2. The lift lug fin material and base region modified
3. A secondary conical shell at the top of the container.
4. The reinforcement plate underneath the lift lug fin from 0.5 in. to 1.0 in.

In the top end 30-ft free drop test of the F-294 in top end (inverted) drop orientation, for the components identified in the closure plug and the container, all Safety Factors, SF's > 1 and Margin of Safety, MS > 0. The margin of safety is based on static UTS. The most vulnerable zones are:

- male flange of the closure plug
- lower cavity tube end cap.

However, there will not be ductile failure of the above two vulnerable F-294 components. Therefore the structural integrity of:

1. the ss304L envelope surrounding the lead shielding in the closure plug AND
2. the ss304L envelope surrounding the lead shielding in the container body

is sound and there are no cracks; thus the lead shielding does not have potential leak paths in a scenario of lead melt.

3 The closure plug bolts will not shear under 132 g's deceleration loads. Consequently, the closure plug shielding will be in place over the inner shell assembly which houses the C-188 Special Form sealed sources.

4. The thermal protection is sound. No damage or loss of thermal protection.

5. Under 132-g's deceleration load in the cavity, the direct stresses in C-188 are well below the yield stress. The C-188 sealed source will not buckle. C-188 sealed source is classified Special Form meeting the 10 CFR 71.77 requirements; therefore C-188 provides the leaktight containment despite the fact that it deforms permanently under Special Form tests. The USNRC source registration number for C-188 is NR-222-S-103-S (see Chapter 4, Appendix 4.4.2).

6. At a location opposite to the impact point, the amount of lead slump is expected to be negligible as all the impact energy is absorbed by the crush shield and container fins and a very small magnitude, if any, is absorbed by the lead shielding. For purposes of post hypothetical shielding evaluation tests, lead slump of 1.4 in. is used. The radiation shielding calculations are presented in Chapter 5, Section 5.4.

Figure 2.10.14-F3
F-294 in Top End Drop Orientation

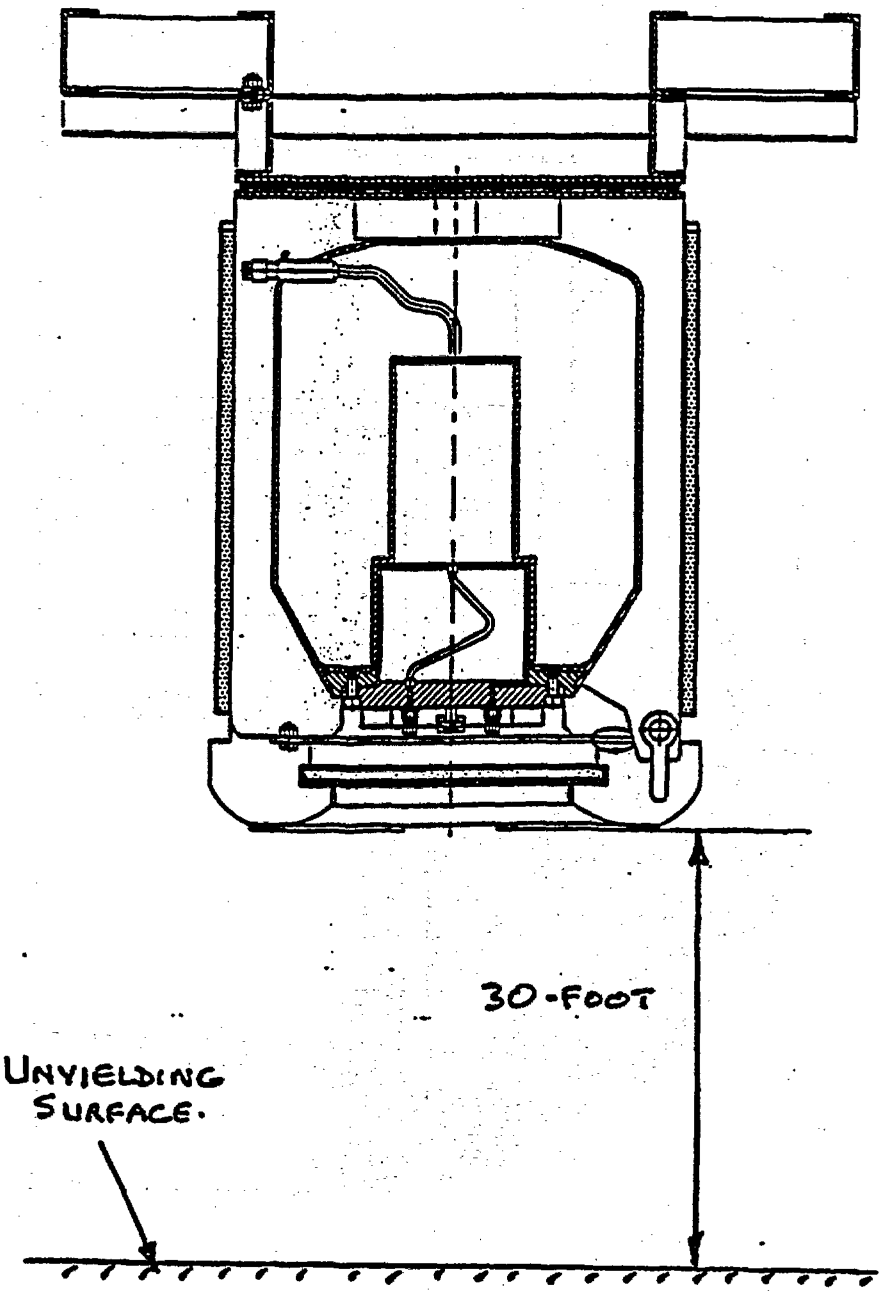


Figure 2.10.14-F4
Top Closure Bolted Joint Details

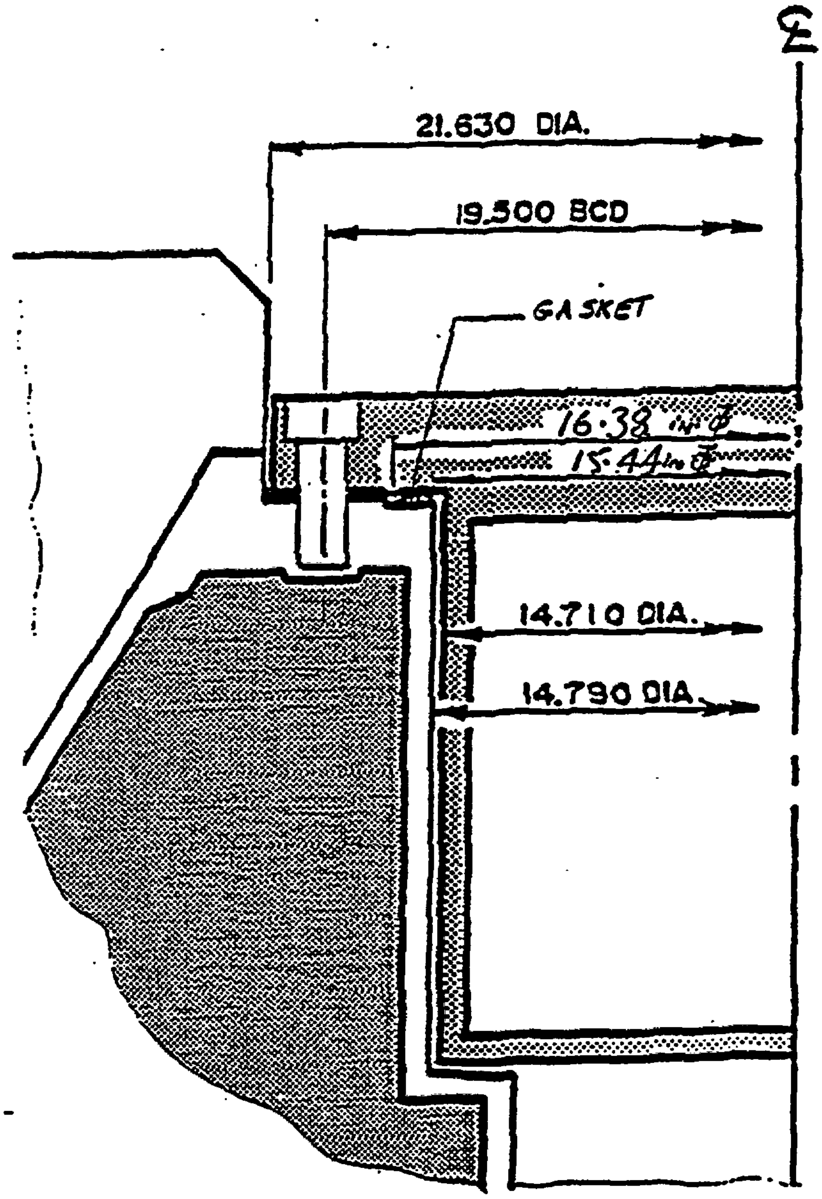


Figure 2.10.14-F5
Ligament Area of the Male Flange

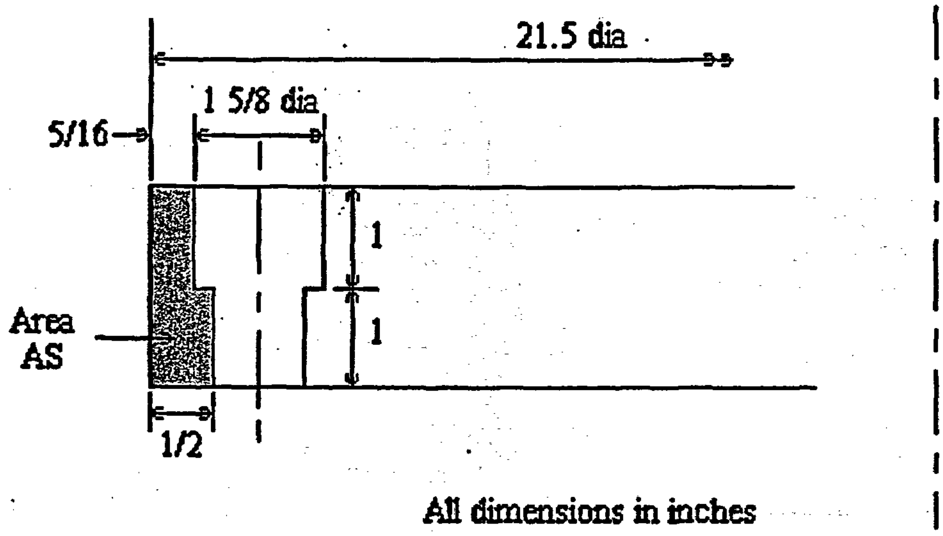


Figure 2.10.14-F6
Weld WCC7 in the Container Upper Cavity

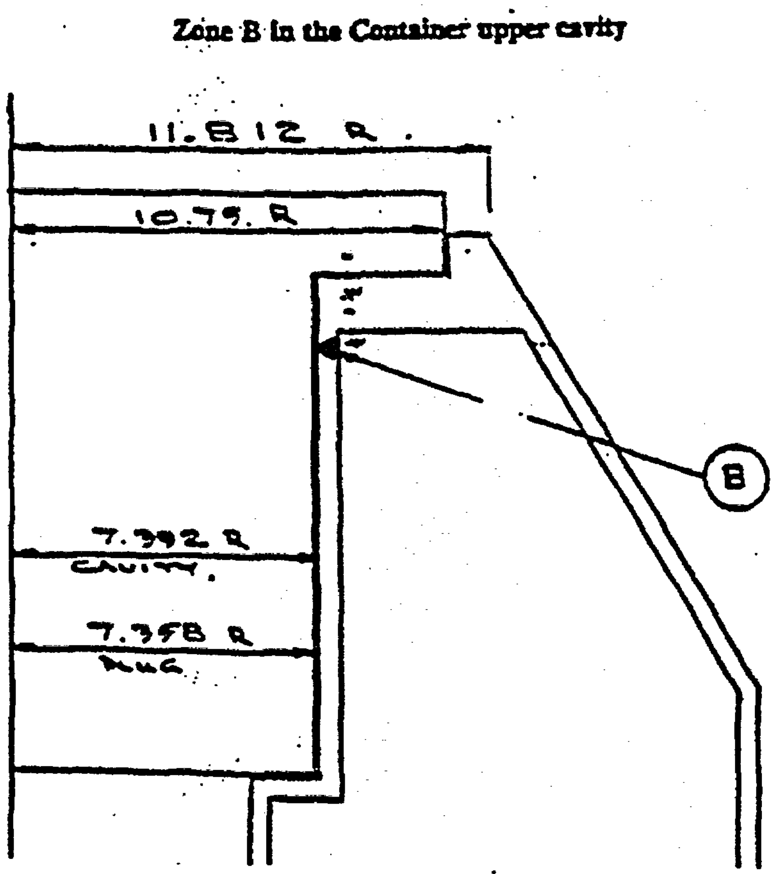


Figure 2.10.14-F7
Bolt Hole in the Ring Flange

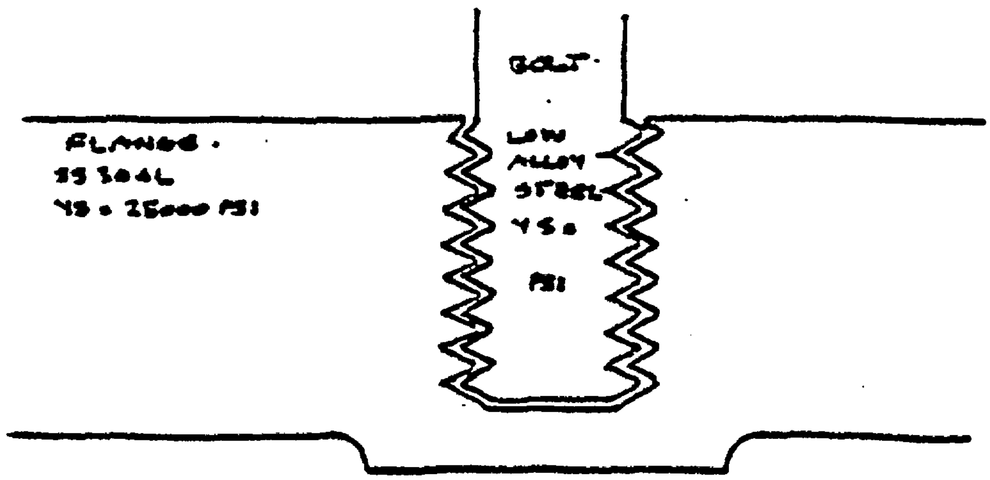


Figure 2.10.14-F8
Container Identification of Welds and Weights of Segments

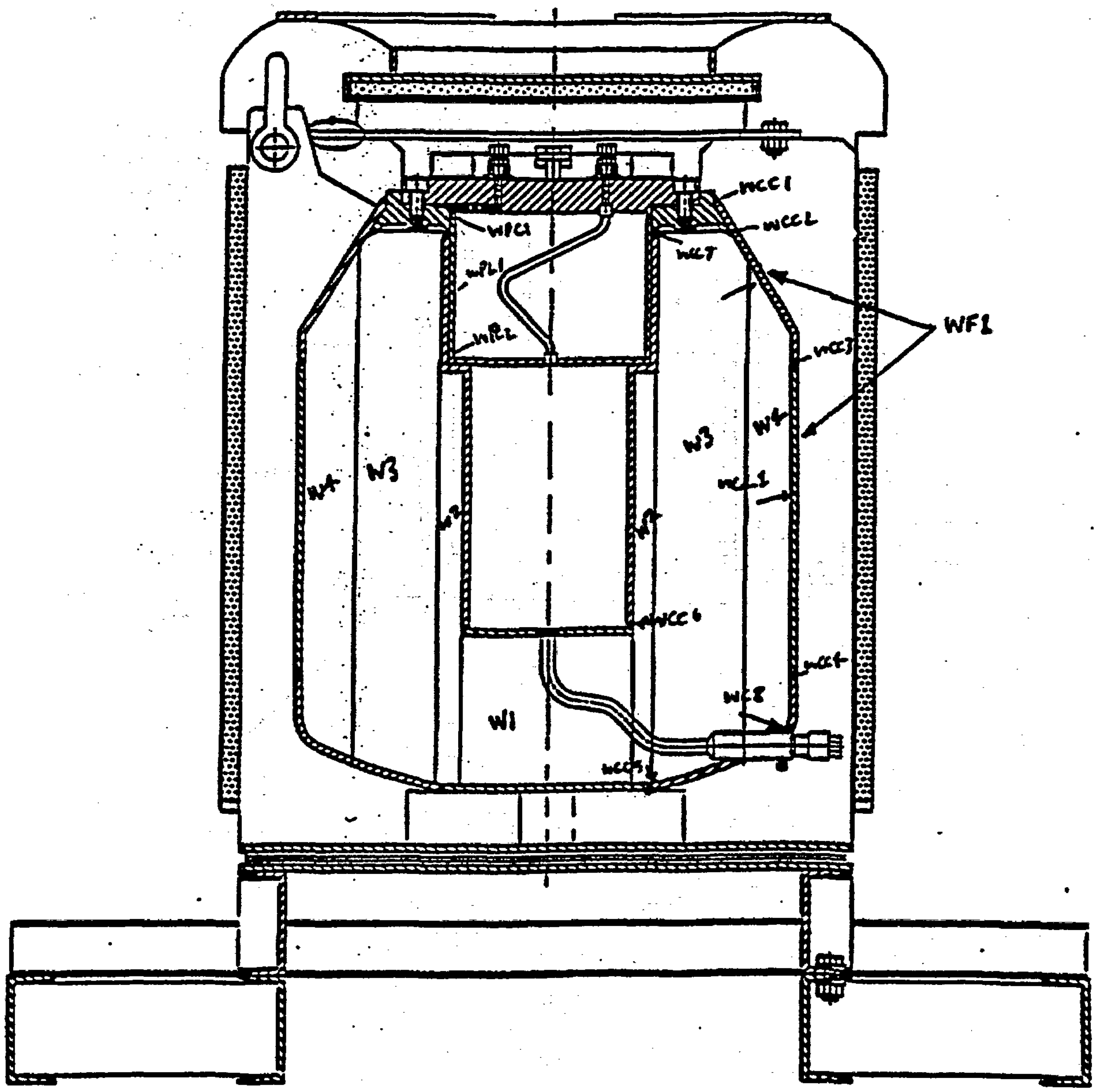


Figure 2.10.14-F9
Cavity Tube Assembly under Axial Load

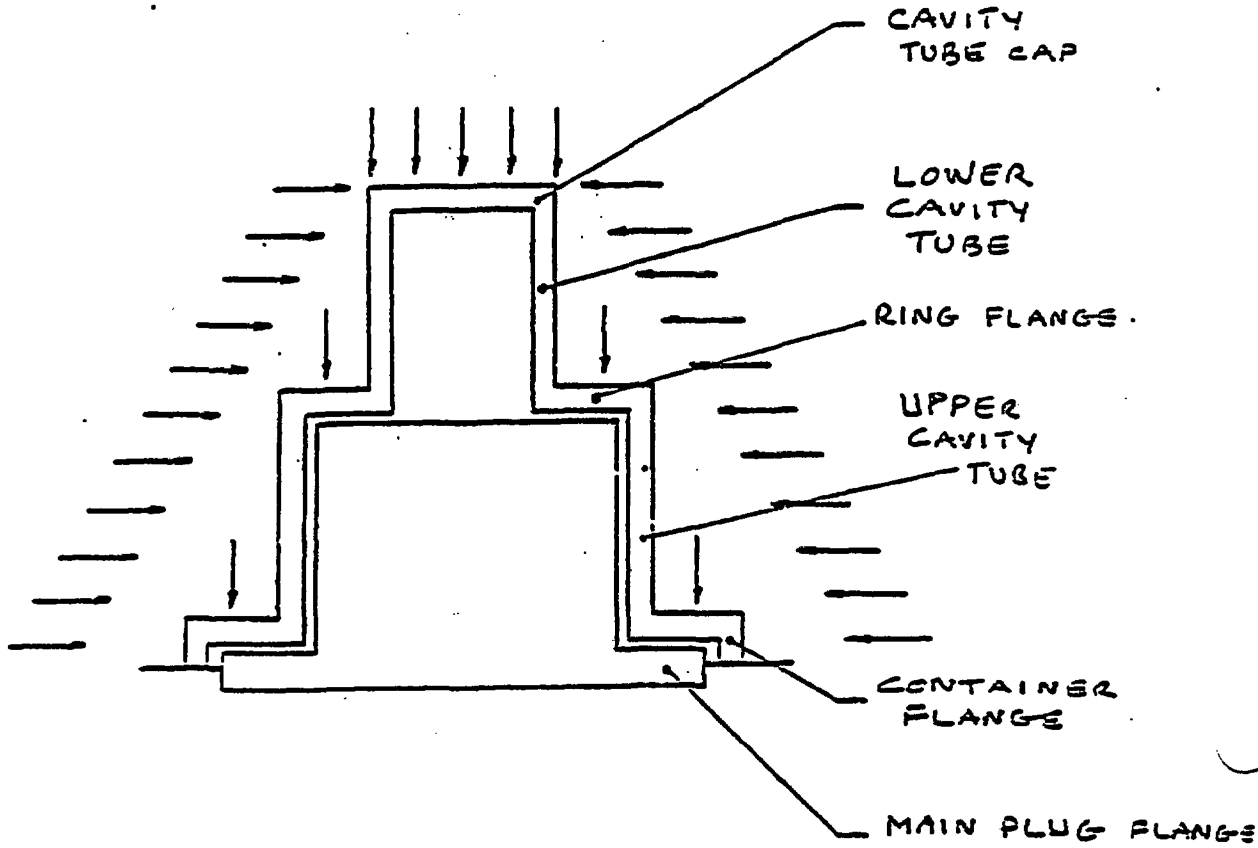


Figure 2.10.14-F10
Lower Cavity Tube and End Cap under Axial Load

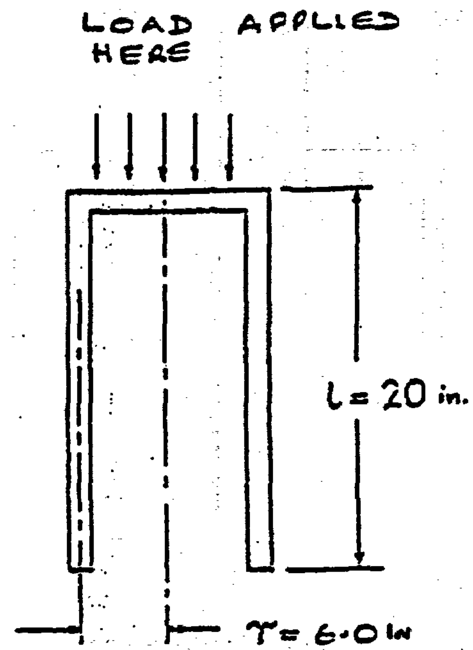


Figure 2.10.14-F11
Lower Cavity Tube End Cap

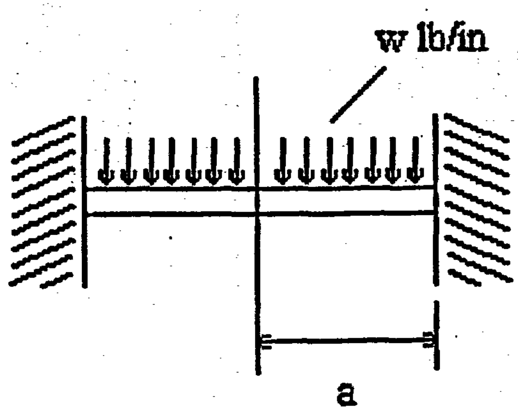


Figure 2.10.14-F12
Upper Cavity Tube

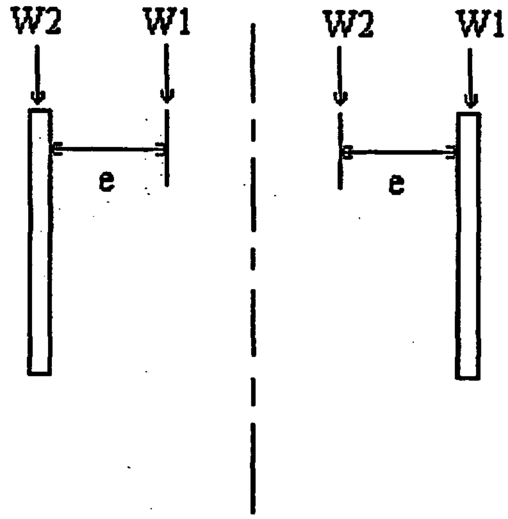


Figure 2.10.14-F13
Upper Cavity Tube Ring Flange

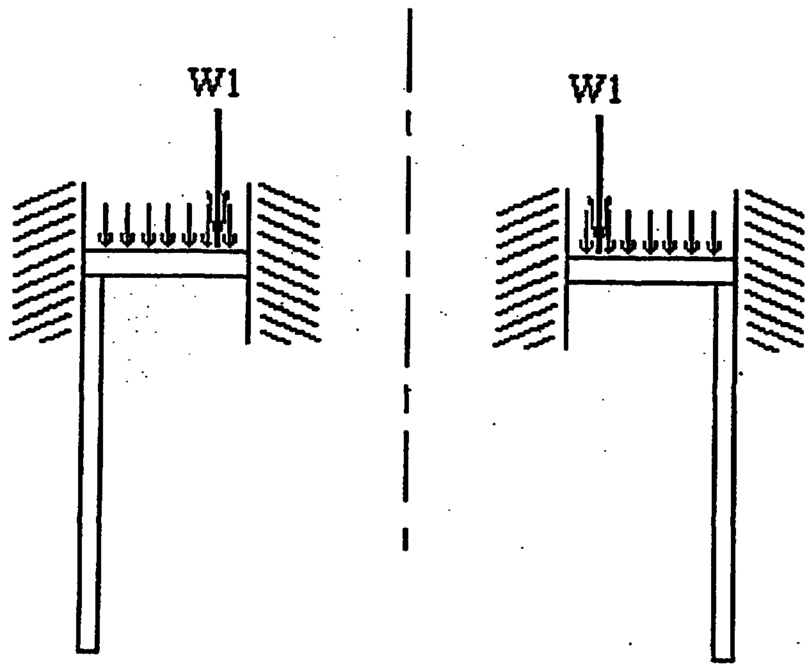


Figure 2.10.14-F14
Container Top Flange under Axial Load

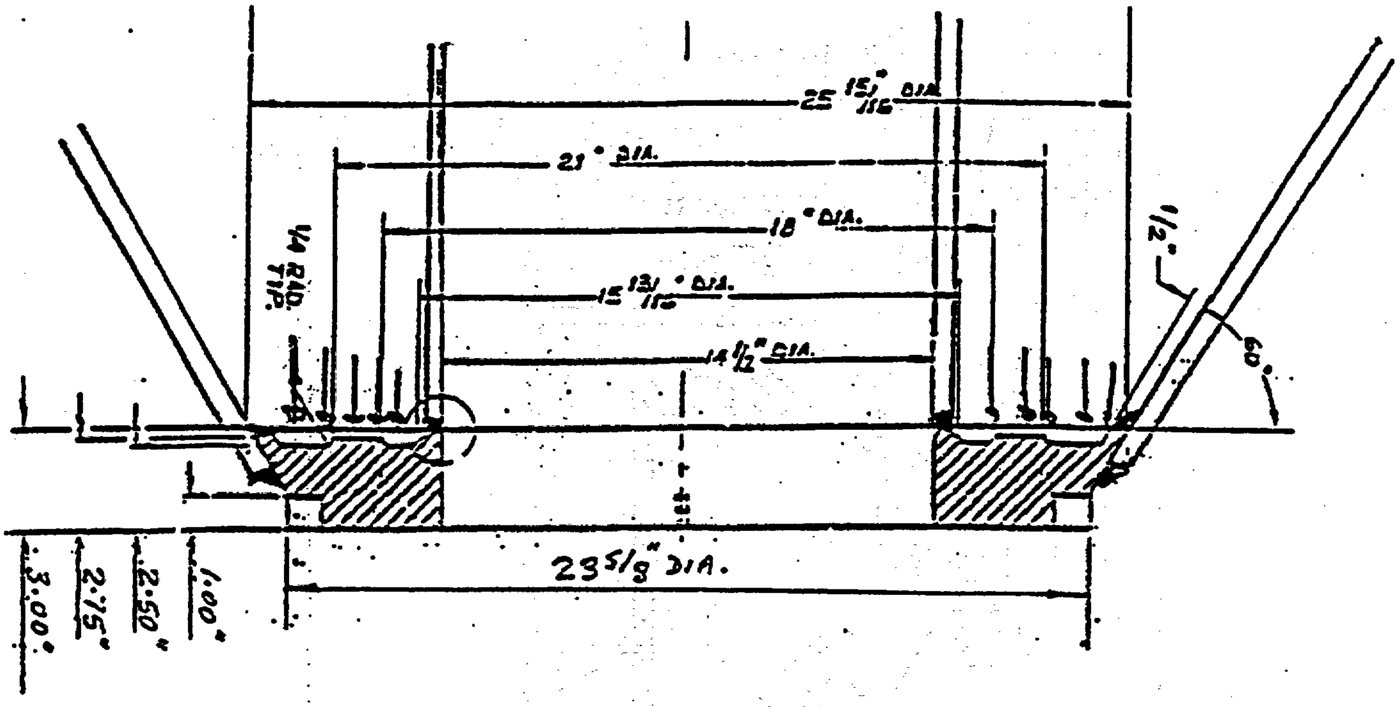


Figure 2.10.14-F15
Container Lift Lug Fin/Shell Area

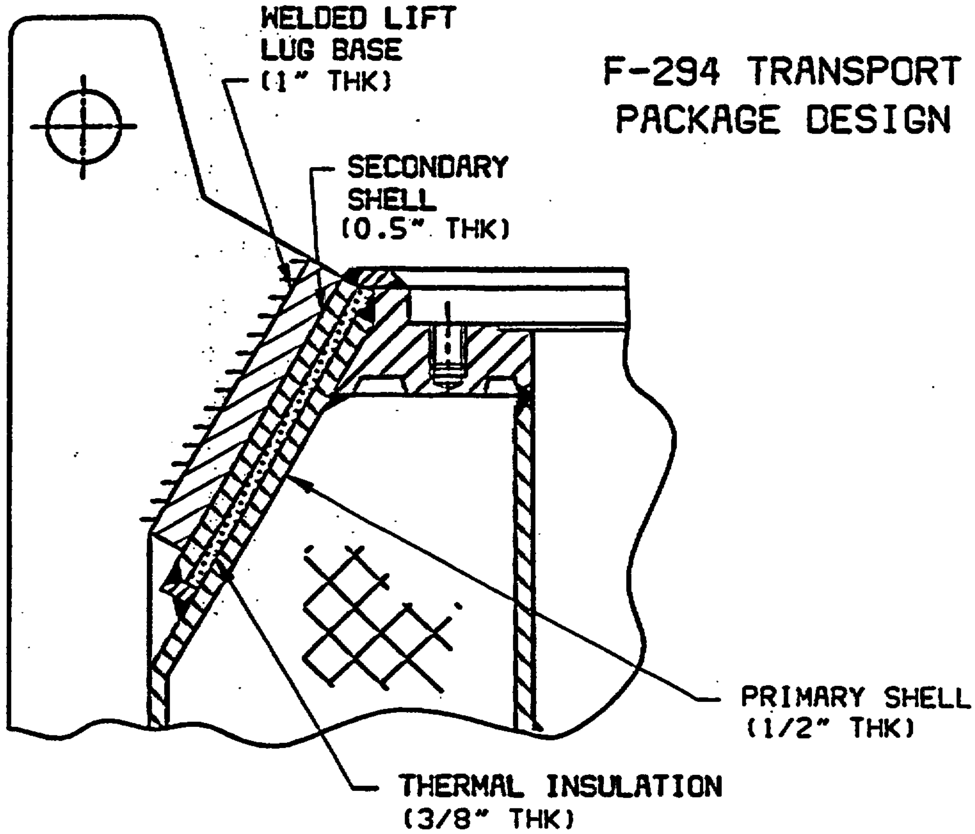


Figure 2.10.14-F16
C-188 Sealed Source under End Impact

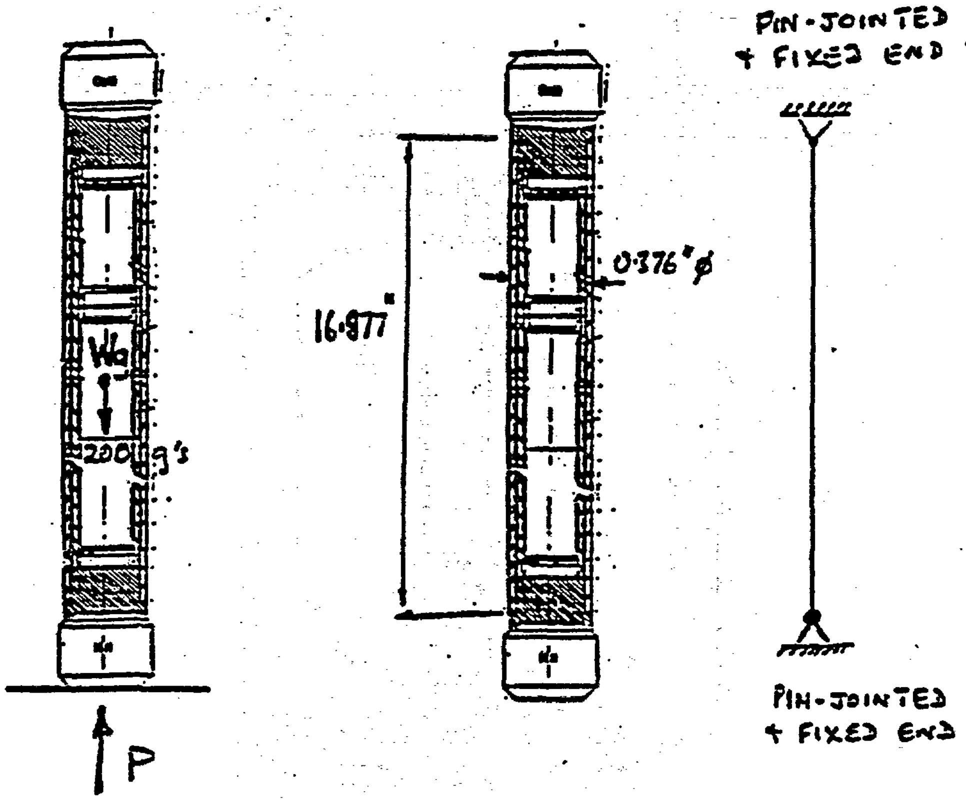
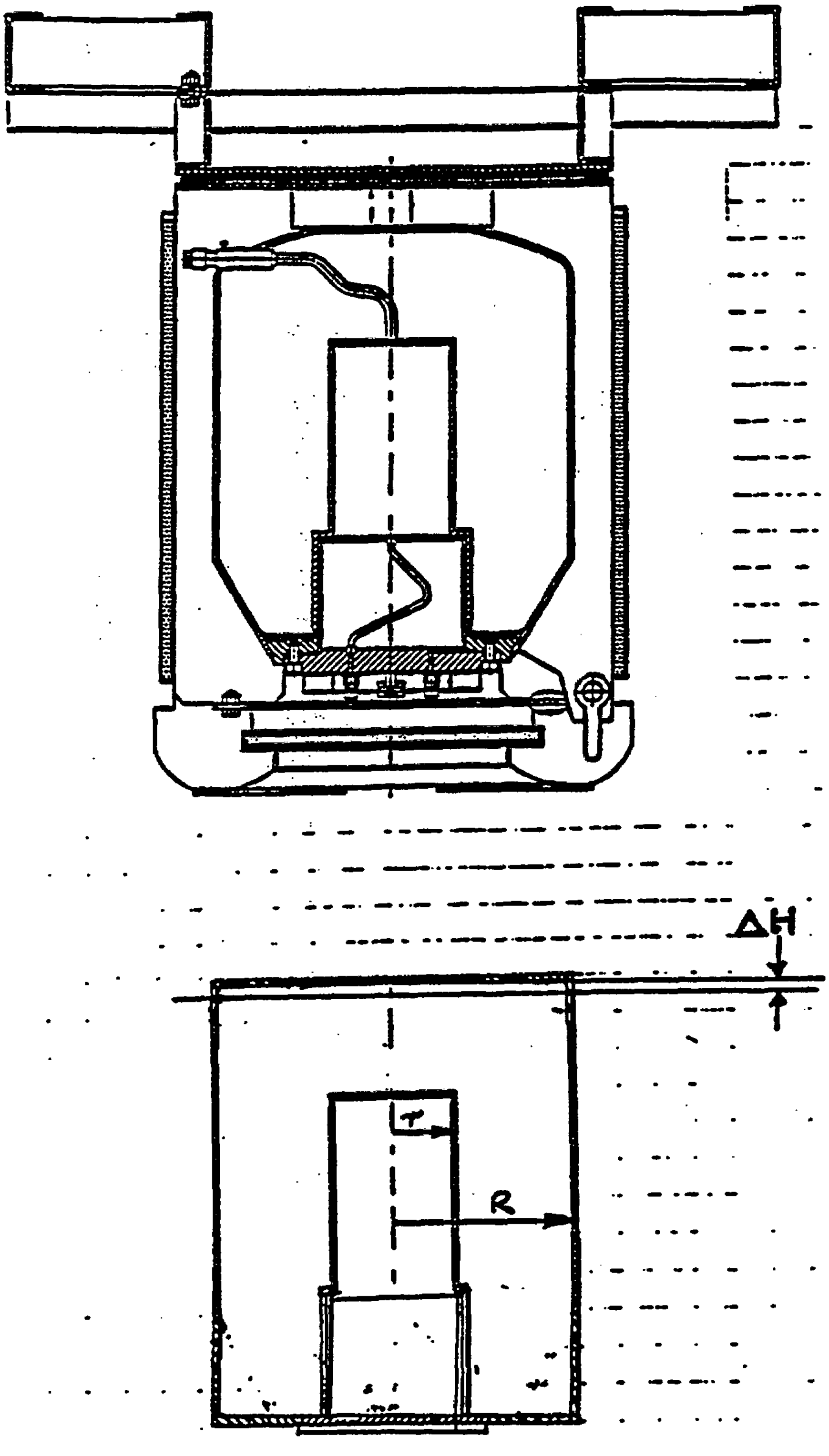


Figure 2.10.14-F17
Lead Slump in the Top End Drop



3. F-294 STRESS ANALYSIS IN END DROP - BOTTOM ORIENTATION

The analysis of F-294 subject to 30-ft drop in the bottom end drop orientation is given in detail.

See Figure 2.10.14-F18, depicting 30-ft drop in the bottom end drop orientation.

Based on measured G-load = 132 g's for the F-294 subjected to 30-ft. free drop test in the top end (inverted) drop orientation, the F-294 container is expected to be subjected to deceleration loads of 132 g's in bottom drop orientation.

3.1 EFFECT OF G-LOADS ON THE LEAD SHIELDED CONTAINER AND COMPONENTS

3.1.1 Fixed skid Assembly

The effective weight on the fixed skid assembly is:

- the container weight inclusive of the plug, crush shield and fireshield = 20,030 lb.
- the weight of the shipping skid = 970 lb. is subtracted from F-294 packaging weight of 21,000 lb.

See Figure 2.10.14-F19.

The skid assembly as per Figure 2.10.14-F20 simplified analysis was presented in the SAR Rev. A. The credit offered by container bottom fins welded to the skid top plate was ignored. Figure 2.10.14-F21 shows a skid assembly with bottom fin above the top skid plate. Analysis of the skid assembly inclusive of the bottom container fin is presented.

Nomenclature

$A_{i=1,5}$ = area of individual sections 1 to 5
Y_b = distance of center of gravity (cog) of individual section from bottom of channel (datum)
M = multiplier of [area, A x moment arm, $_{Yb}$]
I_b = multiplier of [area, A] x [moment arm, $_{YB}$]^2
I_g = 2nd moment of area of individual sections through their cog.
y# = distance of the neutral axis of the composite beam from the bottom of the channel (datum).

Table 2.10.14-T2
Composite Beam Assembly: 2nd Moment of Area

Area	Size	Y_b in.	A in^2	M = A * Y_b in^3	I_b = M * Y_b in^4	I_g in^4
A_1	fin plate 12 x 4	11.125 + 2 = 13.125	2 x 12 x 4 = 96	96 x 13.125 = 1260	1260 x 13.12 = 16537.5	48 x 2^3/12 = 64
A_2	plate 44 x 0.5	8 + 0.75 + 2 + 0.25 = 10.875	44 x 0.5 = 22	22 x 10.875 = 239.25	239.2 x 10.87 = 2,601.8	44 x 0.25^3/12 = 0.057
A_3	plate 2 x 0.5 x 2	8 + 0.75 + 1 = 9.75	0.5 x 2 x 2 = 2	2 x 9.75 = 19.5	19.5 x 9.75 = 190.1	[0.5 x 2^3/12] x 2 = 0.667
A_4	plate 44 x 0.75	8 + 0.25 = 8.375	44 x 0.75 = 33	33 x 8.375 = 276.3	276.3 x 8.375 = 2314.6	44 x 0.375^3/12 = 0.193
A_5	MC8 x 3.5 Channel 8 x 22.8	4.	6.713 x 2 = 13.4	13.4 x 4 = 53.6	53.6 x 4 = 214.4	I_y x 2 = 63.8 x 2 = 127.6
		S	166.4	1,848.7	21,858.4	192.52

Step #1

Calculate the location of neutral axis (N/A) for skid assembly

let y# = the distance from bottom of channel to the neutral axis of the composite beam

Now

y# = Σ[area x moment arm]/Σ[area]
= $\Sigma[A \times Y_b]/\Sigma[A]$
= 1848.7/166.4
= 11.11 in.

Hence the neutral axis is approximately y# = 11.11 in. from the datum (bottom of channel).

Step #2

Calculate I_n = 2nd moment of area of the composite beam

$I_n = I_b + I_g - M^2/A$

where

I_n = 2nd moment of area of the composite beam = in^4
$I_b = \Sigma[Axy^2_b] = 21{,}858.4\ in^4$
I_g = 2nd moment of area of individual sections through their centre of gravity = $192.5\ in^4$
M = for composite section Σ[area x moment arm] = $1{,}848.7\ in^3$
A = for composite section Σ[area] = $166.4\ in^2$

$I_n = I_b + I_g - M^2/A$
$= 21858.4 + 192.5 - [1848.7]^2/166.4$
$= 22{,}050.9 - 20{,}539.$
$= 1{,}511.8\ in^4$

Step #3

Linear load in the plate

With deceleration g-load of 132 g's, the linear load on the 44 in. x 44 in. plate is:

ω = G-load x $W_{CONTAINER\ LESS\ SHIPPING\ SKID}$/length of fixed skid
= 132 g's x 20,030 lb./44 in.
= 60,090 lb./in.

Step #4

Analyse the skid assembly as a composite beam, under linear load ω lb./in.

Maximum bending moment, M_{MAX}

$M_{MAX} = \omega \times l^2/8$
$= 60{,}090 \times 44 \times 44/8$
$= 14.54 \times 10^6$ in-lb.

Step #5

Estimate stresses in the 44 in. x 44 in. top plate of skid assembly

5.1 Bending stresses:

Distance of top plate from neutral axis, c_1

$c_1 = (10.75 - 11.11) = -0.36$ in. (top plate to neutral axis)
$I_n = 1{,}511.88\ in^4$, 2nd moment of area of composite beam

Bending stress at the top plate $\sigma_{b,top}$

$\sigma_{b,top} = M_{MAX} \times c_1/I_n$
$= 14.54 \times 10^6 \times 0.36/1511.88$
$= -3{,}462$ psi.

5.2 Compressive stresses:

The compressive stress in the top plate σ_C

σ_C = Impact load/plate area

= 132 g's x 20,030 lb./44 x 44

= –1,365 psi.

Conclude: It appears that the top plate of the skid assembly shall be subjected to compressive stress of 3,462 + 1,365 = 4,827 psi., which is less than 30,000 psi yield stress of ss304 top plate material. Therefore the top plate of the skid assembly is not likely to yield.

Step #6

Estimate stresses in the 44 in. x 44 in. bottom plate of skid assembly

6.1 Bending stresses:

Distance of bottom plate from neutral axis, c_1

c_1 = (8.75 – 11.11) = –2.36 in. (top plate to neutral axis)

I_n = 1,511.88 in^4, 2nd moment of area of composite beam

Bending stress at the bottom plate. $\sigma_{b,top}$

$\sigma_{b,top}$ = M_{MAX} x c_1/I_n

= 14.54 x 10^6 x (–2.36)/1511.88

= –22,700 psi.

The bottom plate of the skid assembly is ASTM A-36, which has YS = 36,000 psi and UTS = 58,000 psi. Under 132 g's deceleration, the bottom plate of the skid assembly is subjected to the bending stress of 22,700 psi, which is below yield stress. The bottom plate of the skid assembly is not likely to yield.

Step #7

Estimate stresses in the channel of the skid assembly

Bending stresses:

Distance of channel from neutral axis, c_2

c_2 = –11.11 (bottom of channel to neutral axis)

I_n = 1,511.88 in^4, 2nd moment of area of composite beam

Bending stress at the bottom of channel $\sigma_{b,\text{ bottom of channel}}$

$\sigma_{b,\text{ bottom of channel}}$ = M_{MAX} x c_1/I_n

= 14.54x 10^6 x – 11.11/1511.88

= –107,000 psi.

Conclude: The bottom channel will permanently deform.

Step #8

Safety Factors and Margins of Safety.

8.1 Top plate of skid assembly:

The top plate of the skid assembly is ss304. The static UTS = 75,000 psi.

Safety Factor = allowable stress/applied stress

= 75,000/4,830

= 15.52

Margin of Safety = SF – 1 = 15.52 – 1 = 14.52

The top plate of fixed skid assembly is not likely to yield.

8.2 Bottom plate of skid assembly:

The bottom plate of the skid assembly is ASTM A-36.
The static UTS = 58,000 psi.
Safety Factor = allowable stress/applied stress
= 58,000/22,700
= 2.55
Margin of Safety = SF – 1 = 2.55 – 1 = 1.55

The bottom plate of fixed skid assembly is not likely to yield; the plate will not fracture.

8.3 Channel of skid assembly:

The channel of the skid assembly is made of ASTM A-36.
The static UTS = 58,000 psi.
Safety Factor = allowable stress/applied stress
= 58,000/107,000
= 0.54
Margin of Safety = SF – 1 = 0.54 – 1 = –0.46

The channel of the skid assembly will fail; it will deform and bend outwards.

The reinforcing gussets in the channel may restrain excessive bending outwards.

3.1.2 Container Weld WCC5

In the bottom end drop, at the bottom of the container there are a number of welds that retain the shell structure for the lead shielding within the container. We shall examine these welds in their ability to withstand the deceleration loads.

See Figure 2.10.14-F22 for identification of welds and the dimensions.

WCC4 = container outside shell to tori-spherical dished head, butt weld, circumferential.
WCC5 = container closure plate to tori-spherical bottom dished head, butt weld, circumferential.
WF = cooling fins to container shell, tori-spherical dished head, double fillet, weld longitudinal and radial.
Weld designated WCC4: Area $A_{4,\,circumferential} = 2\pi \times 17.500 \times 0.5 \times 0.707 = 38.87$ in^2
Weld designated WCC5: Area $A_{5,\,circumferential} = 2\pi \times 7.5 \times 0.5 \times 0.707 = 16.66$ in^2
Weld designated WF: Area $A_{WF} = 229$ in^2

A_{WF} = no. of fins x no. of fillet welds x thickness of weld x length of weld x 0.707
= 36 x 2 x 0.375 x (13.5 – 4.0) x 0.707 = 181 in^2

Strength of weld in tension: UTS of weld S_{UTS} = 70,000 psi, same as the parent material ss304L.

Assume for fillet welds, a weld joint efficiency of $\eta_1 = 80\%$ (as the welds are liquid penetrant and radiographic inspected) and for butt welds, a weld joint efficiency of $\eta_2 = 100\%$ (as the welds are liquid penetrant examined and fully radiographed).

In the bottom drop orientation the weight of the lead shielding is segmented into four zones: W_1, W_2, W_3, W_4 respectively.

The weight W_1, W_2, W_3 and W_4 is directly acting on the container shell bottom plate, the container tori-spherical dished head, bottom fins and welds WCC4, WCC5, and WF. Therefore the welds WCC4, WCC5 and WF collectively resist the impact of weight $[W_1 + W_2 + W_3 + W_4]$ in bottom end drop orientation.

The estimate of weights W_1, W_2, W_3, W_4 are recaptured here:

W_1 = 566 lb.
W_2 = 950 lb.
W_3 = 5,695 lb.
W_4 = 5,514 lb.

The cumulative impact load due to deceleration load of 132 g's is

$$P_{IMPACT} = [W_1 + W_2 + W_3 + W_4] \times 132 \text{ g's}$$
$$= [566 + 950 + 5{,}695 + 5{,}514] \times 132$$
$$= [12{,}725] \times 132$$
$$= 1.68 \times 10^6 \text{ lb.}$$

The cumulative impact load due to deceleration load of 800 g's is shared between

1. welds WCC4, WCC5 and WF1
2. qty = 36 bottom Fin # 6
3. qty = 9 bottom Fin # 7

1) The collective effective area of welds, inclusive of joint efficiency, is

$$A = \eta_1 \times A_{4,\,circumferential} + \eta_1 \times A_{5,\,circumferential} + \eta_1 \times A_{WF}$$
$$A = 1.0 \times 38.87 + 0.8 \times 16.66 + 0.8 \times 181.$$
$$A = 197 \text{ in}^2$$

2) The direct area of 36 fin #6 is =

= qty. x effective length x thickness
= $36 \times (13.5\text{-}4.5) \times 0.375$
= 121.5 in^2

3) The direct area of 9 fin # 7 is

= qty. x effective length x thickness
= $9 \times (8 - 2) \times 0.375$
= 20.25 in^2

The total area resisting the deceleration load:

$$A_{TOTAL} = A_{WELDS} + A_{FIN\#6} + A_{FIN\#7}$$
$$= 197 + 121.5 + 20.2$$
$$= 338.7 \text{ in}^2$$

The entire deceleration load is taken up by welds, bottom fins #6 and #7, then the average stress on the welds WCC4, WCC5, and WF is

$$\sigma_{AVG.} = P_{IMPACT}/A$$
$$= 1.68 \times 10^6 \text{ lb.}/338.7 \text{ in}^2$$
$$= 4{,}960 \text{ psi.}$$

The average stress in the welds of 4,960 is below the yield stress of 25,000 psi for ss 304L parent metal and far below static UTS of 70,000 psi. So the welds will not fracture.

Safety Factor, $SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress in shear

$$= 0.6 \times 70{,}000/4{,}960$$
$$= 42{,}000/4{,}960$$
$$= 8.46$$

Margin of Safety, $MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 8.46 - 1 = 7.46$

3.2 *SUMMARY OF BOTTOM END DROP ANALYSIS*

1 Based on actual F-294 drop test in the top end (inverted) orientation, the highest measured G-loads in the F-294 plug location is 132 g's. Therefore, based on test data of similar package, the G-load in the bottom end drop orientation of F-294 is expected to be 132 g's.

2. Based on 132 g's deceleration loads, the following components of the F-294 package were stress analyzed; the corresponding stresses or loads, Safety Factors (SF) and Margins of Safety (MS) are shown below:

Container

	Stress (psi)	SF	MS
-weld WCC4, WCC5 and WF1	4,960	8.46	7.46
Fixed skid assembly			
- top plate (ss304)	4,830	15.52	14.52
- bottom plate (A-36)	22,700	2.55	1.55
- channel (bottom flange)	107,000	0.54	–0.46

The margin of safety of F-294 components with the exception of the skid assembly, based on static UTS, is greater than zero (0). Consequently there will be no ductile failure of the shell of the container. Therefore the structural integrity of both

- the ss304 envelope surrounding the lead shielding in the plug AND
- the ss304 envelope surrounding the lead shielding in the container body

is sound (i.e., no cracks); thus the lead shielding does not have potential leak paths in a scenario of lead melt. The structural integrity of the lead shielded cask is sound.

Even though it is shown that the top and bottom plates of the skid assembly are not likely to yield, the top plate and the bottom plate of the skid assembly may deform permanently due to interaction of impact forces transmitted via structural channels. Consequently the fixed skid assembly is likely to deform like a "dished head". The channel flange will deform significantly to the point it will fracture.

3. No loss of thermal protection. The bottom thermal protection (44 x 44 plate), within the fixed skid plates, may be deformed like a "dished head" but not lost as the fixed skid is welded extensively to the container bottom fins (qty = 36 fin #6 and qty = 9 fin #7). The thermal insulation sandwiched between top and bottom plates will remain in place even though the skid plates may deform. Consequently, for the ensuing fire test, the thermal protection shall remain in place to protect the lead cask in the fire test.

4. C-188 sealed source is classified Special Form meeting the 10 CFR 71.77 requirements; therefore C-188 provides the leaktight containment. The USNRC source registration number for C-188 is NR-222-S-103-S (see Chapter 4, Appendix 4.4.2).

5. At a location opposite to the impact point, the amount of lead slump is expected to be negligible as all the impact energy is absorbed by the shipping skid, the fixed skid and container fins and a very small magnitude, if any, remains to be absorbed by the lead shielding. For purposes of post hypothetical shielding evaluation tests in the bottom drop orientation of F-294, lead slump of 1.4 in. estimated for the top end drop orientation of F-294 shall be used. The radiation shielding calculations are presented in Chapter 5, Section 5.4.

Figure 2.10.14-F18
F-294 Bottom End Drop

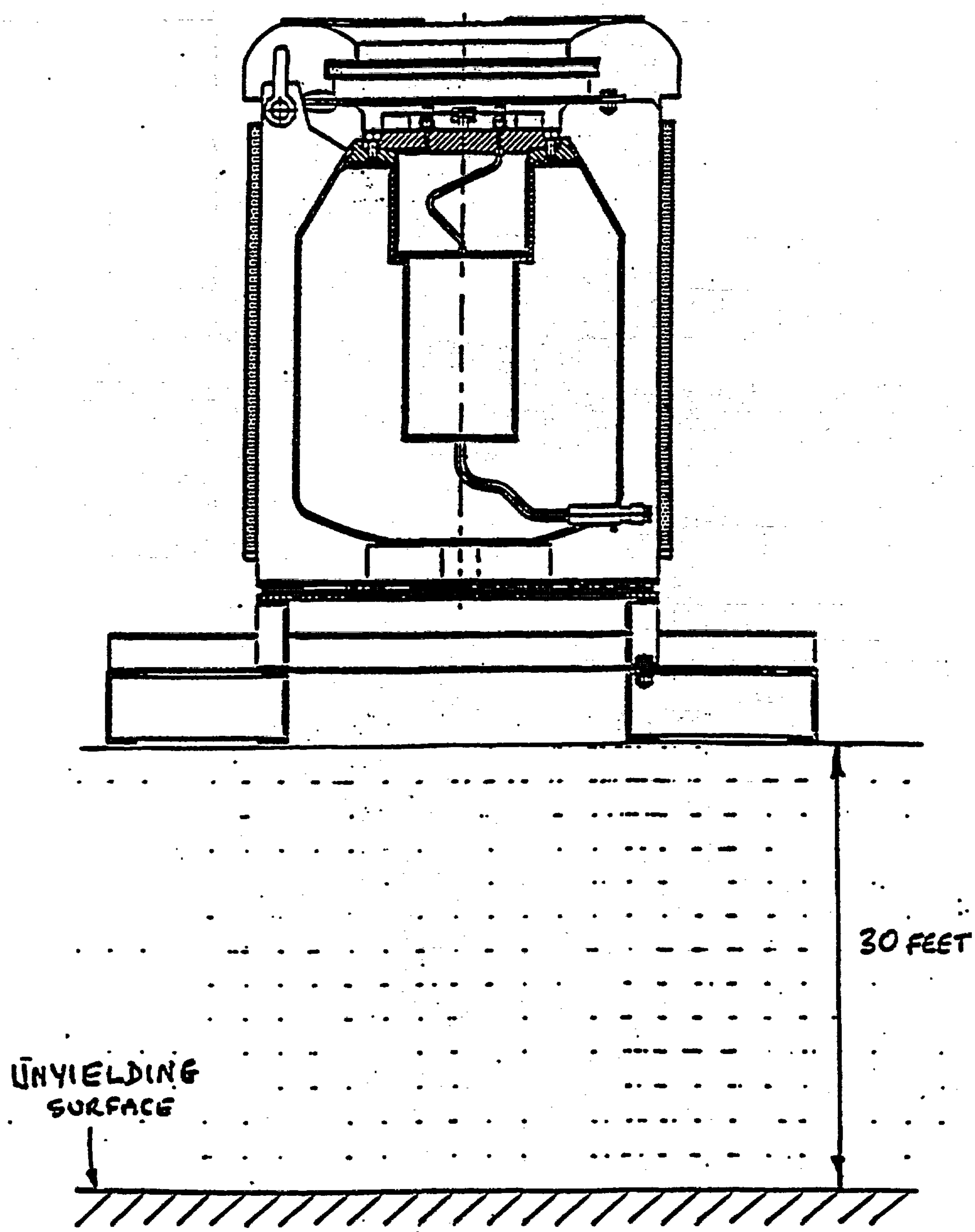


Figure 2.10.14-F19
Loading Arrangement of the Removable Shipping Skid

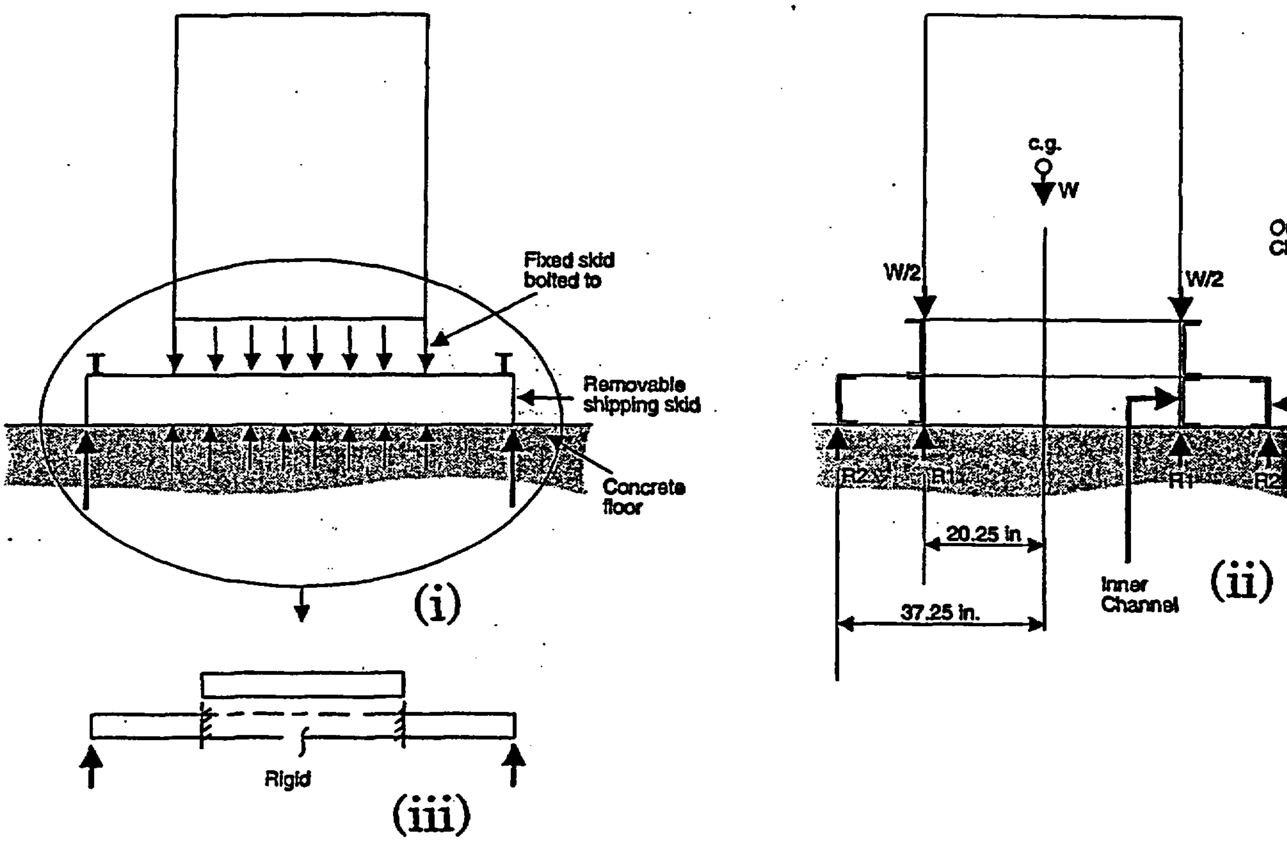
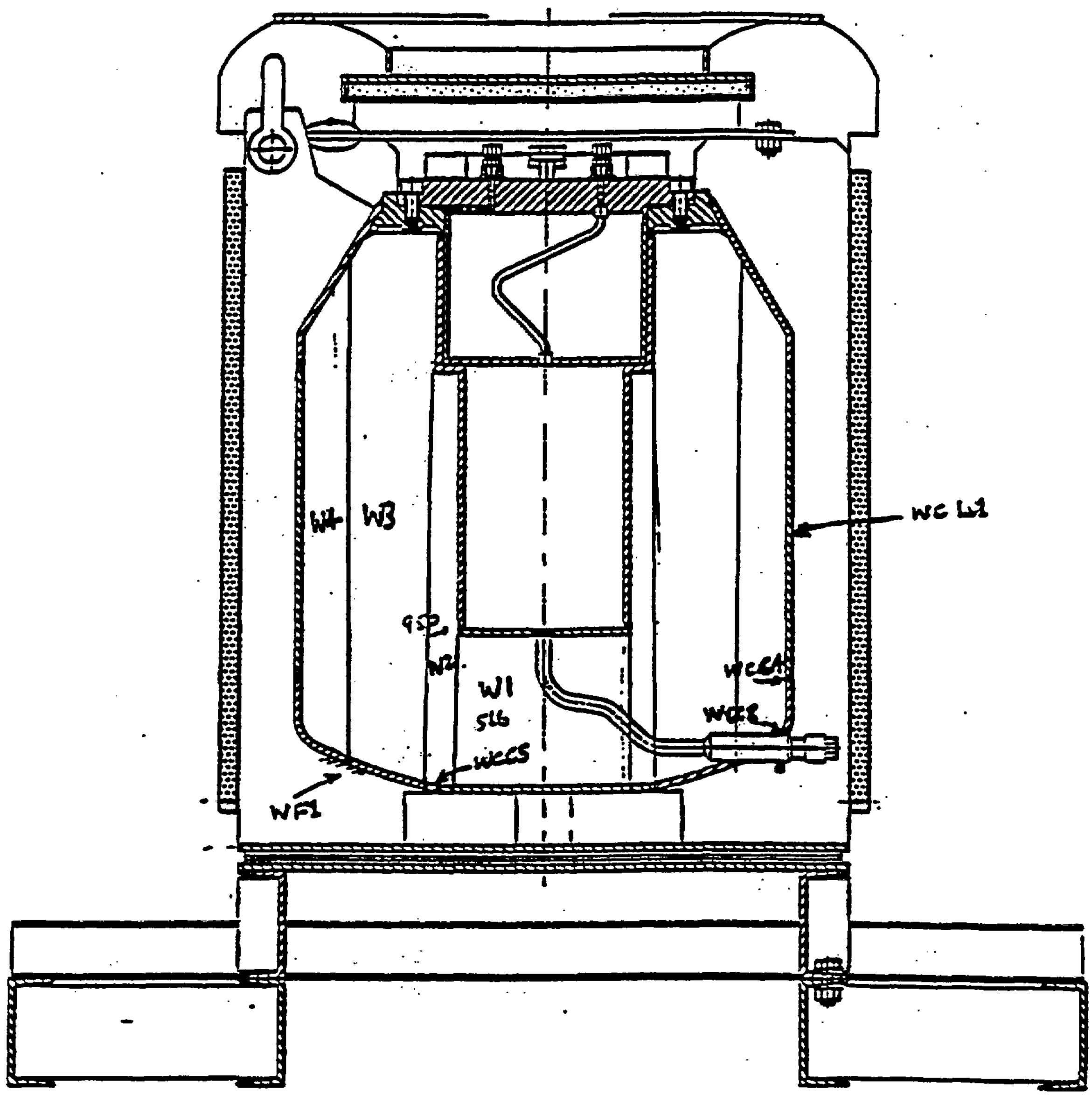


FIGURE WITHHELD UNDER 10 CFR 2.390

Figure 2.10.14-F22
Container in Bottom End Drop # Identification of Welds and Weights



4. STRESS ANALYSIS OF F-294 COMPONENTS IN SIDE DROP

4.1 G-LOADS

See Figure 2.10.14-F23 for Side Drop -Type 1.

See Figure 2.10.14-F24 for Side Drop -Type 2.

Based on measured G-load for F-294 in 30-ft. free drop test of 1) in side oblique drop orientation, highest G-load = 136 g's and 2) in the top end (inverted) drop orientation, highest G-load = 132 g's, it is inferred that for the side drop of F-294, the G-load shall be in the order of 136 g's.

4.2 EFFECT OF G-LOADS ON LEAD SHIELDED CONTAINER AND COMPONENTS

The F-294 component analysis is based on 136 g's.

4.2.1 Lower Cavity Tube Under Side Impact

See Figure 2.10.14-F25.

The analytical model is shown in Figure 2.10.14-F25. The bottom half of the tube is uniformly supported by the lead below it, and the top half is being compressed by the inertial weight, at impact, of the lead above it. For this analysis, the G-load in the cavity is assumed to be 136 g's.

Actual applied pressure, P (psi)

$P = W \times G/A$

where

W = weight

= volume (V) x density of lead (ρ_{LEAD})

V = volume of lead = $d \times h \times L = 12.5 \times 11.25 \times 20 = 2{,}812.5\ in^3$

$\rho_{LEAD} = 0.41\ lb./in^3$

$W = 2{,}812.5 \times 0.41 = 1{,}153.1$ lb.

A = area = $0.5\,\pi\, d\, L = 0.5\,\pi \times 12.5 \times 20 = 393\ in^2$

G = G-load = 136 g's.

$P = WG/A = 1{,}153. \times 136/393 = 399$ psi.

The critical external pressure P_C, at which elastic buckling occurs is calculated below. From Ref.[4], pp. 354, Case 34, Table XVI, Support condition: Curved edges free, straight edges at A and B clamped:

$P_C = Et^3 (k^2 - 1)/[12r^3(1 - \mu^2)]$

where

E = modulus of elasticity of ss304L = 27.6×10^6 psi

μ = Poisson's ratio for stainless steel = 0.3

t = lower cavity tube wall thickness = 0.5 in.

r = lower cavity tube inside radius = 5.75 in.

k = factor from Table XVI (where $k\tan\alpha \times \cot k\alpha = 1$) = 3 for $\alpha = 90°$

$P_C = 27.6 \times 10^6 \times 0.5^3 \times (3^2 - 1)/[12 \times 5.75^3 \times (1 - 0.3^2]$

= 14,930 psi.

Since the collapse pressure P_C (14,930 psi) is greater than the applied pressure P (399 psi), the cavity tube will not buckle. The cavity tube will not ovalize; therefore the source holder will not be compressed as a result of permanent displacement of the cavity wall. In other words, the source to the cavity wall geometry will be maintained before and after the impact test in the side drop orientation.

Factor of Safety (FS) = collapse pressure/applied pressure = 14,930/399 = 37.4
Margin of Safety (MS) = SF – 1 = 37.4 – 1 = 36.4
As the margin of Safety > 0, the lower cavity tube as specified is acceptable.

4.2.2 Shipping Skid to Fixed Skid - Retaining Skid Bolts

See Figure 2.10.14-F26
There are eight (8) retaining skid bolts of 1 in. dia., SAE Gr. 8 (i.e., 150,000 UTS).
Upon impact, the impact load shall be

P_{IMPACT} = $W_{CONTAINER\ LESS\ SHIPPING\ SKID}$ x G-load
= 20,030 lb. x 136 g's
= 2.724×10^6 lb.

Stress in bolt = P_{IMPACT}/ bolt area
= $2.724 \times 10^6 / 8 \times 0.551$
= 620,000 psi

Safety Factor = allowable stress/applied stress
= 0.6 x UTS/620,000 psi
= 0.6 x 150,000 psi/620,000 psi
= 0.193

Margin of Safety = Safety Factor – 1 = 0.193 – 1.0 = –0.807

As the Safety Factor is less than 1, the eight (8) retaining bolts shall be sheared. Consequently, the shipping skid shall be detached from the rest of the package. This is of no consequence as the shipping skid offers no thermal protection during the subsequent fire test. The shipping skid is a non-containment and a non-shielding component of the F-294 package. Therefore, its retention is not considered critical.

4.2.3 Closure Plug Bolts

See Figure 2.10.14-F27.
In the side drop, the closure plug is held to the container by 16 fasteners of 1 in. dia., UNBRAKO (i.e., 180,000 UTS). The clearance between the shank of the fastener and the unthreaded hole is 0.0625 in. The clearance between the plug and the container upper cavity is 0.040 in.

Therefore, in the side impact, the cylindrical side of the plug body will impact prior to the start of shearing of plug/container bolts. Therefore, in this calculation it is assumed that

- the weight of the ss flange of the plug assembly is resisted by 16 bolts.
- the weight of the plug (i.e., lead shielding etc.) is resisted by the one-third (1/3) cylindrical arc of the container upper cavity.

The weight of the plug flange and shield ring is estimated to be

$W_{PLUG\ FLANGE}$ = 500 lb.

The deceleration load is 136 g's. Therefore the impact load on the bolts is

P_{IMPACT} = $W_{PLUG\ FLANGE}$ x G-load
= 500 x 136
= 68,000 lb.

Shear area per bolt, $A_{SHEAR\ AREA}$

$A_{SHEAR\ AREA}$ = 0.551 in^2

Shear stress per bolt, τ

τ = P_{IMPACT}/[$A_{SHEAR\ AREA}$ x number of bolts]
= 68,000/[0.551 x 16]
= 68,000/8.816
= 7,720 psi.

Safety Factor (SF)

SF = allowable stress/applied shear stress
= 0.6 x UTS/τ
= 0.6 x 180,000/7,720
= 14.0

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = SF – 1 = 14 – 1 = 13

As the Margin of Safety > 0, the closure plug bolts as specified are acceptable.

4.2.4 Plug Cylindrical Body

One-third (1/3) of the cylindrical upper cavity body resists the side impact.

$W_{PLUG\ LESS\ FLANGE}$ = 1,070 – 500 = 570 lb.

The impact load, at deceleration of 136 g's is

P_{IMPACT} = $W_{PLUG\ LESS\ FLANGE}$ x 136 g's
= 570 x 136 lb.
= 77,520 lb.

Area resisting the impact A = 0.33 x π 14.790 x 10 = 154.7 in^2

Bearing stress, $\sigma_{bearing}$

$\sigma_{bearing}$ = P_{IMPACT}/A
= 77,520/154.7
= 501 psi.

Safety Factor (SF)

SF = allowable stress/applied compressive stress
= UTS/$\sigma_{bearing}$
= 70,000/501
= 139.7

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = SF – 1 = 139.7 – 1 = 138.7
As the margin of Safety (MS) > 0, the closure plug body as specified is acceptable.

4.2.5 Plug welds WPC1 and WPC2

There are two (2) plug welds that resist the side impact. See Figure 2.10.14-F28, for the weights and dimensions. In addition the plug bolt share the side impact. In the following calculation, it is assumed that the entire deceleration load is taken up by only one weld WCP1; this is conservative.

WPC1: Weld area = π x 12.710 x 0.5 x 0.707 = 14.1 in^2

As the weld is fully radiographed, the joint efficiency is 100%.
Weld WPC1 resists 100% of the weight of the plug assembly.

Therefore the impact load is

P_{IMPACT} = W_{PLUG} x Deceleration load
= 1,070 x 136 g's
= 145,520 lb.

Shear stress, τ = P_{IMPACT}/Weld area
= 145,520/14.1
= 10,320 psi

Safety Factor (SF)

SF = allowable stress/applied shear stress
$= 0.6 \times UTS/\tau$
$= 0.6 \times 70{,}000/10{,}320$
$= 42{,}000/10{,}320$
$= 4.07$

Margin of Safety, $MS_{STRESS\text{-}BASED} = SF - 1 = 4.07 - 1 = 3.07$
As the Margin of Safety (MS) . 0, the closure plug welds as specified are acceptable.

4.2.6 Container Shell

In the side drop, the container shell is subjected to deceleration loads due to 136 g's. In particular the circumferential welds WCC1, WCC2, WCC3, WCC4, WCC5, WCC7 and longitudinal weld WCL1 and longitudinal container to fin fillet welds WF resist the deceleration loads. Figure 2.10.14-F29 depicts the loading.

Step #1a
Estimate the weights carried above weld WCC4.

Weight W_1 = Volume of lead x density of lead
$= [\pi \times 17.5^2 \times 6.125 + \pi \times ((17.5+7.5)/2)^2 \times 5.125] \times 0.410$
$= [5{,}893.7 + 2{,}516] \times 0.410$
$= [8{,}409.7] \times 0.410$
$= 3{,}447$ lb.

Step #1b
Estimate the weights carried above weld WCC3, WCC7, WCL1. See Figure 2.10.14-F29.

The weight of lead above the cavity tube is excluded as that weight directly impacts the cavity tube structure.

Weight W_2 = density of lead x net volume of lead
= density of lead x (volume of lead minus volume of lead projected above cavity)
$= [[\{\pi \times (17.5^2 - 6.25^2) \times 20\} + \{\pi \times ((17.5^2 - 7.9^2) \times 1.8125\} + \{\pi \times 8.688 \times ((17.5 + 12)/2)^2 - 7.9^2\}] - [\{2 \times 6.25 \times 20 \times (17.5 - 6.25)\} + \{1.8125 \times 2 \times 7.9 \times (17.5 - 7.9)\} + \{8.688 \times 2 \times 7.9 \times (((17.5 + 12)/2) - 7.9)\}]]$
$= 0.410 \times [[16{,}790 + 1{,}388 + 4{,}235] - [2{,}812 + 275 + 940]]$
$= 0.410 \times [22{,}413 - 4{,}027]$
$= 0.410 \times 18{,}386$
$= 7{,}538$ lb.

W $= W_1 + W_2$
$= 3{,}447 + 7{,}538$ lb.
$= 10{,}985$ lb.

Step #2
Estimate the impact load based on 136 g's deceleration in side drop orientation.

P_{IMPACT} = Weight W x Deceleration load (136 g's)
= 10,985 lb. x 136 g's
$= 1.493 \times 10^6$ lb.

Step #3
Estimate the effective areas of welds.

There are eight (8) welds that resist this magnitude of impact load. The welds are: WCC1, WCC2, WCC3, WCC4, WCC5, WCC7 and longitudinal weld WCL1 and longitudinal container to fin fillet welds WF. As far as the fin-to-shell welds are concerned, it is assumed the bottom half of the 36 fins resist the impact load.

Area of weld WCC1: $A_{WCC1} = 2\pi \times 11.812 \times 0.5 \times 0.707 = 26.23\ in^2$
Area of weld WCC2: $A_{WCC2} = 2\pi \times 12.812 \times 0.5 \times 0.707 = 28.46\ in^2$
Area of weld WCC3: $A_{WCC3} = 2\pi \times 17.5 \times 0.5 \times 0.707 = 38.87\ in^2$
Area of weld WCC4: $A_{WCC4} = 2\pi \times 17.5 \times 0.5 \times 0.707 = 38.87\ in^2$
Area of weld WCC5: $A_{WCC5} = 2\pi \times 7.5 \times 0.5 \times 0.707 = 16.66\ in^2$
Area of weld WCC7: $A_{WCC7} = 2\pi \times 12 \times 0.5 \times 0.707 = 26.65\ in^2$
Area of weld WCL1: $A_{WCL1} = 26 \times 0.5 \times 0.707 = 9.19\ in^2$
Area of weld WF: A_{WF} = no. of fins x no. of fillet welds x thickness of weld x length of weld x 0.707
$= 18 \times 2 \times 0.375 \times 26 \times 0.707$
$= 248\ in^2$

Joint Efficiency for fillet weld $\eta_1 = 80\%$
Joint efficiency for butt weld $\eta_2 = 100\%$
Effective Area of weld WCC1: $A_{EFFECTIVE, WCC1} = A_{WCC1} \times \eta_1 = 26.23 \times 0.8 = 20.98\ in^2$
Effective Area of weld WCC2: $A_{EFFECTIVE, WCC2} = A_{WCC2} \times \eta_1 = 28.46 \times 0.8 = 22.77\ in^2$
Effective area of weld WCC3: $A_{EFFECTIVE, WCC3} = A_{WCC3} \times \eta_2 = 38.87 \times 1.0 = 38.87\ in^2$
Effective area of weld WCC4: $A_{EFFECTIVE, WCC4} = A_{WCC4} \times \eta_2 = 38.87 \times 1.0 = 38.87\ in^2$
Effective area of weld WCC5: $A_{EFFECTIVE, WCC5} = A_{WCC5} \times \eta_2 = 16.66 \times 0.8 = 13.32\ in^2$
Effective area of weld WCC7: $A_{EFFECTIVE, WCC7} = A_{WCC5} \times \eta_1 = 26.65 \times 0.8 = 21.32\ in^2$
Effective area of weld WCL1: $A_{EFFECTIVE, WCL1} = A_{WCL1} \times \eta_2 = 9.19 \times 1.0 = 9.19\ in^2$
Effective area of weld WF: $A_{EFFECTIVE, WF} = A_{WF} \times \eta_1 = 248.0 \times 0.8 = 198.4\ in^2$

Step #4
Estimate the stress on the welds

$\tau = P_{IMPACT}/[\Sigma\ A_{EFFECTIVE, WCC1} + A_{EFFECTIVE, WCC2} + A_{EFFECTIVE, WCC3} + A_{EFFECTIVE, WCC4}$
$+ A_{EFFECTIVE, WCC5} + A_{EFFECTIVE, WCC7} + A_{EFFECTIVE, WCL1} + A_{EFFECTIVE, WF}]$
$= 5.822 \times 10^6/[20.98 + 22.77 + 38.87 + 38.87 + 13.32 + 21.32 + 9.19 + 198.4]$
$= 1.493 \times 10^6/[363.7]$
$= 4{,}105$ psi

Safety Factor (SF) = allowable stress/applied stress
$= 0.6 \times UTS/\tau$
$= 0.6 \times 70{,}000$ psi/4,105 psi
$= 42{,}000/4{,}105$
$= 10.23$
Margin of Safety, $MS_{STRESS\text{-}BASED} = SF - 1 = 10.23 - 1 = 9.23$

As the Margin of Safety (MS) > 0, the container welds as specified are acceptable.

4.2.7 Container Shell Under the External Cooling Fin

See Figure 2.10.14-F30.
The impact load is acting on the fireshield and then transmitted to external cooling fins welded on the container shell. The magnitude of this impact load is

$$P_{SIDE\ IMPACT} = W_{F\text{-}294} \times \text{G-load} = 21{,}000 \times 136 = 2.856 \times 10^6 \text{ lb.}$$

The impact area is bounded by four fins and 44-inch length of the container. The effective shell impact area that resists this impact is $A_{SHELL\ IMPACT\ AREA} = 4 \times 44 \times 3.142 = 553\ in^2$. The average compressive stress in the shell

$$\sigma_C = P_{SIDE\ IMPACT}/A_{SHELL\ IMPACT\ AREA} = 2.856 \times 10^6/553 = 5{,}170 \text{ psi.}$$

Safety Factor (SF) = allowable stress/applied stress
= UTS/σ_C
= 70,000/5,170
= 13.53

Margin of Safety, $MS_{STRESS\text{-}BASED} = SF - 1 = 13.53 - 1 = 12.53$

As the SF > 1 and as MS > 0, the container shell will not fracture in the zone around the cooling fins and the shell in a 30-ft side drop of the F-294.

4.2.8 C-188 in Side Drop Impact

The C-188 sealed source is classified Special Form meeting the 10 CFR 71.77 requirements; therefore, C-188 provides the leaktight containment. The USNRC source registration number for C-188 is NR-222-S-103-S (see Appendix 4.4.2).

The C-188 is in the F-294 cavity. The C-188 is normally held within the F-313 source holder with three (3) clear spans of 5 in. with the balance of column length free (i.e., overhang). In a side drop, the C-188 loading case is represented in the model as per Figure 2.10.14-F31. The G-load which the C-188 could be subjected to is 136 g's. However, for design analysis we shall use G-load = 1,000 g's to be conservative.

The detailed analysis is presented in Chapter 4, Appendix 4.4.5. It is calculated that the maximum bending stress (beam analysis) is

$$\sigma_{bending} = 47{,}800 \text{ psi}$$

SF = allowable stress/applied stress
= UTS of ss316L at 836°F/$\sigma_{bending}$
= 60,000/47,800
= 1.25

Margin of Safety, MS = SF – 1 = 1.25 – 1 = 0.25

The shear stress, τ = 5,926 psi

SF = allowable stress/applied stress
= UTS of ss316L at 836°F/τ
= 0.6 x 60,000/5,927
= 6.07

Margin of Safety, MS = SF – 1 = 6.07 – 1 = 5.07

As the Margin of Safety > 0, the C-188 in side impact will be structurally sound.

4.2.9 Estimate of Lead Movement or Slump

When the container without the fins is approximated to a cylindrical cask with flat end plates dropped in side drop orientation, the container will absorb energy upon impact in three ways:

1. by deformation of end plates
2. movement of lead
3. deformation of cylindrical outer shell.

A relatively small amount of energy is absorbed in bending the steel shell at the point of impact and is, therefore neglected in this analysis. Such a model is presented in Figure 2.10.14-F32.

Shappert (Ref. [8], page 59) has provided a method of estimating the amount of lead movement for such a cask. We shall apply formula as per Ref. [8], page 59 to estimate lead movement in the F-294 container. It should be noted that 75% of the energy absorption has been accounted for in Appendix 2.10.9, consequently only the remaining 25% of the potential energy due to the 30-ft drop height of the package needs to be considered. However, the 25% factor shall be increased to 36% of 30-ft drop height energy to provide a conservative estimate of the lead slump.

The formula is:

$$WH/t_S RL\sigma_S = [F_1(\theta)][R/t_S(\sigma_{Pb}/\sigma_S) + 2(R/L)(t_e/t_S)] + F_2(\theta)$$

where

W	= effective cask weight = 21,000 lb. – W_{skid} = 21,000 – 980 = 20,020 lb.
H	= effective drop height = 36% of 30 feet = 129.6 in.
$F_1(\theta)$	= $\theta - 1/2(\sin 2\theta)$
$F_2(\theta)$	= $\sin\theta(2 - \cos\theta) - \theta$
R	= the outer shell radius = 18 in.
t_S	= the outer shell thickness = 0.5 in.
L	= length of the shell = 50.25 – 6.0 = 44.25 in.
σ_S	= the dynamic flow stress of ss304 shell, psi = 50,000 psi
σ_{Pb}	= the dynamic flow stress in lead = 5,000 psi
t_e	= thickness of ss304 end plate = 0.5 in.
θ	= the angle defined in Figure 2.10.14-F33, deg.

Above formula is based on assumptions that the yield point stress of the ss304 end piece is the same as that of the ss304 shell and that the end pieces are of equal thickness. In order to use above formula, the angle θ and the cask geometry must be known. The angle θ may be determined from Figure 2.10.14-F34 (reproduced from Ref. [8], Shappert, p 61), which is based on above formula. The maximum displacement of shielding represented by the outer shell flattening, δ, may be calculated by $\delta = R(1 - \cos\theta)$.

Calculate Non-dimensional Resistance Parameter #1.

$$= [R/t_S(\sigma_{Pb}/\sigma_S) + 2(R/L)(t_e/t_S)]$$
$$= [18/0.5(5000/50000) + 2(18/44.25)(0.5/0.5)]$$
$$= [3.6 + 0.8135]$$
$$= [4.4135]$$

Calculate Non-dimensional Energy Parameter #2.

$$= [WH/t_S RL\sigma_S]$$
$$= [20020 \times 129.6/(0.5 \times 18 \times 44.25 \times 50000)]$$
$$= [0.1303]$$

Use nomograph as per Figure 2.10.14-F34, with Parameter #1 = 4.4135 and parameter # 2 = 0.1303. Connect the line between the two parameters and read the value of θ = 20°.

Therefore

$$\delta = R(1 - \cos\theta)$$
$$\delta = 18(1 - \cos(20°))$$
$$\delta = 18(1 - 0.939)$$
$$\delta = 1.086 \text{ in.}$$

Now $\delta = t_S + \Delta_{lead}$

where

t_S = thickness of flattened ss304 shell = 0.5

Δ_{lead} = amount of lead shielding displaced

$\Delta_{lead} = \delta - t_S$
$= 1.086 - 0.5$
$= 0.586$ in.
$= 0.6$ in. (rounded up).

To summarize, in the side drop orientation, it is estimated that the amount of lead shielding displaced in the F-294 container is 0.6 in., which represents approximately 1.5 half-value layers of lead shielding for cobalt-60.

4.3 Summary of Side Drop #1 and #2 Analysis

1. Based on tests of similar packages, it is estimated that the G-loads in side drop can be of the order of 136 g's.
2. Based on 136 g's deceleration load, the following components of the F-294 package were stress analyzed, the corresponding stresses or loads, Safety Factors (SF) and Margins of Safety (MS) are listed here:

Plug

	Stress (psi)	SF	MS
- Bolts, shear	7,720	14	13
-Cylindrical body, bearing	501	139.7	138.7
- Weld: WPC1	10,320	4.07	3.07

Container

	Stress (psi)	SF	MS
- weld group WCC1, WCC2, WCC3, WCC4, WCC5, WCC7, and WF1	4,105	10.23	9.23
- lower cavity tube (buckling)		37.4	36.4
- ext. shell, under cooling fin	5,170	13.53	12.53

Other components

Shipping skid to fixed skid bolts will shear.

In the side drop, the three (3) most vulnerable zones are:

- bolts fastening the shipping skid to the fixed skid
- plug weld WPC1
- container shell ext. welds

It is expected that the bolts fastening the shipping skid to the fixed skid will shear. In the case of the closure plug welds the margin of safety, based on static UTS is greater than zero (0). Consequently, it appears that this will not lead to the ductile failure of the plug welds nor the container external shell welds. Therefore the structural integrity of:

- The ss304 envelope surrounding the lead shielding in the plug is sound and there are no cracks; thus the lead shielding does not have potential leak paths in a scenario of lead melt.
- The ss304 envelope surrounding the lead shielding in the container body is sound and there are no cracks; thus the lead shielding does not have potential leak paths in a scenario of lead melt.
- The closure plug bolts will not shear under 136 g's deceleration loads; consequently the closure plug shielding will be in place over the inner shell assembly which houses the Special Form C-188 sealed sources.

3. There is some damage to the thermal protection. The cylindrical fireshield is flattened by an area approximately 44 in. long and 12 in wide. The thermal insulation shall be compressed, however there is no loss of thermal protection.
4. The C-188 sealed source, in a side drop, is subjected to a maximum bending stress of 47,800 psi, based on 1000 g's deceleration load. The safety factor is 1.25 and the margin of safety is +0.25. There is an additional margin of safety attributed to the design G-load of 1,000 g's versus G-load of 136 g's in the F-294 cavity.
   C-188 sealed source is classified Special Form meeting the 10 CFR 71.77 requirements; therefore, C-188 provides the leaktight containment. The USNRC source registration number for C-188 is NR-222-S-103-S (see Chapter 4, Appendix 4.4.2).
5. Assuming 36% of the impact energy is absorbed by the container cylinder, the lead shielding and the ends, the amount of lead shielding displacement (flattened) is expected to be 0.6 in., which represents approximately 1.5 half-value layers of lead shielding for cobalt-60.

Figure 2.10.14-F23
F-294 in Side Drop #1 (entire length of channel impact)

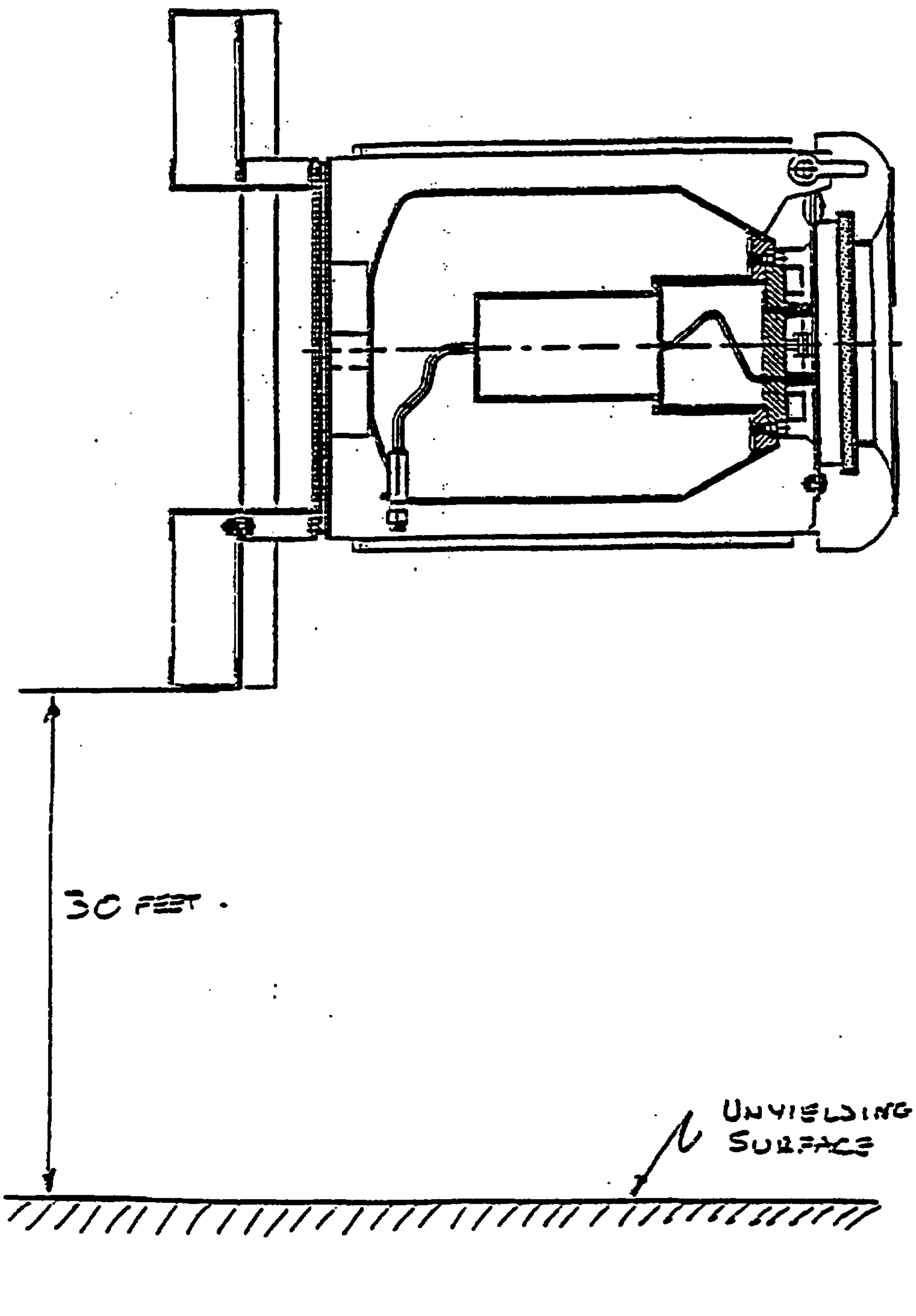


Figure 2.10.14-F24
F-294 Side Drop #2 Orientation (channel impacting on ends)

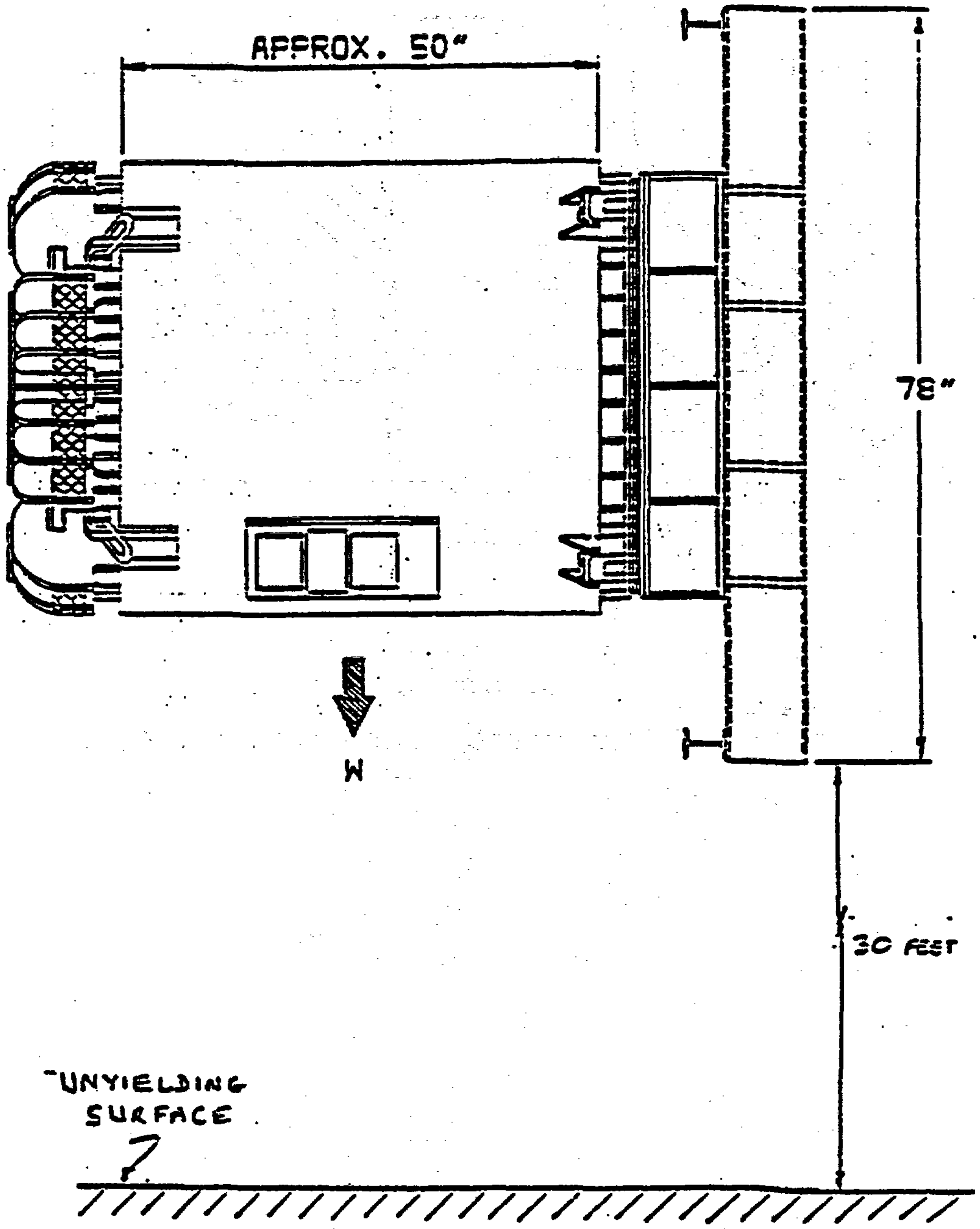


Figure 2.10.14-F25
Side Drop: Lateral Load on the Lower Cavity Tube

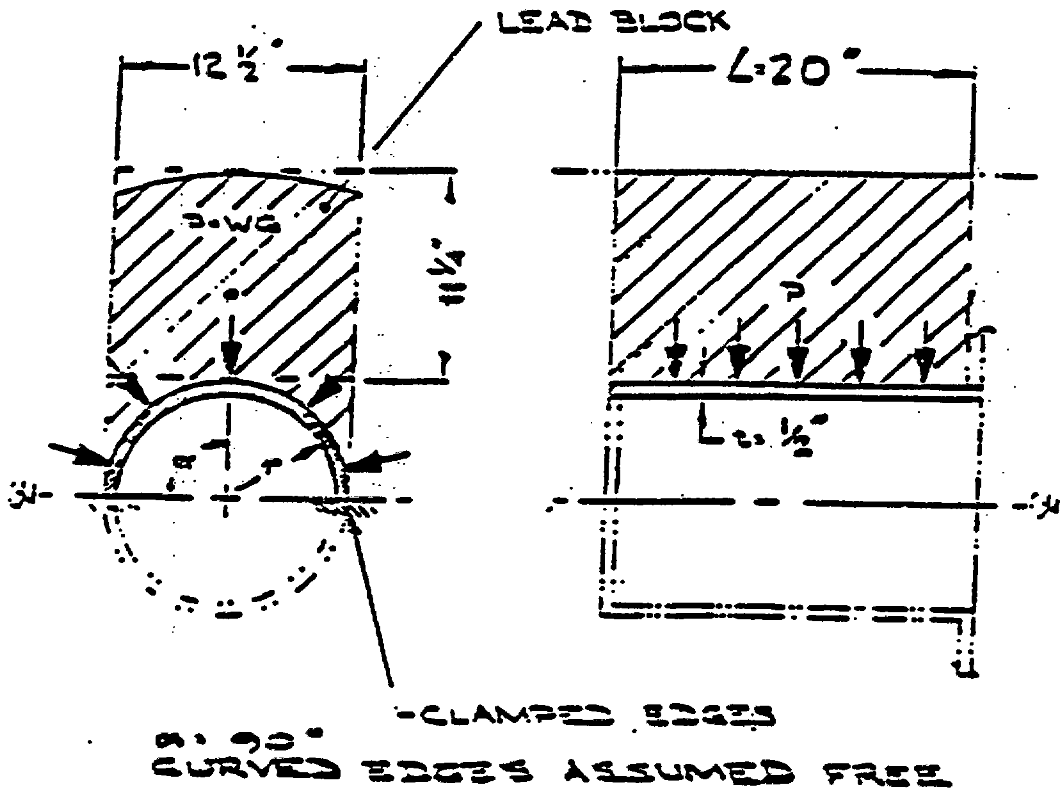


Figure 2.10.14-F26
Shearing Bolts - Shipping Skid to Fixed Skid

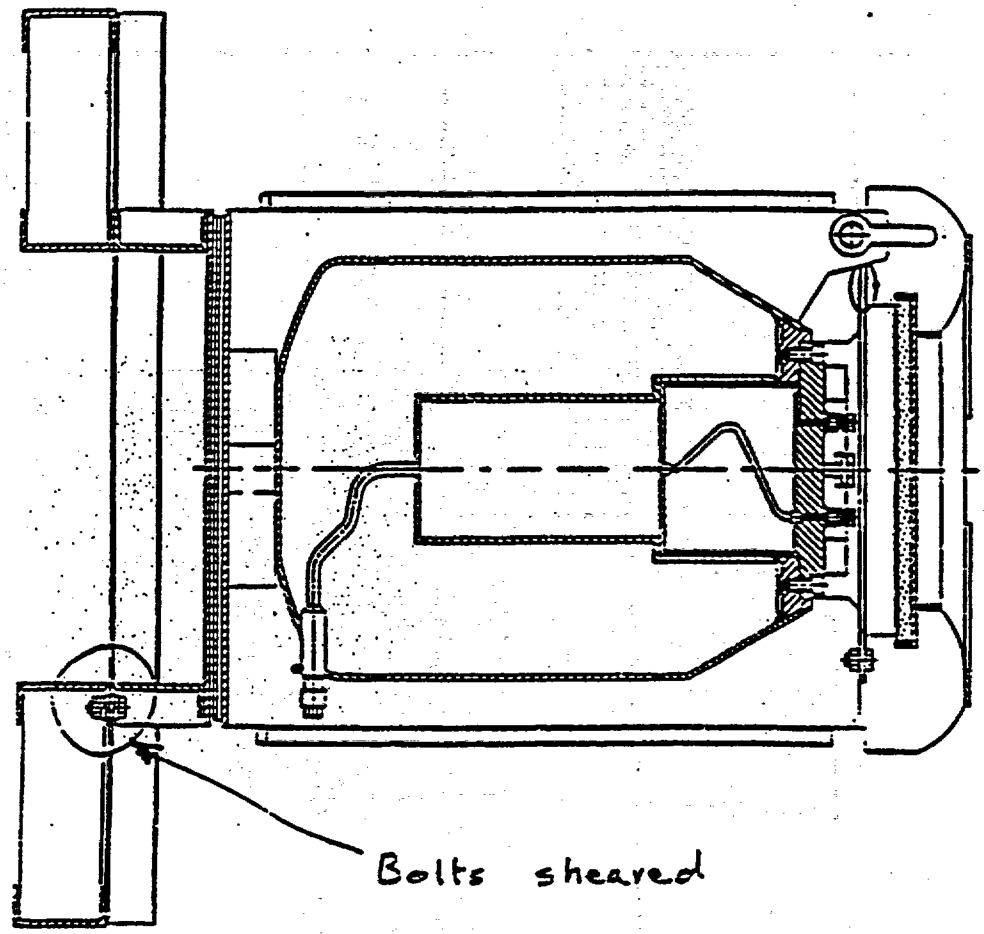


Figure 2.10.14-F27
Plug Cylindrical Body Impacting on Side - Plug Bolt Shearing

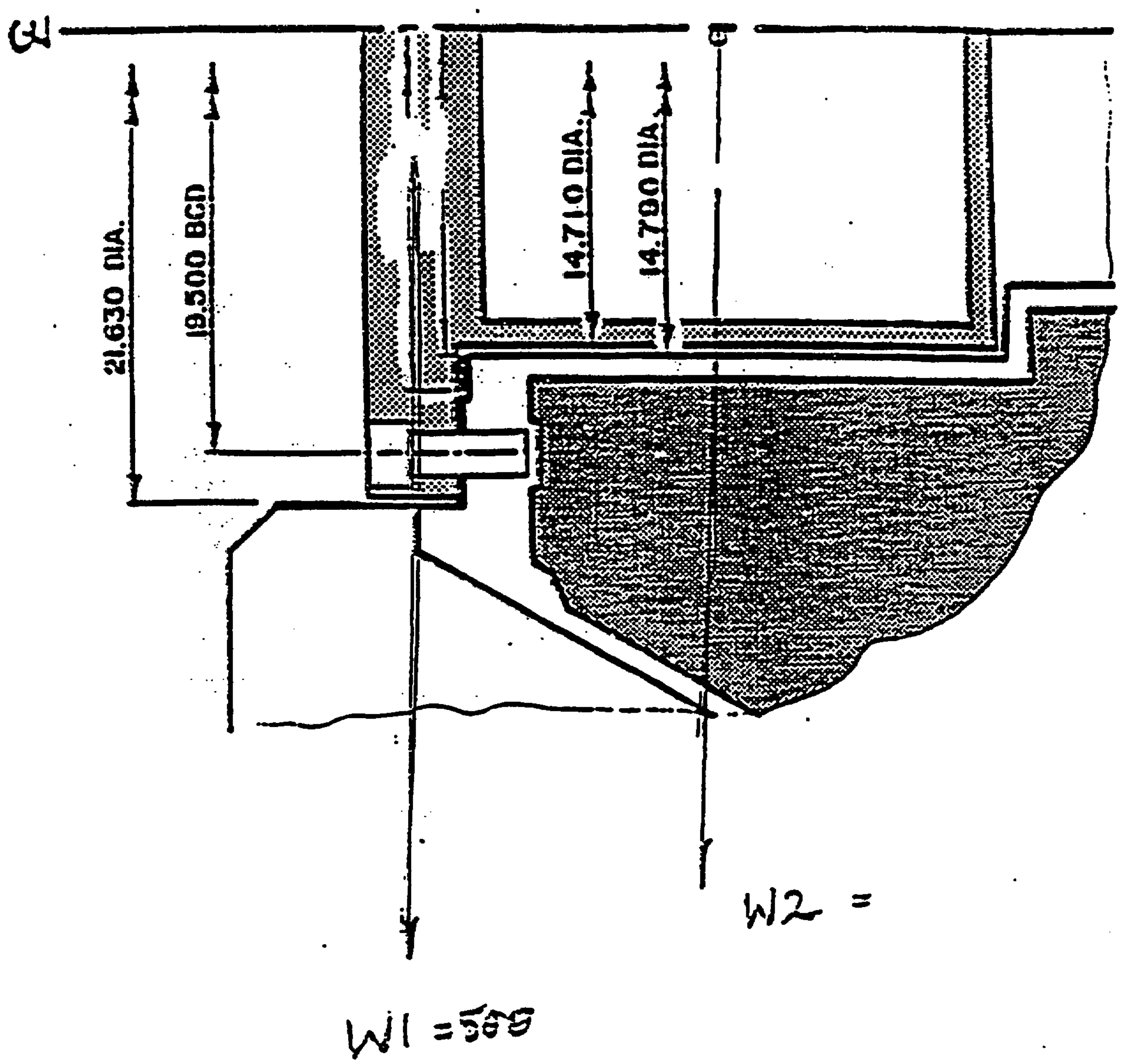


Figure 2.10.14-F28
Plug Cylindrical Body Impacting on Side - Plug Welds

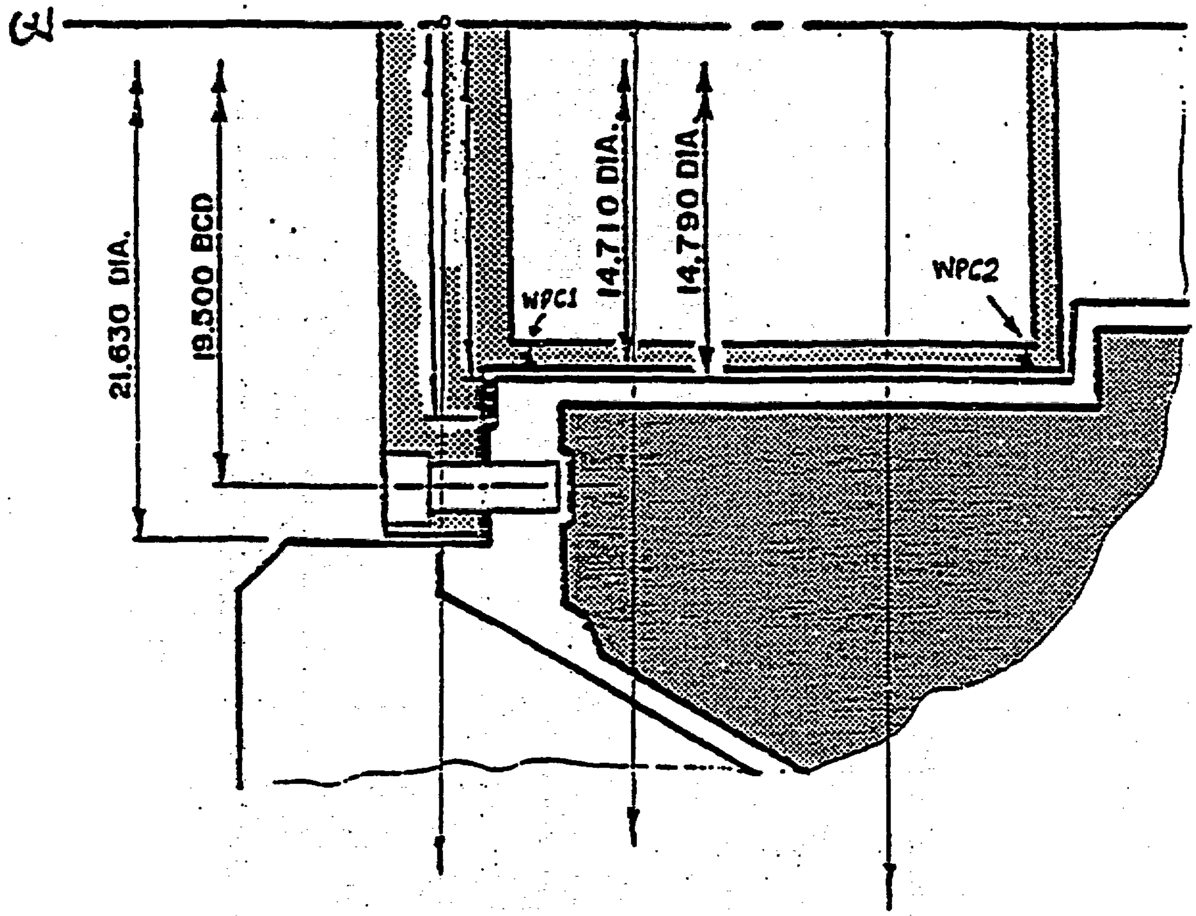


Figure 2.10.14-F29
Container Welds

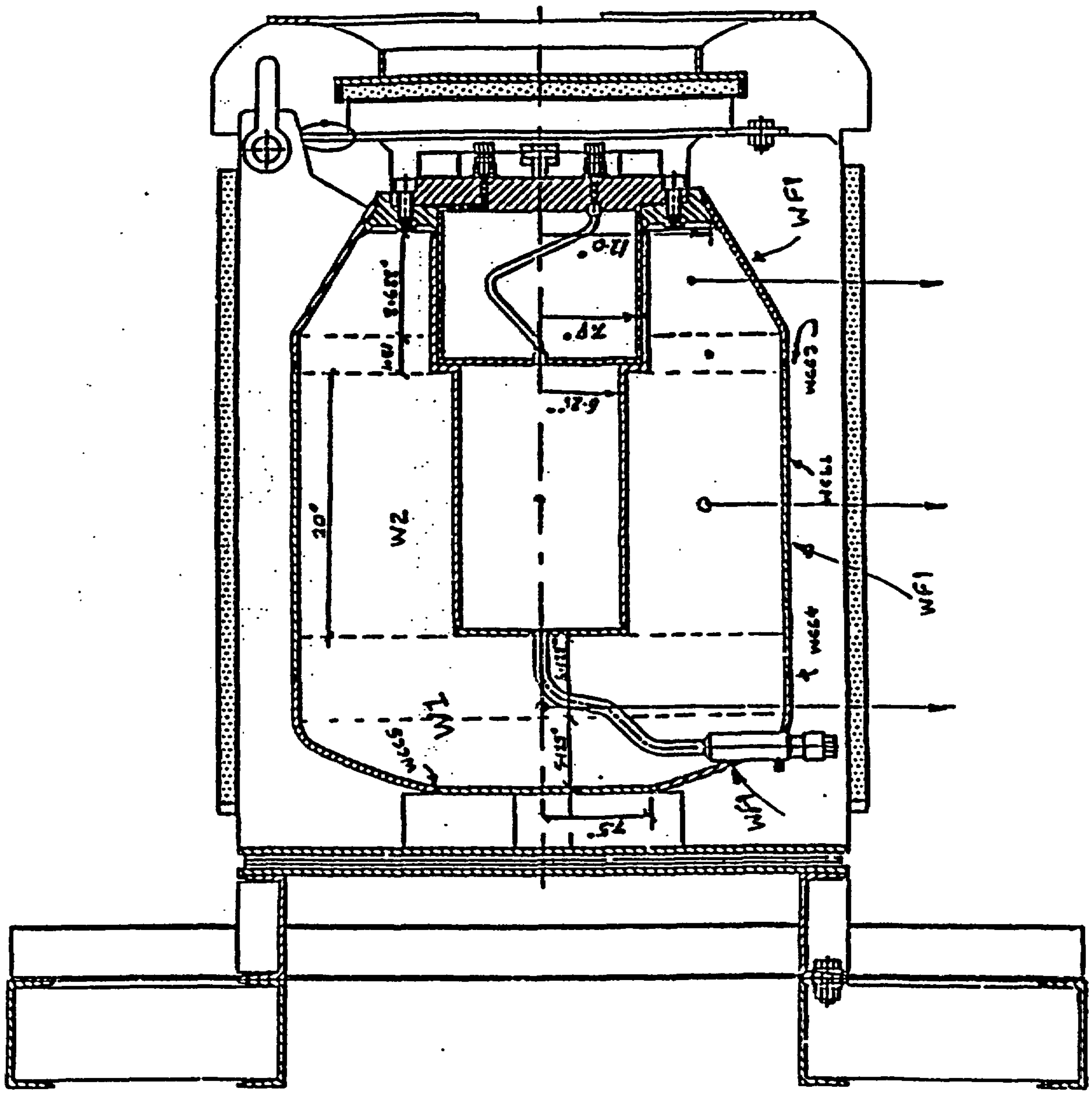


Figure 2.10.14-F30
Container Shell under Fin Side Impact

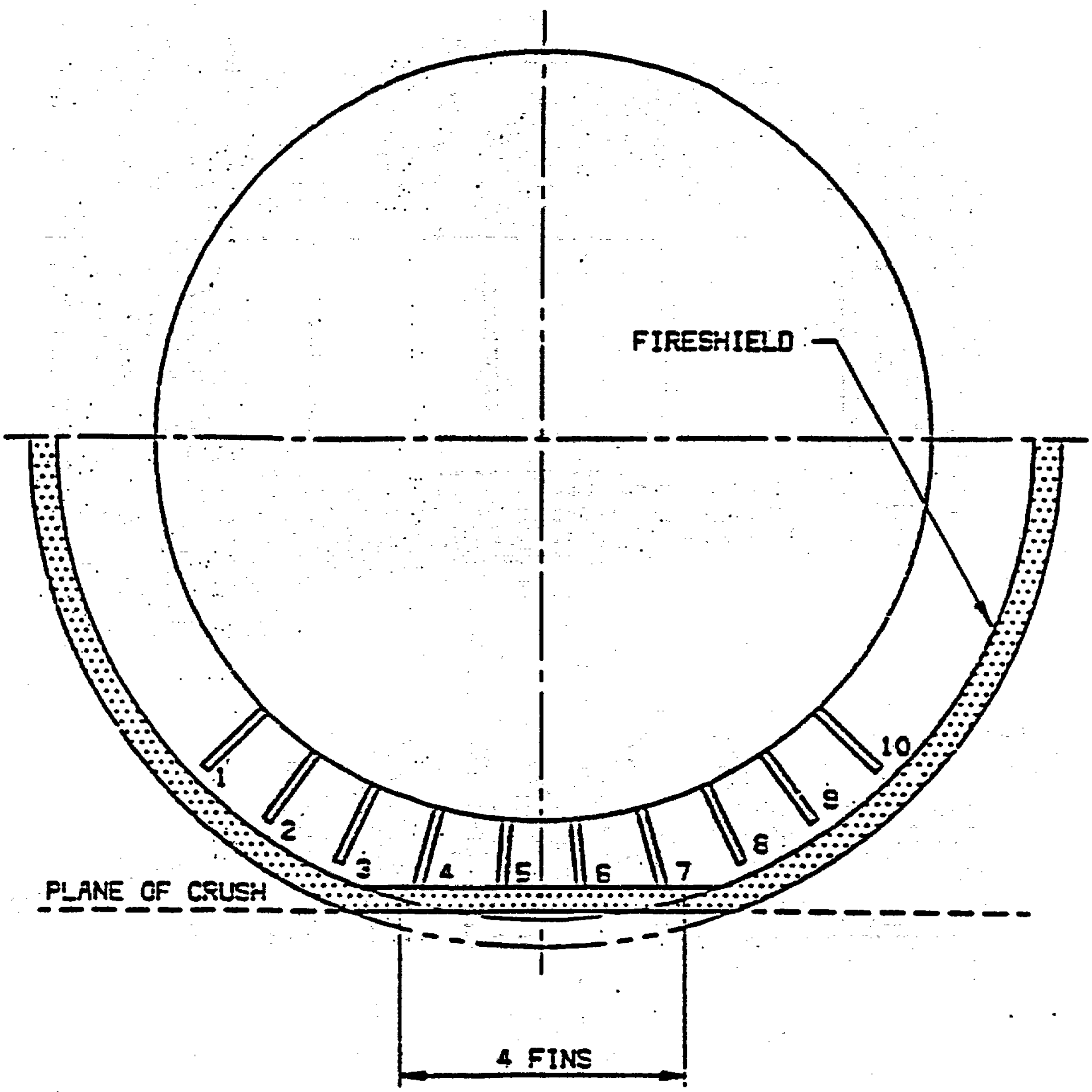
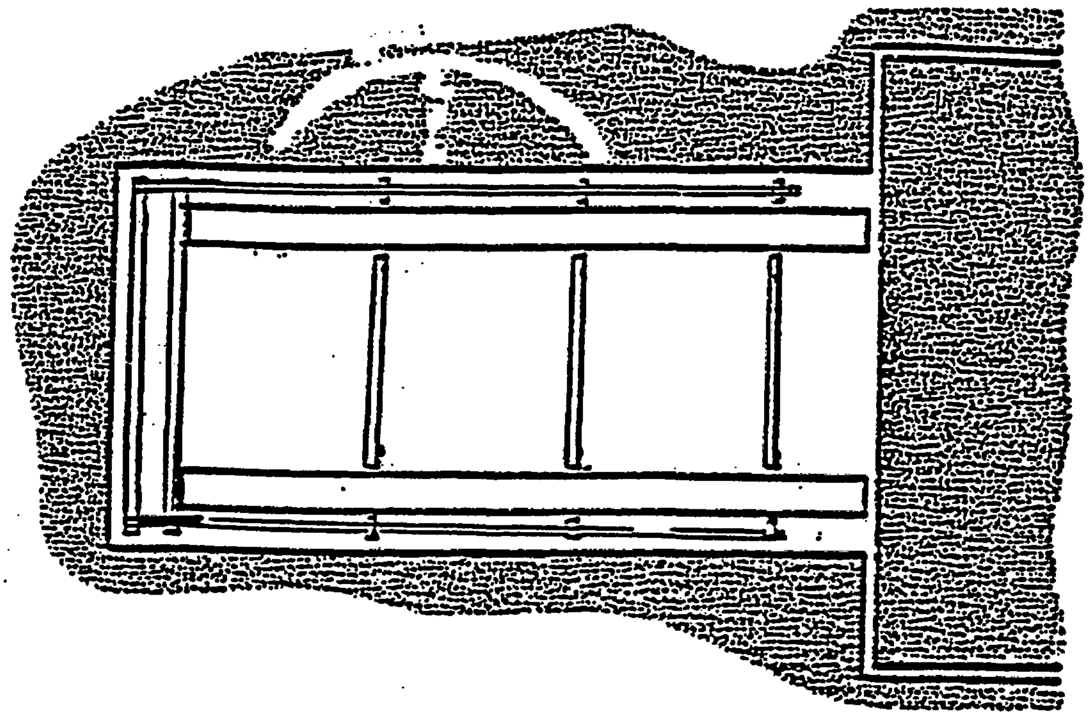


Figure 2.10.14-F31
C-188 Model in a F-294 Side Drop Impact



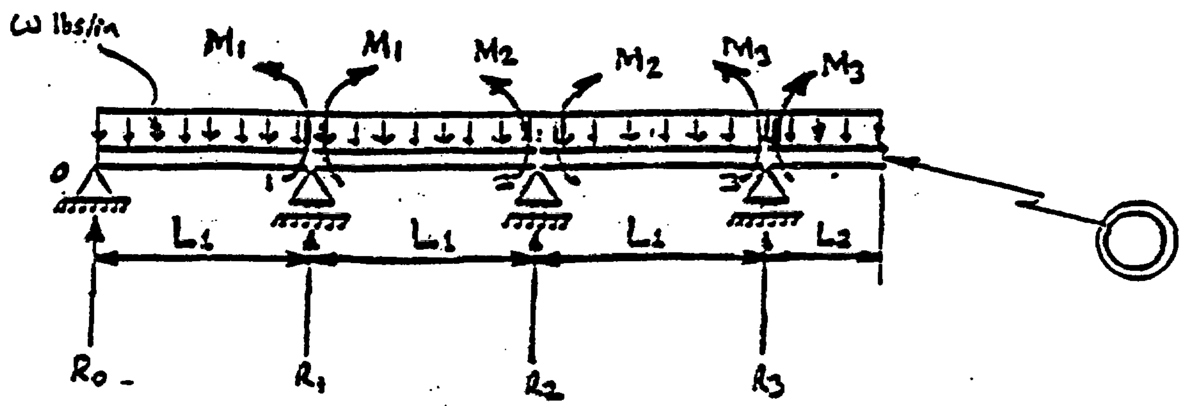
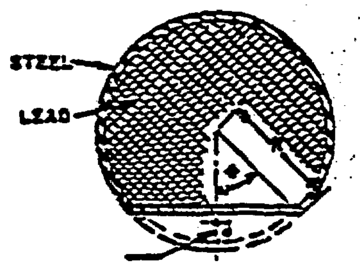
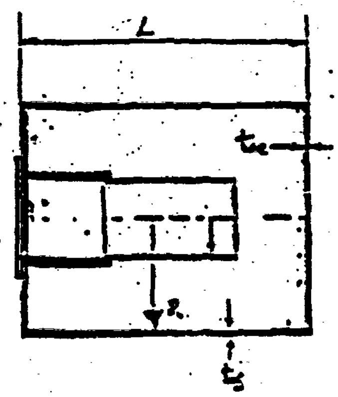


Figure 2.10.14-F32
Container Model for Estimating Lead Slump or Displacement in Side Drop





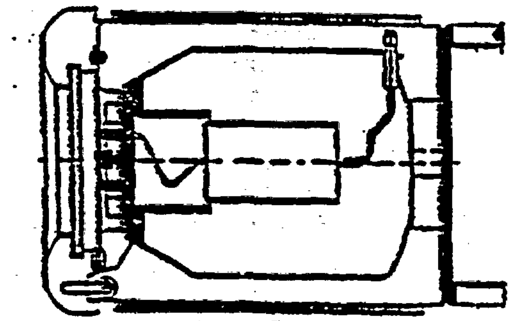


Figure 2.10.14-F33
End View of the Deformation in a Steel-encased Solid Lead Cylinder

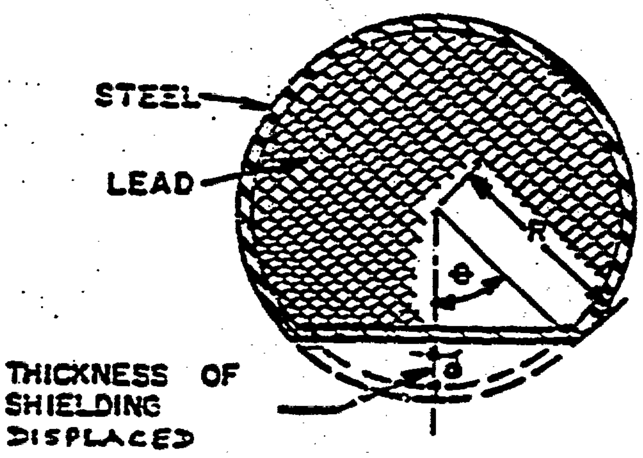
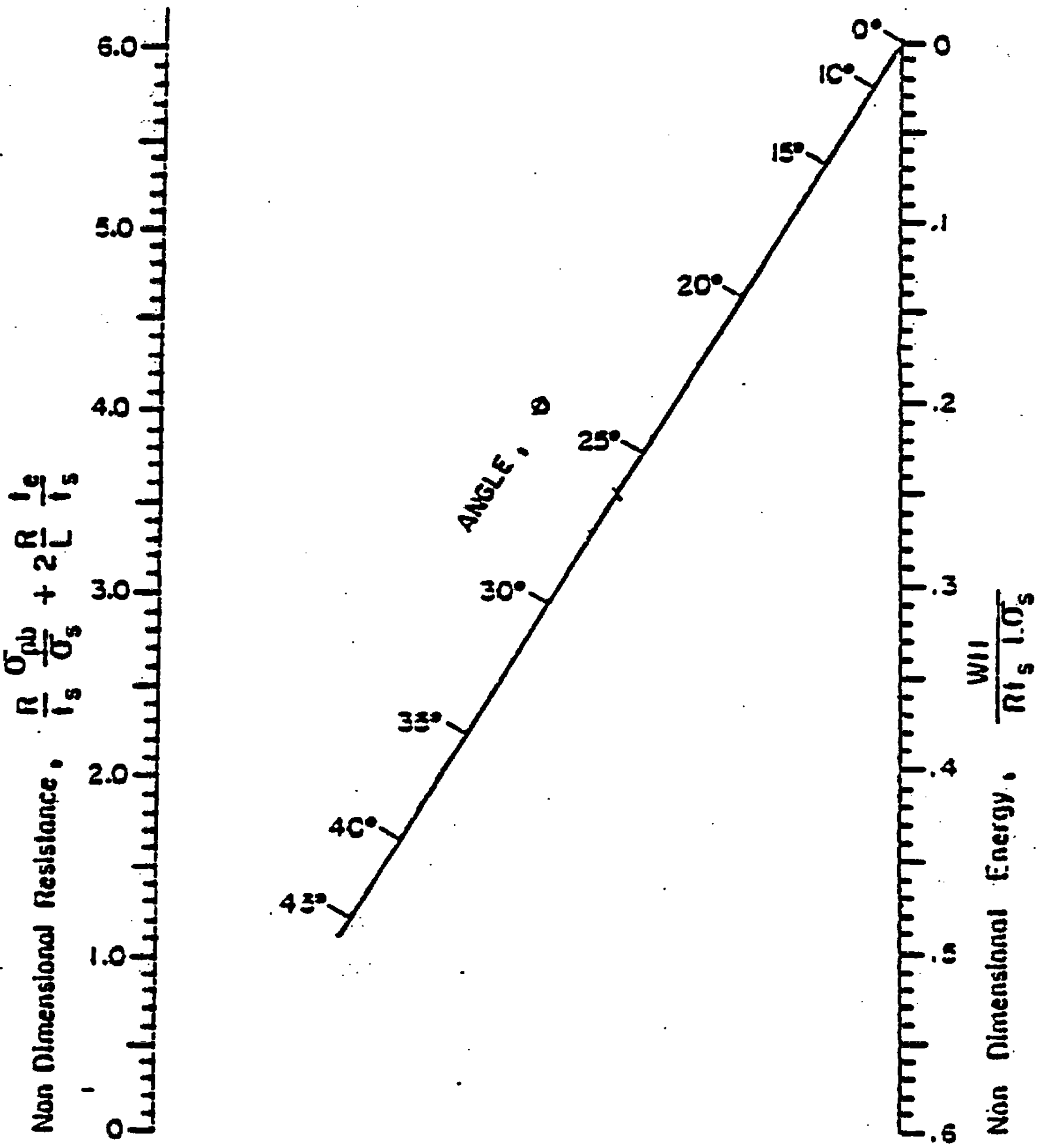


Figure 2.10.14-F34
Nomograph for Determining Half Angle of Flat Developed (θ) due to Impact of a Cylindrical Cask with Axis Horizontal (from Ref. [8], p 61)



5. F-294 STRESS ANALYSIS IN CORNER DROP - TOP

See Figure 2.10.14-F35.

5.1 G-LOADS

30-ft free drop test of F-294 in the top corner (57° from the horizontal) drop test orientation has not been carried out. However the F-294 was subjected to 30-ft free drop test in side oblique drop orientation (36.5° from the horizontal). The details of the test program are given in Chapter 2, Appendix 2.10.12. In the side oblique orientation, the measured G-loads are:

G1= 136 g's (top of closure plug)
G2= LOS (bottom of closure plug) (LOS = Loss of Signal)
G3= 66 g's (bottom of cavity)
G4= 73 g's (bottom of fixed skid).

For the top corner drop, it is estimated that the G-loads will be similar to side oblique corner drop of F-294. Therefore, for the top corner drop, G= 136 g's shall be used to carry out the stress analysis of the F-294 components.

5.2 EFFECT OF G-LOADS ON F-294 COMPONENTS

5.2.1 Buckling of Lower Cavity Tube

See Figures 2.10.14-F36 and 2.10.14-F37.

W_1 = weight of lead borne by steel tube + end cap
= $\pi \times 12.5^2/4 \times 11.25 \times 0.41$
= 566 lb.

G_1 = 136 g's (design)

In this model, the cavity end plate is under external applied pressure as a result of impact. The applied pressure acts on the cavity tube end cap which is transmitted to the lower cavity tube.

Calculations are presented to demonstrate the cavity tube's ability to resist buckling, due to application of eccentric load, during the 30-ft free drop in top corner orientation.

As per equation 27, Chapter 11, Ref. [4], the maximum stress produced in the eccentrically loaded tube is given by

$\sigma = [P/A] * [1 + (ec/r^2) \times \sec\{P \times (L/r)^2/4EA\}^{0.5}]$

where

P = maximum applied load = $W_1 \cos 33° \times G_1 = 566 \times 0.8386 \times 136 = 64{,}552$ lb.
A = area of tube = $\pi (6.25^2 - 5.75^2) = 18.84$ in^2
r = radius of gyration = $1/4(r_O{}^2 + r_I{}^2) = 0.25 \times (6.25^2 - 5.75^2) = 4.246$ in.
c = distance from axis 1 to the extreme fibre on the side nearest the load
= 6.26 (same as the outside radius.
E = 28×10^6 psi
L = 20 in. length of the tube

Evaluate

$= \sec\{P(L/r)^2/4EA\}^{0.5}$
$= \sec\{64{,}552 \times (20/4.246)^2/4 \times 28 \times 10^6 \times 18.84\}^{0.5}$
$= \sec\{0.026\}$
$= \sec\{1.492°\}$
$= 1.0003$

Therefore

σ = [64,552/18.84] * [1+ (3.75 x 6.25/4.246^2) x {1.0003}]
= [64,552/18.84] * [1+1.300]
= [64,552/18.84] * 2.300
= 7,890 psi

Safety Factor (SF) = allowable stress/applied stress
= UTS/σ
= 70,000/7,890
= 8.87

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = SF – 1 = 8.87 – 1= 7.87

For ss304L, the UTS = 70,000 psi and YS = 25,000 psi. As the Margin of Safety (MS) > 0, the cavity lower tube will not buckle.

5.2.2 Bending of Lower Cavity End Plate

See Figure 2.10.14-F38.
The lower cavity end plate (cap) thickness is 0.75 in. thick.

In this model, the cavity end plate is under external applied pressure as a result of impact. The applied pressure acts on the cavity tube end cap.

The applied pressure on the cavity tube cap is

p = weight of lead x in-axial component of g-load of 136 g's/A_{CAP}
= 566 lb. x 136 g's cos33°/[π x 6.25^2]
= 566 lb. x 136 g's x 0.839/122.73
= 526 psi

Is 0.75 in. thick Hastelloy C-276 tube cap strong enough to resist 526 psi maximum applied pressure?

For Hastelloy C-276, the material properties are:
Yield Stress (YS) = 41,000 psi.
Ultimate Tensile Strength (UTS) = 100,000 psi.

From ASME VIII

s = cp/[t/d]^2

where

c = constant depending on end tube to cap joint configuration
= 0.2 ((ASME VIII, Division 1, Figure UG-34 (i))
p = applied pressure = 2,062 psi
t = thickness of cap = 0.75 in.
d = 11.5 in. inside diameter
s = cp/[t/d]^2
s = 0.2 x 526/[0.75/11.5]^2
s = 24,734 psi.

Safety Factor (SF) = allowable stress/applied stress
= UTS/σ
= 100,000/24,734
= 4.04

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = SF – 1 = 4.04 – 1= 3.04

The maximum stress in the end cap s = 24,734 psi is below the YS of 41,000 psi and the static UTS of 100,000 psi. As the Margin of Safety (MS) > 0, the lower cavity end cap will not deform permanently.

5.2.3 Weld WCC6 Between the Cavity Tube to the Cavity End Cap

Check the shear strength of weld WCC6 as per Figure 2.10.14-F43.

Axial load W_A = 566 x G cos 33° = 566 x 136 x 0.839
= 64,852. lb.

Weld area A_{WELD} = π x 11.5 x 0.5 x 0.7 = 12.64 in^2

The weld is fully radiographed.

Shear stress τ = 64,852/12.64 = 5,110 psi, which is less than the YS of 25,000 psi ss304L or UTS of 70,000 psi.

Safety Factor (SF) = allowable stress/applied stress
= 0.6 x UTS/τ
= 0.6 x 70,000/5,110
= 42,000/5,110
= 8.21

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = SF – 1 = 8.21 – 1 = 7.21

As the Margin of Safety (MS) > 0, the weld WCC6 as specified is acceptable.

5.2.4 Plug Bolts

See Figure 2.1-.14-F39.

Estimate bolt stresses based on static UTS

Number of bolts = 16
Total bolt area, $_{ABOLT}$ = 8.816 in^2
Static UTS = 180,000 psi
Weight of plug and contents, $_{WPLUG\ \&\ CONTENTS}$ = 1070 + 45 = 1,115 lb.

Based on deceleration load of 136 g's in the top drop orientation, the applied load on the bolts,

$P_{IMPACT\ AXIAL}$ = weight of plug and contents x Axial component of deceleration G-load
= $W_{PLUG\ \&\ CONTENTS}$ x 136 cos 33°
= 1,115 x 136 x 0.839
= 127,225 lb.

Gasket seating load, F_{SG} = 2,400 lb.
Pressure build-up load W_{plug} = 4,000 lb.

Therefore total load on 16 bolts, P_{TOTAL}

P_{TOTAL} = P_{IMPACT} + F_{SG} + W_{plug}
= 127,225 + 2,400 + 4,000
= 133,225 lb.

What is the tensile stress in the bolt ?

Bolt stress, σ = P_{TOTAL}/A_{BOLT} = 133,225 lb./8.816 in^2
= 15,160 psi.

Based on deceleration load of 136 g's in the top drop orientation, the applied load on the bolt,

$P_{IMPACT\ (SHEAR)}$ = weight of plug and contents x transverse component of deceleration G-load
= $W_{PLUG\ \&\ CONTENTS}$ x 136 sin 33°
= 1,115 x 136 x 0.544
= 82,500 lb.

Gasket seating load, F_{SG} = 2,400 lb.
Pressure build-up load W_{plug} = 4,000 lb.

Therefore total load on 16 bolts, P_{TOTAL}

$$P_{TOTAL} = P_{IMPACT\,(SHEAR)} + F_{SG} + W_{plug}$$
$$= 82{,}500 + 2{,}400 + 4{,}000$$
$$= 88{,}900 \text{ lb.}$$

What is the shear stress in the bolt?

$$\text{Bolt stress, } \tau = P_{TOTAL}/A_{BOLT} = 88{,}900 \text{ lb.}/8.816 \text{ in}^2$$
$$= 10{,}090 \text{ psi.}$$

Combine the tensile and shear stresses to obtain the principal stresses.

$$\sigma_1 = \sigma/2 \pm \sqrt{[(\sigma/2)^2 + \tau^2]}$$
$$= 15{,}160/2 \pm \sqrt{[(15{,}160/2)^2 + (10{,}090)^2]}$$
$$= 7{,}580 \pm 12{,}620$$
$$= 20{,}200 \text{ or}$$
$$\sigma_2 = -5{,}040 \text{ psi}$$

The allowable static UTS at 20°C is 180,000 psi.

Safety Factor $SF_{STRESS\text{-}BASED}$ = allowable stress/maximum applied stress
= static UTS/bolt maximum principal stress
= 180,000 psi/20,200 psi
= 8.91

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = $SF_{STRESS\text{-}BASED} - 1$
= 8.91 − 1
= 7.91

As the Margin of Safety (MS) > 0, the bolts are capable of maintaining a closure joint.

5.2.5 Male Flange

What are the stress levels in the male and female flange of the bolted closure?
See Figure 2.10.14-F40.
It is assumed that the ligament area around the bolt holes is the critical area in terms of failure mode.
Effective ligament area is considered that area 1.5 diameters from bolt hole centerline.

Minimum ligament area in shear around the bolt holes AS.

$$AS = 5/16 * 1 + 0.5 * 1$$
$$= 13/16 \text{ in}^2$$

Number of bolt holes = 16

Based on deceleration load of 136 g's in the top drop orientation, the applied load on the bolts,
$P_{IMPACT\,AXIAL}$ = weight of plug and contents x deceleration G-load

$$= W_{PLUG\,\&\,CONTENTS} \times 136 \cos 33°$$
$$= 1{,}115 \times 136 \times 0.839$$
$$= 127{,}225 \text{ lb.}$$

Gasket seating load, F_{SG} = 2,400 lb.

Pressure build-up load W_{plug} = 4,000 lb.

Therefore total load on ligament area, P_{TOTAL}

$$P_{TOTAL} = P_{IMPACT} + F_{SG} + W_{plug}$$
$$= 127{,}225 + 2{,}400 + 4{,}000$$
$$= 133{,}225 \text{ lb.}$$

Shear stress in the ligament zone, τ

$$\tau = P_{TOTAL}/A_{TOTAL\ LIGAMENT\ AREA}$$
$$= 133{,}225/[16 \times (13/16)]$$
$$= 10{,}250 \text{ psi}$$

$SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress

$$= 0.6 \times UTS/\tau$$
$$= 0.6 \times 70{,}000/10{,}250$$
$$= 42{,}000/10{,}250$$
$$= 4.09$$

$MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 4.09 - 1 = 3.09$

As the Margin of Safety (MS) > 0, the male flange as specified is acceptable.

5.2.6 Female Flange

See Figure 2.10.14-F41.

It is assumed that the joint between the female flange to the cavity liner (location B as per Figure 2.10.14-F41) is the critical area in terms of failure mode. This weld joint is subjected to both axial and shear impact forces in the top corner drop orientation of the package.

Area of the butt weld,

$$A_{WELD} = \pi * D * t * 0.7$$
$$A_{WELD} = \pi * 15.284 * 0.5 * 0.7$$
$$A_{WELD} = 16.8 \text{ in}^2$$

Based on deceleration load of 136 g's in the top drop orientation, the applied load on the bolts,
$P_{IMPACT\ AXIAL}$ = weight of plug and contents x deceleration G-load

$$= W_{PLUG\ \&\ CONTENTS} \times 136 \cos 33°$$
$$= 1{,}115 \times 136 \times 0.839$$
$$= 127{,}225 \text{ lb.}$$

Gasket seating load, F_{SG} = 2,400 lb.
Pressure build-up load W_{plug} = 4,000 lb.

Therefore total load on 16 bolts, P_{TOTAL}

$$P_{TOTAL} = P_{IMPACT} + F_{SG} + W_{plug}$$
$$= 127{,}225 + 2{,}400 + 4{,}000$$
$$= 133{,}225 \text{ lb.}$$

Stress in the weld, σ_{WELD}

$$\sigma_{WELD} = P_{TOTAL}/A_{WELD}$$
$$= 133{,}225 \text{ lb.}/16.8 \text{ in}^2$$
$$= 7{,}930 \text{ psi}$$

For weld with 100% joint efficiency (fully radiographed weld joint)

$SF_{STRESS\text{-}BASED}$ = Allowable stress/applied stress

$$= UTS/\sigma$$
$$= 70{,}000/7{,}930$$
$$= 8.82$$

$MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 8.82 - 1 = 7.72$

Based on deceleration load of 136 g's in the top drop orientation, the applied load on the bolts,
$P_{IMPACT\,(SHEAR)}$ = weight of plug and contents x transverse component of deceleration G-load

$= W_{PLUG\,\&\,CONTENTS} \times 136 \sin 33°$
$= 1{,}115 \times 136 \times 0.544$
$= 82{,}500$ lb.

Gasket seating load, $F_{SG} = 2{,}400$ lb.
Pressure build-up load $W_{plug} = 4{,}000$ lb.

Therefore total load on 16 bolts, P_{TOTAL}

$P_{TOTAL} = P_{IMPACT\,(SHEAR)} + F_{SG} + W_{plug}$
$= 82{,}500 + 2{,}400 + 4{,}000$
$= 88{,}900$

Shear stress in the weld, τ_{WELD}

$\tau_{WELD} = P_{TOTAL}/A_{WELD}$
$= 88{,}900$ lb./16.0 in^2
$= 5{,}290$ psi

For weld with 100% joint efficiency (fully radiographed weld joint),

$SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress
$= 0.6 \times UTS/\sigma$
$= 0.6 \times 70{,}000/5{,}290$
$= 7.93$

$MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED}$
$= 7.93 - 1$
$= 6.93$

As the Margin of Safety (MS) > 0, the female flange as specified is acceptable.

5.2.7 Stripping of Internal Threads of Bolt Hole Under Impact Load

See Figure 2.10.14-F42.

What stresses can the internal threads of the bolt hole in the female flange of the bolted closure withstand without stripping? Effective thread area per bolt hole = 1.44 in^2.

Based on deceleration load of 136 g's in the top drop orientation, the applied load on the bolts,
$P_{IMPACT\,AXIAL}$ = weight of plug and contents x deceleration G-load

$= W_{PLUG\,\&\,CONTENTS} \times 136 \cos 33°$
$= 1{,}115 \times 136 \times 0.839$
$= 127{,}225$ lb.

Gasket seating load, $F_{SG} = 2{,}400$ lb.
Pressure build-up load $W_{plug} = 4{,}000$ lb.
Therefore total load on 16 bolts, P_{TOTAL}

$P_{TOTAL} = P_{IMPACT} + F_{SG} + W_{plug}$
$= 127{,}225 + 2{,}400 + 4{,}000$
$= 133{,}225$ lb.

Shear stress in the bolt hole threads, τ

$\tau = P_{TOTAL}/A_{BOLT\,HOLE\,THREADS}$
$= 133{,}225/[16 \times 1.44]$
$= 5{,}780$ psi.

For stripping of bolt hole threads, the safety factor and margin of safety are:

$SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress
= $0.6 \times UTS/\tau$
= $0.6 \times 70{,}000/5{,}780$
= $42{,}000/5{,}780$
= 7.26

$MS_{STRESS\text{-}BASED}$ = $SF_{STRESS\text{-}BASED}$
= 7.26 – 1
= 6.26

As the Margin of Safety (MS) > 0, the design of the internal threads of the bolt hole is acceptable.

5.2.8 Container Welds

See Figure 2.10.14-F43.
In the top corner drop orientation, the weight of the lead shielding is segmented into four zones: W_1, W_2, W_3, W_4 respectively.

The weight W_1 acts directly on the bottom plate cavity and affects cavity buckling.

The weight W_2 acts directly on the off-set flange between upper and lower cavity and affects buckling of upper cavity.

The weight W_3 is directly acting on the container female flange and weld joints WCC1, WCC2, WCC7 and WF respectively.

The weight W_4 is directly acting on the container conical head and weld joints #WCC3 and WF.

Therefore, collectively, welds WCC1, WCC2, WCC3, WCC7 and WF resist the impact of weight W_3 and W_4 in top corner drop orientation. Not all the weight W_3 and W_4 is directly impacting the welds due to load sharing by inner shell cavity assembly.

The estimate of weights W_1, W_2, W_3, W_4 is given here:

W_1 = 566 lb.
W_2 = 950 lb.
W_3 = 5,695 lb.
W_4 = 5,514 lb.

Step #1

Calculate the axial impact load due to W_3 and W_4.
The cumulative impact load on welds WCC1, WCC2, WCC3, WCC7 and WF due to the deceleration load of 136 g's is $P_{IMPACT\ AXIAL}$

= $[W_3 + W_4] \times 136$ g's $\cos 33°$
= $[5{,}695 + 5{,}514] \times 136 \times 0.839$
= 1.28×10^6 lb.

Step #2

Calculate weld areas.
Weld designated WCC1: Area $A_{1,circumferential} = 2\pi \times 11.812 \times 0.5 \times 0.707 = 26.23$ in^2
Weld designated WCC2: Area $A_{2,circumferential} = 2\pi \times 12.812 \times 0.5 \times 0.707 = 28.46$ in^2
Weld designated WCC3: Area $A_{3,circumferential} = 2\pi \times 17.500 \times 0.5 \times 0.707 = 38.87$ in^2
Weld designated WCC7: Area $A_{7,circumferential} = 2\pi \times 7.392 \times 0.5 \times 0.707 = 16.42$ in^2
Weld designated WF: Area $A_{WF} = 114.5$ in^2

A_{WF} = No. of fins x no. of fillet welds x thickness of weld x length of weld x 0.707
= $18 \times 2 \times 0.375 \times 12 \times 0.707 = 114.5$ in^2

There are 36 fins at the top of the container; however, in the top corner drop orientation it is assumed that only 18 fins to outer container shell welds are effective.

The collective effective area of welds, inclusive of joint efficiency, is

$$A = \eta_1 \times A_{1,circumferential} + \eta_1 \times A_{2,circumferential} + \eta_2 \times A_{3,circumferential} + \eta_2 \times A_{7,circumferential} + \eta_1 \times A_{WF}$$

$$A = 0.8 \times 26.23 + 0.8 \times 28.46 + 1.0 \times 38.87 + 1.0 \times 16.42 + 0.8 \times 114.5$$

$$A = 190.6 \text{ in}^2$$

Step #3

Calculate average stress in the weld due to axial component

The average tensile stress on the welds WCC1, WCC2, WCC3, WCC7 and WF is

$$\sigma_{AVG.} = P_{IMPACT\ AXIAL}/A$$

$$= 1.28 \times 10^6 \text{ lb.}/190.6 \text{ in}^2$$

$$= 6{,}710 \text{ psi.}$$

The average stress in the welds is well above the yield stress of 25,000 psi for ss304L parent metal and below static UTS of 70,000 psi.

Step #4

Calculate the radial impact load due to W_3 and W_4.

The cumulative impact load on welds WCC1, WCC2, WCC3, WCC7 and WF due to deceleration load of 136 g's is $P_{IMPACT\ AXIAL} = [W_3 + W_4] \times 136$ g's sin 33°

$$= [5{,}695 + 5{,}514] \times 136 \times 0.544$$

$$= 0.83 \times 10^6 \text{ lb.}$$

Step #5

Calculate average shear stress in the weld due to transverse component

The average shear stress on the welds WCC1, WCC2, WCC3, WCC7 and WF is

$$\tau_{AVG.} = P_{IMPACT\ TRANSVERSE}/A$$

$$= 0.83 \times 10^6 \text{ lb.}/190.6 \text{ in}^2$$

$$= 4{,}360 \text{ psi.}$$

Combine the tensile and shear stresses to obtain the principal stresses.

$$\sigma_1 = \sigma/2 \pm \sqrt{[(\sigma/2)^2 + \tau^2]}$$

$$= 6{,}710/2 \pm \sqrt{[(6{,}710/2)^2 + (4{,}360)^2]}$$

$$= 3{,}355 \pm 5{,}500$$

$$= 8{,}855 \text{ or}$$

$$\sigma_2 = -2{,}145 \text{ psi}$$

Safety Factor, $SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress

$$= 70{,}000/8{,}855$$

$$= 7.9$$

Margin of Safety $MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 7.9 - 1 = 6.9$

As the Margin of Safety (MS) > 0, the container welds as specified are acceptable.

5.2.9 Container Top Flange

See Figure 2.10.14-F44.

In this model, the container top flange plate is under external applied pressure as a result of impact. The applied pressure acts on the container top flange and the conical shell.

Based on 136 cos 33° = 136 x 0.839 = 114 g's deceleration load axial component, the applied pressure on the container top flange is

p = weight of lead x 114 g's/$A_{RING\ FLANGE}$
= $(W_1 + W_2 + W_3)$ x 114/[π x $(10.5^2 - 7.892^2)$]
= (566 + 950 + 5314) x 114/150.7
= 6,830 x 114/150.7
= 5,170 psi

Is 1.5 in. thick stainless steel plate (ring flange) strong enough to resist 5,170 psi maximum applied pressure?

For stainless steel (ss304L) A-240, the material properties are:

Yield Stress (YS) = 25,000 psi.
Ultimate Tensile Strength (UTS) = 70,000 psi.

Case 77, Table X, Ref. [4].

$s_r = \beta\,\omega\,a^2/t^2$

where

s_r = maximum radial stress
β = constant depending upon a/b = 10.5/7.892 = 1.33, β = 0.03
ω = p = applied pressure = 5,170 psi
t = thickness of ring flange = 1.5 in.
a = 10.5 in. ring flange outside radius
b = 7.892 in. ring flange inside radius
$s_r = \beta\,\omega\,a^2/t^2$
$s_r = 0.03 \times 5{,}170 \times 10.5^2/1.5^2$
s_r = 7,600 psi.

Safety Factor, $SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress
= static UTS/7,600
= 70,000 psi/7,600 psi
= 9.21

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = SF – 1 = 9.21 – 1 = 8.21

The maximum stress in the ring flange s_r = 7,600 psi, which is below YS of 25,000 psi and below UTS of 70,000 psi. As the Margin of Safety (MS) > 0, the ring flange will not deform permanently.

5.2.10 Effect of Peak Force on the SS Shell Directly Under the Foot of the Lift Lug Fin

See Figure 2.10.14-F-45.

There are four (4) lift lug fins on the F-294. Underneath the base of each of the lift lug fins, there are the following components:

- a 1.0 in. thick reinforcement base plate (pad) (material ss304)
- a secondary conical shell 0.5 in. thick (material ss304)
- 0.38 in. thick thermal insulation
- a primary conical shell of the lead cask. (material ss304L).

The 0.5 in. thick ss shell is reinforced with a pad approximately 1.0 in. thick x 6.75 in. wide at top x 7 in. height x 9.5 in. wide at bottom. After the top corner drop, the crush shield displaces (moves) down by 5 in. The lift lug tip is not only recessed 7 in. from top of the non-deformed crush shield, but is also located between the crush shield fins so that the lift lug's impact is marginally delayed. However the 0.5 in thick container fins (qty = 2) adjacent to the lift lug fin are definitely impacted prior to the lift lug fin. The impact load on the container fins has been estimated:

P_{impact} = F-294 weight x G-load
= 21,000 x 136
= 2.856 x 10^6 lb.

The (bearing) compressive load on the secondary conical shell wall at the base of the lift lug fin is computed as follows:

σ_C = Peak force/effective secondary conical shell area under compression
= P_{impact}/A
= $[\, 2.856\text{x } 10^6 \,]/(10.52 \text{ x } 11)$
= $[2.856\text{x } 10^6]/115.7$
= 24,680 psi.

Safety Factor, $SF_{STRESS\text{-}BASED}$ = allowable stress for secondary shell ss304/applied stress
= static UTS/24,680
= 75,000 psi/24,680 psi
= 3.03

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = SF − 1 = 3.03 − 1 = 2.03

Since the maximum stress σ_1 = 24,680 psi in the container secondary conical shell wall is less than the yield stress of 30,000 psi and static ultimate compressive stress of the secondary conical dished head (material ss304 UTS = 75,000 psi), the container reinforced wall will not rupture (dynamic). The container wall at the foot of the lift lug fin, will not be deformed plastically. It must be noted that the estimated stress and the deformation of the container wall are based on instantaneous "peak force" and therefore they are fairly conservative. As the secondary conical shell takes most of the impact, the container primary conical shell wall is protected by the secondary conical shell. Therefore the structural integrity of the primary conical shell is sound. As the Margin of Safety (MS) > 0, the design of the reinforcement feature around the lift lug fin base is acceptable.

5.2.11 C-188 Sealed Source Under Top Corner Impact

The case of the C-188 sealed source capsule under top corner impact is presented here. The model chosen to represent this case is given in Figure 2.10.14-F46. The effective G-load in the cavity of F-294 is 136 g's. Therefore the stress developed in the capsule outer shell only will be due to the mass of the entire C-188 at 136 g's. The weight of C-188 is $W_{C\text{-}188}$ = 230 grams = 0.51 lb.

The support reaction P_{AXIAL} due to 136-g level is:

$P_{AXIAL} = -W_{C\text{-}188}$ x G-load axial component = −0.51 x 136 cos 33° = 0.51 x 136 x 0.839 lb.
= 58.2 lb.

The axial stress for this condition is given by:

$\sigma_{comp.}$ = $P_{AXIAL}/A_{outer\ shell,\ min.\ wall}$
= $58.2/(\pi/4\ (0.376^2 - 0.338^2))$
= 58.2/0.0213
= 2,740 psi.

$P_{TRANSVERSE} = -W_{C\text{-}188}$ x G-load transverse component = −0.51 x 136 sin 33° = 37.4 lb.

The transverse stress for this condition is given by:

$\tau_{shear.}$ = $P_{TRANSVERSE}/A_{outer\ shell,\ min.\ wall}$
= $37.8/(\pi/4\ (0.376^2 - 0.338^2))$
= 37.8/0.0213
= 1,780 psi.

Combine the compressive and shear stresses to obtain the principal stresses.

$\sigma_1 = \sigma/2 \pm \sqrt{[(\sigma/2)^2 + \tau^2]}$
$= 2{,}740/2 \pm \sqrt{[(2{,}740/2)^2 + (1{,}780)^2]}$
$= 1{,}370 \pm 2{,}250$
$= 3{,}620$ or
$\sigma_2 = -880$ psi

Safety Factor (SF) = allowable stress/applied stress
= UTS for ss316L at 836°F/applied stress
= 60,000 psi/3,620 psi
= 16.6

Margin of Safety = SF – 1 = 16.6 – 1 = 15.6
The yield stress of ss316L at 836 °F = 16,000 psi. [Ref.[26]]

As the maximum principal stress (3,620) < Yield Stress (16,000 psi), the tube shall not yield in the top corner drop nor fracture (dynamic) as the maximum principal stress 3,620 psi < static UTS of 60,000 psi.

Let us examine the C-188 sealed source capsule under end impact for buckling. The model chosen to represent this case is shown in Figure 2.10.14-F46. The ends of the capsule are free to rotate, translation is fixed because the ends of the C-188 are trapped between the bottom plate of the F-313 source carrier and the shield plug. Any restraining of the C-188 sealed source capsule by intermediate spacer plates of the F-313 source holder has been ignored. Any additional restraining by the inner capsule of C-188 has also been ignored.

The critical buckling load (Euler load) is given by

$P_{cr} = \pi^2 EI/[kl]^2$

where

E = modulus of elasticity = 23.8×10^6 psi at 836°F
I = 2nd moment of area = $\pi/64\ (0.376^4 - 0.326^4) = 4.335 \times 10^{-4}$ in^4
l = length of the column = 17.777 – 0.9 = 16.877 in.
k = effective length factor, dependent of the conditions of fixity of the column.

In this case, the column is free to rotate i.e., hinge i.e., zero moment reaction, but translation is zero. Therefore the column end condition code is "pin-jointed and fixed end". In this case, K = 1.2 (Ref.[24] CISC Handbook 1967).

Therefore

$P_{cr} = \pi^2 \times 23.8 \times 10^6 \times 4.267 \times 10^{-4}/(1.2 \times 16.877)^2$
= 245 lb.

The weight of the C-188, $W_{C\text{-}188}$ = 0.51 lb.
Therefore the G-load in the cavity which may initiate buckling of C-188:

P_{IMPACT} = G-load axial component x $W_{C\text{-}188}$
= 136 x cos 33° x 0.51
= 136 x 0.51
= 58.2 lb.

For C-188, as the applied impact load P_{IMPACT} (58.2 lb.) < the critical buckling load P_{cr} (245 lb.), the C-188 shall not be subject to buckling. Factor of Safety (FS) = 245/58.2= 4.2

As the Factor of Safety (FS) > 1, it is concluded that the C-188 sealed source will not yield nor buckle in the top corner drop impact. It must be noted that the C-188 source is a Special Form source and meets 10 CFR Para.71.77; therefore C-188 provides the leaktight containment. For C-188, the USNRC source registration number is NR-222-S-103-S (see Appendix 4.4.2).

5.3 SUMMARY OF TOP CORNER DROP ANALYSIS

1. Based on data of similar tested packages, for F-294 the g-load in the top end drop orientation is expected to be 136 g's.
2. The following components of the F-294 package were stress analyzed; the corresponding stresses or loads, Safety Factors (SF) and Margins of Safety (MS) are listed here:

Plug

	Stress (psi)	SF	MS
- bolts: avg. bolt stress	20,200	8.91	7.91
- male flange shear stress	10,250	4.09	3.09
- female flange-tension, weld (WCC7)	7,930	8.82	7.82
- female flange-shear, weld (WCC7)	5,290	7.93	6.93
- stripping bolt hole, shear	5,780	7.26	6.26

Container

	Stress (psi)	SF	MS
- weld group WCC1, WCC2, WCC7, WCC3, WF	8,855	7.9	6.9
- lower cavity tube (buckling)	7,890	8.87	7.87
- lower cavity tube end cap	24,734	4.04	3.04
- container top flange	7,600	9.21	8.21
- ext. secondary conical shell, local area under lift lug	24,680	3.03	2.03
- weld, cavity end cap/tube (WCC6)	5,110	8.21	7.21

In the top corner 30-ft drop of F-294, for all the components in the container and the closure plug, the margin of safety is greater than 0. Consequently there will be no ductile failure of the components in the container and the closure plug.
Therefore the structural integrity of

- the ss304L envelope surrounding the lead shielding in the plug AND
- the ss304L envelope surrounding the lead shielding in the container body

is sound and there are no cracks; thus the lead does not have potential leak paths to escape in a scenario of lead melt. In addition, it is shown that lead would not melt in the F-294 lead-cask in a regulatory fire test of F-294 (see Chapter 3 for details).

3. The closure plug bolts will not shear under 136 g's deceleration loads. Consequently, the closure plug shielding will be in place over the inner shell assembly which houses the C-188 Special Form sealed sources
4. Thermal protection: The top corner of the cylindrical fireshield will be displaced towards the container cavity. The top fireshield, which is integral with the crush shield, shall be displaced toward the top closure plug. The conical shell is double wall construction and the space is filled with thermal insulation. In all three (3) zones, the thermal insulation will be compressed locally but there will be no loss of thermal protection.
5. C-188 sealed source: the C-188, in a top corner impact, has been demonstrated to withstand the deceleration load of 136 g's in the F-294 cavity. The C-188 is not likely to yield nor buckle. It must be noted that the C-188 source is a Special Form source and meets 10 CFR Para.71.77; therefore C-188 provides the leaktight containment. For C-188, the USNRC source registration number is NR-222-S-103-S (see Chapter 4, Appendix 4.4.2).

Figure 2.10.14-F35
F-294 in Top Corner Drop Impact

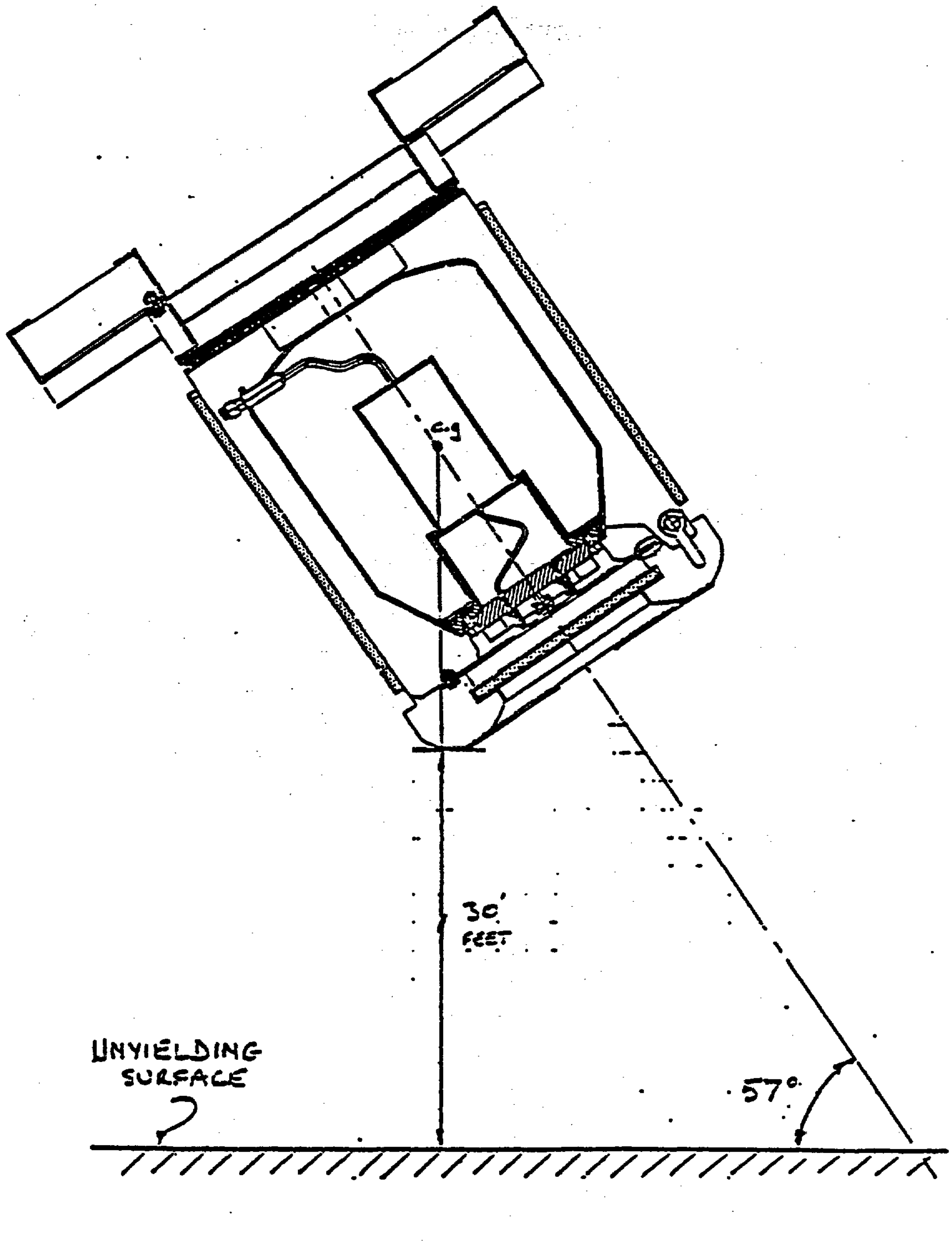


Figure 2.10.14-F36
Lower Cavity Tube under Impact Load

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Figure 2.10.14-F37
Lower Cavity Tube under Eccentric Loading

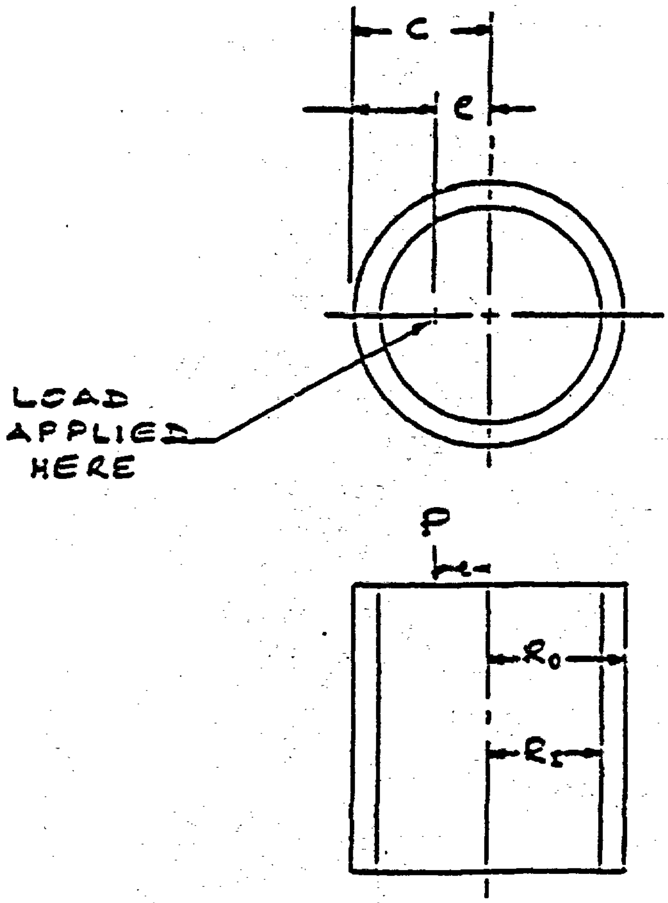


Figure 2.10.14-F38
Lower Cavity Tube End Cap under Impact Load

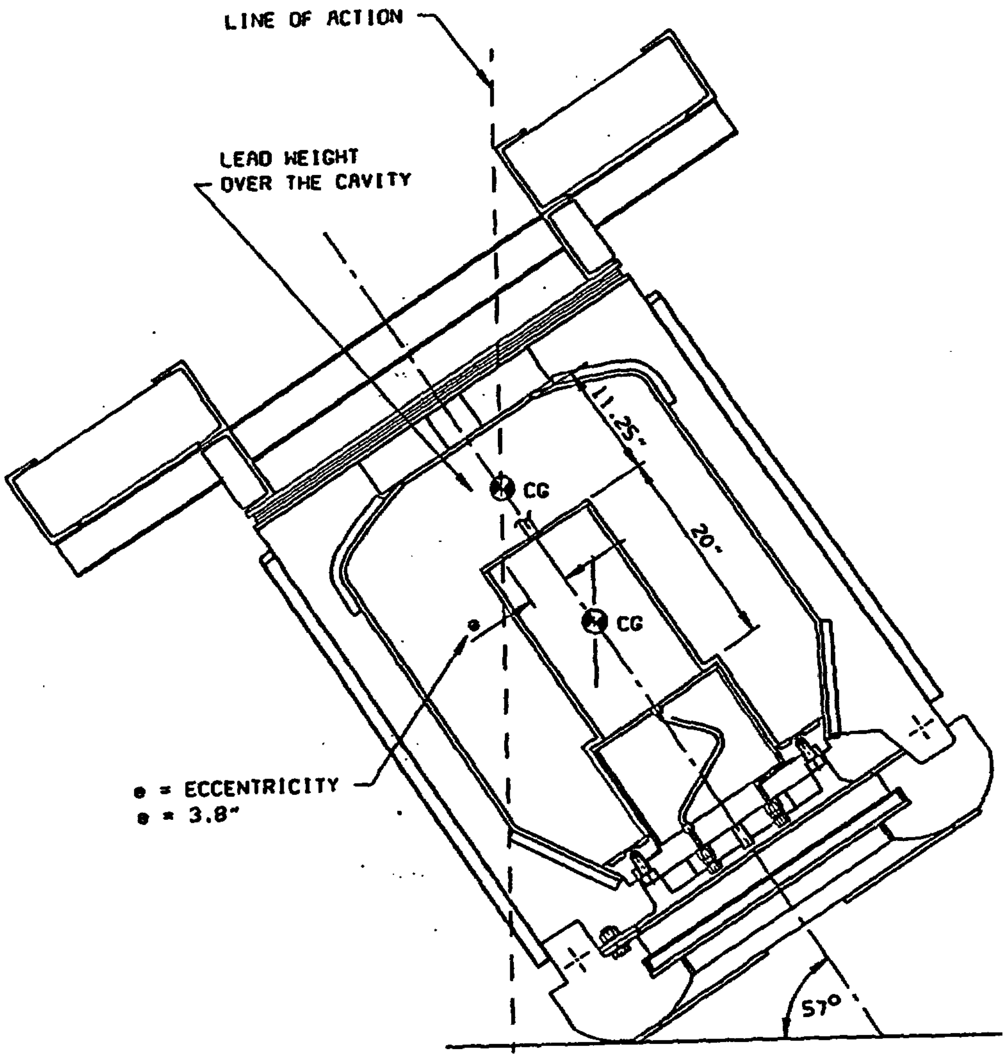


Figure 2.10.14-F39
Plug Bolts under Impact Load

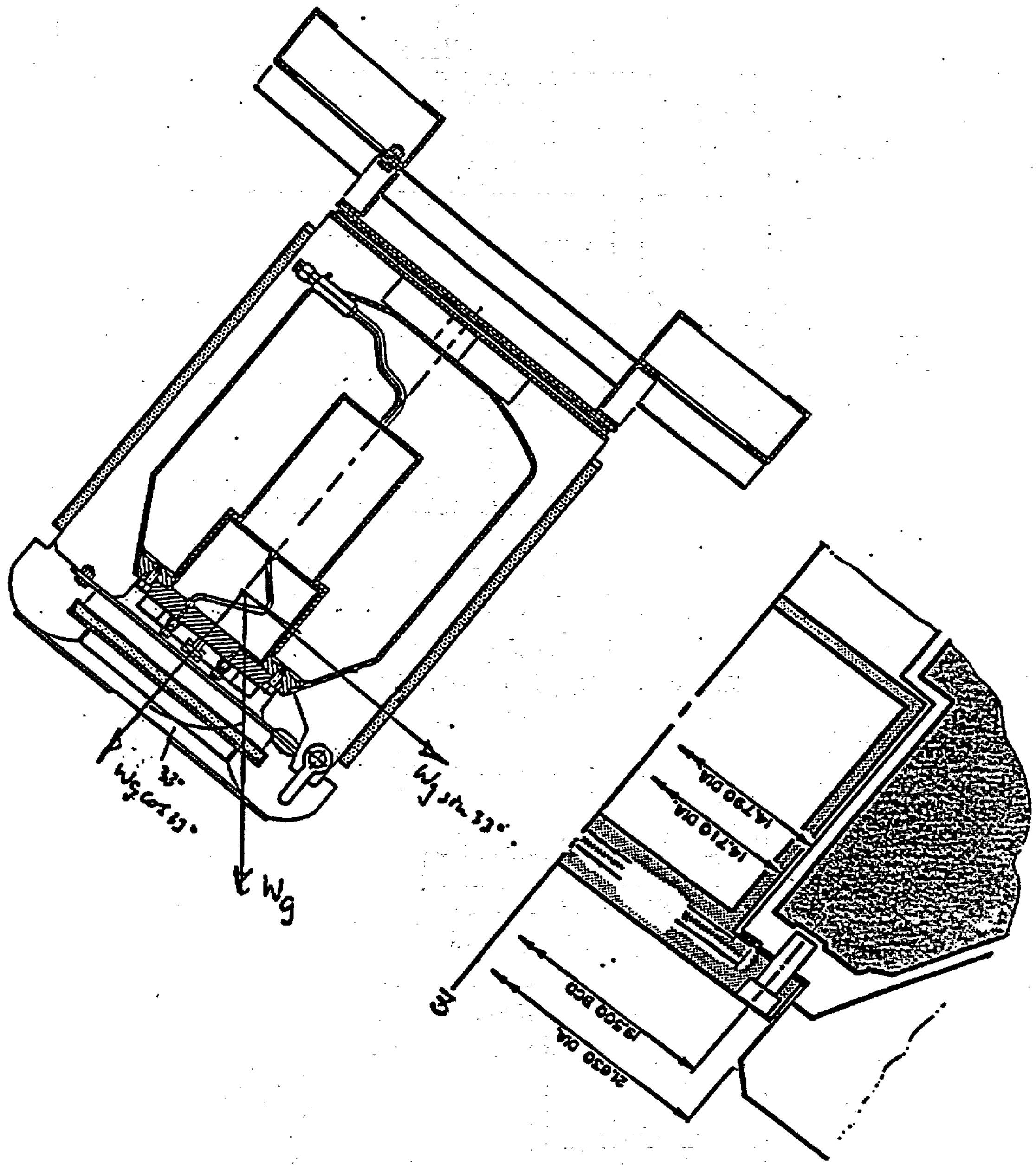


Figure 2.10.14-F40
Plug Flange under Impact Load

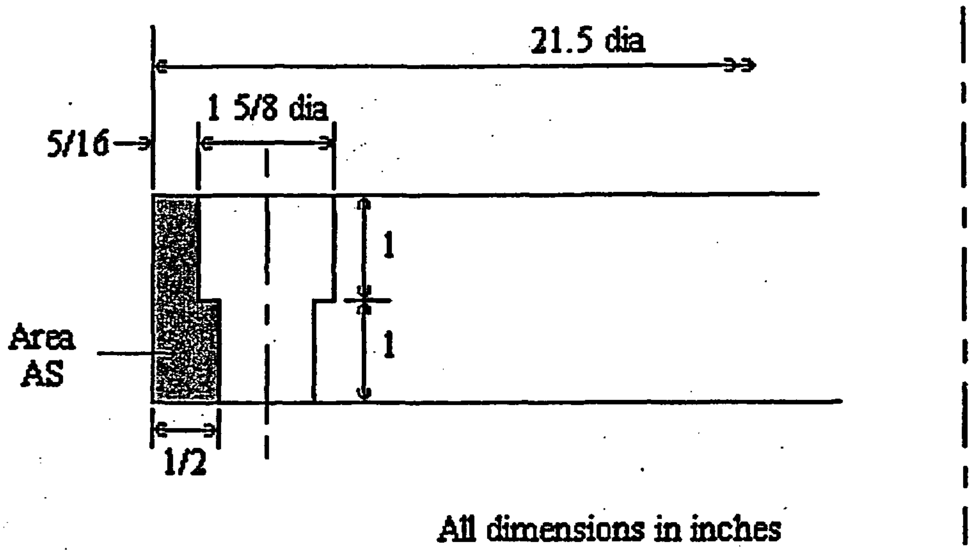


Figure 2.10.14-F41
Container Upper Cavity Weld WCC7

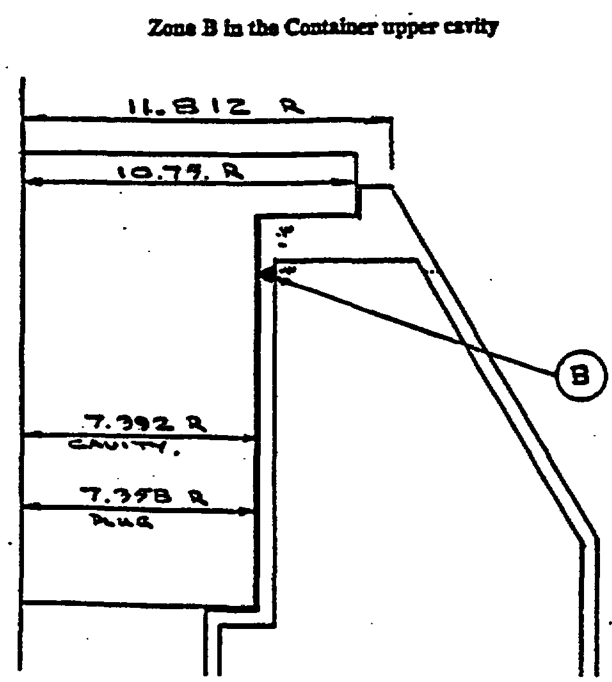


Figure 2.10.14-F42
Stripping of the Bolt Hole in the Closure Flange

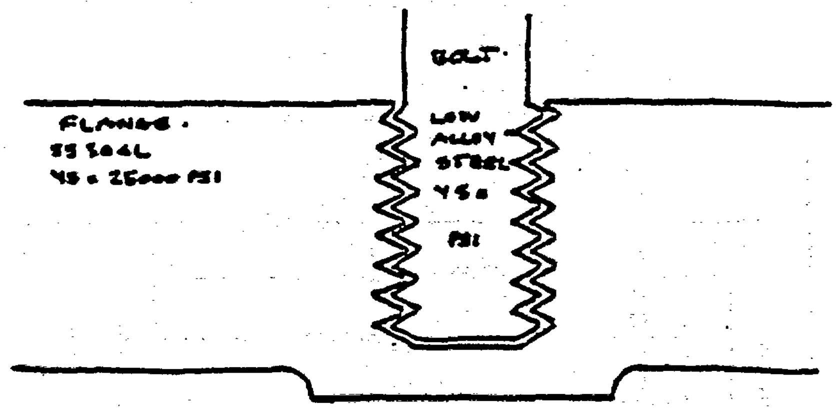


Figure 2.10.14-F43
Container: Identification of Welds

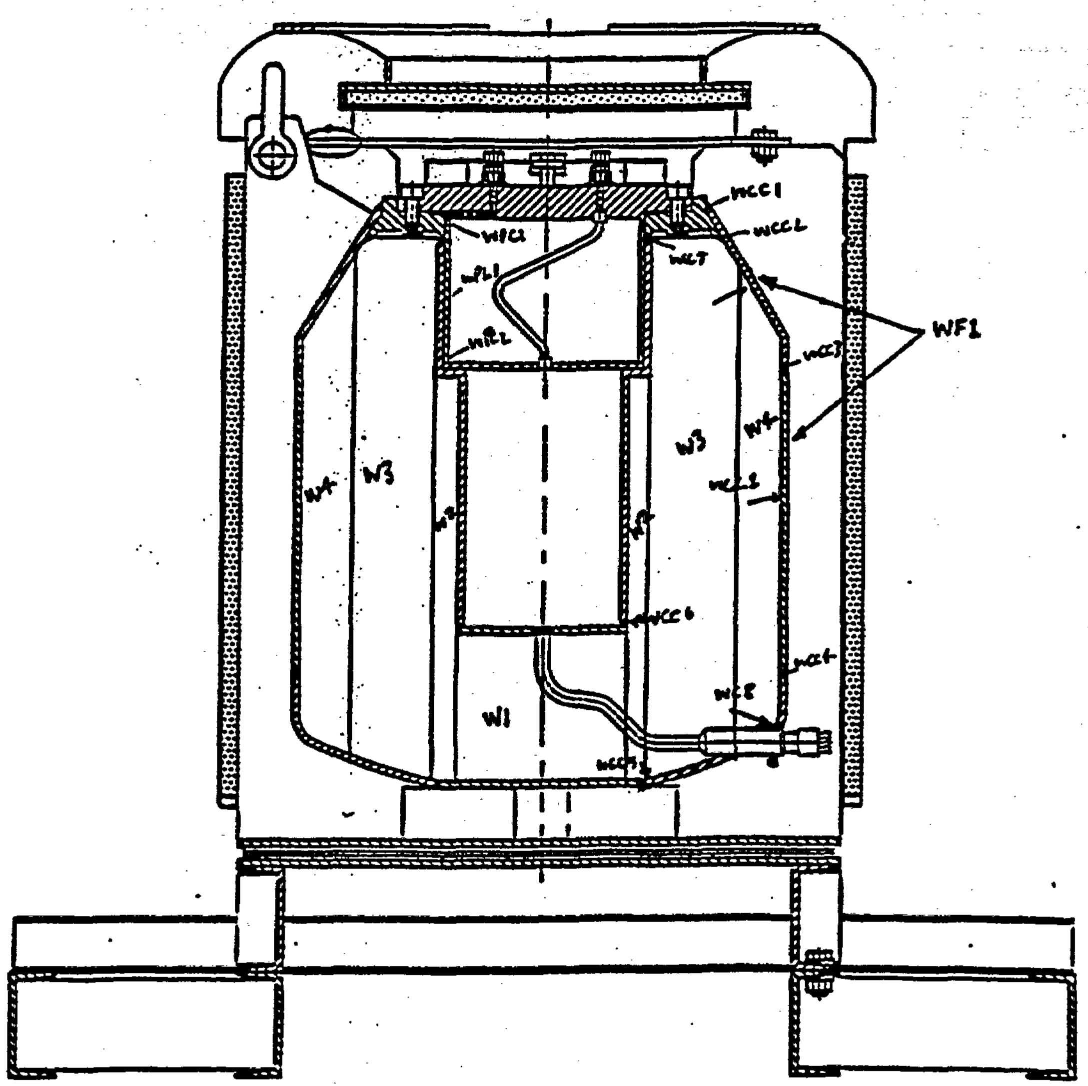


Figure 2.10.14-F44
Container Flange Under impact

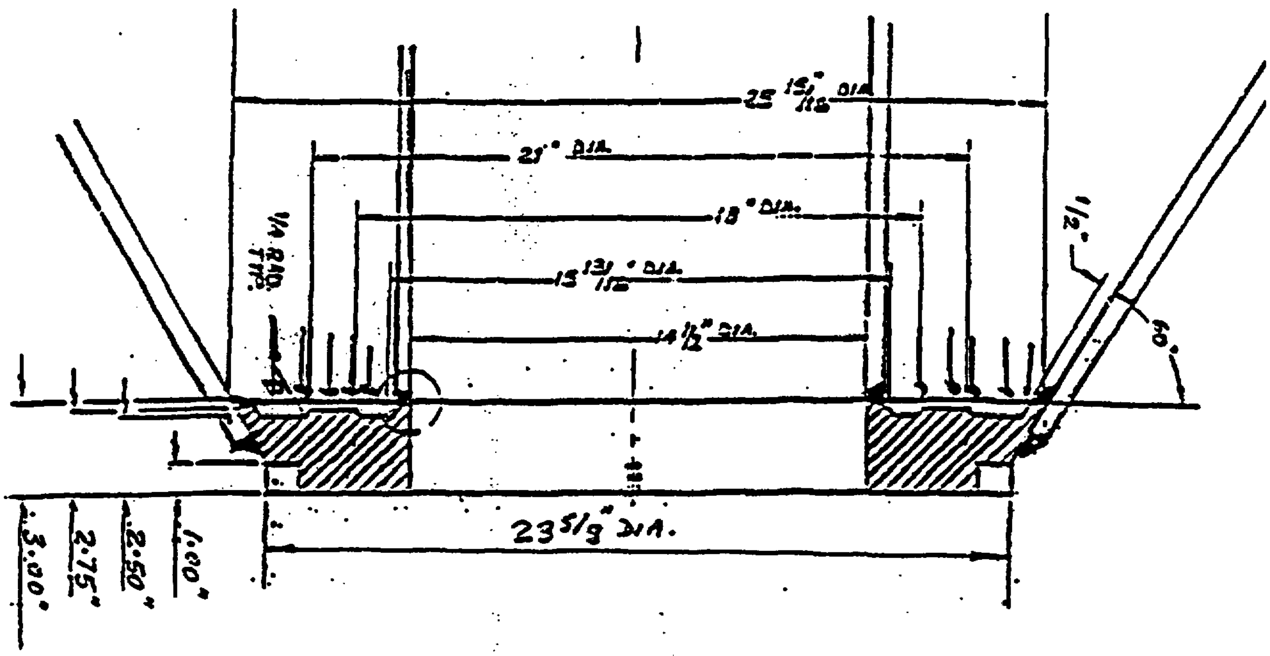


Figure 2.10.14-F45
Container Shell under the Base of Lift Lug Fin

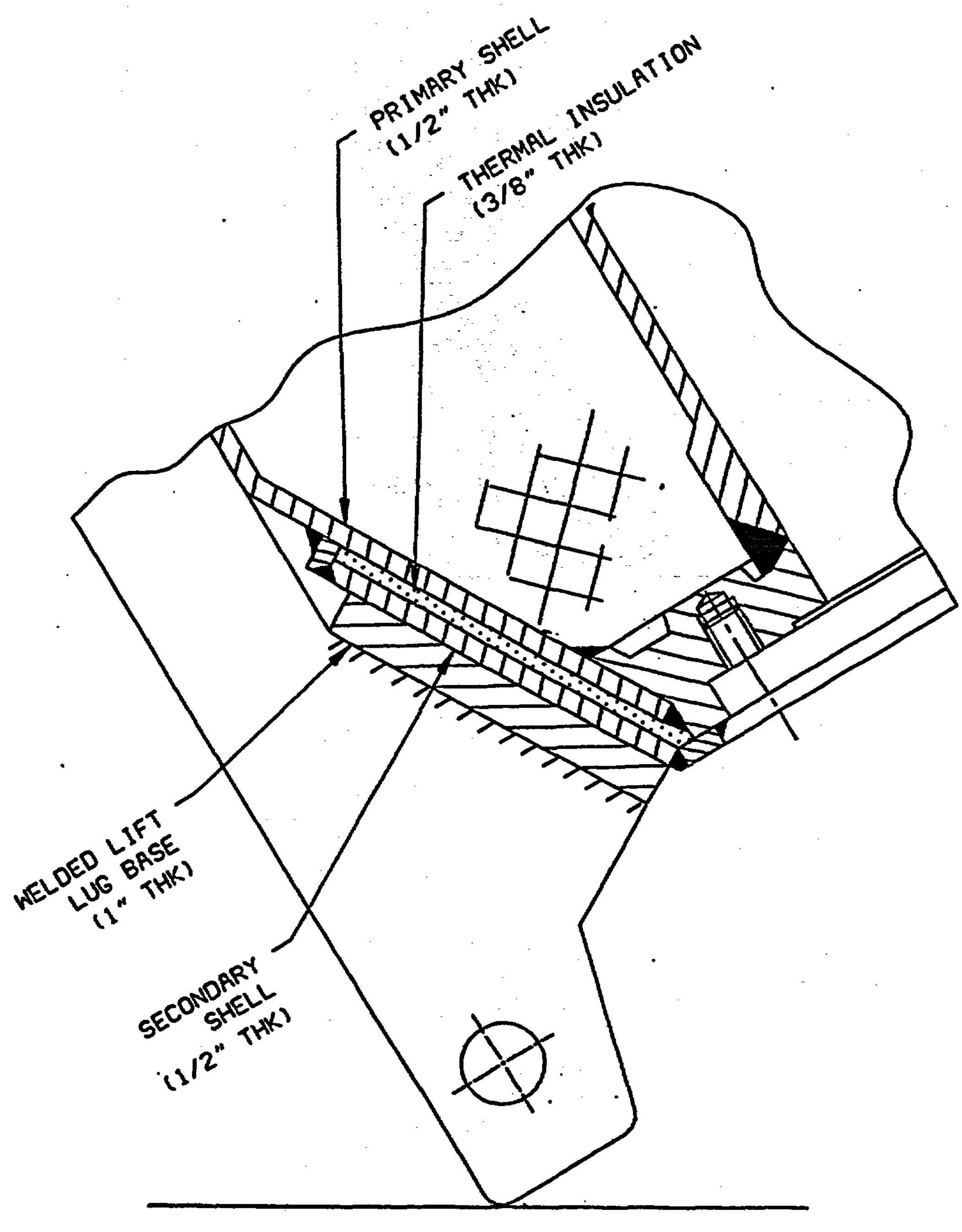
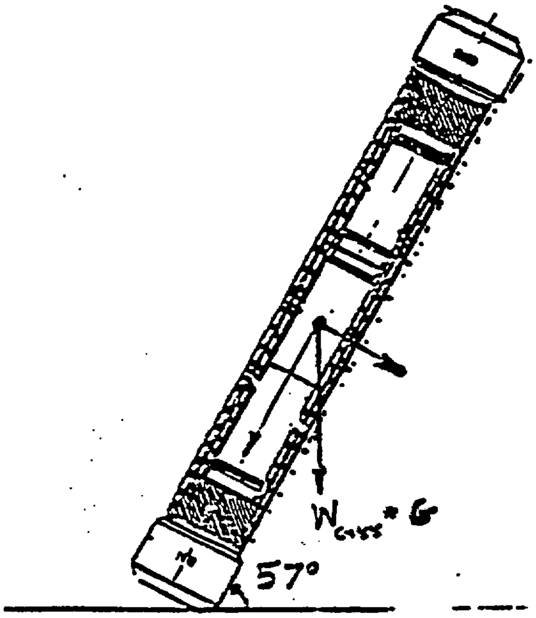


Figure 2.10.14-F46
C-188 in Top Corner Drop



6. F-294 STRESS ANALYSIS IN OBLIQUE SIDE DROP ORIENTATION

See Figure 2.10.14-F47.

6.1 G-LOADS

Actual 30-ft free drop test of F-294 in side oblique drop orientation was carried out. The details of the test program are given in Chapter 2, Appendix 2.10.12. In the side oblique orientation (36.5° from the horizontal), the measured G-loads are:

- G1= 136 g's (top of closure plug)
- G2= LOS (bottom of closure plug)
- G3= 66 g's (bottom of cavity)
- G4= 73 g's (bottom of fixed skid).

Therefore, for the side oblique corner drop, G= 136 g's shall be used to carry out the stress analysis of the F-294 components.

6.2 EFFECT OF G-LOADS ON F-294 COMPONENTS

6.2.1 Buckling of Lower Cavity Tube

See Figures 2.10.14-F48 and 2.10.14-F49.

W_1 = weight of lead borne by steel tube + end cap
$= \pi \times 12.5^2/4 \times 11.25 \times 0.41$
$= 566$ lb.

G_1 = 136 g's (design)

In this model, the cavity end plate is under external applied pressure as a result of impact. The applied pressure acts on the cavity tube end cap which is transmitted to the lower cavity tube.

Calculations are presented to demonstrate the cavity tube's ability to resist buckling, due to application of eccentric load, during the 30-ft free drop in top corner orientation.

As per equation 27, Chapter 11, Ref. [4], the maximum stress produced in the eccentrically loaded tube is given by

$$\sigma = [P/A] * [1 + (ec/r^2) \text{x} \sec\{P\text{x}(L/r)^2/4EA\}^{0.5}]$$

where

P = maximum applied load = $W_1 \cos 53.5° \text{x}\ G_1 = 566 \times 0.5948 \times 136 = 45{,}800$ lb.
A = area of tube = $\pi\ (6.25^2 - 5.75^2) = 18.84\ \text{in}^2$
r = radius of gyration = $1/4(r_o^2+r_i^2) = 0.25 \times (6.25^2 - 5.75^2) = 4.246$ in.
c = distance from axis 1 to the extreme fibre on the side nearest the load
= 6.26 (same as the outside radius.
E = 28×10^6 psi
L = 20 in. length of the tube

Evaluate

$= \sec\{P(L/r)^2/4EA\}^{0.5}$
$= \sec\ \{45{,}800\text{x}\ (20/4.246)^2/4 \times 28 \times 10^6 \times 18.84\}^{0.5}$
$= \sec\ \{0.0219\}$
$= \sec\ \{1.257°\}$
$= 1.0003$

Therefore

σ = [45,800/18.84] * [1 + (3.75 x 6.25/4.246^2) x {1.0003}]
= [45,800/18.84] * [1 + 1.300]
= [45,800/18.84] * 2.300
= 5,600 psi

Safety Factor (SF) = allowable stress/applied stress
= UTS/σ
= 70,000/5,600
= 12.5

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = SF – 1 = 12.5 – 1= 11.5

For ss304L, the UTS = 70,000 psi and YS = 25,000 psi. As the Margin of Safety (MS) > 0, the cavity lower tube will not deform permanently.

6.2.2 Bending of Lower Cavity End Plate

See Figure 2.10.14-F50.

The lower cavity end plate (cap) thickness is 0.75 in. thick.

In this model, the cavity end plate is under external applied pressure as a result of impact. The applied pressure acts on the cavity tube end cap.

The applied pressure on the cavity tube cap is

p = weight of lead x in-axial component of g-load of 136 g's/A_{CAP}
= 566 lb. x 136 g's cos53.5°/[π x 6.25^2]
= 566 lb. x 136 g's x 0.595/122.73
= 373 psi

Is 0.75 in. thick Hastelloy C-276 tube cap strong enough to resist 373 psi maximum applied pressure?

For Hastelloy C-276, the material properties are:
Yield Stress (YS) = 41,000 psi.
Ultimate Tensile Strength (UTS) = 100,000 psi.

From ASME VIII

s = cp/[t/d]^2

where

c = constant depending on end tube to cap joint configuration
= 0.2 ((ASME VIII, Division 1, Figure UG-34 (i))
p = applied pressure = 373 psi
t = thickness of cap = 0.75 in.
d = 11.5 in. inside diameter
s = cp/[t/d]^2
s = 0.2 x 373/[0.75/11.5]^2
s = 17,540 psi.

Safety Factor (SF) = allowable stress/applied stress
= UTS/σ
= 100,000/17,540
= 5.7

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = SF – 1 = 5.7 – 1= 4.7

The maximum stress in the end cap s = 17,540 psi is below the YS of 41,000 psi and the static UTS of 100,000 psi. As the Margin of Safety (MS) > 0, the lower cavity end cap will not deform permanently.

6.2.3 Weld WCC6 Between the Cavity Tube to the Cavity End Cap

Check the shear strength of weld WCC6 as per Figure 2.10.14-55

Axial load W_A = 566 x G cos 53.5° = 566 x 136 x 0.595
= 45,800. lb.

Weld area A_{WELD} = π x 11.5 x 0.5 x 0.7 = 12.64 in^2

The weld is fully radiographed.

Shear stress τ = 45,800/12.64 = 3,630 psi, which is less than the YS of 25,000 psi ss304L or UTS of 70,000 psi.

Safety Factor (SF) = allowable stress/applied stress
= 0.6 x UTS/τ
= 0.6 x 70,000/3,630
= 42,000/3,630
= 11.5

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = SF – 1 = 11.5 – 1 = 10.5

As the Margin of Safety (MS) > 0, the weld WCC6 as specified is acceptable.

6.2.4 Plug Bolts

See Figure 2.1-.14-F51.
Estimate bolt stresses based on static UTS

Number of bolts = 16
Total bolt area, $_{ABOLT}$ = 8.816 in^2
Static UTS = 180,000 psi

Weight of plug and contents, $w_{PLUG\ \&\ CONTENTS}$ = 1070 + 45 = 1,115 lb.

Based on deceleration load of 136 g's in the top drop orientation, the applied load on the bolts,
$P_{IMPACT\ AXIAL}$ = weight of plug and contents x axial component of deceleration G-load
= $W_{PLUG\ \&\ CONTENTS}$ x 136 cos 53.5°
= 1,115 x 136 x 0.595
= 90,225 lb.

Gasket seating load, F_{SG} = 2,400 lb.
Pressure build-up load W_{plug} = 4,000 lb.

Therefore total load on 16 bolts, P_{TOTAL}

$P_{TOTAL} = P_{IMPACT} + F_{SG} + W_{plug}$
= 90,225 + 2,400 + 4,000
= 96,625 lb.

What is the tensile stress in the bolt ?

Bolt stress, σ = P_{TOTAL}/A_{BOLT} = 96,225 lb./8.816 in^2
= 10,920 psi.

Based on deceleration load of 136 g's in the top drop orientation, the applied load on the bolt,
$P_{IMPACT\ (SHEAR)}$ = weight of plug and contents x transverse component of deceleration G-load
= $W_{PLUG\ \&\ CONTENTS}$ x 136 sin 53.5°
= 1,115 x 136 x 0.804
= 121,920 lb.

Gasket seating load, F_{SG} = 2,400 lb.

Pressure build-up load W_{plug} = 4,000 lb.

Therefore total load on 16 bolts, P_{TOTAL}

$$P_{TOTAL} = P_{IMPACT\,(SHEAR)} + F_{SG} + W_{plug}$$
$$= 121{,}920 + 2{,}400 + 4{,}000$$
$$= 128{,}320 \text{ lb.}$$

What is the shear stress in the bolt?

$$\text{Bolt stress, } \tau = P_{TOTAL}/A_{BOLT} = 128{,}320 \text{ lb.}/8.816 \text{ in}^2$$
$$= 14{,}560 \text{ psi.}$$

Combine the tensile and shear stresses to obtain the principal stresses.

$$\sigma_1 = \sigma/2 \pm \sqrt{[(\sigma/2)^2 + \tau^2]}$$
$$= 10{,}920/2 \pm \sqrt{[(10{,}920/2)^2 + (14{,}560)^2]}$$
$$= 5{,}460 \pm 18{,}200$$
$$= 23{,}660 \text{ or}$$
$$\sigma_2 = -12{,}740 \text{ psi}$$

The allowable static UTS at 20°C is 180,000 psi.

Safety Factor, $SF_{STRESS\text{-}BASED}$ = allowable stress/maximum applied stress
= static UTS/bolt maximum principal stress
= 180,000 psi/23,660 psi
= 7.60

Margin of Safety, $MS_{STRESS\text{-}BASED}$ = $SF_{STRESS\text{-}BASED} - 1$
= 7.60 – 1
= 6.60

As the Margin of Safety (MS) > 0, the bolts are capable of maintaining a closure joint.

6.2.5 Male Flange

What are the stress levels in the male and female flange of the bolted closure?
See Figure 2.10.14-F52.

It is assumed that the ligament area around the bolt holes is the critical area in terms of failure mode. Effective ligament area is considered that area 1.5 diameters from bolt hole centerline.

Minimum ligament area in shear around the bolt holes AS.

$$AS = 5/16 * 1 + 0.5 * 1$$
$$= 13/16 \text{ in}^2$$

Number of bolt holes = 16

Based on deceleration load of 136 g's in the top drop orientation, the applied load on the bolts,

$P_{IMPACT\,AXIAL}$ = weight of plug and contents x deceleration G-load

$$= W_{PLUG\,\&\,CONTENTS} \times 136 \cos 53.5°$$
$$= 1{,}115 \times 136 \times 0.595$$
$$= 90{,}225 \text{ lb.}$$

Gasket seating load, F_{SG} = 2,400 lb.

Pressure build-up load W_{plug} = 4,000 lb.

Therefore total load on ligament area, P_{TOTAL}

$$P_{TOTAL} = P_{IMPACT} + F_{SG} + W_{plug}$$
$$= 90{,}225 + 2{,}400 + 4{,}000$$
$$= 96{,}625 \text{ lb.}$$

Shear stress in the ligament zone, τ

τ $= P_{TOTAL}/A_{TOTAL\ LIGAMENT\ AREA}$
$= 96{,}225/[16 \times (13/16)]$
$= 7{,}400$ psi

$SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress
$= 0.6 \times UTS/\tau$
$= 0.6 \times 70{,}000/7{,}400$
$= 42{,}000/7{,}400$
$= 5.67$

$MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 5.67 - 1 = 4.67$

As the Margin of Safety (MS) > 0, the male flange as specified is acceptable.

6.2.6 Female Flange

See Figure 2.10.14-F53.

It is assumed that the joint between the female flange to the cavity liner (location B as per Figure 2.10.14-F53) is the critical area in terms of failure mode. This weld joint is subjected to both axial and shear impact forces in the top corner drop orientation of the package.

Area of the butt weld,

$A_{WELD} = \pi * D * t * 0.7$
$A_{WELD} = \pi * 15.284 * 0.5 * 0.7$
$A_{WELD} = 16.8\ in^2$

Based on deceleration load of 136 g's in the top drop orientation, the applied load on the bolts,

$P_{IMPACT\ AXIAL}$ = weight of plug and contents x deceleration G-load
$= W_{PLUG\ \&\ CONTENTS} \times 136 \cos 53.5°$
$= 1{,}115 \times 136 \times 0.595$
$= 90{,}225$ lb.

Gasket seating load, $F_{SG} = 2{,}400$ lb.

Pressure build-up load $W_{plug} = 4{,}000$ lb.

Therefore total load on 16 bolts, P_{TOTAL}

$P_{TOTAL} = P_{IMPACT} + F_{SG} + W_{plug}$
$= 90{,}225 + 2{,}400 + 4{,}000$
$= 96{,}625$ lb.

Stress in the weld, σ_{WELD}

$\sigma_{WELD} = P_{TOTAL}/A_{WELD}$
$= 96{,}625\ lb./16.8\ in^2$
$= 5{,}750$ psi

For weld with 100% joint efficiency (fully radiographed weld joint)

$SF_{STRESS\text{-}BASED}$ = Allowable stress/applied stress
$= UTS/\sigma$
$= 70{,}000/5{,}750$
$= 12.28$

$MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 12.28 - 1 = 11.28$

Based on deceleration load of 136 g's in the top drop orientation, the applied load on the bolts,

$P_{IMPACT\ (SHEAR)}$ = weight of plug & contents x transverse component of deceleration G-load

$= W_{PLUG\ \&\ CONTENTS} \times 136 \sin 53.5°$

$= 1{,}115 \times 136 \times 0.804$

$= 121{,}800$ lb.

Gasket seating load, $F_{SG} = 2{,}400$ lb.

Pressure build-up load $W_{plug} = 4{,}000$ lb.

Therefore total load on 16 bolts, P_{TOTAL}

$P_{TOTAL} = P_{IMPACT\ (SHEAR)} + F_{SG} + W_{plug}$

$= 121{,}800 + 2{,}400 + 4{,}000$

$= 128{,}200$

Shear stress in the weld, τ_{WELD}

$\tau_{WELD} = P_{TOTAL}/A_{WELD}$

$= 128{,}200 \text{ lb.}/16.8 \text{ in}^2$

$= 7{,}630$ psi

For weld with 100% joint efficiency (fully radiographed weld joint),

$SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress

$= 0.6 \times UTS/\sigma$

$= 0.6 \times 70{,}000/7{,}630$

$= 5.4$

$MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED}$

$= 5.4 - 1$

$= 4.4$

As the Margin of Safety (MS) > 0, the female flange as specified is acceptable.

6.2.7 Stripping of Internal Threads of Bolt Hole Under Impact Load

See Figure 2.10.14-F54.

What stresses can the internal threads of the bolt hole in the female flange of the bolted closure withstand without stripping? Effective thread area per bolt hole = 1.44 in^2.

Based on deceleration load of 136 g's in the side oblique drop orientation, the applied load on the bolts,

$P_{IMPACT\ AXIAL}$ = weight of plug and contents x Deceleration G-load

$= W_{PLUG\ \&\ CONTENTS} \times 136 \cos 53.5°$

$= 1{,}115 \times 136 \times 0.595$

$= 90{,}225$ lb.

Gasket seating load, $F_{SG} = 2{,}400$ lb.

Pressure build-up load $W_{plug} = 4{,}000$ lb.

Therefore total load on 16 bolts, P_{TOTAL}

$P_{TOTAL} = P_{IMPACT} + F_{SG} + W_{plug}$

$= 90{,}225 + 2{,}400 + 4{,}000$

$= 96{,}625$ lb.

Shear stress in the bolt hole threads, τ

$\tau = P_{TOTAL}/A_{BOLT\ HOLE\ THREADS}$

$= 96{,}625/[16 \times 1.44]$

$= 4{,}195$ psi.

For stripping of bolt hole threads, the safety factor and margin of safety are:

$SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress
= 0.6 x UTS/τ
= 0.6 x 70,000/4,195
= 42,000/4,195
= 10.01

$MS_{STRESS\text{-}BASED}$ = $SF_{STRESS\text{-}BASED}$
= 10.01 – 1
= 9.01

As the Margin of Safety (MS) > 0, the design of the internal threads of the bolt hole is acceptable.

6.2.8 Container Welds

See Figure 2.10.14-F55.
In the top corner drop orientation, the weight of the lead shielding is segmented into four zones: W_1, W_2, W_3, W_4 respectively.

The weight W_1 acts directly on the bottom plate cavity and affects cavity buckling.

The weight W_2 acts directly on the off-set flange between upper and lower cavity and affects buckling of upper cavity.

The weight W_3 is directly acting on the container female flange and weld joints WCC1, WCC2, WCC7 and WF respectively.

The weight W_4 is directly acting on the container conical head and weld joints #WCC3 and WF.

Therefore, collectively, welds WCC1, WCC2, WCC3, WCC7 and WF resist the impact of weight W_3 & W_4 in top corner drop orientation. Not all the weight W_3 and W_4 is directly impacting the welds due to load sharing by inner shell cavity assembly.

The estimate of weights W_1, W_2, W_3, W_4 is given here:

W_1 = 566 lb.
W_2 = 950 lb.
W_3 = 5,695 lb.
W_4 = 5,514 lb.

Step #1
Calculate the axial impact load due to W_3 and W_4.
The cumulative impact load on welds WCC1, WCC2, WCC3, WCC7 and WF due to the deceleration load of 136 g's is $P_{IMPACT\ AXIAL}$

= $[W_3 + W_4]$ x 136 g's cos 53.5°
= [5,695 +5,514] x 136 x 0.595
= 0.907×10^6 lb.

Step #2
Calculate weld areas.

Weld designated WCC1: Area $A_{1,circumferential} = 2\pi \times 11.812 \times 0.5 \times 0.707 = 26.23\ in^2$
Weld designated WCC2: Area $A_{2,circumferential} = 2\pi \times 12.812 \times 0.5 \times 0.707 = 28.46\ in^2$
Weld designated WCC3: Area $A_{3,circumferential} = 2\pi \times 17.500 \times 0.5 \times 0.707 = 38.87\ in^2$
Weld designated WCC7: Area $A_{7,circumferential} = 2\pi \times 7.392 \times 0.5 \times 0.707 = 16.42\ in^2$
Weld designated WF: Area $A_{WF} = 114.5\ in^2$

A_{WF} = No. of fins x no. of fillet welds x thickness of weld x length of weld x 0.707
= 18 x 2 x 0.375 x 12 x 0.707 = 114.5 in^2

There are 36 fins at the top of the container; however, in the top corner drop orientation it is assumed that only 18 fins to outer container shell welds are effective.

The collective effective area of welds, inclusive of joint efficiency, is

$$A = \eta_1 \times A_{1,circumferential} + \eta_1 \times A_{2,circumferential} + \eta_2 \times A_{3,circumferential} + \eta_2 \times A_{7,circumferential} + \eta_1 \times A_{WF}$$

$$A = 0.8 \times 26.23 + 0.8 \times 28.46 + 1.0 \times 38.87 + 1.0 \times 16.42 + 0.8 \times 114.5$$

$$A = 190.6\ in^2$$

Step #3

Calculate average stress in the weld due to axial component

The average tensile stress on the welds WCC1, WCC2, WCC3, WCC7 and WF is

$$\sigma_{AVG.} = P_{IMPACT\ AXIAL}/A = 0.907 \times 10^6\ lb./190.6\ in^2 = 4{,}760\ psi.$$

The average stress in the welds is well above the yield stress of 25,000 psi for ss304L parent metal and below static UTS of 70,000 psi.

Step #4

Calculate the radial impact load due to W_3 and W_4.

The cumulative impact load on welds WCC1, WCC2, WCC3, WCC7 and WF due to deceleration load of 136 g's is $P_{IMPACT\ AXIAL} = [W_3 + W_4] \times 136$ g's sin 53.5°

$$= [5{,}695 + 5{,}514] \times 136 \times 0.804 = 1.226 \times 10^6\ lb.$$

Step #5

Calculate average shear stress in the weld due to transverse component

The average shear stress on the welds WCC1, WCC2, WCC3, WCC7 and WF is

$$\tau_{AVG.} = P_{IMPACT\ TRANSVERSE}/A = 1.226 \times 10^6\ lb./190.6\ in^2 = 6{,}432\ psi.$$

Combine the tensile and shear stresses to obtain the principal stresses.

$$\sigma_1 = \sigma/2 \pm \sqrt{(\sigma/2)^2 + \tau^2]}$$
$$= 4{,}760/2 \pm \sqrt{[(4{,}760/2)^2 + (6{,}432)^2]}$$
$$= 2{,}380 \pm 6{,}858$$
$$= 9{,}238 \text{ or}$$
$$\sigma_2 = -4{,}478\ psi$$

Safety Factor, $SF_{STRESS\text{-}BASED}$ = allowable stress/applied stress
= 70,000/9,238
= 7.5

Margin of Safety $MS_{STRESS\text{-}BASED} = SF_{STRESS\text{-}BASED} - 1 = 7.5 - 1 = 6.5$

As the Margin of Safety (MS) > 0, the container welds as specified are acceptable.

6.2.9 Container Top Flange

See Figure 2.10.14-F56.

In this model, the container top flange plate is under external applied pressure as a result of impact. The applied pressure acts on the container top flange and the conical shell.

Based on 136 cos 53.5° = 136 x 0.595 = 81 g's deceleration load axial component, the applied pressure on the container top flange is

$$
\begin{aligned}
p &= \text{weight of lead} \times 81 \text{ g's}/A_{RING\ FLANGE} \\
&= (W_1 + W_2 + W_3) \times 81/[\pi \times (10.5^2 - 7.892^2)] \\
&= (566 + 950 + 5314) \times 81/150.7 \\
&= 6{,}830 \times 81/150.7 \\
&= 3{,}671 \text{ psi}
\end{aligned}
$$

Is 1.5 in. thick stainless steel plate (ring flange) strong enough to resist 3,671 psi maximum applied pressure?

For stainless steel (ss304L) A-240, the material properties are:

Yield Stress (YS) = 25,000 psi.

Ultimate Tensile Strength (UTS) = 70,000 psi.

Case 77, Table X, Ref. [4].

$$s_r = \beta\, \omega\, a^2/t^2$$

where

s_r = maximum radial stress

β = constant depending upon a/b = 10.5/7.892 = 1.33, β = 0.03

ω = p = applied pressure = 3,671 psi

t = thickness of ring flange = 1.5 in.

a = 10.5 in. ring flange outside radius

b = 7.892 in. ring flange inside radius

$$
\begin{aligned}
s_r &= \beta\, \omega\, a^2/t^2 \\
s_r &= 0.03 \times 3{,}671 \times 10.5^2/1.5^2 \\
s_r &= 5{,}400 \text{ psi.}
\end{aligned}
$$

$$
\begin{aligned}
\text{Safety Factor, } SF_{STRESS\text{-}BASED} &= \text{allowable stress/applied stress} \\
&= \text{static UTS}/5{,}400 \\
&= 70{,}000 \text{ psi}/5{,}400 \text{ psi} \\
&= 12.96
\end{aligned}
$$

Margin of Safety, $MS_{STRESS\text{-}BASED} = SF - 1 = 12.96 - 1 = 11.96$

The maximum stress in the ring flange s_r = 5,400 psi, which is below YS of 25,000 psi and below UTS of 70,000 psi. As the Margin of Safety (MS) >), the ring flange will not deform permanently.

6.2.10 Effect of Peak force on the SS Shell Directly Under the Foot of the Lift Lug Fin

See Figure 2.10.14-F-57.

There are four (4) lift lug fins on the F-294. Underneath the base of each of the lift lug fins, there are the following components:

- a 1.0 in. thick reinforcement base plate (pad) (material ss304)
- a secondary conical shell 0.5 in. thick (material ss304)
- 0.38 in. thick thermal insulation
- a primary conical shell of the lead cask (material ss304L)

The 0.5 in. thick ss shell is reinforced with a pad approximately 1.0 in. thick x 6.75 in. wide at top x 7 in. height x 9.5 in. wide at bottom. After the side corner drop, the crush shield displaces (moves) down by 5 in. The lift lug tip is not only recessed 7 in from top of the non-deformed crush shield, but is also located between the crush shield fins so that the lift lug's impact is marginally delayed. However the 0.5 in thick container fins (qty = 2) adjacent to the lift lug fin are definitely impacted prior to the lift lug fin. The impact load on the container fins has been estimated:

$$P_{impact} = \text{F-294 weight} \times \text{G-load} = 21{,}000 \times 136 = 2.856 \times 10^6 \text{ lb.}$$

The (bearing) compressive load on the secondary conical shell wall at the base of the lift lug fin is computed as follows:

$$\sigma_C = \text{Peak force/effective secondary conical shell area under compression} = P_{impact}/A = [2.856\text{x } 10^6]/(10.52 \times 11) = [2.856\text{x } 10^6]/115.7 = 24{,}680 \text{ psi.}$$

Safety Factor, $SF_{STRESS\text{-}BASED}$ = allowable stress for secondary shell ss304/applied stress
= static UTS/24,680
= 75,000 psi/24,680 psi
= 3.03

Margin of Safety, $MS_{STRESS\text{-}BASED} = SF - 1 = 3.03 - 1 = 2.03$

Since the maximum stress σ_1 = 24,680 psi in the container secondary conical shell wall is less than the yield stress of 30,000 psi and static ultimate compressive stress of the secondary conical dished head (material ss304 UTS = 75,000 psi), the container reinforced wall will not rupture (dynamic). The container wall at the foot of the lift lug fin, will not be deformed plastically. It must be noted that the estimated stress and the deformation of the container wall are based on instantaneous "peak force" and load sharing has been ignored and therefore they are fairly conservative. As the secondary conical shell takes most of the impact, the container primary conical shell wall is protected by the secondary conical shell. Therefore the structural integrity of the primary conical shell is sound. As the Margin of Safety (MS) > 0, the design feature of the reinforcement around the base of the lift lug fin is acceptable.

6.2.11 C-188 Sealed Source Under Top Corner Impact

The case of the C-188 sealed source capsule under top corner impact is presented here. The model chosen to represent this case is given in Figure 2.10.14-F58. The effective G-load in the cavity of F-294 is 136 g's. Therefore the stress developed in the capsule outer shell only will be due to the mass of the entire C-188 at 136 g's. The weight of C-188 is $W_{C\text{-}188}$ = 230 grams = 0.51 lb.

The support reaction P_{AXIAL} due to 136-g level is:

$$P_{AXIAL} = -W_{C\text{-}188} \times \text{G-load axial component} = -0.51 \times 136 \cos 53.5° = 0.51 \times 136 \times 0.595 \text{ lb.} = 41.3 \text{ lb.}$$

The axial stress for this condition is given by:

$$\sigma_{comp.} = P_{AXIAL}/A_{outer\ shell,\ min.\ wall} = 41.3/(\pi/4\,(0.376^2 - 0.338^2)) = 41.3/0.0213 = 1{,}940 \text{ psi.}$$

$$P_{TRANSVERSE} = -W_{C\text{-}188} \times \text{G-load transverse component} = -0.51 \times 136 \sin 53.5° = 55.8 \text{ lb.}$$

The transverse stress for this condition is given by:

$\tau_{shear.}$ $= P_{TRANSVERSE}/A_{outer\ shell,\ min.\ wall}$
$= 55.8/(\pi/4\ (0.376^2 - 0.338^2))$
$= 55.8/0.0213$
$= 2{,}620$ psi.

Combine the compressive and shear stresses to obtain the principal stresses.

σ_1 $= \sigma/2 \pm \sqrt{[\ (\sigma/2)^2 + \tau^2\ ]}$
$= 1{,}940/2 \pm \sqrt{[\ (1{,}940/2)^2 + (2{,}640)^2]}$
$= 970 \pm 2{,}794$
$= 3{,}764$ or
σ_2 $= -1{,}824$ psi

Safety Factor (SF) = allowable stress/applied stress
= UTS for ss316L at 836°F/applied stress
= 60,000 psi/3,764 psi
= 15.4

Margin of Safety = SF – 1 = 15.4 – 1 = 14.4
The yield stress of ss316L at 836 °F = 16,000 psi. [Ref. [26]]

As the maximum principal stress (3,764) < Yield Stress (16,000 psi), the tube shall not yield in the top corner drop nor fracture (dynamic) as the maximum principal stress 3,764 psi < static UTS of 60,000 psi.

Let us examine the C-188 sealed source capsule under end impact for buckling. The model chosen to represent this case is shown in Figure 2.10.14-F46. The ends of the capsule are free to rotate, translation is fixed because the ends of the C-188 are trapped between the bottom plate of the F-313 source carrier and the shield plug. Any restraining of the C-188 sealed source capsule by intermediate spacer plates of the F-313 or F-457 source holder has been ignored. Any additional restraining by the inner capsule of C-188 has also been ignored.

The critical buckling load (Euler load) is given by

P_{cr} $= \pi^2 EI/[kl]^2$

where

E = modulus of elasticity = 23.8×10^6 psi at 836°F
I = 2nd moment of area = $\pi/64\ (0.376^4 - 0.326^4) = 4.335 \times 10^{-4}\ in^4$
l = length of the column = 17.777 – 0.9 = 16.877 in.
k = effective length factor, dependent of the conditions of fixity of the column.

In this case, the column is free to rotate i.e., hinge i.e., zero moment reaction, but translation is zero. Therefore the column end condition code is "pin-jointed and fixed end". In this case, K = 1.2 (Ref. [24] CISC Handbook 1967).

Therefore

P_{cr} $= \pi^2 \times 23.8 \times 10^6 \times 4.267 \times 10^{-4}/(1.2 \times 16.877)^2$
$= 245$ lb.

The weight of the C-188, $W_{C\text{-}188} = 0.51$ lb.

Therefore the G-load in the cavity which may initiate buckling of C-188:

P_{IMPACT} = G-load axial component x $W_{C\text{-}188}$
= 136 x cos 53.5° x 0.51
= 41.3 lb.

For C-188, as the applied impact load P_{IMPACT} (41.3 lb.) < the critical buckling load P_{cr} (245 lb.), the C-188 shall not be subject to buckling. Factor of Safety (FS) = 245/41.3= 5.93
As the Factor of Safety (FS) > 1, it is concluded that the C-188 sealed source will not yield or buckle in the side oblique corner drop impact. It must be noted that the C-188 source is a Special Form source and meets 10 CFR Para.71.77; therefore C-188 provides the leaktight containment. For C-188, the USNRC source registration number is NR-222-S-103-S (see Chapter 4, Appendix 4.4.2).

6.3 SUMMARY OF SIDE OBLIQUE CORNER DROP ANALYSIS

1. For F-294 the g-load in the side oblique drop orientation is 136 g's (measured).
2. The following components of the F-294 package were stress analyzed; the corresponding stresses or loads, Safety Factors (SF) and Margins of Safety (MS) are listed here:

Plug

	Stress (psi)	SF	MS
- bolts: avg. bolt stress	23,660	7.6	5.6
- male flange shear stress	7,400	5.67	4.67
- female flange-tension, weld (WCC7)	5,750	12.28	11.28
- female flange-shear, weld (WCC7)	7,630	5.4	4.4
- stripping bolt hole, shear	4,195	10.01	9.01

Container

	Stress (psi)	SF	MS
- weld group WCC1, WCC2, WCC7, WCC3, WF	9,238	7.5	6.5
- lower cavity tube (buckling)	5,600	12.5	11.5
- lower cavity tube end cap	17,540	5.7	4.7
- container top flange	5,400	12.96	11.96
- ext. secondary conical shell, local area under lift lug	24,680	3.03	2.03
- weld, cavity end cap/tube (WCC6)	3,630	11.5	10.5

In the side oblique corner 30-ft drop of F-294, for all the components in the container and the closure plug, the margin of safety is greater than 0. Consequently there will be no ductile failure of the components in the container and the closure plug.
Therefore the structural integrity of

- the ss304L envelope surrounding the lead shielding in the plug AND
- the ss304L envelope surrounding the lead shielding in the container body

is sound and there are no cracks; thus the lead does not have potential leak paths to escape in a scenario of lead melt. In addition, it is shown that lead would not melt in the F-294 lead-cask in a regulatory fire test of F-294.(see Chapter 3 for details).

3. The closure plug bolts will not shear under 136 g's deceleration loads. Consequently, the closure plug shielding will be in place over the inner shell assembly which houses the C-188 Special Form sealed sources

4. Thermal protection: The top corner of the cylindrical fireshield will be displaced towards the container cavity. The top fireshield, which is integral with the crush shield, shall be displaced toward the top closure plug. The conical shell is double wall construction and the space is filled with thermal insulation. In all three (3) zones, the thermal insulation shall be compressed locally but there shall be no loss of thermal protection.

5. C-188 sealed source: the C-188, in a side oblique corner impact, has been demonstrated to withstand the deceleration load of 136 g's in the F-294 cavity. The C-188 is not likely to yield nor buckle. It must be noted that the C-188 source is a Special Form source and meets 10 CFR Para.71.77; therefore C-188 provides the leaktight containment. For C-188, the USNRC source registration number is NR-222-S-103-S (See Chapter 4, Appendix 4.4.2).

Figure 2.10.14-F47
F-294 in Side Oblique Corner Drop Impact

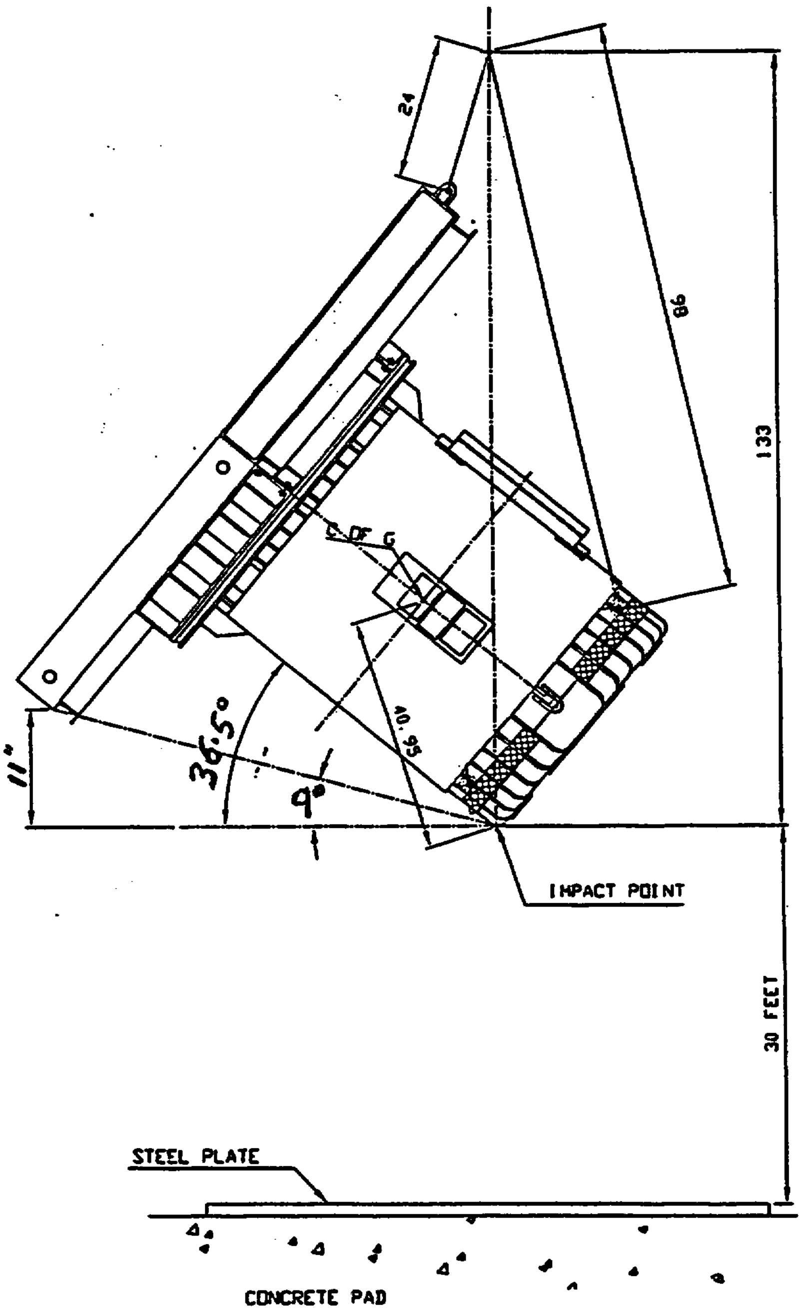


Figure 2.10.14-F48
Lower Cavity Tube under Impact Load

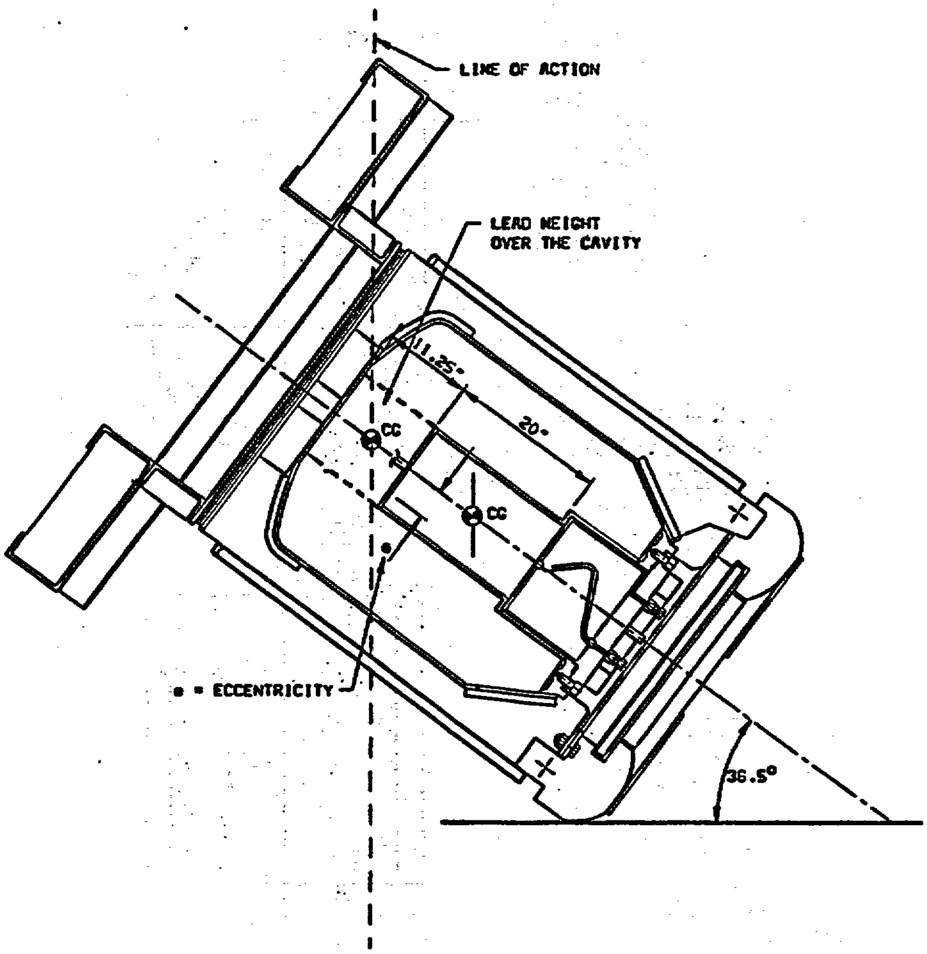


Figure 2.10.14-F49
Lower Cavity Tube under Eccentric Loading

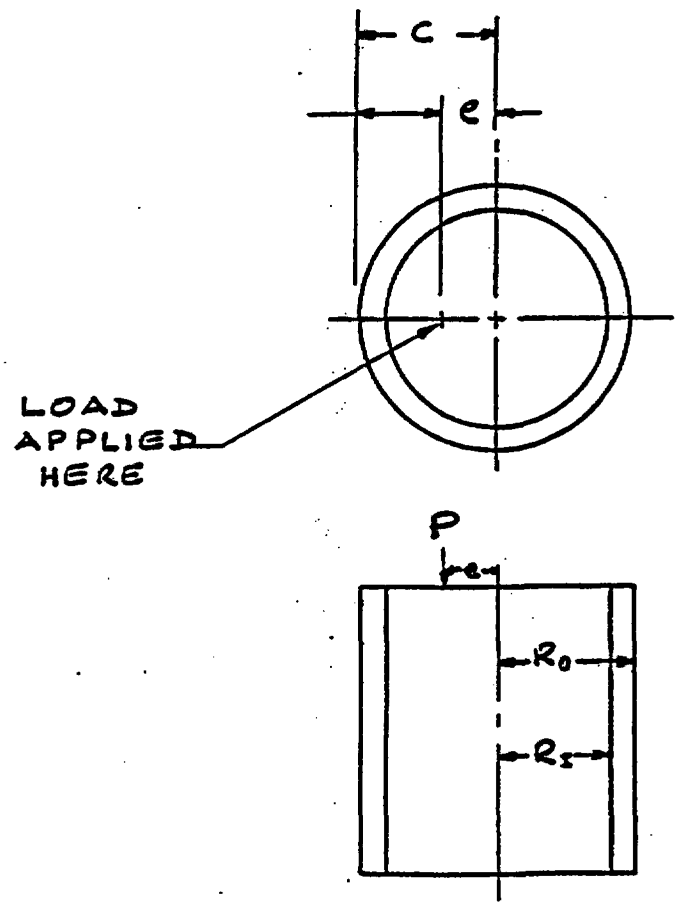


Figure 2.10.14-F50
Lower Cavity Tube End Cap under Impact Load

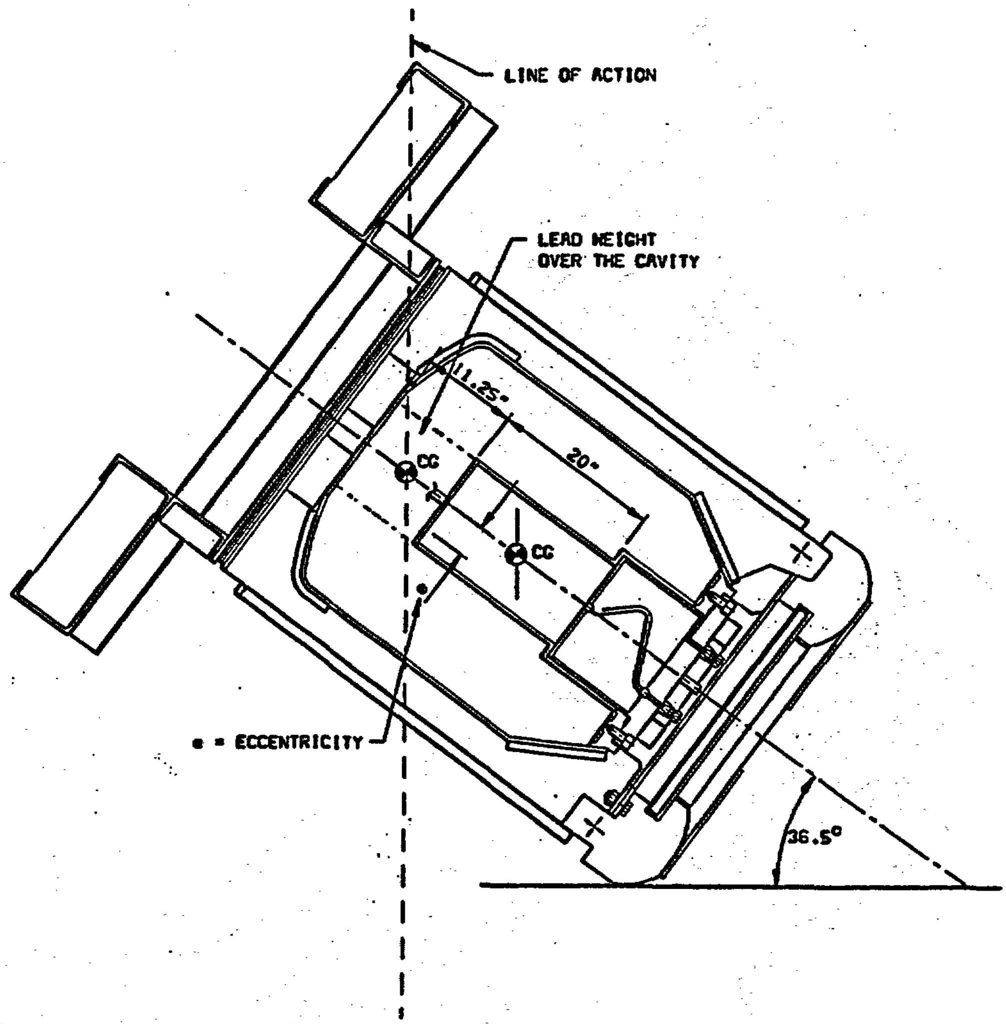


Figure 2.10.14-F51
Plug Bolts under Impact Load

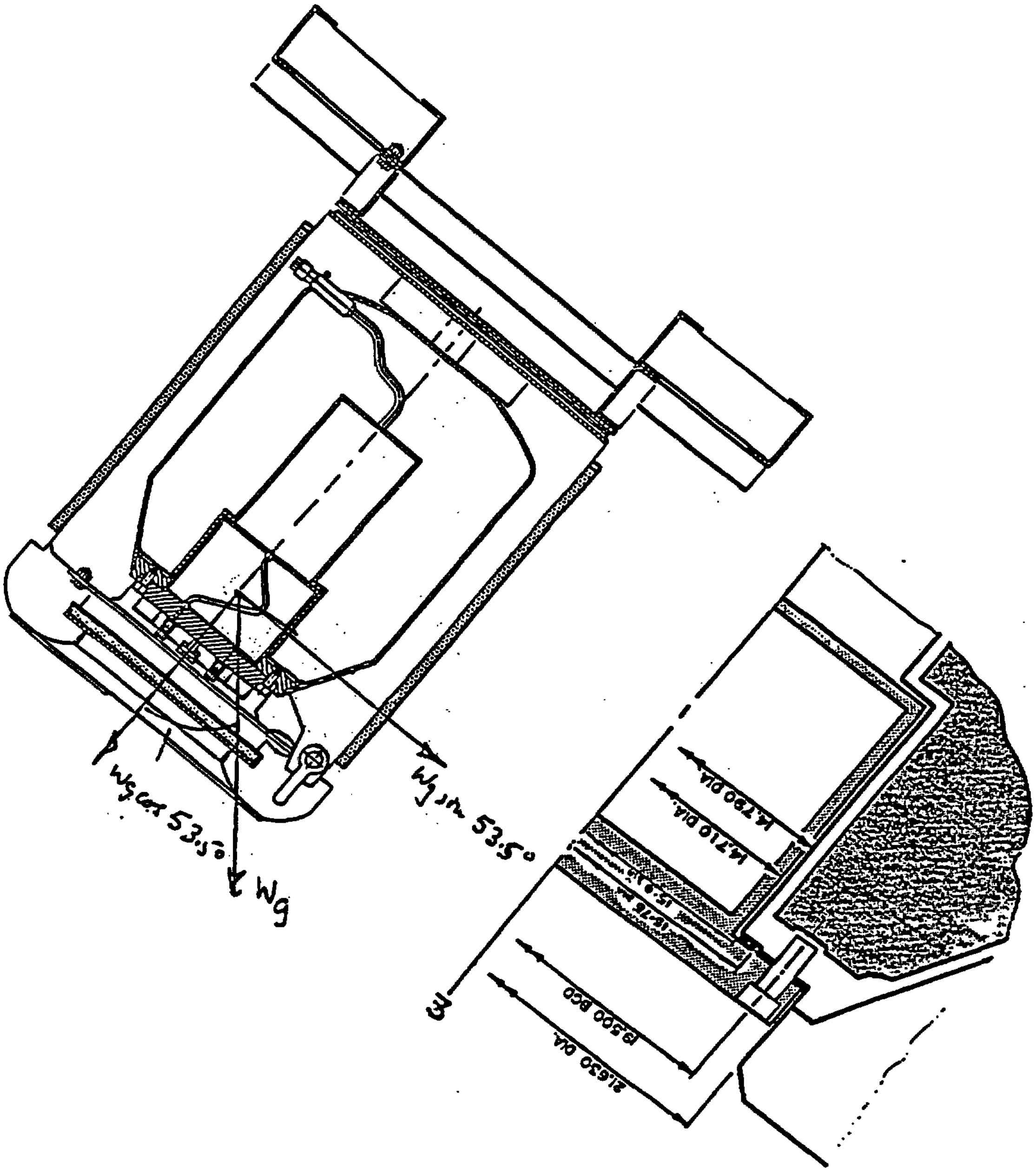


Figure 2.10.14-F52
Plug Flange under Impact Load

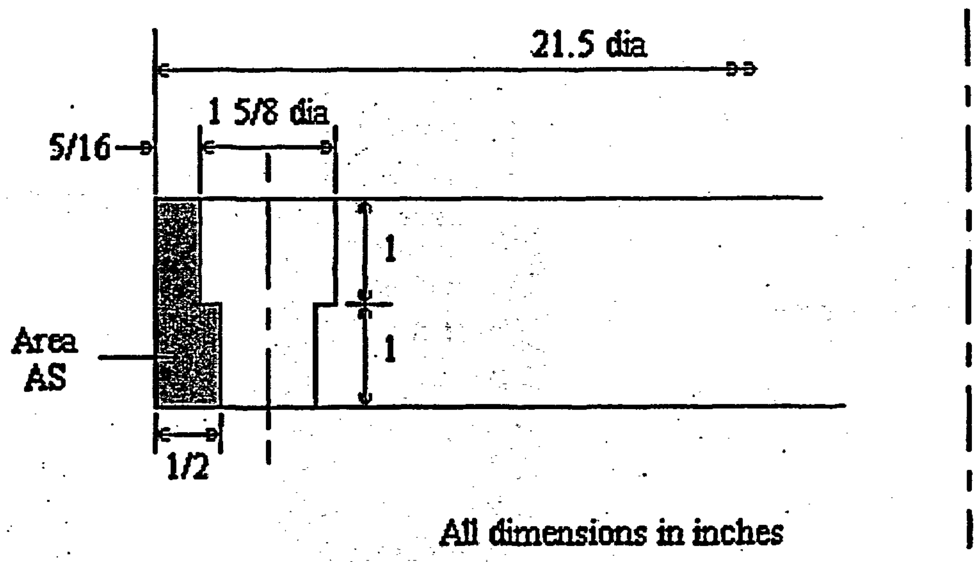


Figure 2.10.14-F53
Container Upper Cavity Weld WCC7

Zone B in the Container upper cavity

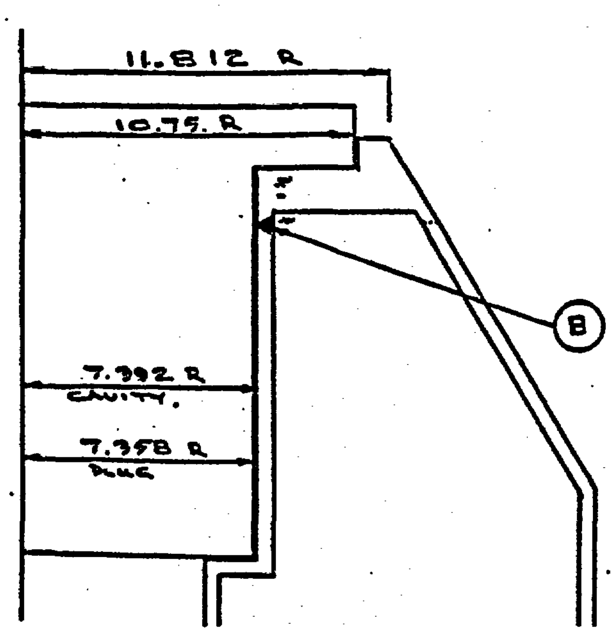


Figure 2.10.14-F54
Stripping of the Bolt Hole in the Closure Flange

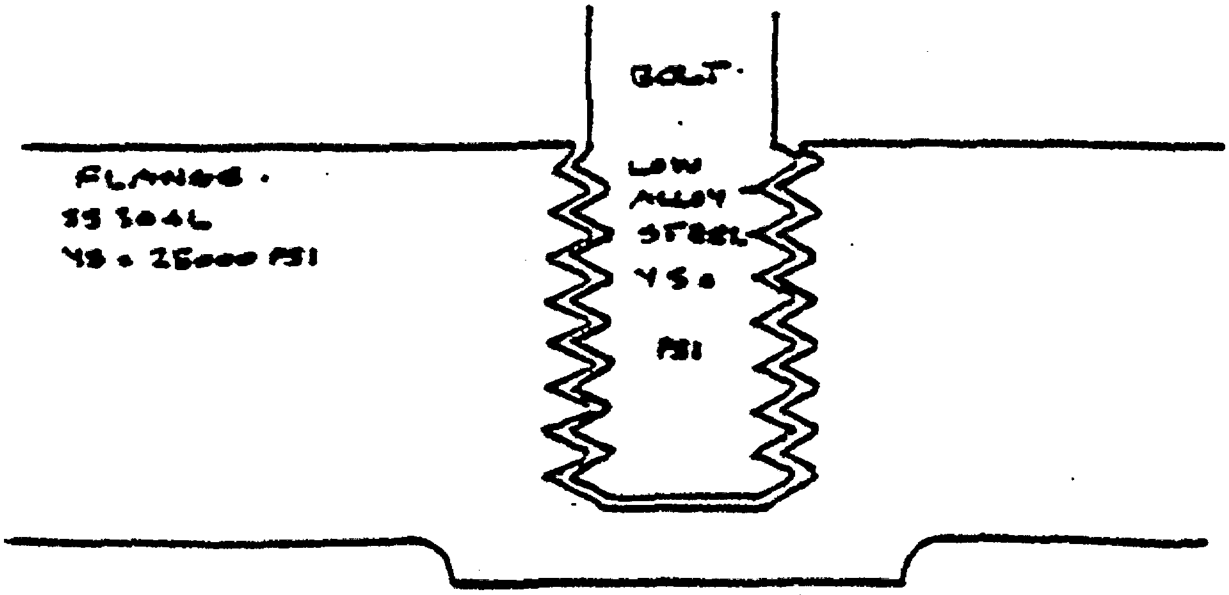


Figure 2.10.14-F55
Container: Identification of Welds

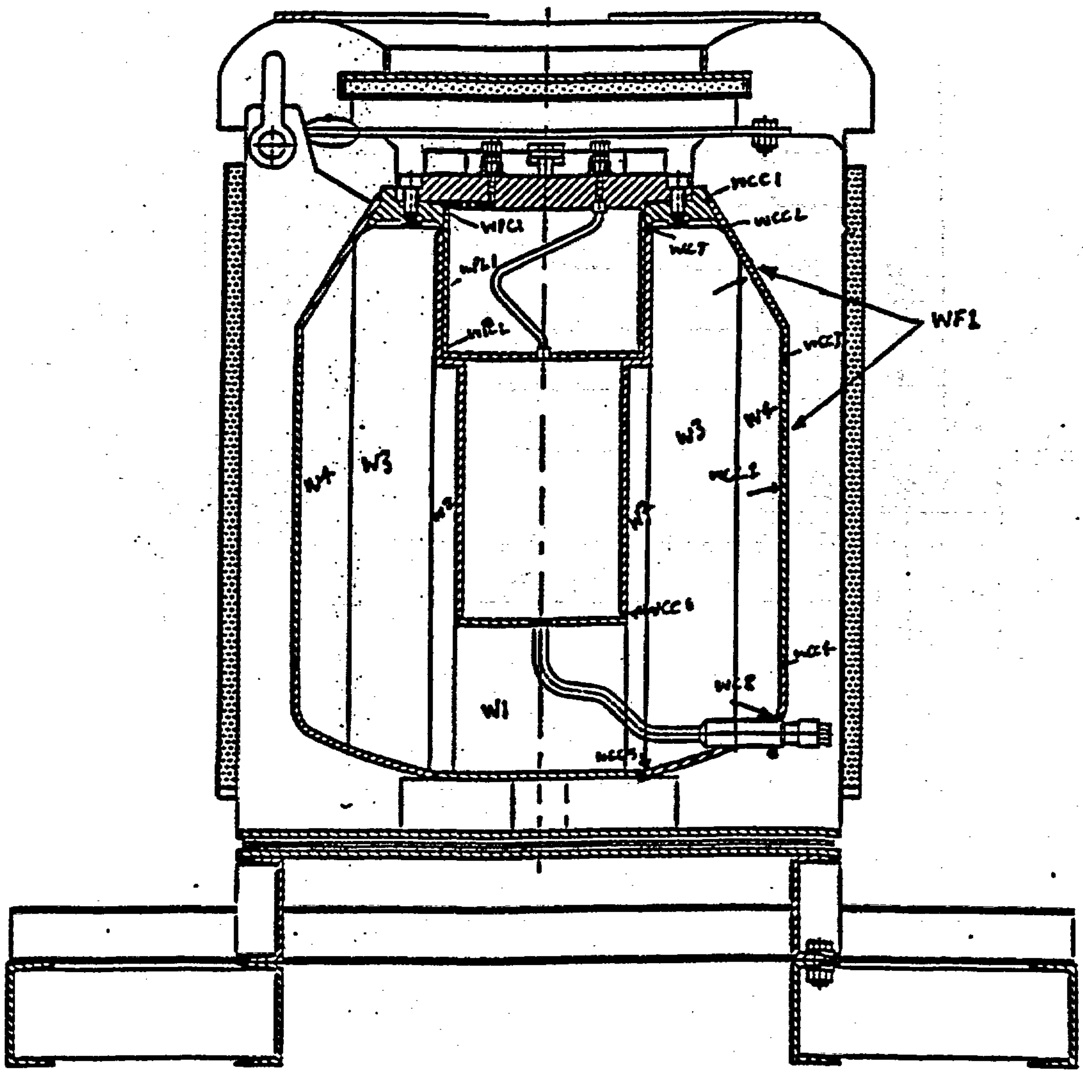


Figure 2.10.14-F56
Container Flange under Impact

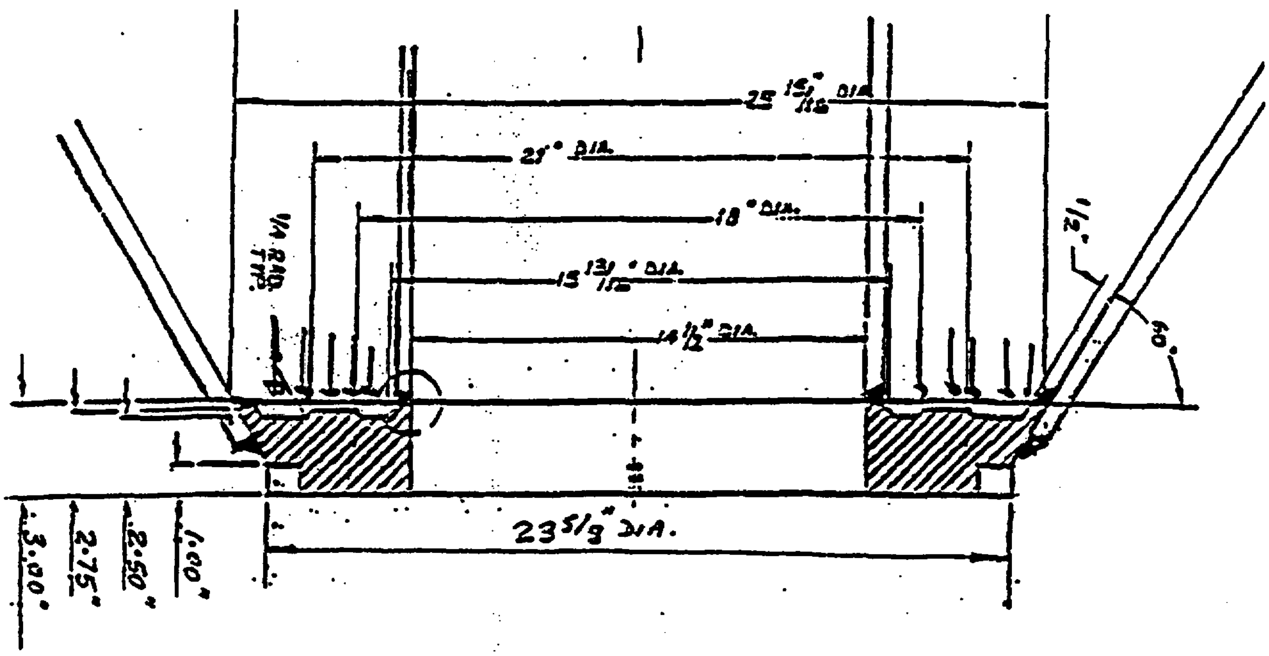


Figure 2.10.14-F57
Container Shell under the Base of Lift Lug Fin

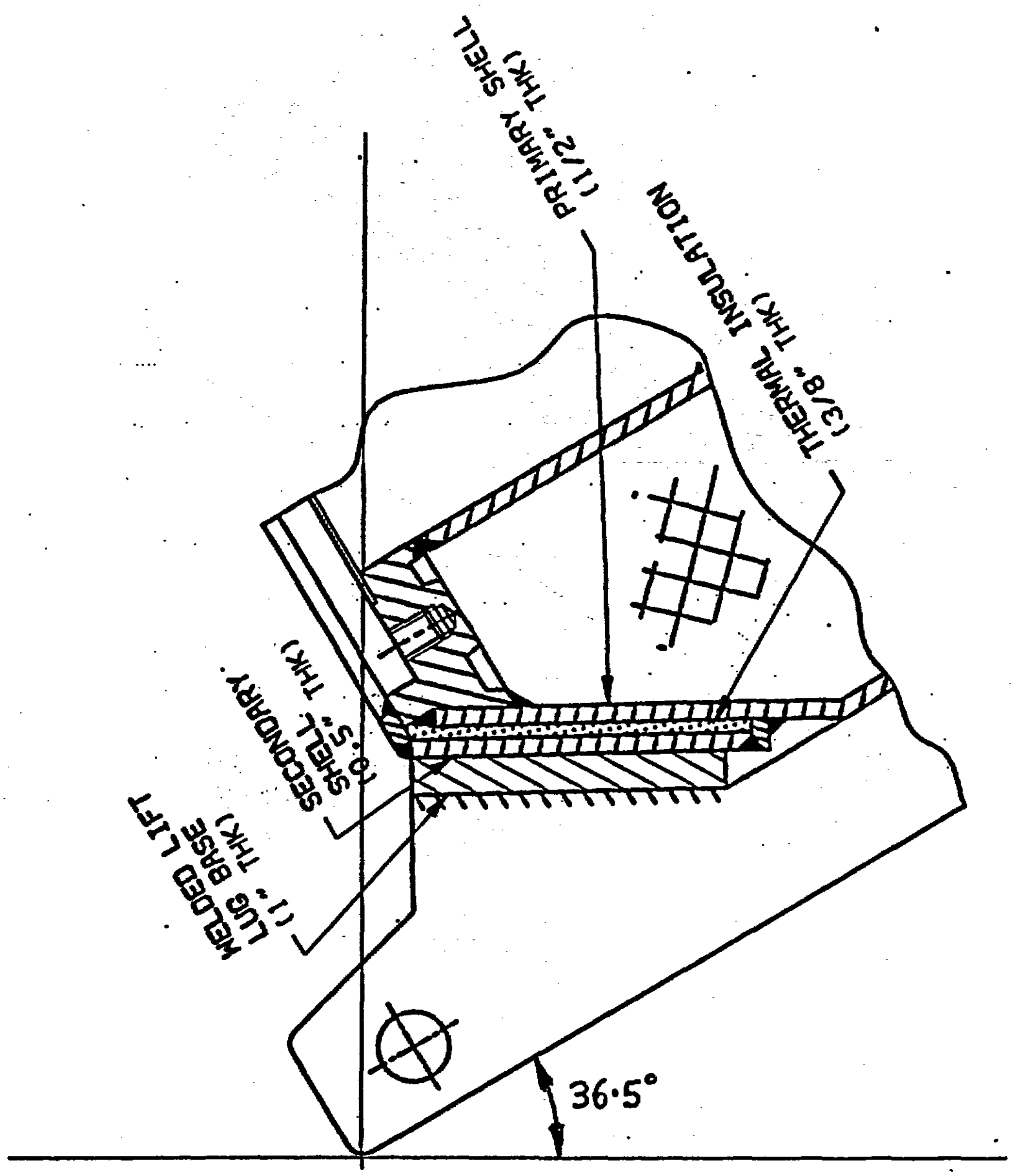
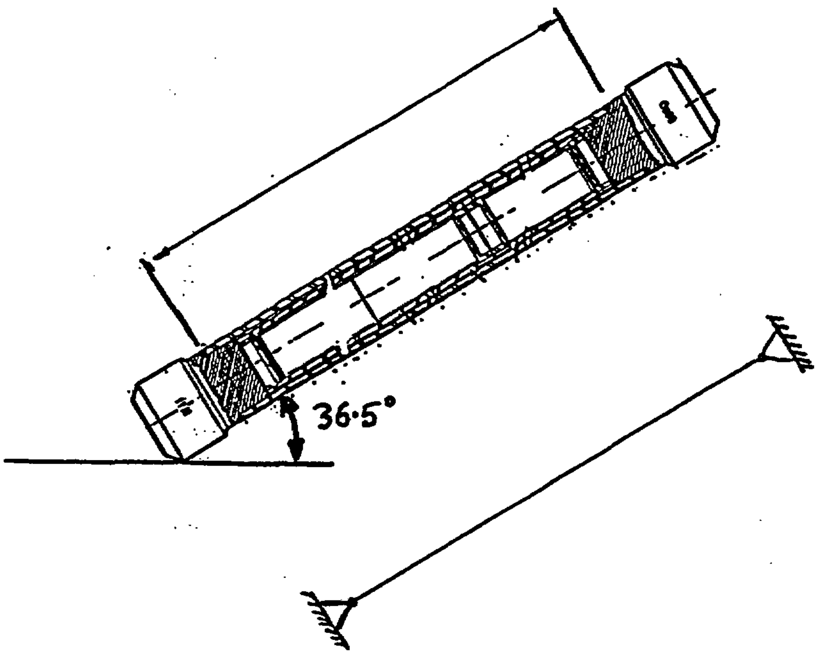


Figure 2.10.14-F58
C-188 in Side Oblique Corner Drop



7. SUMMARY

7.1 TOP END DROP ANALYSIS

1. The highest measured G-load for the F-294 subjected to 30-ft. free drop test in the top end (inverted) drop orientation, is 132 g's.
2. Using 132 g's deceleration load at the crush shield/container impact point, the following components of the F-294 package were stress analyzed; the corresponding stresses or loads, Safety Factors (SF) and Margins of Safety (MS) are listed here:

Closure Plug

	Stress (psi)	SF	MS
- bolts: avg. bolt stress	17,420	10.33	9.33
- male flange shear stress	11,820	3.55	2.55
- female flange - WCC7 weld	9,150	7.65	6.65
- stripping bolt hole, shear	6,670	6.29	5.29
- welds WPC1	10,438	6.7	5.7

Container

	Stress (psi)	SF	MS
- weld group WCC1, WCC2, WCC7, WCC3 and WF1	5,243	8.01	7.01
- lower cavity tube (buckling)		3,130.0	3,129.0
- lower cavity tube end cap	28,683	3.48	2.48
- upper cavity tube (buckling)		232,000.0	231,999.0
- upper cavity tube ring flange	8,346	8.38	7.38
- container top flange	5,280	13.2	12.2
- ext. reinforced secondary conical shell, local region under lift lug	12,184	5.74	4.74

The major changes are:

1. Lower cavity end plate thickness from 0.5 in. to 0.75 in. thick.
2. The lift lug fin material & base region modified
3. A secondary conical shell at the top of the container.
4. The reinforcement plate underneath the lift lug fin from 0.5 in. to 1.0 in.

In the top end 30-ft free drop test of the F-294 in top end (inverted) drop orientation, for the components identified in the closure plug and the container, all Safety Factors, SF's > 1 and Margin of Safety, MS > 0. The margin of safety is based on static UTS. The most vulnerable zones are:

- male flange of the closure plug
- lower cavity tube end cap.

However, there will not be ductile failure of the above two (2) vulnerable F-294 components.

Therefore the structural integrity of:

- the ss304L envelope surrounding the lead shielding in the closure plug AND
- the ss304L envelope surrounding the lead shielding in the container body

is sound and there are no cracks; thus the lead shielding does not have potential leak paths in a scenario of lead melt.

3 The closure plug bolts will not shear under 132 g's deceleration loads. Consequently, the closure plug shielding will be in place over the inner shell assembly which houses the C-188 Special Form sealed sources.

4. The thermal protection is sound. No damage or loss of thermal protection.

5. Under 132-g's deceleration load in the cavity, the direct stresses in C-188 are well below the yield stress. The C-188 sealed source will not buckle. C-188 sealed source is classified Special Form meeting the 10 CFR 71.77 requirements; therefore C-188 provides the leaktight containment despite the fact that it deforms permanently under Special Form tests. The USNRC source registration number for C-188 is NR-222-S-103-S (see Chapter 4, Appendix 4.4.2).

6. At a location opposite to the impact point, the amount of lead slump is expected to be negligible as all the impact energy is absorbed by the crush shield and container fins and a very small magnitude, if any, is absorbed by the lead shielding. For purposes of post hypothetical shielding evaluation tests, lead slump of 1.4 in. is used. The radiation shielding calculations are presented in Chapter 5, Section 5.4.

7.2 BOTTOM END DROP ANALYSIS

1 Based on actual F-294 drop test in the top end (inverted) orientation, the highest measured G-loads in the F-294 plug location is 132 g's. Therefore, based on test data of similar package, the G-load in the bottom end drop orientation of F-294 is expected to be 132 g's.

2. Based on 132 g's deceleration loads, the following components of the F-294 package were stress analyzed; the corresponding stresses or loads, Safety Factors (SF) and Margins of Safety (MS) are shown below:

Container

	Stress (psi)	SF	MS
-weld WCC4, WCC5 & WF1	4,960	8.46	7.46
Fixed skid assembly			
- top plate (ss304)	4,830	15.52	14.52
- bottom plate (A-36)	22,700	2.55	1.55
- channel (bottom flange)	107,000	0.54	–0.46

The margin of safety of F-294 components with the exception of the skid assembly, based on static UTS, is greater than 0. Consequently there will be no ductile failure of the shell of the container. Therefore the structural integrity of both

- the ss304 envelope surrounding the lead shielding in the plug AND
- the ss304 envelope surrounding the lead shielding in the container body

is sound (i.e. no cracks); thus the lead shielding does not have potential leak paths in a scenario of lead melt. The structural integrity of the lead shielded cask is sound.

Even though it is shown that the top and bottom plates of the skid assembly are not likely to yield, the top plate and the bottom plate of the skid assembly may deform permanently due to interaction of impact forces transmitted via structural channels. Consequently the fixed skid assembly is likely to deform like a "dished head". The channel flange will deform significantly to the point it will fracture.

3. No loss of thermal protection. The bottom thermal protection (44 x 44 plate), within the fixed skid plates, may be deformed like a "dished head" but not lost as the fixed skid is welded extensively to the container bottom fins (qty = 36 fin #6 and qty = 9 fin #7). The thermal insulation sandwiched between top and bottom plates will remain in place even though the skid plates may deform. Consequently, for the ensuing fire test, the thermal protection shall remain in place to protect the lead cask in the fire test.
4. C-188 sealed source is classified Special Form meeting the 10 CFR 71.77 requirements; therefore C-188 provides the leaktight containment. The USNRC source registration number for C-188 is NR-222-S-103-S (see Chapter 4, Appendix 4.4.2).
5. At a location opposite to the impact point, the amount of lead slump is expected to be negligible as all the impact energy is absorbed by the shipping skid, the fixed skid and container fins and a very small magnitude, if any, remains to be absorbed by the lead shielding. For purposes of post hypothetical shielding evaluation tests in the bottom drop orientation of F-294, lead slump of 1.4 in. estimated for the top end drop orientation of F-294 shall be used. The radiation shielding calculations are presented in Chapter 5, Section 5.4.

7.3 SIDE DROP ANALYSIS

1. Based on tests of similar packages, it is estimated that the G-loads in side drop can be 136 g's.
2. Based on 136 g's deceleration load, the following components of the F-294 package were stress analyzed, the corresponding stresses or loads, Safety Factors (SF) and Margins of Safety (MS) are listed here:

Plug

	Stress (psi)	SF	MS
- Bolts, shear	7,720 psi	14.0	13.0
-Cylindrical body, bearing	501 psi	139.7	138.7
- Weld: WPC1	10,320 psi	4.07	3.07

Container

	Stress (psi)	SF	MS
- weld group WCC1, WCC2, WCC3, WCC4, WCC5, WCC7 and WF1	4,105	10.23	9.23
- lower cavity tube (buckling)		37.4	36.4
- ext. shell, under cooling fin	5,170	13.53	12.53

Other components
Shipping skid to fixed skid bolts will shear.
In the side drop, the three (3) most vulnerable zones are:

- bolts fastening the shipping skid to the fixed skid
- plug weld WPC1
- container shell ext. welds

It is expected that the bolts fastening the shipping skid to the fixed skid will shear. In the case of the closure plug welds the margin of safety, based on static UTS is greater than 0. Consequently, it appears that this will not lead to the ductile failure of the plug welds nor the container external shell welds. Therefore the structural integrity of:

- The ss304 envelope surrounding the lead shielding in the plug is sound and there are no cracks; thus the lead shielding does not have potential leak paths in a scenario of lead melt.
- The ss304 envelope surrounding the lead shielding in the container body is sound and there are no cracks; thus the lead shielding does not have potential leak paths in a scenario of lead melt.
- The closure plug bolts will not shear under 136 g's deceleration loads, consequently the closure plug shielding will be in place over the inner shell assembly which houses the Special Form C-188 sealed sources.

3. There is some damage to the thermal protection. The cylindrical fireshield is flattened by an area approximately 44 in. long and 12 in. wide. The thermal insulation will be compressed, however there is no loss of thermal protection.
4. The C-188 sealed source, in a side drop, is subjected to a maximum bending stress of 47,800 psi, based on 1,000 g's deceleration load. The safety factor is 1.25 and the margin of safety is +0.25. There is an additional margin of safety attributed to the design G-load of 1,000 g's versus G-load of 136 g's in the F-294 cavity.
   C-188 sealed source is classified Special Form meeting the 10 CFR 71.77 requirements; therefore C-188 provides the leaktight containment. The USNRC source registration number for C-188 is NR-222-S-103-S (See Chapter 4, Appendix 4.4.2).
5. Assuming 36% of the impact energy is absorbed by the container cylinder, the lead shielding and the ends, the amount of lead shielding displacement (flattened) is expected to be 0.6 in., which represents approximately 1.5 half-value layers of lead shielding for cobalt-60.

7.4 TOP CORNER DROP ANALYSIS

1. Based on data of similar tested packages, for F-294 the g-load in the top corner drop orientation is expected to be of the order of 136 g's.
2. The following components of the F-294 package were stress analyzed; the corresponding stresses or loads, Safety Factors (SF) and Margins of Safety (MS) are listed here:

Plug

	Stress (psi)	SF	MS
- bolts: avg. bolt stress	20,200	8.91	7.91
- male flange shear stress	10,250	4.09	3.09
- female flange-tension, weld (WCC7)	7,930	8.82	7.82
- female flange-shear, weld (WCC7)	5,290	7.93	6.93
- stripping bolt hole, shear	5,780	7.26	6.26

Container

	Stress (psi)	SF	MS
- weld group WCC1, WCC2, WCC7, WCC3, WF	8,855	7.90	6.90
- lower cavity tube (buckling)	7,890	8.87	7.87
- lower cavity tube end cap	24,734	4.04	3.04
- container top flange	7,600	9.21	8.21
- ext. secondary conical shell, local area under lift lug	24,680	3.03	2.03
- weld, cavity end cap/tube (WCC6)	5,110	8.21	7.21

In the top corner 30-ft drop of F-294, for all the components in the container and the closure plug, the margin of safety is greater than zero (0). Consequently there will be no ductile failure of the components in the container and the closure plug.
Therefore the structural integrity of

- the ss304L envelope surrounding the lead shielding in the plug AND
- the ss304L envelope surrounding the lead shielding in the container body

is sound and there are no cracks; thus the lead does not have potential leak paths to escape in a scenario of lead melt. In addition, it is shown that lead would not melt in the F-294 lead-cask in a regulatory fire test of F-294.(see Chapter 3 for details).

3. The closure plug bolts will not shear under 136 g's deceleration loads. Consequently, the closure plug shielding will be in place over the inner shell assembly which houses the C-188 Special Form sealed sources
4. Thermal protection: The top corner of the cylindrical fireshield will be displaced towards the container cavity. The top fireshield, which is integral with the crush shield, shall be displaced toward the top closure plug. The conical shell is double wall construction and the space is filled with thermal insulation. In all 3 zones, the thermal insulation shall be compressed locally but there shall be no loss of thermal protection.
5. C-188 sealed source: the C-188, in a top corner impact, has been demonstrated to withstand the deceleration load of 136 g's in the F-294 cavity. The C-188 is not likely to yield nor buckle. It must be noted that the C-188 source is a Special Form source and meets 10 CFR Para.71.77; therefore C-188 provides the leaktight containment. For C-188, the USNRC source registration number is NR-222-S-103-S (See Chapter 4, Appendix 4.4.2).

7.5 SIDE OBLIQUE DROP ANALYSIS

For F-294 subject to 30-ft. free drop test, the safety factors and margin of safety of the F-294 components in each F-294 drop test orientation are re-captured here.

1. For F-294 the g-load in the side oblique drop orientation is 136 g's (measured).
2. The following components of the F-294 package were stress analyzed; the corresponding stresses or loads, Safety Factors (SF) and Margins of Safety (MS) are listed here:

Plug

	Stress (psi)	SF	MS
- bolts: avg. bolt stress	23,660	7.6	6.6
- male flange shear stress	7,400	5.67	4.67
- female flange-tension, weld (WCC7)	5,750	12.28	11.28
- female flange-shear, weld (WCC7)	7,630	5.4	4.4
- stripping bolt hole, shear	4,195	10.01	9.01

Container

	Stress (psi)	SF	MS
- weld group WCC1, WCC2, WCC7, WCC3, WF	9,238	7.5	6.5
- lower cavity tube (buckling)	5,600	12.5	11.5
- lower cavity tube end cap	17,540	5.7	4.7
- container top flange	5,400	12.96	11.96
- ext. secondary conical shell, local area under lift lug	24,680	3.03	2.03
- weld, cavity end cap/tube (WCC6)	3,630	11.5	10.5

In the side oblique corner 30-ft drop of F-294, for all the components in the container and the closure plug, the margin of safety is greater than zero (0). Consequently there will be no ductile failure of the components in the container and the closure plug.

Therefore the structural integrity of

- the ss304L envelope surrounding the lead shielding in the plug AND
- the ss304L envelope surrounding the lead shielding in the container body

is sound and there are no cracks; thus the lead does not have potential leak paths to escape in a scenario of lead melt. In addition, it is shown that lead would not melt in the F-294 lead-cask in a regulatory fire test of F-294.(see Chapter 3 for details).

3. The closure plug bolts will not shear under 136 g's deceleration loads. Consequently, the closure plug shielding will be in place over the inner shell assembly which houses the C-188 Special Form sealed sources

4. Thermal protection: The top corner of the cylindrical fireshield will be displaced towards the container cavity. The top fireshield, which is integral with the crush shield, shall be displaced toward the top closure plug. The conical shell is double wall construction and the space is filled with thermal insulation. In all 3 zones, the thermal insulation shall be compressed locally but there shall be no loss of thermal protection.

5. C-188 sealed source: the C-188, in a side oblique corner impact, has been demonstrated to withstand the deceleration load of 136 g's in the F-294 cavity. The C-188 is not likely to yield nor buckle. It must be noted that the C-188 source is a Special Form source and meets 10 CFR Para.71.77; therefore C-188 provides the leaktight containment. For C-188, the USNRC source registration number is NR-222-S-103-S (See Chapter 4, Appendix 4.4.2).

8. CONCLUSIONS

8.1 The highest measured G-loads of the full scale F-294, subjected to 30-ft free drop tests are:

1. top end drop orientation: G = 136 g's
2. side oblique drop orientation: G = 132 g's

8.2 The stress analysis of the F-294, in all drop test orientations, demonstrate that adequate safety factors and margins of safety exist such that the integrity of the stainless steel envelope around the lead shielding is sound.

8.3 The stress analysis of the F-294, in all drop orientations, demonstrate the closure plug will remain fastened to the container of the F-294 package and the structural integrity of C-188 sources is sound. Therefore it is demonstrated that the containment system integrity is sound.

8.4 The results of the actual F-294 drop tests as presented in Chapter 2, Appendix 2.10.12 substantiate the stress analysis presented in Chapter 2, Appendix 2.10.14.