Safety Analysis Report for the Eco-Pak® OP Uranium Oxide Transport Unit

Submitted By

Eco-Pak Specialty Packaging
Division of CBC

Elizabethton, Tennessee 37643

Revision 2

SAFETY ANALYSIS REPORT FOR THE ECO-PAK® OP URANIUM OXIDE TRANSPORT UNIT

(Revision 2, January 2000)

Submitted by:

Eco-Pak Specialty Packaging
Division of The Columbiana Boiler Company
Columbiana, Ohio 44408

REVISION 2

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SECTION ONE GENERAL INFORMATION

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SAFETY ANALYSIS REPORT
FOR THE
MODEL ECO-PAK® OP URANIUM OXIDE
TRANSPORT UNIT
(Revision 2, January 2000)

Submitted by:

Eco-Pak Specialty Packaging
Division of The Columbiana Boiler Company
Columbiana, Ohio 44408

1. GENERAL INFORMATION

This Safety Analysis Report for the Eco-Pak® OP Uranium Oxide Transport Unit is submitted in support of the Eco-Pak Specialty Packaging request for approval of the subject package and issuance of a Type A Fissile Material Certificate of Compliance for the package in compliance with the requirements of 10CFR71 and IAEA Safety Standards Series No. ST-1, 1996 edition. The package is also designed in conformance with the requirements of 49CFR173.24, 173.410, 173.412 and 173.417

The Eco-Pak® OP Uranium Oxide Transport Unit (OP-TU) represents a new approach to the shipment of uranium oxide pellets and powder using a geometrically safe configuration in a double walled shipping package that results in additional containment and damage prevention capabilities. The Eco-Pak® OP Transport Unit is based on patented designs also employed in the manufacture of Eco-Pak Specialty Packaging containers used to ship high hazard chemicals, including poisonous inhalation hazards.

The Eco-Pak® OP uses a strong, lightweight and closed-cell phenolic foam similar in composition to the phenolic foam used in the ESP-30X Overpack for transportation of uranium hexafluoride. This phenolic foam formulation contains virtually no free chlorides; the foam used in Eco-Pak® OP Uranium Oxide Transport Units has a less than 200 ppm total chloride content, a level considered acceptable in previous packaging designs.

1.1 Introduction

The Eco-Pak® OP is designed for shipment of fissile radioactive material, specifically uranium oxide powder or pellets. The package has been extensively tested to verify its conformance with the requirements of 10CFR71 for shipment of these materials. This Safety Analysis Report contains documentation and the conclusions reached from that testing.

The package is designed in a geometrically-safe configuration and criticality evaluations in this report assume that water does leak into the inner storage vessels. Therefore, water-tightness of the storage vessels is not assumed.

1.2 Package Description

1.2.1 Packaging

The Eco-Pak® OP Uranium Oxide Transport Unit is a roughly cubical package, approximately 45" x 45" x 62" high. The outer shell and the four internal containment cylinders of the transport unit are constructed of 11 ga mild steel.

Each internal containment cylinder features double closures (not including the actual storage vessel). Both the inner and outer closures are ½" thick mild steel bolted and silicone-gasketed lids. The inner lid has a diameter of 14" and the outer lid is 16 5/8" in diameter.

The inner storage vessel is a double-walled container constructed of 3/16" thick ASTM A-240, Series 300 Stainless Steel with fire-retardant, closed-cell phenolic foam per ESP Specification ESP-PF-2 (Appendix 2.10.2) in the annulus of the package. It also employs a silicone-gasketed, bolted lid of 5/8" thick x 11 5/8" diameter manufactured of the same grade steel.

The cavity between the outer walls and the internal containment cylinders of the transport unit is also filled with ESP-PF-2 fire-retardant closed-cell phenolic foam.

The Eco-Pak® OP UO_2 Transport Unit and vessels are fabricated in accordance with Eco-Pak Specialty Packaging Drawing No. OP-TU-SAR, Sheets 1 through 4 (see Appendix 1.3.1); this drawing is complete with dimensions, tolerances, fabrication details, materials list and specifications, and weld specifications.

1.2.1.1 Gross Weights

The gross weights of a loaded Eco-Pak® OP are as follows:

Component	Weight (kgs)	Weight (lbs)
Eco-Pak® OP Transport Unit	749	1648
Eco-Pak® OP Storage Vessel (4 at 78 kgs each)	312	686
UO_2 Maximum Load (161.75 kgs per vessel)	647	1423
Maximum Gross Weight of Loaded Package	**1708**	**3757**

1.2.1.2 Materials of Construction

The materials of construction for the Eco-Pak® OP are as follows:

Transport Unit	
Skin	ASTM A569 Carbon Steel
Plates and angles	ASTM A36 Carbon Steel
Bolts, nuts, washers	A325 Carbon Steel
Foam	ESP Specification ESP-PF-2 Closed-Cell Phenolic Foam
Gasket	Silicone
Lifting Shackles	Forged Carbon Steel
Ceramic Fiber Insulation	ESP Specification ESP-CFI-1 (See Appendix 2.10.2)
Storage Vessel	
Outer shell	ASTM A569 Carbon Steel
Inner shell	ASTM A-240, Series 304 Stainless Steel
Bolts	ASTM A-193 B8M, Class 1 Stainless Steel
Nuts & washers	304/18-8 Stainless Steel
Lid	ASTM A-240, Series 304 Stainless Steel
Foam	ESP Specification ESP-PF-2 Closed-Cell Phenolic Foam
Gasket	Silicone

1.2.1.3 Outer and Inner Protrusions

There is one outer protrusion on the Eco-Pak® OP: the fusible cap which is positioned on the top of the transport unit. This protrusion, which is designed to allow venting of any gasses which might be generated in the foam during a fire event, extends approximately 2 ½ inches from the center of the top surface of the unit and is not considered to be an impediment to stacking or handling of the unit. There are no inner protrusions on the Eco-Pak® OP Transport Unit.

1.2.1.4 Lifting and Tie down Devices

The Eco-Pak® OP Transport Unit may be lifted either by means of four shackles attached to the top angle frame or by forklift tines placed under the unit's reinforced bottom. There are no specific provisions for tiedown of the unit. The tare weight of an empty transport unit is a nominal 749 kilograms; the maximum gross weight of a loaded package is 1708 kilograms.

1.2.1.5 Shielding

Shielding is not required for contents of the Eco-Pak® OP Transport Unit.

1.2.1.6 Pressure Relief Systems

There are no pressure relief systems other than the fusible cap for venting gasses generated by the fire-retardant, closed-cell phenolic foam between the outer walls and containment cylinders. There are no pressure relief devices which will vent the storage vessel contents.

1.2.1.7 Closures

A triple closure system is employed by the Eco-Pak® OP Transport Unit. Each storage vessel in the Eco-Pak® OP is secured by bolting the 5/8" thick lid to the vessel with twelve (12) ½" bolts. Each storage vessel is inserted into an internal containment cylinder which is itself then secured with a ½" thick lid using twelve (12) ½" bolts. Finally, the ½" thick external lid is attached using twelve (12) ½" bolts. Each lid is also sealed with 1/4" thick silicone gaskets.

1.2.1.8 Containment

Containment of the package contents is provided by the inner storage vessel. This vessel, with walls of 3/16" thick stainless steel, is designed to replace the use of 24 ga. Pails used in previous packages for shipment of the materials requested in the report. Although the triple containment provisions of the package will provide leak tight conditions for the storage vessel contents, all evaluations of criticality contained in Section Six of this report conservatively assume complete water inleakage to the contents.

1.2.2 Operational Features

The Eco-Pak® OP Transport Unit is closed by a total of twenty-four (24) ½-inch diameter bolts. The gaskets are 1/4-inch thick 50-70 durometer silicone rubber with a maximum continuous temperature rating of 400^{0}F.

Each storage vessel within the OP Transport Unit is closed by twelve (12) ½-inch diameter bolts. The gaskets for the storage vessels are 1/4-inch 50-70 durometer silicone rubber with a maximum continuous temperature rating of 400^{0}F.

The transport unit is lifted by four (4) shackles attached to the top angle frame of the transport unit. The transport unit may also be lifted by fork truck tines under the bottom of the unit.

1.2.3 Contents of Packaging

1.2.3.1 Type and Form of Materials

The Eco-Pak® OP Uranium Oxide Transport Unit is used for the safe transport of uranium oxide meeting the following criteria:

(a) Uranium oxide powder enriched to no greater than 4.5 weight percent in the ^{235}U isotope with a maximum load of 161.75 kgs (356 lbs) per 7 ¾-inch diameter storage vessel and a maximum load per package of 647 kgs (1423 lbs) manufactured per ESP Drawing No. OP-TU-SAR (See Appendix 1.3.2);

(b) Uranium oxide powder enriched to no greater than 5.0 weight percent in the ^{235}U isotope with a maximum load of 161.75 kgs (356 lbs) per 7-inch diameter storage vessel and a maximum load of 647 kgs (1423 lbs) manufactured per ESP Drawing No. OP-TU-SAR (See Appendix 1.3.2);

(c) Uranium oxide pellets or a mixture of powder and pellets enriched to no greater than 5.0 weight percent in the ^{235}U isotope with a maximum load of 161.75 kgs (356 lbs) per 7-inch diameter storage vessel and a maximum load of 647 kgs (1423 lbs) manufactured per ESP Drawing No. OP-TU-SAR (See Appendix 1.3.2);

(d) Uranium-bearing materials in the form of solids, or solidified or dewatered materials. Uranium may be enriched to 5.0 weight percent ^{235}U with a maximum load of 161.75 kgs (356 lbs) per 7-inch diameter storage vessel and a maximum load of 647 kgs (1423 lbs) manufactured per ESP Drawing No. OP-TU-SAR, Sheet 1 (Appendix 1.3.2). Uranium may be enriched to 4.5 weight percent ^{235}U with a maximum load of 161.75 kgs (356 lbs) per 7 ¾-inch diameter storage vessel and a maximum load of 647 kgs (1423 lbs) manufactured per ESP Drawing No. OP-TU-SAR, Sheet 2 (Appendix 1.3.2). Uranium-bearing materials may include oxides, carbides, silicates or other compounds of uranium. Pellets or previously pelletized materials are not allowed for transport in the 7 ¾-inch diameter vessel and must be excluded. Materials with a hydrogen density greater than water must be excluded. Compounds of uranium may be mixed with other non-fissile materials with the exception of oils, deuterium, tritium, and beryllium.

1.2.3.2 Maximum Quantities of Materials per Package

Subject to the limitations described in Section 1.2.3.1, the maximum load weight per storage vessel is 161.8 kg with a total maximum UO_2 load of 647 kg per Eco-Pak® OP Transport Unit.

1.3 Appendices

1.3.1 Eco-Pak Specialty Packaging Drawing No. OP-TU-SAR, Sheets 1 & 2
Eco-Pak® OP-TU Oxide Transport Unit

1.3.2 Eco-Pak Specialty Packaging Drawing No. OP-TU-SAR, Sheets 1, 3 & 4
Eco-Pak® OP-VA 7" Oxide Vessel and 7 ¾" Oxide Vessel

1.3.3 Epoxy Paint Data and Material Safety Data Sheets

Appendix 1.3.1

ESP Drawing No. OP-TU-SAR, Sheets 1 & 2
Eco-Pak® OP-TU Oxide Transport Unit

GENERAL NOTES

1. GROSS WEIGHTS
   THE GROSS WEIGHTS OF A LOADED ESP OP-TU ARE AS FOLLOWS:

COMPONENT	WEIGHT (KGS)	WEIGHT (LBS)
ESP OP-TU	749	1,648
TYPE A VESSEL	78	172
MAXIMUM LOAD PER VESSEL	161 3/4	356
MAXIMUM VESSEL WEIGHT PER PACKAGE	312	686
MAXIMUM LOAD PER PACKAGE	647	1,423
MAXIMUM GROSS WEIGHT OF LOADED PACKAGE	1,708	3,757

2. MATERIALS OF CONSTRUCTION
   THE MATERIALS OF CONSTRUCTION FOR THE ESP-OP-TU ARE AS FOLLOWS:

SQ. TUBE	ASTM A500 GRADE B CARBON STEEL
SKIN	ASTM A569 CARBON STEEL
PLATES	ASTM A36 CARBON STEEL
S/S PLATES	ASTM TYPE 304 STAINLESS STEEL
FLAT BAR AND ANGLES	ASTM A36 CARBON STEEL
OP-TU C/S BOLTS	ASTM A325
FOAM	ESP SPECIFICATION ESP-PF-2 REV. 1 CLOSED CELL PHENOLIC FOAM
GASKETS	SILICON SPONGE RUBBER, CLOSED CELL MED. DENSITY TEMP. RATED TO 400°F AND NEOPRENE RUBBER AS INDICATED BY FAB. RECORD
LIFTING SHACKLES	FORGED CARBON STEEL WITH A SAFETY FACTOR OF 5
VESSEL S/S BOLTS	ASTM A193 B8M CLASS 1
THREAD INSERTS	300 SERIES OR 18-8 STAINLESS STEEL

3. FINISH
   PAINT ALL EXTERNAL SURFACES AND ALL SURFACES IN CONTACT WITH FOAM USING THE MILAGE AS REQUIRED BY THE MANUFACTURE'S SPECIFICATION FOR RED OXIDE PRIMER (AN EXAMPLE OF A TYPICAL ONE IS ATTACHED) ALL PAINTING SHALL BE IN ACCORDANCE WITH WRITTEN PROCEDURES IN ACCORDANCE WITH MANUFACTURE'S REQUIREMENTS
   PAINT ALL EXTERNAL SURFACES WITH AN ADDITIONAL (2 MIL MIN.) TOP COAT OF A CATALYZED URETHANE ACRYLIC ENAMEL IN ACCORDANCE WITH MANUFACTURE'S SPECIFICATIONS

4. PLACARD AND LABEL ALL FOUR (4) SIDES

5. ALL WELDING PROCEDURES AND PERSONNEL SHALL BE QUALIFIED IN ACCORDANCE WITH AWS D1.1 OR ASME SECTION IX

6. NDT PERSONNEL SHALL BE CERTIFIED IN ACCORDANCE WITH ASNT-TC-1A. VISUAL INSPECTORS MAY BE CERTIFIED IN ADDITION TO OR IN LIEU OF ASNT-TC-1A AS AN AWS-CWI OR CAWI.

7. NAMEPLATE SHALL BE ATTACHED AFTER PAINTING BY SPOT WELDING AND PAINT RETOUCHED.

8. GENERAL SHOP TOLERANCES ARE ±3/8" UNLESS NOTED. ALL MATERIAL TOLERANCES SHALL BE AS REQUIRED UNDER THE APPROPRIATE MATERIAL SPECIFICATION.

9. MAGNETIC PARTICLE TESTING COMPLETED ON ALL EXTERNAL TRANSPORT UNIT WELDS UNLESS OTHERWISE SPECIFIED SHALL BE 10%.

10. STENCILING SHALL BE OF A CONTRASTING COLOR AND BE A MINIMUM OF 1" IN HEIGHT UNLESS NOTED. THE FOLLOWING SHALL BE ON THE NEAR SIDE AND THE FAR SIDE. AT A MINIMUM THE FOLLOWING SHALL BE SHOWN:

DESIGN ID NUMBER:	USA/---/-- TYPE - (2" LETTERS)	
MODEL NUMBER:	ESP-OP-TU	
OWNERS NAME	----------------	
OWNERS ADDRESS:	CITY. STATE AND/OR COUNTRY	
	RADIOACTIVE MATERIAL URANIUM OXIDE	
	GROSS WEIGHT	LBS
		KGS

11. ALL CLOSURE BOLTS SHALL BE TORQUED PRIOR TO SHIPMENT TO 75 FT. LBS. + 5 - 0

12. ESP-OP-TU ID PLATE
   A. PLATE SHALL BE A MIN. OF 11" WIDE x 15" LONG x 20 GAUGE SHEET, ASTM A-240 TYPE 304/304L STAINLESS STEEL.
   B. AT A MINIMUM THE FOLLOWING INFORMATION SHALL BE ENGRAVED/ ETCHED ON TO THE ID PLATE IN LETTER HEIGHTS AS FOLLOWS:

USA/----/--		1/2"
RADIOACTIVE MTL. TYPE --		3/8"
MFG. BY: ECO-PAK SPECIALTY PACKAGING		3/8"
A DIVISION OF CBC		3/8"
QA APPROVAL NO:		3/8"
OWNER SERIAL NO.		3/8"
MODEL NO. ESP-OP-TU ESP S/N:		3/8"
PKG. TARE WGTS IN LBS AND KGS		3/8"
DATE	PACKAGE	3/8"
MM/YR	---LB	3/8"
	---KG	3/8"
MAX. GROSS WEIGHT 3762 LBS		3/8"
1708 KGS		3/8"

   C. TRANSPORT UNIT SHALL BE WEIGHED WITH ALL HARDWARE AND NAMEPLATE.
   D. WEIGHT TOLERANCE IS ±2 LBS OR ±1 KG. ALL WEIGHTS SHALL BE ROUNDED UP TO THE NEXT WHOLE NUMBER.

13. TYPE A VESSEL - THE FOLLOWING INFORMATION MUST BE PLACED ON THE VESSEL LID AND BODY BY EITHER PERMANENT STENCIL OR NAMEPLATE

OP-TU ____ VESSEL	1/4" MIN
S/N_______	1/4" MIN
_____% MAX. U-235 ENRICHMENT	1/4" MIN
DATE OF MFG:_______	1/4" MIN
TARE WGT:______LBS / _____KGS	1/4" MIN

14. CERAMIC FIBER PAPER PER ESP-CFI-1 REV. 0
    CERAMIC FIBER BOARD PER ESP-CFI-1 REV. 0

15. GASKETS SHALL BE INSTALLED USING AN APPROPRIATE MATERIAL AS DESCRIBED IN STANDARD OPERATING PROCEDURES.

16. CERTIFICATIONS, TEST REPORTS AND QA RECORDS FOR THIS PACKAGE SHALL BE STORED AND MAINTAINED AS REQUIRED BY THE QUALITY ASSURANCE PROGRAM.

17. SHACKLES ARE RATED AT 6,000 LBS. AND HAVE A SAFETY FACTOR OF 5

18. GASKET MATERIAL: SILICONE SPONGE MEDIUM DENSITY CLOSED CELL RATED FOR CONTINUOUS USE AT 400°F AND NEOPRENE RUBBER 50-70 DUROMETER A AS NOTED

19. ESP-PF-2 REV. 1 CLOSED CELL PHENOLIC FOAM LOW CHLORIDE 200 PPM OR LESS WITH A DENSITY OF 6.0 TO 8.0 LBS PER CUBIC FOOT

Rev. No.	Change	Date	By
⑨			
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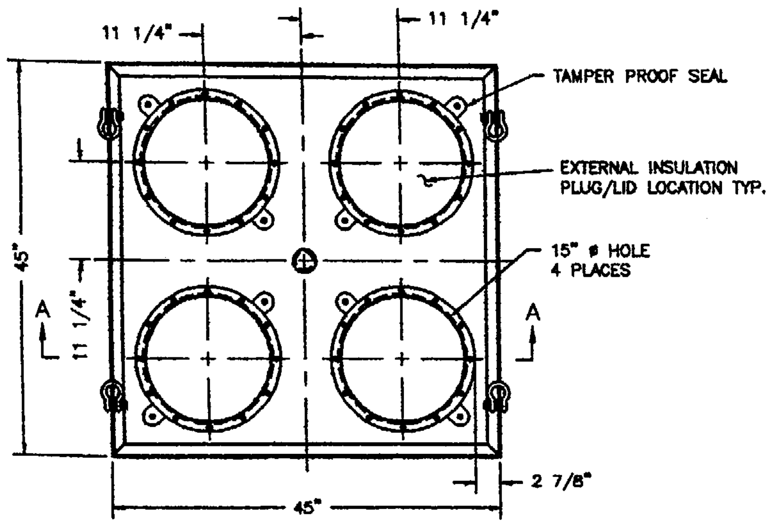
④			
③			
②			
①	MODIFIED FINISH SPEC. & WEIGHTS IN LBS	12/13/99	ARM

• REVISIONS •

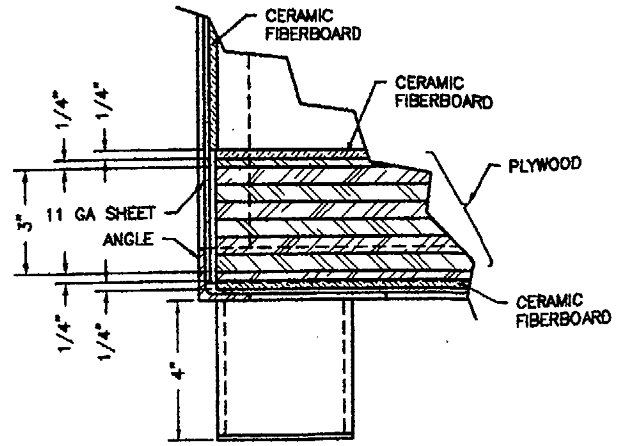
THE COLUMBIANA BOILER CO.
COLUMBIANA, OHIO

OP-TU
PROTECTIVE SHIPPING PACKAGE
& TYPE A VESSELS

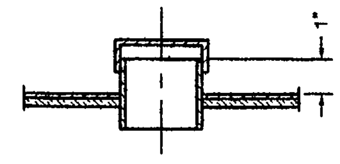
Checked:	Date: 6/99	Drawing Number: OP-TU-SAR
App'd By:	Dr'n By: ARM	
App'd By:	Scale: NONE	REV. 1 SHEET 1 OF 4



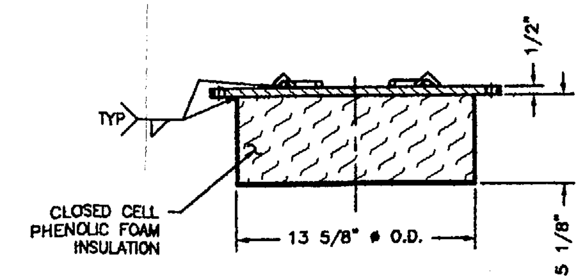
TOP VIEW
(COVERS NOT SHOWN)



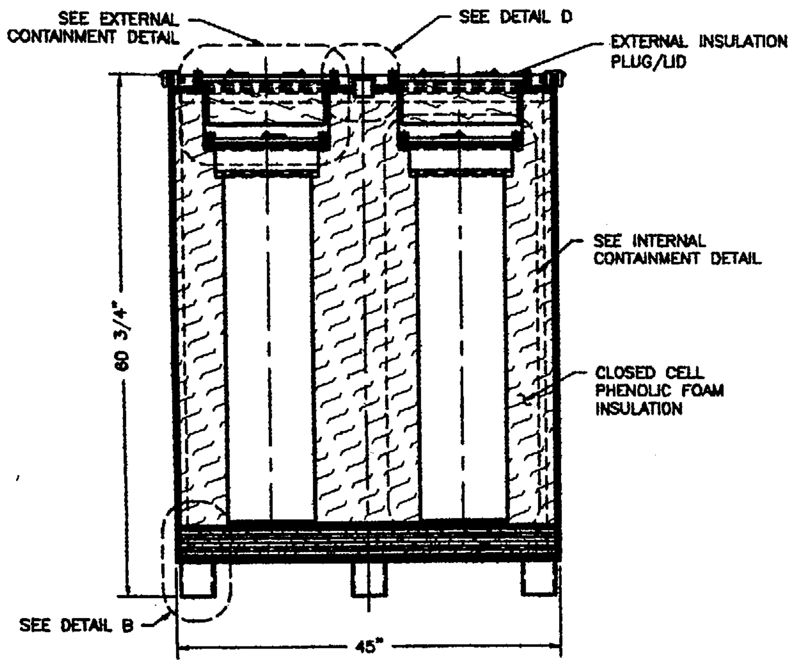
DETAIL B



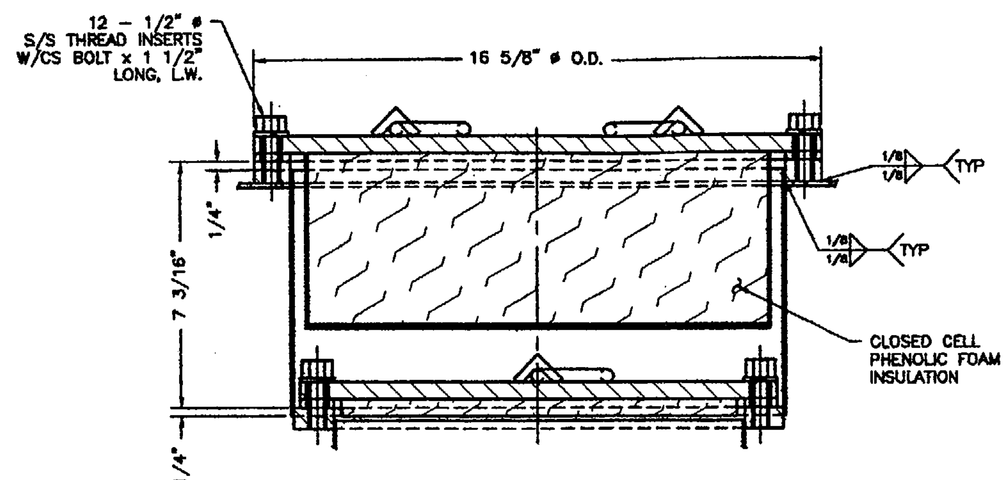
DETAIL D



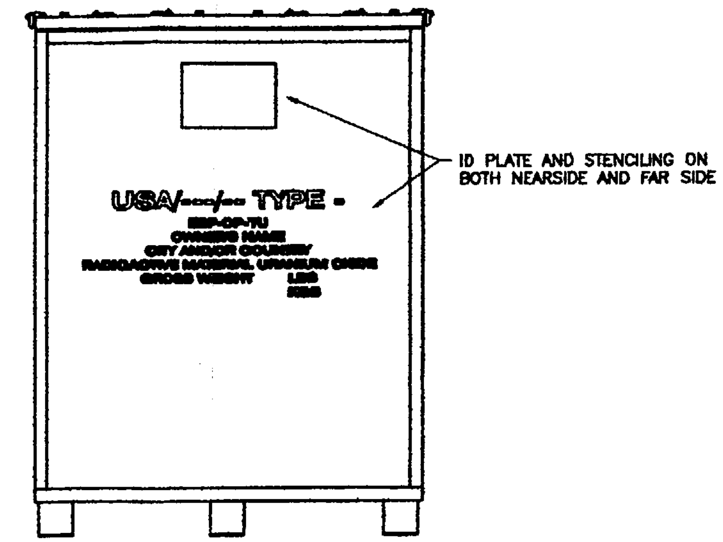
INSULATED LID DETAIL



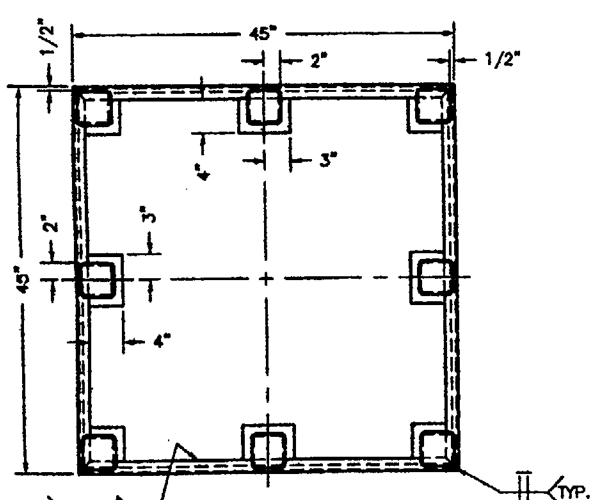
SECTION A-A



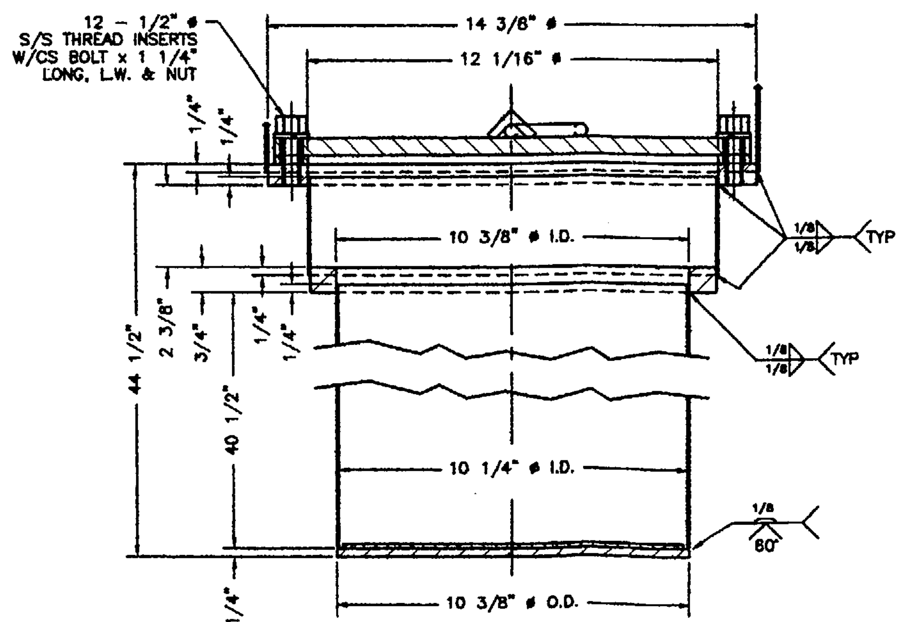
EXTERNAL CONTAINMENT DETAIL



ELEVATION WITH STENCILING



BOTTOM VIEW



INTERNAL CONTAINMENT DETAIL

NOTES:

SEE THESE DRAWINGS FOR OPTIONS ON OXIDE VESSEL.
SHEET 3 OP-TU-SAR (OP-VA 7)
SHEET 4 OP-TU-SAR (OP-VA 8)

1/4" CERAMIC FIBER BOARD IS AFFIXED TO INSIDE OF ALL PANELS (7) 4 SIDE, 1 TOP & 2 BOTTOM

1/8" CERAMIC FIBER PAPER IS AFFIXED TO OUTSIDE OF ALL 4 TUBESAND BETWEEN DURABOARD AND PANELS IN ALL CORNERS

Rev. No.	Change	Date	By
1	ADDED NOTES	12/13/99	ARM

REVISIONS

THE COLUMBIANA BOILER CO.
COLUMBIANA, OHIO

OP-TU
PROTECTIVE SHIPPING PACKAGE
& TYPE A VESSEL

Date 8/99 | Dr'n By ARM | Scale NONE | DRAWING NUMBER OP-TU-SAR | REV. 1 | SHEET 2 OF 4

Appendix 1.3.2

ESP Drawing Nos. OP-TU-SAR, Sheets 1, 3 & 4
Eco-Pak® OP-VA
7" Oxide Vessel and 7 ¾" Oxide Vessel

GENERAL NOTES

1. GROSS WEIGHTS
   THE GROSS WEIGHTS OF A LOADED ESP OP-TU ARE AS FOLLOWS:

COMPONENT	WEIGHT (KGS)	WEIGHT (LBS)
ESP OP-TU	749	1,648
TYPE A VESSEL	78	172
MAXIMUM LOAD PER VESSEL	161 3/4	356
MAXIMUM VESSEL WEIGHT PER PACKAGE	312	686
MAXIMUM LOAD PER PACKAGE	647	1,423
MAXIMUM GROSS WEIGHT OF LOADED PACKAGE	1,708	3,757

2. MATERIALS OF CONSTRUCTION
   THE MATERIALS OF CONSTRUCTION FOR THE ESP-OP-TU ARE AS FOLLOWS:

SQ. TUBE	ASTM A500 GRADE B CARBON STEEL
SKIN	ASTM A569 CARBON STEEL
PLATES	ASTM A36 CARBON STEEL
S/S PLATES	ASTM TYPE 304 STAINLESS STEEL
FLAT BAR AND ANGLES	ASTM A36 CARBON STEEL
OP-TU C/S BOLTS	ASTM A325
FOAM	ESP SPECIFICATION ESP-PF-2 REV. 1 CLOSED CELL PHENOLIC FOAM
GASKETS	SILICON SPONGE RUBBER, CLOSED CELL MED. DENSITY TEMP. RATED TO 400°F AND NEOPRENE RUBBER AS INDICATED BY FAB. RECORD
LIFTING SHACKLES	FORGED CARBON STEEL WITH A SAFETY FACTOR OF 5
VESSEL S/S BOLTS	ASTM A193 B8M CLASS 1
THREAD INSERTS	300 SERIES OR 18-8 STAINLESS STEEL

3. FINISH
   PAINT ALL EXTERNAL SURFACES AND ALL SURFACES IN CONTACT WITH FOAM USING THE MILAGE AS REQUIRED BY THE MANUFACTURE'S SPECIFICATION FOR RED OXIDE PRIMER (AN EXAMPLE OF A TYPICAL ONE IS ATTACHED) ALL PAINTING SHALL BE IN ACCORDANCE WITH WRITTEN PROCEDURES IN ACCORDANCE WITH MANUFACTURE'S REQUIREMENTS
   PAINT ALL EXTERNAL SURFACES WITH AN ADDITIONAL (2 MIL MIN.) TOP COAT OF A CATALYZED URETHANE ACRYLIC ENAMEL IN ACCORDANCE WITH MANUFACTURE'S SPECIFICATIONS

4. PLACARD AND LABEL ALL FOUR (4) SIDES

5. ALL WELDING PROCEDURES AND PERSONNEL SHALL BE QUALIFIED IN ACCORDANCE WITH AWS D1.1 OR ASME SECTION IX

6. NDT PERSONNEL SHALL BE CERTIFIED IN ACCORDANCE WITH ASNT-TC-1A. VISUAL INSPECTORS MAY BE CERTIFIED IN ADDITION TO OR IN LIEU OF ASNT-TC-1A AS AN AWS-CWI OR CAWI.

7. NAMEPLATE SHALL BE ATTACHED AFTER PAINTING BY SPOT WELDING AND PAINT RETOUCHED.

8. GENERAL SHOP TOLERANCES ARE ±3/8" UNLESS NOTED. ALL MATERIAL TOLERANCES SHALL BE AS REQUIRED UNDER THE APPROPRIATE MATERIAL SPECIFICATION.

9. MAGNETIC PARTICLE TESTING COMPLETED ON ALL EXTERNAL TRANSPORT UNIT WELDS UNLESS OTHERWISE SPECIFIED SHALL BE 10%.

10. STENCILING SHALL BE OF A CONTRASTING COLOR AND BE A MINIMUM OF 1" IN HEIGHT UNLESS NOTED. THE FOLLOWING SHALL BE ON THE NEAR SIDE AND THE FAR SIDE. AT A MINIMUM THE FOLLOWING SHALL BE SHOWN:

DESIGN ID NUMBER:	USA/---/-- TYPE -	(2" LETTERS)
MODEL NUMBER:	ESP-OP-TU	
OWNERS NAME	---------------	
OWNERS ADDRESS:	CITY. STATE AND/OR COUNTRY	
	RADIOACTIVE MATERIAL URANIUM OXIDE	
	GROSS WEIGHT	LBS
		KGS

11. ALL CLOSURE BOLTS SHALL BE TORQUED PRIOR TO SHIPMENT TO 75 FT. LBS. + 5 - 0

12. ESP-OP-TU ID PLATE
    A. PLATE SHALL BE A MIN. OF 11" WIDE x 15" LONG x 20 GAUGE SHEET, ASTM A-240 TYPE 304/304L STAINLESS STEEL.
    B. AT A MINIMUM THE FOLLOWING INFORMATION SHALL BE ENGRAVED/ ETCHED ON TO THE ID PLATE IN LETTER HEIGHTS AS FOLLOWS:

USA/----/--		1/2"
RADIOACTIVE MTL. TYPE --		3/8"
MFG. BY: ECO-PAK SPECIALTY PACKAGING		3/8"
A DIVISION OF CBC		3/8"
QA APPROVAL NO:		3/8"
OWNER SERIAL NO.		3/8"
MODEL NO. ESP-OP-TU ESP S/N:		3/8"
PKG. TARE WGTS IN LBS AND KGS		3/8"
DATE	PACKAGE	3/8"
MM/YR	---LB	3/8"
	---KG	3/8"
MAX. GROSS WEIGHT 3762 LBS		3/8"
1708 KGS		3/8"

    C. TRANSPORT UNIT SHALL BE WEIGHED WITH ALL HARDWARE AND NAMEPLATE.
    D. WEIGHT TOLERANCE IS ±2 LBS OR ±1 KG. ALL WEIGHTS SHALL BE ROUNDED UP TO THE NEXT WHOLE NUMBER.

13. TYPE A VESSEL - THE FOLLOWING INFORMATION MUST BE PLACED ON THE VESSEL LID AND BODY BY EITHER PERMANENT STENCIL OR NAMEPLATE

OP-TU ____ VESSEL	1/4" MIN
S/N________	1/4" MIN
_____% MAX. U-235 ENRICHMENT	1/4" MIN
DATE OF MFG:________	1/4" MIN
TARE WGT:______LBS / ______KGS	1/4" MIN

14. CERAMIC FIBER PAPER PER ESP-CFI-1 REV. 0
    CERAMIC FIBER BOARD PER ESP-CFI-1 REV. 0

15. GASKETS SHALL BE INSTALLED USING AN APPROPRIATE MATERIAL AS DESCRIBED IN STANDARD OPERATING PROCEDURES.

16. CERTIFICATIONS, TEST REPORTS AND QA RECORDS FOR THIS PACKAGE SHALL BE STORED AND MAINTAINED AS REQUIRED BY THE QUALITY ASSURANCE PROGRAM.

17. SHACKLES ARE RATED AT 6,000 LBS. AND HAVE A SAFETY FACTOR OF 5

18. GASKET MATERIAL: SILICONE SPONGE MEDIUM DENSITY CLOSED CELL RATED FOR CONTINUOUS USE AT 400°F AND NEOPRENE RUBBER 50-70 DUROMETER A AS NOTED

19. ESP-PF-2 REV. 1 CLOSED CELL PHENOLIC FOAM LOW CHLORIDE 200 PPM OR LESS WITH A DENSITY OF 6.0 TO 8.0 LBS PER CUBIC FOOT

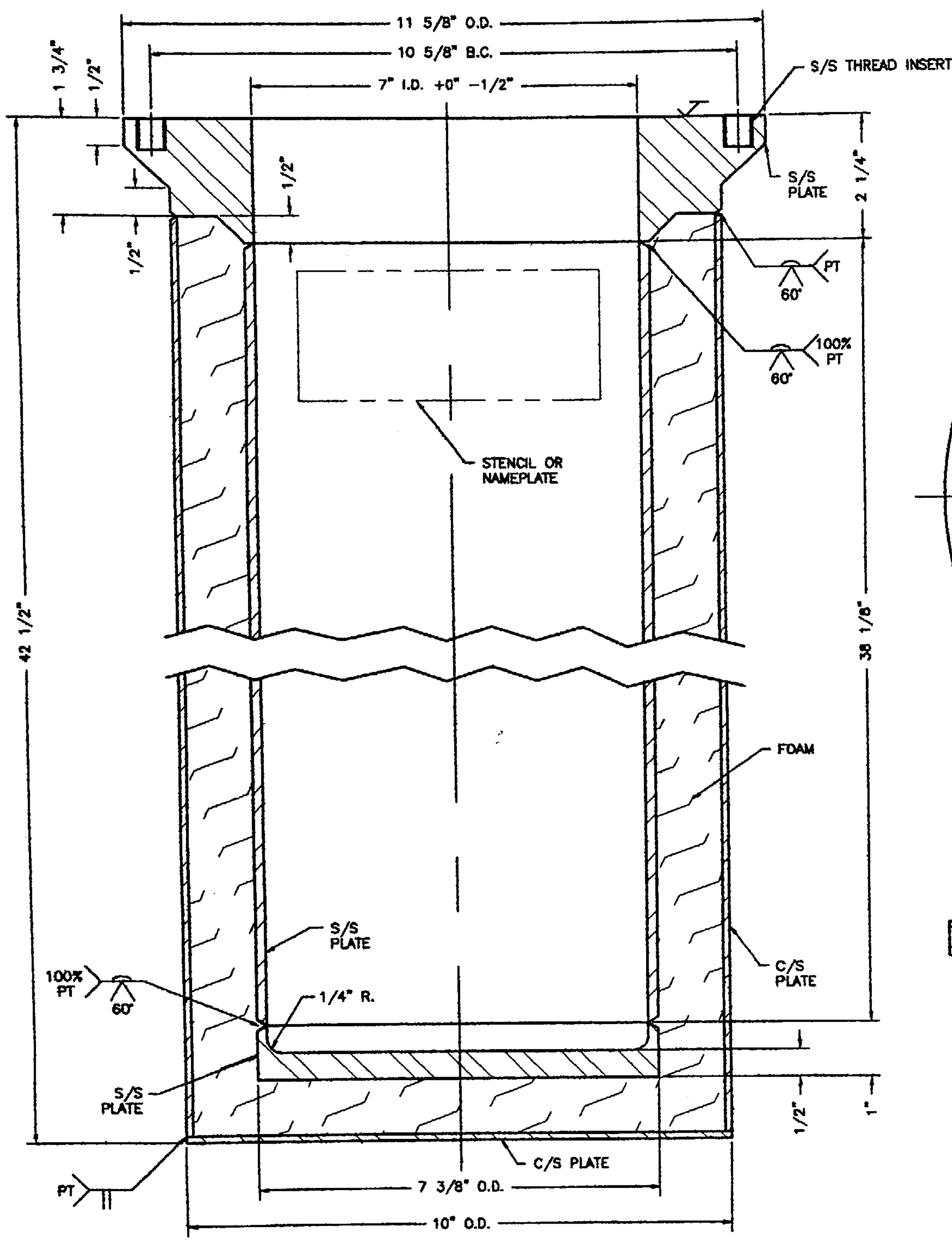
Rev. No.	Change	Date	By
9			
8			
7			
6			
5			
4			
3			
2			
1	MODIFIED FINISH SPEC. & WEIGHTS IN LBS	12/13/99	ARM

• REVISIONS •

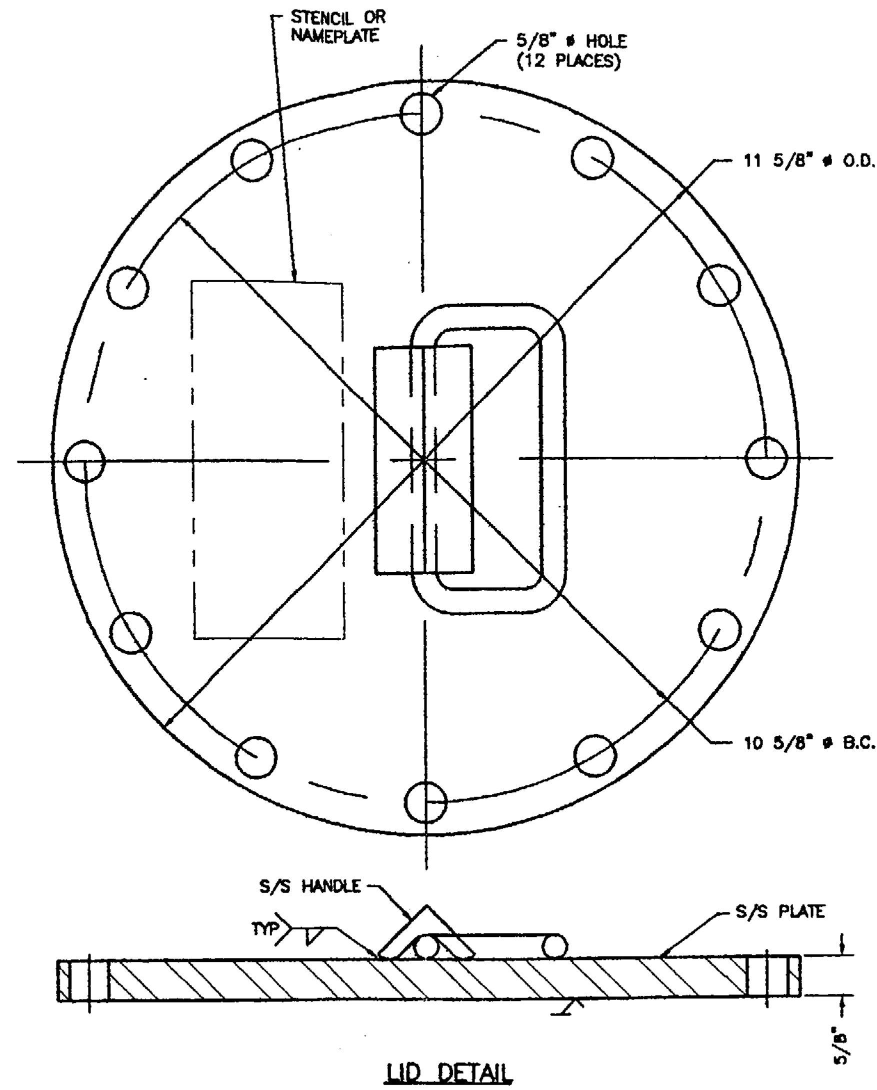
THE COLUMBIANA BOILER CO.
COLUMBIANA, OHIO

OP-TU
PROTECTIVE SHIPPING PACKAGE
& TYPE A VESSELS

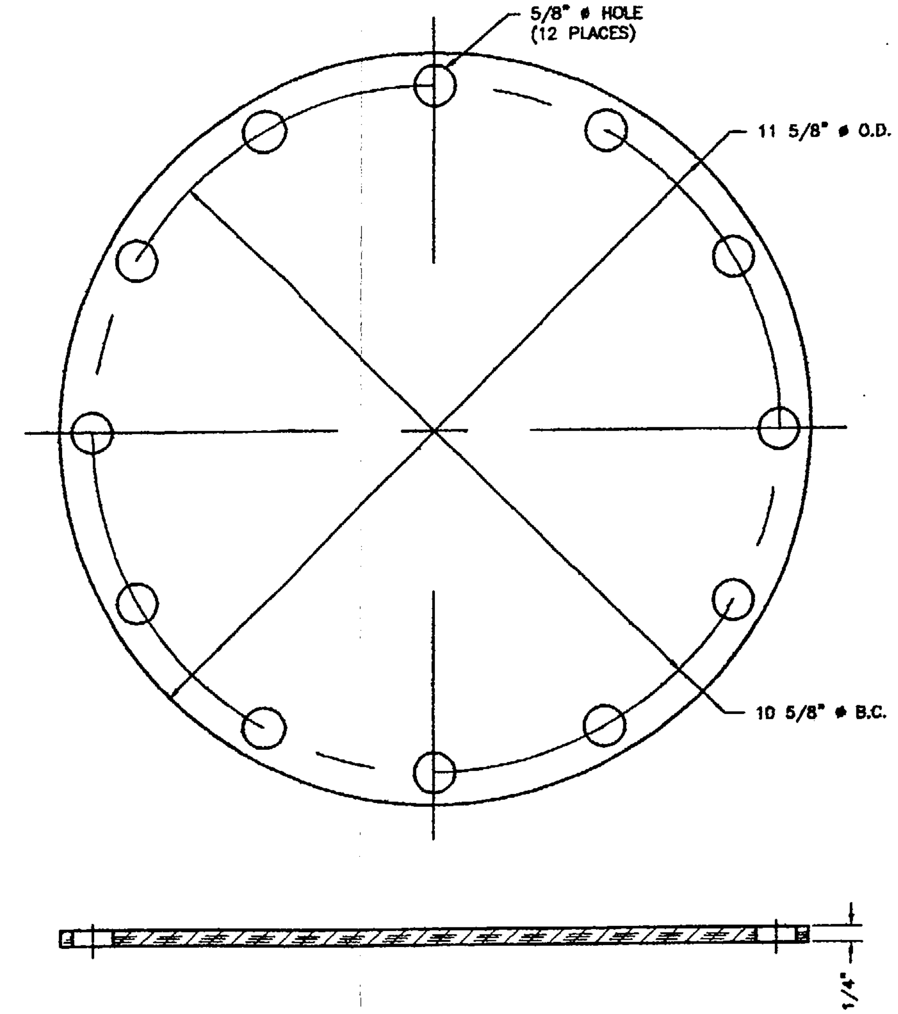
Checked: WMR | Date: 6/99 | Drawing Number: OP-TU-SAR
Appr'd By: TR | Dr'n By: ARM
Appr'd By: | Scale: NONE | REV. 1 | SHEET 1 OF 4



STORAGE VESSEL DETAIL



LID DETAIL



GASKET DETAIL

NOTES:

TOLERANCES: +0 -1/8"

Rev. No.	Change	Date	By
9			
8			
7			
6			
5			
4			
3			
2			
1	CHANGED NDT FROM MT TO PT	01/04/200[illegible]	ARM

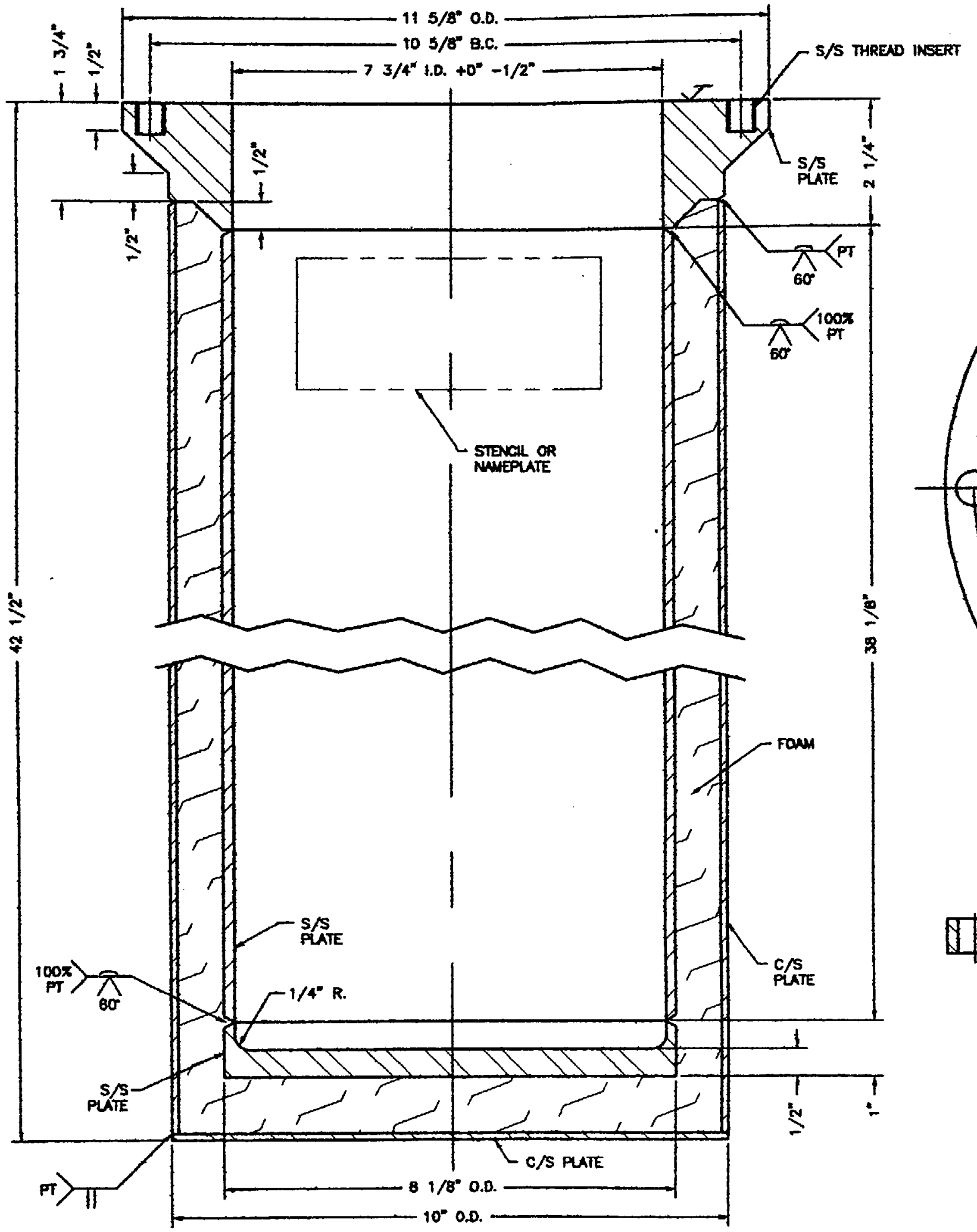
• REVISIONS •

THE COLUMBIANA BOILER CO.

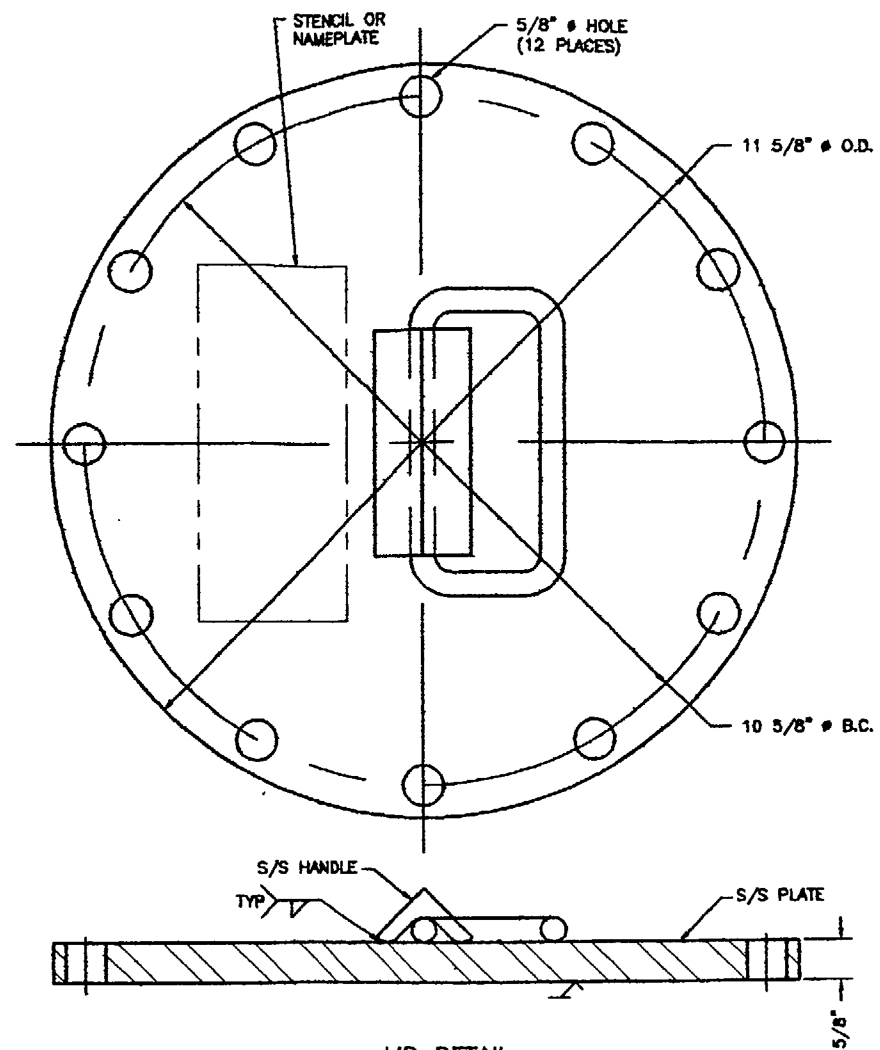
COLUMBIANA, OHIO

GENERAL ARRANGEMENT
ECO-PAK OP-VA 7"
OXIDE VESSEL

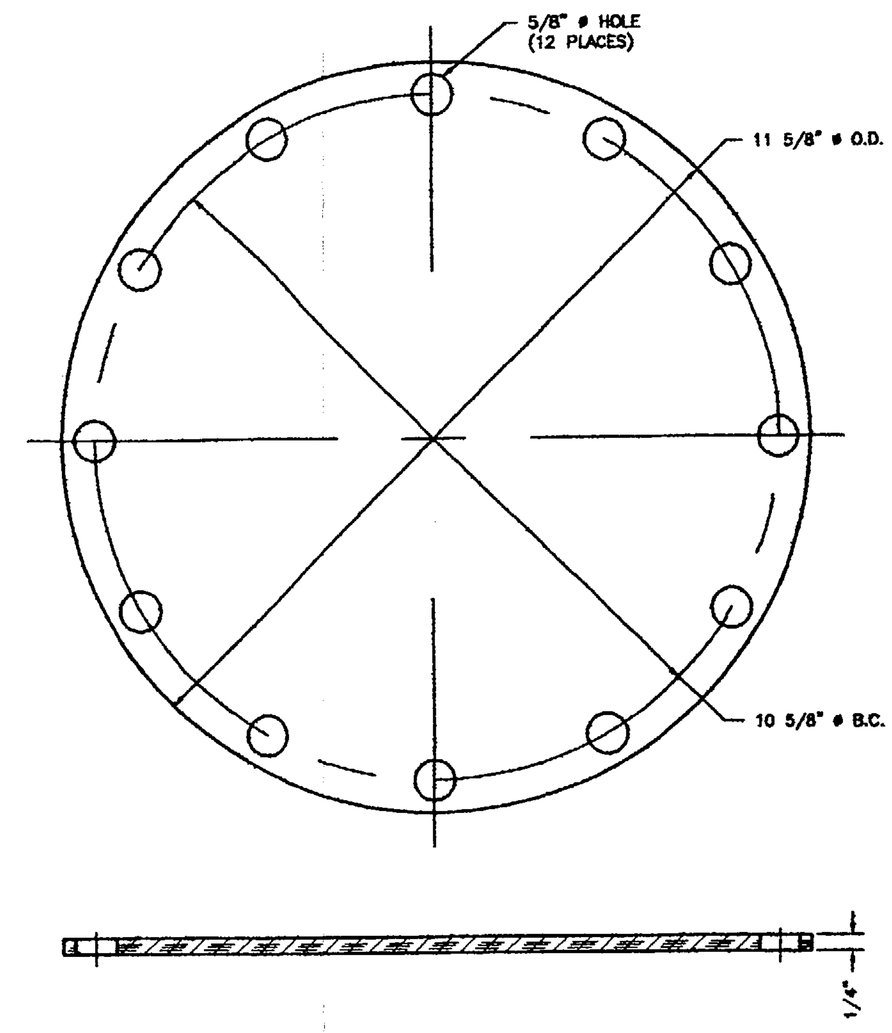
Checked: WMA	Date: 8/99	DRAWING NUMBER OP-TU-SAR
Appr'd By: [illegible]	Dr'n By: ARM	
Appr'd By:	Scale: NONE	REV. 1 SHEET 3 OF 4



STORAGE VESSEL DETAIL



LID DETAIL



GASKET DETAIL

NOTES:

TOLERANCES: +0 -1/8"

Rev. No.	Change	Date	By
9			
8			
7			
6			
5			
4			
3			
2			
1	CHANGED I.D. & MT TO PT	12/21/99	ARM

• REVISIONS •

THE COLUMBIANA BOILER CO.

COLUMBIANA, OHIO

GENERAL ARRANGEMENT
ECO-PAK OP-VA 7-3/4"
OXIDE VESSEL

Checked: JMH	Date: 8/99	DRAWING NUMBER OP-TU-SAR
Appr'd By: TR	Dr'n By: ARM	
Appr'd By:	Scale: NONE	REV. 1 SHEET 4 OF 4

Appendix 1.3.3
Epoxy Paint Data and Material Safety Data Sheets

SHERWIN WILLIAMS® CHEMICAL COATINGS

PRODUCT DATA **CC-A12**

CATALYZED EPOXY PRIMER

PART A - RED OXIDE E61 R C22
PART B - CATALYST V66 T C1

PRODUCT DESCRIPTION

Catalyzed Epoxy Primer E61 R C22/V66 T C1 is a two-component epoxy primer system offering excellent adhesion and corrosion resistance. Its' fast dry makes it ideal for production line application. It is especially suitable for use under POLANE® Polyurethane topcoats where superior corrosion resistance is needed.

Advantages:

- Very fast drying for a catalyzed epoxy.
- Excellent corrosion resistance.
- No "sweat-in" time required - can be applied immediately after mixing.
- Long working pot life.
- Free of lead hazards.
- Recommended primer under POLANE® Polyurethanes for best corrosion resistance on metal.
- Meets transformer specifications when topcoated with POLANE HS.
- Ideal primer for structural steel, farm and construction equipment, railroad equipment, machinery, transformers, castings, etc. when topcoated with POLANE Polyurethanes.
- Excellent chemical resistance.
- Ideal for application to untreated steel.

CC-A12 7/94 2001485

CHARACTERISTICS

Color:	Red Oxide
Gloss:	Under 30 units
Mix Ratio:	4 parts E61 R C22 1 part V66 T C1 2 parts R7 K 54
Volume Solids:	E 61 R C22 - 44% ± 2% V66 T C1 - 39% ± 2%
Catalyzed and Reduced:	30.7%
Viscosity:	E61 R C22 - 30 to 50 seconds Zahn #5 V66 T C1 - 10 to 20 seconds Zahn #5
Spreading Rate: Catalyzed and Reduced:	480 sq.ft./gal. at 1 mil (dry film, no application loss)
Working Pot Life:	8 hours
Package Life:	1 year
Drying:	Air dry 77°F, (25°C) 50% RH, 1.5 mils dry film
To Touch:	20-30 minutes
Tack Free:	1-2 hours
To Recoat:	1-2 hours
Force Dry:	20' at 140°F
Flash Point:	Under 100°F

Air Quality Data:

Photochemically Reactive. Volatile Organic Compounds (VOC) - E61 R C22 as packaged (maximum) 4.0 lb/gal (480 gms/ltr) V66 T C1 as packaged (maximum) 4.15 lb/gal (490 gms/ltr). Catalyzed 4:1 and reduced 50% (maximum) with R7 K 54 - 5.60 lb/gal (672 gms/ltr). Free of lead hazards. Contains chromates.

Product Limitations:

1. Topcoat only with POLANE Polyurethanes and catalyzed epoxy topcoats.
2. If primed parts are stored outside for long periods before topcoating, the chalk must be removed before painting or reprime with a thin coat of catalyzed epoxy primer.
3. On sand blasted surfaces, primer thickness must be 1 mil greater than the profile to insure best corrosion resistance. Multiple coats may be required.

SPECIFICATIONS

Surface Preparation:

Metal:
Apply to properly cleaned and/or treated metal surface. Treatment may consist of a proprietary surface chemical treatment (Zinc or Iron Phosphate). See also Metal Preparation Brochure CC-T1.

Aluminum:
Prime with Industrial Wash Primer P60 G 2.

Galvanized Iron:
Apply E61 R C22/V66 T C1 directly to aged weathered galvanize. If new galvanize, prime with Industrial Wash Primer P60 G 2.

Blasted Surfaces:
Dry film thickness must be 1 mil greater than depth of profile for best corrosion resistance.

Application:

Recommended Film Thickness:
Wet: 4-6 mils
Dry: 1.2-1.8 mils

Conventional Spray: Reduce 30-40% with R7 K 54 to 30-45 seconds Zahn #2.

Airless Spray: Reduce 0-10% with R7 K 54. For smooth appearance and good film build operate at 1800-2200 PSI with a .013 tip.

Clean Up:

Use R7 K 54

MSDS:

If a Material Safety Data Sheet is required, contact your local Sherwin-Williams Representative.

Safety Cautions:

DANGER! Contents are FLAMMABLE. Vapors may cause flash fires. Keep away from heat, sparks, and open flame. During use and until all vapors are gone: Keep area ventilated — Do not smoke — Extinguish all flames, pilot lights, and heaters — Turn off stoves, electric tools and appliances, and any other sources of ignition.

CONTAINS: VOLATILE ORGANIC COMPOUNDS ALCOHOLS, EPOXY RESIN POLYAMIDE RESIN, STRONTIUM CHROMATE

HARMFUL IF INHALED — MAY AFFECT THE BRAIN OR NERVOUS SYSTEM, CAUSING DIZZINESS, HEADACHE OR NAUSEA. IRRITATES EYES, SKIN AND RESPIRATORY TRACT. MAY CAUSE ALLERGIC SKIN REACTION. CAN BE ABSORBED THROUGH THE SKIN.

Use only with adequate ventilation, Wear an appropriate properly fitted vapor/particulate respirator

(continued on back)

(continued from column 3)

(NIOSH/ MSHA approved) during and after application, unless air monitoring demonstrates vapor/mist levels are below applicable limits. Follow respirator manufacturer's directions for respirator use.

Do not permit contact with skin and eyes. Components and mixed product can be absorbed through the skin and may cause allergic skin reaction. Wear neoprene gloves and goggles. Wash hands after using. Keep container closed when not in use. Do not transfer contents to other containers for storage.

FIRST AID:

If INHALED: If affected, remove from exposure. Restore breathing. Keep warm and quiet.

If on SKIN: Wash affected area thoroughly with soap and water. Remove contaminated clothing. Launder before re-use.

If in EYES: Flush eyes with large amounts of water for 15 minutes. Get medical attention.

If SWALLOWED: Get medical attention immediately.

SPILL AND WASTE

Remove all sources of ignition. Ventilate and remove with inert absorbent. Incinerate in approved facility. Do not incinerate closed container. Dispose of in accordance with Federal, State, and Local regulation regarding pollution.

DELAYED EFFECTS FROM LONG TERM OVEREXPOSURE: Contains solvents which can cause permanent brain and nervous system damage. Intentional misuse by deliberately concentrating and inhaling the contents can be harmful or fatal.

Contains Strontium Chromate which can cause cancer.

This product must be mixed before use. Before opening the packages, READ AND FOLLOW WARNING LABELS ON ALL COMPONENTS.

DO NOT TAKE INTERNALLY
KEEP OUT OF THE REACH OF CHILDREN
FOR INDUSTRIAL USE ONLY

NOTE:

The information, rating and opinions stated here pertain to the material currently offered and represent the results of tests believed to be reliable. However, due to variations in customer handling and methods of application which are not known or under our control, The Sherwin-Williams Company cannot make any warranties or guarantees as to the end result.

MATERIAL SAFETY DATA SHEET

V66TC1
07 00

MANUFACTURER'S NAME
THE SHERWIN-WILLIAMS COMPANY
101 Prospect Avenue N.W.
Cleveland, OH 44115

EMERGENCY TELEPHONE NO.
(216) 566-2917

DATE OF PREPARATION
13-DEC-99

INFORMATION TELEPHONE NO.
(216) 566-2902

Section I -- PRODUCT IDENTIFICATION

PRODUCT NUMBER
V66TC1

HMIS CODES	
Health	2*
Flammability	3
Reactivity	0

PRODUCT NAME
Catalyzed Epoxy Primer Part B
PRODUCT CLASS
Coreactant for 2-package Epoxy Coating

Section II -- HAZARDOUS INGREDIENTS

INGREDIENT CAS No.	% by WT	ACGIH TLV	OSHA PEL	UNITS	V.P.
1-Butanol 71-36-3	44 C	50	50	PPM (Skin)	5.50
Polyamide. Unknown	22	Not Established			0.00
Quartz 14808-60-7	0.3	0.1	0.1	MG/M3 as Resp. Dust	
Talc 14807-96-6	33	2	2	MG/M3 as Resp. Dust	

Section III -- PHYSICAL DATA

PRODUCT WEIGHT -- 9.38 lb./gal.
SPECIFIC GRAVITY -- 1.13
BOILING POINT -- 243-244 F
VOLATILE VOLUME -- 61 %
VOC (Theoretical) -- 4.15 lb. 497 gm. (less Federally Exempt Solvents)

EVAPORATION RATE -- Slower than Ether
VAPOR DENSITY -- Heavier than Air
MELTING POINT -- N.A.
SOLUBILITY IN WATER -- N.A.

Section IV -- FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	LEL	UEL
92 F PMCC	1.4	11.2

FLAMMABILITY CLASSIFICATION
RED LABEL -- Flammable, Flash below 100 F
EXTINGUISHING MEDIA
Carbon Dioxide, Dry Chemical, Foam

Continued on page 2

UNUSUAL FIRE AND EXPLOSION HAZARDS

Keep containers tightly closed. Isolate from heat, electrical equipment, sparks, and open flame. Closed containers may explode when exposed to extreme heat. Application to hot surfaces requires special precautions. During emergency conditions overexposure to decomposition products may cause a health hazard. Symptoms may not be immediately apparent. Obtain medical attention.

SPECIAL FIRE FIGHTING PROCEDURES

Full protective equipment including self-contained breathing apparatus should be used. Water spray may be ineffective. If water is used, fog nozzles are preferable. Water may be used to cool closed containers to prevent pressure build-up and possible autoignition or explosion when exposed to extreme heat.

Section V -- HEALTH HAZARD DATA

ROUTES OF EXPOSURE

Exposure may be by INHALATION and/or SKIN or EYE contact, depending on conditions of use. Alcohols and acetates can be absorbed through the skin. Follow recommendations for proper use, ventilation, and personal protective equipment to minimize exposure.

ACUTE Health Hazards

EFFECTS OF OVEREXPOSURE

Irritation of eyes, skin and respiratory system. May cause nervous system depression. Extreme overexposure may result in unconsciousness and possibly death.

SIGNS AND SYMPTOMS OF OVEREXPOSURE

Headache, dizziness, nausea, and loss of coordination are indications of excessive exposure to vapors or spray mists.

Redness and itching or burning sensation may indicate eye or excessive skin exposure.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE

May cause allergic skin reaction in susceptible persons.

EMERGENCY AND FIRST AID PROCEDURES

If INHALED:	If affected, remove from exposure. Restore breathing. Keep warm and quiet.
If on SKIN:	Wash affected area thoroughly with soap and water. Remove contaminated clothing and launder before re-use.
If in EYES:	Flush eyes with large amounts of water for 15 minutes. Get medical attention.
If SWALLOWED:	Get medical attention.

CHRONIC Health Hazards

Crystalline Silica (Quartz, Cristobalite) is listed by IARC and NTP. Long term exposure to high levels of silica dust, which can occur only when sanding or abrading the dry film, may cause lung damage (silicosis) and possibly cancer.

Prolonged overexposure to solvent ingredients in Section II may cause adverse effects to the liver and urinary systems.

Reports have associated repeated and prolonged overexposure to solvents with permanent brain and nervous system damage.

Section VI -- REACTIVITY DATA

STABILITY -- Stable

CONDITIONS TO AVOID

None known.

Continued on page 3

INCOMPATIBILITY
None known.
HAZARDOUS DECOMPOSITION PRODUCTS
By fire: Carbon Dioxide, Carbon Monoxide
HAZARDOUS POLYMERIZATION
Will not occur

Section VII -- SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED
Remove all sources of ignition. Ventilate and remove with inert absorbent.
WASTE DISPOSAL METHOD
Waste from this product may be hazardous as defined under the Resource Conservation and Recovery Act (RCRA) 40 CFR 261.
Waste must be tested for ignitability to determine the applicable EPA hazardous waste numbers.
Incinerate in approved facility. Do not incinerate closed container. Dispose of in accordance with Federal, State, and Local regulations regarding pollution.

Section VIII -- PROTECTION INFORMATION

PRECAUTIONS TO BE TAKEN IN USE
Use only with adequate ventilation. Avoid breathing vapor and spray mist. Do not get in eyes or on skin. Wash hands after using.
This coating may contain materials classified as nuisance particulates (listed "as Dust" in Section II) which may be present at hazardous levels only during sanding or abrading of the dried film. If no specific dusts are listed in Section II, the applicable limits for nuisance dusts are ACGIH TLV 10 mg./m3 (total dust), 3 mg./m3 (respirable fraction), OSHA PEL 15 mg./m3 (total dust), 5 mg./m3 (respirable fraction).
VENTILATION
Local exhaust preferable. General exhaust acceptable if the exposure to materials in Section II is maintained below applicable exposure limits. Refer to OSHA Standards 1910.94, 1910.107, 1910.108.
RESPIRATORY PROTECTION
If personal exposure cannot be controlled below applicable limits by ventilation, wear a properly fitted organic vapor/particulate respirator approved by NIOSH/MSHA for protection against materials in Section II.
When sanding or abrading the dried film, wear a dust/mist respirator approved by NIOSH/MSHA for dust which may be generated from this product, underlying paint, or the abrasive.
PROTECTIVE GLOVES
Wear gloves which are recommended by glove supplier for protection against materials in Section II.
EYE PROTECTION
Wear safety spectacles with unperforated sideshields.
OTHER PROTECTIVE EQUIPMENT
Use of barrier cream on exposed skin is recommended.

Section IX -- PRECAUTIONS

DOL STORAGE CATEGORY
1C

Continued on page 4

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING

Contents are FLAMMABLE. Keep away from heat, sparks, and open flame.

During use and until all vapors are gone: Keep area ventilated - Do not smoke - Extinguish all flames, pilot lights, and heaters - Turn off stoves, electric tools and appliances, and any other sources of ignition.

Consult NFPA Code. Use approved Bonding and Grounding procedures.

Keep container closed when not in use. Transfer only to approved containers with complete and appropriate labeling. Do not take internally. Keep out of the reach of children.

OTHER PRECAUTIONS

This product must be mixed with other components before use. Before opening the packages, READ AND FOLLOW WARNING LABELS ON ALL COMPONENTS.

Intentional misuse by deliberately concentrating and inhaling the contents can be harmful or fatal.

Section X -- OTHER REGULATORY INFORMATION

SARA 313 (40 CFR 372.65C) SUPPLIER NOTIFICATION

CAS No.	CHEMICAL/COMPOUND	% by WT	% Element
71-36-3	1-Butanol	44	

CALIFORNIA PROPOSITION 65

WARNING: This product contains a chemical known to the State of California to cause cancer.

TSCA CERTIFICATION

All chemicals in this product are listed, or are exempt from listing, on the TSCA Inventory.

The above information pertains to this product as currently formulated, and is based on the information available at this time. Addition of reducers or other additives to this product may substantially alter the composition and hazards of the product. Since conditions of use are outside our control, we make no warranties, express or implied, and assume no liability in connection with any use of this information.

MATERIAL SAFETY DATA SHEET

E61RC22
08 00

MANUFACTURER'S NAME
THE SHERWIN-WILLIAMS COMPANY
101 Prospect Avenue N.W.
Cleveland, OH 44115

EMERGENCY TELEPHONE NO.
(216) 566-2917

DATE OF PREPARATION
13-DEC-99

INFORMATION TELEPHONE NO.
(216) 566-2902

Section I -- PRODUCT IDENTIFICATION

PRODUCT NUMBER

E61RC22

HMIS CODES	
Health	2*
Flammability	3
Reactivity	0

PRODUCT NAME
Catalyzed Epoxy Primer Part A, Red Oxide
PRODUCT CLASS
Base component for 2-package Epoxy Coating

Section II -- HAZARDOUS INGREDIENTS

INGREDIENT / CAS No.	% by WT	ACGIH TLV	OSHA PEL	UNITS	V.P.
Toluene. 108-88-3	5	50	100	PPM (Skin)	22.00
	STEL		150	PPM (Skin)	
2-Propanol 67-63-0	1	400	400	PPM	33.00
	STEL	500	500	PPM	
1-Butanol 71-36-3	6 C	50	50	PPM (Skin)	5.50
1-Methoxy-2-propanol 107-98-2	15	Not Established			10.90
Methyl Ethyl Ketone. 78-93-3	4	200	200	PPM	70.00
	STEL	300	300	PPM	
Isobutyl Acetate. 110-19-0	4	150	150	PPM	12.50
Amyl Acetate. 628-63-7	2	100	100	PPM	4.00
Epoxy Polymer. Unknown	28	Not Established			0.00
Kaolin 1332-58-7	13	2	5	MG/M3 as Resp. Dust	
Talc 14807-96-6	7	2	2	MG/M3 as Resp. Dust	
Strontium Chromate. 7789-06-2	6	0.0005		MG/M3	0.00
Chromium VI (as Cr)	1.47	0.05		MG/M3	

Continued on page 2

Section III -- PHYSICAL DATA

PRODUCT WEIGHT	10.61 lb./gal.	EVAPORATION RATE	Slower than Ether
SPECIFIC GRAVITY	1.28	VAPOR DENSITY	Heavier than Air
BOILING POINT	174-306 F	MELTING POINT	N.A.
VOLATILE VOLUME	56 %	SOLUBILITY IN WATER	N.A.
VOC (Theoretical)	4.01 lb.	480 gm. (less Federally Exempt Solvents)	

Section IV -- FIRE AND EXPLOSION HAZARD DATA

FLASH POINT	LEL	UEL
40 F PMCC	1.0	12.7

FLAMMABILITY CLASSIFICATION

RED LABEL -- Flammable, Flash below 100 F

EXTINGUISHING MEDIA

Carbon Dioxide, Dry Chemical, Foam

UNUSUAL FIRE AND EXPLOSION HAZARDS

Keep containers tightly closed. Isolate from heat, electrical equipment, sparks, and open flame. Closed containers may explode when exposed to extreme heat. Application to hot surfaces requires special precautions. During emergency conditions overexposure to decomposition products may cause a health hazard. Symptoms may not be immediately apparent. Obtain medical attention.

SPECIAL FIRE FIGHTING PROCEDURES

Full protective equipment including self-contained breathing apparatus should be used. Water spray may be ineffective. If water is used, fog nozzles are preferable. Water may be used to cool closed containers to prevent pressure build-up and possible autoignition or explosion when exposed to extreme heat.

Section V -- HEALTH HAZARD DATA

ROUTES OF EXPOSURE

Exposure may be by INHALATION and/or SKIN or EYE contact, depending on conditions of use. Alcohols and acetates can be absorbed through the skin. Follow recommendations for proper use, ventilation, and personal protective equipment to minimize exposure.

ACUTE Health Hazards

EFFECTS OF OVEREXPOSURE

Irritation of eyes, skin and respiratory system. May cause nervous system depression. Extreme overexposure may result in unconsciousness and possibly death.

SIGNS AND SYMPTOMS OF OVEREXPOSURE

Headache, dizziness, nausea, and loss of coordination are indications of excessive exposure to vapors or spray mists.

Redness and itching or burning sensation may indicate eye or excessive skin exposure.

MEDICAL CONDITIONS AGGRAVATED BY EXPOSURE

May cause allergic skin reaction in susceptible persons.

Continued on page 3

EMERGENCY AND FIRST AID PROCEDURES

If INHALED: If affected, remove from exposure. Restore breathing. Keep warm and quiet.

If on SKIN: Wash affected area thoroughly with soap and water. Remove contaminated clothing and launder before re-use.

If in EYES: Flush eyes with large amounts of water for 15 minutes. Get medical attention.

If SWALLOWED: Get medical attention.

CHRONIC Health Hazards

Chromates are listed by IARC and NTP. Studies have associated exposure to Chromium VI compounds with an increased risk of respiratory cancer.

Methyl Ethyl Ketone may increase the nervous system effects of other solvents.

Prolonged overexposure to solvent ingredients in Section II may cause adverse effects to the liver, urinary, cardiovascular and reproductive systems.

Reports have associated repeated and prolonged overexposure to solvents with permanent brain and nervous system damage.

Section VI -- REACTIVITY DATA

STABILITY -- Stable

CONDITIONS TO AVOID

None known.

INCOMPATIBILITY

None known.

HAZARDOUS DECOMPOSITION PRODUCTS

By fire: Carbon Dioxide, Carbon Monoxide, Oxides of Metals in Section II

HAZARDOUS POLYMERIZATION

Will not occur

Section VII -- SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IN CASE MATERIAL IS RELEASED OR SPILLED

Remove all sources of ignition. Ventilate and remove with inert absorbent.

WASTE DISPOSAL METHOD

Waste from this product may be hazardous as defined under the Resource Conservation and Recovery Act (RCRA) 40 CFR 261.

Waste must be tested for ignitability and extractability to determine the applicable EPA hazardous waste numbers.

Incinerate in approved facility. Do not incinerate closed container. Dispose of in accordance with Federal, State, and Local regulations regarding pollution.

Section VIII -- PROTECTION INFORMATION

PRECAUTIONS TO BE TAKEN IN USE

Use only with adequate ventilation. Avoid breathing vapor and spray mist. Do not get in eyes or on skin. Wash hands after using.

This coating may contain materials classified as nuisance particulates (listed "as Dust" in Section II) which may be present at hazardous levels only during sanding or abrading of the dried film. If no specific dusts are listed in Section II, the applicable limits for nuisance dusts are ACGIH TLV 10 mg./m3 (total dust), 3 mg./m3 (respirable fraction), OSHA PEL 15 mg./m3 (total dust), 5 mg./m3 (respirable fraction).

Continued on page 4

VENTILATION

Local exhaust preferable. General exhaust acceptable if the exposure to materials in Section II is maintained below applicable exposure limits. Refer to OSHA Standards 1910.94, 1910.107, 1910.108.

RESPIRATORY PROTECTION

If personal exposure cannot be controlled below applicable limits by ventilation, wear a properly fitted organic vapor/particulate respirator approved by NIOSH/MSHA for protection against materials in Section II.

When sanding, wirebrushing, abrading, burning or welding the dried film, wear a particulate respirator approved by NIOSH/MSHA for protection against non-volatile materials in Section II.

PROTECTIVE GLOVES

Wear gloves which are recommended by glove supplier for protection against materials in Section II.

EYE PROTECTION

Wear safety spectacles with unperforated sideshields.

OTHER PROTECTIVE EQUIPMENT

Use of barrier cream on exposed skin is recommended.

Section IX -- PRECAUTIONS

DOL STORAGE CATEGORY

1B

PRECAUTIONS TO BE TAKEN IN HANDLING AND STORING

Contents are FLAMMABLE. Keep away from heat, sparks, and open flame.

During use and until all vapors are gone: Keep area ventilated - Do not smoke - Extinguish all flames, pilot lights, and heaters - Turn off stoves, electric tools and appliances, and any other sources of ignition.

Consult NFPA Code. Use approved Bonding and Grounding procedures.

Keep container closed when not in use. Transfer only to approved containers with complete and appropriate labeling. Do not take internally. Keep out of the reach of children.

OTHER PRECAUTIONS

This product must be mixed with other components before use. Before opening the packages, READ AND FOLLOW WARNING LABELS ON ALL COMPONENTS.

Intentional misuse by deliberately concentrating and inhaling the contents can be harmful or fatal.

Section X -- OTHER REGULATORY INFORMATION

SARA 313 (40 CFR 372.65C) SUPPLIER NOTIFICATION

CAS No.	CHEMICAL/COMPOUND	% by WT	% Element
108-88-3	Toluene.	5	
71-36-3	1-Butanol	6	
78-93-3	Methyl Ethyl Ketone.	4	
	Chromium Compound.	6	1.5

CALIFORNIA PROPOSITION 65

WARNING: This product contains chemicals known to the State of California to cause cancer and birth defects or other reproductive harm.

TSCA CERTIFICATION

All chemicals in this product are listed, or are exempt from listing, on the TSCA Inventory.

Continued on page 5

The above information pertains to this product as currently formulated, and is based on the information available at this time. Addition of reducers or other additives to this product may substantially alter the composition and hazards of the product. Since conditions of use are outside our control, we make no warranties, express or implied, and assume no liability in connection with any use of this information.

SECTION TWO STRUCTURAL EVALUATION

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(continued)

LIST OF FIGURES

2. *STRUCTURAL EVALUATION*

2.1 Structural Design

2.1.1 Discussion

The Eco-Pak® OP UO_2 Transport Unit described in this report is a roughly cubical package consisting of an outer shell and four internal cylinders. The cylinders are configured in a square pattern in line with the four corners of the outer shell. Space between the cylinders and the outer wall are filled with ESP-PF-2 closed-cell phenolic foam.

Each cylinder is individually closed using 12 bolts equally spaced which seal a 14" in diameter blind flange to an angle ring welded to the top of each cylinder. An outer flange (16 5/8-inches in diameter) located on the outer skin of the transport unit provides secondary closure and secondary containment to the cylinders. This outer flange is bolted to a large angle ring using 12 ½-inch bolts equally spaced around the angle ring.

A storage vessel is inserted inside each cylinder. Each storage vessel is a double-walled container which is also sealed by means of 12 ½-inch bolts with an 11 5/8-inch diameter blind flange.

The Eco-Pak® OP design is described in Eco-Pak Specialty Packaging Drawing No. OP-TU-SAR, Sheets 1 through 4 (see Appendices 1.3.1 and 1.3.2).

2.1.2 Design Criteria

The Eco-Pak® OP was designed to meet all of the performance requirements of 10CFR71, Subpart E for Type A fissile materials. The primary containment vessel is the stainless steel storage vessel. The transport unit is designed in a geometrically-safe configuration and criticality evaluations (See Section Six) in this report assume that water does leak into the inner containers. Therefore, water-tightness of the containers is not assumed.

The Eco-Pak OP Transport Unit and storage vessels shall be manufactured under a quality assurance program that meets the requirements of 10CFR71, Subpart H. All welding shall be conducted by welders qualified to ASME, Section IX using acceptable welding procedures. All inspection shall be conducted by personnel qualified under ASNT-TC-1A and/or for visual inspection certified as an AWS certified welding inspector or assistant.

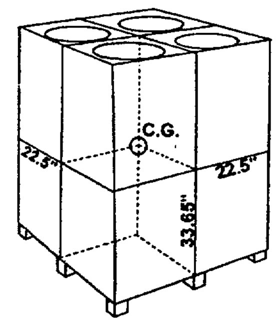
For normal conditions of transport, compliance of the Eco-Pak® OP is demonstrated through the evaluation described in Section 2.6 below.

Compliance of the Eco-Pak® OP with requirements for hypothetical accident conditions testing are described in Section 2.7 below.

2.2 ***Weights and Centers of Gravity***

The weights and centers of gravity of the Eco-Pak® OP Transport Unit, its storage vessels and its UO_2 contents were tabulated by Law Engineering Industrial Services of Charlotte, North Carolina and are included in **Appendix 2.10.1**. The sides of a loaded package are the same dimension (45 inches). Based on properties of the materials of construction and the proposed uranium oxide lading, the center of gravity was determined to be located 33.65 inches from the absolute base (including the legs) of the package along a vertical axis in the physical center of the package. (See **Figure 2.1-1**).

Figure 2.1-1



2.3 ***Mechanical Properties of Materials***

2.3.1 Metal Properties

Property/Material	300 Series SS	Grade 304/18-8 SS Bolts	A569 CS	A36 CS	A325 CS Bolts
Min Yield Strength (psi x 1,000)	25	30	**	36	92
Min Tensile Strength (psi x 1,000)	70	75	**	58-80	120
Elongation in 2" (%)	40	30*	**	21-23	N/A

* Elongation in 4D (%)
** Specification A569 is a chemistry-based material. Mechanical properties are not specified.

2.3.2 Insulation Properties

Property/Material	ESP-PF-2 Foam
Closed Cell Content (%)	80-92
Density (lb/cu-ft)	6.0-8.0
Thermal Conductivity (Btu/hr sq-ft ^{0}F/in)	0.15-0.299

2.4 *General Standards for All Packages*

The Eco-Pak® OP Transport Unit meets the General Standards for All Packages per 10CFR71.43 in that it easily meets the minimum size requirements, it is equipped with provisions for security seals, the transport unit and its storage vessels provide complete containment under Normal Conditions of Transport, the storage vessels are well protected against accidental or unauthorized operation, and, although a fusible cap is used to vent gasses that might be generated by the transport unit insulation during a fire event, there is no pressure relief valve nor any provision for continuous venting of the lading. Since there is essentially no source of internal heat (i.e., decay heat is negligible), the external surfaces will not exceed 38^0C in still air in the shade at 38^0C. Other General Standard provisions are also met as described below:

2.4.1 Minimum Package Size

The Eco-Pak® OP easily exceeds the minimum package size requirements.

2.4.2 Tamperproof Feature

The Eco-Pak® OP features four locations (one at each cylinder) for installing tamper indicating devices, typically individually-numbered seals, which would disclose any unauthorized entry into the package.

2.4.3 Positive Closure

The Eco-Pak® OP- TU is closed with a total of twenty-four (24) ½-inch bolts. The storage vessels for use within the unit are closed with a total of twelve (12) ½-inch bolts.

2.4.4 Chemical and Galvanic Reactions

There are two combinations of the Eco-Pak® OP-TU and/or storage vessel materials of construction with a potential to react chemically or galvanically. The first combination found in the transport unit is carbon steel, primer, ceramic fiber board, phenolic foam, and ceramic fiber paper. The second combination found in the storage vessels is stainless steel, primer and phenolic foam. Accelerated corrosion testing (Appendix 2.10.6) to represent a 20-year service life was performed on samples representing a cross-section of the transport unit and the storage vessels. In actuality, the samples did not have an exterior coating of a catalyzed urethane enamel as specified in Drawing No. OP-TU-SAR (Appendix 1.3.1 and 1.3.2), which would have been a more correct cross-section of the Eco-Pak® OP. Therefore, the testing performed was significantly more severe than normal operating conditions over a 20-year service life.

Law Engineering in conjunction with the Materials Engineering Department at Auburn University conducted Humid Atmosphere Primer Adhesion and Ferric Chloride Solution

Corrosion tests. Weight loss and corrosion results were favorable in these water, water vapor and chloride rich environments. Although there was significant blistering of the primer during the 30-day Humid Atmosphere Test, there was only 55/100th of 1 percent weight loss. Subsequently, during the highly corrosive environment of the Ferric Chloride Test, there was indications of primer blistering and peeling, plus minor pitting, but the weight loss experienced was only 3.5%. The samples did not have a coating of catalyzed urethane enamel, as specified in Drawing No. OP-TU-SAR, which represented a condition significantly more severe than normal operating conditions.

2.5 *Lifting and Tie-down Devices*

The Eco-Pak® OP Transport Unit can be lifted by fork-truck tines in which case it is supported by the reinforced bottom of the unit. It can also be lifted by four shackles attached to the body. The lifting condition is analyzed in Section 2.5.1 using the working load limit for the shackles and determining their factor of safety.

2.5.1 Lifting Devices

The Eco-Pak® OP Transport Unit is lifted using four shackles (½-inch stock diameter, 5/8-inch pin diameter, steel). The working load limit for the ½-inch shackles is 6000 pounds. The safety factor for a fully loaded transport unit with storage vessels is:

$SF=(4*6000)/3757.6 = 6.4$

2.5.2 Tiedown Devices

There are no specific provisions for tiedown of the Eco-Pak® OP Transport Unit.

2.6 *Normal Conditions of Transport*

2.6.1 Heat

Effects from heat due to normal conditions of transport are described in Section 3.

2.6.2 Cold

An ambient temperature of -40^{0}F with no insolation and no decay heat results in a package with a uniform temperature of -40^{0}F. An ambient temperature of -40^{0}F will not have an adverse effect on the Eco-Pak® OP. The ductility of the steel in the package is not seriously affected by temperatures in this range.

The UO_2 storage vessel is fabricated of ASTM A-240, 300 Series stainless steel which is also not seriously affected by temperatures in this range.

2.6.3 Reduced External Pressure

The internal pressure of a filled storage vessel will range from 0 to 14.7 psia (corresponding to UO_2 temperatures of 0^0F to 130^0F, respectively). A reduced external pressure of 3.5 psia will result in a net internal pressure of 3.5 psig. This pressure is less than the design internal pressure of the storage vessel (169 psig).

2.6.4 Increased External Pressure

An increased external pressure of 20 psia would result in a net external pressure of 20 psig (conservatively assumed minimum storage vessel cavity pressure of 0 psia). The storage vessel is designed for an external pressure of 25 psig.

2.6.5 Vibration

Vibration incident to transport has no measurable effect on the Eco-Pak® OP Transport Unit. Bolted lids of the transport unit firmly hold the UO_2 storage vessels to prevent movement during transport. The bolted package closures are tightened down on lock washers to prevent loosening due to vibration.

2.6.6 Water Spray

A one-hour water spray simulating rainfall at a rate of 2 in/hr will have practically no effect on the Eco-Pak® OP-TU. A welded steel jacket totally encloses the foam insulation in the Eco-Pak® OP-TU and there are no penetrations. Each of the closures used in the package are sealed with silicone gaskets designed to prevent water inleakage during normal transportation and contents of the internal storage vessel are essentially triple sealed.

2.6.7 Free Drop

When subjected to a free drop from a height of 4 feet (1.2 meters) onto a flat, essentially unyielding horizontal surface, the package must maintain its integrity and not suffer a reduction in effectiveness. Damage resulting from the four foot free drop could result in some local deformation of the transport unit, but any local damage due to the drop would not result in any reduction in the packaging effectiveness.

Results of the 30 foot hypothetical accident drops, performed in the orientation for which maximum damage is expected and outlined in Section 2.7, indicate that these drops do not result in damage to the storage vessels which would allow the release of radioactive materials. Therefore, the less severe 4 foot free drop would not result in loss or dispersal of radioactive contents.

There would likewise be no significant increase in external surface radiation levels since only the storage vessel is required to meet shielding requirements. Additionally no criticality concerns exist since, as shown in Section Six, criticality is maintained using a geometrically-safe configuration which was not significantly altered under the more extreme hypothetical accident conditions.

2.6.8 Corner Drop

When subjected to a corner drop from a height of 4 feet (1.2 meters) onto a flat, essentially unyielding horizontal surface, the package must maintain its integrity and not suffer a reduction in effectiveness. Damage resulting from the four foot free drop could result in some local deformation of the transport unit, but any local damage due to the drop would not result in any reduction in the packaging effectiveness.

Results of the 30 foot hypothetical accident drops, performed in the orientation for which maximum damage is expected (including a corner drop) and outlined in Section 2.7, indicate that these drops do not result in damage to the storage vessel which would allow the release of radioactive materials. Therefore, the less severe 4 foot free drop would not result in loss or dispersal of radioactive contents.

2.6.9 Compression

The minimum vertical projected area of the phenolic foam in the Eco-Pak® OP is:

$(44.5)\ (44.5) = 1980\ in^2$

Five times the weight of the package is: $(5)\ (1708\ kgs) = 8540\ kgs$

This is equivalent to a pressure of: $8540\ kgs\ /\ 1980 in^2 = 4.3\ psi$

This pressure is less than the minimum compressive strength of the foam which is 84 psi. This assumption neglects the presence of the storage vessels and the steel shells of the transport unit.

$M.S. = (84/4.3) - 1 = 18.5$

2.6.10 Penetration

Dropping a 13 pound rod as described in 10CFR71 will have a negligible effect on the steel walls of the Eco-Pak® OP Transport Unit. Puncture drop tests conducted as part of the Hypothetical Accident Conditions testing showed that minimal damage was done to the package's integrity as a result of these more severe tests. Therefore, a penetration test using a 13 pound rod as described in 10CFR71 would have practically no impact on the transport unit's ability to provide containment of the package contents.

2.6.11 Conclusion

As shown in Section Six, calculations of criticality for the packaging are not dependent on the package preventing water inleakage. Therefore, damage from free drop tests which might result in such inleakage would not affect concerns with criticality. Additionally, since the geometrically-safe configuration used for design of the transport unit would not be changed significantly by normal conditions of transport, there are no concerns with a decrease in the effectiveness of the package. Further, results of hypothetical accident testing show that containment is maintained after such testing. The Normal Conditions of Transport requirements of 10CFR71 present much less demanding conditions and, therefore, the Eco-Pak® OP Transport Unit can easily meet the requirements for Normal Conditions of Transport..

The analyses presented in Section 2.6 show that normal loads will not result in any significant structural damage of the Eco-Pak® OP Transport Unit and the containment function of the storage vessels will be maintained.

2.7 Hypothetical Accident Conditions

A full-scale representative Eco-Pak® OP Transport Unit containing four storage vessels with simulated loads was subjected to the sequence of drop, puncture and fire tests of the hypothetical accident conditions of 10CFR71.73.

In addition, tests were conducted on samples of the basic materials used in the manufacture of Eco-Pak® OP Transport Units to determine the effect of different temperatures on their physical characteristics. Metal samples were subjected to Charpy "V" impact tests (see Appendix 2.10.3) and ESP-PF-2 foam insulation samples (See Appendices 2.10.2 and 2.10.3) were analyzed at three temperature ranges: +100^{0}F, 67-74^{0}F and -20^{0}F. Although the physical characteristics of the foam samples were essentially unaffected by the different temperatures, metal samples tested at the -20^{0}F range did exhibit reduced strength. Therefore, package temperatures for test articles used for hypothetical accident condition testing were maintained at a minimum of -20^{0}F prior to drop tests.

A detailed test program is provided as Appendix 2.10.4.

Test Program Summary

Each storage vessel was loaded with an average of 161.75 kgs of steel shot designed to simulate the maximum load to be carried by the Eco-Pak® OP Transport Unit.

The storage vessels were fitted with several different temperature recording tapes and thermocouples, then loaded into the transport unit. The transport unit was secured following the torque sequence described in Section 7.

The package was then cooled to a temperature of approximately -31^{0}F in a cooling chamber. After cooling, the package was subjected to a 30 foot free drop onto the package bottom, an orientation determined to be most detrimental to the package. This test was followed by a 30 foot free drop with the center of gravity over one of the corners and a closure of the package at an angle of 47.5^0 from horizontal. The package was then subjected to an additional 30 foot free drop onto a top edge of the package at an angle of 50^0 from horizontal. The package was then subjected to a 40 inch puncture drop onto the center of the package side. External damage was recorded after each drop.

The impact of the 30 foot drop onto the package edge dislodged the thermocouple pod attached to the outside surface of the package and the contacts had been damaged.. Although it was a variance from the established procedure, the cylinder which contained the storage vessel equipped with thermocouples was opened to re-attach the devices. This decision was made based on the observation that the cylinder in question had received little, if any, damage as a result of the drop tests. After the thermocouple leads were re-attached, the storage vessel was re-loaded into the package and sealed. Other than this event, the package was not opened during the test sequence.

The package was warmed to 100^{0}F in preparation for the 30 minute fire test. The package was then subjected to a 30 minute fully engulfing diesel fuel fire.

After the package had cooled following the fire, the transport unit was opened and the storage vessels removed. The inner containment cylinders were examined for traces of leakage which may have resulted from the hypothetical accident testing. Temperature readings were noted from the temperature recording tapes on the storage vessels.

The results of the tests and analyses demonstrate that the Eco-Pak® OP Transport Unit effectively protects the storage vessel from damage. The test report is provided in Appendix 2.10.4 with additional documentation in Appendix 2.10.5.

2.7.1 Free Drop on Bottom

A full-scale Eco-Pak® OP Transport Unit was used for the 10CFR71 hypothetical accident compliance testing. The test was performed onto the package bottom; as indicated above, this drop was determined to be the one which would result in the most potential damage to the storage vessels. The test setup for the bottom drop test is shown in Figure 2.7-2.

The 30 foot drop test was performed at low temperature to evaluate the adequacy of the package to perform under reduced temperature. Due to the low thermal conductivity of the package, the storage vessels probably did not reach -20^{0}F; the transport unit was cooled to -31^{0}F.

After being removed from the cooling chamber, the package was positioned with the bottom parallel to the ground and raised 30 feet as measured from the bottom of the package.

The package was dropped onto a target pad of 10' x 10' x 6' reinforced concrete imbedded in the ground. The concrete slab was covered by a 1" thick steel plate attached to the slab using J-bolts. The estimated weight of the target pad is approximately 95,000 pounds.

External deformation data was recorded and documented with both video and still photography. (See Appendices 2.10.4 and 2.10.5 for photos). Damage is summarized in Section 2.7.10. The package was not opened after the 30 foot drop, but was prepared for an additional 30-foot drop.

2.7.2 <u>Free Drop on Corner</u>

The package was positioned upside-down with the center of gravity over a top corner and closure at an angle of 47.5E from horizontal. It was then raised to a height of 30 feet above the target as measured from the low corner. The test setup for the corner drop test is shown in Figure 2.7-3.

External deformation data was recorded and documented with both video and still photography. (See Appendices 2.10.4 and 2.10.5 for photos). Damage is summarized in Section 2.7.10. The package was not opened, but was prepared for an additional 30 foot free drop.

2.7.3 <u>Free Drop on Edge</u>

The package was positioned at an angle of 50^0 from horizontal with the center of gravity over a top edge (opposite the corner that was the target of the last drop) as the lowest point of the package. It was then raised to a height of 30 feet above the target as measured from the low corner. The test setup for the edge drop test is shown in Figure 2.7-4.

The impact of the 30 foot drop onto the package edge dislodged the thermocouple pod attached to the outside surface of the package and there was a fear that the contacts had been damaged..

External deformation data was recorded and documented with both video and still photography. (See Appendices 2.10.4 and 2.10.5 for photos). Damage is summarized in Section 2.7.10. The package was not opened after this drop, but was prepared for the 40-inch puncture drop test.

2.7.4 Puncture Drop on Side

The package was positioned on its side with the top perpendicular to the ground and raised 40 inches above the puncture bar as measured from the center of the side of the package closest to the bar. The test setup for the side puncture drop test is shown in Figure 2.7-5.

External deformation data was recorded and documented with both video and still photography. (See Appendices 2.10.4 and 2.10.5 for photos). Damage is summarized in Section 2.7.8.

Examination of the thermocouple leads revealed that the damage they had sustained as a result of the 30 foot drop on the package edge had rendered the thermocouples inoperative. Although it was a variance from the established procedure, the cylinder which contained the storage vessel equipped with thermocouples was opened to re-attach the devices. This decision was made based on the observation that the cylinder in question had received little, if any, damage as a result of the drop tests. After the thermocouple leads were re-attached, the storage vessel was re-loaded into the package, sealed and the package was moved to a warming oven in preparation for thermal testing.

2.7.5 Thermal

The package had been instrumented with thermocouples and maximum temperature sensors prior to being loaded into the package. The maximum temperature sensors had a range of 125^0F - 500^0F and were in the form of irreversible self-adhesive temperature tapes with heat sensitive indicators sealed under transparent heat resistant windows.

The package had been heated to 100^0F in the warming oven prior to the thermal test. After being removed from the oven, the package was mounted 40 inches above the surface of the diesel fuel source. The test stand was water cooled during the fire to prevent collapse of the structure during the fire test.

The test stand was comprised of a 25' x 25' fuel pool centered in a 30' x 30' containment pan. Figures 2.7-6 and 2.7-7 illustrate the fire test configuration. No. 2 diesel fuel was floated on water within the 25' x 25' fuel pan.

During the time of the thermal test, wind speed averaged between 4-6 mph. The fire was totally engulfing and lasted for 31 minutes. The package was left on the test stand for 15 hours and allowed to cool before moving.

Photographs (Appendices 2.10.4 and 2.10.5) and video of the thermal test were taken.

2.7.6 Immersion - Fissile Material

As required in 10CFR71.73(c)(5), "in those cases where water inleakage has not been assumed for criticality analysis the hypothetical accident conditions shall include immersion under a head of water of at least three feet in the attitude for which maximum leakage is expected." The criticality analysis presented in Section 6 assumes that water does enter the storage vessel following the hypothetical accident conditions, therefore immersion testing was not conducted.

2.7.7 Immersion - All Packages

Under 10CFR71.73(c)(6), a second immersion test is required on an undamaged package under 50 feet of water (21.7 psig). An immersion test evaluation was conducted to comply with 10CFR71(c)(6) by Law Engineering and is included as Appendix 2.10.7. This evaluation concluded that the vessels, which contained the materials would remain unaffected by fifty foot of water (21.7 psig) and is therefore acceptable.

2.7.8 Summary of Damage and Test Results

Damage from the full compliance testing has been documented through photographs (Appendices 2.10.4 and 2.10.5) and video.

Transport Unit Damage

The 30 foot drop on the package bottom resulted in slight buckling of all sides of the transport unit. All visible welds remained intact. The bottom of the package bowed slightly as a result of the impact.

The 30 foot drop on the package corner resulted in a marked deflection of the impacted corner. The force of the impact caused the upper gaskets to bulge slightly and sheared the heads of three of the bolts on the cylinder lid closest to the impact corner although the lids remained securely attached to the package.

The 30 foot drop on the package edge resulted in additional buckling of the skirt on the impacted edge including slight separation of the edge at the corner. The protective cover placed over the thermocouples (not part of a standard package) was sheared off as a result of the impact and that caused damage to the thermocouples attached to the cylinder inside.

The 40 inch puncture test on the package side resulted in an indentation in the package side. The skin of the package did not tear and there was no additional weld damage.

The damage following the 30 minute fire is shown in photographs provided in Appendices 2.10.4 and 2.10.5.

Storage Vessel Damage

There was no discernable damage done to the storage vessels as a result of the hypothetical accident testing.

Prior to drop testing, the original geometric configuration of the cylinders holding the storage vessels was measured. The external measurement of the geometric configuration of these cylinders was measured after drop testing was completed. (See Figure 2.7-8 for comparative figures.) After the storage vessels were removed from the transport unit, readings of the irreversible maximum temperature tapes were recorded. (See Figure 2.10.4-1) The geometric configuration of the bottom of the cylinders holding the storage vessels were measured and noted. The locations where measurements were taken and the shifts recorded in the cylinders are represented in Figure 2.7-9.

Evaluation of the measurements showed no variation which would adversely affect the criticality of the lading. (See Section Six.)

2.7.9 Conclusion

Based on the results of the tests, the Eco-Pak® OP Transport Unit will absorb the required energy and successfully protect the storage vessels from damage which would render them incapable of meeting the requirements of 10CFR71 after undergoing hypothetical accident events described in 10CFR71.73. The compliance testing demonstrated that:

The geometrically-safe configuration of the Eco-Pak® OP was not significantly compromised as a result of the hypothetical accident testing;

The Eco-Pak® OP Transport Unit provided sufficient thermal protection to prevent the internal temperature of the storage vessel to reach a temperature which would lead to degradation of the gasketing for the vessels and to a loss of contents;

Therefore, the Eco-Pak® OP Transport Unit will provide adequate protection to the storage vessels against the hypothetical accident conditions of 10CFR71.73.

Figure 2.7-1
Eco-Pak® OP Transport Unit Testing Program

Proc.#	Action (Proceed if Successful)	Decision
1	Fill Storage Vessels with Shot.	
4	Place Temperature Recording Tapes on Storage Vessels and Eco-Pak® OP Interior Surfaces	
5	Load Storage Vessels into Transport Unit	
6	Place Package into Cold Storage to Maximum Temperature of -20^0F	
7	Remove Package from Cold Storage	
8	Perform 30 foot Free Drop onto Package Bottom	
9	Record Damage and Measure Crush Area	
10	Perform 30 foot Free Drop on Package Corner	
11	Record Damage and Measure Crush Area	
12	Perform 30 foot Free Drop on Package Edge	
13	Record Damage and Measure Crush Area	
14	Perform 40 inch Puncture Drop onto Package Side	
15	Record Damage and Measure Crush Area	
16	Measure and Record External Cylinder Dimensions	If cylinders are no longer in geometrically safe configuration, testing is terminated.
17	Warm Package to 100^0F	
18	Perform 30 minute Fire Test	
19	Cool Package	
20	Record External Damage from Fire Test	
21	Open Transport Unit	
22	Remove Storage Vessels from Transport Unit	
23	Record Temperature Tape Readings	
24	Measure and Record Internal Cylinder Dimensions	
25	Examine Internal Containment Cylinders for Indication of Loss of Contents from Storage Vessels	If material is found in cylinders, testing is terminated.
27	**TESTING COMPLETE**	Transport unit passes

Figure 2.7-2
Free Drop on Bottom

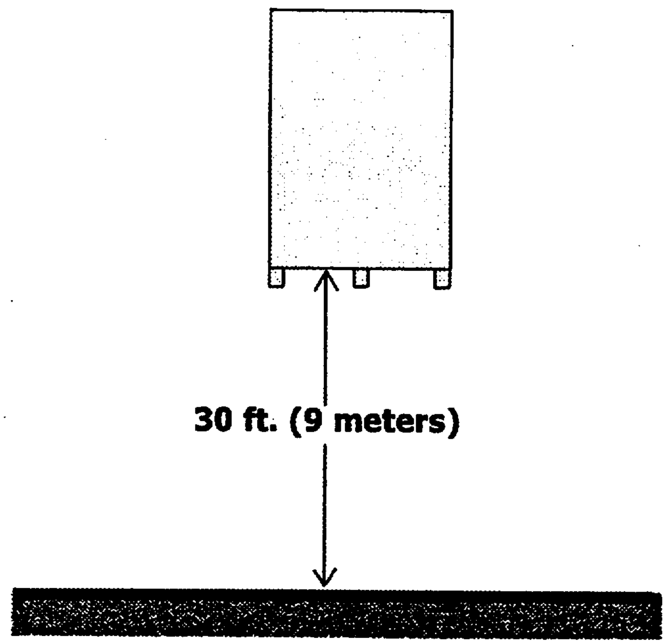


Figure 2.7-3
Free Drop on Corner

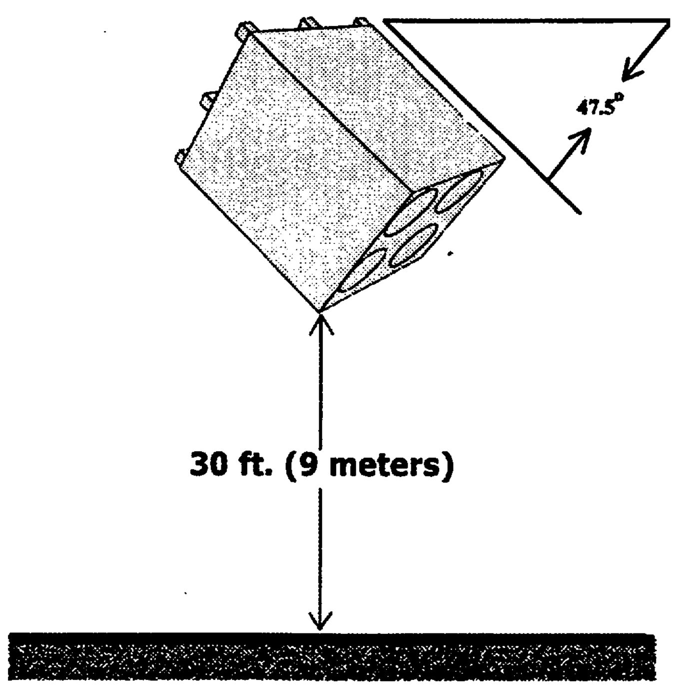


Figure 2.7-4
Free Drop on Edge

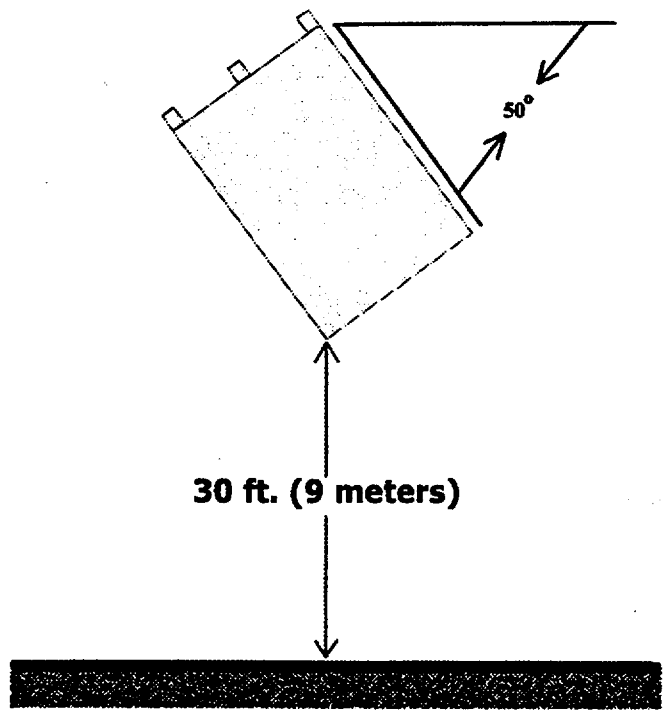


Figure 2.7-5
Puncture Drop on Side

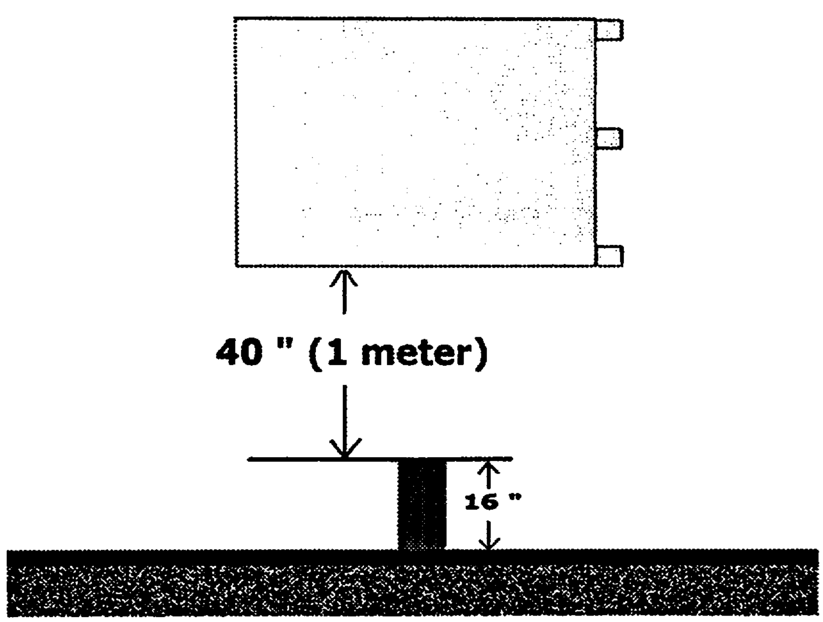


Figure 2.7-6

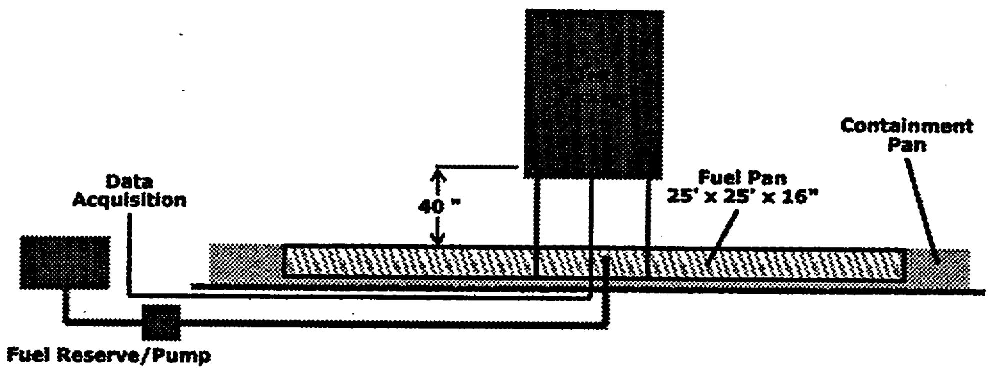


Figure 2.7-7

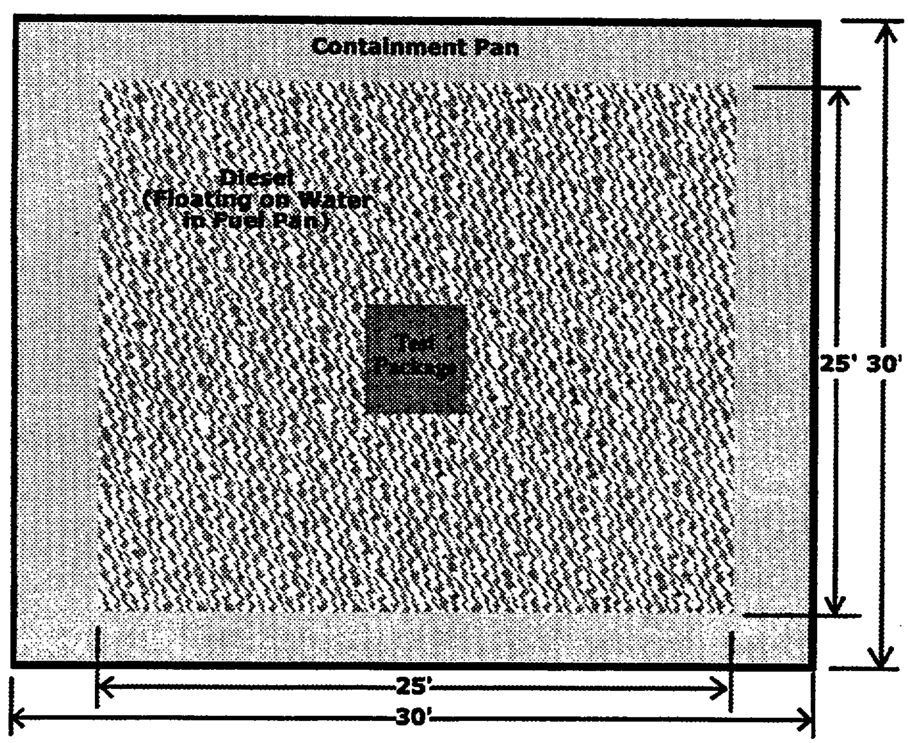
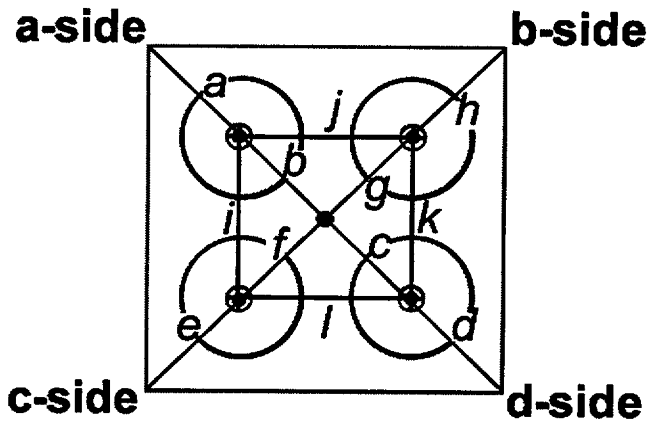
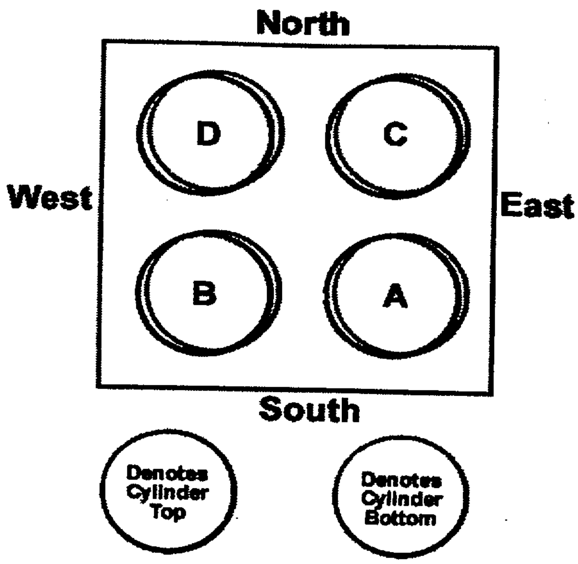


Figure 2.7-8



Line Segment	Measurement Before Drop Testing (mm)	Measurement After Drop Testing (mm)
a	395	405
b	391	395
ab	786	800
c	392	407
d	397	394
cd	789	801
e	398	NR
f	391	386
ef	789	NR
g	391	408
h	395	390
gh	786	798
i	567	561
j	563	563
k	563	562
l	566	575

Figure 2.7-9



Bottom Cylinder Shift Measurements After Testing		
Cylinder	East Shift *(in.)*	North Shift (in.)
A	3.5	1.75
B	3.75	1.5
C	3.375	1.5
D	3.625	1.125

2.8 Special Form

Special form material as defined in 10CFR71 is not applicable to the Eco-Pak® OP.

2.9 Fuel Rods

This section is not applicable to the Eco-Pak® OP Transport Unit.

2.10 Appendices

2.10.1	Law Engineering Report on Centers of Gravity
2.10.2	Material and Equipment Specification of ESP-PF-2 Phenolic Foam and ESP-CFI-1 Ceramic Fiber Insulation
2.10.3	Law Engineering Report on Charpy "V" Impact Tests and Comparative Tests on ESP-PF-2 Foam Samples
2.10.4	Compliance Testing of the Eco-Pak® OP Transport Unit
2.10.5	Southwest Research Institute Performance Evaluation of the Eco-Pak® OP Uranium Oxide Transport Unit
2.10.6	Chemical and Galvanic Reactions Analysis
2.10.7	Fifty Foot Immersion Analysis
2.10.8	Test Damage Sketches

Appendix 2.10.1

Law Engineering Report on Centers of Gravity

LAW
ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

March 9, 1998

Eco-Pak,
Specialty Packaging
125 Iodent Way,
Elizabethton, TN 37643

Attention: Ms. Heather Little

Subject: **Center of Gravity of ESP-440 Shipping Container Box**
Law Engineering Industrial Services Project 10825-7-7094

Dear Ms. Little:

As per your request and as authorized by your Purchase Order Number 3573, Law Engineering Industrial Services (LEIS) has completed the engineering analysis of the ESP-440 shipping container box. The purpose of this analysis was to find the center of gravity of the box and to calculate the container position angles with respect to the drop test configurations in accordance with Title CFR Part 71.73 (Hypothetical Accident Conditions).

Two drawings are attached with this letter as described below.

SHEET 1 of 2: POSITION OF THE CONTAINER BOX WHEN POINT "A" IS ALIGNED WITH THE CENTER OF GRAVITY.
Location of point "A" is shown in the drawing.

SHEET 2 OF 2: POSITION OF THE CONTAINER BOX WHEN TOP EDGE "A-A" ALIGNED WITH THE CENTER OF GRAVITY.
Top edge "A-A" is shown in the drawing.

Law Engineering Industrial Services appreciates the opportunity to assist you with this project. Please contact this office at 704-357-8600 if you have any questions.

Sincerely,
LAW ENGINEERING INDUSTRIAL SERVICES

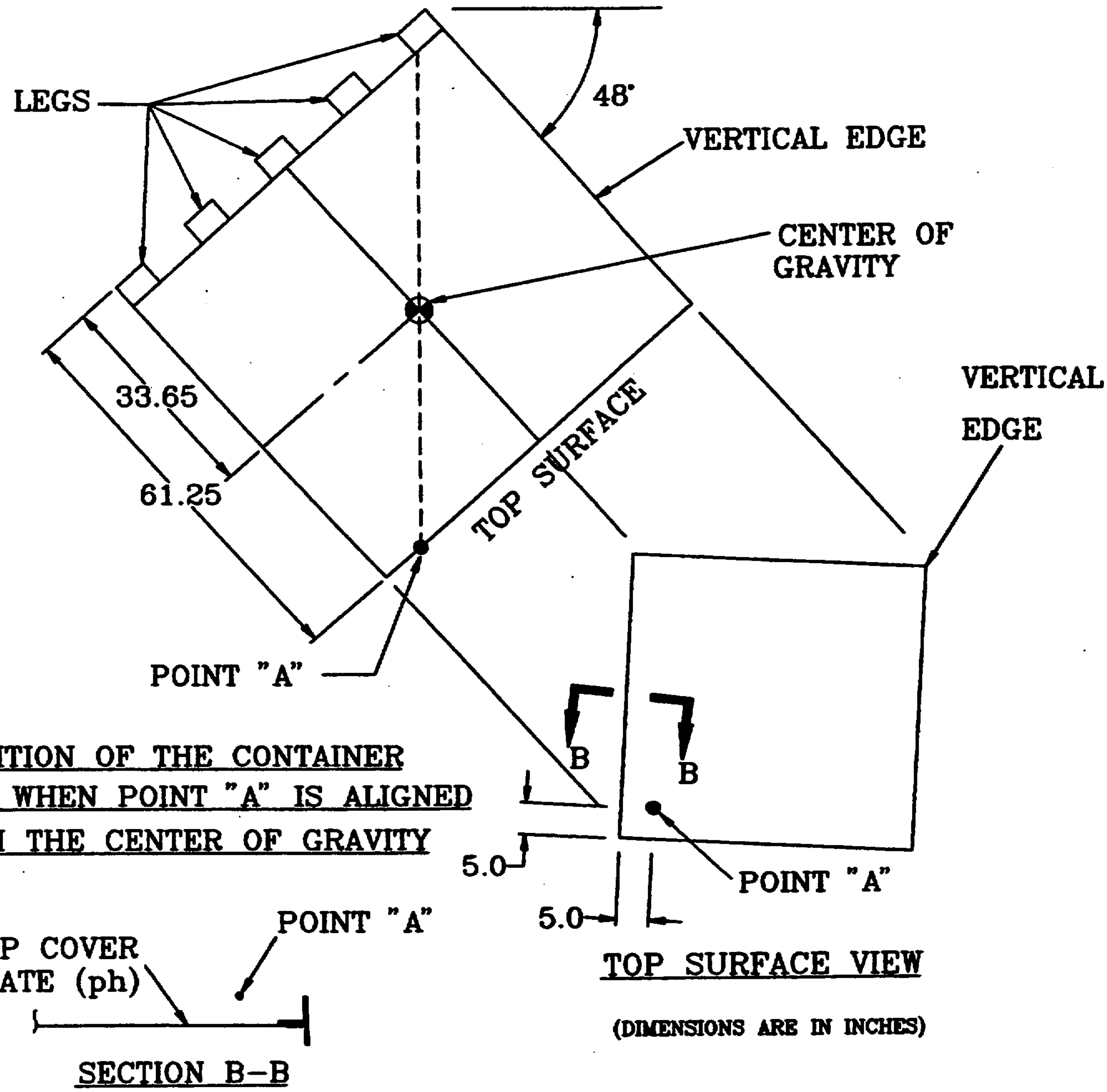
M N Parikh
Mike N. Parikh, P.E.
Project Engineer

Dennis Tignor
Dennis Tignor, P.E.
Senior Mechanical Engineer

Attachment: Sheet 1 and 2 (2 Sets)

LAW ENGINEERING INDUSTRIAL SERVICES
2801 YORKMONT ROAD, SUITE 200 • CHARLOTTE, NC 28208
P.O. BOX 19667 • CHARLOTTE, NC 28219
(704) 357-8600 • FAX (704) 357-8637

DROP TEST



(DIMENSIONS ARE IN INCHES)

NOTES:

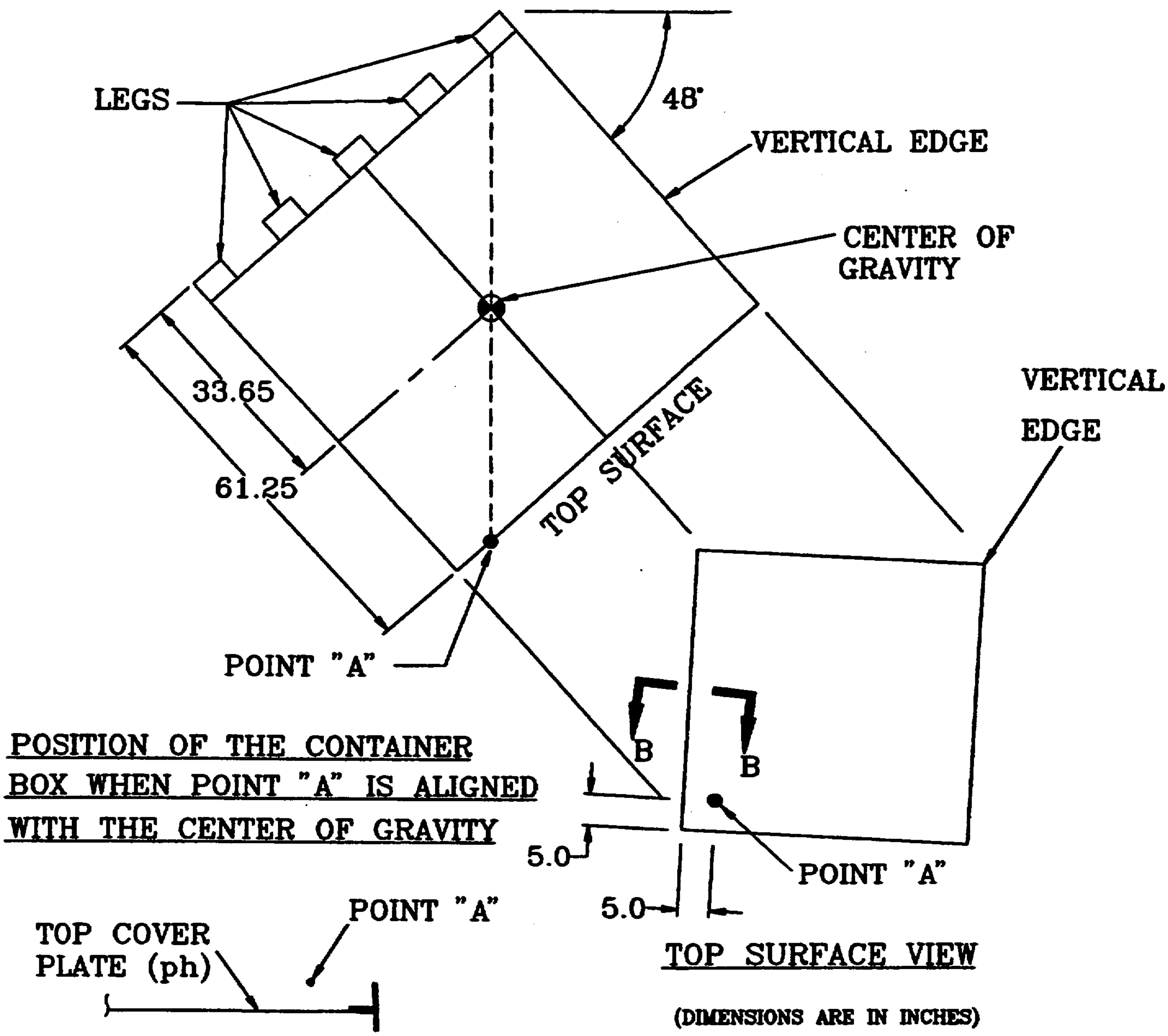
1. APPROX. CONTAINER WT 2275 LBS.
2. ASSUME DENSITIES AS FOLLOWS,
   C/S OR S/S 490 PCF
   PLYWOOD 30 PCF
   SILICON/NEOPRENE 75 PCF
   FIBREX PAPER 45 PCF
   PLUG MATERIAL 14.5 PCF
   URANIUM OXIDE 112.37 PCF
3. WELD MATERIAL WEIGHT IS SMALL AND THEREFORE IT IS NEGLECTED.
4. REF. DRAWING # 71497/50

LAW ENGINEERING
INDUSTRIAL SERVICES
CHARLOTTE, NORTH CAROLINA

ESP-440 SHIPPING CONTAINER BOX
ECO-PAK SPECIALITY PACKING
ELIZABETHTON, TN. 37643

JOB#:10825-7-7094	FIG: 1 OF 2
DRAWN BY: MNP	SCALE: NTS
APPR'D BY: JD [signature]	DATE: 11-17-97

DROP TEST



SECTION B–B

(DIMENSIONS ARE IN INCHES)

NOTES:

1. APPROX. CONTAINER WT 2275 LBS.
2. ASSUME DENSITIES AS FOLLOWS,
   C/S OR S/S 490 PCF
   PLYWOOD 30 PCF
   SILICON/NEOPRENE 75 PCF
   FIBREX PAPER 45 PCF
   PLUG MATERIAL 14.5 PCF
   URANIUM OXIDE 112.37 PCF
3. WELD MATERIAL WEIGHT IS SMALL AND THEREFORE IT IS NEGLECTED.
4. REF. DRAWING # 71497/50

LAW ENGINEERING
INDUSTRIAL SERVICES
CHARLOTTE, NORTH CAROLINA

ESP–440 SHIPPING CONTAINER BOX
ECO–PAK SPECIALITY PACKING
ELIZABETHTON, TN. 37643

JOB#:10825–7–7094	FIG: 1 OF 2
DRAWN BY: MNP	SCALE: NTS
APPR'D BY: JD for DT	DATE: 11–17–97

Appendix 2.10.2

Material and Equipment Specification of ESP-PF-2 Closed-Cell Phenolic Foam and ESP-CFI-1 Ceramic Fiber Insulation

ECO-PAK SPECIALTY PACKAGING
COLUMBIANA, OHIO

SPECIFICATION NO.: ESP-PF-2

PROCEDURE TYPE: MATERIAL AND EQUIPMENT SPECIFICATION

DESCRIPTION: ESP-PF-2 CLOSED-CELL PHENOLIC FOAM SPECIFICATION

This page is a record of revisions to this procedure. Remarks indicate a brief description of the revision and are not a part of the procedure.

REVISION	DATE	AFFECTED PAGE (s)	REMARKS
0	5/25/98	ALL	ORIGINAL
1	9/3/99	ALL	REGULATORY & TECHNICAL ADJUSTMENTS

APPROVALS

QA MANAGER	CBC EXEC VP OF MANUFACTURING OPERATIONS	ESP PRESIDENT

Eco-Pak Specialty Packaging
Material and Equipment Specification
ESP-PF-2
Closed-Cell Phenolic Foam

Scope

This specification shall cover material requirements for the installation of ESP-PF-2 closed-cell phenolic foam with a density range of 6.0-8.0 pounds per cubic foot (pcf) for all nuclear and chemical shipping containers manufactured by Eco-Pak Specialty Packaging, a division of The Columbiana Boiler Company.

Elemental Components

The ESP-PF-1 closed-cell phenolic foam shall have at a minimum the following elemental percentages, each with a tolerance of ± 10%.

Hydrogen	7%
Carbon	58%
Oxygen	32%
Nitrogen	1%
Aluminum	7.5%

BASIC PHYSICAL PROPERTIES

Density

Density measurement of test samples must be performed in accordance with ASTM D-1622. Density measurement of phenolic foam installed in nuclear or chemical packaging will be by simple calculation of the phenolic foam weight divided by the package cavity volume.

Compressive Strength

Testing was performed in accordance with ASTM D-1621, *Compressive Properties of Rigid Cellular Plastics.* The following densities have been tested to obtain a general compressive strength range by two different outside laboratories. Examples of this testing are found in Attachment 1. The compressive strength ranges are as follows:

Density (pcf)	Compressive Strength Range (psi)
6.0	80 - 200
8.0	150 - 300

Foam Glue (Resin & Catalyst)

1. Store in airtight storage containers.
2. Maximum shelf life at an average temperature below 70°F is three (3) months from date of receipt.
3. Maximum shelf life at a temperature of 50°F is six months from date of manufacture.

Note: These dates shall be marked on the storage container or manufacturer's certificates as required.

Temperatures

1. Receptacles and Foam Bun shall be at ambient temperature.
2. The Foam Glue components shall be at ambient temperature prior to mixing.

OPERATING PROCEDURES

See Work Instructions WI-78 for Phenolic Foam Installation.

Red oxide primer (2 mil min.) shall be applied to all surfaces in contact with this foam as specified in Drawing No. OP-TU-SAR, Sheet 1, Note 3, in accordance with Manufacturer's suggested application.

QUALITY ASSURANCE

Production

Prior to production of each product utilizing ESP-PF-2 closed-cell phenolic foam, Quality Assurance or Engineering shall establish the correct weight of the foam materials required to produce the correct density. Quality Assurance shall verify that the density of the foam bun installed in each package is correct when received. QA shall also record the package weight before and after the foam installation and divide the difference by the volume of the foam cavity in order to account for the foam glue.

Records

A foaming record (see Attachment 4 for guideline) must be completed for foam installation of individual packages and shall become a part of the final QA Record. This record shall include at a minimum: foam components, weights before and after foaming, and QA verifications.

The fabricator will also keep all records from the independent laboratory verifying the chloride content of the phenolic resin and the random yearly analysis of the phenolic foam. This is for verification that the overall chloride content of the phenolic foam is below 200 ppm.

ATTACHMENTS

1. Compressive Strength Test Reports
2. Test Reports for Thermal Conductivity, Flame Retardancy, Specific Heat and Water Absorption
3. Sample Chloride Analysis
4. Sample Foam Installation Record

ATTACHMENT 1

Compressive Strength Test Reports

LAW ENGINEERING INDUSTRIAL SERVICES

A DIVISION OF LAW ENG & ENV. SVCS., INC.
2801 YORKMONT ROAD, SUITE 200 • CHARLOTTE, N.C. 28208
P.O. BOX 19667 • CHARLOTTE, N.C. 28219-9667
PHONE 704-357-8600 •FAX 704-357-8637

ECO-PAK SPECIALTY PACKAGING
Laboratory Testing, ASTM D 1621-94
Law Engineering Industrial Services Project 10810-8-7008 Phase 09
Purchase Order Number 5032
August 4, 1998

Low Density Samples

SAMPLE ID+	MASS (lbs)	VOLUME (ft^3)	DENSITY (lbs/ft^3)	PEAK LOAD(lbs)	AREA (in^2)	COMPRESSIVE STRENGTH(psi)
A	0.0326	0.0049	6.65	393.45	4.00	98.36
B	0.0314	0.0050	6.28	399.17	4.24	94.07
C	0.0294	0.0047	6.26	341.72	4.06	84.18
D	0.0310	0.0049	6.33	513.61	4.14	124.06
E	0.0308	0.0049	6.29	496.14	4.12	120.47
F	0.0298	0.0048	6.21	477.91	4.03	118.53

Rate = 0.200 in/min
Preload = 1.00 lbs

\+ Sample I.D. Nos. arbitrarily assigned by LEIS

Respectfully submitted,

Lakshman Santanam
Charlotte Technical Center Manager

LAW ENGINEERING INDUSTRIAL SERVICES

A DIVISION OF LAW ENG. & ENV. SVCS., INC.

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P.O. BOX 19667 • CHARLOTTE, N.C. 28219-9667
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ECO-PAK SPECIALTY PACKAGING
Laboratory Testing, ASTM D 1621-94
Law Engineering Industrial Services Project 10810-8-7008 Phase 04
March 18, 1998

High Density Samples
(Direction 2)

TEST TEMP.	SAMPLE ID+	MASS (lbs)	VOLUME (ft^3)	DENSITY (lbs/ft^3)	PEAK LOAD(lbs)	AREA (in^2)	COMPRESSIVE STRENGTH(psi)
100°F	BB	0.0390	0.0049	8.04	645.60	4.01	160.86
100°F	CC	0.0388	0.0047	8.20	659.34	3.91	168.75
100°F	DD	0.0374	0.0048	7.82	591.42	4.03	146.88
74°F	EE	0.0382	0.0048	7.93	652.47	3.99	163.66
74°F	FF	0.0370	0.0046	8.03	686.81	3.89	176.40
74°F	GG	0.0374	0.0048	7.87	655.53	4.01	163.34
-20°F	HH	0.0376	0.0048	7.83	727.26	4.01	181.21
-20°F	II	0.0386	0.0049	7.93	760.84	4.01	189.90
-20°F	JJ	0.0378	0.0048	7.88	815.78	3.99	204.63

+ Sample I.D. Nos. arbitrarily assigned by LEIS

Respectfully submitted,

Lakshman Santanam
Charlotte Technical Center Manager

ATTACHMENT 3

Sample Chloride Analysis

LAW ENGINEERING (DUSTRIAL SERVICES
A DIVISION OF LAW ENG. & ENV. SVCS., INC.
2801 YORKMONT ROAD, SUITE 200 • CHARLOTTE, NC 28208
P.O. BOX 19667 • CHARLOTTE, NC 28219-9667
PHONE 704-357-8600 •FAX 704-357-8637

REPORT OF CHEMICAL ANALYSIS

Client: ECO-PAK SPECIALTY PACKAGING
Division of CBCo
125 Iodent Way
Elizabethton, TN 37643
Attn: Ms. Heather Little

Project: General
Office: LEIS Charlotte
Lab No.: 10810-8-7008 Phase 09
Page 1 of 1
Date: August 10, 1998

Client P.O. No.: 5032
Material: Reported as Client Submitted Foam Sample ESP-PF-2
Lot No.: Not Reported
Date Tested: Completed August 10, 1998
Procedure: In accordance with Client's Instructions and general accordance with Standard Laboratory Practices for Analytical Techniques.

Test Results (mg/kg)

LEIS Piece No.	Total Halogens as Chlorides	Leachable Halogens as Chlorides	Sulfates	pH	Comments
7-29-98-1Ce1	65.2	45.0	273	2.81	Foam Sample

Reviewed by: [signature]
Lakshman Santanam
Technical Center Manager

Respectfully submitted,
LAW ENGINEERING INDUSTRIAL SERVICES

[signature]
Larry Coble, Technical Leader

ATTACHMENT 4

Sample Foam Installation Record

Eco-Pak Specialty Packaging
OP-TU Installation Record
for the ESP-PF-2 Phenolic Foam Insulation

Serial No.________________________ Date________________________

Materials	Dimensions (in.)	Weight (lbs)	Manufacturer/Product	Lot or Batch No.
Foam Bun				
Foam Glue				

CONTAINER WEIGHTS (LBS)

Weight Before Installation: ______________

Weight After Installation: ______________

TOTAL FOAM WEIGHT: ______________

Operator____

Inspected by QA____

Eco-Pak Specialty Packaging
OP-VA Installation Record
for the ESP-PF-2 Phenolic Foam Insulation

Serial No.____________________ Date____________________

Materials	Dimensions (in.)	Weight (lbs)	Manufacturer/Product	Lot or Batch No.
Foam Tube				

VESSEL WEIGHTS (LBS)

Weight Before Installation: ____________

Weight After Installation: ____________

TOTAL FOAM WEIGHT: ____________

Operator____

Inspected by QA______________________________________

ECO-PAK SPECIALTY PACKAGING
ELIZABETHTON, TN

SPECIFICATION NO.: ESP-CFI-1

PROCEDURE TYPE: MATERIAL AND EQUIPMENT SPECIFICATION

DESCRIPTION: ESP-CFI-1 CERAMIC FIBER INSULATION SPECIFICATION

This page is a record of revisions to this procedure. Remarks indicate a brief description of the revision and are not a part of the procedure.

REVISION	DATE	AFFECTED PAGE (s)	REMARKS
0	5/25/98	ALL	ORIGINAL

APPROVALS

QA MANAGER	CBC EXEC VP OF MANUFACTURING OPERATIONS	ESP PRESIDENT

Eco-Pak Specialty Packaging
Material and Equipment Specification
ESP-CFI-1
Ceramic Fiber Insulation

SCOPE

This specification shall cover the material requirements for the installation of both ceramic fiber paper and board insulation for the Eco-Pak® OP Transport Unit.

BASIC PHYSICAL PROPERTIES

Paper

Ceramic Fiber Paper shall meet the basic physical properties as listed below.

Density = 10-12 lbs/ft^3
Thickness = 0.13 in. (3 mm)
Thermal Conductivity = 1.26 ± 0.05 Btu-in/hr-ft^2°F at 2000°F

Board

Ceramic Fiber Board shall meet the basic physical properties as listed below.

Density = 15-18 lbs/ft^3 (242-290 kg/m^3)
Thickness = 0.25 in. (6 mm)
Thermal Conductivity = 1.53 ± 0.05 Btu-in/hr-ft^2°F at 1800°F

STORAGE REQUIREMENTS

Store the Ceramic Fiber Paper and Board insulation in area with relatively low humidity at ambient temperature.

OPERATING PROCEDURES

See SOP 6.12.

QUALITY ASSURANCE

Production

Quality Assurance shall verify that the density and thickness of the ceramic fiber insulation is correct when received and prior to installation.

Records

A ceramic fiber insulation installation record (Attachment 4) must be completed for each individual package and shall become a part of the final QA Record. This record shall include at a minimum: verification of density and thickness and verification that each required piece of insulation was installed.

ATTACHMENTS

1. Product Specification including the basic physical properties
2. Ceramic Fiber Insulation Installation Record

Eco-Pak Specialty Packaging
OP-TU Installation Record
for the ESP-CFI-1 Ceramic Fiber Insulation

I. Ceramic Fiber Paper

OP-TU Serial No.	Dimensions (in.)	Manufacturer/Product	Lot or Batch No.

II. Ceramic Fiber Board

OP-TU Serial No.	Dimensions (in.)	Manufacturer/Product	Lot or Batch No.

Appendix 2.10.3

Law Engineering Report on Charpy "V" Impact Tests and Comparative Tests on ESP-PF-2 Foam Samples

LAW ENGINEERING INDUSTRIAL SERVICES
A DIVISION OF LAW ENG. & ENV. SVCS., INC.
2801 YORKMONT ROAD, SUITE 200 • CHARLOTTE, NC 28208
P.O. BOX 19667 • CHARLOTTE, NC 28219-9667
PHONE 704-357-8600 •FAX 704-357-8637

REPORT OF CHARPY "V" IMPACT TEST

Client: ECO-PAK SPECIALTY PACKAGING
Division of CBC
125 Iodent Way
Elizabethton, TN 37643
Attn: Mr. Mike Aronold

Project: General
Office: LEIS Charlotte
Lab No.: 10810-8-7008 Ph04

Date: March 13, 1998

Client P.O. No.: Not Reported
Material: Reported as 6" Square X 1/2" Thick Plate Sample, ASTM A-36
Heat/Lot No.: Reported and Marked as JA8495
Date Tested: Completed March 13, 1998
Specimen Size: 10mm (0.394") X 10mm (0.394" - Full Size)
Test Temperature: See Below
Procedure: In accordance with Client's Instructions and ASTM A370-92

Test Results

Leis Piece No.	Impact Strength (ft. lbs.)	Lateral Expansion (in.)	Percent Shear (%)	Comments
[illegible]7-98-1CB1	125	0.092	*	+100°F
[illegible]-27-98-1CB2	125	0.097	*	"
2-27-98-1CB3	125	0.093	*	"
2-27-98-1CB4	99	0.079	60	+67°F
2-27-98-1CB5	90	0.075	60	"
2-27-98-1CB6	98	0.079	70	"
2-27-98-1CB7	11	0.015	0	-20°F
2-27-98-1CB8	16	0.020	0	"
2-27-98-1CB9	21	0.027	0	"

*Specimen did not break. Unable to determine shear.

Respectfully Submitted,
LAW ENGINEERING INDUSTRIALS SERVICES

Reviewed By:
Lakshman Santanam
Technical Center Manager

Larry Coble, Technical Leader

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A DIVISION OF LAW ENG. & ENV. SVCS., INC.
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PHONE 704-357-8600 •FAX 704-357-8637

REPORT OF CHARPY "V" IMPACT TESTING

Client: ECO-PAK SPECIALTY PACKAGING
Division of CBC
125 Iodent Way
Elizabethton, TN 37643
Attn: Mr. Mike Aronold

Project: General
Office: LEIS Charlotte
Lab No.: 10810-8-7008 Ph04

Date: March 13, 1998

Client P.O. No.: Not Reported
Material: Reported as 6" Square X 1/2" Thick Plate Sample, ASTM A-572, Gr 50 Type 2
Heat/Lot No.: Reported and Marked as 422X1291
Date Tested: Completed March 13, 1998
Specimen Size: 10mm (0.394") X 10mm (0.394" - Full Size)
Test Temperature: See Below
Procedure: In accordance with Client's Instructions and ASTM A370-92

Test Results

T 's ce No.	Impact Strength (ft. lbs.)	Lateral Expansion (in.)	Percent Shear (%)	Comments
2-27-98-2CB1	111	0.080	25	+100°F
2-27-98-2CB2	110	0.075	30	"
2-27-98-2CB3	116	0.082	25	"
2-27-98-2CB4	116	0.078	80	+67°F
2-27-98-2CB5	109	0.074	75	"
2-27-98-2CB6	121	0.076	70	"
2-27-98-2CB7	111	0.037	25	-20°F
2-27-98-2CB8	110	0.033	25	"
2-27-98-2CB9	112	0.030	25	"

Respectfully Submitted,
LAW ENGINEERING INDUSTRIALS SERVICES

Reviewed By: Lakshman Santanam
Technical Center Manager

Larry Goble, Technical Leader

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PHONE 704-357-8600 •FAX 704-357-8637

REPORT OF CHARPY "V" IMPACT TESTING

Client: ECO-PAK SPECIALTY PACKAGING
Division of CBC
125 Iodent Way
Elizabethton, TN 37643
Attn: Mr. Mike Aronold

Project: General
Office: LEIS Charlotte
Lab No.: 10810-8-7008 Ph04
Page 1 of 1
Date: March 13, 1998

Client P.O. No.: Not Reported
Material: Reported as 6" Square X 13GA Thick Sheet Sample, ASTM A-569
Heat/Lot No.: Reported and Marked as 9708488
Date Tested: Completed March 13, 1998
Specimen Size: 10mm (0.394") X 2.5mm (0.099" - Subsize)
Test Temperature: See Below
Procedure: In accordance with Client's Instructions and ASTM A370-92

Test Results

Leis Piece No.	Impact Strength (ft. lbs.)	Lateral Expansion (in.)	Percent Shear (%)	Comments
[illegible]7-98-3CB1	20	0.048	50	+100°F
[illegible]-27-98-3CB2	19	0.046	60	"
2-27-98-3CB3	19	0.045	60	"
2-27-98-3CB4	21	0.045	70	+67°F
2-27-98-3CB5	22	0.046	70	"
2-27-98-3CB6	21	0.046	70	"
2-27-98-3CB7	21	0.045	50	-20°F
2-27-98-3CB8	21	0.051	50	"
2-27-98-3CB9	20	0.048	50	"

Reviewed By: [signature]
Lakshman Santanam
Technical Center Manager

Respectfully Submitted,
LAW ENGINEERING INDUSTRIALS SERVICES

[signature]
Larry Coble, Technical Leader

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ECO-PAK SPECIALTY PACKAGING
Laboratory Testing, ASTM D 1621-94
Law Engineering Industrial Services Project 10810-8-7008 Phase 04
March 18, 1998

Low Density Samples
(Direction 1)

TEST TEMP.	SAMPLE ID+	MASS (lbs)	VOLUME (ft^3)	DENSITY (lbs/ft^3)	PEAK LOAD(lbs)	AREA (in^2)	COMPRESSIVE STRENGTH(psi)
100°F	A	0.0322	0.0050	6.48	658.58	4.19	157.22
100°F	B	0.0320	0.0050	6.40	641.79	4.19	153.21
100°F	C	0.0320	0.0050	6.46	615.84	4.20	146.78
74°F	D	0.0322	0.0047	6.85	673.84	4.13	162.98
74°F	E	0.0314	0.0049	6.43	623.47	4.12	151.30
74°F	F	0.0326	0.0049	6.69	628.05	4.15	151.41
-20°F	G	0.0318	0.0049	6.44	647.13	4.17	155.25
-20°F	H	0.0322	0.0049	6.53	639.97	4.18	153.28
-20°F	I	0.0314	0.0048	6.54	615.08	4.05	152.01

+ Sample I.D. Nos. arbitrarily assigned by LEIS

Respectfully submitted,

Lakshman Santanam
Charlotte Technical Center Manager

LAW ENGINEERING INDUSTRIAL SERVICES

A DIVISION OF LAW ENG. & ENV. SVCS., INC.

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PHONE 704-357-8600 •FAX 704-357-8637

ECO-PAK SPECIALTY PACKAGING
Laboratory Testing, ASTM D 1621-94
Law Engineering Industrial Services Project 10810-8-7008 Phase 04
March 18, 1998

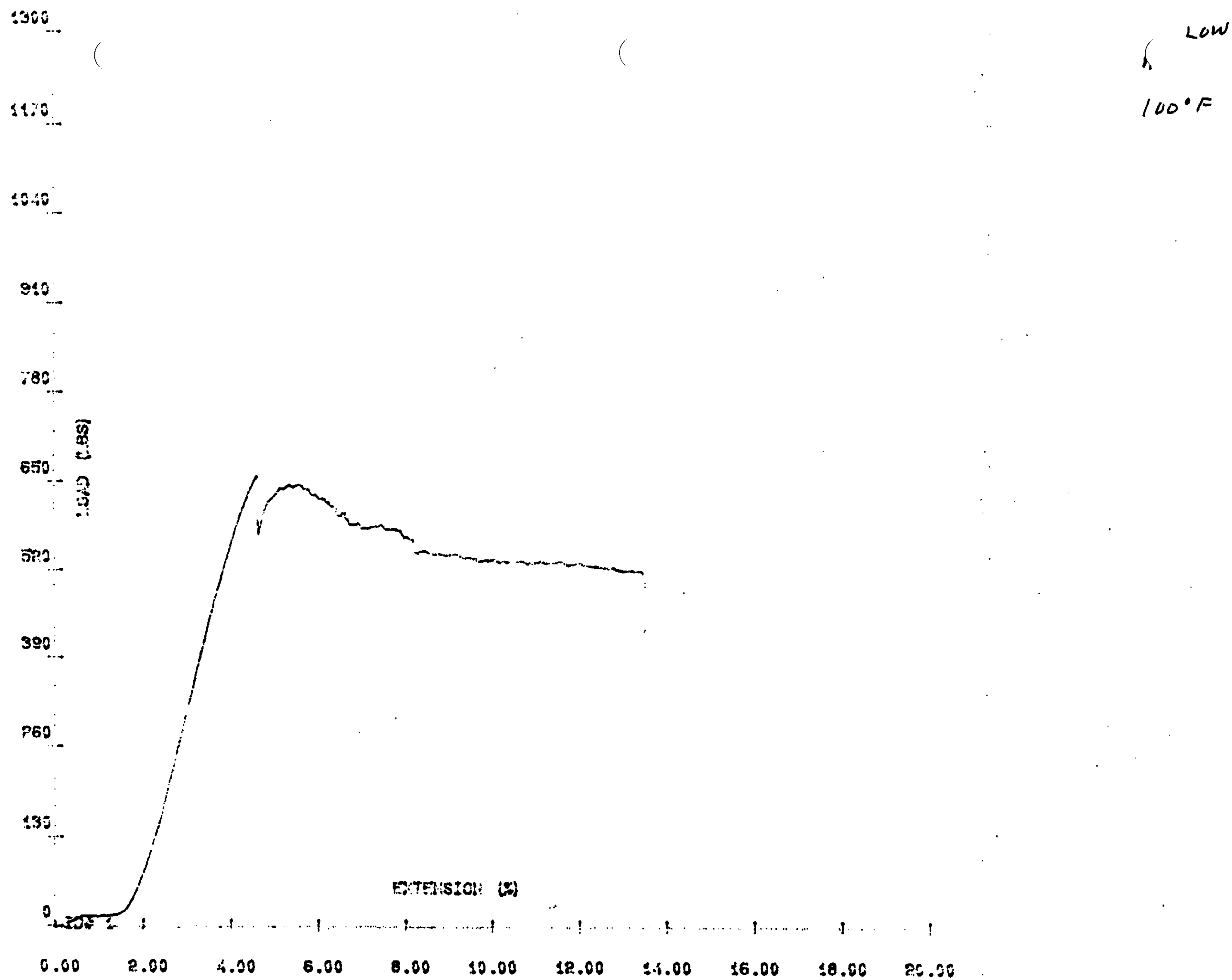
Low Density Samples
(Direction 2)

TEST TEMP.	SAMPLE ID+	MASS (lbs)	VOLUME (ft^3)	DENSITY (lbs/ft^3)	PEAK LOAD(lbs)	AREA (in^2)	COMPRESSIVE STRENGTH(psi)
100°F	J	0.0314	0.0049	6.41	457.11	4.20	108.79
100°F	K	0.0322	0.0049	6.58	425.06	4.05	105.04
100°F	L	0.0324	0.0051	6.40	439.56	4.19	104.98
74°F	M	0.0310	0.0047	6.54	403.69	4.07	99.10
74°F	N	0.0310	0.0048	6.53	411.33	3.93	104.60
74°F	O	0.0302	0.0046	6.51	425.82	3.97	107.19
-20°F	P	0.0300	0.0047	6.42	438.80	4.02	109.17
-20°F	Q	0.0322	0.0048	6.68	439.56	3.99	110.08
-20°F	R	0.0344	0.0049	7.09	486.87	4.09	118.95

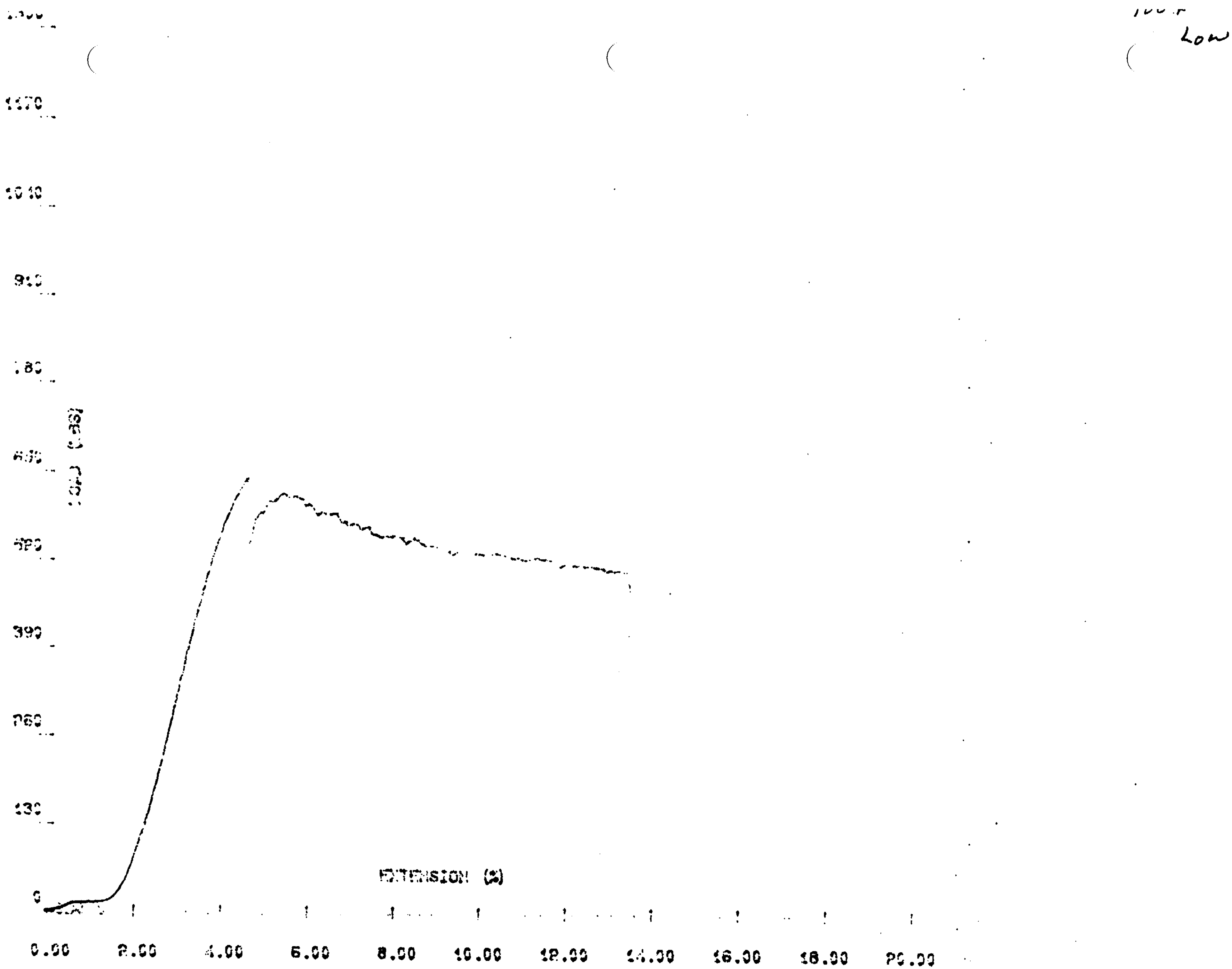
+ Sample I.D. Nos. arbitrarily assigned by LEIS

Respectfully submitted,

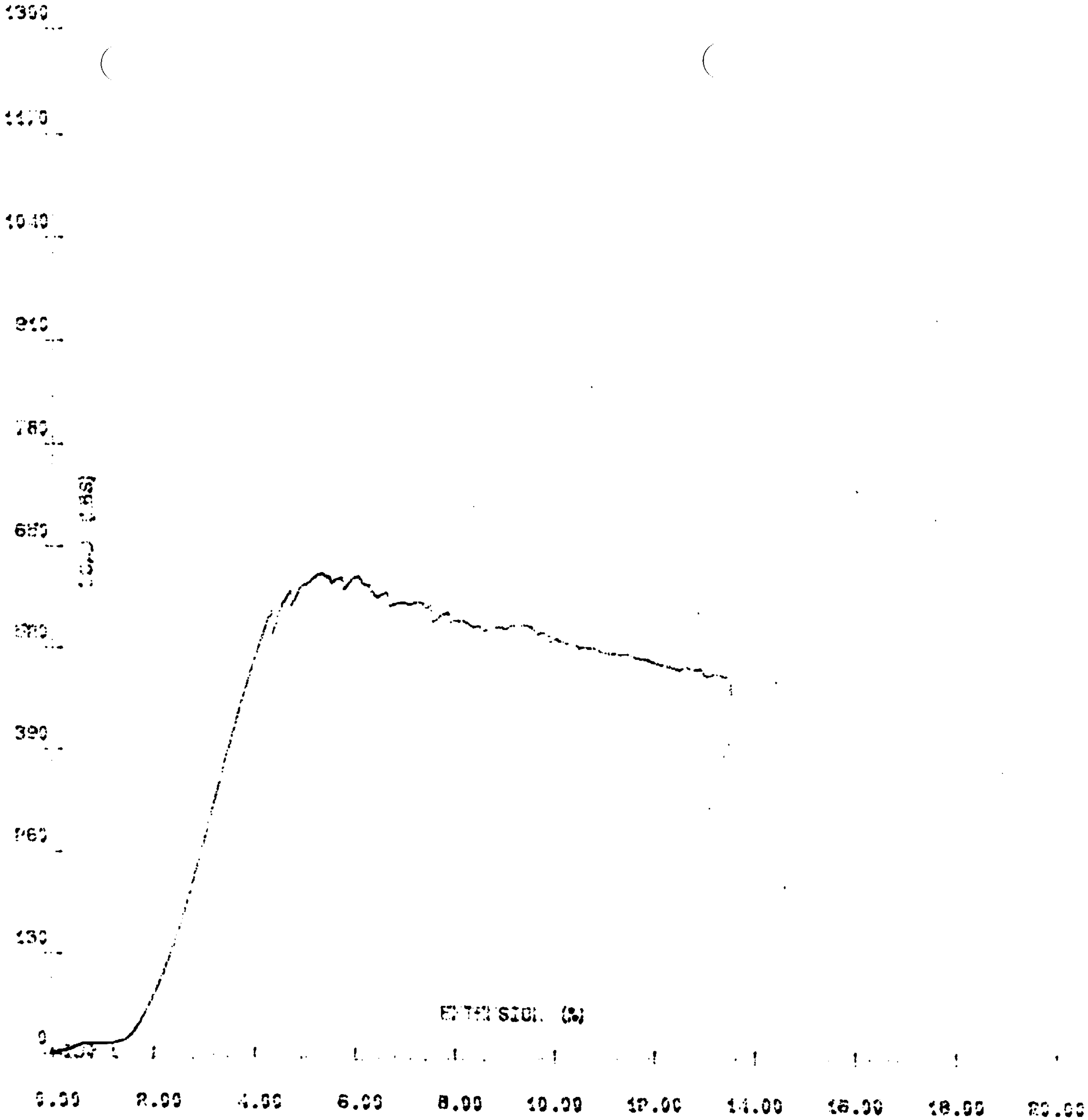
Lakshman Santanam
Charlotte Technical Center Manager



LOW
100°F
1300
1170
1040
910
780
650
520
390
260
130
0
LOAD (LBS)
EXTENSION (%)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

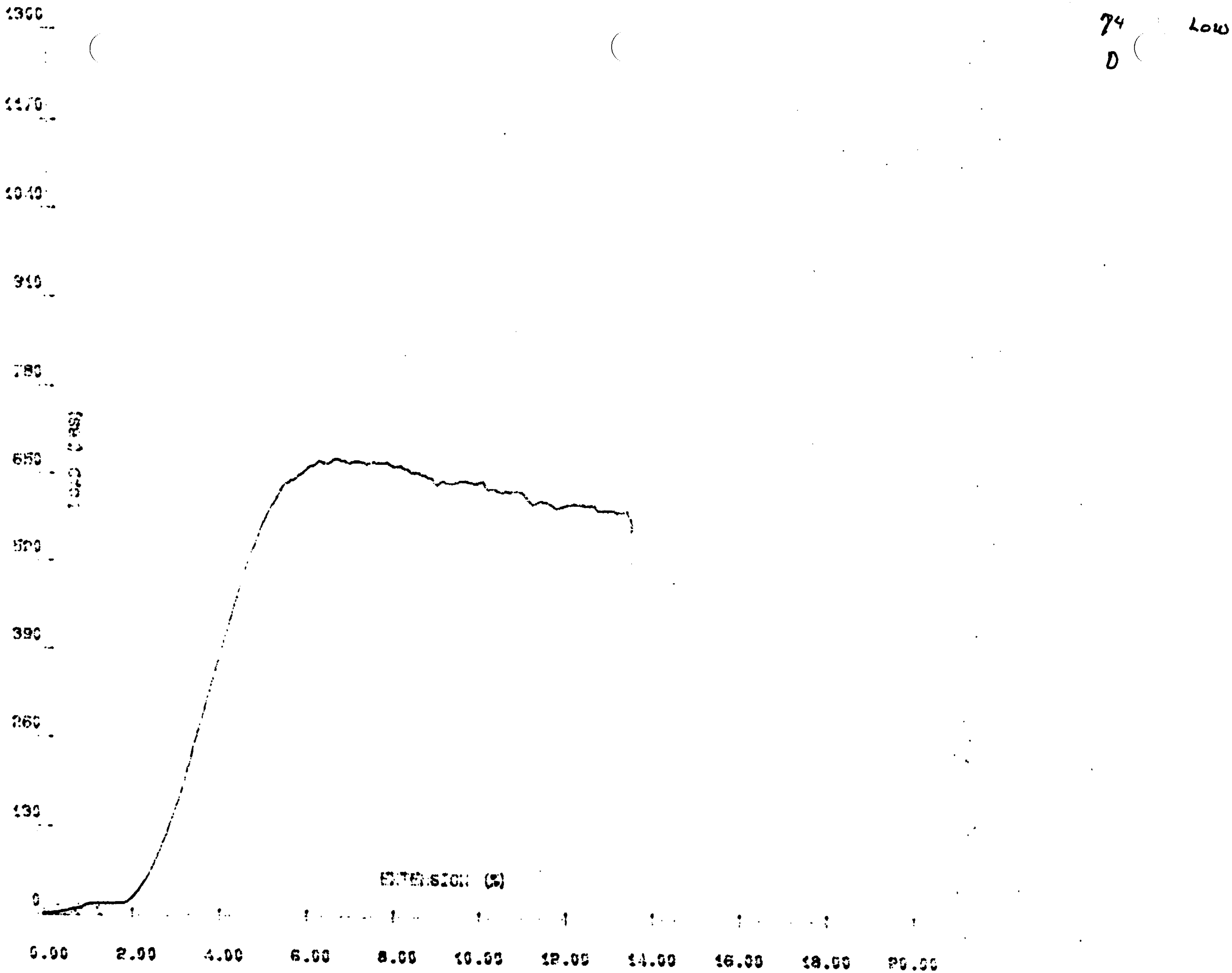


1170
1040
910
390
260
130
0
EXTENSION (%)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
Low



LOAD (LBS)
EXTENSION (%)
0
130
260
390
520
650
780
910
1040
1170
1300
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

Low


74
D
Low
1300
1170
1040
910
780
650
520
390
260
130
0
EXTENSION (%)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

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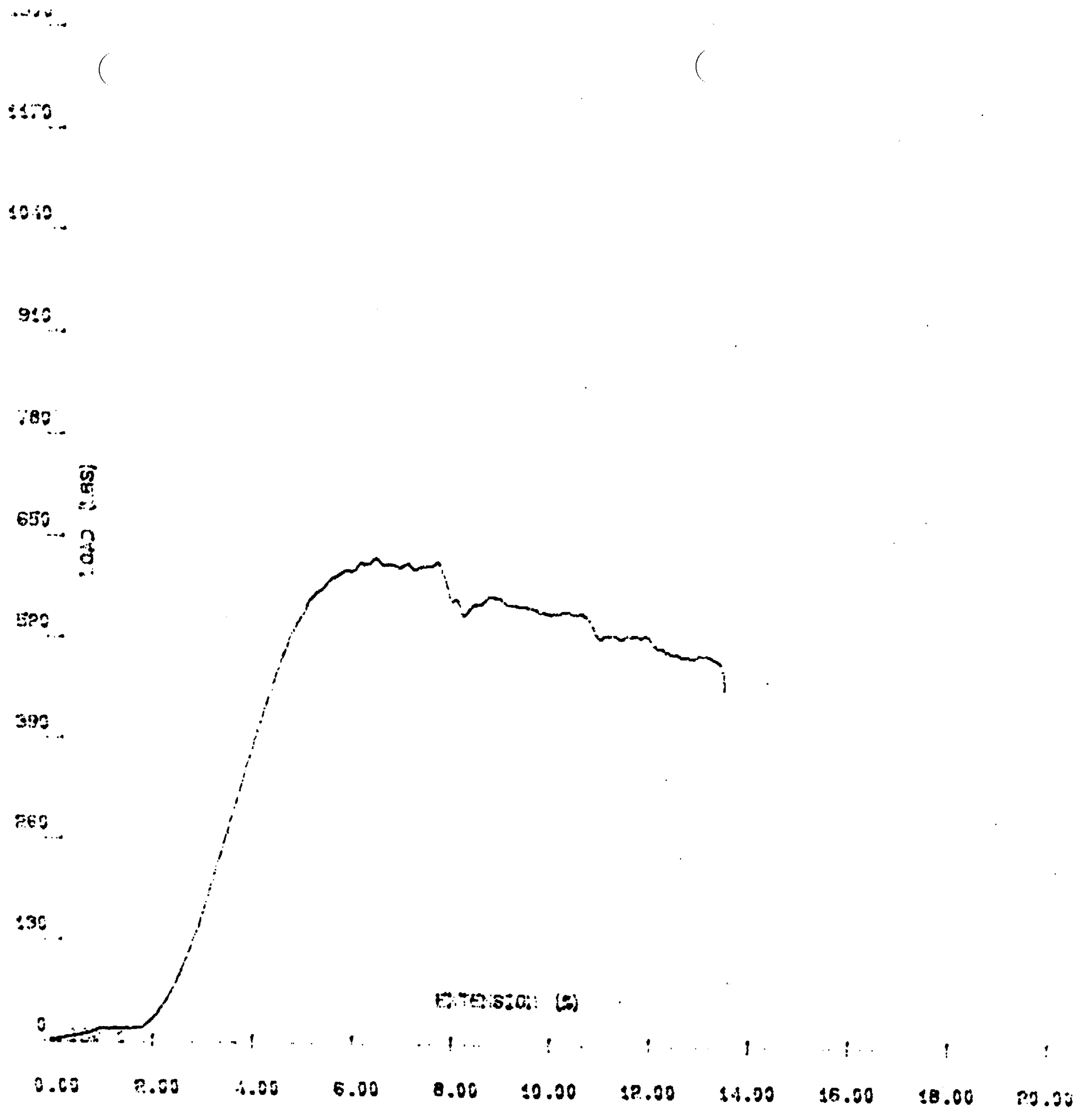
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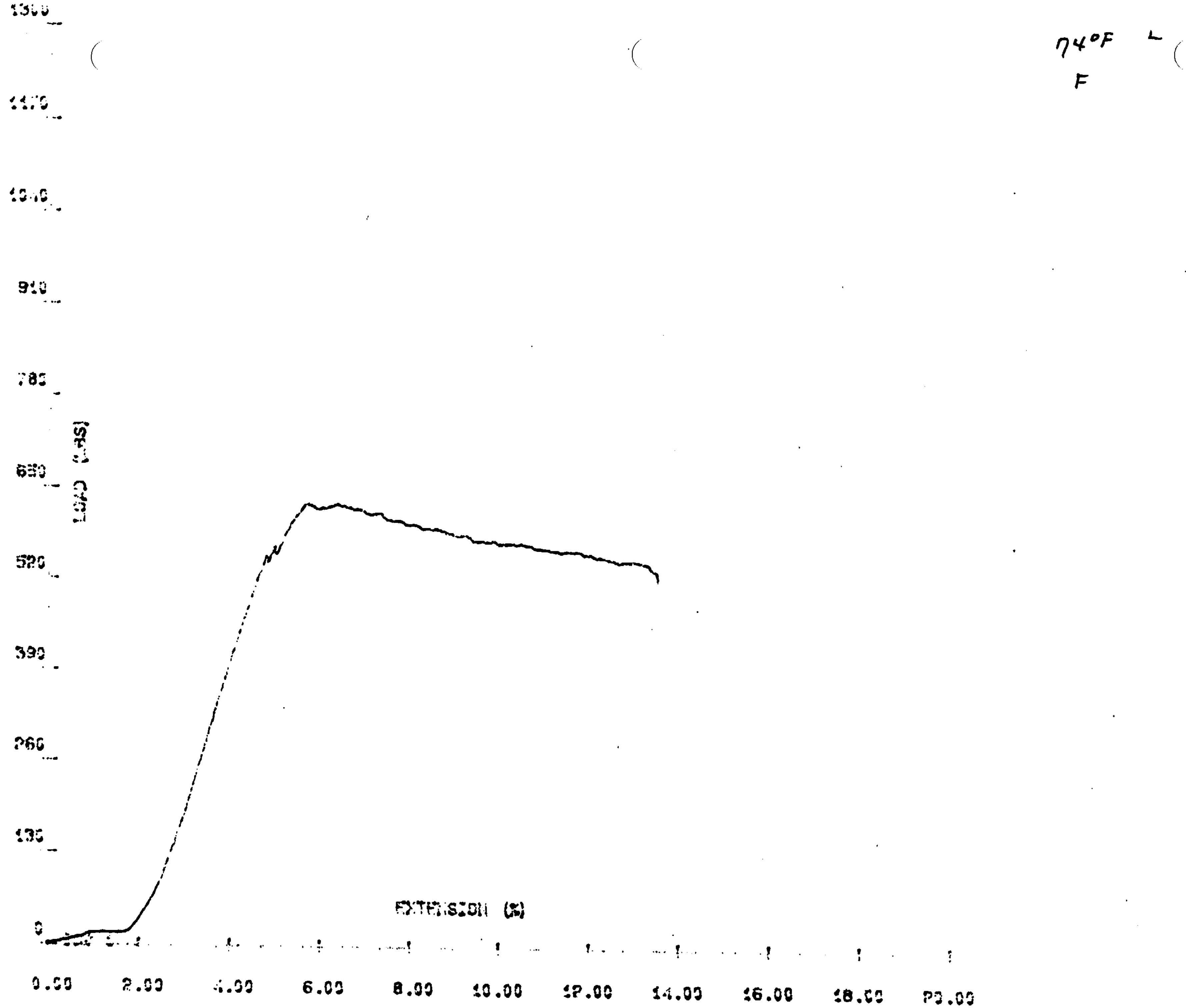
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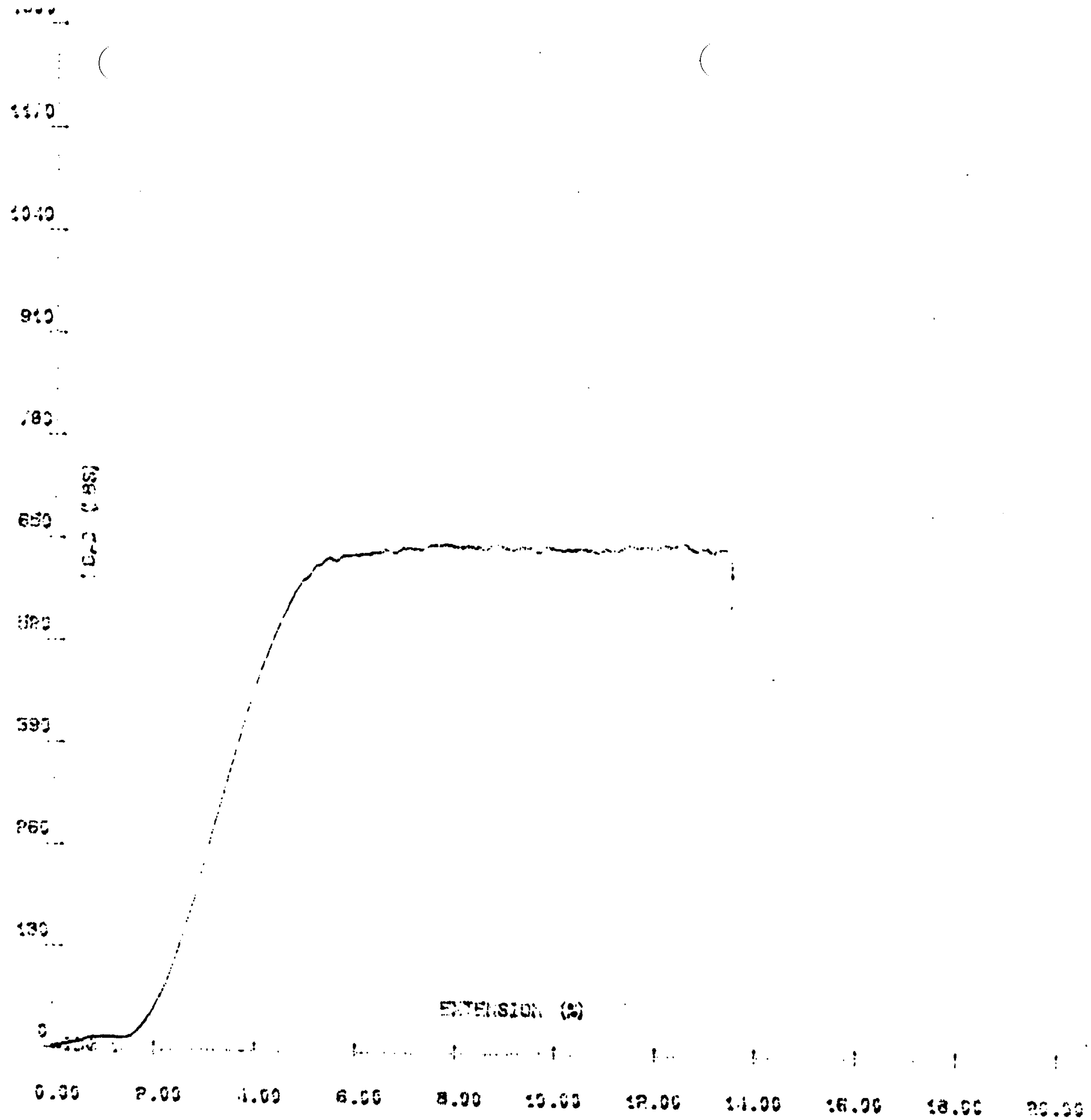

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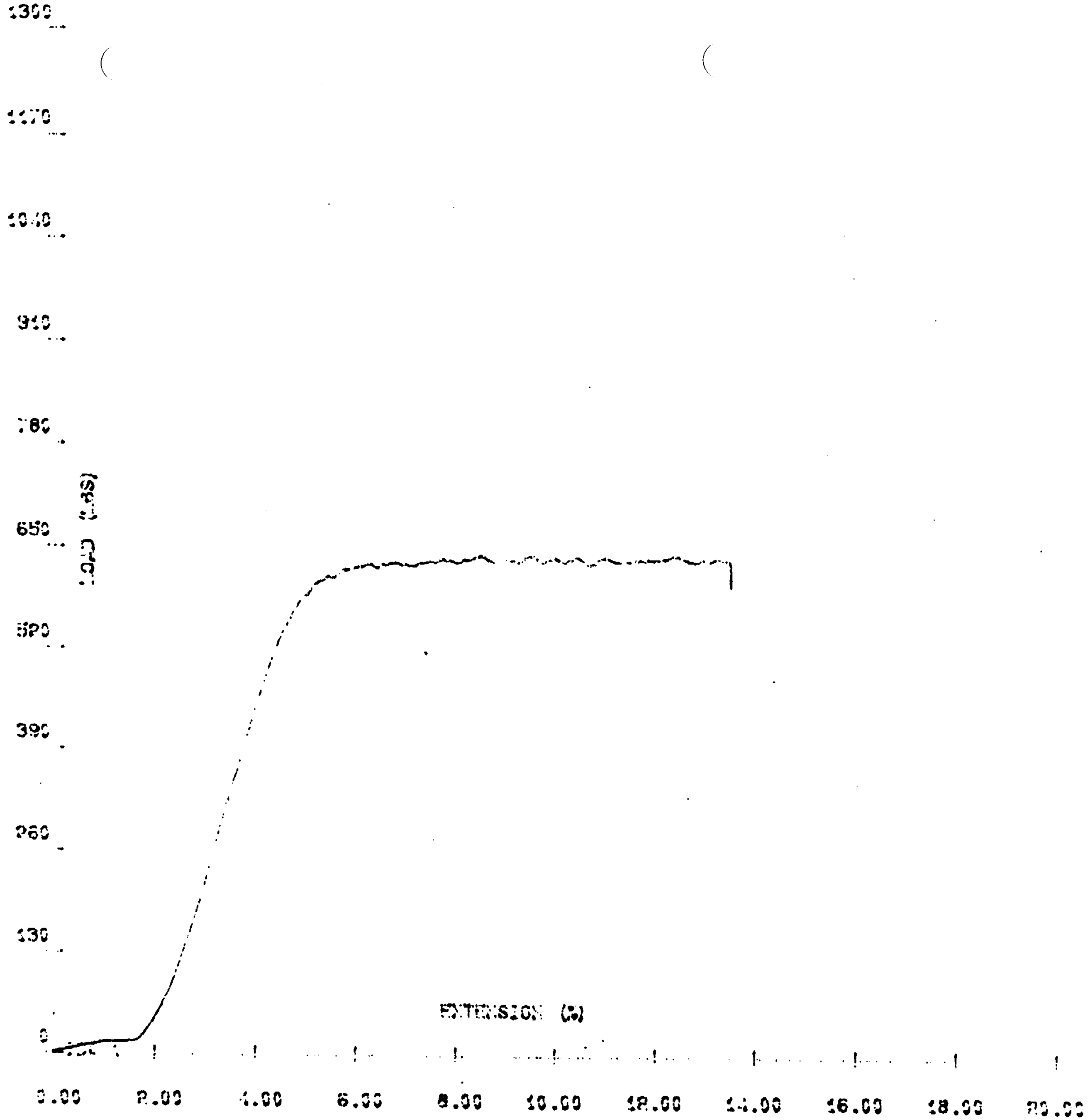

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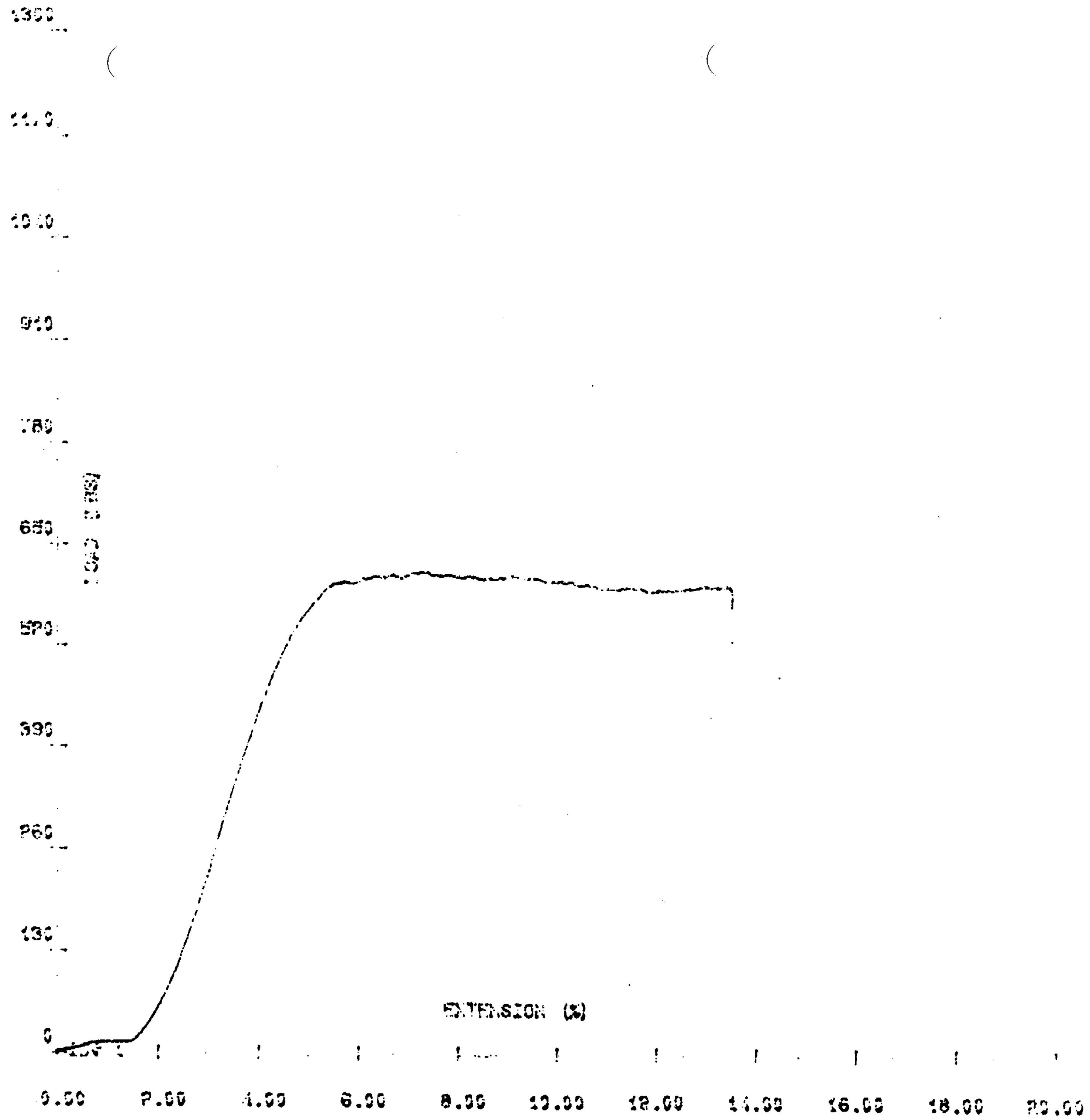

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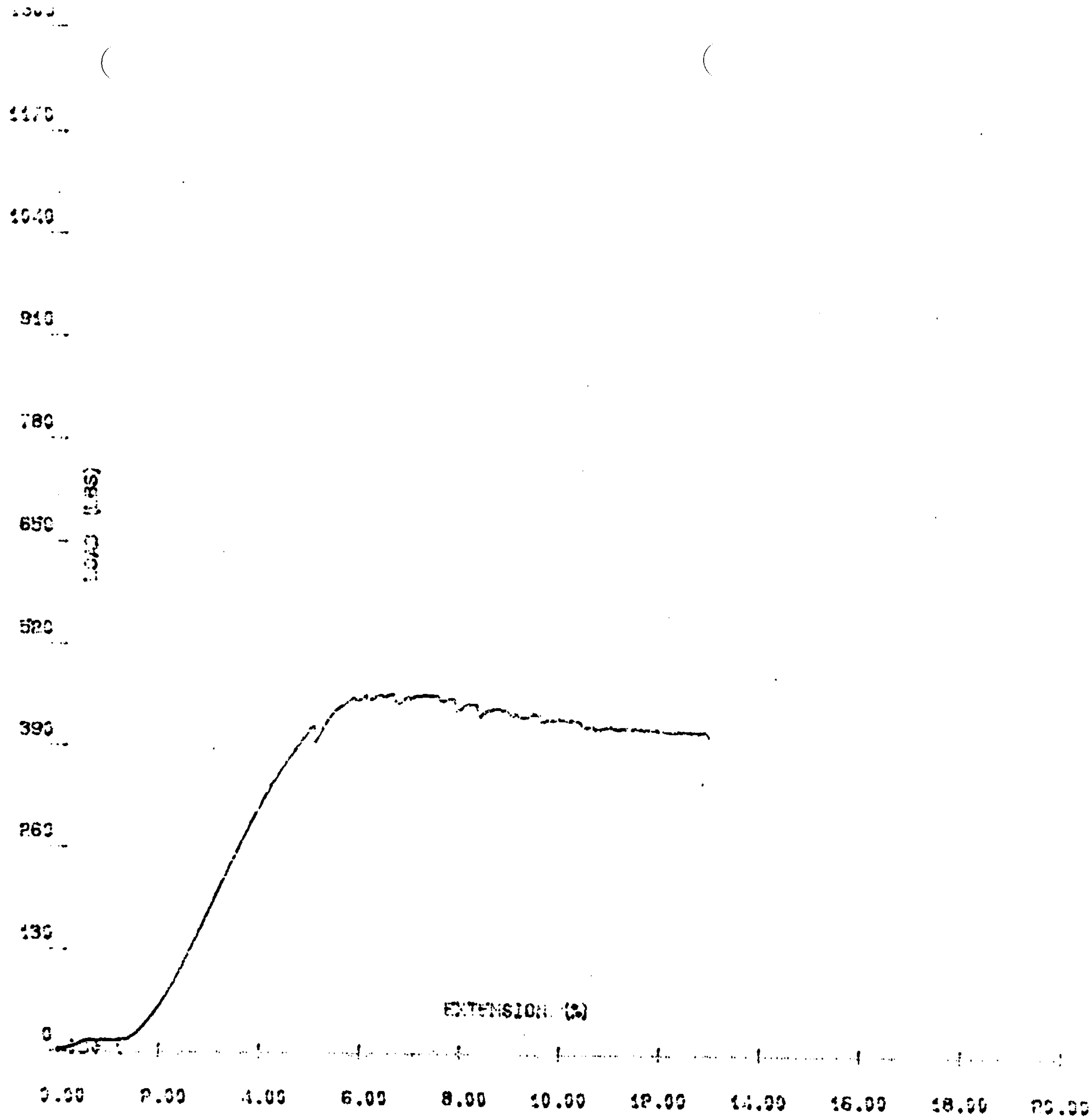
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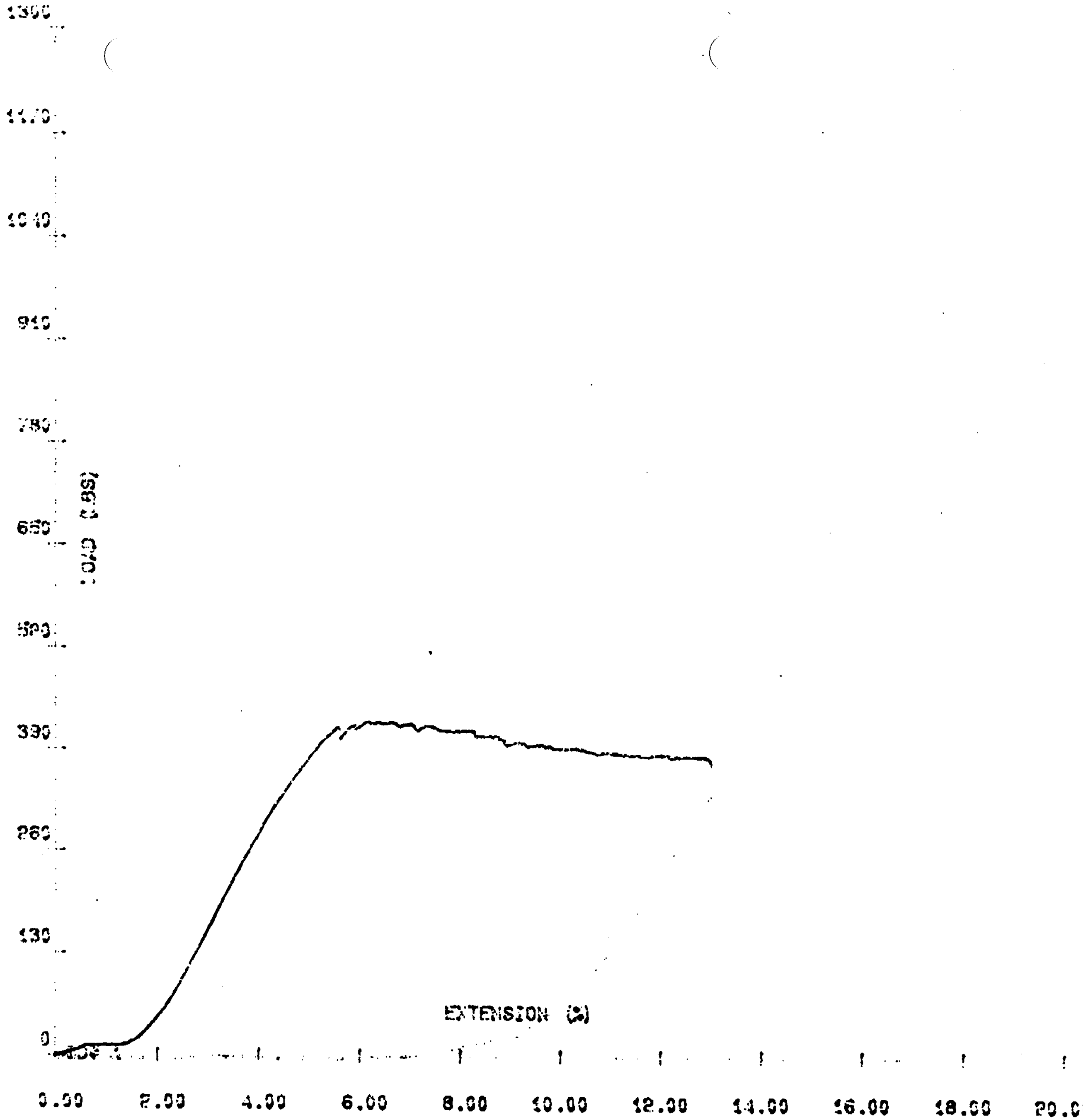
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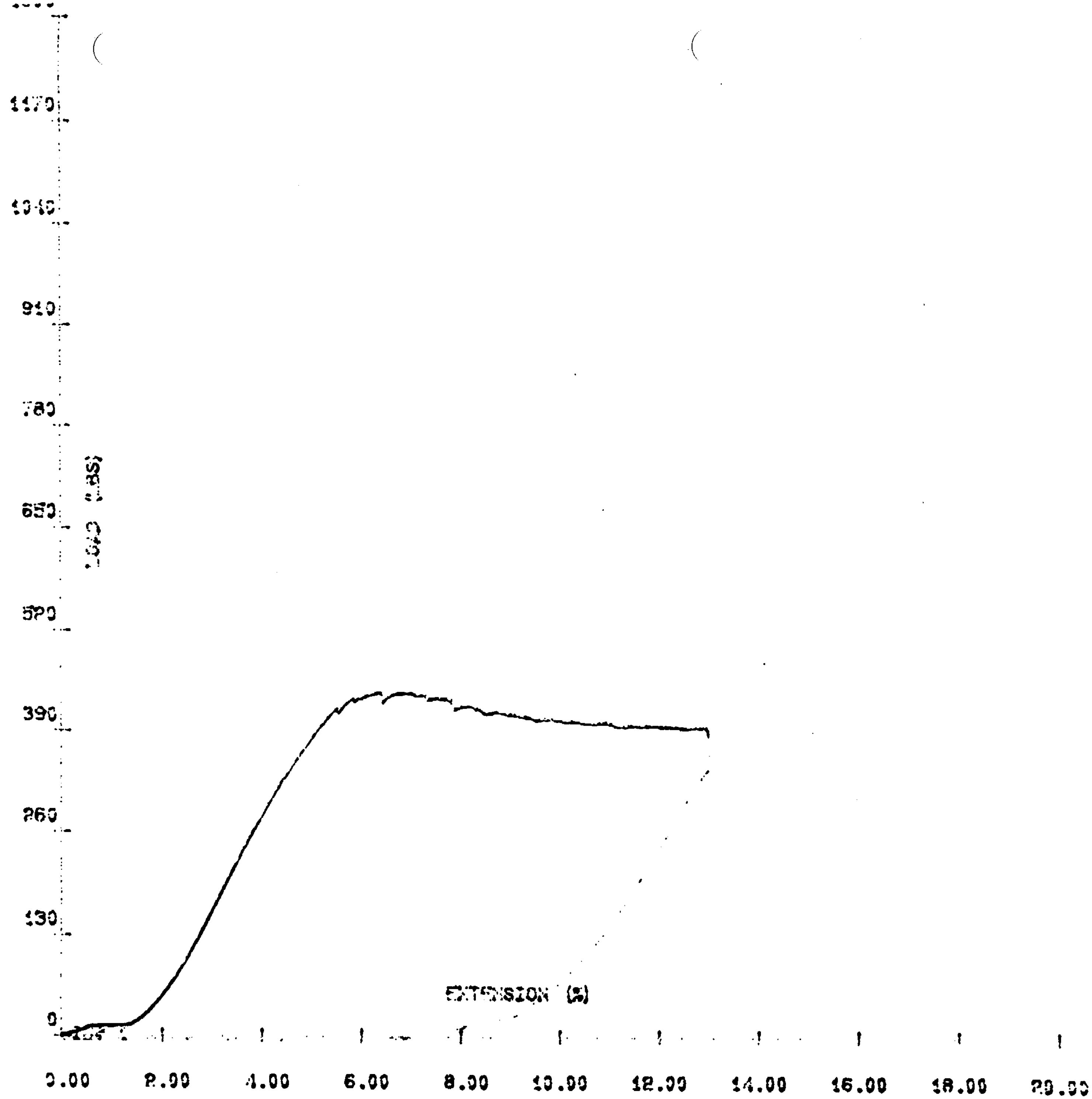

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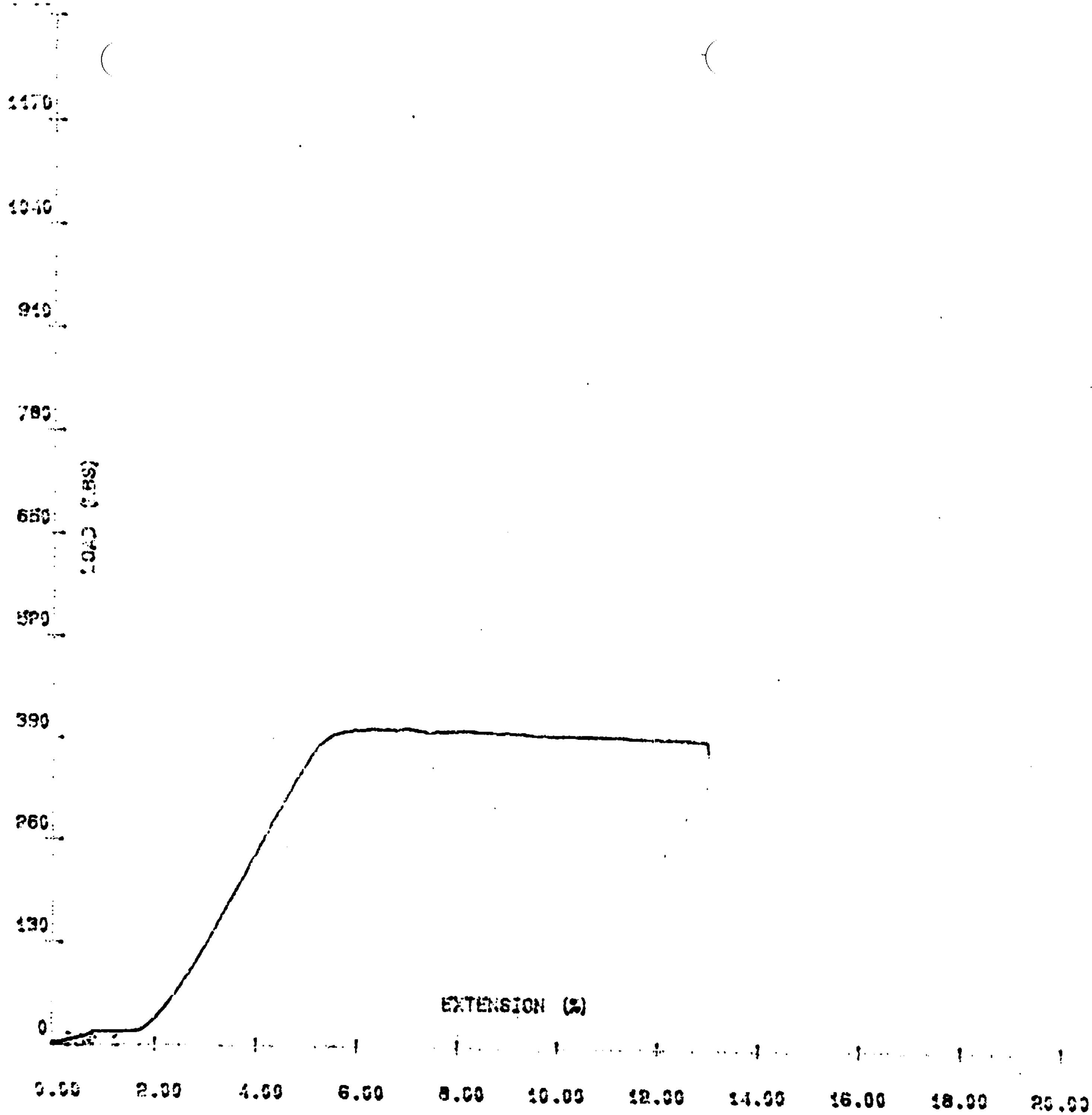

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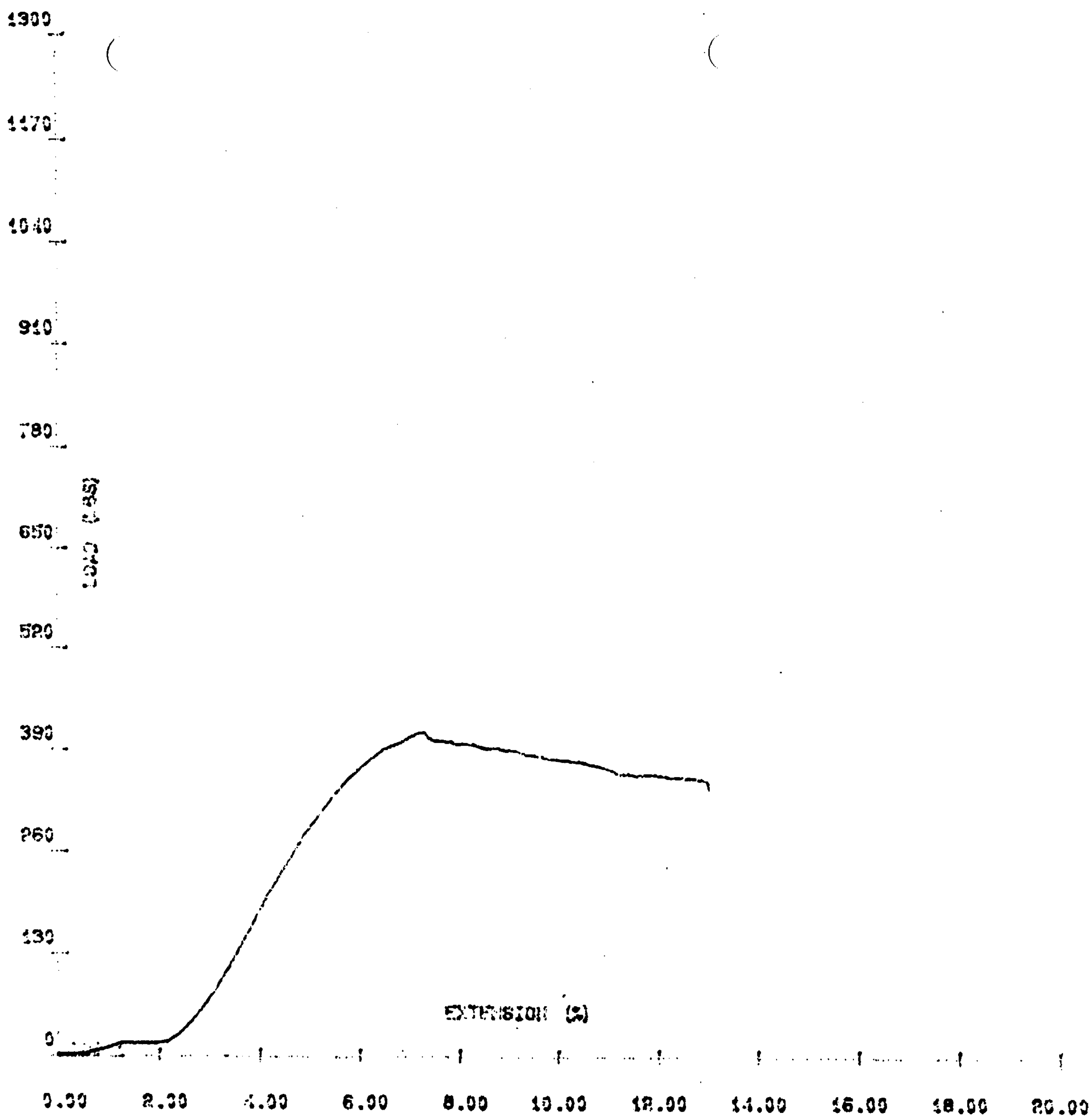
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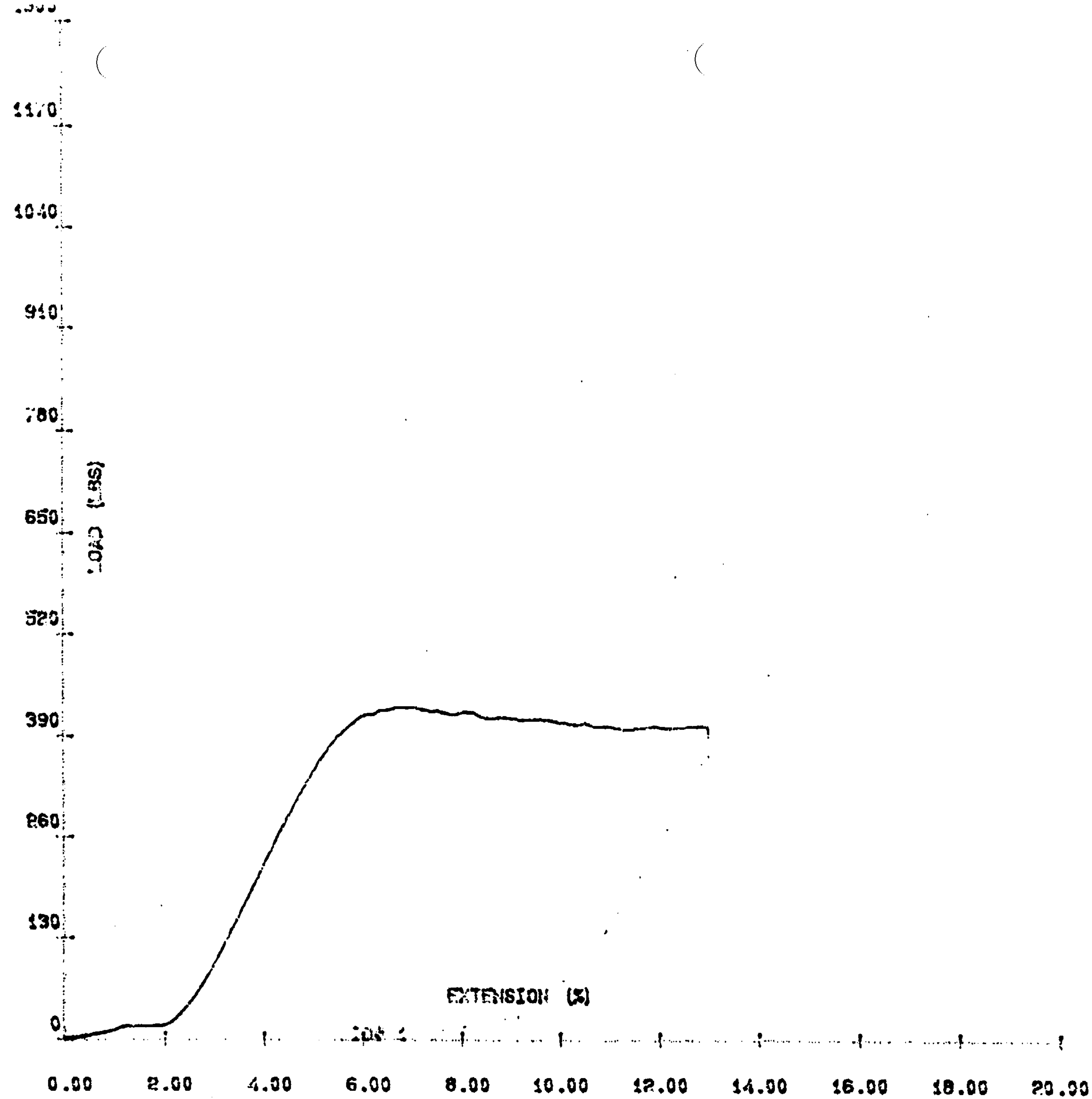

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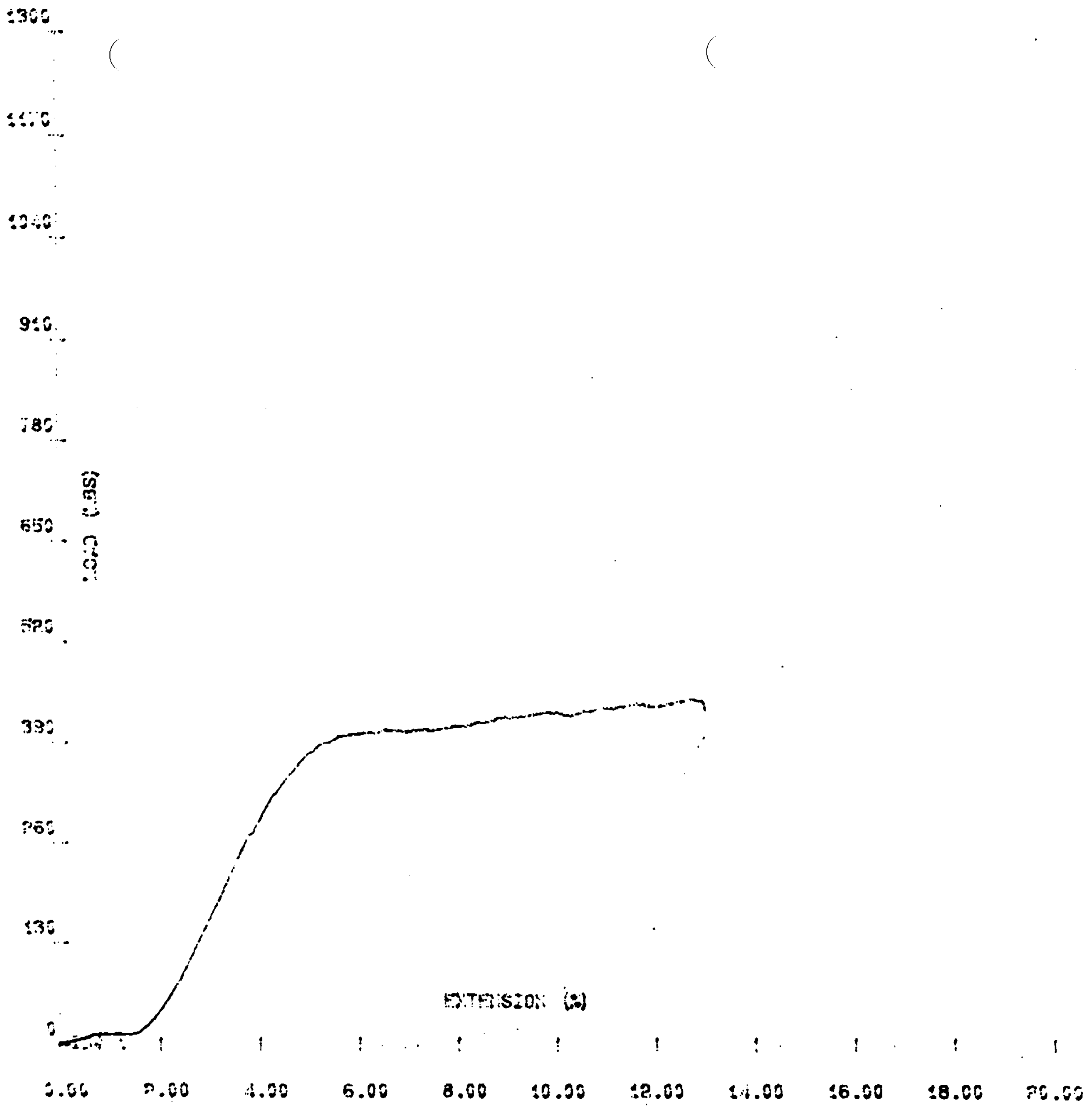

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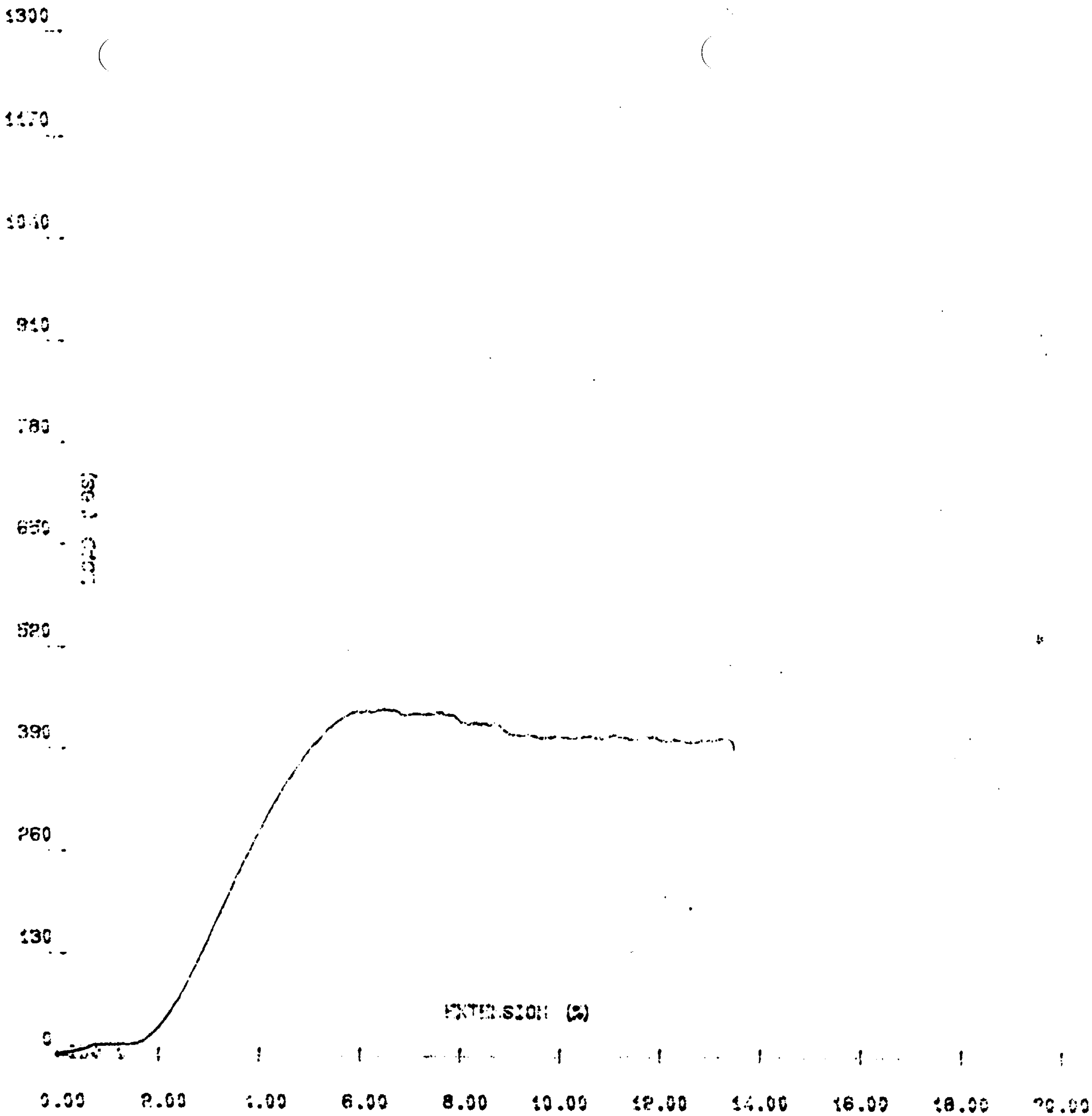
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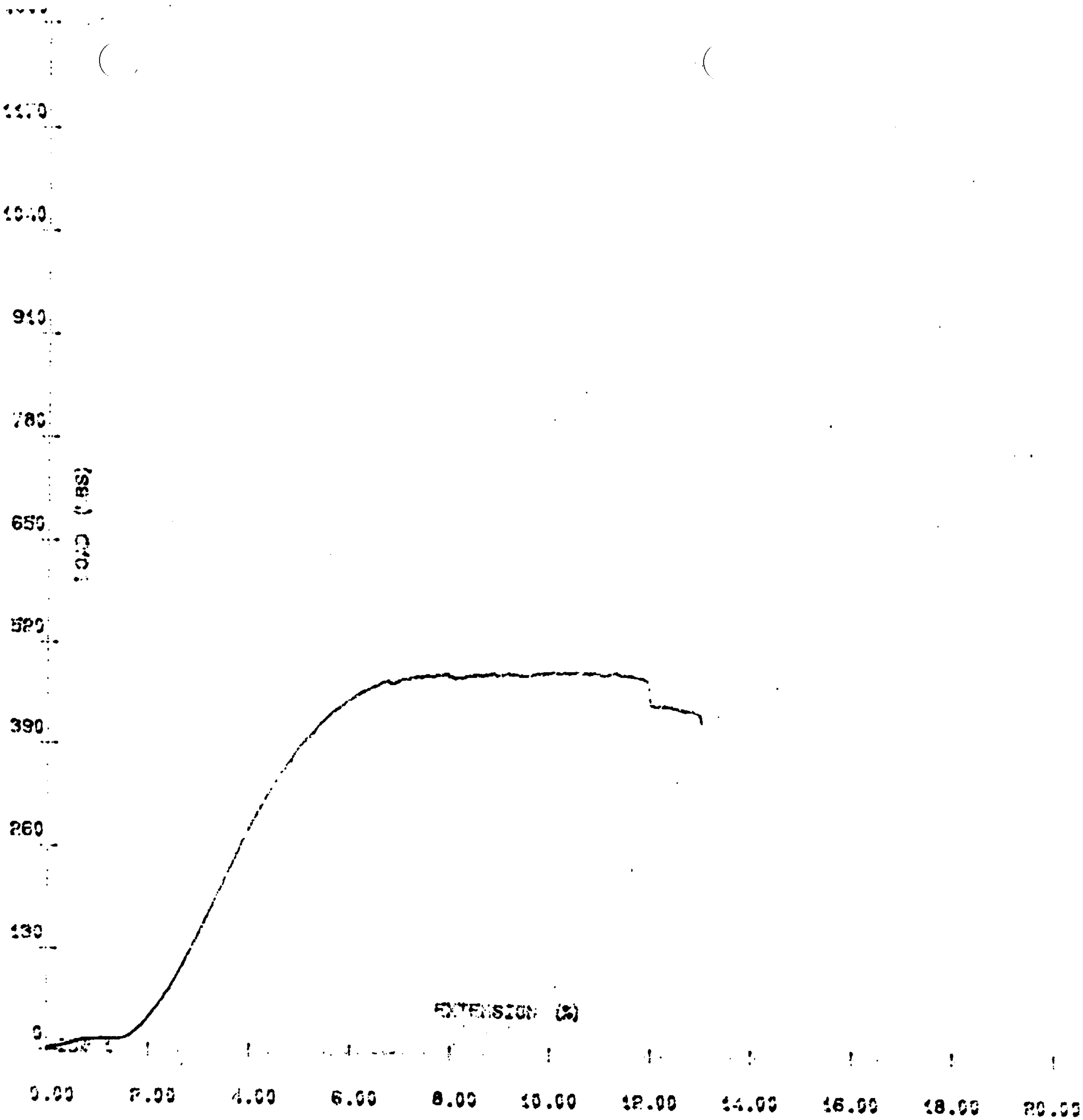

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Appendix 2.10.4

Compliance Testing of the Eco-Pak® OP Transport Unit

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LIST OF FIGURES

LIST OF PHOTOS

APPENDIX 2.10.4
COMPLIANCE TESTING OF THE ECO-PAK® OP TRANSPORT UNIT

2.10.4.1 Introduction

This section describes the compliance testing performed on the Eco-Pak® OP Transport Unit loaded with four storage vessels. Drop orientations for testing were chosen based on indications of potential for worst damage (see Section 2.7 "Hypothetical Accident Conditions"). Conclusions arrived based on these tests are also provided in Section 2.7.

The Eco-Pak® OP was tested in 30 foot free drop and 40 inch puncture drop tests in several orientations. Temperature of the package was reduced to approximately -20^{0}F to maximize the g loading during testing. Insulating properties of the package prevented the interior of the package from reaching -20^{0}F.

2.10.4.2 Test Article

The test article consisted of four UO_2 storage vessels, loaded with steel shot to simulate a standard load, and an Eco-Pak® OP Transport Unit as described in Appendices 1.3.1 and 1.3.2.

Storage Vessel

Four stainless steel storage vessels (see Appendix 1.3.2) were used in the testing. The combined weight of all four empty storage vessels was 312 kilograms.

Eco-Pak® OP Transport Unit

The Eco-Pak® OP Transport Unit was a prototype built expressly for testing. The transport unit was built according to the drawings supplied in Appendix 1.3.1 and procedures outlined throughout this SAR. The transport unit was examined prior to testing and no significant damage was identified. The transport unit weighed 749 kgs empty.

2.10.4.3 Test Facility

Drop Pad

The drop pad was an existing facility that was specifically designed for this type of testing. It is shown in Photo 2.10.4p-1. The pad consisted of a 10' x 10' x 6' reinforced concrete slab embedded in the ground, the upper surface of which was covered by a 1" thick steel plate attached to the slab using J-bolts. The heads of the bolts were covered during tests to limit secondary damage. The drop pad weight is estimated to be 95,000 pounds, not including any effective mass of the very compact soil surrounding the pad.

Puncture Ram

A puncture ram (See Photo 2.10.4p-5) was attached to the center of the test pad for puncture testing using eight bolts. The ram was fabricated out of 6 inch diameter solid steel section welded to a two-inch thick steel plate. The distance from the top of the steel plate to the top of the puncture ram was 16 inches. There was no significant damage to the ram as a result of the testing and there was no indication of movement of the ram during any testing.

Wind Speed

The wind speed and direction instrumentation was in an open air site adjacent to the test facility. (See Photo 2.10.4p-3)

Cooling Chamber

A chamber built expressly for this test series provided low temperature conditioning of the test package. The facility (See Photo 2.10.4p-4) was constructed near the drop test site to minimize time between removal of the test package from the chamber and drop testing. The structure was plywood lined with 3-4" of insulating Styrofoam. Cooling was supplied by liquid nitrogen. Insertion and removal of the test package was done through the top, which was removable. Personnel access was through a single door in the side of the chamber. Thermal monitoring was routed from the chamber to an adjacent building for acquisition and control of the flow of liquid nitrogen.

Test Article Release Mechanism

The test package was positioned over the test pad with a crane (Photo 2.10.4p-2) and released during drop tests with a quick release mechanism using a D-ring pin in mechanical jaws. The D-ring was attached to a wire rope sling supporting the test package. For release, pneumatic pressure was supplied to release the locking pin and allow the jaws to open.

Video Equipment

Documentation of the drops was done with video. Two shooting angles were used. A two-paneled plywood backdrop (Photo 2.10.4p-1) was painted off-white and placed behind the drop pad for reference. Each panel measured 12 feet high and 16 feet wide and each contained a grid of black lines on one foot center. Horizontal lines were parallel to the drop pad.

Furnace

A 13 feet wide by 17 feet long by 9 feet high furnace was used to condition the package prior to fire testing. Temperatures inside the furnace are maintained by a series of burners fired by natural gas that are spaced around the interior walls. Test packages were placed into the furnace using an overhead crane.

Fire Test Site

The fire tests were conducted at a remote test facility equipped with a portable control room and weather station.

Three containment pans, fabricated out of steel structural sections and plates, were used to provide the prescribed fire while maintaining personnel safety. The pool consisted of a series of three square sections 15' x 15', 25' x 25' and 30' x 30' (See Figures 2.7-6 and 2.7-7). Water was placed in each section to about 2-4 inches below the top of the pool structure. Diesel fuel was floated on the inner two sections to provide the engulfing flame. Sufficient fuel was placed in the sections at the beginning of the test to achieve the required burn time. (Photo 2.10.4p-6)

Fire Test Stand

A welded steel stand was centered in the fire test pans to support the package during the fire (Photo 2.10.4p-6). The stand was cooled with a water jacket to prevent buckling during the fire. An immersion pump circulated water through the support stand jacket during testing.

2.10.4.4 Test Description

Load Each Storage Vessel

Each storage vessel was loaded with approximately 162 kgs of steel shot to simulate corresponding loads of uranium oxide.

A silicone gasket was placed on the closure and the lid was bolted into position using twelve (12) ½-inch bolts using torque levels of 78±5 ft-lbs.

Prepare the Storage Vessel and the Eco-Pak® OP Transport Unit

Storage Vessel: Maximum temperature sensors and thermocouples were attached at specified locations on the outer surface of the storage vessels. The maximum temperature sensors had a range of 125-500^{0}F and were in the form of irreversible self-adhesive temperature monitors consisting of heat sensitive indicators sealed under transparent heat resistant windows.

Load Storage Vessels into Eco-Pak® OP Transport Unit

A storage vessel was placed into each of four internal containment cylinders and gaskets were placed on the angle ring openings of the cylinders. The lids were then bolted into place, using twelve (12) ½-inch bolts on each cylinder closure. Each bolt was tightened using 78±5 ft-lbs of torque.

Silicone gaskets were placed on the outer closure angle rings for each containment cylinder and cylinder lids (included attached insulation plug) were bolted closed using twelve (12) ½-inch bolts. Each bolt was tightened using 78±5 ft-lbs of torque.

Cooling of Package

The test package was installed in the cooling chamber for conditioning prior to testing.

Remove Package from Storage

The test package was removed from the cooling chamber and quickly oriented for the drop testing. The temperature of the test article was measured.

Perform 30 ft Free Drop onto Bottom and Record Damages

The test package was positioned with the bottom parallel to the ground. Temperatures of the test package, the wind speed, and the ambient temperatures were recorded prior to the drop.

The package was lifted to a height of 30 ft (determined using a 30 ft line with a plumb bob attached to the bottom of the package) using a crane. The release of the test item was by the pneumatically-actuated quick release mechanism described above. The test package was not guided during the drop.

After impact the package was observed and deformation data was recorded. Color photographs of the extent of damage were taken. The package was not opened, but was prepared immediately for the next drop.

Perform 30 ft Free Drop onto Corner and Record Damages

The test package was positioned upside-down at an angle of 47.5^0 from horizontal with the center of gravity above a leading corner and closure of the package. Temperatures of the test package, the wind speed, and the ambient temperatures were recorded prior to the drop.

The package was lifted to a height of 30 ft (determined using a 30 ft line with a plumb bob attached to the lowest point of the corner) using a crane. The release of the test item was by the pneumatically-actuated quick release mechanism described above. The test package was not guided during the drop.

After impact the package was observed and deformation data was recorded. Color photographs of the extent of damage were taken. The package was not opened, but was prepared immediately for the next drop.

Perform 30 ft Free Drop onto Edge and Record Damages

The test package was positioned upside-down at an angle of 50^0 from horizontal with the center of gravity over a leading edge (opposite the previously tested corner) of the package. Temperatures of the test package, the wind speed, and the ambient temperatures were recorded prior to the drop.

The package was lifted to a height of 30 ft (determined using a 30 ft line with a plumb bob attached to the edge facing the target pad) using a crane. The release of the test item was by the pneumatically-actuated quick release mechanism described above. The test package was not guided during the drop.

After impact the package was observed and deformation data was recorded. Color photographs of the extent of damage were taken. The package was not opened, but was immediately prepared for the next drop test.

Perform 40 inch Puncture Test onto Side and Record Damages

The test package was positioned with the bottom perpendicular to the ground and the side centered directly above the puncture bar. The temperature of the test package, the wind speed, and the ambient temperature were recorded prior to the drop.

The package was lifted to a height of 40 inches, again determined by using a 40 inch line with a plumb bob attached to the bottom of the package. The test item was released by the pneumatically-actuated quick release mechanism. Again, no guidance of the test package was provided during the drop.

After impact the package was observed and deformation data was recorded. Color photographs of the extent of damage were taken.

Examination of the thermocouple leads showed that the impact of the 30 foot drop onto the package edge had damaged the contacts. Although it was a variance from the established procedure, the cylinder which contained the storage vessel equipped with thermocouples was opened to re-attach the devices. This decision was made based on the observation that the cylinder in question had received little, if any, damage as a result of the drop tests. After the thermocouple leads were re-attached, the storage vessel was re-loaded into the package and sealed.

Warm Test Package to 100EF

The test package was installed in a furnace and a nominal temperature of 100^{0}F was maintained on the package for a period of 24 hours prior to fire testing. The test package was transported to the fire facility wrapped in blankets within a wooden box to minimize cooling.

Perform 30 Minute Fire Event

The test package was placed on the test stand with its base 40 inches from the fuel source.

Wind speed was continuously monitored prior to and during the fire. Wind speeds averaging 4 to 6 mph were considered acceptable for conducting the test.

The fire test pan was filled with water and No. 2 diesel fuel. The required amount of fuel was estimated and filled in the pan prior to the test. The package was set on a stand 40 inches above the fuel surface. The stand was water cooled to prevent collapse during the fire. The fire pan was surrounded by 30' x 30' primary containment pan filled with water only (Photo 2.10.4p-8).

The standing diesel fuel was lit with a torch and the Eco-Pak® OP Transport Unit was subjected to a 30 minute fully engulfing fuel/air fire.

Cool Package and Record External Damage

Following the fire, the package was allowed to cool naturally and no external sources were used to stop any continued burning of the package.

Open Transport Unit and Record Internal Damage

The transport unit was opened for post-test inspection. The storage vessels were removed and measurements were taken.

2.10.4.5 Summary and Results of Tests

Testing was conducted at Southwest Research Institute (SwRI), San Antonio, Texas in accordance with written test procedures.

The average wind speed was 2 mph. The package temperature was -31^{0}F.

The package was positioned with the bottom parallel to the ground and raised 30 feet as measured from the bottom of the package. (Photo 2.10.4p-8) The weight of the test package was 1708 kgs. No closures broke or were loosened, although the outer skin of the package rippled and the bottom bowed outward as a result of the impact. (Photo 2.10.4p-9)

No tears or breaks in the package were observed.

The package was positioned upside down at an angle of 47.5^0 from horizontal with the center of gravity over a top corner and closure. The package was raised and dropped 30 feet as measured from the lowest point of the corner of the package. (Photo 2.10.4p-10) No closures broke or were loosened, although the corner was flattened by the impact. (Photo 2.10.4p-11).

The package was positioned upside down at an angle of 50^0 from horizontal with the center of gravity over the edge opposite the previously dropped corner. The package was raised and dropped 30 feet as measured from the lowest point of the edge of the package. (Photo 2.10.4p-12) No closures broke or were loosened, although the edge was turned inward by the impact. (Photo 2.10.4p-13).

The package was then positioned with the side parallel to the ground and centered over the puncture ram. The package was then raised 40 inches as measured from the point of impact. (Photo 2.10.4p-14) The package deformed at the puncture location, but there were no tears in the skin. All closures remained intact and the punch did not expose any foam. (Photo 2.10.4p-15).

The impact of the 30 foot drop onto the package edge dislodged the thermocouple pod attached to the outside surface of the package and the contacts had been damaged. Although it was a variance from the established procedure, the cylinder which contained the storage vessel equipped with thermocouples was opened to re-attach the devices. This decision was made based on the observation that the cylinder in question had received little, if any, damage as a result of the drop tests. After the thermocouple leads were re-attached, the storage vessel was re-loaded into the package and sealed.

The package was placed in a furnace and heated to 100^0F in preparation for the thermal test.

The fire test pan was filled with water and No. 2 diesel fuel. The package was set on a stand 40 inches above the fuel surface. (Photo 2.10.4p-16).

Wind speed and direction were continuously monitored prior to the fire. Steady wind speeds averaging 4-6 mph were recorded prior to the fire. Once wind direction was steady and away from the instrumentation, conditions were considered acceptable for fire testing. The package temperature immediately prior to the test was approximately 104^0F.

The standing diesel fuel was lit with a torch. The test package was subjected to a 30 minute fully engulfing fuel/air fire (Photos 2.10.4p-17 and 2.10.4p-18).

The package was left on the test stand and it was monitored during cool down. (Photo 2.10.4p-19)

The locations of the temperature tapes on each storage vessel are illustrated in Figure 2.10.4-1, which provides the maximum temperatures indicated from both thermocouples and temperature tapes.

A post test inspection was conducted on the package once it was returned to the main test facility. The bolts did not open due to the fire and the closures did not open significantly as a result of the fire testing. There was minimal buckling of the package outer skin due to the fire test.

The package was opened carefully for post test inspection. All gaskets were intact. (Photos 2.10.4p-20 and 2.10.4p-21).

Maximum temperatures were recorded from the temperature sensitive labels.

The storage vessels were examined for any sign of damage. None was found. (Photo 2.10.4p-22).

The internal containment cylinders were examined for traces of shot that may have been forced from the storage vessels due to testing. No residue was found.

The containment cylinders were measured to determine if they had shifted as a result of testing. No significant movement was found. (Figure 2.7-9)

2.10.4.6 Conclusion

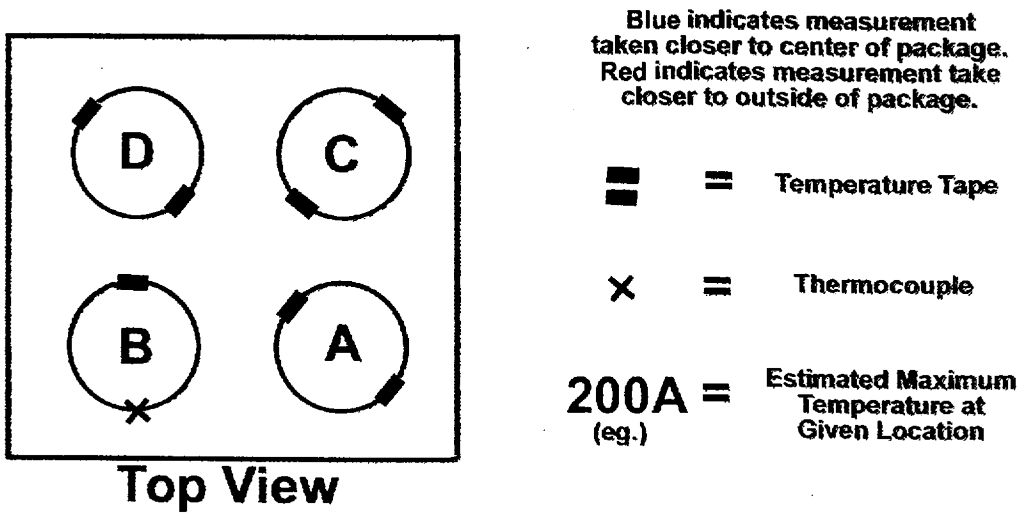
The compliance testing of the Eco-Pak® OP packaging resulted in the following:

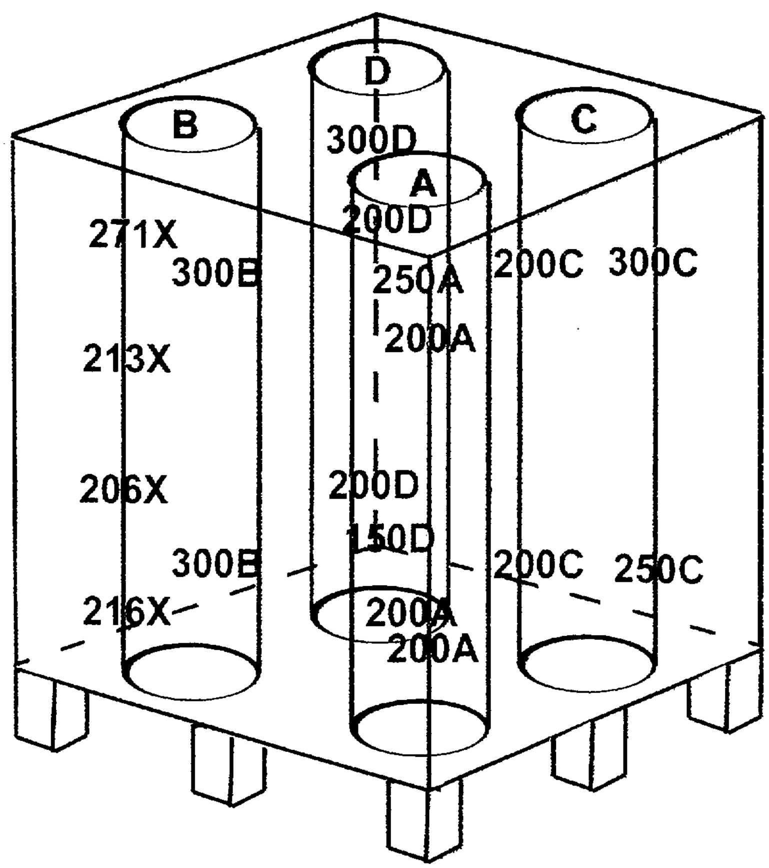
- The Eco-Pak® OP Transport Unit successfully protected the storage vessels and, as shown in Figure 2.7-8 and Figure 2.7-9, maintained their geometrically-safe configuration throughout the test series.

- Examination of the storage vessels showed that no significant damage was done to any of them as a result of the Hypothetical Accident Testing.

- Thermal evaluations of the package (described in detail in Section 3) showed the transport unit capable of preventing damage to the gaskets and of maintaining containment of the lading.

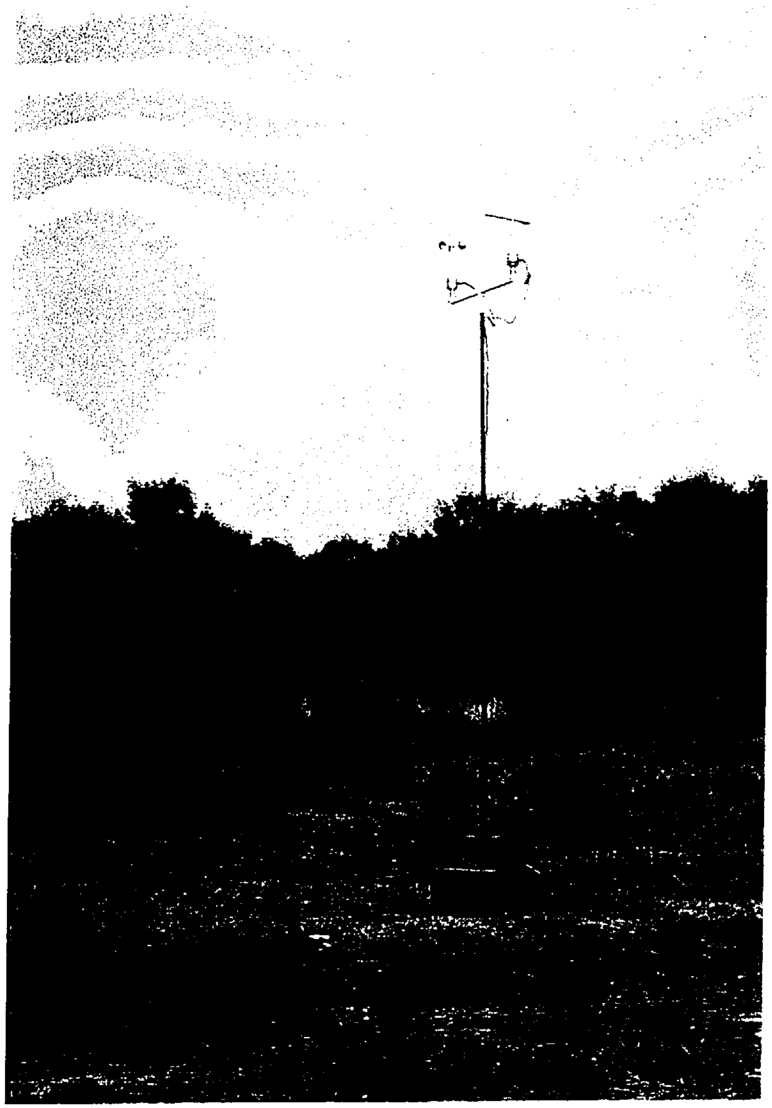
Figure 2.10.4-1
Temperature Tape and Thermocouple Readings



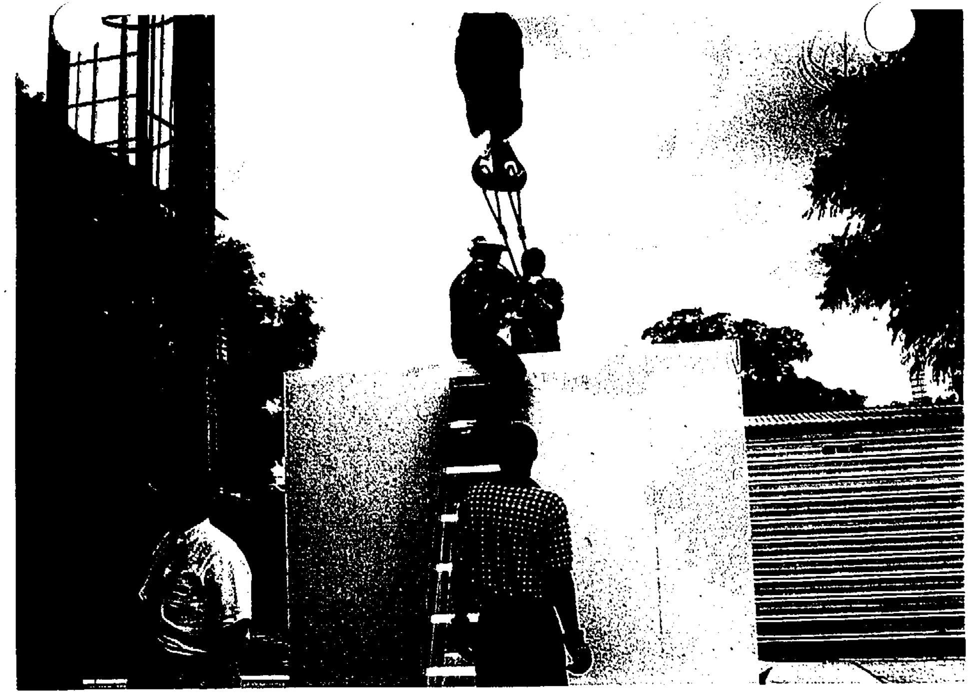


2.10.4p-1 Drop Pad and Photographic Backdrop

2.10.4p-2 Crane

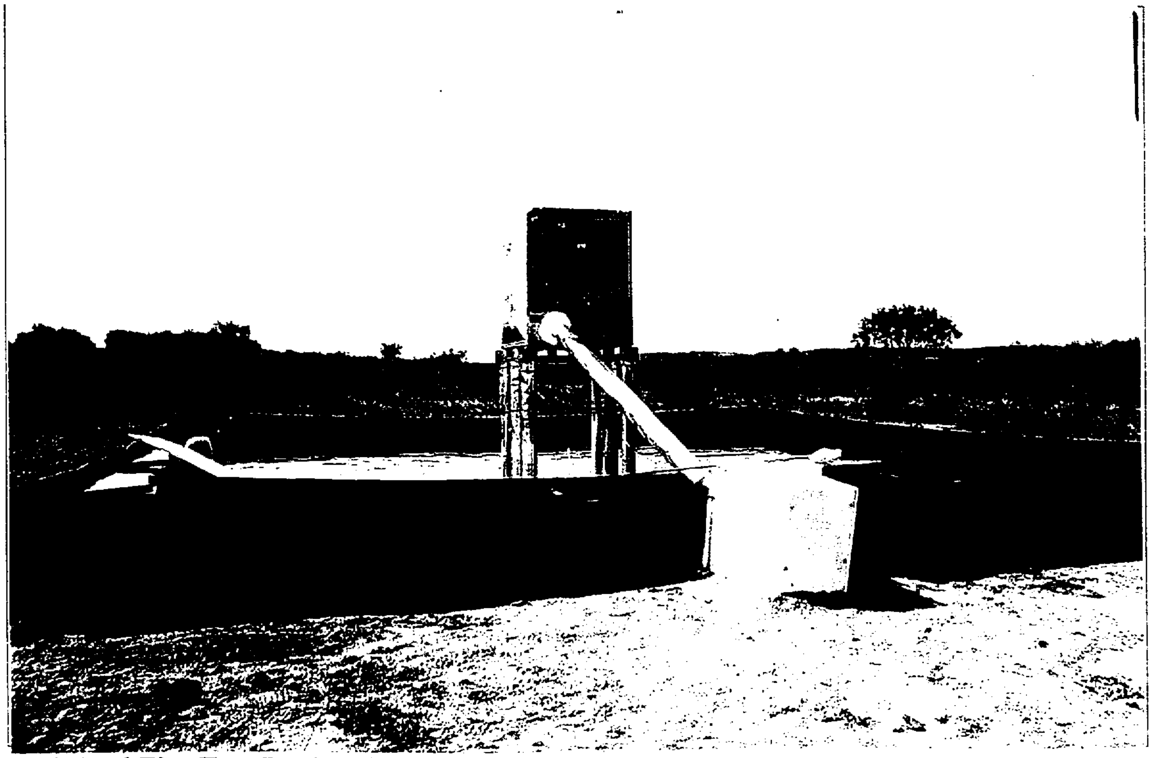


2.10.4p-3 Wind Speed and Direction Instrumentation

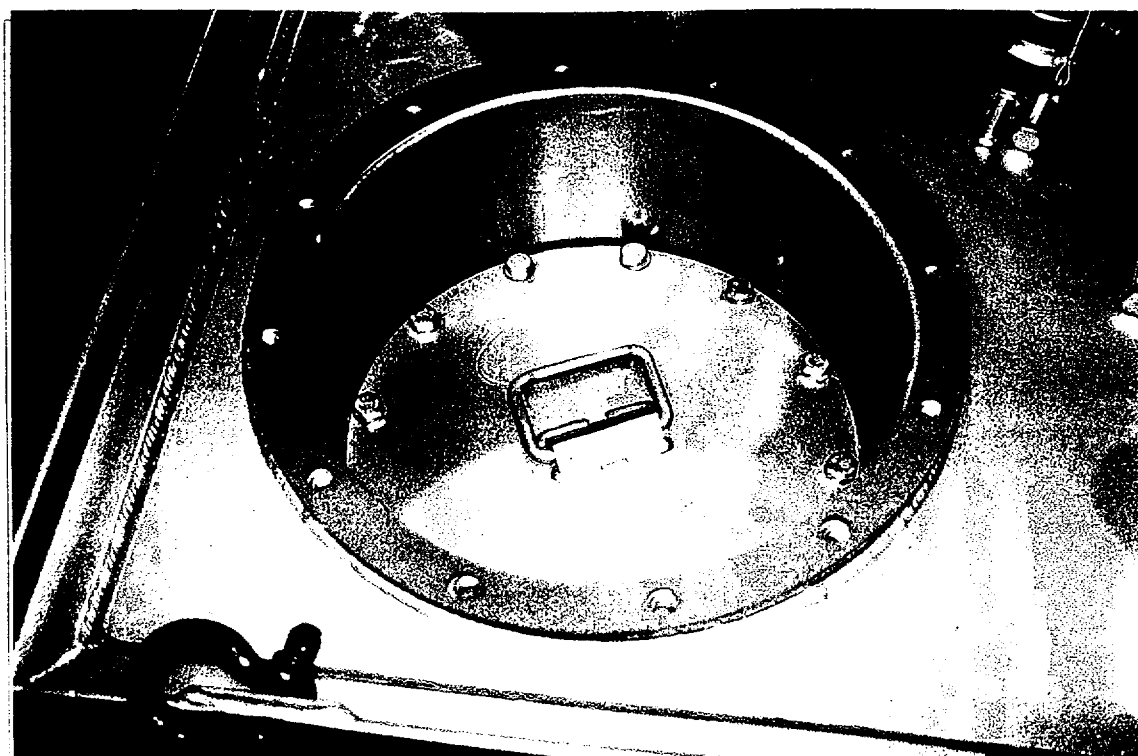


2.10.4p-4 Cooling Chamber

2.10.4p-5 Puncture Ram

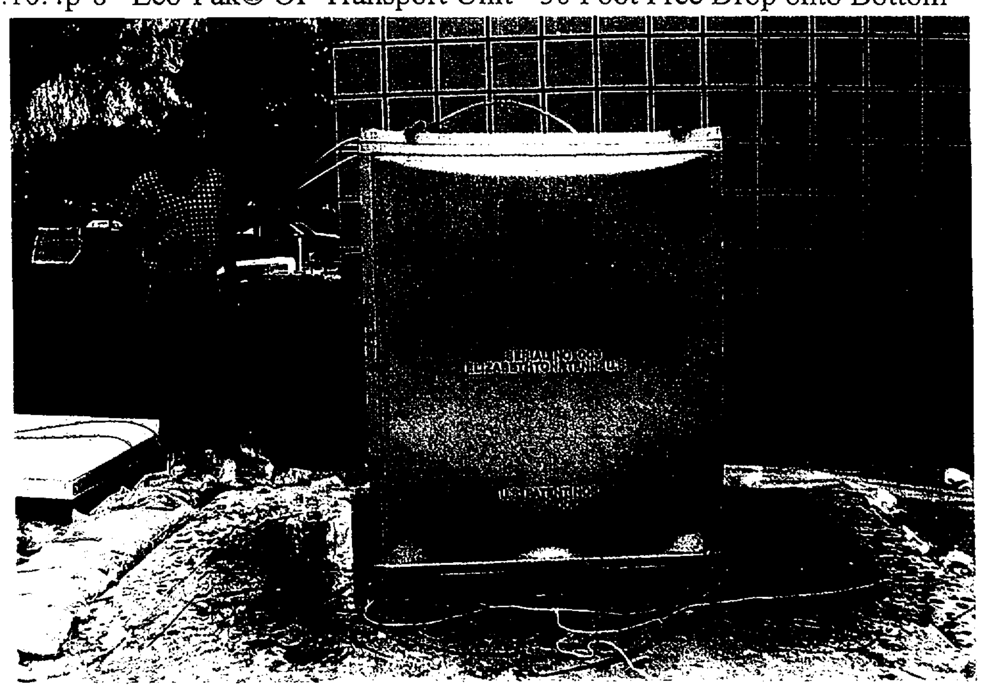


2.10.4p-6 Fire Test Pool and Fire Test Stand



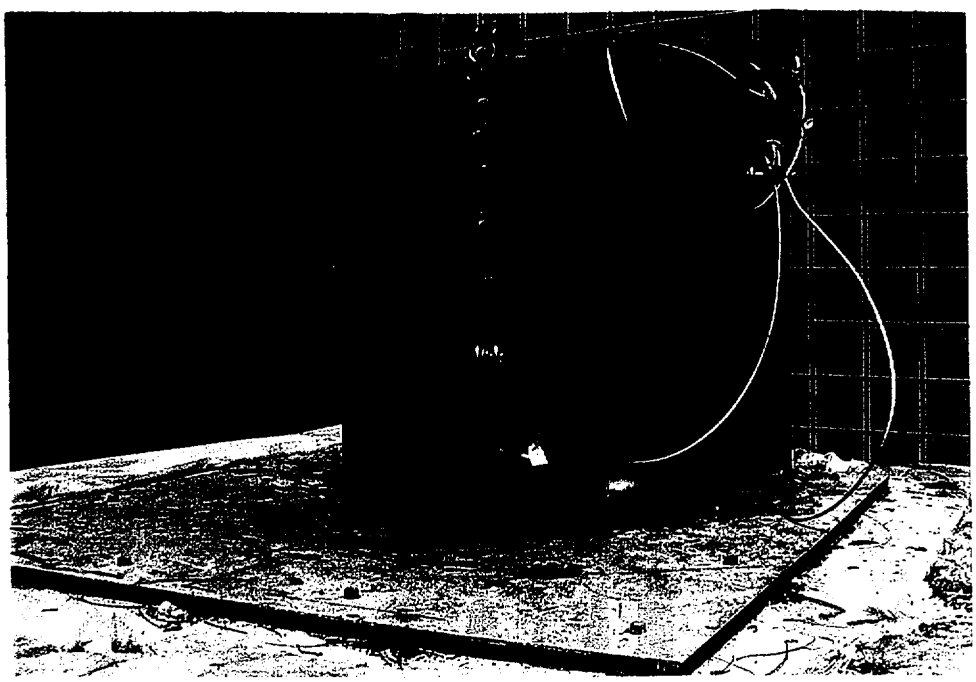
2.10.4p-7 Storage Vessel in Transport Unit, Inner Lid Closed

2.10.4p-8 Eco-Pak® OP Transport Unit - 30 Foot Free Drop onto Bottom

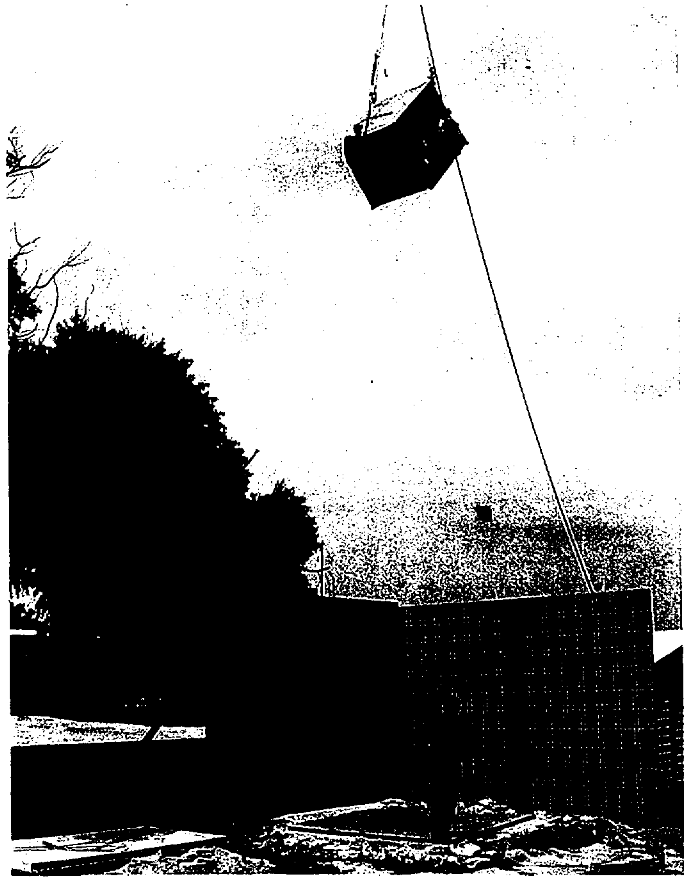


2.10.4p-9 Eco-Pak® Transport Unit - Damage Following Bottom Drop

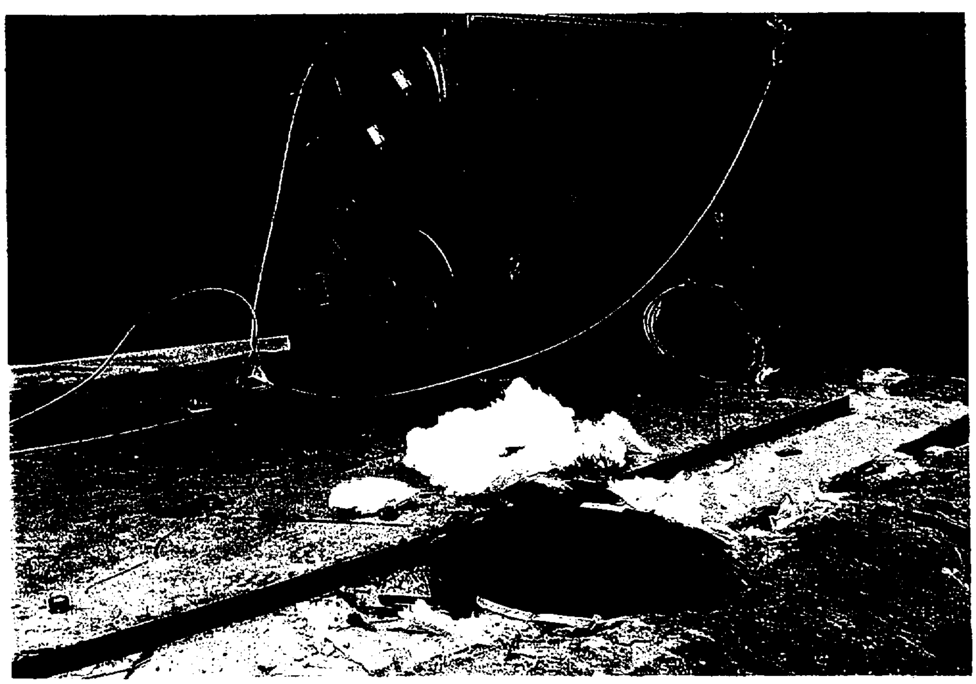
2.10.4p-10 Eco-Pak® OP Transport Unit - 30 Foot Free Drop onto Corner



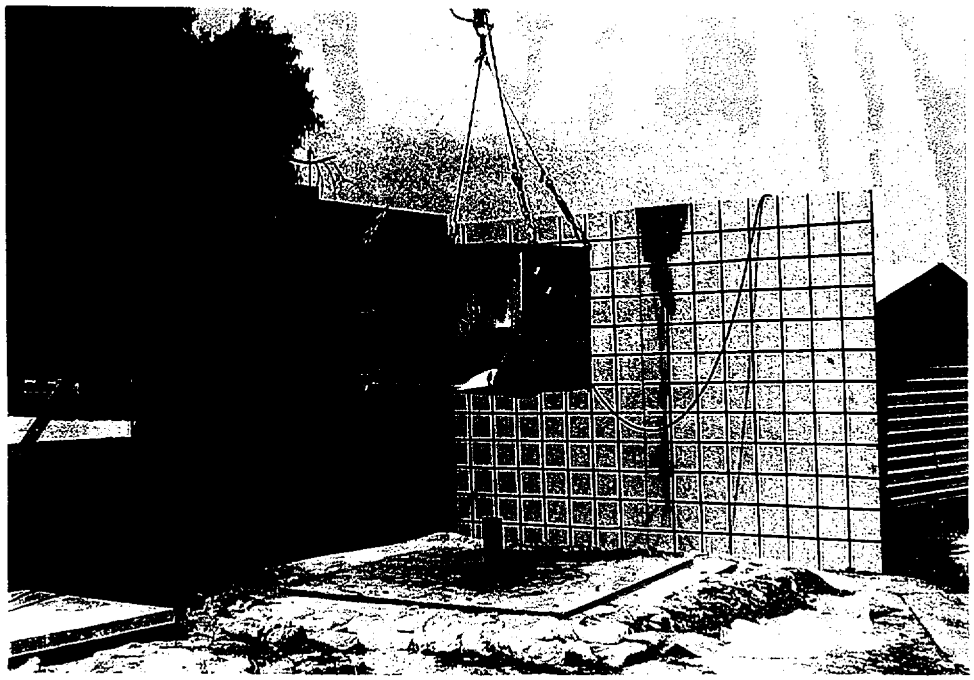
2.10.4p-11 Eco-Pak® OP Transport Unit - Damage Following Corner Drop



2.10.4p-12 Eco-Pak® OP Transport Unit - 30 Foot Free Drop onto Edge

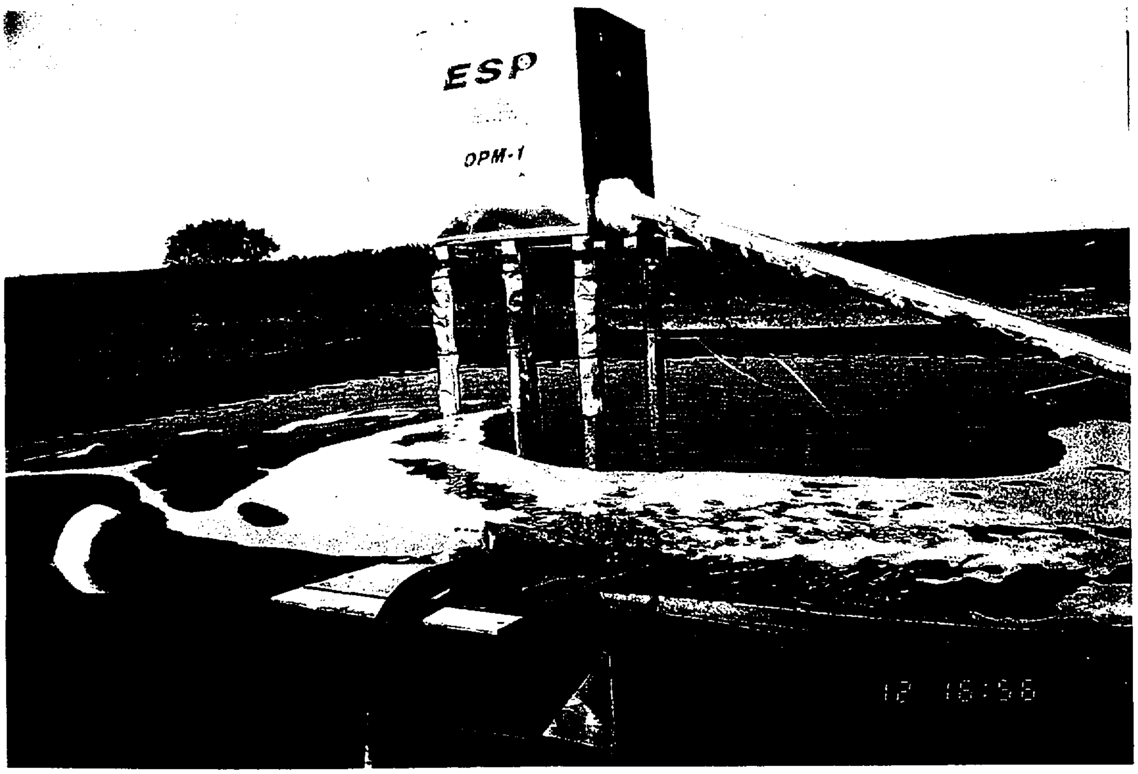


2.10.4p-13 Eco-Pak® OP Transport Unit - Damage Following Edge Drop



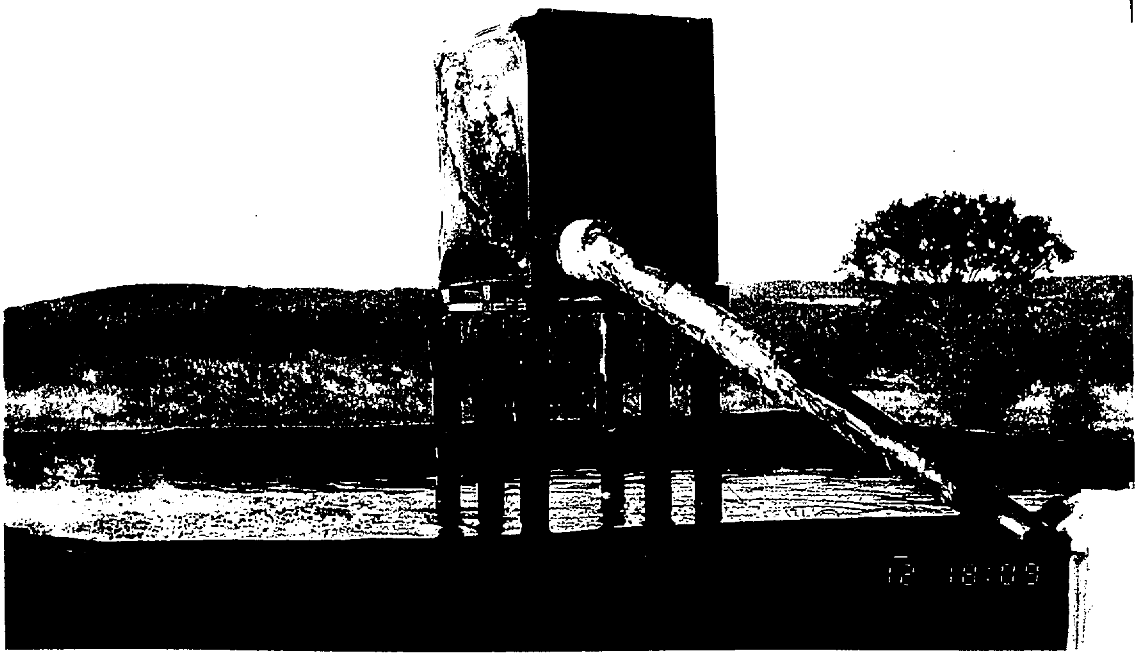
2.10.4p-14 Eco-Pak® OP Transport Unit - 40 Inch Puncture Drop onto Side

2.10.4p-15 Eco-Pak® OP Transport Unit - Damage Following Side Drop



2.10.4p-16 Eco-Pak® OP Transport Unit - Preparing for Fire Testing

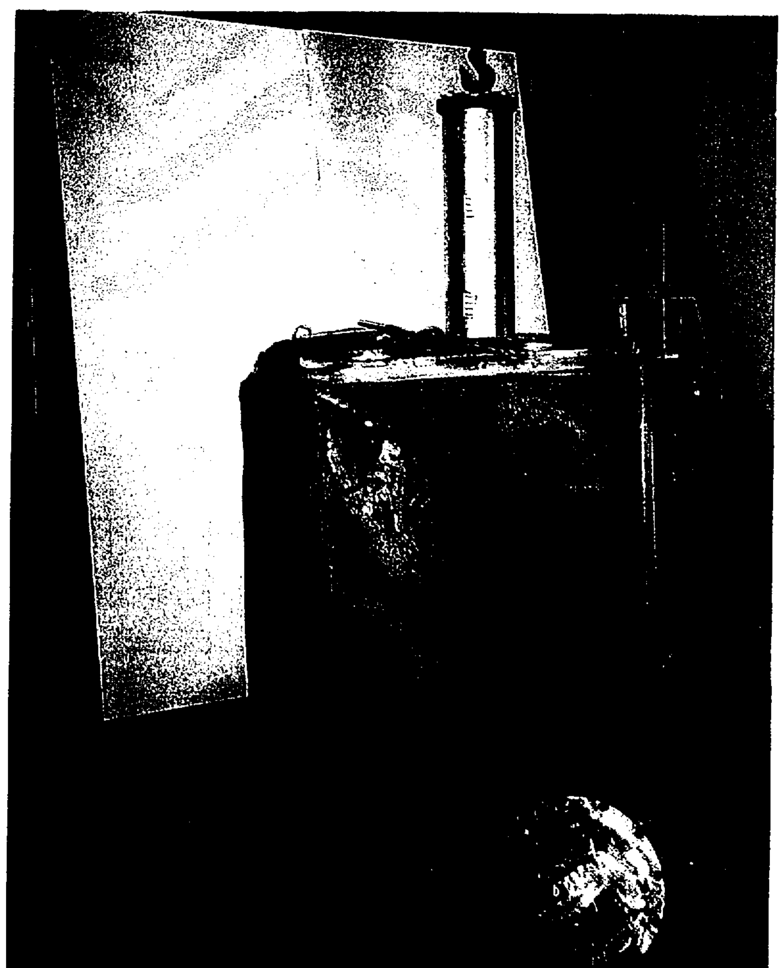

2.10.4p-17 Eco-Pak® OP Transport Unit - Fully Engulfed



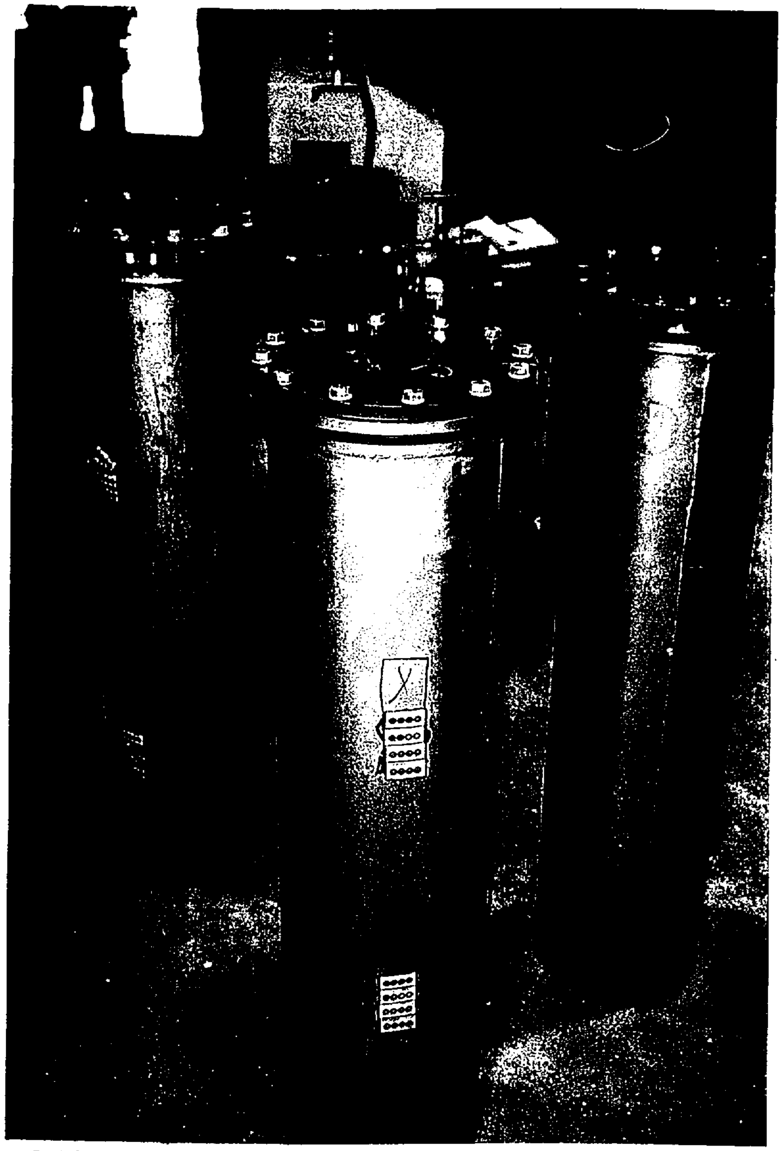
2.10.4p-18 Eco-Pak® OP Transport Unit - Fire Complete

2.10.4p-19 Eco-Pak® OP Transport Unit - Condition Following Cooldown

2.10.4p-20 Eco-Pak® OP Transport Unit - Opening the Package After Fire Test



2.10.4p-21 Eco-Pak® OP Transport Unit - Removing Storage Vessels



2.10.4p-22 Storage Vessel Condition Following Tests

Appendix 2.10.5

Southwest Research Institute Performance Evaluation of the Eco-Pak® OP Uranium Oxide Transport Unit

SOUTHWEST RESEARCH INSTITUTE

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PERFORMANCE EVALUATION OF UO_2 SHIPPING CONTAINERS UNDER HYPOTHETICAL ACCIDENT CONDITIONS SPECIFIED IN TITLE 10 CFR PART 71.73

FINAL REPORT
SwRI Project No. 01-1680b
August 1998

Prepared for:

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SAN ANTONIO, TEXAS

HOUSTON, TEXAS • DETROIT, MICHIGAN • WASHINGTON, DC

ABSTRACT

This report describes the methods and guidelines Southwest Research Institute (SwRI) followed for the preparation, instrumentation, and conditioning of test specimens; performance of drop tests, leakage tests, and fire endurance tests; reporting of test results; and all applicable documentation of these tasks in accordance with the requirements specified in SwRI Proposal No. 01-21593a and Eco-Pak Specialty Packaging (ESP), Division of Columbiana Boiler Company (CBC) Purchase Order No. 4319. This report includes the program objective, quality assurance requirements, test personnel qualifications, test facilities and instrumentation calibration, test procedure, test item description, test results, and applicable documentation.

The objective of this program was to conduct physical and fire performance evaluation tests of ESP's OPM-1 Uranium Oxide (UO_2) Shipping Package in accordance with the hypothetical accident conditions specified in Title 10 CFR Part 71.73, to verify the performance under the specified conditions. The OPM-1 UO_2 shipping package was subjected first to the physical tests simulating hypothetical accident conditions for free drop and puncture described in Title 10 CFR 71.73 (c), (1) and (3). Following the drop tests, the OPM-1 UO_2 shipping package was subjected to the thermal effects of the fully engulfing hydrocarbon pool fire exposure described in Title 10 CFR 71.73 (c), (4). Following each test, the physical condition of the OPM-1 UO_2 shipping package was inspected and the results were recorded. The following table summarizes the results for the pre-drop/post-fire helium leak tests.

Table 1. Helium Leakage Test Results.
Test Item: OPM-1, SN003, Vessels A/B/C/D

TEST	REQUIREMENT (std cc/sec)	MEASUREMENT (std cc/sec)	PASS/FAIL
Pre-Drop Helium			
Vessel A	$\leq 1.0 \times 10^{-7}$	1.0×10^{-7}	Pass
Vessel B	$\leq 1.0 \times 10^{-7}$	0.8×10^{-9}	Pass
Vessel C	$\leq 1.0 \times 10^{-7}$	0.9×10^{-9}	Pass
Vessel D	$\leq 1.0 \times 10^{-7}$	0.8×10^{-9}	Pass
Post-Fire Helium			
Vessel A	$\leq 1.0 \times 10^{-7}$	2.0×10^{-9}	Pass
Vessel B	$\leq 1.0 \times 10^{-7}$	1.9×10^{-9}	Pass
Vessel C	$\leq 1.0 \times 10^{-7}$	4.0×10^{-9}	Pass
Vessel D	$\leq 1.0 \times 10^{-7}$	5.0×10^{-9}	Pass

The following table summarizes the results of the drop testing performed on the OPM-1. The test item received some damage following the drop test that was considered acceptable by ESP personnel.

Table 2. OPM-1 SN003 Drop Testing Performed.

Procedure	Dates	Comments
Conditioning Before Drop	6/10/98 6/11/98	Test item insulation temperature -35°C (-31°F)
30-ft Drop (upright orientation)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel
30-ft Drop (corner)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel
30-ft Drop (edge)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel
40-in Drop (puncture)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel

The Department of Fire Technology conducted the 30-min pool fire test described in Title 10 CFR 71.73 (c), (4) on June 12, 1998. The average initial temperature of the thermocouple fitted vessel was 104°F. The maximum single point temperature recorded on the surface of the vessel during the 30-min pool fire exposure test was 267.1°F (Thermocouple [TC] 4 at 30 min), and the average of the maximum TC readings was 196°F.

The maximum single point temperature recorded on the surface of the vessel during the 15-hr cool down period was 215.8°F (TC 1 at 14 min), and the average of the maximum TC readings was 205°F.

Following completion of the post-fire helium leakage tests, all vessels were inspected and found to be undamaged and in good condition with no loss of contents.

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1.0 INTRODUCTION

This report describes the methods and guidelines Southwest Research Institute (SwRI) followed for the preparation, instrumentation, and conditioning of test specimens; performance of drop tests, leakage tests, and fire endurance tests; reporting of test results; and all applicable documentation of these tasks in accordance with the requirements specified in SwRI Proposal No. 01-21593a and Eco-Pak Specialty Packaging (ESP), Division of Columbiana Boiler Company (CBC) Purchase Order No. 4319. This report includes the program objective, quality assurance requirements, test personnel qualifications, test facilities and instrumentation calibration, test procedure, test item description, test results, and applicable documentation.

2.0 PROGRAM OBJECTIVE

The objective of this program was to conduct physical and fire performance evaluation tests of ESP's OPM-1 Uranium Oxide (UO_2) Shipping Packages in accordance with the hypothetical accident conditions specified in Title 10 CFR Part 71.73, to verify the performance under the specified conditions. The OPM-1 UO_2 shipping package was subjected first to the physical tests simulating hypothetical accident conditions for free drop and puncture described in Title 10 CFR 71.73 (c), (1) and (3). Following the drop tests, the OPM-1 UO_2 shipping package was subjected to the thermal effects of the fully engulfing hydrocarbon pool fire exposure described in Title 10 CFR 71.73 (c), (4). Following each test, the physical condition of the OPM-1 UO_2 shipping package was inspected, and the results were recorded.

3.0 PROGRAM ORGANIZATION

The scope of work described in this report was performed by SwRI personnel at SwRI facilities. The program was supported by four of SwRI's 11 technical divisions, each with facilities, capabilities, and technical expertise necessary to successfully perform this program in a professional, cost effective, and timely manner. Figure 3-1 shows the organizational chart for SwRI's technical divisions, and Figure 3-2 depicts the program organizational chart.

The overall program was managed by Mr. James R. Griffith Jr., P.E., FPE, Project Manager in the Department of Fire Technology in the Chemistry and Chemical Engineering Division. The physical (drop) testing was performed by the Structural Dynamics and Environmental Testing Group in the Mechanical and Fluids Engineering Division. The leakage tests were performed by the Test and

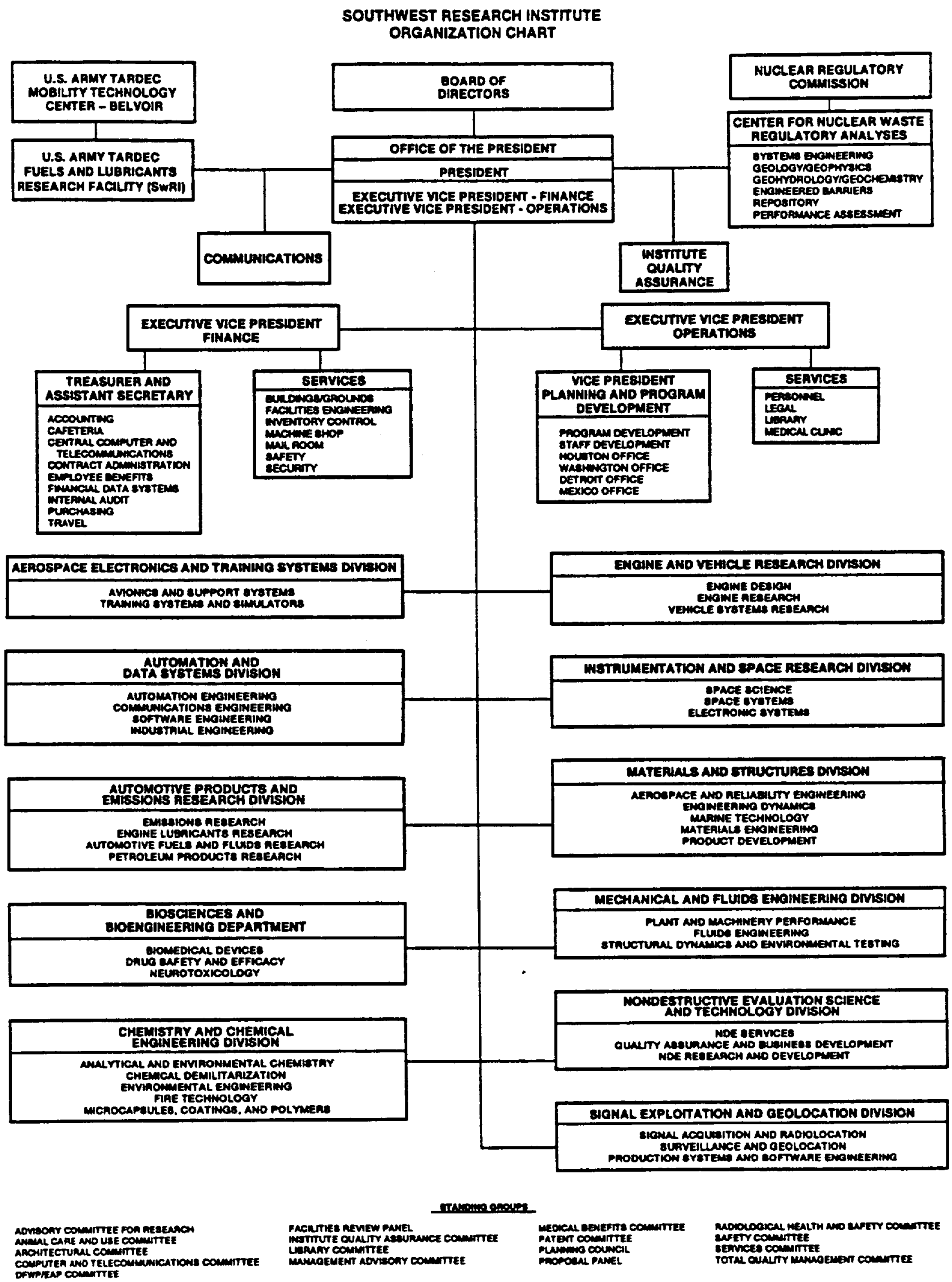


Figure 3-1. SwRI Organizational Chart.

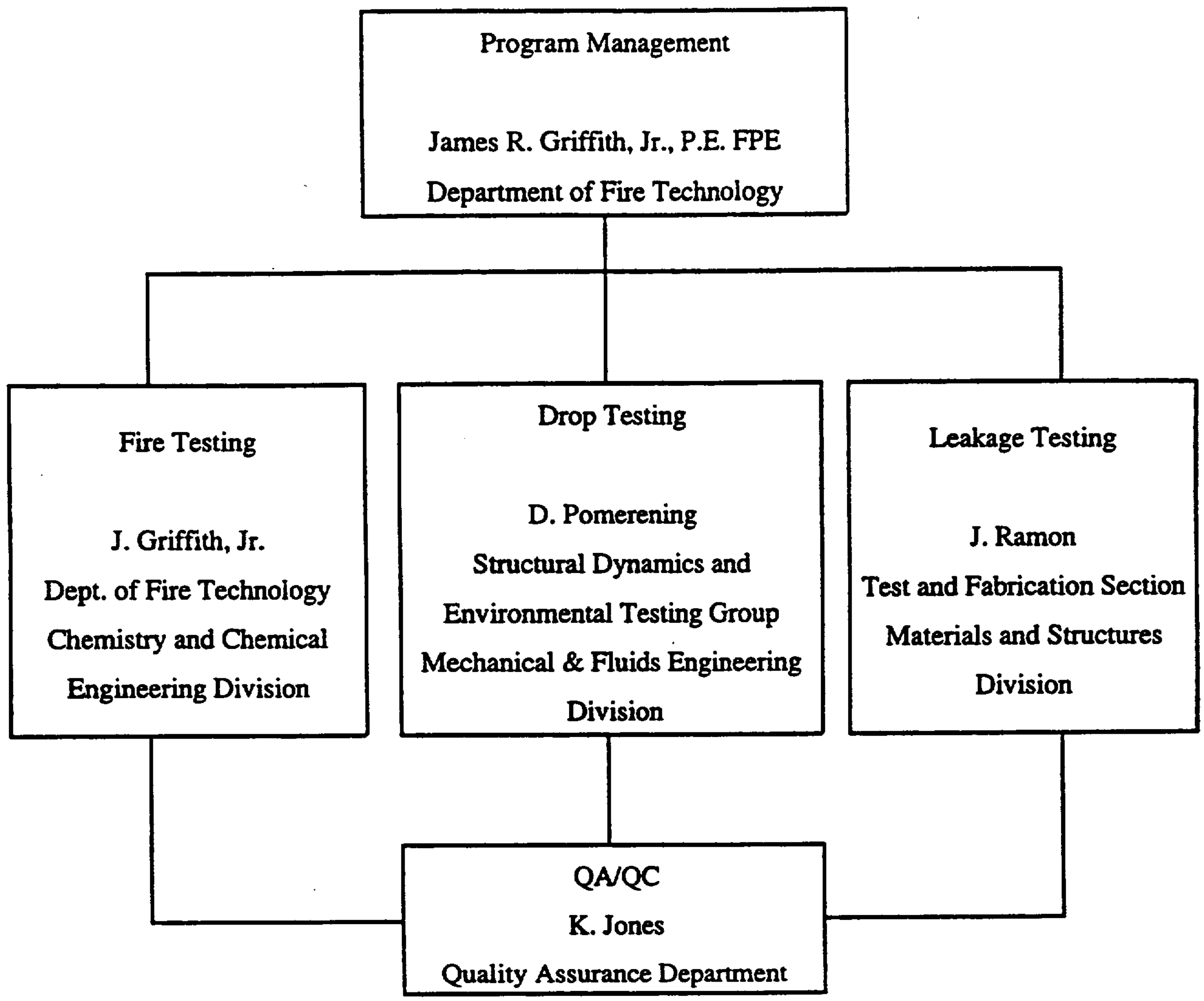


Figure 3-2. Program Organizational Chart.

Fabrication Section of the Materials and Structures Division. SwRI's Quality Assurance Department provided independent surveillance, quality checks, and inspections during the course of this program, as required. The following sections provide further information for each of the supporting technical divisions.

4.0 QUALITY ASSURANCE REQUIREMENTS

All test activities for ESP were monitored and controlled under SwRI's Nuclear Quality Assurance Program Manual (NQAPM) and/or the Department of Fire Technology Quality Assurance Manual (DFTQAM). The NQAPM and DFTQAM meet the requirements of Title 10 CFR 50, Appendix B, and meet or exceed the requirements of Title 10 CFR 71, Subpart H. SwRI prepared a Project Quality Plan (PQP) Document No. NPQP-98-01-1680, which identified the specific sections of the NQAPM or DFTQAM which apply, and addressed specific requirements identified in the contract. SwRI Quality Assurance/Quality Control (QA/QC) personnel provided independent surveillance, quality checks, and inspections during the course of this program.

5.0 TEST ITEM IDENTIFICATION

Eco-Pak Specialty Packaging, Division of Columbiana Boiler Company, was responsible for the design, fabrication, and delivery of the OPM-1 UO_2 shipping container, which consisted of the overpack and four internal UO_2 vessels. ESP performed the initial test item preparation including filling the vessels with clean steel shot and ballast material, and load measurements.

The OPM-1 was identified as SN003 and the internal vessels were labeled A, B, C, and D. The OPM-1 shipping container was constructed in accordance with the detail drawings provided by ESP. Dimensional measurements prior to the drop tests and following the drop and fire tests appear in Appendix C, Construction Details and Dimensional Measurements.

6.0 TEST FACILITIES

6.1 Leakage Testing Facilities

The leakage testing phase of this program utilized various equipment, instrumentation, and dedicated facilities to perform helium leak tests.

The helium leakage tests were performed with the Department's VEECO MS-40 portable automatic leak detector manufactured by VEECO Instruments, Inc. The MS-40 is a fully automatic, dual mode, turbomolecular pumped portable leak detector. The sensitivity of the MS-40 is 4×10^{-11} std cc/sec air equivalent and leak rate range of 10×10^{0} to 4×10^{-11} std cc/sec air equivalent with external pump.

6.2 Drop Testing Facilities

6.2.1 Environmental Conditioning

Low temperature conditioning of the test item before drop testing was done in a chamber built specifically for this project. The facility, shown in Figure 6-1 and Figure A-1 of Appendix A, was constructed in close proximity to the drop test site to minimize time between removal of the test item from conditioning and drop testing. The test chamber was a plywood box with rigid foam insulation. A removable top was provided for insertion and removal of the test item. A single insulated door was provided for access to the test item. Cooling to the facility was supplied by liquid nitrogen. Thermal monitoring was routed from the chamber to an adjacent building for acquisition and control of the flow of liquid nitrogen. A Watlow controller, referenced to a thermocouple (TC) measuring air temperature in the chamber, controlled the supply of liquid nitrogen. Additional thermocouples were used to monitor the air temperature in the chamber and test item temperatures during conditioning. These data were processed using a Fluke Hydra data logger attached to a computer for data storage. For reporting purposes, data files were reduced following the testing.

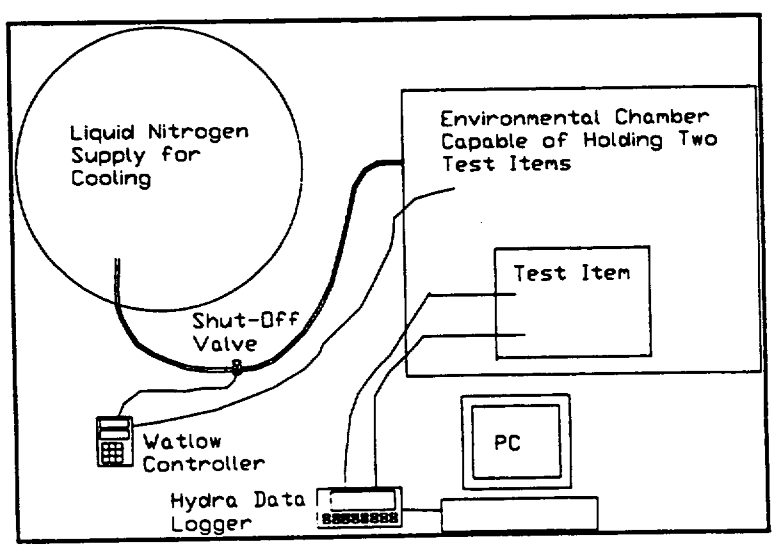


Figure 6-4. Low-Temperature Environmental Conditioning Chamber.

6.2.2 Wind Instrumentation

Wind speed was measured using a hand held anemometer supplied and monitored by fire Technology personnel.

6.2.3 Test Pad

The drop pad, an existing test facility that was specifically designed for this type of testing, is shown in Figure A-1 of Appendix A. The test facility consists of a 10 x 10 x 6-ft reinforced concrete slab embedded in the ground. A 1-in. thick steel plate, attached to the slab using J-bolts, covers the upper surface of the concrete slab. The entire facility weight is estimated to be 95,000 lb. This does not include any effective mass of the surrounding soil, which is very compact.

A plywood photographic backdrop was constructed for this project, Figure A-1 of Appendix A. Each side of this structure was 12 ft high and 16 ft wide. The backdrop was painted and had a grid of black lines on 1-ft centers covering the surface. The horizontal lines were parallel to the drop pad. For the puncture testing, a puncture bar was attached using 8 bolts to the center of the drop pad. The puncture bar was fabricated out of a 6-in. diameter solid steel section welded to a 2-in. thick steel plate. The 6-in. diameter section was recessed into the plate to insure adequate strength. The distance from the top of the steel plate to the top of the puncture bar was 16 in. There was no significant damage to the puncture bar as a result of the testing. There was no indication of motion of the puncture bar during any testing.

A crane was used to handle the test items for the drop testing. The crane was situated so that it could pull the item out of the conditioning box and handle it for the drops (Figure A-1 of Appendix A). SwRI personnel provided the crane operator instructions on how to position the test item for drops. During all testing, there was no tendency of the test item to move before the drop, as a result of crane operations or wind conditions.

The orientation of the test item was controlled by the use of wire rope slings, specifically designed for this test. Adjustments of the orientation were made using turnbuckles attached at the required locations. The orientation of the test item was verified using the Smartlevel digital instrument.

The drop height was measured using two calibrated plumb bobs. The length of the plumb bobs was adjusted using a calibrated tape measure. The plumb bobs were attached to the test item at the impact point. The crane was used to raise the item to the required height. The impact point and location of the bob was adjusted as required prior to removal of the plumb bob from the test item.

For drops, the test item was released using a quick release mechanism. Under normal conditions, the jaws of the release hold a D-ring pin in place. The D-ring is attached to the wire rope sling supporting the test item. For release, pneumatic pressure is supplied to release the locking pin and allow the jaws to open.

6.3 Fire Testing Facilities

The Department of Fire Technology has more than 30,000 sq ft of laboratory space housing advanced fire science analysis equipment and state-of-the-art full-scale furnaces used to evaluate the fire endurance and fire resistance of full-scale construction elements and assemblies. SwRI's large-scale horizontal furnace (Figure 6-2) was used to condition the test item at elevated temperature prior to conducting the pool fire test.

The Department operates a remote test facility located approximately 40 miles from SwRI's San Antonio facility. The remote test facility is isolated on approximately 15,000 acres and has full utility service. The facility is equipped with a mobile technical support trailer housing state-of-the-art rapid data acquisition equipment, environmental condition station, high-speed computer equipment, and photo/video documentation equipment. The test facility and a diagram of the pool fire test setup are shown in Figures 6-3 and 6-4.

7.0 EQUIPMENT AND INSTRUMENTATION CALIBRATION

All applicable test and measurement equipment were calibrated in accordance with the NPQP. Test and measurement equipment calibration certificates are found in Appendix B. The instrumentation used during testing are listed in Table 7-1.

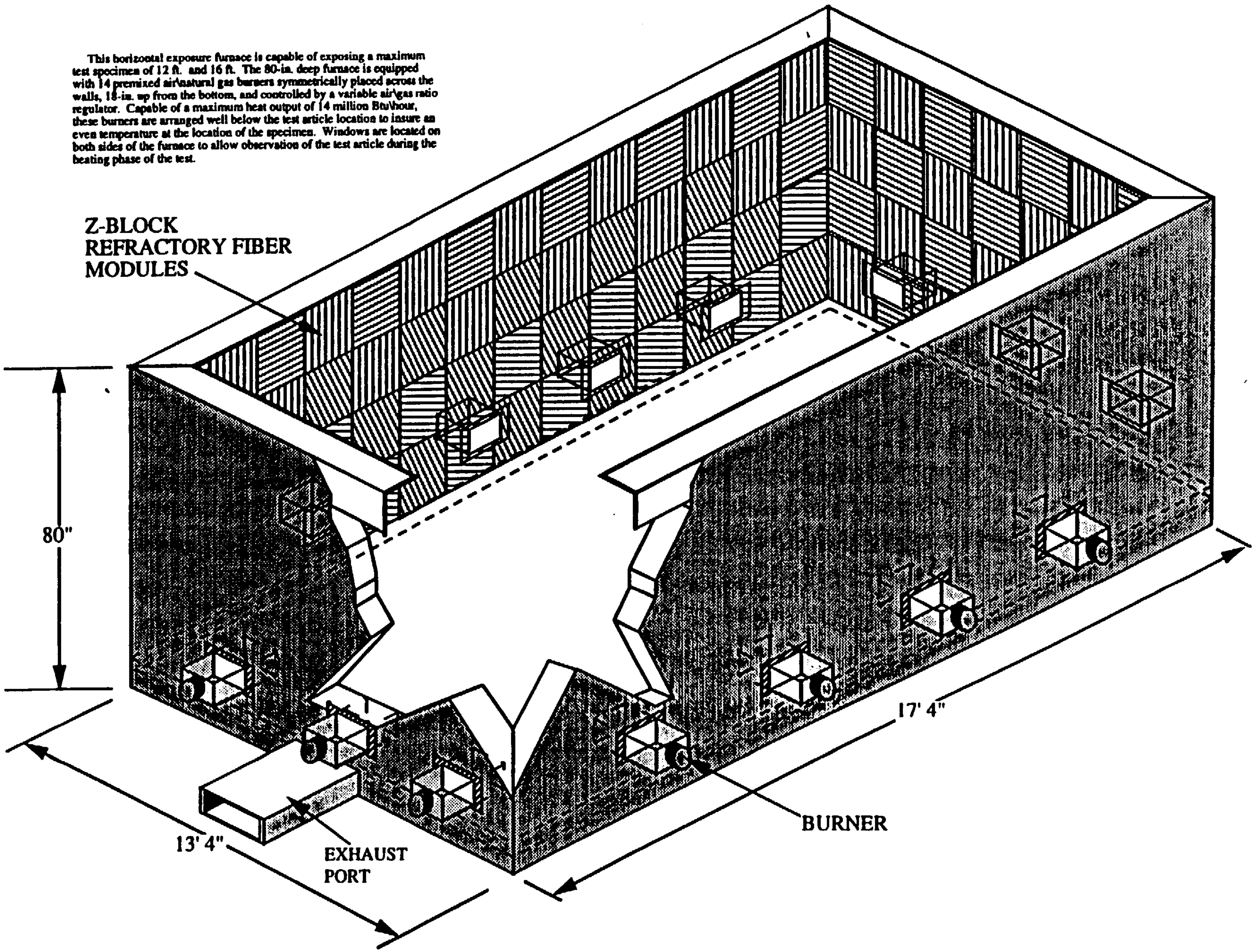


Figure 6-2. SwRI's Large-Scale Horizontal Furnace.

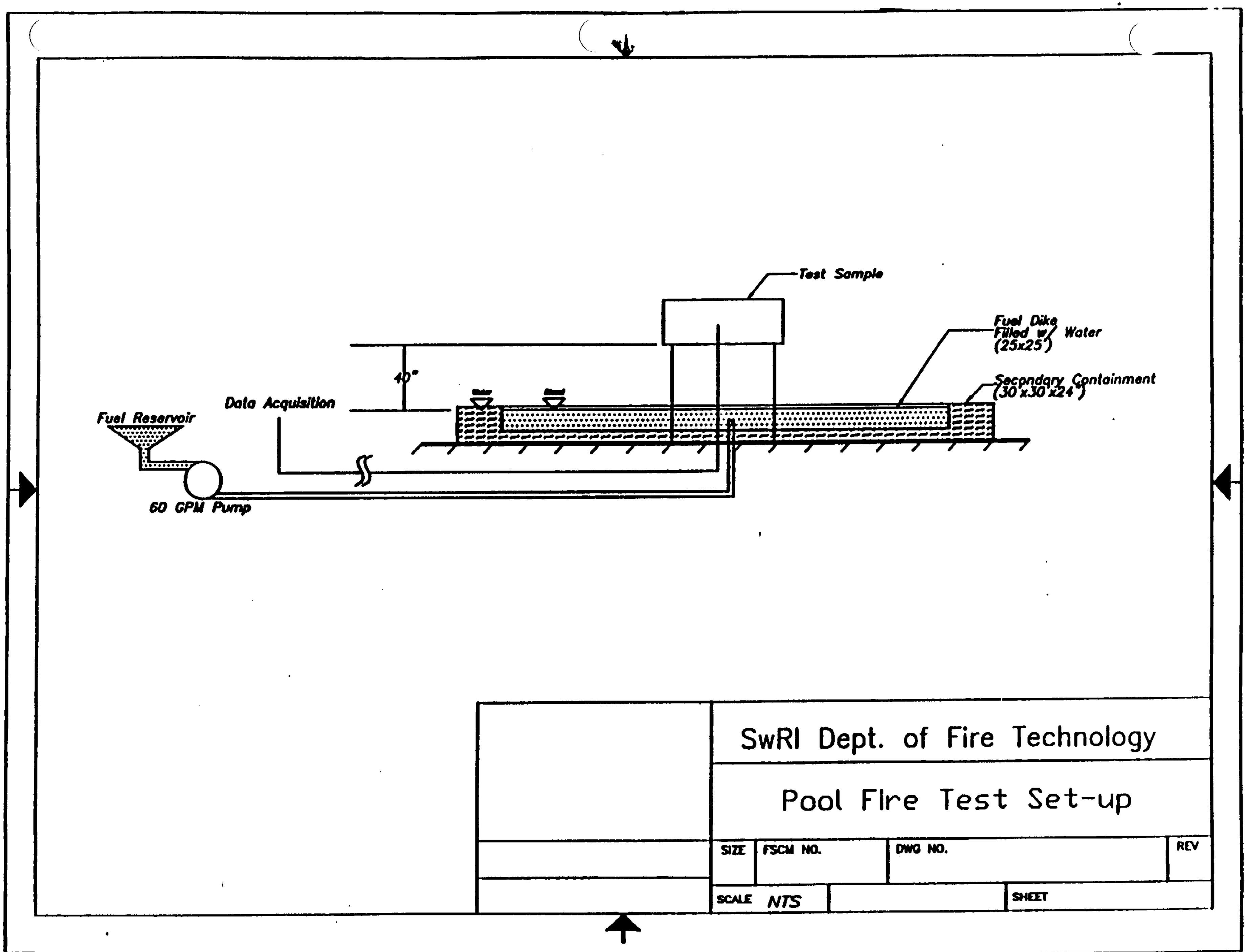


Figure 6-3. Pool Fire Test Setup.

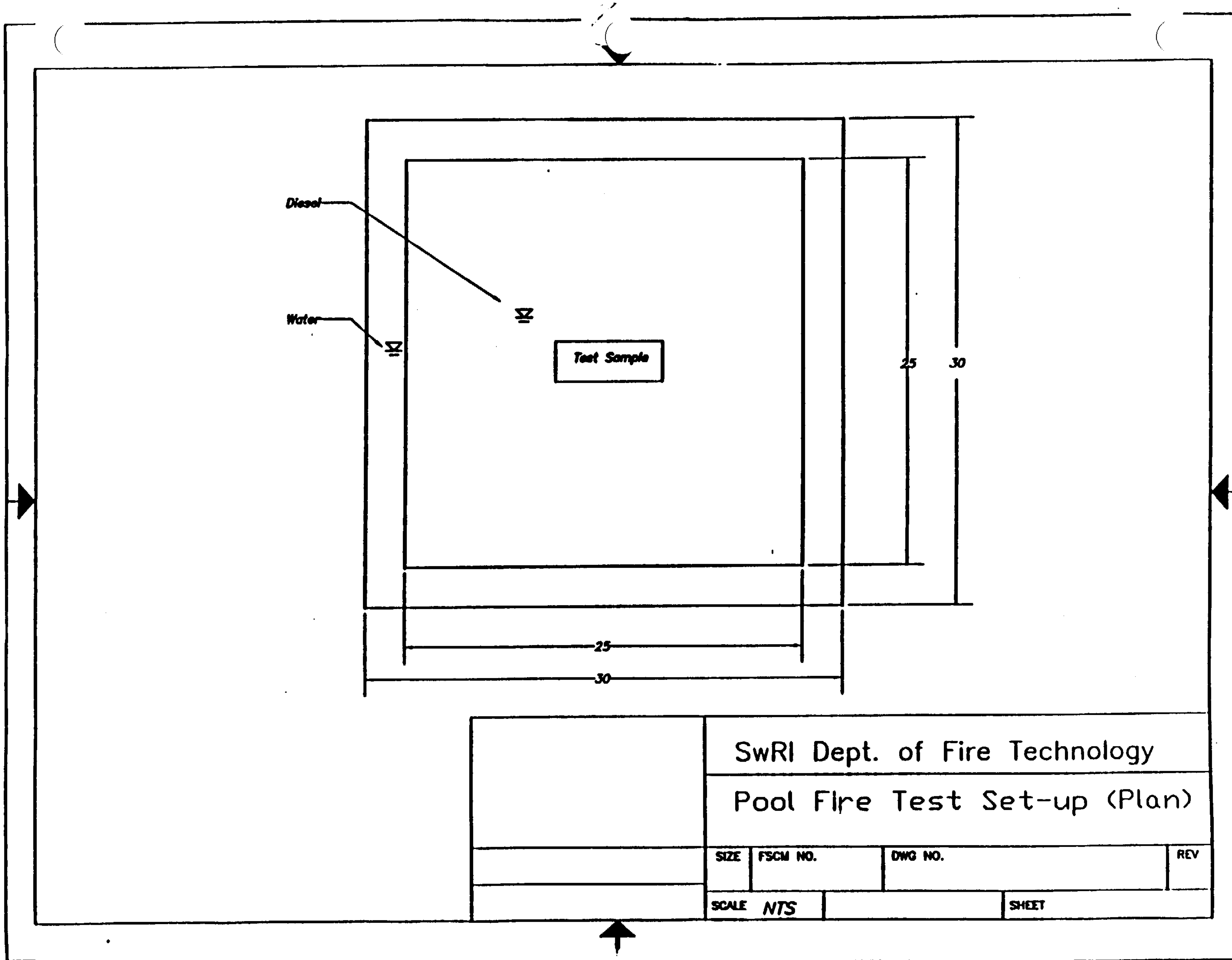


Figure 6-4. Pool Fire Test Setup.

Table 7-1. Test Instrumentation.

Item	Model	S/N	Calibration Due Date	Comments
Data Logger	Fluke Hydra	6114608	28 Feb 1998	Calibration Overdue, readings verified using Omega Thermal Monitor
Thermal Monitor	Omega	26591	19 Aug 1998	Single channel verification of Hydra
Thermal Controller	Watlow 942		NA	Control only with independent monitoring
Plumb Bob 30 foot Drop Height	NA	NA	before use 11 June 1998	Length based on calibrated tape measure, s/n 30-100T cal due 16 Dec 1998
Plumb Bob 40-in Drop Height	NA	NA	before use 11 June 1998	Length based on calibrated tape measure, s/n 30-100T cal due 16 Dec 1998
Level	Smartlevel Series 200	PLL-001	11 March 1999	Certificate # 28947
Data Acquisition	Fluke Helios	4889002	11 Aug 1998	Fire tests
Weather Station	NA	492	1 Dec 1998	Fire tests
Inconel Sheathed TC's (Vessel)	NA	LOT#M069751	NA	Fire tests
Inconel Sheathed TC's (Flames)	NA	LOT#M294709	NA	Fire tests
Air Velocity Meter	NA	94030180	24 Oct 1998	Drop Tests
Psychrometer	NA	J82244-1	19 June 1998	All tests
Dead Weight Tester	1305B100	8371009	9 April 1998	Leakage Tests
Transducer	GP-43F-150-7159	3979	9 April 1998	Leakage tests
Veeco	7MS-40	0555	28 March 1999	Helium leak detector

8.0 TEST PROCEDURE

8.1 Initial/Final Inspection and Preparation of Test Item

SwRI performed initial inspection to verify the pretest condition of the OPM-1 UO_2 shipping package and vessels. Photographs of the condition of the vessels were taken as necessary. The new vessels were provided to SwRI pre-filled with clean steel shot and ballast material to simulate a full payload. ESP conducted an initial leakage test to confirm that the vessels were airtight. See Appendix C for construction details and drawings of the OPM-1 UO_2 shipping package.

SwRI installed temperature measuring devices as necessary to monitor the temperature of the vessels during the tests. The temperature measuring devices were selected to insure that the required information could be obtained without adversely affecting the performance of the system. This includes both the temperature time histories and the peak temperature readings. Slight modification of the vessels and overpack was required to attach the temperature measuring devices. See Figure 8-1 for TC and thermal tape locations for the vessels.

Helium leakage tests were performed following the initial inspection and preparation of the OPM-1 package and completion of the pool fire test to insure that the internal vessels remained air tight.

8.2 Leakage Tests

Leakage tests were performed on the internal vessels prior to conducting the drop tests and following the pool fire exposure test The helium leak tests were performed by evacuating the vessels to the required pressure using a ruffing vacuum pump. The vessel pressure was reduced to the required level, helium was introduced in the region surrounding the O-ring seals, and the leak rate was measured with a helium leak detector and recorded.

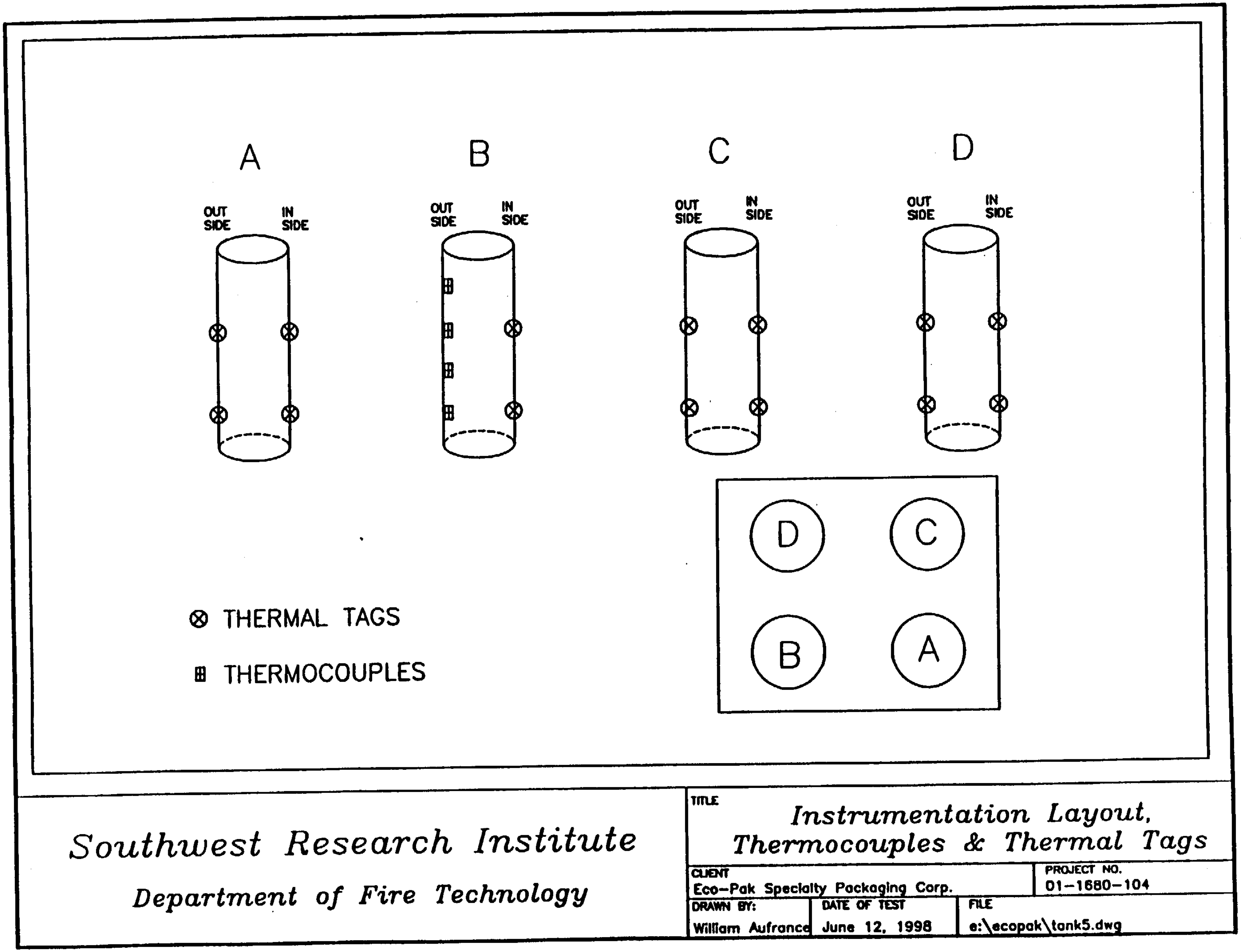


Figure 8-1. Instrumentation Layout.

8.3 Drop Testing

The initial physical tests of the OPM-1 UO_2 shipping package were a series of drop tests as described in Title 10 CFR 71.73 (c), (1) & (3).

A crane was utilized to raise the test items to the proper height. The test item was supported by a wire rope sling designed to insure that the test item would fall in the proper orientation.

An air-actuated, quick-release mechanism was used, and no guidance of the test item was provided during the drop. Prior to each drop test, the average wind speed, direction, and air temperature were measured to determine if they were within acceptable limits.

There were four drops of the OPM-1 package in the drop testing phase. The first drop test performed was a 30-ft drop onto the flat surface of the pad with the test item in a vertical, upright position. The second drop was a 30-ft drop onto a corner of the specimen. Drop No. 3 was onto an edge of the test item, again from a height of 30-ft. The final drop test was a 40-in. drop onto a puncture bar attached to the center of the steel plate on the drop pad. The puncture bar was constructed of a 6-in. diameter mild steel bar welded into a 2-in. thick steel plate. This plate was, in turn, bolted to the steel plate on top of the drop surface. Following all drops, the damage to the OPM-1 UO_2 shipping package was observed and recorded.

Data recorded for each drop test included: normal speed video, color photographs, and measurements of deformations and atmospheric conditions. A backdrop with horizontal and vertical lines spaced at 1-ft increments was provided for reference during the drop event. No acceleration time histories were obtained during the drop. Following the drop test, the test items were inspected, and the damage to the overpack was noted. Photo/video documentation was taken, after which the test items were submitted for fire exposure tests.

8.4 Fire Performance Evaluation

Following the drop tests, the test items were transported to SwRI's Department of Fire Technology for elevated temperature thermal conditioning prior to performing the pool fire test at SwRI's remote test facility. The test item was placed in SwRI's large-scale horizontal furnace, and conditioned to a temperature of 100-120°F for a minimum of 24 hr prior to the test. Temperature measurements were made at locations specified in the test procedure with the approval of the client.

Immediately following the elevated temperature thermal soak, the test article was insulated and transported to the remote test site, positioned on the test fixture, and exposed to the specified pool fire conditions for a minimum 30-min period. Documentation consisted of normal speed video and still photography at a minimum of two locations. The pool fire dimensions were 25 x 25 ft. Fuel was pumped into the pool fire pan during the test at a rate appropriate to maintain a fully engulfed pool fire for 30 min.

Following extinguishment, temperature data was recorded during the cool down period. During cool down, the test article was protected from precipitation and wind effects to eliminate enhanced cooling of the test article. The test article was then transported to SwRI for further analysis and the post-fire leakage test.

9.0 TEST RESULTS

9.1 Leakage Test Results

Initial helium leakage tests were performed on the vessels prior to conducting the drop tests and following completion of the pool fire exposure test. The acceptance criteria specified that any leakage greater than 1.0×10^{-7} std cc/sec of air is considered a failure.

The pre-drop helium leakage test was performed on June 9, 1998. A ruffing vacuum pump was used to evacuate the vessels to the required pressure of less than 1×10^{-3} atm (1×10^{-3} atm = .0147 psi = .761 Torr). The background helium leakage rate was measured, and helium was introduced in the region surrounding the O-ring seals. The leakage rate was measured after 15 to 25 min with the helium leak detector, and the results were recorded.

Following completion of the pool fire exposure test, on June 15, 1998, the final post-fire helium leakage tests were performed on the internal vessels. A ruffing vacuum pump was used to evacuate the vessels to the required pressure, and the background helium leakage rate was measured. Helium was introduced in the region surrounding the O-ring seals, and the leakage rate was measured after 15 min with the helium leak detector.

Following completion of the post-fire helium leakage tests, all vessels were inspected and found to be undamaged and in good condition with no loss of contents. Table 9-1 summarizes results for the pre-drop/post-fire helium leak tests. Data log sheets for all leakage tests are found in Appendix D.

Table 9-1. Leakage Test Results.
Test Item: OPM-1 SN003 Vessels A/B/C/D

TEST	REQUIREMENT (std cc/sec)	MEASUREMENT (std cc/sec)	PASS/FAIL
Pre-Drop Helium			
Vessel A	$\leq 1.0 \times 10^{-7}$	1.0×10^{-7}	Pass
Vessel B	$\leq 1.0 \times 10^{-7}$	0.8×10^{-9}	Pass
Vessel C	$\leq 1.0 \times 10^{-7}$	0.9×10^{-9}	Pass
Vessel D	$\leq 1.0 \times 10^{-7}$	0.8×10^{-9}	Pass
Post Fire Helium			
Vessel A	$\leq 1.0 \times 10^{-7}$	2.0×10^{-9}	Pass
Vessel B	$\leq 1.0 \times 10^{-7}$	1.9×10^{-9}	Pass
Vessel C	$\leq 1.0 \times 10^{-7}$	4.0×10^{-9}	Pass
Vessel D	$\leq 1.0 \times 10^{-7}$	5.0×10^{-9}	Pass

9.2 Drop Testing

The testing outlined in this section was designed to demonstrate the performance of the shipping configurations under hypothetical accident conditions.

The drop testing included the following major steps:

1) Conditioning to -20°F of OPM-1.
2) 30-ft drop test of SN003 in vertical orientation.
3) Physical inspections of unit.
4) 30-ft drop test of SN003 on corner.
5) Physical inspections of unit.
6) 30-ft drop test of SN003 on edge.
7) Physical inspections of unit.
8) 40-in. puncture test of SN003
9) Physical inspections of unit.

Test facilities utilized for performance of the work under this project were adequate to accomplish the objectives of the project.

9.2.1 Assumptions

A basic assumption made for this testing was that the drops made are the worst case condition as required by 10 CFR Part 71. ESP defined these configurations.

9.2.2 Environmental Conditioning

The low temperature conditioning was done in a chamber to achieve the required test item temperature, -29°C (-20°F), on the insulation. To measure this temperature, a TC was installed in a hole drilled 2 in. deep in the overpack. The hole was sealed with RTV to prevent air infiltration. To accelerate cooling, the air temperature in the chamber was varied. The target air temperature was -40°C (-40°F), the minimum transportation temperature specified by ESP. In some cases, the air temperature was set lower than this to accelerate the cooling. Because of the thermal mass and insulation of the test item, its response to changes in the air temperature was slow.

Conditioning was performed until the test item had reached the required temperature. During the testing process (removal from the conditioning chamber, drop angle adjustments, drops, and physical inspection), the test item temperature rose. This low-temperature conditioning met the intent of the low-temperature requirements of 10 CFR Part 71.

Plots of the chamber air temperature and test item temperatures are included in this report as Figure 9-1. Low-temperature conditioning of the OPM-1 SN003 test item started on June 10, 1998, at 2:00 p.m. The chamber air temperature was set to a nominal -40°C (-40°F). Approximately three hours into the conditioning, the solenoid valve stuck in the open position and the chamber air temperature dropped. This condition was fixed within 5 min, and the air temperature rapidly returned to the set point. By 7:10 a.m. on June 11, 1998, the test item temperature was at the required level.

On June 11, 1998, at 1:59 p.m., OPM-1 SN003 was removed from the chamber, and the assigned drop tests were performed. At the time of removal from the conditioning chamber, the insulation had a temperature of -35°C (-31°F).

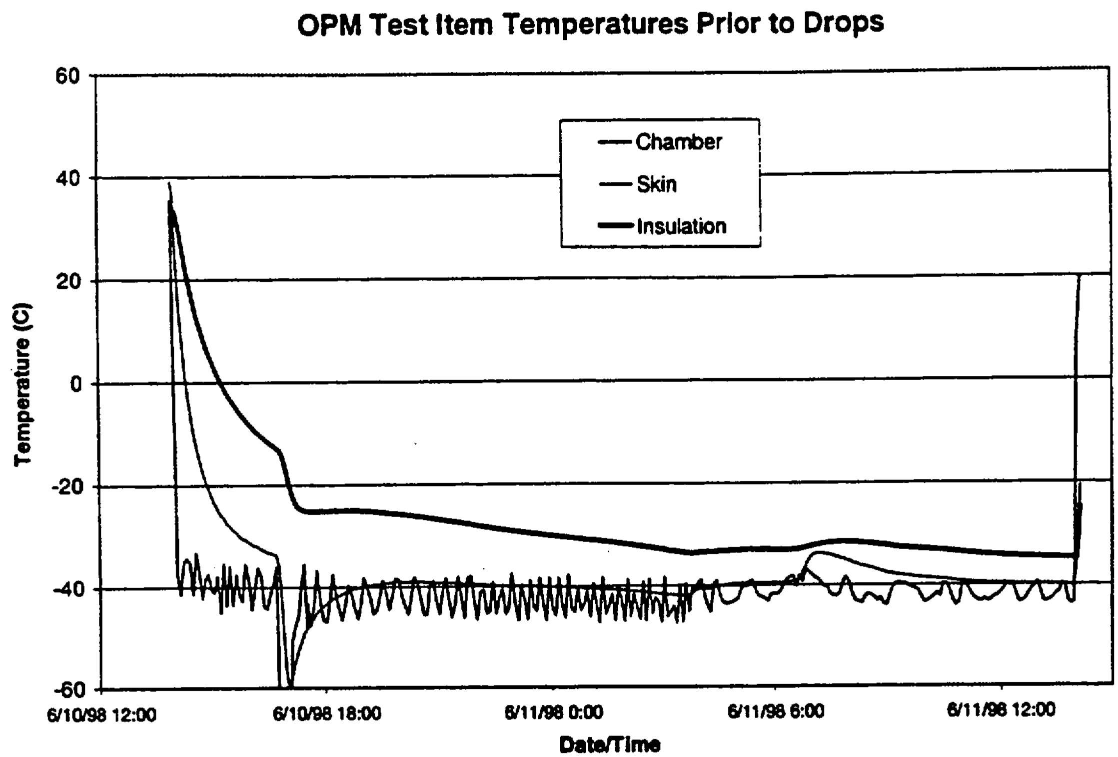


Figure 9-1. OPM-1 Low-Temperature Conditioning Time History.

9.2.3 Drop Testing

Drop testing was performed with the cooled and undamaged OPM-1 test item. After low-temperature conditioning, the test item was removed from the chamber. Immediately before opening the chamber, the test item temperature was -35°C (-31°F). The test item was raised to the required drop height with the crane. The drop height was determined using the calibrated plumb bob attached to the first impact point on the test item. The release of the test item was by a pneumatically actuated quick-release mechanism. No guidance of the test item was provided during the drop. Drop testing was performed under conditions that did not affect the results of the test. The average wind speed was noted, and found to be sufficiently low, so that the packaging did not rotate during testing.

Four tests were performed on OPM-1 SN003. The first was a 30-ft drop onto the flat surface of the pad with the test item in a vertical orientation. The damage to the overpack exterior was measured and recorded following this testing. The second drop was a 30-ft drop onto one corner of the test item. The damage to the exterior was again measured and recorded following this testing. The third test was a 30-ft drop onto an edge of the test item, and the last test was a 40-in. drop onto a puncture bar. Following each of these tests, the damage to the test item was measured and recorded.

Table 9-2 and the explanations that follow summarize the testing performed on this test item. All testing was completed successfully, and all phases of this testing were witnessed by SwRI QA/QC and ESP personnel.

Table 9-2. OPM-1 SN003 Drop Testing Performed.

Procedure	Dates	Comments
Conditioning Before Drop	6/10/98 6/11/98	Test item insulation prior to drop tests, -35°C (-31°F)
30-ft Drop (upright orientation)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel
30-ft Drop (corner)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel
30-ft Drop (edge)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel
40-in. Drop (puncture)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel

Test 1 (vertical drop), pre-test conditions:

- Drop Angle 0 degrees (measured from vertical)
- Drop Height 30 ft to impact face
- Wind Speed < 2.4 mph

The test item was released cleanly and impacted the pad at the desired orientation. The test item impacted the drop pad and remained upright on its end. There was visible warping of exterior sheet metal, as well as compaction of the legs and base metal on the bottom of the test item. Videos were taken of the drop event. The condition of the test item can be seen in Figure A-2 of Appendix A. As a result of the drop, the exterior of the test item was damaged. Deformation data of the exterior was measured and recorded by Fire Technology personnel and reported in Appendix C. Color photographs showing the extent of damage were taken.

Test 2 (corner drop), pre-test conditions:

- Drop Angle 42.5 degrees (measured from vertical)
- Drop Height 30 ft to impact face
- Wind Speed < 3.4 mph

The test item was released cleanly and the drop was made (Figure A-3 of Appendix A) with the impact in the proper location. Following the drop, the test item settled onto its top after the impact on one of its corners. There was visible compaction and deformation of the impact corner. Deformation of the unit was measured and recorded by Fire Technology personnel and reported in Appendix C. Videos were taken of the drop event, and color photographs showing the extent of damage were taken.

Test 3 (edge drop), pre-test conditions:

- Drop Angle — 40 degrees (measured from vertical)
- Drop Height — 30 ft to impact face
- Wind Speed — < 1.5 mph

The test item was released cleanly and the drop was made (Figure A-4 of Appendix A) with the impact in the proper location. Following the drop, the test item came to rest on its side after impacting the appropriate edge. Deformation of the unit was measured and recorded by Fire Technology personnel and reported in Appendix C. Color photographs and video showing the extent of the damage were taken.

The severe impact during the edge drop test broke welds holding the thermocouple protective plate to the test item, and the thermocouple leads to the instrumented vessel were sheared off. The decision was made to continue with the puncture drop test and complete the drop test phase before repairing the thermocouples.

Test 4 (puncture drop), pre-test conditions:

Drop Angle	90 degrees (impact on a side [measured from vertical])
Drop Height	40 in. to impact face
Wind Speed	< 0.9 mph

The test item was released cleanly and the drop was made (Figure A-5 of Appendix A) with the impact in the proper location. The OPM-1 unit impacted the puncture bar in the correct orientation and then rolled off the bar, coming to rest a few feet off of the drop pad. Deformation of the unit was measured and recorded by Fire Technology personnel and reported in Appendix C. Color photographs and video showing the extent of the damage were taken.

Following the drop tests, the thermocouple leads were inspected and found to have sustained irreparable damage. Although the test protocol specified that the test item remained closed until the fire test was completed, SwRI determined that the need for thermocouple data during the fire test outweighed the concern for keeping the test item sealed. This decision was based on the fact that the remaining three vessels would remain undisturbed and unaffected by removing the instrumented vessel. Furthermore, the drop sites were selected to minimize the damage to the side of the test item housing the instrumented vessel, so the remaining vessels were subjected to the worst case damage.

The outer and inner lids of the test item housing the instrumented vessel did not sustain serious damage during the drop tests and were easily removed. The vessel was removed from the test item, new thermocouples were welded to the vessel and the inner and outer lids were secured.

9.3 Fire Performance Evaluation Test

The OPM-1 package was placed in SwRI's large-scale horizontal furnace and conditioned to a temperature of 100-120°F. Immediately following the elevated temperature thermal soak, the test article was insulated and transported to the remote test site. The elapsed time the test item was at the conditioned temperature was more than 24 hr, consisting of furnace exposure, transportation, and setup time before the pool fire was ignited.

The pool fire test described in Title 10 CFR 71.73 (c), (4) was performed on June 12, 1998. Ms. Heather Little representing ESP was present to witness the test. Following initial startup procedures and transfer of 2000 gal of diesel fuel to the burn pan, the data acquisition equipment was verified and the fuel was ignited to begin the 30-min pool fire test. Table 9-3 lists the significant observations during the pool fire exposure and post-test cool down period.

Following extinguishment, temperature data were recorded during the cool down period. During the cool down, the test article was protected from precipitation and wind effects to eliminate enhanced cooling of the test article. The test article was then transported to SwRI for further analysis and the post-fire leakage test. Various time-temperature profiles and test condition graphs taken before and during the pool fire exposure and cool down period are shown in Figures 9-2 to 9-9. Table 9-4 shows the maximum temperature and time of occurrence for each vessel thermocouple during the 30-min pool fire exposure and subsequent cool down period. Figure 9-10 shows the maximum temperature reading recorded by the secondary instrumentation, which consisted of temperature-sensitive labels located next to the TC's to monitor the maximum temperature during the pool fire exposure and cool down period.

Table 9-3. Pool Fire Test Observations.

TIME (Min:Sec)	OBSERVATIONS
-0:45	Pool fire ignited to begin pre-burn.
0:00	Pre-burn completed. Flames fully developed across pool surface.
1:00	Test item engulfed in flames, light wind pushes pool flames west.
3:00	Test item engulfed in flames, light wind pushes pool flames west.
4:30	Wind lets up momentarily, pool flames nearly vertical.
5:00	Test item engulfed in flames, flames again pushed westward, intermittent view of test item.
6:00	Wind lessens, pool flame near vertical, fire plume seen emitting from top of test item.
8:45	Pool flame still nearly vertical, fire plume from test item intensifies.
10:00	Pool flame vertical, test item fire plume continues to burn.
15:00	Pool flame intermittently vertical, test item fire plume continues to burn.
20:00	Pool flame intermittently vertical, test item fire plume continues to burn.
25:00	Light wind pushes pool flames westward, intermittent view of test item, flame plume from top continues to burn.
30:00	Light wind pushes pool flames westward, intermittent view of test item, flame plume from top continues to burn.
31:00	Flames beginning to subside, residual burning allowed to self extinguish.
43:15	Initial inspection of test item.
50:00	Temperature monitoring of test item continuing (no stop between burn and cool-down period).
No significant observations for remainder of cool down period (11 hr).	

Tabular data for the TC measurements appear in Appendix E. Photographic documentation for the fire tests appears in Appendix F.

CLIENT: ECO-PAK SPECIALITY PACKAGING
SwRI PROJECT No.: 01-1680-102b
DATE: 12 JUNE 1998
FILE ID: 162ECH1.DAT
163ECH2.DAT

ELEVATED TEMPERATURE SOAK
OPM-1

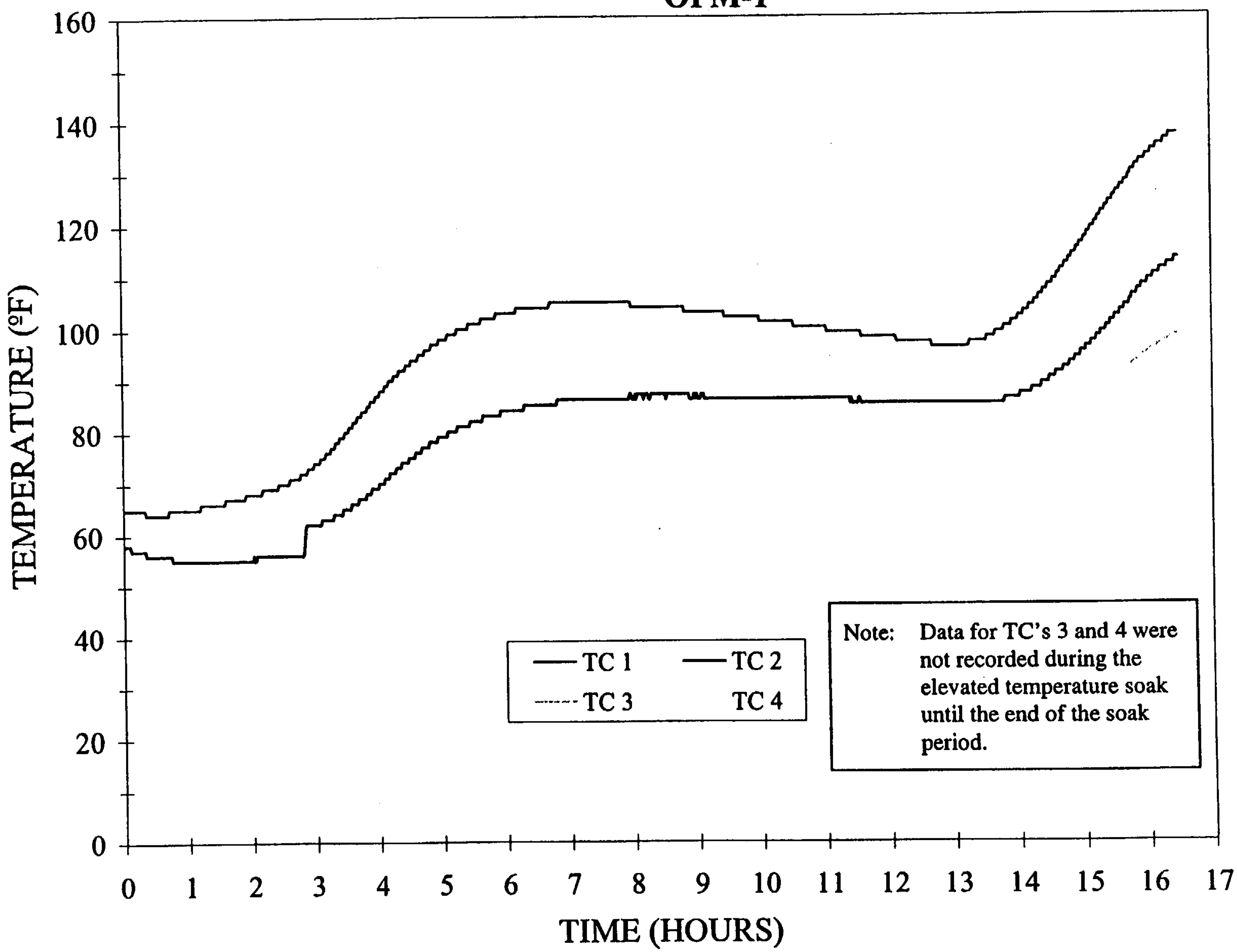


Figure 9-2. Vessel Thermocouple Readings.

CLIENT: ECO-PAK SPECIALTY PACKAGING
SwRI PROJECT No.: 01-1680-102b
DATE: 12 JUNE 1998
FILE ID: 163OPMW1.DAT

OPM-1 PRE-TEST DATA
SPECIMEN THERMOCOUPLES

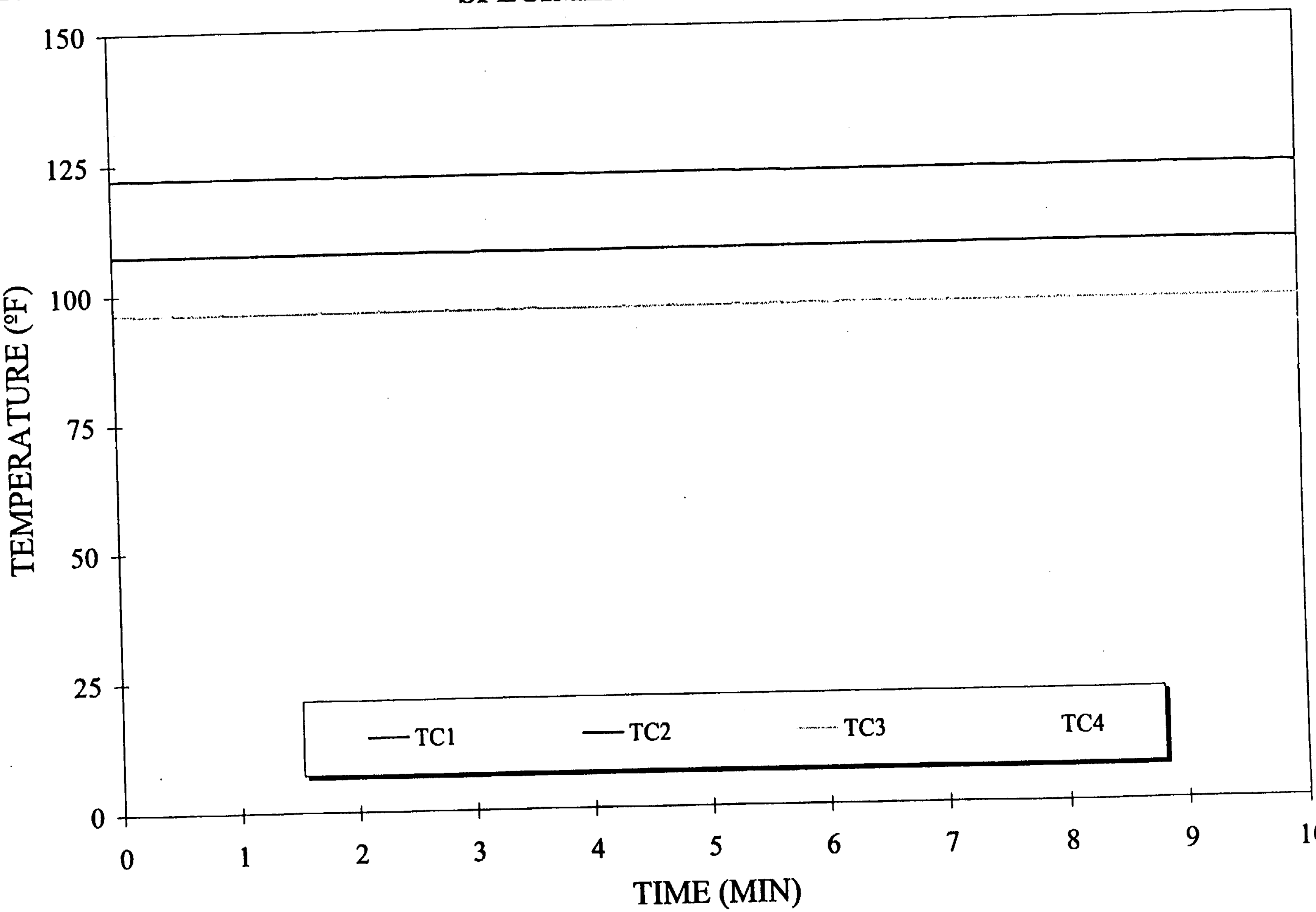


Figure 9-3. Vessel Thermocouple Readings.

CLIENT: ECO-PAK SPECIALTY PACKAGING
SwRI PROJECT No.: 01-1680-102b
DATE: 12 JUNE 1998
FILE ID: 163OPMT1.DAT

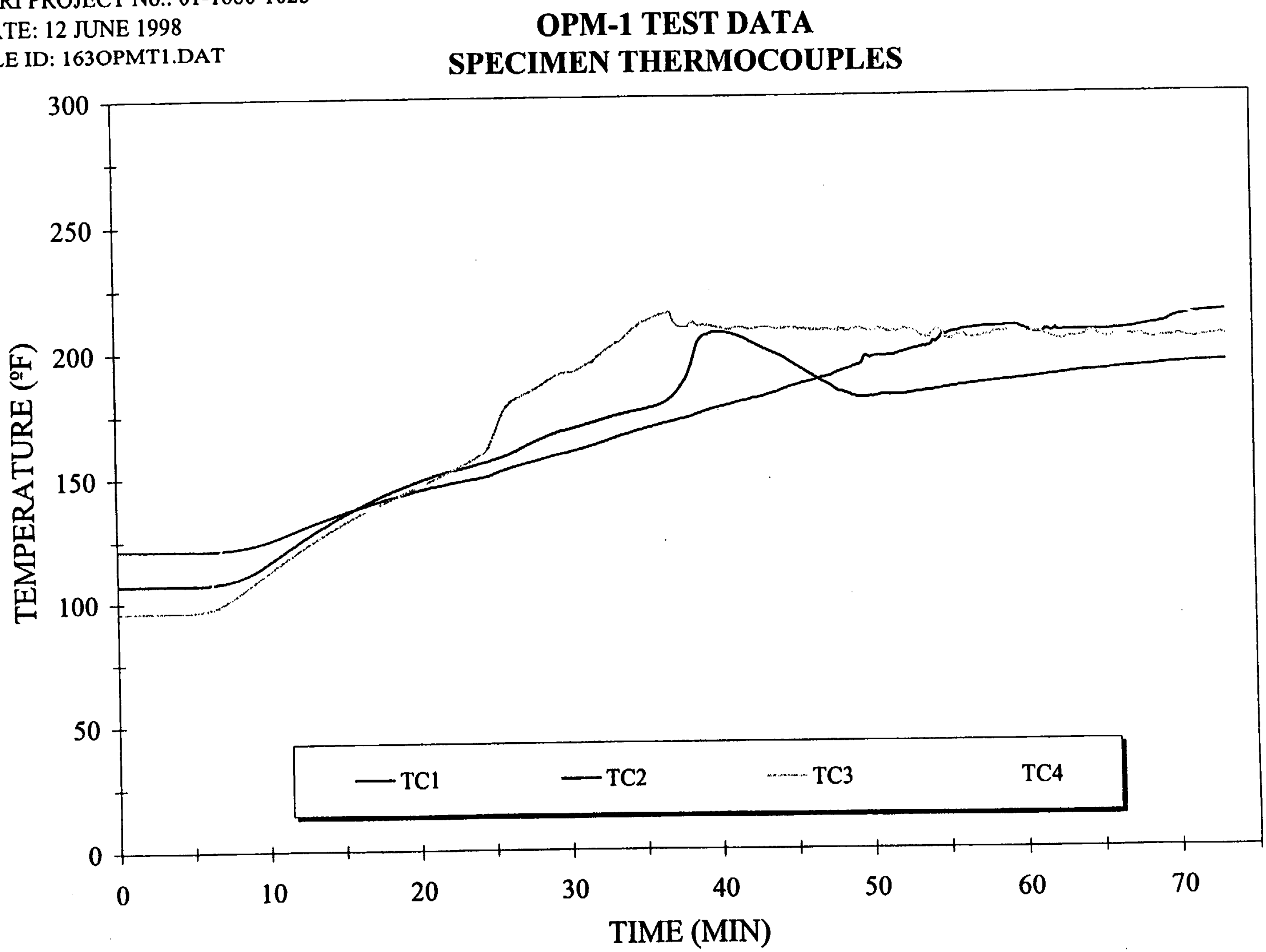


Figure 9-4. Vessel Thermocouple Readings.

CLIENT: ECO-PAK SPECIALTY PACKAGING
SwRI PROJECT No.: 01-1680-102b
DATE: 12 JUNE 1998
FILE ID: 163OPMC1.DAT

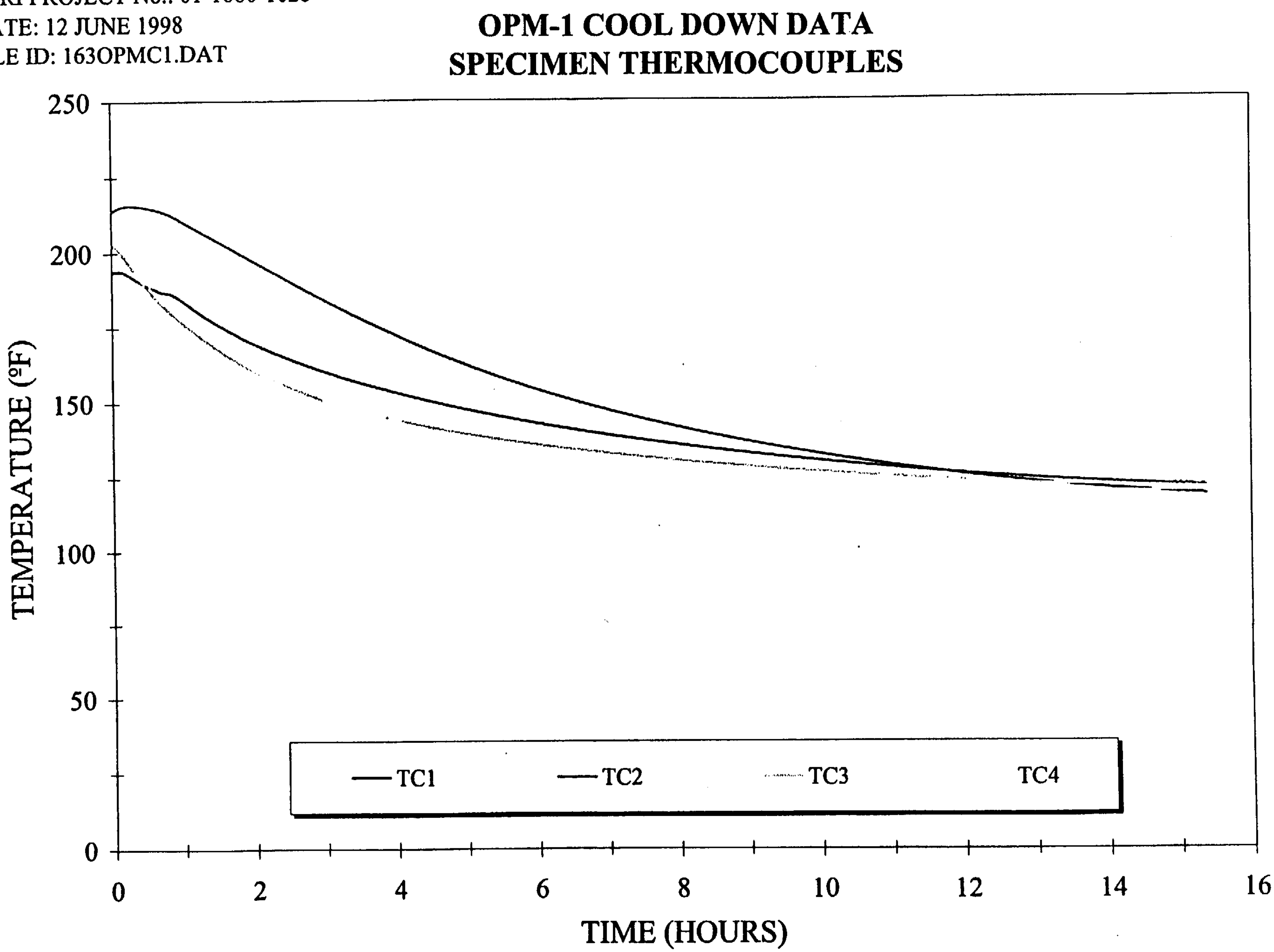


Figure 9-5. Vessel Thermocouple Readings.

CL. . ECO-PAK SPECIALTY PACKAGING
SwRI PROJECT No.: 01-1680-102b
DATE: 12 JUNE 1998
FILE ID: 163OPMT1.DAT

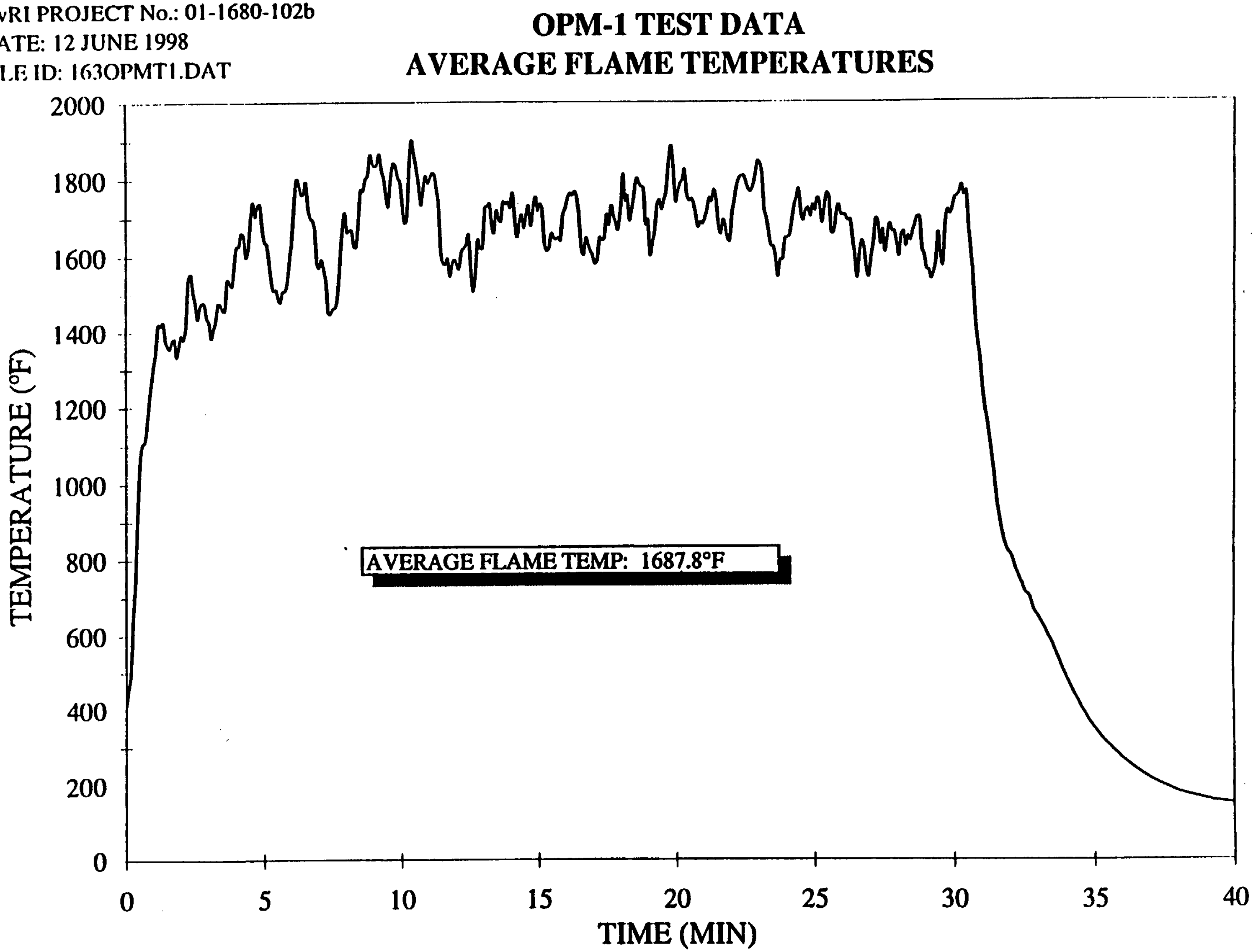


Figure 9-6. Pool Flame Thermocouple Readings.

CLIENT: ECO-PAK SPECIALTY PACKAGING
SwRI PROJECT No.: 01-1680-102b
DATE: 12 JUNE 1998
FILE ID: 163OPMT1.DAT

OPM-1 TEST DATA
AMBIENT TEMPERATURES

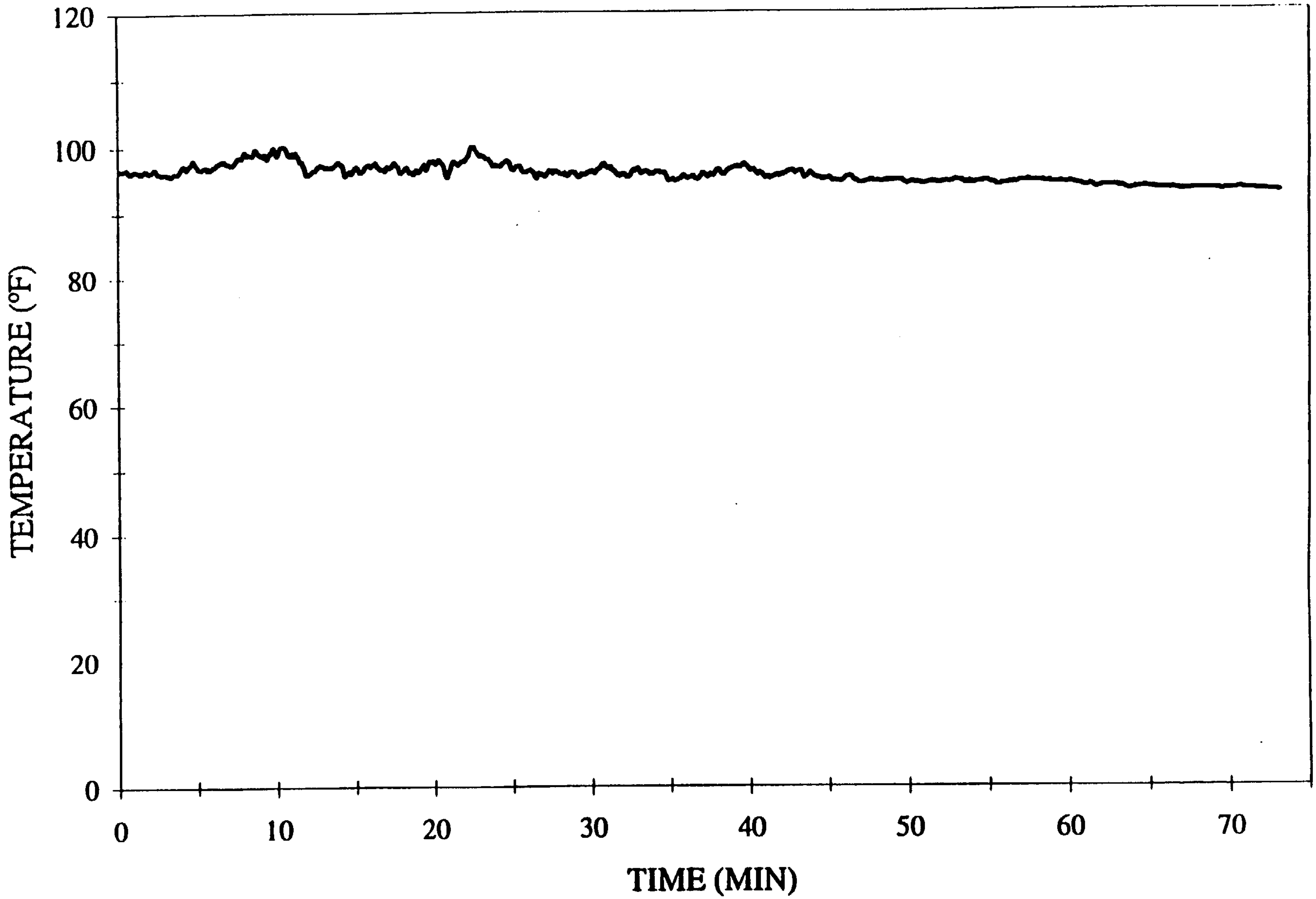


Figure 9-7. Ambient Test Temperature Readings.

CLII (ECO-PAK SPECIALTY PACKAGING
SwRI PROJECT No.: 01-1680-102b
DATE: 12 JUNE 1998
FILE ID: 163OPMT1.DAT

OPM-1 TEST DATA
WIND SPEED

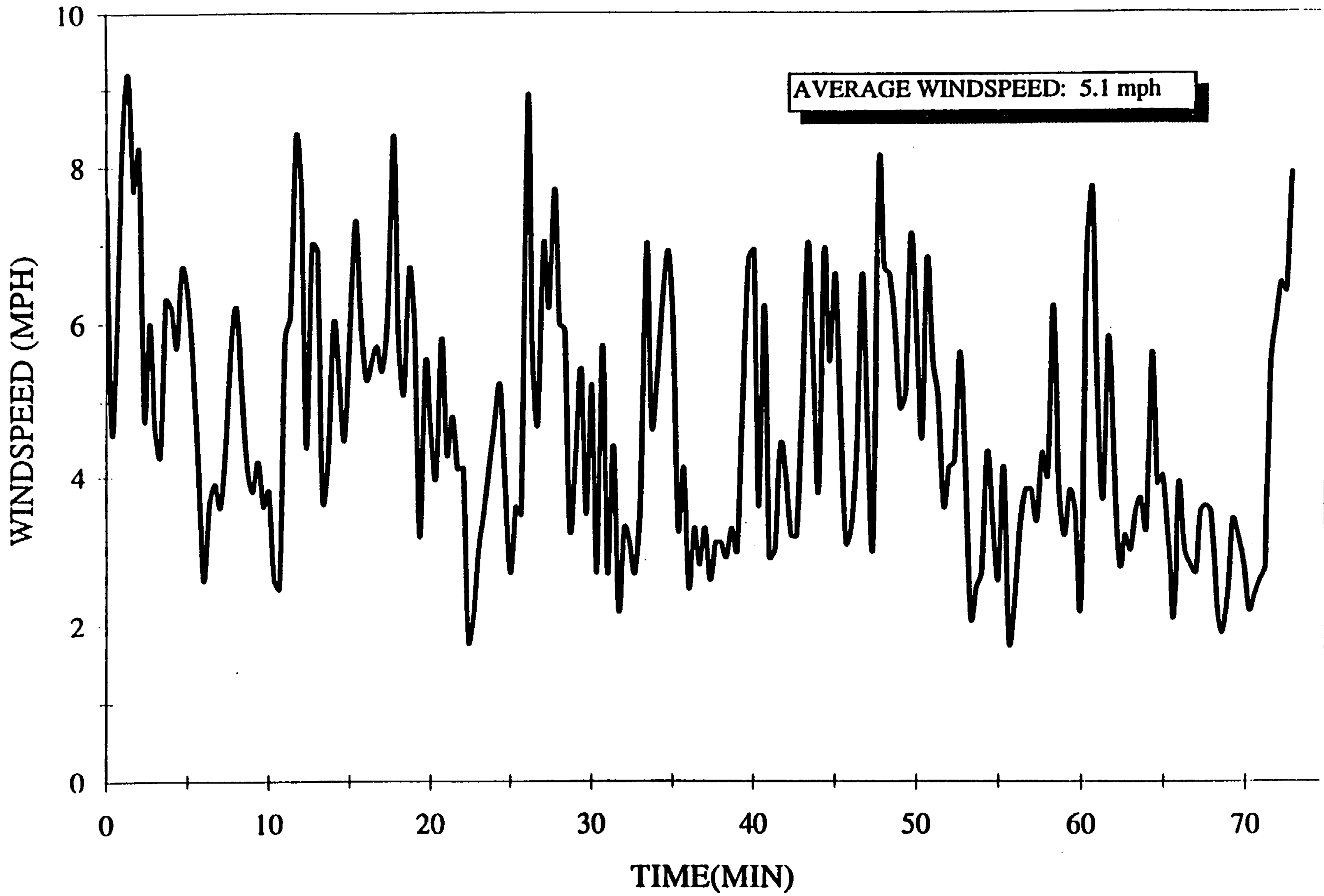


Figure 9-8. Test Wind Speed Readings.

CLI (ECO-PAK SPECIALTY PACKAGING
SwRI PROJECT No.: 01-1680-102b
DATE: 12 JUNE 1998
FILE ID: 163OPMC1.DAT

OPM-1 COOL DOWN DATA
AMBIENT TEMPERATURES

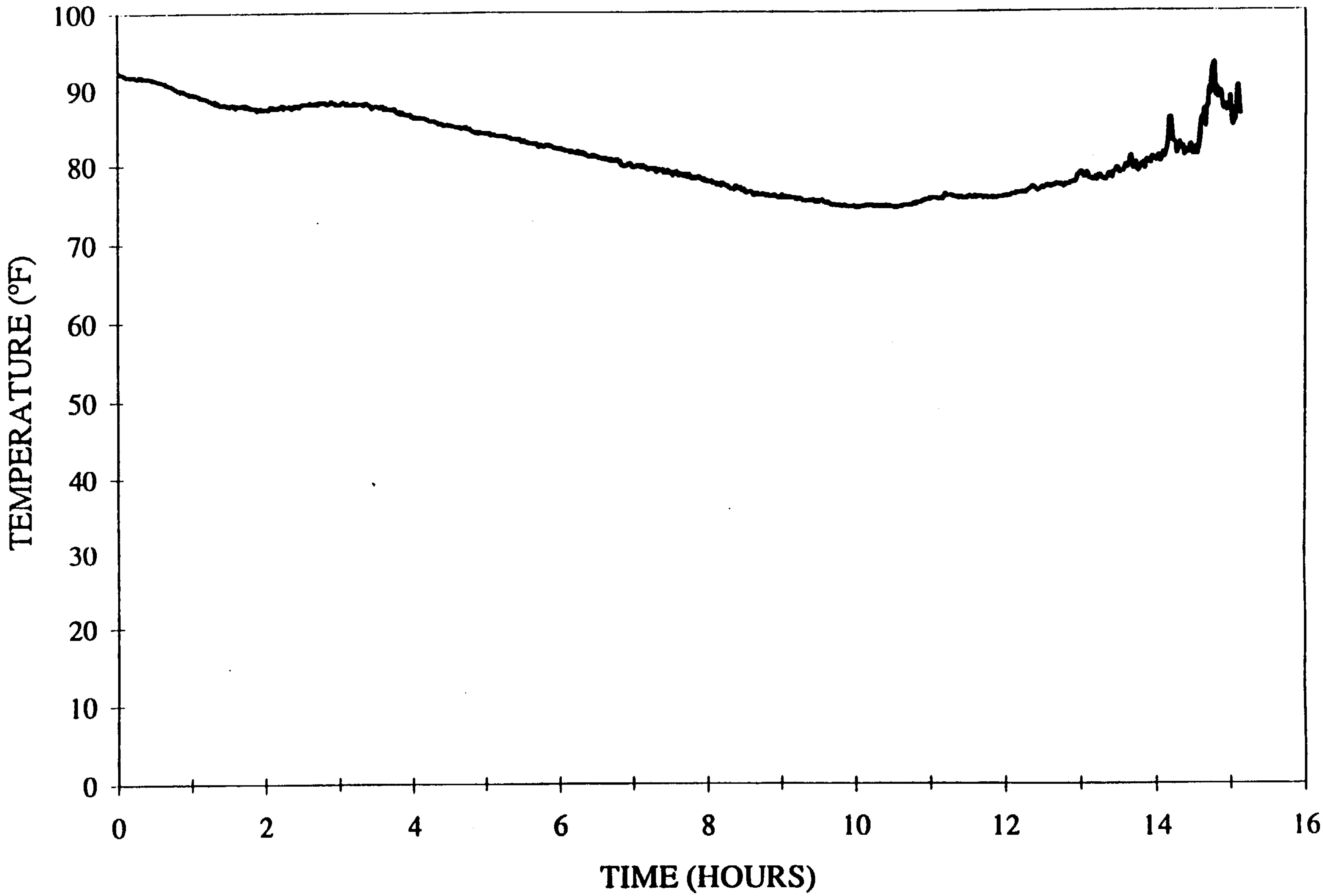
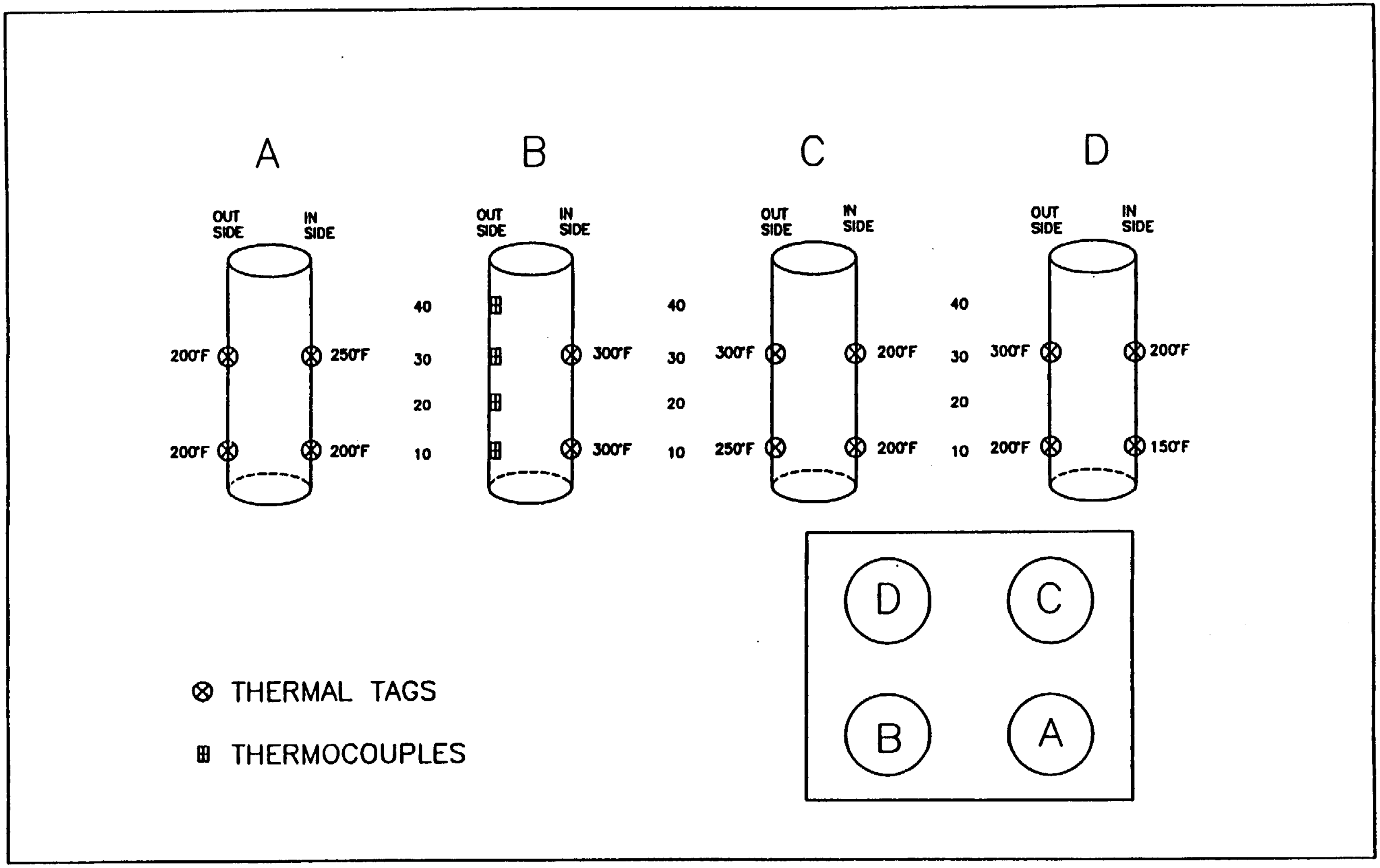


Figure 9-9. Ambient Cool Down Temperature Readings.



Southwest Research Institute Department of Fire Technology	TITLE Instrumentation Layout, Thermocouples & Thermal Tags		
	CLIENT Eco-Pak Specialty Packaging Corp.		PROJECT NO. 01-1680-104
	DRAWN BY: William Aufrance	DATE OF TEST June 12, 1998	FILE e:\ecopak\tank5.dwg

Figure 9-10. Secondary Instrumentation Temperature Readings.

Table 9-4. OPM-1 Maximum Temperature Readings.

TC. No.	Fire Exposure < 30 Min. Max. Temp (°F)	Fire Exposure < 30 Min. Time (Min)	Cool Down > 73 Min. Max. Temp (°F)	Cool Down > 73 Min. Time (Min after 30)
1	159.2	30	215.8	14
2	168.4	30	194	6
3	191.0	30	203.2	0
4	267.1	30	208.8	0

10.0 SUMMARY OF TEST RESULTS

Table 10-1 summarizes the results for the pre-drop/post-fire helium leak tests.

Table 10-1. Helium Leakage Test Results.
Test Item: OPM-1, SN003, Vessels A/B/C/D

TEST	REQUIREMENT (std cc/sec)	MEASUREMENT (std cc/sec)	PASS/FAIL
Pre-Drop Helium			
Vessel A	$\leq 1.0 \times 10^{-7}$	1.0×10^{-7}	Pass
Vessel B	$\leq 1.0 \times 10^{-7}$	0.8×10^{-9}	Pass
Vessel C	$\leq 1.0 \times 10^{-7}$	0.9×10^{-9}	Pass
Vessel D	$\leq 1.0 \times 10^{-7}$	0.8×10^{-9}	Pass
Post Fire Helium			
Vessel A	$\leq 1.0 \times 10^{-7}$	2.0×10^{-9}	Pass
Vessel B	$\leq 1.0 \times 10^{-7}$	1.9×10^{-9}	Pass
Vessel C	$\leq 1.0 \times 10^{-7}$	4.0×10^{-9}	Pass
Vessel D	$\leq 1.0 \times 10^{-7}$	5.0×10^{-9}	Pass

Table 10-2 summarizes the results of the drop testing performed on The OPM-1. The test item received some damage during the drop tests that was considered acceptable by ESP personnel.

Table 10-2. OPM-1 SN003 Drop Testing Performed.

Procedure	Dates	Comments
Conditioning Before Drop	6/10/98 6/11/98	Test item insulation temperature prior to drop tests, -35°C (-31°CF)
30-ft Drop (upright orientation)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel
30-ft Drop (corner)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel
30-ft Drop (edge)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel
40-in Drop (puncture)	6/11/98	Good drop
Exterior Physical Measurements	6/11/98	By Fire Technology personnel

The Department of Fire Technology conducted the 30-min pool fire test described in Title 10 CFR 71.73 (c), (4) on June 12, 1998. The average initial temperature of the thermocouple fitted cylinder was 104°F. The maximum single point temperature recorded on the surface of the cylinder during the 30-min pool fire exposure test was 267.1°F (TC 4 at 30 min), and the average of the maximum TC readings was 196°F.

The maximum single point temperature recorded on the surface of the cylinder during the 15-hr cool down period was 215.8°F (TC 1 at 14 min), and the average of the maximum TC readings was 205°F.

Following completion of the post-fire helium leakage tests, all vessels were inspected and found to be undamaged and in good condition with no loss of contents.

APPENDIX A

DROP TESTING - PHOTOGRAPHIC DOCUMENTATION

(Consisting of 10 Pages)

Figure A-1. Drop Pad with concrete Slab, Steel Impact Plate, Backdrop, and Crane.

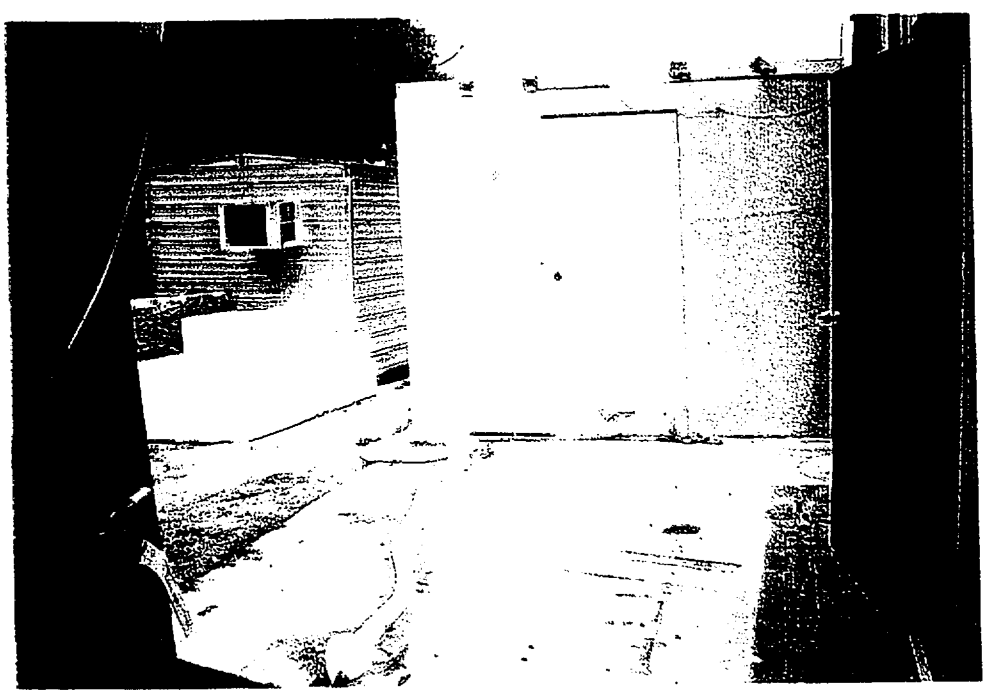


Figure A-2. Low-Temperature Conditioning Room.

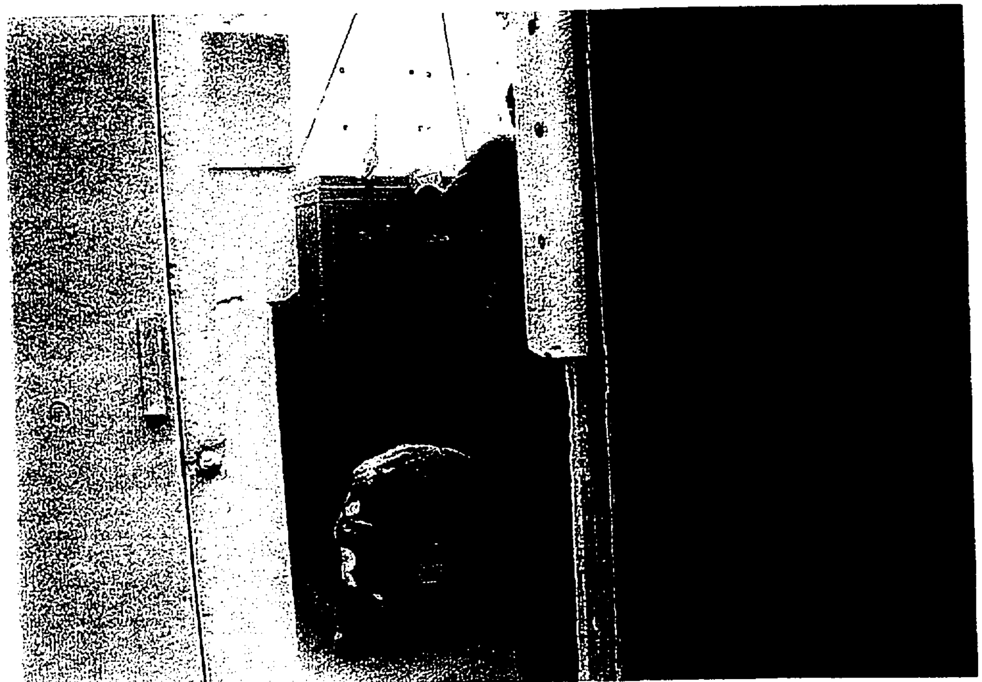


Figure A-3. Test Specimen During Removal from Conditioning Room.

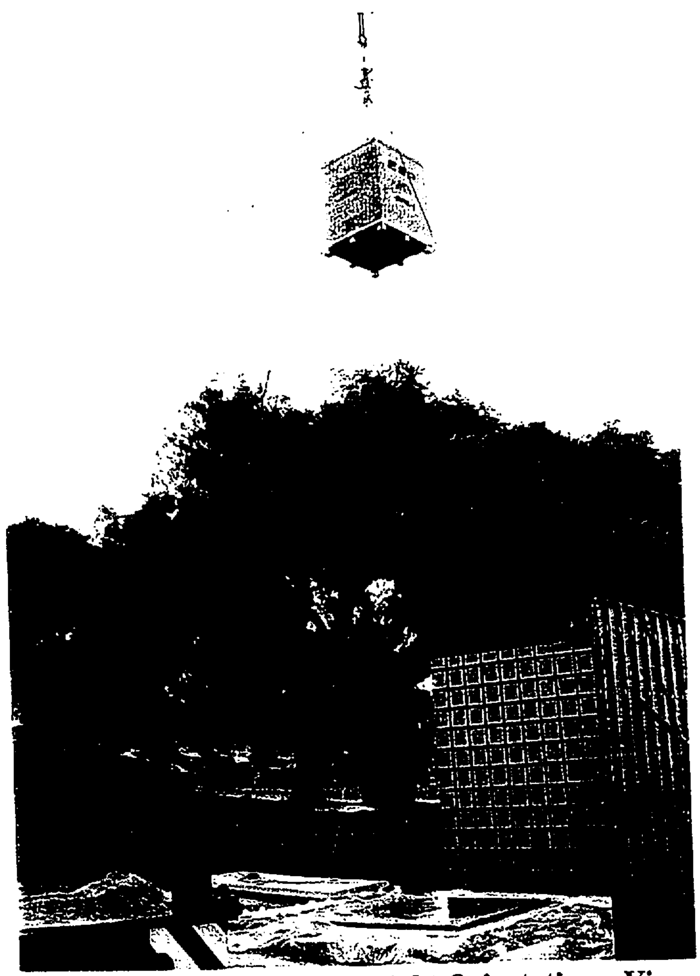


Figure A-4. 30-ft Drop Upright Orientation— View of Vertical Position.

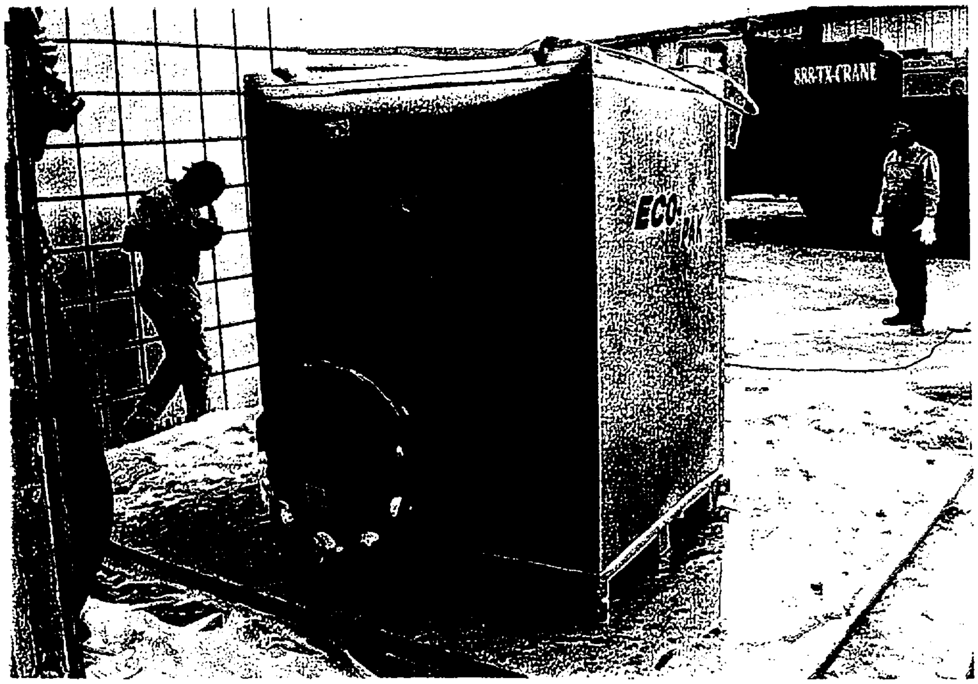


Figure A-5. 30-ft Drop Upright Orientation—Test Item Following Drop (Front)

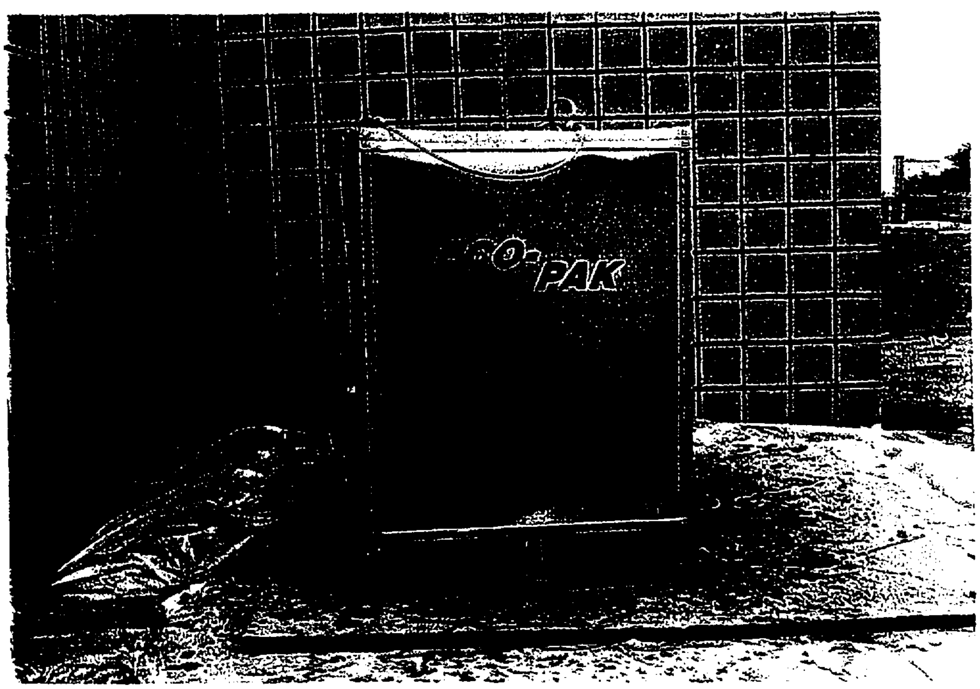


Figure A-6. 30-ft Drop Upright Orientation—Test Item Following Drop (Back).

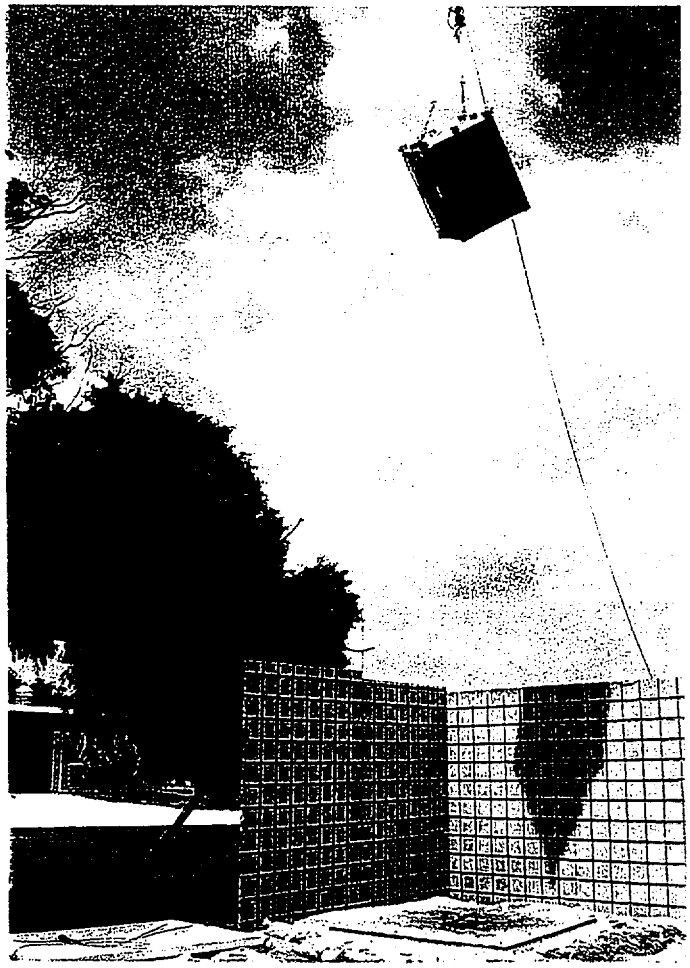


Figure A-7. 30-ft Drop Corner Orientation—View of Corner Drop Position.

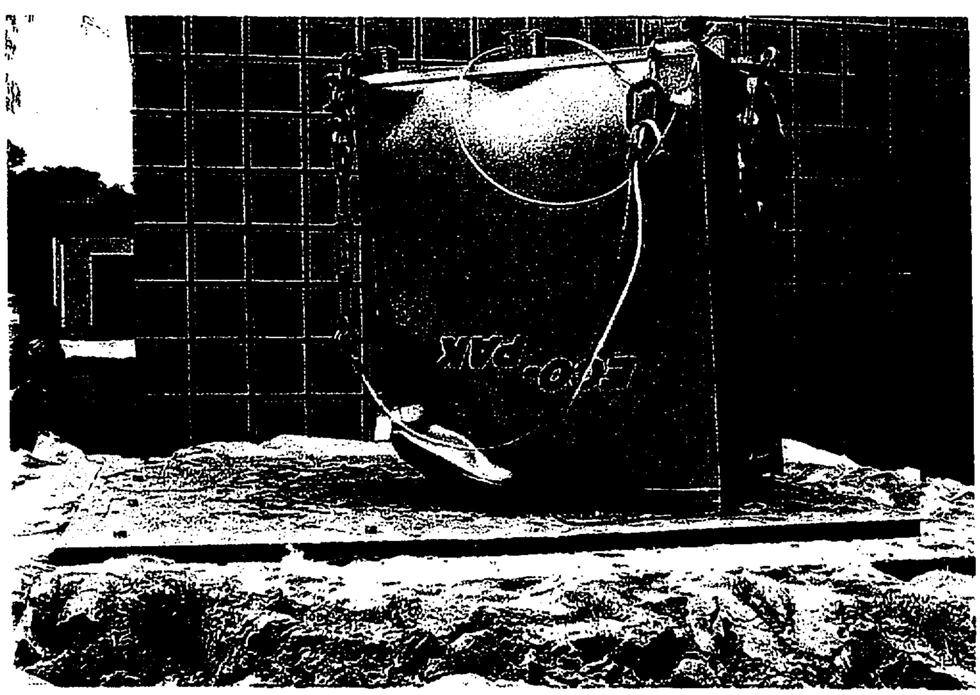


Figure A-8. 30-ft Drop Corner Orientation—Test Item After Drop.

Figure A-9. 30-ft Drop Corner Orientation—Test Item After Drop.

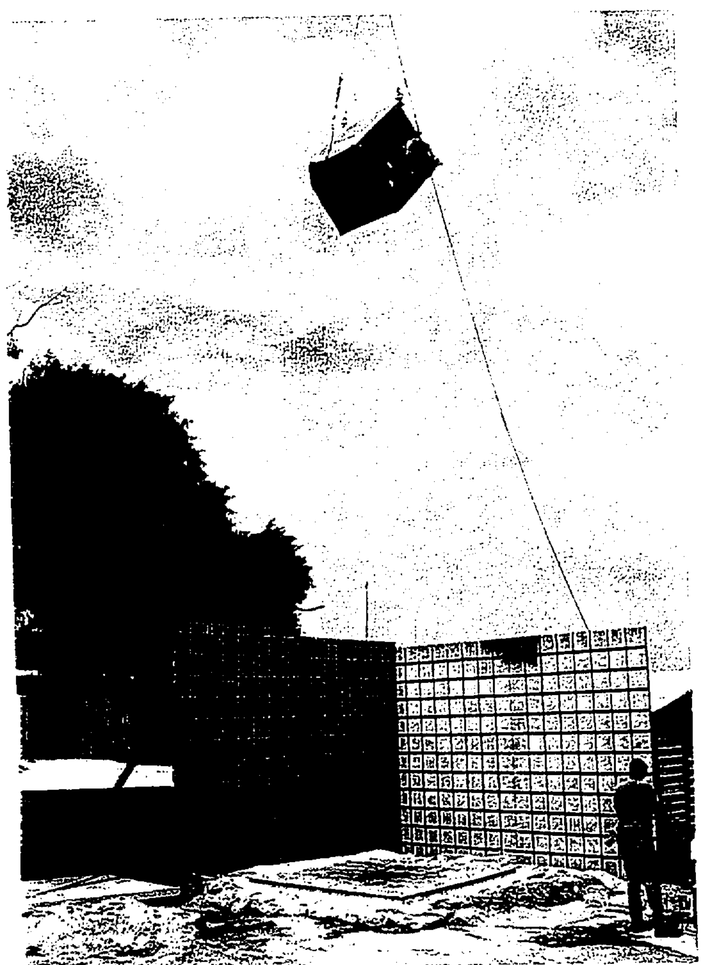


Figure A-10. 30-ft Drop Edge Orientation— View of Edge Drop Position.

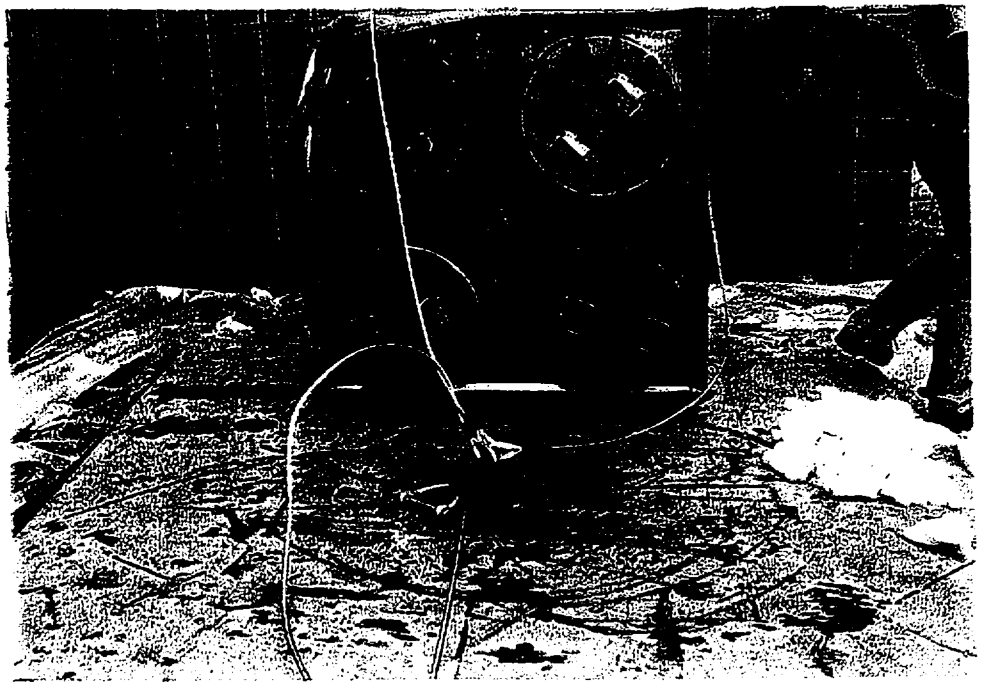


Figure A-11. 30-ft Drop Edge Orientation—Test Item After Drop.

Figure A-12. 30-ft Drop Edge Orientation—Inspection of Damaged Thermocouples After Test.

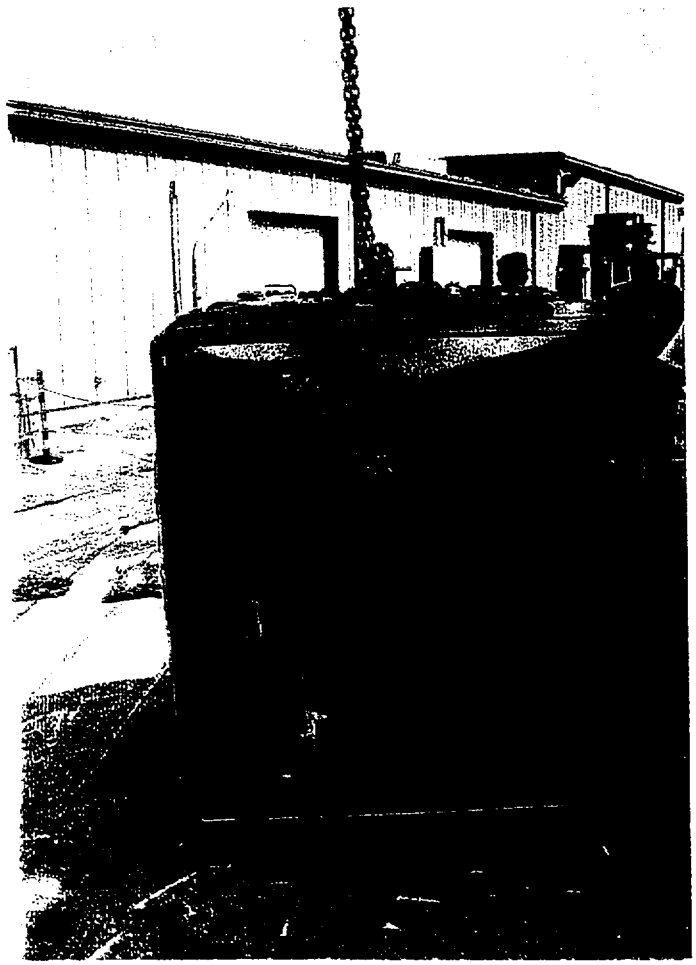


Figure A-17. Post Drop View of Damage Following Drop Tests.

Figure A-18. Post Drop View of Damage Following Drop Tests.

APPENDIX B

TEST AND MEASURING EQUIPMENT CALIBRATION CERTIFICATES

(Consisting of 15 Pages)

Southwest Research Institute
6220 Culebra Road
San Antonio, TX 78238
Department of Quality Assurance
Calibration Laboratory

Certificate of Calibration

21 April 1997

Issued to: MARK MERCER DIV06 B81
Manufacturer/Model: ASHCROFT 1305B100
Description: DEAD WEIGHT TESTER
Serial Number: 8371009
Asset Number: 000760

Environmental Conditions

Temperature: 72.0 Deg. F **Humidity:** 64%

Calibration Information

Calibration was in accordance with requirements of MIL-STD-45662A and ANSI/NCSL Z540-1-1994. Measurements are traceable to the National Institute of Standards and Technology (NIST). This report may not be reproduced except in full without written approval of the originator. Inspection and test data are on file and available for inspection.

Calibration Date: 9 Apr 97 **Calibration Procedure:** PCP-8.10/4-19-93

Interval: 12 months **Accuracy:** *

Next Calibration Due: 9 Apr 98 **Received:** In Tolerance

Remarks: CALIBRATED BY TECHNOLOGY & CALIBRATION.
*ACCURACY .01% F.S.=10000 PSI/.03% F.S.=2000

Certificate # 25028

Signed: [signature]

LAST PAGE OF REPORT
Total Pages Printed: 1

TECH CAL
TECHNOLOGY & CALIBRATION, INC.

4120 SIEGEL
HOUSTON, TEXAS 77009-3923
FAX 713/692-1722
713/692-1600

Pressure Instrument Certification

Issued To: *Southwest Research*
San Antonio, Texas

This is to certify that this pressure instrument/device has been tested and calibrated in accordance with Technology & Calibration's procedure, PCP-8.10/4-19-93, with pressure measuring instruments certified to N.I.S.T. traceable standards. Certified in accordance with ANSI/NCSL, Z540-1 and ISO 10012-1. This certification performed under Technology & Calibration's quality assurance program dated 4-19-93, Rev.0. All calibrations performed at 72 degrees F. plus or minus 2 degrees F. and less than 65% relative humidity.

NOTE: The collective uncertainty of the measurement standards does not exceed 25% of the acceptable tolerance for each characteristic of the measuring and test equipment being certified.

Manufacturer	**Ashcroft**
Serial Number	**8371009**
Model / Type	**D. W. Tester**
Project Number	**51458**
Date	**04-09-97**
Recall Date	**04-09-98**
Verified Units	**PSI**
Verified Range	**10000.0**
Rated Accuracy	**0.01%**
P.O. Number	**38056**
Technician	**S. Hyde**
Remarks	**High Piston Dia. = .125**

Standard Serial No.	Standard Manufacturer	Calibration Date	Recall Date	N.I.S.T. Traceable No.
15544	Ametek	04-04-97	04-04-98	822/254480
70795	Ametek	07-01-96	07-01-97	822/251645
22028	Chandler	04-08-97	04-08-98	822/256610
CM58216	Heise	06-26-96	06-26-97	731/243669

Calibrated By: *Chandler, Heise, Marklyn Lab.*

Quality Representative

Technology and Calibration, Inc.

Pressure Instrument Calibration Report

Manufacturer:	Ashcroft	Customer:	Southwest Research
Model / Type:	D. W. Tester	Location:	San Antonio, Texas
Serial Number:	8371009	P.O. Number:	38056
Date:	04-09-97	Recall Date:	04-09-98
Capacity:	10000.0	Report Number:	51458
Resolution:	1.0	Technician:	S. Hyde

As Found Condition

Rated Accuracy: 0.01 % F/S Instrument Performance

	Standard	Inst. Reading	% Deveation
Units: PSI	0.0	0.0	0.00
	2500.0	2500.0	0.00
	5000.0	5000.0	0.00
	7500.0	7500.0	0.00

As Left Condition

Standard	Inst. Reading	% Deviation
1000.0	1000.0	0.0
2000.0	2000.0	0.0
4000.0	4000.0	0.0
6000.0	5000.0	0.0
8000.0	8000.0	0.0
10000.0	10000.0	0.0

* No error shown if less than 50 percent of the rated accuracy

Remarks: High Piston Dia. =.125

ANALOG / DIGITAL PRESSURE INDICATOR CALIBRATION

MARINE TECHNOLOGY DEPARTMENT
UNDERWATER ENGINEERING LABORATORY / BLDG. 81

Transducer / Pressure Gage No. /Serial No. 3979	Mfg.& Model No. TRANSDUCERS INC GP-48F-150-7159
Digital Indicator / Mfg.& Model No. Bell/Howell Serial No. MOD. 5332-SP-445, S/N 16301	Use at: For UF6 Internal Pressure Tests SwRI PROJ. No. 01-1680
Dead Weight Tester/ Mfg.& Model No. Serial No. Ashcroft 1305B100, S/N 8371009	Calibration Due Date: 9 APRIL 98

PRESSURE Indicator Reading (Psig)	DEAD WEIGHT TESTER Applied Load (Psig)	PRESSURE Indicator Reading (Psig)	DEAD WEIGHT TESTER Applied Load (Psig)
0	0	80	80
20	20	0	0
40	40		
60	60		
80	80		
100	100		
120	120		

REMARKS:

Cal. Performed using low Press Piston Assy. of Dead wt. Tester No. 8371009

Shunt Cal.Verification : N/A

Certificate No. : 01-1680-A

Calibration Performed By: [signature]

Calibration Date: 3-9-98	Next Calibration Due Date: 4-9-98
QC Staff:	Date:
Lab Supervisor: [signature]	Date: 3-9-98

SwRI UEL-DOP-65.5.0(8/5/97)-QA Form UEL-1-A (c:\data\jr\qauel-65.jr\jdq)

Terminal Drive, Plainview, NY 11803 Veeco 516-349-8300 • Fax: 516-349-7009

Veeco Instruments Inc.

CALIBRATION CERTIFICATE

incompliance with
ANSI/NCSL Z540-1-1994
ISO-10012-1:1992E

Veeco Instruments Inc. certifies the calibrated leak referenced below is accurate in accordance with measurement technique that compares, through the use of a Veeco Mass Spectrometer Leak Detector, each unit against a primary standard, serial number 0001ᵃ and / or 0003ᵇ. These standards are certified and calibrated by the National Institute of Standards and Technology (NIST). The reference Mass Spectrometer Leak Detector is continuously calibrated and becomes the instrument used to certify the Calibrated Leak. This instrument is maintained and calibrated in accordance with Veeco Standard Calibration Procedure for Helium Calibrators CP001-MS Rev. A.

We recommend the Calibrated Leak be returned to Veeco Instruments Inc. for recalibration annually.

NOTE: Calibrated Leaks should be stored and shipped with valve open.

MODEL: 7MS40 SERIAL NO: 0555

CAL DATE: 03/28/1997 CERTIFICATION NO: LB67607

The above sensitivity calibrator has been calibrated as of this date with the following results:

Helium Leak Rate:

0.0035 ± 10% Micron cu.ft/hr.
3.5×10^{-8} ± 10% Std. cc./sec.

Air Leak Rate Through Equivalent Leak:

0.0013 ± 10% Micron cu.ft/hr.
1.3×10^{-8} ± 10% Std. cc./sec.

Calibration Temperature: 22 °C

Temperature Coefficient = ± 3% per degree C   Leak rate decreases less than 5% per year

Final Inspection By: ____________
(Calibrating Laboratory Technician)

a- NIST Test Number 251779-96R T144   b- NIST Test Number: 258587-97 T160

SOUTHWEST RESEARCH INSTITUTE
DEPARTMENT OF FIRE TECHNOLOGY
INSTRUMENTATION RECORD SHEET

Item: ECO-PAK

Test Date: 20-21 MAR 1998

Project No.: 01-1680-102

Test ID: OPM1 - 002 / ESP-30X 001

Critical Test Equipment/Materials	Serial No./ID No.	Calibration Expiration Date
Helios	4889002	11 AUG 98
Weather Station	492	1 Dec 98
TC's Sample	Lot # M069751	N/A
TC's Flame	Lot # M294709	N/A
Radiometer west	87188	N/A
Radiometer East	87183	N/A
~~Thermometer~~	~~2 Sept 9~~	
Thermometer	206	2 Sept 98

Personnel List:

Jim Griffith
Bill Bendele
Raul Duarte
Joe Anderson
Able Deltoyos
Alex
Michael Suerie

Southwest Research Institute
6220 Culebra Road
San Antonio, TX 78238
Department of Quality Assurance
Calibration Laboratory

Certificate of Calibration

12 February 1998

Issued to: BILL BENDELE DIV01 B143
Manufacturer/Model: FLUKE 2289A
Description: HELIOS I COMPUTER FRONT END
Serial Number: 4889002
Asset Number: 000249

Environmental Conditions

Temperature: 75.00 Deg. F **Humidity:** 33 % RH

Calibration Information

Calibration was in accordance with requirements of MIL-STD-45662A and ANSI/NCSL Z540-1-1994. Measurements are traceable to the National Institute of Standards and Technology (NIST). This report may not be reproduced except in full without written approval of the originator. Inspection and test data are on file and available for inspection.

The uncertainty of the calibration was sufficient to determine that the instrument met the manufacturer's specifications.

Calibration Date: 11 Feb 98 **Calibration Procedure:** MFG MANUAL P/N 793547, 4/86

Interval: 6 months

Next Calibration Due: 11 Aug 98 **Received:** In Tolerance

Remarks: CALIBRATED WITH 5 EA. ISOTHERMAL INPUT CONNE
CTOR S/N'S 488-1 THRU 488-5

Standards Used

Asset	MFR	Model	Description	Serial No.	Due Cal
000182	FLUKE	5700A	CALIBRATOR	5200003	2 Jul 99
004528	KAYE INSTRU	K150-2C	ICE POINT/REFERENCE	701173	4 Apr 98

Signed: [signature]

Title: Cal Tech

LAST PAGE OF REPORT
Total Pages Printed 1

Certificate # 28517

6220 Culebra Road
San Antonio, TX 78238
Department of Quality Assurance
Calibration Laboratory

Certificate of Calibration

17 December 1997

Issued to: BILL BENDELE DIV01 B143
Manufacturer/Model: QUALIMETRICS, INC. 1005
Description: WEATHER STATION
Serial Number: 492
Asset Number: 005072

Environmental Conditions

Temperature: 0 Deg. F **Humidity:** 0 % RH

Calibration Information

Calibration was in accordance with requirements of MIL-STD-45662A and ANSI/NCSL Z540-1-1994 Measurements are traceable to the National Institute of Standards and Technology (NIST). This report may not be reproduced except in full without written approval of the originator. Inspection and test data are on file and available for inspection.

The uncertainty of the calibration was sufficient to determine that the instrument met the manufacturer's specifications.

Calibration Date: 1 Dec 97 **Calibration Procedure:** MFG

Interval: 12 months

Next Calibration Due: 1 Dec 98 **Received:** In Tolerance

Remarks: CALIBRATED BY QUALIMETRICS, SACRAMENTO, CA.
NOT ON 'ASL'. CAL DEVIATION EXEC. 97-CD-44.

Results

WEATHER STATION CONSISTS OF: MODULE RACK #1005 S/N 492
MICRO RESPONSE ANEMOMETER #2030 S/N 795
MICRO RESPONSE VANE #2020 S/N 1203
CUP ASSEMBLY

Signed:

Title:

LAST PAGE OF REPORT
Total Pages Printed 1

Certificate # 27285

DURO-SENSE CORPORATION
20801 Higgins Court, Torrance, CA 90501
Phone: (310) 533-6877 Fax: (310) 533-0330

TO: Southwest Research
6220 Culebra Rd.
San Antonio, TX 78284

Date: March 9, 1998
Calib No.: 45094A
Cust. P.O.: 75567
Calibration Cycle: 6 Months

CALIBRATION CERTIFICATE

This will certify that your Type 'K' T/C Assy # MTC-B-1252-G-WP-GDW was/were calibrated on March 9, 1998 against our standard, which is traccable to the National Institute of Standards Technology. Re-Calibration should occur no later than September 9, 1998.

Ambient Temperature:	76.70°F
Furnace Atmosphere:	Air
Humidity:	38.20%
Temperature Points:	300°F, 600°F, 900°F
Lot #:	MO69751

CALIBRATION RESULTS ARE AS FOLLOWS:

Standard S/N	Corrections 300°F	600°F	900°F
39	+0.2°F	+0.6°F	+0.9°F
40	+0.3°F	+0.5°F	+0.8°F
41	+0.3°F	+0.6°F	+1.0°F
42	+0.4°F	+0.7°F	+0.9°F
43	+0.3°F	+0.6°F	+1.0°F
44	+0.2°F	+0.5°F	+1.0°F
45	+0.2°F	+0.6°F	+0.9°F
46	+0.3°F	+0.5°F	+0.9°F
47	+0.2°F	+0.5°F	+0.8°F
48	+0.4°F	+0.8°F	+1.0°F

Calibration procedure I A W ISO 10012-1 1992(E). ANSI/NCSL Z540-1-1994 AMS 2750C
The calibration of thermocouples is subject to change during use. The amount of change depends on factors such as temperature, time and condition of use.
Total Uncertainty of Readings is Less Than .01%

N.I.S.T. Recertification Date: February 5, 1999	We hereby certify that the above is a true copy of our records.
Leeds and Northrup K-5: Model 7555	DURO-SENSE CORPORATION
Precision Potentiometer S/N: 1752900	
Eppley Standard Cell: Model 100 - S/N 700851	
Cage Code: 58042	
Master Std. Thermocouple: Type 'S'	Quality Control Department
N.I.S.T Test Numbers: 259557	

DURO-SENSE CORPORATION
20801 Higgins Court, Torrance, CA 90501
Phone: (310) 533-6877 Fax: (310) 533-0330

TO: Southwest Research
6220 Culebra Rd.
San Antonio, TX 78284

Date: March 9, 1998
Calib No.: 45094A
Cust. P.O.: 75567
Calibration Cycle: 6 Months

CALIBRATION CERTIFICATE

This will certify that your Type 'K' T/C Assy # MTC-B-1252-G-WP-GDW was/were calibrated on March 9, 1998 against our standard, which is traceable to the National Institute of Standards Technology. Re-Calibration should occur no later than September 9, 1998.

Ambient Temperature:	76.70 °F
Furnace Atmosphere:	Air
Humidity:	38.20%
Temperature Points:	300 °F, 600 °F, 900 °F
Lot #:	MO69751

CALIBRATION RESULTS ARE AS FOLLOWS:

Standard S/N	Corrections 300 °F	600 °F	900 °F
49 ✓	+0.3 °F	+0.5 °F	+0.9 °F
50 ✓	+0.2 °F	+0.7 °F	+1.0 °F

Calibration procedure I A W ISO 10012-1 1992(E) ANSI/NCSL Z540-1-1994 AMS 2750C
The calibration of thermocouples is subject to change during use The amount of change depends on factors such as temperature, time and condition of use
Total Uncertainty of Readings is Less Than 01%

N.I.S.T. Recertification Date: February 5, 1999	We hereby certify that the above is a true copy of our records. DURO-SENSE CORPORATION
Leeds and Northrup K-5: Model 7555	
Precision Potentiometer S/N: 1752900	
Eppley Standard Cell: Model 100 - S/N 700851	
Cage Code: 58042	
Master Std. Thermocouple: Type 'S'	Quality Control Department
N.I.S.T. Test Numbers: 259557	

DURO-SENSE CORPORATION
20801 Higgins Court, Torrance, CA 90501
Phone: (310) 533-6877 Fax: (310) 533-0330

TO: Southwest Research
6220 Culebra Rd.
San Antonio, TX 78284

Date: March 9, 1998
Calib No.: 45094A
Cust. P.O.: 75567
Calibration Cycle: 6 Months

CALIBRATION CERTIFICATE

This will certify that your Type 'K' T/C Assy # MTC-B-1252-G-WP-GDW was/were calibrated on March 9, 1998 against our standard, which is traceable to the National Institute of Standards Technology. Re-Calibration should occur no later than September 9, 1998.

Ambient Temperature:	76.70 °F
Furnace Atmosphere:	Air
Humidity:	38.20%
Temperature Points:	300 °F, 600 °F, 900 °F
Lot #:	MO69751

CALIBRATION RESULTS ARE AS FOLLOWS:

Standard S/N	Corrections 300 °F	600 °F	900 °F
51	+0.3 °F	+0.7 °F	+1.0 °F
52	+0.4 °F	+0.6 °F	+0.9 °F
53	+0.2 °F	+0.5 °F	+0.8 °F
54	+0.4 °F	+0.7 °F	+1.0 °F
55	+0.3 °F	+0.6 °F	+0.9 °F
56	+0.4 °F	+0.8 °F	+1.0 °F

Calibration procedure I A W ISO 10012-1 1992(E), ANSI/NCSL Z540-1-1994 AMS 2750C
The calibration of thermocouples is subject to change during use. The amount of change depends on factors such as temperature, time, and condition of use.
Total Uncertainty of Readings is Less Than .01%

N.I.S.T. Recertification Date: February 5, 1999	
Leeds and Northrup K-5: Model 7555	
Precision Potentiometer S/N: 1752900	
Eppley Standard Cell: Model 100 - S/N 700851	
Cage Code: 58042	
Master Std. Thermocouple: Type 'S'	
N.I.S.T. Test Numbers: 259557	

We hereby certify that the above is a true copy of our records.
DURO-SENSE CORPORATION

Quality Control Department

Flame TC's

DURO-SENSE CORPORATION
20801 Higgins Court, Torrance, CA 90501
Phone: (310) 533-6877 Fax: (310) 533-0330

TO:	Southwest Research Institute	Date:	March 18, 1998
	6220 Culebra Rd.	Calib No.:	45218
	San Antonio, TX 78284	Cust. P.O.:	75567
		Calibration Cycle:	6 Months

CALIBRATION CERTIFICATE

This will certify that your Type 'K' T/C Assy # **MTC-B-1252-G-GDW** was/were calibrated on **March 18, 1998** against our standard, which is traceable to the National Institute of Standards Technology. Re-Calibration should occur no later than **September 18, 1998.**

Ambient Temperature:	**78.20°F**
Furnace Atmosphere:	**Air**
Humidity:	**38.40%**
Temperature Points:	**300°F, 600°F, 900°F**
Lot #:	**M294709**

CALIBRATION RESULTS ARE AS FOLLOWS:

Standard S/N	Corrections 300°F	600°F	900°F
65	+0.4°F	+0.6°F	+1.0°F
66	+0.3°F	+0.7°F	+0.9°F
67	+0.4°F	+0.8°F	+1.0°F
68	+0.2°F	+0.5°F	+0.8°F
69	+0.3°F	+0.7°F	+1.0°F
70	+0.4°F	+0.6°F	+0.9°F
71	+0.3°F	+0.7°F	+0.9°F
72	+0.2°F	+0.6°F	+1.0°F

Calibration procedure I.A.W ISO 10012-1:1992(E), ANSI/NCSL Z540-1-1994, AMS 2750C
The calibration of thermocouples is subject to change during use. The amount of change depends on factors such as temperature, time, and condition of use.
Total Uncertainty of Readings is Less Than .01%

N.I.S.T. Recertification Date: February 5, 1999	We hereby certify that the above is a true copy of our records.
Leeds and Northrup K-5: Model 7555	**DURO-SENSE CORPORATION**
Precision Potentiometer S/N: 1752900	
Eppley Standard Cell: Model 100 - S/N 700851	
Cage Code: 58042	
Master Std. Thermocouple: Type 'S'	
N.I.S.T. Test Numbers: 259557	Quality Control Department

CERTIFICATE OF CALIBRATION

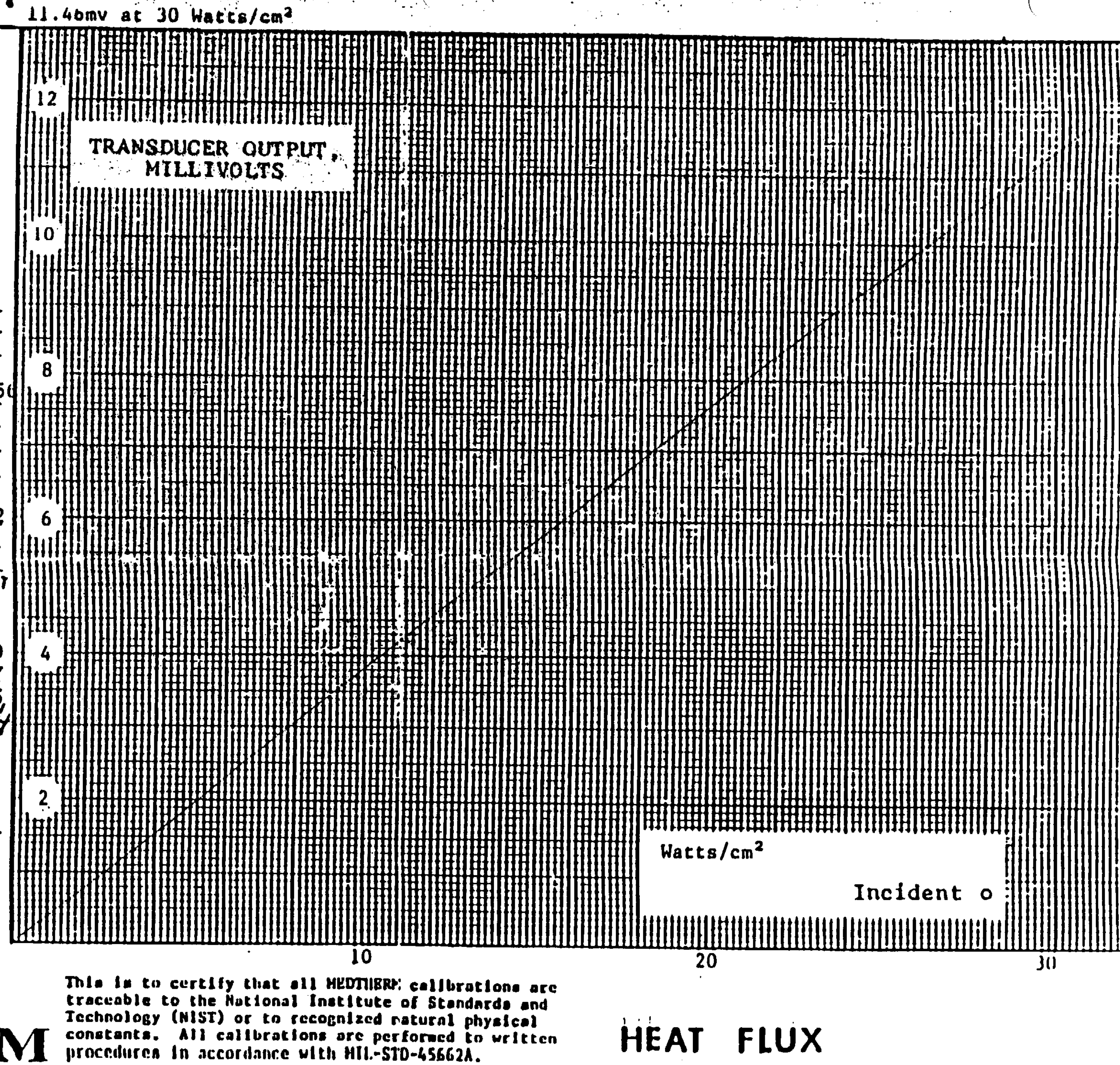
DATE 3/6/95
CUSTOMER Southwest Res.
CUSTOMER P.O. 51109

MODEL NO. 48NPT-EP-25F-21156
SERIAL NO. 87188
ABSORPTIVITY 0.96
WINDOW TYPE None
SENSOR - Schmidt-Boelter
REFERENCE STANDARD 325732
TESTED BY
QC ACCEPTANCE MEDTHERM INSPECT NO. 2 TEST ACCEPT

CERTIFIED CALIBRATION SUBSCRIBED AND SWORN TO BEFORE ME THIS 6th DAY OF March 19 95

Glenda Conner
Glenda Conner

GLENDA CONNER NOTARY PUBLIC ALABAMA STATE AT LARGE



This is to certify that all MEDTHERM calibrations are traceable to the National Institute of Standards and Technology (NIST) or to recognized natural physical constants. All calibrations are performed to written procedures in accordance with MIL-STD-45662A.

MEDTHERM CORPORATION
POST OFFICE BOX 412 / HUNTSVILLE, ALABAMA 35804 / TELEPHONE 837-2000

SwRI Project No. 01-1680b

10.95mv at 30 Watts/cm²

CERTIFICATE OF CALIBRATION

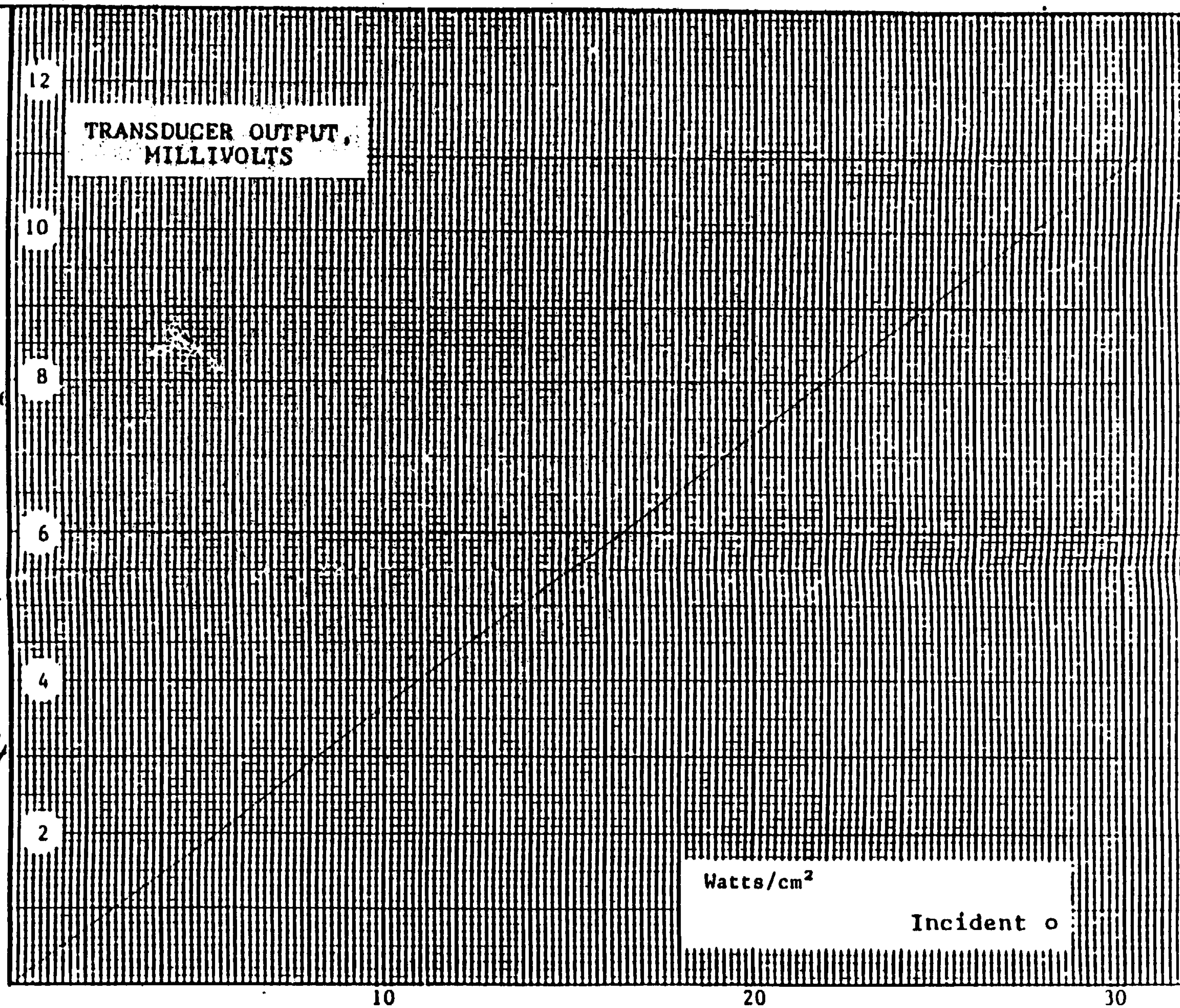
DATE 3/6/95
CUSTOMER Southwest Res.
CUSTOMER P.O. 51109

MODEL NO. 48NPT-EP-25F-21156
SERIAL NO. 87183
ABSORPTIVITY 0.96
WINDOW TYPE None
SENSOR - Schmidt-Boelter
REFERENCE STANDARD 325732
TESTED BY TB
QC ACCEPTANCE MEDTHERM INSPECT NO. 2 TEST ACCEPT

CERTIFIED CALIBRATION SUBSCRIBED AND SWORN TO BEFORE ME THIS 6th DAY OF March 19 95

Glenda Conner

GLENDA CONNER NOTARY PUBLIC ALABAMA STATE AT LARGE



This is to certify that all MEDTHERM calibrations are traceable to the National Institute of Standards and Technology (NIST) or to recognized natural physical constants. All calibrations are performed to written procedures in accordance with MIL-STD-45662A.

HEAT FLUX

MEDTHERM CORPORATION

POST OFFICE BOX 412 / HUNTSVILLE, ALABAMA 35804 / TELEPHONE (205) 837-2000

SwRI Project No. 01-1680b

Southwest Research Institute
6220 Culebra Road
San Antonio, TX 78238
Department of Quality Assurance
Calibration Laboratory

Certificate of Calibration

2 September 1997

Issued to: BILL BENDELE DIV01 B143
Manufacturer/Model: OMEGA 871
Description: DIGITAL THERMOMETER
Serial Number: 206
Asset Number: 002016

Environmental Conditions

Temperature: 74.0 Deg. F **Humidity:** 40%

Calibration Information

Calibration was in accordance with requirements of MIL-STD-45662A and ANSI/NCSL Z540-1-1994. Measurements are traceable to the National Institute of Standards and Technology (NIST). This report may not be reproduced except in full without written approval of the originator. Inspection and test data are on file and available for inspection.

Calibration Date: 2 Sep 97 **Calibration Procedure:** CLCP-TT-001

Interval: 12 months **Accuracy:** MFG SPECS

Next Calibration Due: 2 Sep 98 **Received:** In Tolerance

Remarks:

Standards Used

Asset	MFR	Model	Description	Serial No.	Due Cal
005325	XITRON TECH	2000M	PORTABLE V/A/T CALIBRA	20007920002	1 Apr 98

Certificate # 26525 Signed:

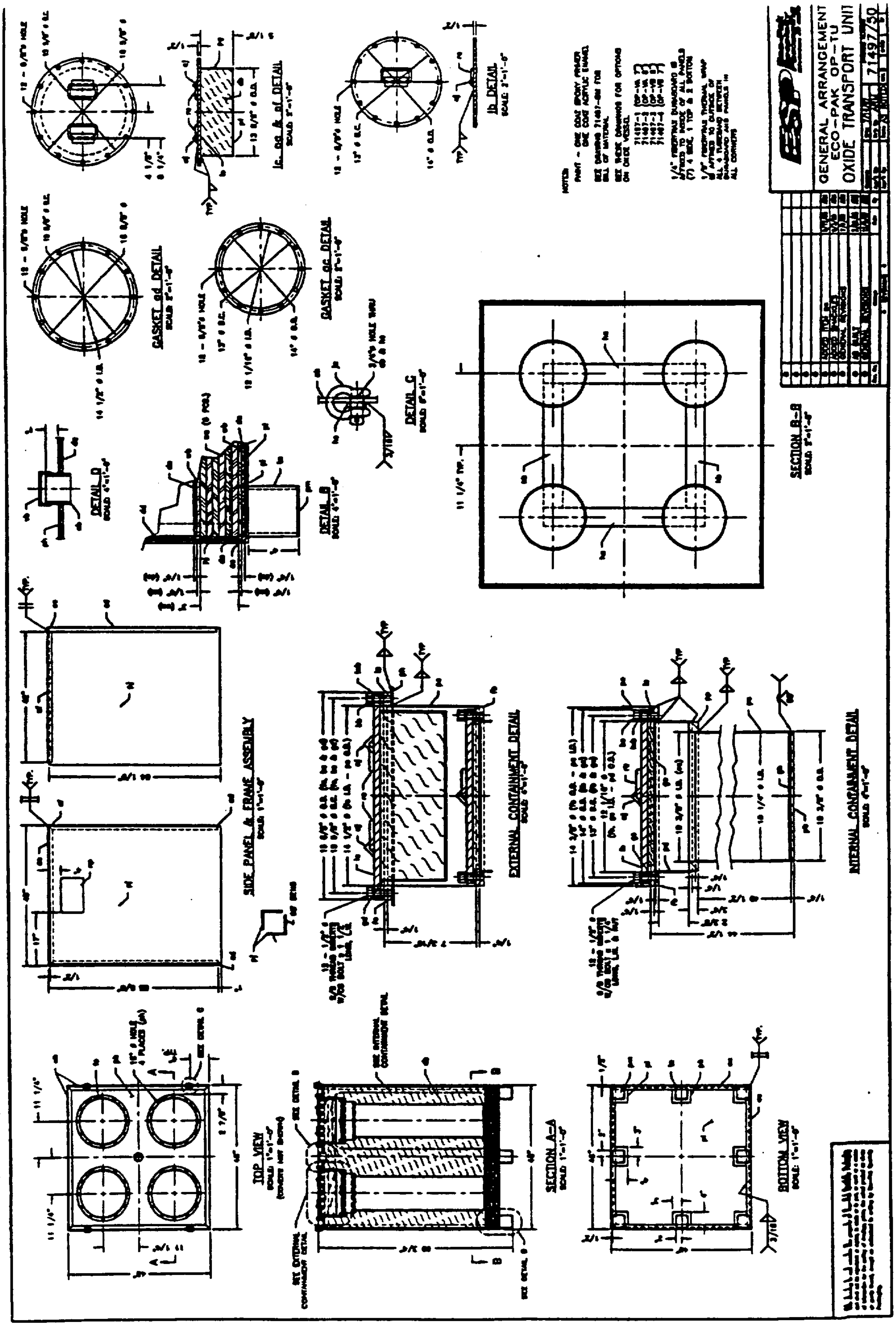
LAST PAGE OF REPORT
Total Pages Printed 1

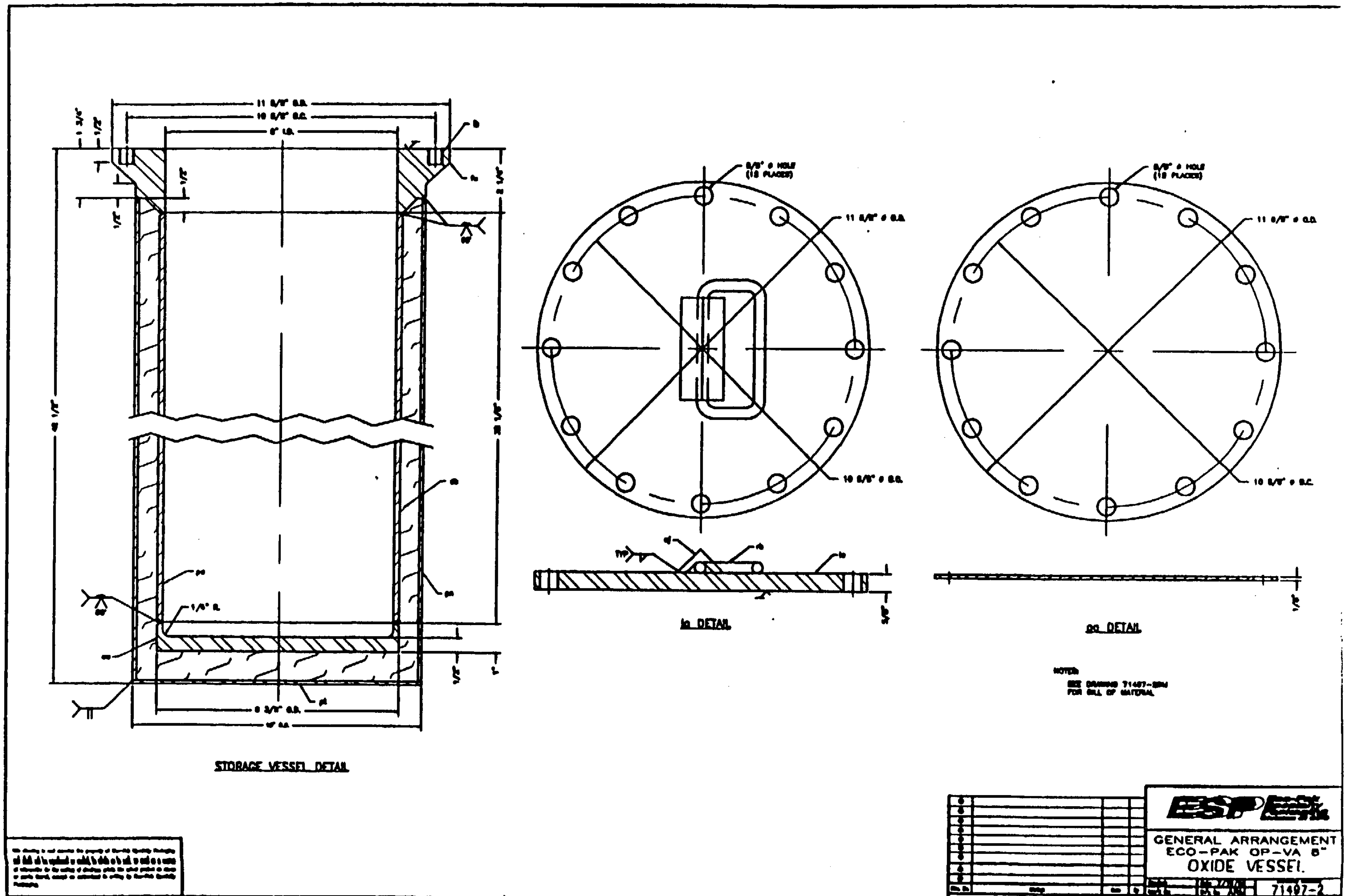
APPENDIX C

CONSTRUCTION DETAILS AND DIMENSIONAL MEASUREMENTS

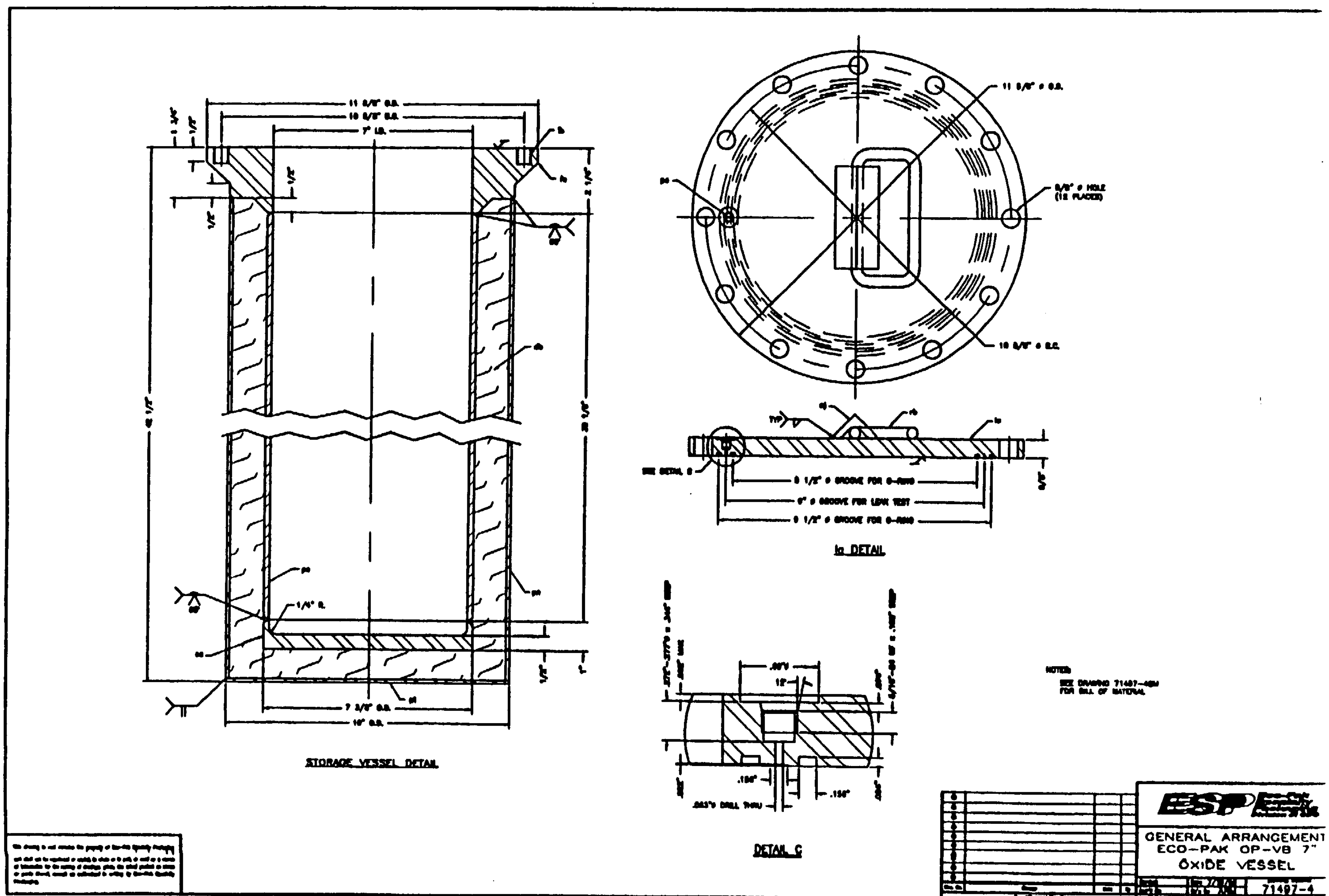
(Consisting 7 Pages)

T[...]ent contains proprietary information of E[...]cialty Packaging and is to be returned upon request. Its contents may not be disclosed to other manufacturers or used for other than the expressed written purpose for which loaned without the consent of Eco-Pak Specialty Packaging. U.S. Patent Nos. 5,595,319 & 5,395,007. Foreign Patents Pending.




STORAGE VESSEL DETAIL
GENERAL ARRANGEMENT
ECO-PAK OP-VA
OXIDE VESSEL
71497-2

ument contains proprietary information of Specialty Packaging and is to be returned upo... quest. Its contents may not be disclosed to other manufacturers or used for other than the expressed written purpose for which loaned without the consent of Eco-Pak Specialty Packaging. U.S. Patent Nos. 5,595,319 & 5,395,007. Foreign Patents Pending.



SwRI Project No.: 01-1680
Test Date: June 11, 1998
Test Item: OPM-1: SN 003 Refer to attached Figure for required measurements. (mm)

Pre-Drop Measurements		After 30-Ft Free-Drop on Bottom		After 30-Ft Free-Drop on Corner
a	395	a side → CENTER	795	795
b	391	a COVER → CENTER	189	187
c	392	d COVER → CTR	195	199
d	397	d SIDE → CTR	802	807
e	398	C SIDE → CTR	795	NR
f	391	C COVER - CTR	190	193
g	391	b COVER - CTR	194	195
h	395	b SIDE → CENTER	802	800
i	567	MEASUREMENTS BETWEEN COVERS	145	145
j	563	" "	145	147
k	563	" "	146	146
l	566	" "	145	149
w-top	1140			
x-top	1145			
y-top	1140			
z-top	1140			
a-side	1444			
B ~~j~~-side	1440			
C ~~e~~-side	1442			
D ~~f~~-side	1441			
w-bottom	1141	1137		1137
x-bottom	1145	1135		1135
y-bottom	1145	1138		1139
z-bottom	1140	1138		1138

WINDSPEED < 210 FPM WINDSPEED < 340 ft/min

W:\fire\jrg\1680drop.frm

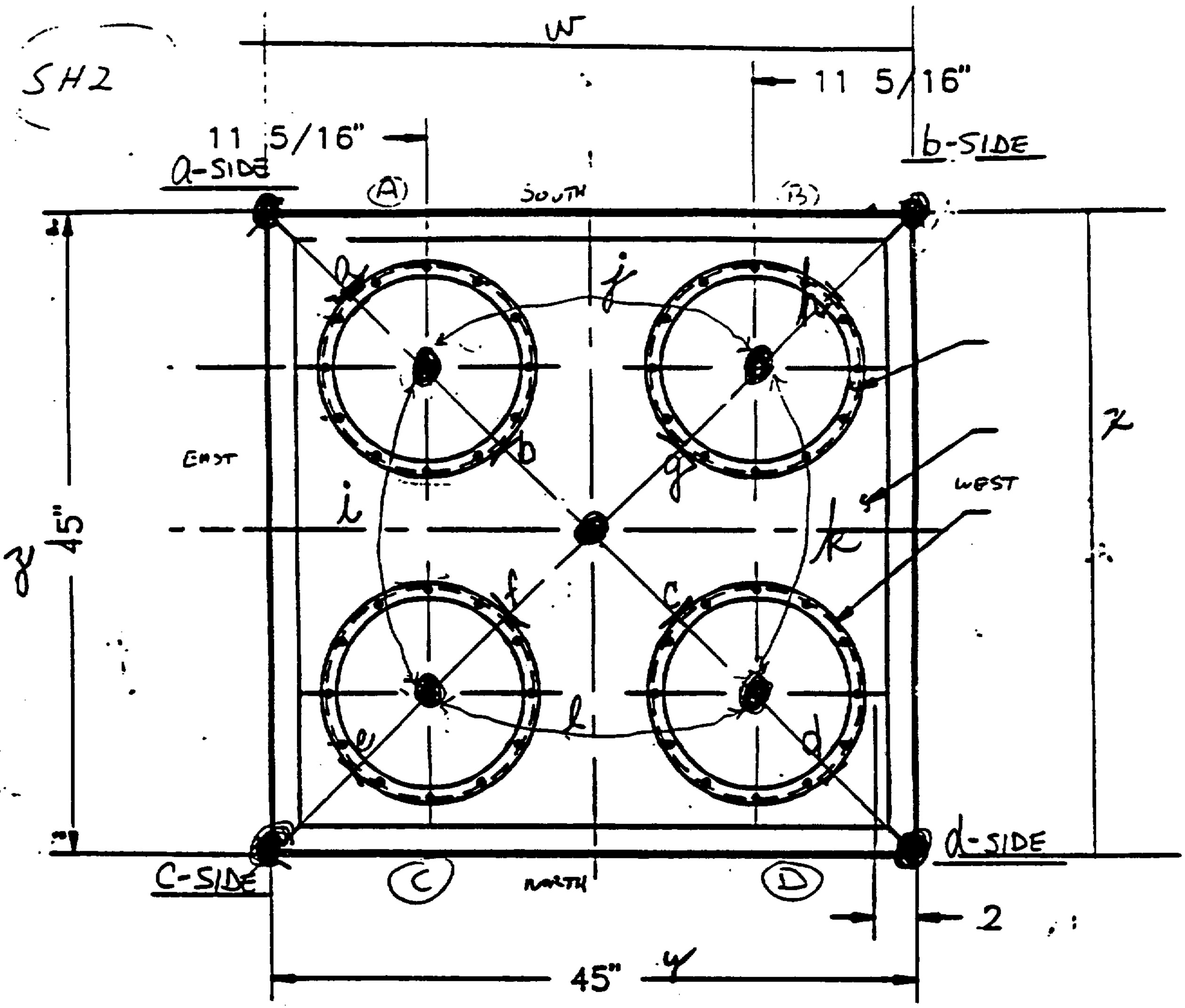
SwRI Project No.: 01-1680
Test Date: June 11, 1998
Test Item: OPM-1: SN _003__

Measurements per figure

	After 30-Ft Free-Drop on Edge	After 40-in. Free-Drop on Side
a	805	a. 405
b	193	b. 395
c	197	c. 407
d	NR	d. 394
e	NR	e. — NR
f	194	f. 386
g	195	g. 408
h	NR	h. 390
i	146	i 561
j	152	j 563
k	155	k 562
l	150	l. 575
w-top		
x-top		
y-top		
z-top		
a-side		
j-side		
e-side		
f-side		
w-bottom		
x-bottom		
y-bottom		
z-bottom		

WINDSPEED < 400 ft/min   WINDSPEED < 400 ft/min
PUNCTURE DEPTH - 65 mm

W:\fire\jrg\1680drop.frm

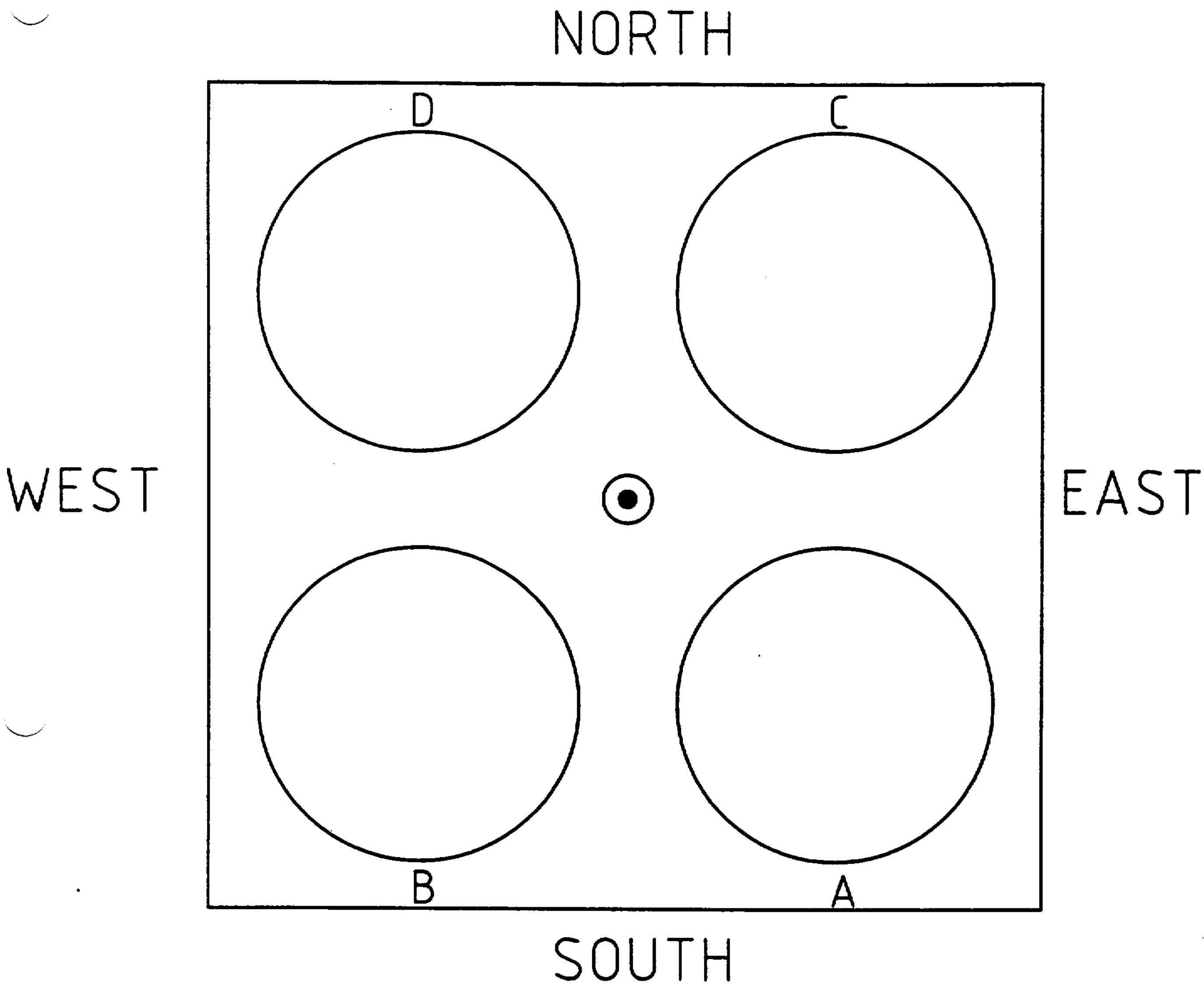


TOP VIEW

SCALE: 1"=1'-0"

(COVERS NOT SHOWN)

DROP NO.	LOCATION
1. 30 FT drop	BOTTOM
4 ~~2~~. 40-IN. PUNCTURE	SIDE: y, NORTH SIDE FOR FIRE TEST
2 ~~3~~. 30FT drop	CORNER: C-SIDE
3 ~~4~~. 30FT drop	EDGE: Z, WEST SIDE FOR FIRE TEST



CYL. A 3-1/2" LEAN TO THE EAST & 1-3/4" LEAN TO THE NORTH
CYL. B 3-3/4" LEAN TO THE EAST & 1-1/2" LEAN TO THE NORTH
CYL. C 3-3/8" LEAN TO THE EAST & 1-1/2" LEAN TO THE NORTH
CYL. D 3-5/8" LEAN TO THE EAST & 1-1/8" LEAN TO THE NORTH

NOTE: MEASUREMENTS ARE RELATIVE MOVEMENT OF THE BOTTOM OF THE 'ESSEL CONTAINER WITH RESPECT TO THE TOP.

APPENDIX D

LEAKAGE AND DROP TEST DATA LOGS

(Consisting of 7 Pages)

6-9-98

OPM TANK A He LEAK Tests (PRE DROP)

1:32P START VACUMN
LEAK RATE ZERO: 2.2×10^{-9} STD cc/sec
START He FLOW
1:45P: 5.4×10^{-8} STD cc/sec
2:10P: 1.0×10^{-7} STD cc/sec (EER)

OPM TANK B

2:20P START VACUMN
2:30P: LEAK RATE ZERO - 1.5×10^{-9} STD cc/sec
START He FLOW
2:45P: LEAK RATE = 0.8×10^{-9} STD cc/sec (EER)

OPM TANK C

3:00P START VACUMN
3:05P - LEAK RATE ZERO = 1.9×10^{-9} STD cc/sec
START He FLOW
3:20P - LEAK RATE = 0.9×10^{-9} STD cc/sec (EER)

OPM TANK D

3:25P START VACUMN
3:30P - LEAK RATE ZERO = 1.5×10^{-9} STD cc/sec
START He FLOW
3:45P - LEAK RATE = 0.8×10^{-9} STD cc/sec (EER)

6-15-98 Post-Test He. Leak Testing

OPM TANK A

11:30A - START VACUMN

11:45A - Leak Rate Zero = 0.7 X 10^{-9} STD cc/sec
START He FLOW

12:00 A - Leak Rate: 2.0X10^{-9} STD cc/sec (DER)

OPM TANK B

12:05A - Start Vacumn
12:10 - Leak Rate = 1.5X10^{-9} STD cc/sec

1:11P - Leak Rate Zero = 0.2X10^{-10} STD cc/sec
Start He Flow

1:28P - Leak Rate = 1.9X10^{-9} std cc/sec (DER)

OPM TANK C

1:33P - Start Vacumn
Veeco FAILED 09/07 ERROR CODES
2:42P - Switch To Veeco MS20 - Calibrate & Restart Testing w/TANK C

2:45P - Start Vacumn w/MS 20
Leak Rate Zero: 3.8X10^{-9} std cc/sec

Start He Flow

3:00P - Leak Rate: 4.0X10^{-9} STD cc/sec (DER)

OPM TANK D
3:07 P - START VACUMN
3:10P - Leak Rate Zero = 3.8X10^{-9} STD cc/sec
3:25P - Leak Rate = 5.0X10^{-9} STD cc/sec (DER)

SwRI 51 QA

SOUTHWEST RESEARCH INSTITUTE
STRUCTURAL DYNAMICS AND
ENVIRONMENTAL TESTING

TEST ITEM IDEN. ECO-PAK PAGE 1 OF ____

TEST PROCEDURE REF. ______ PROJECT NO.: 01 1680 301

TEST NAME STRING CALIBRATION

Date	Time	Observations
6/11/98		EQUIPMENT LIST: MASTER MECH MODEL MMP100 100' TAPE, S/N 30-100T, CAL DUE 12/16/98; TWINE.
		MEASURED 30' + 39.5" ON TAPE AND MARKED STRING. SwRI 51 QA

Test Conducted by: [signature]

SOUTHWEST RESEARCH INSTITUTE
STRUCTURAL DYNAMICS AND
ENVIRONMENTAL TESTING

TEST ITEM IDEN. OPM SQUARE CANNISTER PAGE 1 OF 2

TEST PROCEDURE REF. ______________ PROJECT NO.: 01-1680-301

TEST NAME OPM DROP TESTING.

Date	Time	Observations
6/10/98	14:00	PUT TEST ITEM IN THERMAL CHAMBER SET AIR TEMPERATURE INSIDE CHAMBER AT −40 °C. BEGIN COOLING AND RECORDING DATA FOR CHAMBER AIR, SKIN OF TEST ITEM, AND INSIDE OF INSULATION.
6/10/98	17:00	TC #9 (CHAMBER) −39.4 TC # 10 (SKIN) −50.7 TC # 11 (INSULATION) −24.7. WATLOW REPROGRAMMED − SINCE CHAMBER TEMP WAS DOWN TO −100 °C.
6/10/98	21:25	TC # 9 (CHAMBER) −43.4 °C TC # 10 (SKIN) −39.3 °C TC # 11 (INSULATION) −27.28 °C LIQUID NITROGEN TANK ≈ 1/2 FULL.

Test Conducted by: [signature]

SOUTHWEST RESEARCH INSTITUTE
STRUCTURAL DYNAMICS AND
ENVIRONMENTAL TESTING

TEST ITEM IDEN. OPM SQUARE CANNISTER PAGE 2 OF 2

TEST PROCEDURE REF. ______ PROJECT NO.: 01-1680-301

TEST NAME OPM DROP TESTING.

Date	Time	Observations
6/11/98	07:10	TC #9 -39.57
		TC #10 -33.68
		TC #11 -31.95
		LIQUID NITROGEN ≈ 3/8 FULL.
6/11/98	14:00	BEGIN REMOVING TEST ITEM FROM CHAMBER FOR DROP TESTS.

Test Conducted by: [signature]

SOUTHWEST RESEARCH INSTITUTE
STRUCTURAL DYNAMICS AND
ENVIRONMENTAL TESTING

TEST ITEM IDEN. ECO PAK OPM 1 S/N 3 PAGE 1 OF ____

TEST PROCEDURE REF. ____________ PROJECT NO.: 01-1680-301

TEST NAME Drop Test

Date	Time	Observations
6-11-98	1359	LN_2 cooling turned off. Insulation temperature is -35°C.
		Drop will be 30 feet onto bottom: Flat bottom freedrop
	1413	Wind speed* TSI Velocicheck 8330 S/N 94030180 Rev C Cal due 10-98 *Temp. also
	1415	Ambient Temp. = 96°F, 395 ft/min wind speed.
	1423	Rope was attached to test item to stabilize swing at 30ft.
	1424	Wind speed: 210 ft/min
	1425	Drop
	1427	Good drop. No toppling. Looks like all visible welds intact. Slight buckling of sides. Checked all sides.
	1439	Equipment for inclination measurement: Smart level Series 200 S/N PLL001 Cal'd 3/11/98 due 3/11/99.
		Drop will be 30ft as follows: CG over top corner free drop.
	1516	Angle measured at 47.5°
	1523	Wind speed = 240 ft/min. Ambient temp = 96°F
	1524	" " 300 ft/min. " " 96°F
	1524	Drop

Test Conducted by: Eric M. Dones

SOUTHWEST RESEARCH INSTITUTE
STRUCTURAL DYNAMICS AND
ENVIRONMENTAL TESTING

TEST ITEM IDEN. ECO PAK OPM 1 S/N 3 PAGE 2 OF ____

TEST PROCEDURE REF. ____ PROJECT NO.: 01-1680-301

TEST NAME Drop Test

Date	Time	Observations
6-11-98	1526	Comments: good drop. Cylinder gaskets hanging out all four corners (sheared?). 3 bolt heads sheared off cylinder cover (dropped corner). All welds are visibly intact. 1 visible crack
		Next drop CG over top edge (chime) free drop from 30 ft.
	1555	Angle measured at: 50.0°
	1602	Wind speed: 130 ft/min. Ambient temp: 96°F
	1603	Drop
	1604	Protective cover for thermocouples sheared off. Edge deformation noticed. T/Cs sheared off. ~~Edge~~ END Corner skirt separation on edge dropped.
		Next drop: side puncture drop at 39.5"
	1631	Angle measured at: 1.0°
	1639	Wind speed: 81 ft/min; Ambient temp.: 96°F
	1639	Drop
	1640	Good drop. Target hit. Unit toppled such that impact surface was "up". No further weld seam damage

Test Conducted by: Eric M. Dems

APPENDIX E

FIRE TEST DATA

(Consisting of 14 Pages)

ECO-PAK SPECIALITY PACKAGING
OPM-1 ELEVATED HEAT SOAK

DATE: 12-Jun-98
FILE: 162ECH1.DAT
163ECH2.DAT

SwRI PROJECT NO: 01-1680-102b
TEST TYPE: 10CFR 71.73(C),(4)

TIME	TC1	TC2	TC3	TC4
0:00	65	58	-	-
0:05	65	58	-	-
0:10	65	57	-	-
0:15	65	57	-	-
0:20	65	57	-	-
0:25	64	56	-	-
0:30	64	56	-	-
0:35	64	56	-	-
0:40	64	56	-	-
0:45	65	56	-	-
0:50	65	55	-	-
0:55	65	55	-	-
1:00	65	55	-	-
1:05	65	55	-	-
1:10	65	55	-	-
1:15	66	55	-	-
1:20	66	55	-	-
1:25	66	55	-	-
1:30	66	55	-	-
1:35	66	55	-	-
1:40	67	55	-	-
1:45	67	55	-	-
1:50	67	55	-	-
1:55	68	55	-	-
2:00	68	55	-	-
2:05	68	56	-	-
2:10	68	56	-	-
2:15	69	56	-	-
2:20	69	56	-	-
2:25	69	56	-	-
2:30	70	56	-	-
2:35	70	56	-	-
2:40	71	56	-	-
2:45	71	56	-	-
2:50	72	58	-	-
2:55	73	62	-	-
3:00	74	62	-	-
3:05	74	62	-	-
3:10	75	63	-	-
3:15	76	63	-	-
3:20	78	64	-	-
3:25	79	64	-	-

ECO-PAK SPECIALITY PACKAGING
OPM-1 ELEVATED HEAT SOAK

DATE: 12-Jun-98
FILE: 162ECH1.DAT
163ECH2.DAT

SwRI PROJECT NO: 01-1680-102b
TEST TYPE: 10CFR 71.73(C),(4)

TIME	TC1	TC2	TC3	TC4
3:30	80	65	-	-
3:35	81	66	-	-
3:40	82	66	-	-
3:45	84	67	-	-
3:50	85	68	-	-
3:55	86	69	-	-
4:00	87	69	-	-
4:05	88	70	-	-
4:10	89	71	-	-
4:15	90	72	-	-
4:20	91	73	-	-
4:25	92	74	-	-
4:30	93	75	-	-
4:35	94	75	-	-
4:40	95	76	-	-
4:45	96	77	-	-
4:50	96	78	-	-
4:55	97	78	-	-
5:00	98	79	-	-
5:05	98	79	-	-
5:10	99	80	-	-
5:15	100	81	-	-
5:20	100	81	-	-
5:25	100	81	-	-
5:30	101	82	-	-
5:35	101	82	-	-
5:40	102	83	-	-
5:45	102	83	-	-
5:50	102	83	-	-
5:55	103	83	-	-
6:00	103	84	-	-
6:05	103	84	-	-
6:10	103	84	-	-
6:15	104	84	-	-
6:20	104	85	-	-
6:25	104	85	-	-
6:30	104	85	-	-
6:35	104	85	-	-
6:40	104	85	-	-
6:45	105	85	-	-
6:50	105	86	-	-
6:55	105	86	-	-

ECO-PAK SPECIALITY PACKAGING
OPM-1 ELEVATED HEAT SOAK

DATE: 12-Jun-98
FILE: 162ECH1.DAT
163ECH2.DAT

SwRI PROJECT NO: 01-1680-102b
TEST TYPE: 10CFR 71.73(C),(4)

TIME	TC1	TC2	TC3	TC4
7:00	105	86	-	-
7:05	105	86	-	-
7:10	105	86	-	-
7:15	105	86	-	-
7:20	105	86	-	-
7:25	105	86	-	-
7:30	105	86	-	-
7:35	105	86	-	-
7:40	105	86	-	-
7:45	105	86	-	-
7:50	105	86	-	-
7:55	105	86	-	-
8:00	104	86	-	-
8:05	104	87	-	-
8:10	104	86	-	-
8:15	104	86	-	-
8:20	104	87	-	-
8:25	104	87	-	-
8:30	104	87	-	-
8:35	104	87	-	-
8:40	104	87	-	-
8:45	104	87	-	-
8:50	103	87	-	-
8:55	103	86	-	-
9:00	103	87	-	-
9:05	103	87	-	-
9:10	103	86	-	-
9:15	103	86	-	-
9:20	103	86	-	-
9:25	103	86	-	-
9:30	102	86	-	-
9:35	102	86	-	-
9:40	102	86	-	-
9:45	102	86	-	-
9:50	102	86	-	-
9:55	102	86	-	-
10:00	101	86	-	-
10:05	101	86	-	-
10:10	101	86	-	-
10:15	101	86	-	-
10:20	101	86	-	-
10:25	101	86	-	-

ECO-PAK SPECIALITY PACKAGING
OPM-1 ELEVATED HEAT SOAK

DATE: 12-Jun-98
FILE: 162ECH1.DAT
163ECH2.DAT

SwRI PROJECT NO: 01-1680-102b
TEST TYPE: 10CFR 71.73(C),(4)

TIME	TC1	TC2	TC3	TC4
10:30	101	86	-	-
10:35	100	86	-	-
10:40	100	86	-	-
10:45	100	86	-	-
10:50	100	86	-	-
10:55	100	86	-	-
11:00	100	86	-	-
11:05	99	86	-	-
11:10	99	86	-	-
11:15	99	86	-	-
11:20	99	86	-	-
11:25	99	86	-	-
11:30	99	85	-	-
11:35	98	85	-	-
11:40	98	85	-	-
11:45	98	85	-	-
11:50	98	85	-	-
11:55	98	85	-	-
12:00	98	85	-	-
12:05	98	85	-	-
12:10	97	85	-	-
12:15	97	85	-	-
12:20	97	85	-	-
12:25	97	85	-	-
12:30	97	85	-	-
12:35	97	85	-	-
12:40	97	85	-	-
12:45	96	85	-	-
12:50	96	85	-	-
12:55	96	85	-	-
13:00	96	85	-	-
13:05	96	85	-	-
13:10	96	85	-	-
13:15	96	85	-	-
13:20	97	85	-	-
13:25	97	85	-	-
13:30	97	85	-	-
13:35	98	85	-	-
13:40	99	85	-	-
13:45	99	85	-	-
13:50	100	86	-	-
13:55	101	86	-	-

ECO-PAK SPECIALITY PACKAGING
OPM-1 ELEVATED HEAT SOAK

DATE: 12-Jun-98
FILE: 162ECH1.DAT
163ECH2.DAT

SwRI PROJECT NO: 01-1680-102b
TEST TYPE: 10CFR 71.73(C),(4)

TIME	TC1	TC2	TC3	TC4
14:00	101	86	-	-
14:05	102	87	-	-
14:10	103	87	-	-
14:15	104	88	-	-
14:20	106	88	-	-
14:25	107	89	-	-
14:30	108	90	-	-
14:35	109	91	-	-
14:40	111	91	-	-
14:45	112	92	-	-
14:50	113	93	-	-
14:55	115	94	-	-
15:00	116	95	-	-
15:05	118	96	-	-
15:10	119	97	-	-
15:15	121	98	-	-
15:20	122	99	-	-
15:25	124	100	-	-
15:30	125	102	-	-
15:35	126	103	-	-
15:40	128	104	-	-
15:45	129	105	92	86
15:50	131	106	93	87
15:55	132	108	94	87
16:00	133	108	94	88
16:05	134	109	95	88
16:10	135	110	96	89
16:15	135	111	96	89
16:20	136	112	97	90
16:25	137	112	97	90

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE POOL FIRE TEMPERATURES

DATE: 12 JUNE 1998
FILE: OPMT1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
0:00	121	107	96	91
0:01	121	107	96	91
0:02	121	107	96	91
0:03	121	107	96	91
0:04	121	107	96	91
0:05	121	107	96	92
0:06	121	107	97	102
0:07	121	108	99	123
0:08	122	110	103	133
0:09	123	112	107	146
0:10	125	116	112	152
0:11	127	120	116	161
0:12	129	124	120	168
0:13	131	128	124	175
0:14	134	131	128	171
0:15	136	135	131	171
0:16	138	138	135	176
0:17	139	141	138	178
0:18	141	143	141	180
0:19	143	146	143	181
0:20	144	148	146	183
0:21	146	150	149	193
0:22	147	152	152	198
0:23	148	153	155	203
0:24	149	155	158	211
0:25	151	157	166	225
0:26	153	159	179	241
0:27	155	162	182	253
0:28	156	164	185	261
0:29	158	167	189	264
0:30	159	168	191	267
0:31	161	170	193	269
0:32	163	172	197	270
0:33	165	174	202	271
0:34	167	175	206	270
0:35	168	176	211	269
0:36	170	178	213	266
0:37	171	182	211	264
0:38	173	190	209	260
0:39	175	205	209	257
0:40	177	206	208	255
0:41	178	205	208	252

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE POOL FIRE TEMPERATURES

DATE: 12 JUNE 1998
FILE: OPMT1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
0:42	179	203	207	250
0:43	181	200	208	248
0:44	183	197	207	247
0:45	185	193	208	244
0:46	186	190	207	242
0:47	188	186	207	240
0:48	190	182	208	239
0:49	192	180	207	237
0:50	196	180	206	235
0:51	196	181	206	234
0:52	197	181	206	233
0:53	199	182	206	231
0:54	200	182	204	230
0:55	205	183	203	229
0:56	206	184	204	228
0:57	207	185	203	227
0:58	207	186	205	226
0:59	208	186	206	224
1:00	207	187	206	223
1:01	205	188	205	222
1:02	206	188	203	221
1:03	206	189	203	220
1:04	206	190	204	219
1:05	206	190	204	218
1:06	206	191	204	217
1:07	206	191	204	216
1:08	208	191	203	215
1:09	208	192	203	214
1:10	211	192	204	213
1:11	212	193	203	212
1:12	213	193	203	211
1:13	213	193	204	210

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE COOL DOWN TEMPERATURES

DATE: 12 JUNE 1998 — **SwRI PROJECT NO: 01-1680-102B**

FILE: 163OPMC1.DAT — **TEST TYPE: 10CFR 71.73(C),(4)**

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
0:00	214	194	203	209
0:05	215	194	201	205
0:10	216	194	199	202
0:15	216	193	196	198
0:20	216	191	193	195
0:25	215	190	191	193
0:30	215	189	188	190
0:35	215	188	186	187
0:40	214	187	184	185
0:45	213	187	182	183
0:50	213	186	180	182
0:55	212	185	178	180
1:00	210	184	176	178
1:05	209	182	175	177
1:10	208	181	173	175
1:15	207	180	172	174
1:20	206	178	170	172
1:25	205	177	169	170
1:30	204	176	168	169
1:35	203	175	166	167
1:40	201	174	165	166
1:45	200	172	164	165
1:50	199	171	163	163
1:55	198	170	161	162
2:00	197	169	160	161
2:05	196	169	159	160
2:10	195	168	158	158
2:15	194	167	158	157
2:20	193	166	157	156
2:25	191	165	156	155
2:30	190	164	155	154
2:35	189	164	154	153
2:40	188	163	153	152
2:45	187	162	153	152
2:50	186	161	152	151
2:55	185	161	151	150
3:00	184	160	150	149
3:05	183	159	150	148
3:10	182	159	149	148
3:15	181	158	149	147
3:20	180	158	148	146
3:25	179	157	147	146

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE COOL DOWN TEMPERATURES

DATE: 12 JUNE 1998 — **SwRI PROJECT NO: 01-1680-102B**
FILE: 163OPMC1.DAT — **TEST TYPE: 10CFR 71.73(C),(4)**

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
3:30	178	156	147	145
3:35	177	156	146	145
3:40	176	155	146	144
3:45	175	155	145	143
3:50	174	154	145	143
3:55	173	154	144	142
4:00	172	153	144	142
4:05	171	153	144	141
4:10	170	152	143	141
4:15	170	152	143	140
4:20	169	151	142	140
4:25	168	151	142	140
4:30	167	150	141	139
4:35	166	150	141	139
4:40	165	149	141	138
4:45	164	149	140	138
4:50	164	148	140	138
4:55	163	148	140	137
5:00	162	147	139	137
5:05	161	147	139	136
5:10	161	147	139	136
5:15	160	146	138	136
5:20	159	146	138	136
5:25	158	145	138	135
5:30	158	145	137	135
5:35	157	145	137	135
5:40	156	144	137	134
5:45	156	144	136	134
5:50	155	143	136	134
5:55	154	143	136	133
6:00	154	143	136	133
6:05	153	142	135	133
6:10	153	142	135	133
6:15	152	142	135	132
6:20	151	141	135	132
6:25	151	141	134	132
6:30	150	141	134	132
6:35	150	140	134	131
6:40	149	140	134	131
6:45	149	140	133	131
6:50	148	139	133	131
6:55	148	139	133	131

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE COOL DOWN TEMPERATURES

DATE: 12 JUNE 1998
FILE: 163OPMC1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
7:00	147	139	133	130
7:05	146	138	132	130
7:10	146	138	132	130
7:15	145	138	132	130
7:20	145	138	132	129
7:25	144	137	132	129
7:30	144	137	131	129
7:35	143	137	131	129
7:40	143	136	131	129
7:45	143	136	131	128
7:50	142	136	130	128
7:55	142	136	130	128
8:00	141	135	130	128
8:05	141	135	130	128
8:10	140	135	130	127
8:15	140	135	130	127
8:20	139	134	129	127
8:25	139	134	129	127
8:30	139	134	129	127
8:35	138	134	129	127
8:40	138	133	129	126
8:45	137	133	129	126
8:50	137	133	128	126
8:55	137	133	128	126
9:00	136	132	128	126
9:05	136	132	128	126
9:10	136	132	128	125
9:15	135	132	127	125
9:20	135	132	127	125
9:25	134	131	127	125
9:30	134	131	127	125
9:35	134	131	127	125
9:40	133	131	127	125
9:45	133	130	127	124
9:50	133	130	126	124
9:55	132	130	126	124
10:00	132	130	126	124
10:05	132	130	126	124
10:10	131	129	126	124
10:15	131	129	126	124
10:20	131	129	126	123
10:25	130	129	125	123

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE COOL DOWN TEMPERATURES

DATE: 12 JUNE 1998
FILE: 163OPMC1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
10:30	130	129	125	123
10:35	130	128	125	123
10:40	129	128	125	123
10:45	129	128	125	123
10:50	129	128	125	123
10:55	129	128	125	122
11:00	128	127	124	122
11:05	128	127	124	122
11:10	128	127	124	122
11:15	127	127	124	122
11:20	127	127	124	122
11:25	127	127	124	122
11:30	127	126	124	122
11:35	126	126	124	122
11:40	126	126	124	122
11:45	126	126	124	121
11:50	126	126	123	121
11:55	125	126	123	121
12:00	125	125	123	121
12:05	125	125	123	121
12:10	125	125	123	121
12:15	124	125	123	121
12:20	124	125	123	121
12:25	124	125	123	121
12:30	124	125	123	121
12:35	124	124	122	120
12:40	123	124	122	120
12:45	123	124	122	120
12:50	123	124	122	120
12:55	123	124	122	120
13:00	123	124	122	120
13:05	122	124	122	120
13:10	122	123	122	120
13:15	122	123	122	120
13:20	122	123	122	120
13:25	122	123	122	120
13:30	121	123	122	120
13:35	121	123	121	120
13:40	121	123	121	120
13:45	121	123	121	120
13:50	121	123	121	120
13:55	121	123	121	119

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE COOL DOWN TEMPERATURES

DATE: 12 JUNE 1998 **SwRI PROJECT NO: 01-1680-102B**
FILE: 163OPMC1.DAT **TEST TYPE: 10CFR 71.73(C),(4)**

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
14:00	120	122	121	119
14:05	120	122	121	119
14:10	120	122	121	119
14:15	120	122	121	119
14:20	120	122	121	119
14:25	120	122	121	119
14:30	120	122	121	119
14:35	119	122	121	119
14:40	119	122	121	119
14:45	119	122	121	119
14:50	119	122	121	119
14:55	119	121	121	119
15:00	119	121	121	119
15:05	119	121	121	119
15:10	119	122	121	119
15:15	118	121	121	119
15:20	118	121	121	119

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: OPMT1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME	FLAME THERMOCOUPLES				
(h:mm)	FTC 1	FTC 2	FTC 3	FTC 4	AVERAGE
0:00	216	129	420	882	412
0:01	977	1243	1857	1136	1303
0:02	1098	1227	2026	1211	1391
0:03	1081	1542	1769	1310	1426
0:04	1197	1449	2298	1564	1627
0:05	1247	1723	1945	1641	1639
0:06	1366	1553	1918	1730	1641
0:07	1259	1518	1996	1506	1570
0:08	1336	1946	2074	1299	1664
0:09	1615	2247	1944	1529	1834
0:10	1614	2051	1928	1336	1732
0:11	1684	2228	1784	1510	1802
0:12	1152	1566	2004	1589	1578
0:13	1406	2049	2073	1372	1725
0:14	1563	2104	1942	1446	1764
0:15	1527	2086	2010	1321	1736
0:16	1625	1960	2062	1350	1749
0:17	1234	1862	1976	1249	1580
0:18	1638	2142	2026	1440	1811
0:19	1222	1911	1972	1309	1603
0:20	1565	2108	2020	1369	1765
0:21	1371	2045	1837	1535	1697
0:22	1278	1951	1704	1895	1707
0:23	1770	2123	1716	1752	1840
0:24	1264	1888	1851	1586	1647
0:25	1352	2043	1954	1517	1717
0:26	1348	1953	1953	1570	1706
0:27	1329	1866	2005	1159	1590
0:28	1175	1749	2039	1428	1598
0:29	1150	1553	1964	1581	1562
0:30	1495	2087	1985	1423	1748
0:31	799	1607	1910	684	1250
0:32	328	915	1741	254	809
0:33	198	558	1649	160	641
0:34	162	334	1291	130	479
0:35	128	212	924	120	346
0:36	117	159	686	110	268
0:37	112	135	507	106	215
0:38	106	119	386	108	180
0:39	104	124	312	101	160
0:40	101	131	260	99	148
0:41	99	128	224	98	137

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: OPMT1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME	FLAME THERMOCOUPLES				
(h:mm)	FTC 1	FTC 2	FTC 3	FTC 4	AVERAGE
0:42	99	121	198	98	129
0:43	99	120	178	99	124
0:44	98	120	166	97	120
0:45	97	117	155	96	117
0:46	97	116	149	96	114
0:47	97	108	142	96	111
0:48	97	106	136	96	109
0:49	97	102	131	95	106
0:50	96	103	127	95	105
0:51	96	103	125	95	105
0:52	95	105	122	95	104
0:53	95	106	120	94	104
0:54	95	107	119	95	104
0:55	95	106	119	95	104
0:56	95	104	118	95	103
0:57	95	106	119	94	104
0:58	95	102	117	95	102
0:59	95	103	117	94	102
1:00	94	102	116	94	102
1:01	95	102	115	94	101
1:02	94	100	113	94	100
1:03	94	100	112	94	100
1:04	94	100	111	94	100
1:05	94	99	110	94	99
1:06	94	98	109	94	99
1:07	94	97	108	93	98
1:08	94	98	107	93	98
1:09	93	99	107	93	98
1:10	93	99	107	93	98
1:11	93	97	107	93	98
1:12	93	96	107	93	97
1:13	93	96	105	93	97

APPENDIX F

FIRE TEST PHOTOGRAPHIC DOCUMENTATION

(Consisting of 8 Pages)

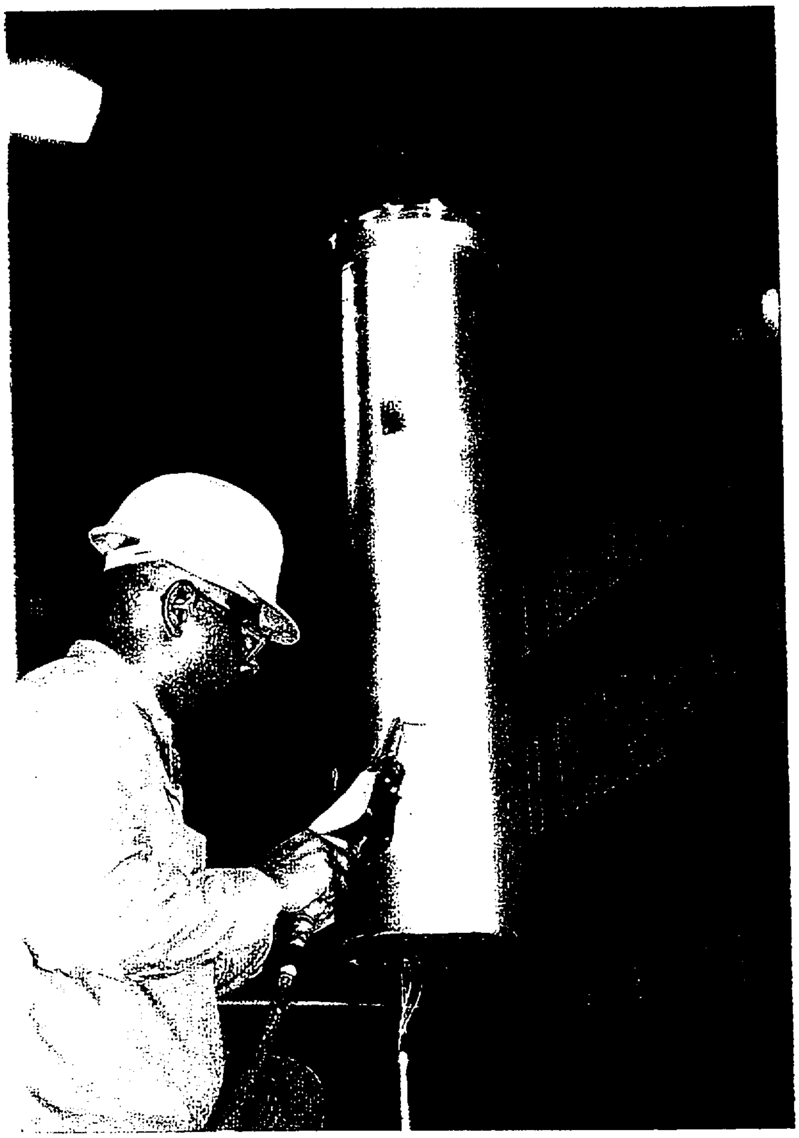


Figure F-1. Hookup of Temperature Instrumentation.

Figure F-2. View of Vessel – Outfitted with Thermocouples.

Figure F-3. OPM-1 Package Prior to Pool Fire Test.

Figure F-4. Side View of OPM-1 Prior to Pool Fire Test.

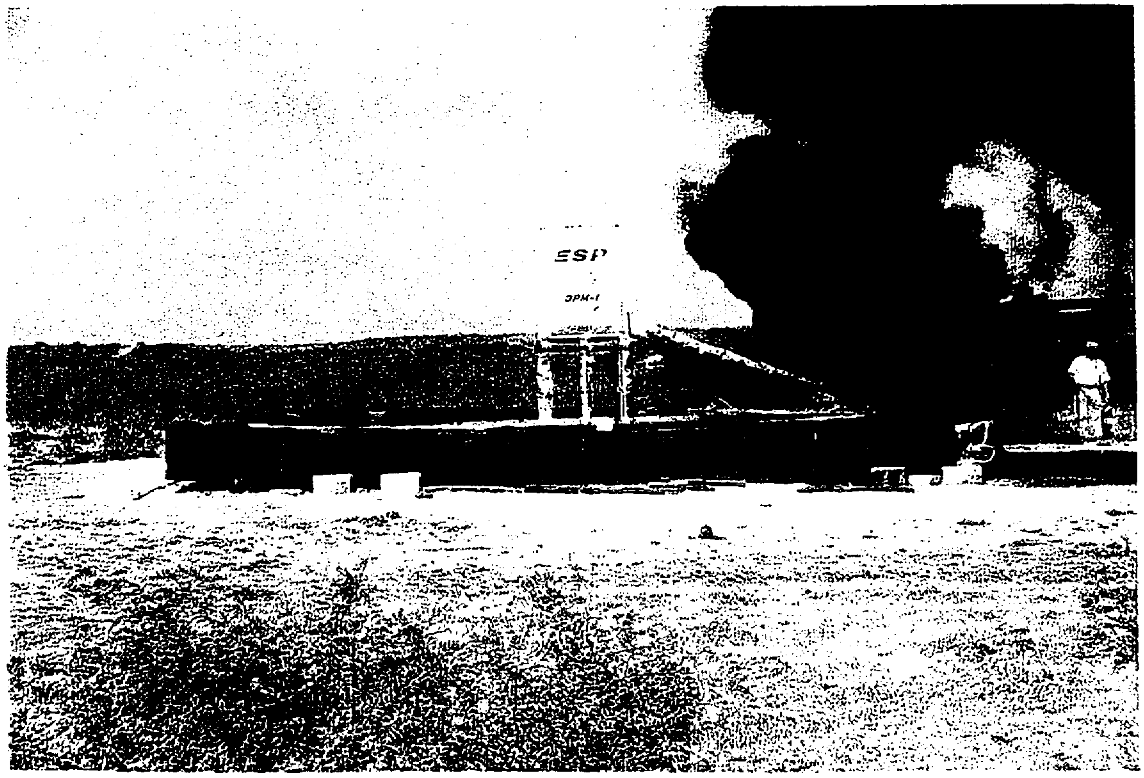


Figure F-5. OPM-1 Package at Start of 30-Min Pool Fire Test.


Figure 6. OPM-1 Package During 30-Min Pool Fire Test.

Figure F-7. OPM-1 Package at End of 30-Min Pool Fire Test.

Figure F-8. OPM-1 Package 3 Min After 30-Min Pool Fire Test.

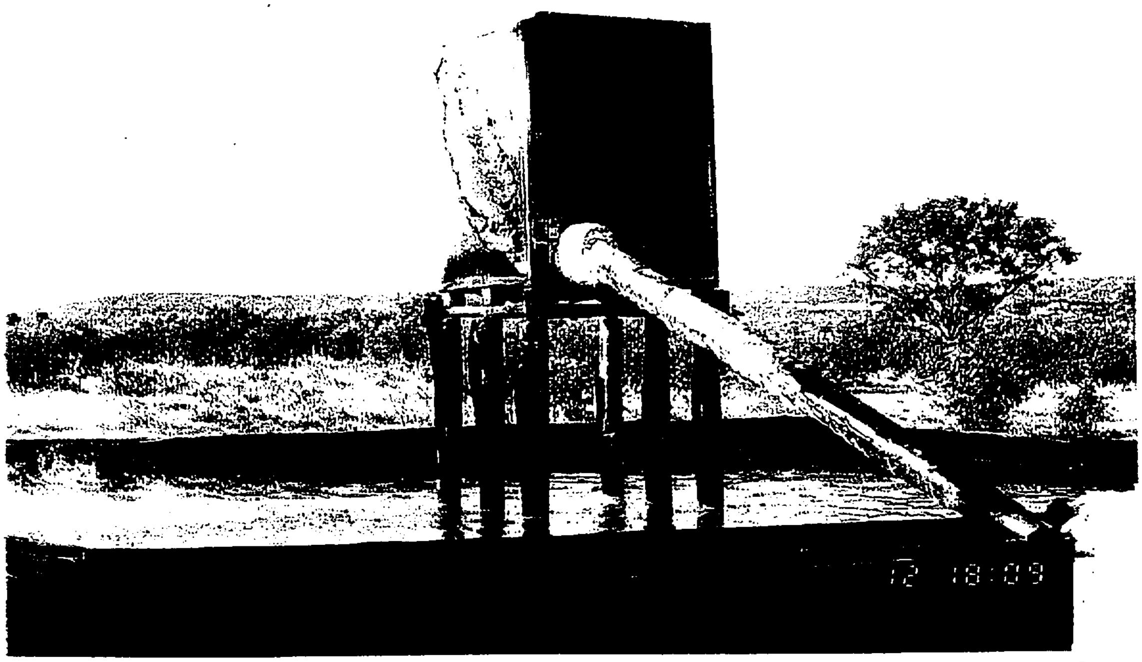


Figure F-9. OPM-1 Package Following 30-Min Pool Fire Test and Burnout of Residual Fuel.

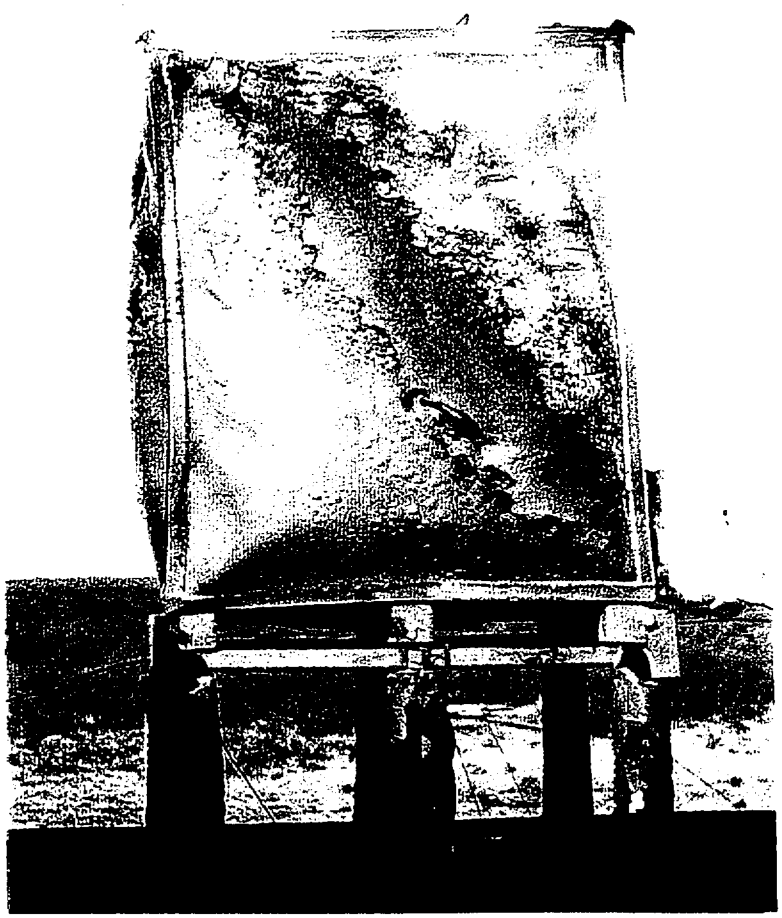


Figure F-10. Side View of OPM-1 Package Following 30-Min Pool Fire Test.

Appendix 2.10.6

Chemical and Galvanic Reactions Analysis

LAW
LAWGIBB Group Member

September 2, 1999

Mr. Mike Arnold
Eco-Pak Specialty Packaging
200 West Railroad Street
Columbiana, Ohio 44408

Subject: Accelerated Laboratory Testing
Carbon Steel Samples and Stainless Steel Samples
Eco-Pak Specialty Packaging
LAW Job Number: 10810-9-7003, Phase 03

Dear Mr. Arnold:

As authorized by signing our Proposal Acceptance Sheet 4542ME9, dated January 21, 1999, and your Purchase Order Number 5173, Law Engineering and Environmental Services (LAW) has completed humid atmosphere primer adhesion and ferric chloride solution corrosion tests on carbon steel samples and stainless steel samples provided to us by Eco-Pak. The purpose of our work was to evaluate the performance of carbon steel samples and stainless steel samples in various configurations as described later in this report. This report contains test procedures and results. Testing was performed by Dr. Bryan A. Chin, Profession and Chairman of the Materials Engineering Department at Auburn University in Auburn, Alabama. Testing was periodically witnessed by Mr. Lakshman Santanam of LAW.

HUMID ATMOSPHERE PRIMER ADHESION TESTS

Scope

Humid Atmosphere tests were conducted to evaluate primer adhesion using the following samples: carbon steel + primer + duraboard + PF-2 foam + fiber paper sandwich and stainless steel + primer + scribe + PF-2 foam sandwich. The test provided information on the adhesion, blistering, and creepage of the primer to carbon steel and stainless steel in these application configurations.

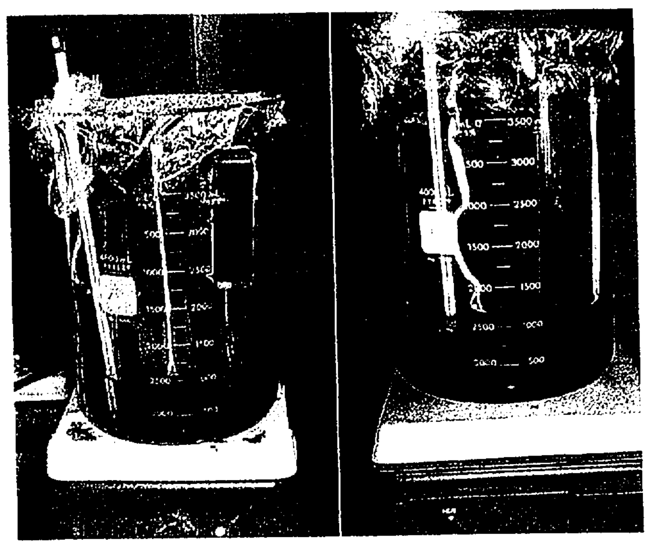
LAW Engineering and Environmental Services,Inc.
Industrial Services Business Segment
2801 Yorkmont Road, Suite 200 • Charlotte, NC 28208
P.O. Box 19667 • Charlotte, NC 28219
704-357-8600 • Fax: 704-357-8637

Test Procedures

Test Set-Up

4000ml beakers were set on hotplates with 1000ml of distilled water in them. The beakers were covered to maintain a humid temperature for the specimens. The hotplates were set so the water temperature was held at 90°C. The temperature was monitored three times daily for the thirty-day test duration. Samples were suspended above the distilled water using glass rods and monofilament fishing line. Figure 1 illustrates the test set-up. Table 1 describes how the samples are organized.

Figure 1. Foam sandwiches during humidity testing (composite photo). Beakers (L to R) A and C



Specimen Preparation

As-Received Material

Carbon steel (6" x 6" x 0.125") and stainless steel plates (6" x 6" x 0.120") that were supplied by ESP were cut into 1" x 2" standard size specimens in accordance with ASTM specification G48. The specimen edges were ground to remove any burrs and rough edges. Figure 2 shows a representative sample.

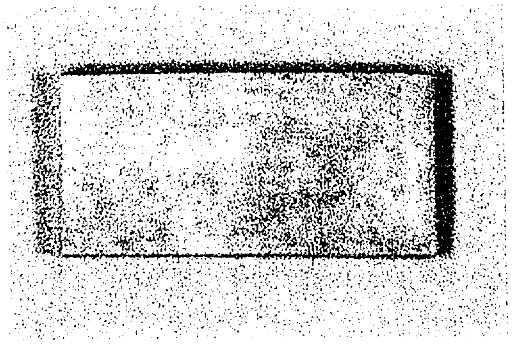


Figure 2. Prepared Corrosion Sample

Carbon steel (6" x 6" x 0.125") and stainless steel plates (6" x 6" x 0.120) were received, already primed with an epoxy coating. These plates were also cut into 1" x 2" standard size specimens. The edges were ground, the surface prepared, and the edges painted with ESP supplied epoxy paint. Painting was performed in accordance with ESP supplied procedures. The specimens were allowed to dry for 48 hours prior to measurement and testing.

Primer Coated Specimens-Scribed

Standard size specimens of coated stainless steel were inscribed on one side. The scribe was made using a tungsten carbide scribing tool in accordance with ASTM D1654. The scribe was made on a diagonal to maximize the length of the scribe. These specimens were used to test adhesion of the coating at the scribe mark when exposed to corrosive environments. Figure 3 shows a scribed specimen.

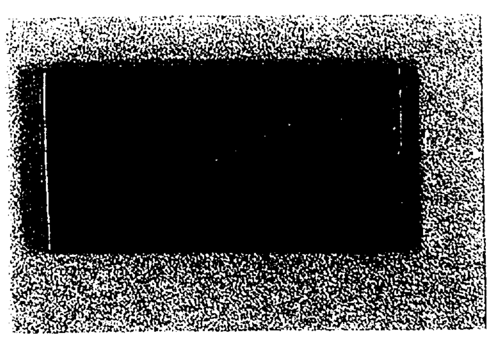


Figure 3. Scribed Corrosion Sample

Foam Sandwich Specimens

Sections of the PF-2 foam material (ESP supplied) were cut into 1" x 2" x 6" specimens using a band saw. The foam sandwich is held together with a rubber band. Figure 4 shows a foam sandwich prior to testing.

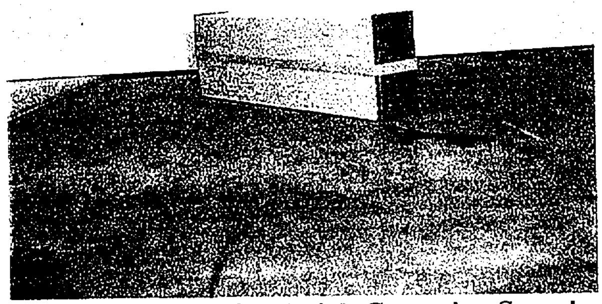


Figure 4. Foam Sandwich Corrosion Sample

Special Sandwich Specimens

Two sandwiches were constructed which consisted of primer coated carbon steel, duraboard (as received), 3 inches of PF-2 foam, fiber paper (as received), and primer coated carbon steel.

Specimen Evaluation

Photographic Evaluation

All specimens were photographed to record visual changes induced by the test. Figures 5 and 6 show typical post test conditions for representative samples.

Specimen Weight Evaluation

All specimens were weighed prior to testing and were again weighed after the 30-day testing period. The specimens were dried in air prior to weighing.

Creepage Evaluation of Primer Coated Specimens

The stainless specimens performed satisfactorily due to the corrosion resistance of the stainless steel.

Conclusions

The humid atmosphere test caused the primer coating to blister on all the sandwich specimens. Individual specimens showed minor blistering. Tables 2 and 3 give a brief description of all the samples involved in the humid atmosphere tests.

The primer coating blisters extensively on the exposed side of the carbon steel sandwich samples. On the foam side, the foam acts as a backing which aids the adherence of the primer and thereby reducing corrosion. Blistering of the primer coating was moderate on the foam side of the sandwich samples.

Figure 5. Exposed surface of sample #A1 (carbon steel + primer + special sandwich). Note extensive blistering of surface

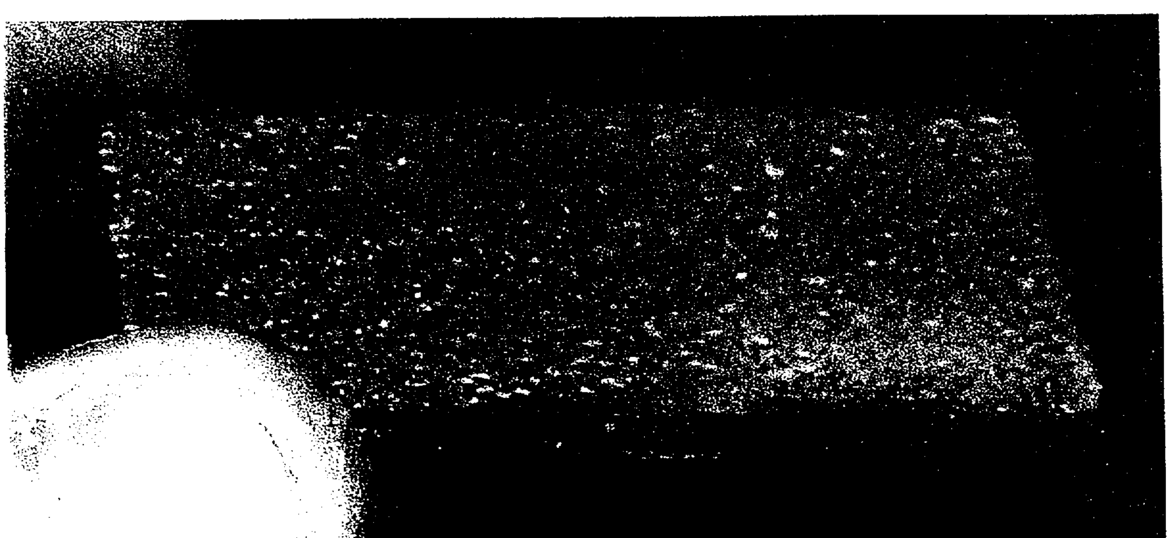


Figure 6. Foam surface of sample #A1 (carbon steel + primer + special sandwich). Note wrinkling of primer surface

Table 1. Specimens in the Humid Atmosphere Baths

Humid Atm Bath	Specimen	Specimen No.
Bath A	Stainless Steel + Primer + Scribe + PF-2 foam + Primer + Stainless Steel	Y6, Y7
	Carbon Steel + Primer (Special Sandwich) PF-2 foam sandwich with duraboard and paper inserts	A0, A1, A2, A3
Bath C	Stainless Steel + Primer + Scribe + PF-2 foam + Primer + Stainless Steel	Y2, Y3

Table 2. Summary Results for all Humidity Test Specimens

SPECIMEN/TYPE	SANDWICH TYPE	WT. LOSS % NEGATIVE INDICATES GAIN	PITTING	BLISTERING	NOTES
A0 carbon steel + primer	Special sandwich PF-2 foam + duraboard & paper	-0.45%	No	Extensive, Back is wrinkled	2 large blisters covering entire front, back is wrinkled
A1 carbon steel + primer	Special sandwich PF-2 foam + duraboard & paper	0.0029%	No	Extensive, Back is wrinkled	2 large blisters cover entire front, back is wrinkled
A2 carbon steel + primer	Special sandwich PF-2 foam + duraboard & paper	-0.13%	No	Extensive, Back is wrinkled	2 large blisters cover entire front, back is wrinkled
A3 carbon steel + primer	Special sandwich PF-2 foam + duraboard & paper	0.098%	2 on primer side of metal	Front and back wrinkled	Paint on primer side of metal removed for observation
Y2 stainless steel + primer + scribe	PF-2	0.06%	No	Front peeled	Back 80% blistered
Y3 stainless steel + primer + scribe	PF-2	-0.25%	No	Front peeled	Back 70% blistered
Y6 stainless steel + primer + scribe	PF-2	-0.045%	No	Front peeled	Back 25% blistered
Y7 stainless steel + primer + scribe	PF-2	-0.096%	No	Front 25% blistered	Back 50% wrinkled and peeled

Table 3. Summary of Corrosion Test Results

Specimen Description	**30 Day Humid Atm Test @ 90°C**
Carbon Steel + Primer (Special sandwich, PF-2 foam with duraboard and fiber paper inserts)	0.12% weight gain, major blistering
Stainless Steel + Primer + Scribe (PF-2 foam sandwich)	0.08% weight gain, major blistering

FERRIC CHLORIDE SOLUTION CORROSION TESTS

Scope

Ferric chloride corrosion tests were performed in accordance with ASTM specification G48 to evaluate the corrosion resistance of the following samples: carbon steel + primer + duraboard + PF-2 foam + fiber paper and stainless steel + primer + scribe + PF-2 foam. The test provided information on the relative resistance of the samples and the performance of the primer in corrosive environments.

Test Procedure

Ferric Chloride Bath Preparation

100 grams of ferric chloride, $FeCl_3$, were mixed in 900 ml of distilled water in accordance with ASTM specification G48. Four beakers containing 3500 ml of solution (for specimens with foam) were prepared. A recirculating water bath was used to heat beakers containing the foam samples (figure 7). All beakers were maintained at 50°C and the test was conducted for 30 days. Nonconductive glass rods, specimen holders and monofilament fishing line were used to suspend the specimens in the corrosive solutions in accordance with ASTM specification G48. Temperature of the solutions was measured and recorded three times daily. Evaporated water was replaced with distilled water as needed. Table 4 lists the specimen identification numbers along with the corresponding corrosion bath numbers.

Test Set-Up

The corrosion baths were set up as shown in Figure 7.

Carbon steel (6" x 6" x 0.125") and stainless steel plates (6" x 6" x 0.120") were received, already primed with an epoxy coating. These plates were also cut into 1"x 2" standard size specimens. The edges were ground, the surface prepared and the edges painted with the ESP supplied epoxy paint. Painting was performed in accordance with ESP supplied procedures. The specimens were allowed to dry for 48 hours prior to measurement and testing.

Primer Coated Specimens-Scribed

Standard size specimens of coated stainless steel were inscribed on one side. The scribe was made using a tungsten carbide scribing tool in accordance with ASTM D1654. The scribe was made on a diagonal to maximize the length of the scribe. These specimens were used to test adhesion of the coating at the scribe mark when exposed to corrosive environments. Figure 9 shows a scribed specimen.

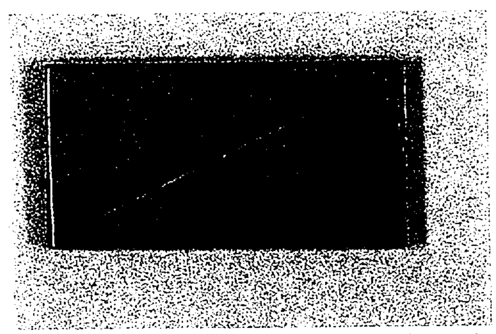


Figure 9. Scribed Corrosion Sample

Foam Sandwich Specimens

Sections of the PF-2 foam material (ESP supplied) were cut into 1" x 2" x 6"specimens using a band saw. The foam sandwich is held together with a rubber band.

Figure 10 shows a foam sandwich prior to testing.

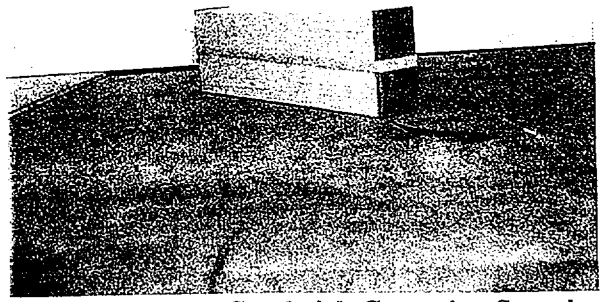


Figure 10. Foam Sandwich Corrosion Sample

Special Sandwich Specimens

Two sandwiches were constructed which consisted of primer coated carbon steel, duraboard (as received), 3 inches of PF-2 foam, fiber paper (as received), and primer coated carbon steel.

Specimen Evaluation

Photographic Examination

All test specimens were photographed prior to and after testing to record visual changes induced by the test. Figures 11 through 13 show the post test condition of typical specimens.

Specimen Weight Evaluation

All specimens were weighed prior to testing. After testing, all specimens were air dried and then weighed prior to further evaluation.

Pitting Evaluation

All stainless steel specimens were examined for pitting. Standard procedures defined by ASTM G48 and 46 were used. Care was taken to retain the primer paint which had flaked off for future analysis. prior to pit depth measurement of stainless steel samples, the specimens were cleaned using running water and a soft bristle brush to remove corrosion products. The specimen was then dipped in methanol and allowed to dry to eliminate residual water. A dial indicator with needle point was used to measure the pit depths. Calibration of the dial indicator was performed using standard gauge blocks. Pit density was obtained by counting the number of pits on the surface. The 10 deepest pits were measured on both sides of the 1" x 2" specimens. Table 5 shows the details of the measurements. Some specimens were deeply etched by the test. This is noted in Table 5 and occurred under the rubber bands used to secure the foam between the steel end pieces.

Blister Evaluation of Primer Coated Specimens

All coated specimens were examined for blisters on the surface. The 5 largest blisters were examined and recorded. Table 6 shows the details of the evaluation. The primer coated specimens that were inscribed were also affected by loss of adhesion. This is reported in Table 7 as the distance from the scribe over which the coating failed. Some samples also showed extensive wrinkling of the primer.

Conclusions

Tables 8 and 9 give a brief description of the samples tested in the ferric chloride corrosion test.
The ferric chloride corrosion test resulted in the following conclusions:

The extent of specimen corrosion was largely determined by the adherence of the primer to the metal. Primer application procedures are very important to metal adherence. In cases where primer adherence was achieved, corrosion was greatly reduced. In addition, the foam acts as a backing, which aids the primer coating adhere to the steel, thereby reducing corrosion.

A significant amount of the weight loss measured in the stainless steel specimens occurred due to "etching" under the rubber band that was used to hold the sandwich together. Approximately 15% of the length of the specimen was covered by the rubber band. The through wall pit that occurred in sample Z2 was located beneath the rubber band. It is our opinion that this accelerated corrosion under the rubber band can be attributed to oxygen depletion due to the presence of the rubber band.. In areas of the specimen away from the rubber band, through wall pitting did not occur. It therefore may be surmised that the majority of the weight loss occurred in the specimen due to corrosion beneath the rubber band.

Figure 11. Sample #B4 exposed side (carbon steel + special foam sandwich). Covered by five large blisters.

Figure 12. Sample #B4 foam side (carbon steel + special foam sandwich). This side has wrinkled edges.

Figure 13. Sample #Z2 exposed side (stainless steel + primer + scribe + PF-2 foam). The pit at the bottom center goes all the way through.

Table 4. Specimens Identification and Corrosion Bath Numbers

Ferric Chloride Bath No.	Specimen	Specimen No.
Bath 9	Carbon Steel + Primer (Special Sandwich) PF-2 sandwich w/duraboard and fiber paper	B4, B5, B6, B7
Bath 11	Stainless Steel + Primer + Scribe PF-2 sandwich	Y8, Y9, Z1, Z2

Table 5. Corrosion Induced Pitting

Specimen Description	Specimen No.	Average Pit Size (mm) 10 each side	Pit Depth (mm) (Max/Avg) 10 each side	Pit Density (Pits/m^2)
Primed stainless (scribed)	Y8	Etched	0.51 max	
Primed stainless (scribed)	Y9	Etched	0.28 max	
Primed Stainless (scribed)	Z1	Etched	0.38 max	
Primed Stainless (scribed)	Z2	6.01	2.62/2.18	2,325

Table 6. Blistering

Specimen Description	Specimen No.	Blister Diameter (mm)	Blister density (Blisters/m^2)
Primed Carbon Steel	B4	25x25, 19x16, 6.39, 7.27	3100
	B5	21.92, 17.82, 7.85, 6.45, 4.64	3875
	B6	25.00, 14.4, 10.71, 14.86, 3.5	10850
	B7	23.53, 25.71, 4.12, 4.46, 5.01	11625
Primed Stainless Steel	On all the stainless samples, the primer coating peeled off		

Table 7. Creepage

Specimen Material	Specimen No.	Creepage (mm)
Primed Stainless Steel	All stainless steel specimens peeled	

Table 8. Summary Results for all Ferric Chloride Test Specimens

SPECIMEN/TYPE	SANDWICH TYPE	WT. LOSS % NEGATIVE INDICATES GAIN	PITTING	BLISTERING	NOTES
B4 carbon steel + primer	Special sandwich PF-2 foam + duraboard & paper	0.79%	No	Large blisters covering front	Back blistered along edges.
B5 carbon steel + primer	Special sandwich PF-2 foam + duraboard & paper	1.14%	No	Large blisters covering 80%front	Small flat blisters on back
B6 carbon steel + primer	Special sandwich PF-2 foam + duraboard & paper	0.15%	No	Large blisters covering 85% front	Scattered blisters 75% coverage
B7 carbon steel + primer	Special sandwich PF-2 foam + duraboard & paper	0.93%	No	Large blisters covering 80% front	Small blisters 70% coverage
Y8 stainless steel + primer + scribe	PF-2	7.7%	Etched at rubber band	Front peeled	Back etched and peeled
Y9 stainless steel + primer + scribe	PF-2	5.28%	Etched at rubber band	Front peeled	Back etched and peeled
Z1 stainless steel + primer + scribe	PF-2	6.21%	Etched at rubber band	Front peeled	Back etched and peeled
Z2 stainless steel + primer + scribe	PF-2	12.88%	Yes, also etched at rubber band	Front peeled	Back etched and peeled

Table 9. Summary of Corrosion Test Results

Specimen Description	**30 Day Ferric Chloride Test @ 50°C**
Stainless Steel + Primer + Scribe (PF-2 foam sandwich)	8% weight loss, primer peeled off. Deep etching on foam side and rubber band, one specimen had deep pitting
Carbon Steel + Primer (Special sandwich, PF-2 foam with duraboard & fiber paper inserts)	0.75% weight loss, 60% blistering, good adhesion on foam side

In summary, short term accelerated laboratory tests were performed to simulate and predict long term corrosion behavior. The objectives of these tests were to quantitatively and qualitatively assess the effects of chemical, galvanic or other reactions among or between the foam, the structural components and the primer applied to these components.

Humid atmosphere and ferric chloride tests were conducted to evaluate the effects of water, water vapor and a chloride rich environment on the various configurations. The test results indicate that adherence of the primer to the steel is important from a corrosion standpoint. In instances where the primer adhered to the steel, corrosion was greatly reduced. In addition, the foam acts as a backing, enhancing the adherence of the primer.

A significant amount of the weight loss measured in the stainless steel specimens occurred due to "etching" under the rubber band that was used to hold the sandwich together. Approximately 15% of the length of the specimen was covered by the rubber band. The through wall pit that occurred in sample Z2 was located beneath the rubber band. It is our opinion that this accelerated corrosion under the rubber band can be attributed to oxygen depletion due to the presence of the rubber band. In areas of the specimen away from the rubber band, through wall pitting did not occur. It therefore may be surmised that the majority of the weight loss occurred in the specimen due to corrosion beneath the rubber band.

Law Engineering and Environmental Services appreciates the opportunity of working with you on this project. If there are any questions concerning the information contained in this report or if we may be of further assistance, please contact us at your convenience.

Respectfully submitted,

Lakshman Santanam, P.E.
Director of Projects
Assistant Vice President

Hussein M. Sadek
Corporate Consultant/NDE
Assistant Vice President

Appendix 2.10.7

Fifty Foot Immersion Analysis

LAW

LAWGIBB Group Member

January 7, 2000

Eco-Pak Specialty Packaging
Division of CBC
200 West Railroad Street
Columbiana, OH 44408

Attention: Mr. Mike Arnold/Mr. Jerry Rasel

Subject: **Report of Finite Element Analysis (FEA)**
Eco-Pak OP-TU, Oxide Transport Unit
Law Engineering and Environmental Services Project 10810-9-7003, Phase 15

Dear Mr. Arnold:

As authorized by your purchase order number 7229 and by signing our annual Proposal Acceptance Sheet, Law Engineering and Environmental Services (LAW) is pleased to present this report of Finite Element Analysis (FEA) for the Eco-Pak OP-TU, Oxide Transport Unit. The purpose of this analysis was to determine the affects of a 50-foot head of water on the subject transport unit in accordance with the requirements of 10 CFR (Code of Federal Regulation) 71.73 (5). This report provides our understanding of the background information; services performed, and results.

Background Information

Mr. Mike Arnold of Eco-Pak Specialty Packaging requested LAW to perform an engineering analysis for the Eco-Pak OP-TU, Oxide Transport Unit when it is subjected to an external pressure that would be produced by a 50-foot water head (21.7 psi) in accordance with the requirements of 10 CFR 71.73 (5). Eco-Pak Specialty Packaging provided the following drawings:

- General Arrangement, ECO-PAK OP-TU Oxide Transport Unit, Drawing No. 71497/50 dated 7/9/98.
- Bill of Material, ECO-PAK OP-TU Oxide Transport Unit, Drawing No. 71497-BM dated 7/13/98

LAW Engineering and Environmental Services, Inc
2801 Yorkmont Road • Charlotte, NC 28208
704-357-8600 • Fax: 704-357-8638

Services Performed

The subject box container is 45 inches by 45 inches and 60.75 inches tall and has various structural components such as angle frames, legs, side panels, and top and bottom panels. These components are constructed from carbon steel materials. From the drawings, an FEA computer model was constructed using plate elements, see Appendix A attached with this report. Please note that, in our computer model, we included the structural components since they support the majority of the external pressure load. In our analysis we increased the structural components thicknesses to simulate support materials such as plywood, duraboard and phenolic form.

The following material properties were assumed for calculating the element resultant thickness:

Plate Material	**Carbon Steel**	**Plywood**	**Insulation (Duraboard)**	**Phenolic Form**
Plate Thickness	**Varies**	**Varies**	**Varies**	**Varies**
E =Young's Modulus	**30,000 ksi**	**2,000 ksi**	**2,000 ksi**	**1,000 ksi**

We assumed the following properties for carbon steel material:

Plate Material	**Carbon Steel**
' =Poison's Ratio	**0.29**
Density	**0.283 lbs/cu. inch**
G, Shear Modulus	**11,630 ksi**

The following assumptions were made to calculate the external pressure of 21.7 psi:

- Water density 62.4 per cubic foot
- Water temperature 68° F
- 50-foot head of water

For the FEA stress analysis, the calculated external pressure load was applied equally on the computer model elements that would come in contact with the water. We also applied the constraints or boundary conditions on the computer model by fixing the nodes located on the edges of the container. From the results of our analysis, the maximum stress was compared to the yield limit of the material.

There are four cylinder containers symmetrically located inside the subject box container. These cylinders are constructed from carbon steel material and are measured 40.75 inches long, 10.25 inches inside diameter and 0.1196 inches (11 GA) shell thickness. These cylinders have flat top and bottom welded heads. We analyzed these cylinders for buckling and collapsing for the external pressure of 21.7 psi. in the event outside box container failed or was over the yield stress limit.

Results Obtained

Figures 1 to 4 in Appendix B, attached with this report, show the stress and deflection contours in the container due to an external pressure of 21.7 psi. This FEA analysis result shows stress values linearly proportional to strain values. As explained in Figure 1 of Appendix C, attached to this report, the stress higher than the yield stress does not represent the actual stress but a pseudo stress value. The strain corresponding to the pseudo stress was used to estimate actual stress values from an approximation of the stress-strain curve.

The following material properties were assumed for ASTM A-36 material:

Assumed Yield Strength = 36 ksi
Young's Modulus = 30,000 ksi
Strain at Yield stress = 0.0012 in/in

Calculations were performed for two extreme cases of Ultimate Tensile Strength of 58 and 80 ksi, representing the minimum and maximum values for A-36 steel.

Approximate stress from pseudo (computer model) stress

(Assuming Ultimate Tensile Strength is 58 ksi at 0.200 in/in strain)

External Pressure	Maximum Pseudo-Stress in ksi	Calculated Strain from Pseudo-Stress in inch/inch	Extrapolated Stress from Stress-Strain Curve in ksi	Yield Stress In ksi	Maximum Deflection In Model
21.7 psi	256	0.00853	36.81	36	6.474 inches

Approximate stress from pseudo (computer model) stress

(Assuming Ultimate Tensile Strength is 80 ksi at 0.200 in/in strain)

External Pressure	Maximum Pseudo-Stress in ksi	Calculated Strain from Pseudo-Stress in inch/inch	Extrapolated Stress from Stress-Strain Curve in ksi	Yield Stress In ksi	Maximum Deflection In Model
21.7 psi	256	0.00853	37.62	36	6.474 inches

Based on our FEA analysis results, the maximum stress in the outside box container structure exceeds the yield stress limit of 36 ksi when it is subjected to an external pressure of 21.7 psi but is less than the ultimate tensile stress.

Because the outside box container structure is over stressed, we calculated the buckling and collapsing stresses in the inside cylinder containers for an external pressure of 21.7 psi. Considering the physical size of the cylinder and an external pressure of 21.7 psi **stresses in the cylinder are less than the buckling and collapse stress limits.**

Qualifications

This report summarizes our engineering evaluation of the Eco-Pak OP-TU container when subjected to an external pressure of 21.7 psi. The results of our evaluation are based on the drawings, FEA analysis, and information provided to us. Any conditions discovered which deviate from the data contained in this report should be provided to us for our review.

Law Engineering and Environmental Services appreciates the opportunity to assist you with this project. Please contact this office at 704-357-8600 if you have any questions.

Sincerely,

LAW ENGINEERING AND ENVIRONMENTAL SERVICES

M.N. Parikh

Mike N. Parikh, P.E.
Senior Professional

James W. Page

James W. Page, P.E.
Corporate Consultant

Attachment: Appendix A – 2 Figures of the container.
Appendix B – 4-stress and deflection color plots.
Appendix C – Stress –Strain Curve.

Appendix A

Figure 1: Isometric view of the container with hidden lines.

Figure 2: Isometric view of the container without hidden lines.

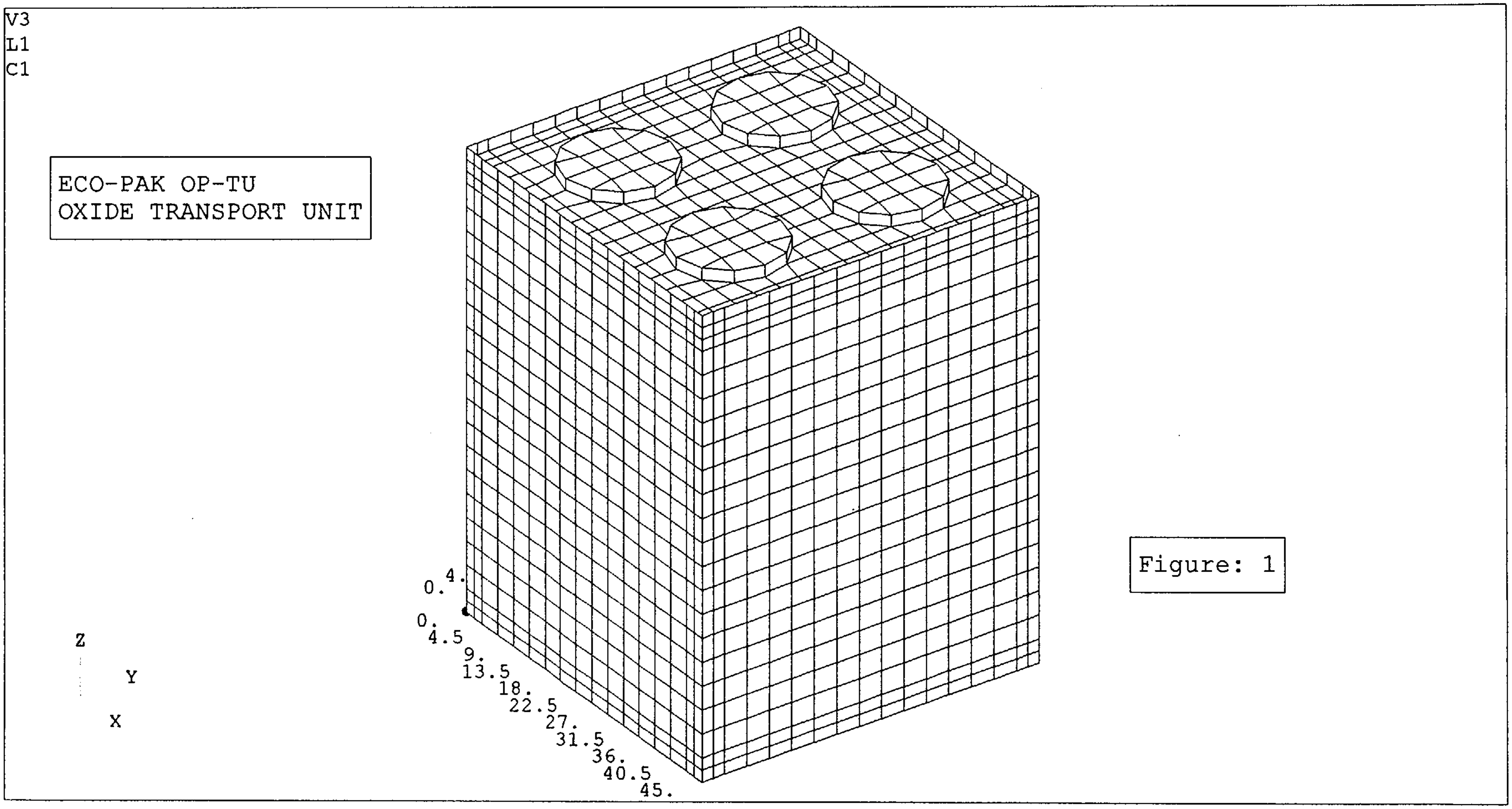

V3
L1
C1
ECO-PAK OP-TU
OXIDE TRANSPORT UNIT
0.
4.
0.
4.5
9.
13.5
18.
22.5
27.
31.5
36.
40.5
45.
Z
Y
X

Figure: 1

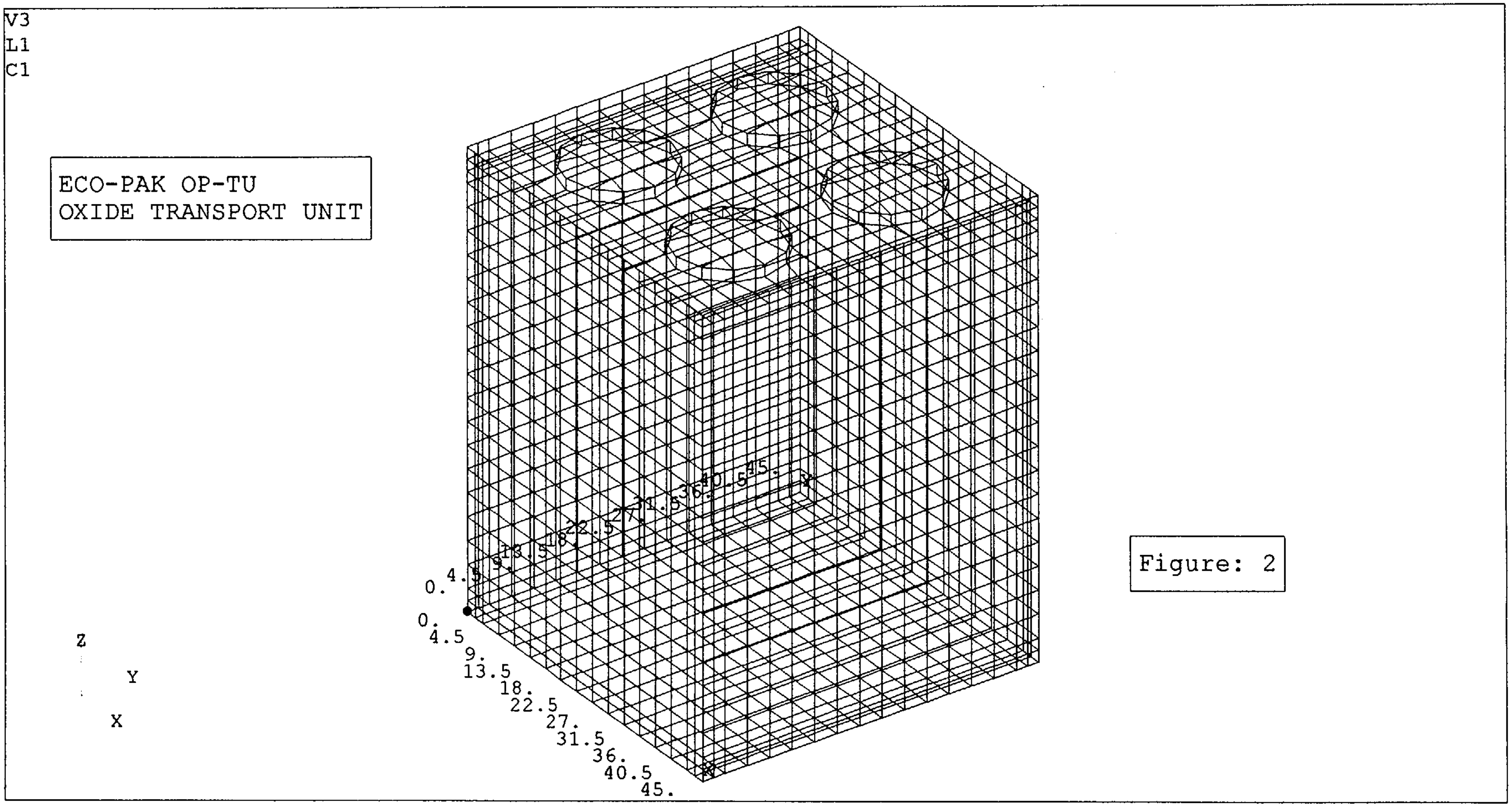

V3
L1
C1
ECO-PAK OP-TU
OXIDE TRANSPORT UNIT
Z
Y
X
0.
4.5
9.
13.5
18.
22.5
27.
31.5
36.
40.5
45.

Figure: 2

Appendix B

Figure 1: Major stress color contour plot deflected view (shown top surface)

Figure 2: Major stress color contour plot deflected view (shown bottom surface)

Figure 3: Total deflection color plot (shown top surface)

Figure 4: Total deflection color plot (shown bottom surface)

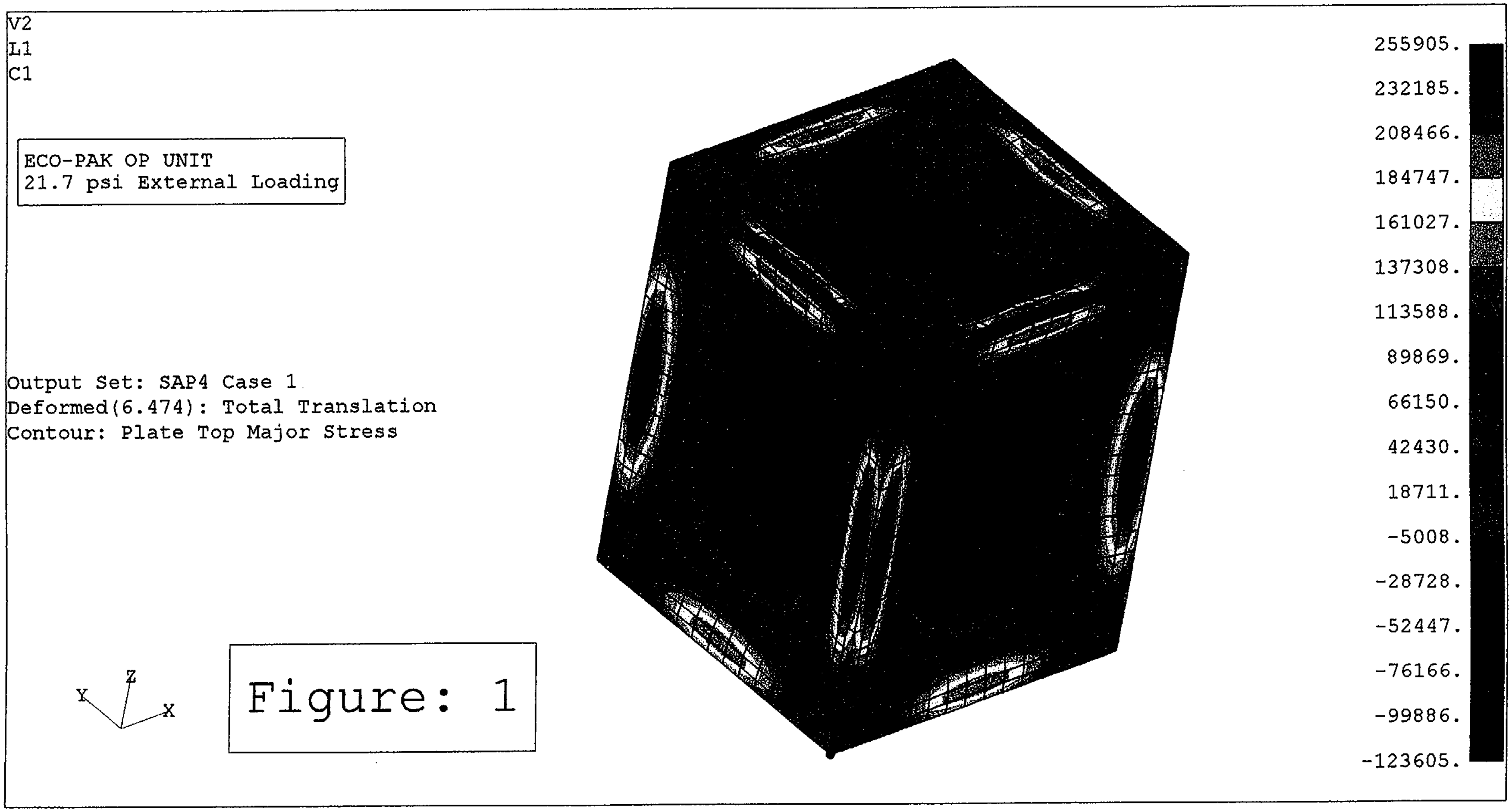
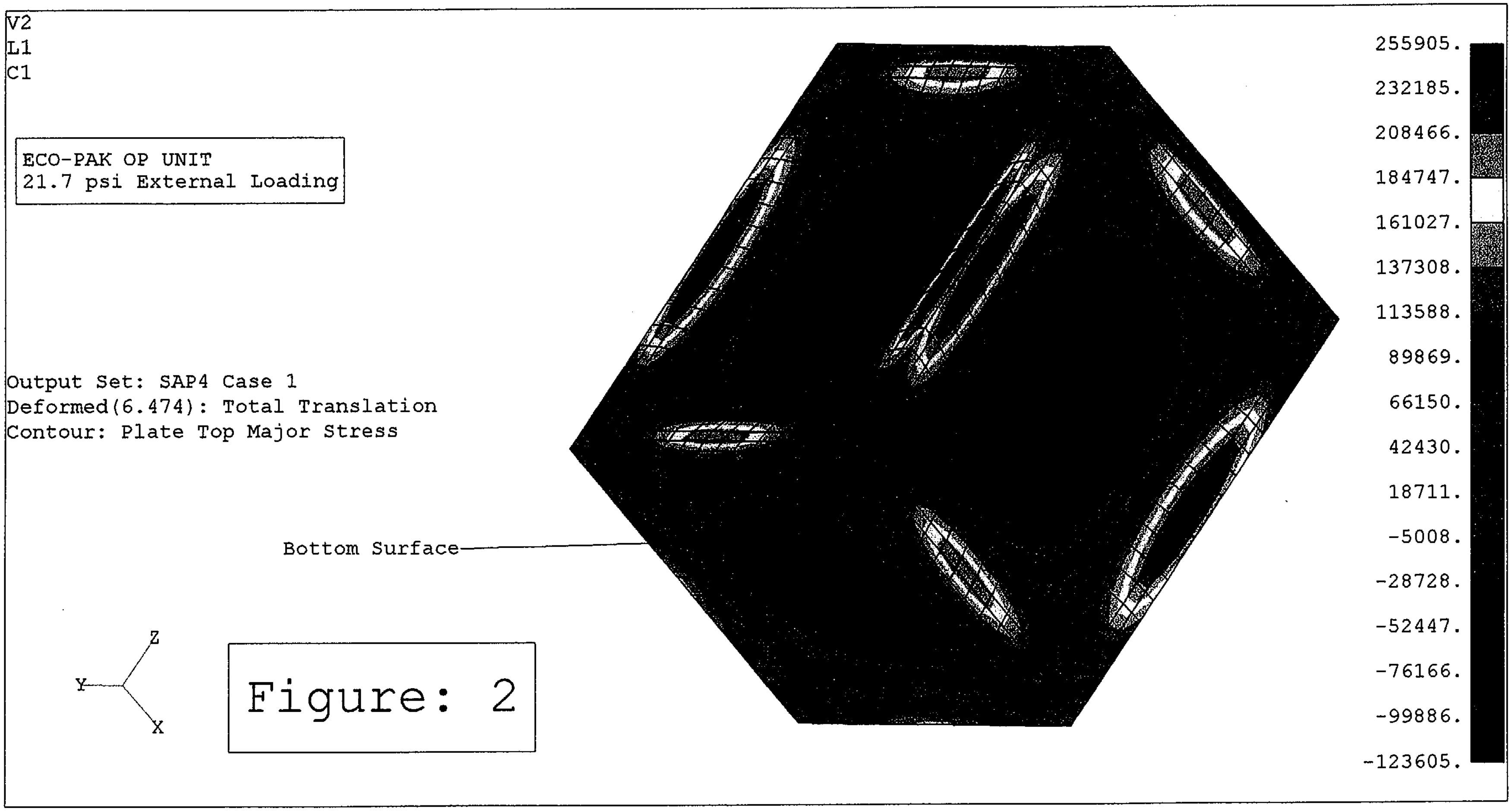

V2
L1
C1
ECO-PAK OP UNIT
21.7 psi External Loading
Output Set: SAP4 Case 1
Deformed(6.474): Total Translation
Contour: Plate Top Major Stress
Y
Z
X
255905.
232185.
208466.
184747.
161027.
137308.
113588.
89869.
66150.
42430.
18711.
-5008.
-28728.
-52447.
-76166.
-99886.
-123605.

Figure: 1

ECO-PAK OP-TU, OXIDE TRANSPORT UNIT



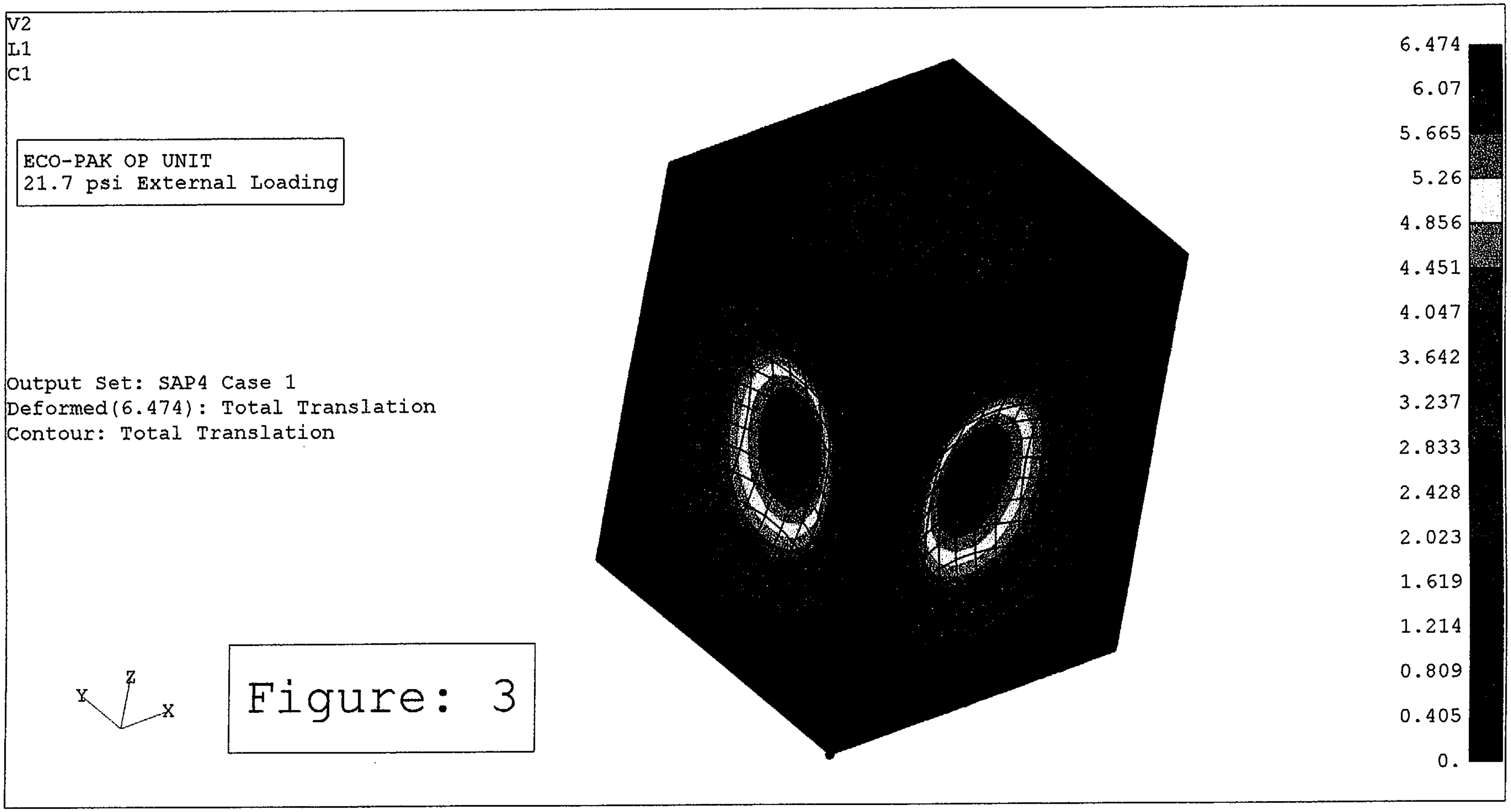

V2
L1
C1
ECO-PAK OP UNIT
21.7 psi External Loading
Output Set: SAP4 Case 1
Deformed(6.474): Total Translation
Contour: Total Translation
Y
Z
X
6.474
6.07
5.665
5.26
4.856
4.451
4.047
3.642
3.237
2.833
2.428
2.023
1.619
1.214
0.809
0.405
0.

Figure: 3

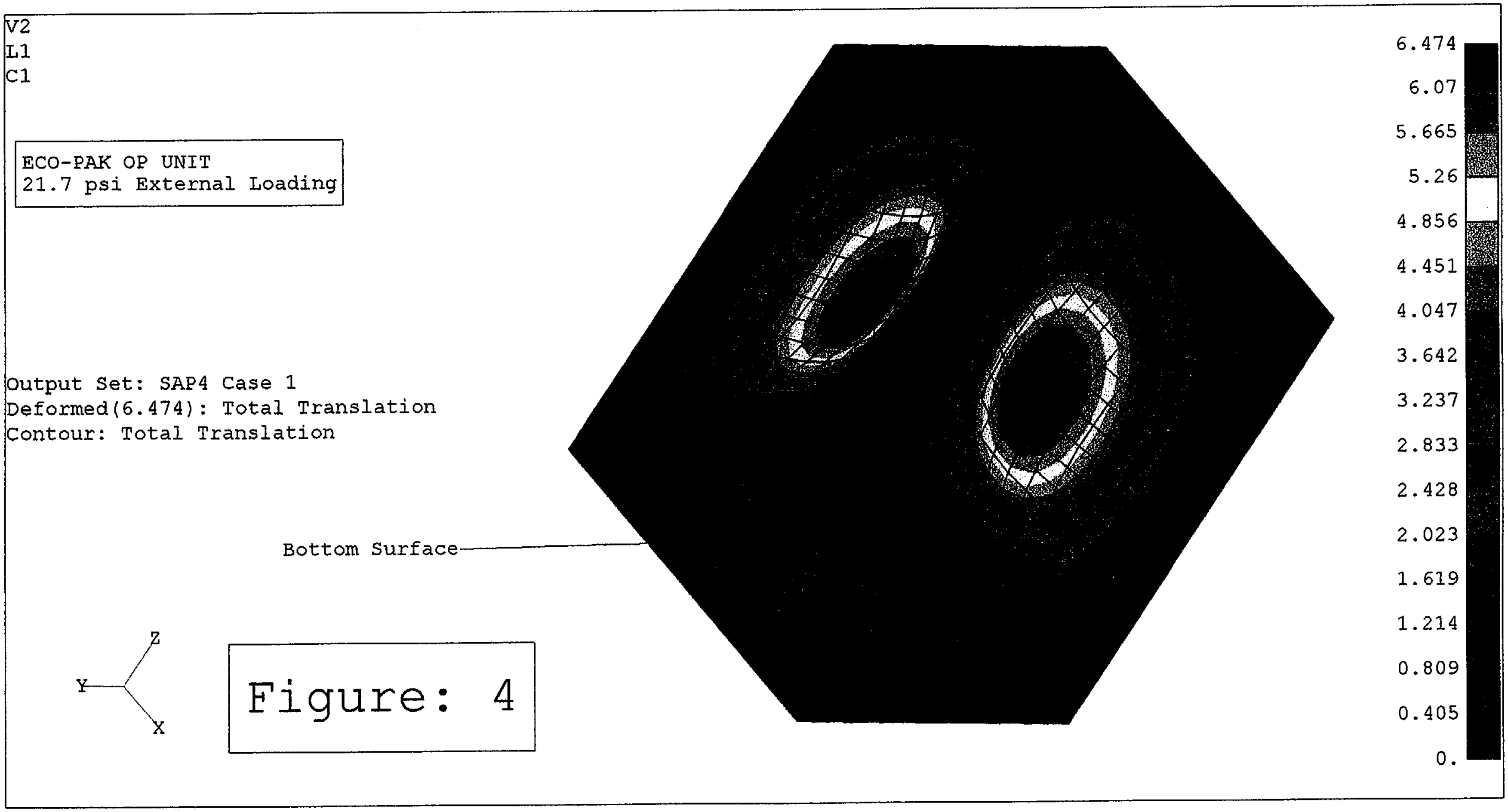
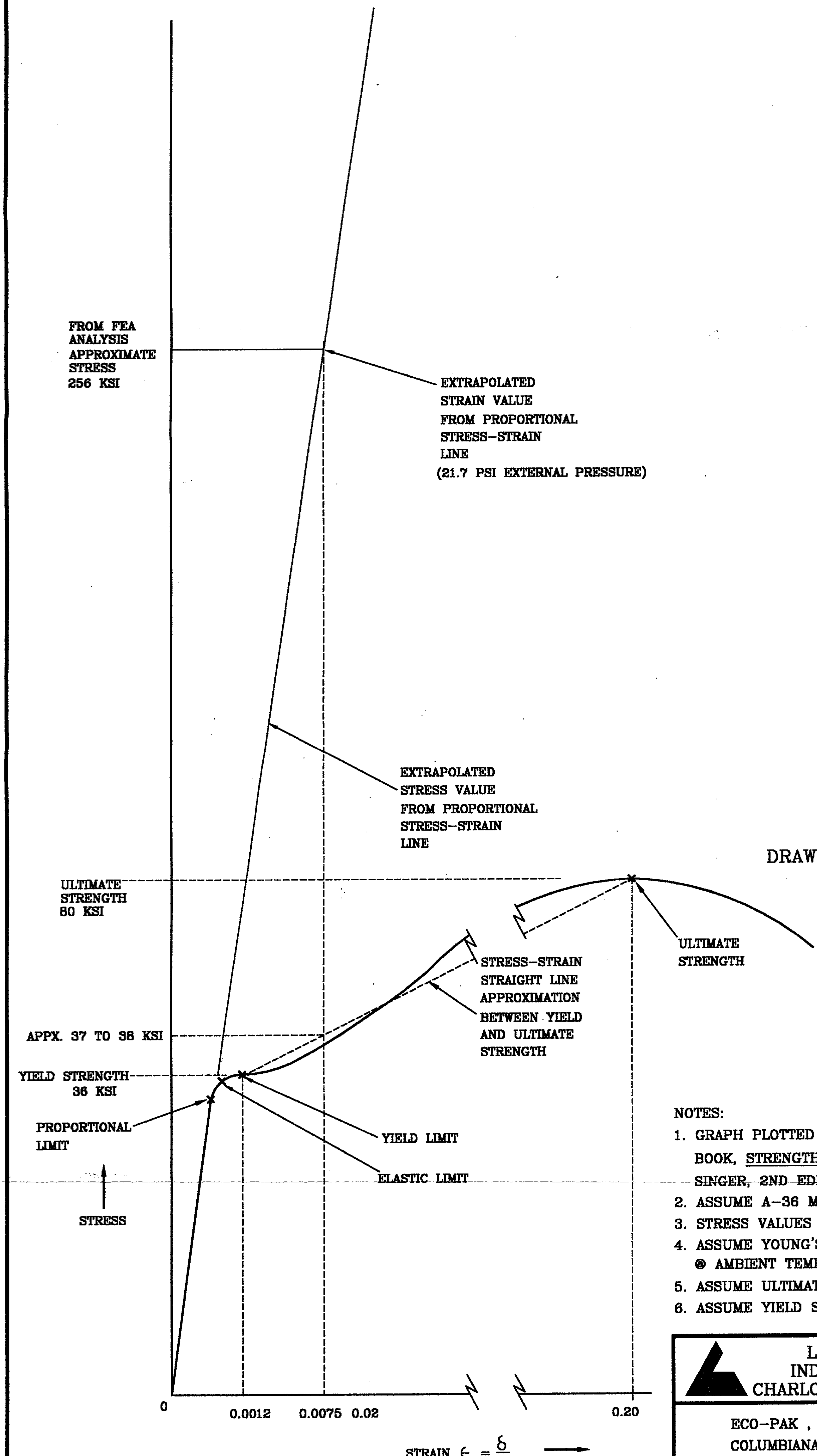

V2
L1
C1
ECO-PAK OP UNIT
21.7 psi External Loading
Output Set: SAP4 Case 1
Deformed(6.474): Total Translation
Contour: Total Translation
Bottom Surface
Z
Y
X
6.474
6.07
5.665
5.26
4.856
4.451
4.047
3.642
3.237
2.833
2.428
2.023
1.619
1.214
0.809
0.405
0.

Figure: 4

Appendix C

Stress-Strain Curve



DRAWING NOT TO SCALE

NOTES:

1. GRAPH PLOTTED FROM THE REFERENCE BOOK, STRENGTH OF MATERIAL BY SINGER, 2ND EDITION
2. ASSUME A-36 MATERIAL
3. STRESS VALUES ARE APPROXIMATE.
4. ASSUME YOUNG'S MODULUS = 30,000 KSI @ AMBIENT TEMP.
5. ASSUME ULTIMATE STRENGTH = 80 KSI
6. ASSUME YIELD STRENGTH = 36 KSI

TYPICAL STRESS-STRAIN DIAGRAM

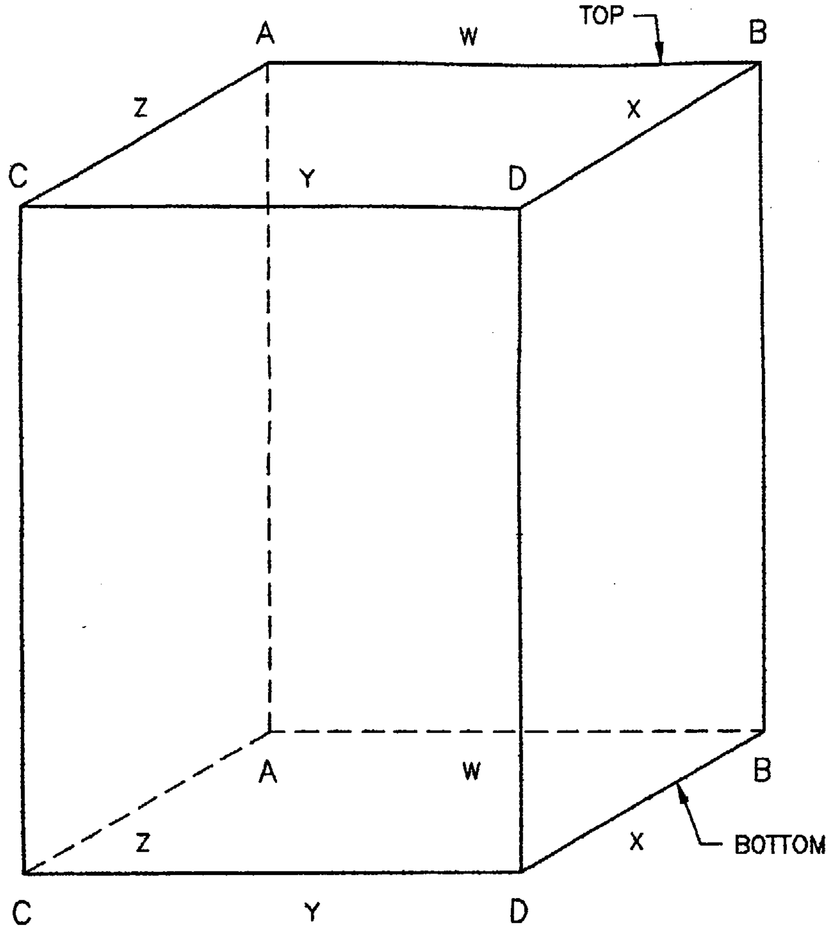
LAW ENGINEERING
INDUSTRIAL SERVICES
CHARLOTTE, NORTH CAROLINA

ECO-PAK , OP -TRANSFER UNIT
COLUMBIANA BOILER COMPANY

JOB#: 10810-9-7003	FIGURE: 1
DRAWN BY: MNP	SCALE: NTS
APPR'D BY: JWP	DATE:12-21-99

Appendix 2.10.8

Test Damage Sketches

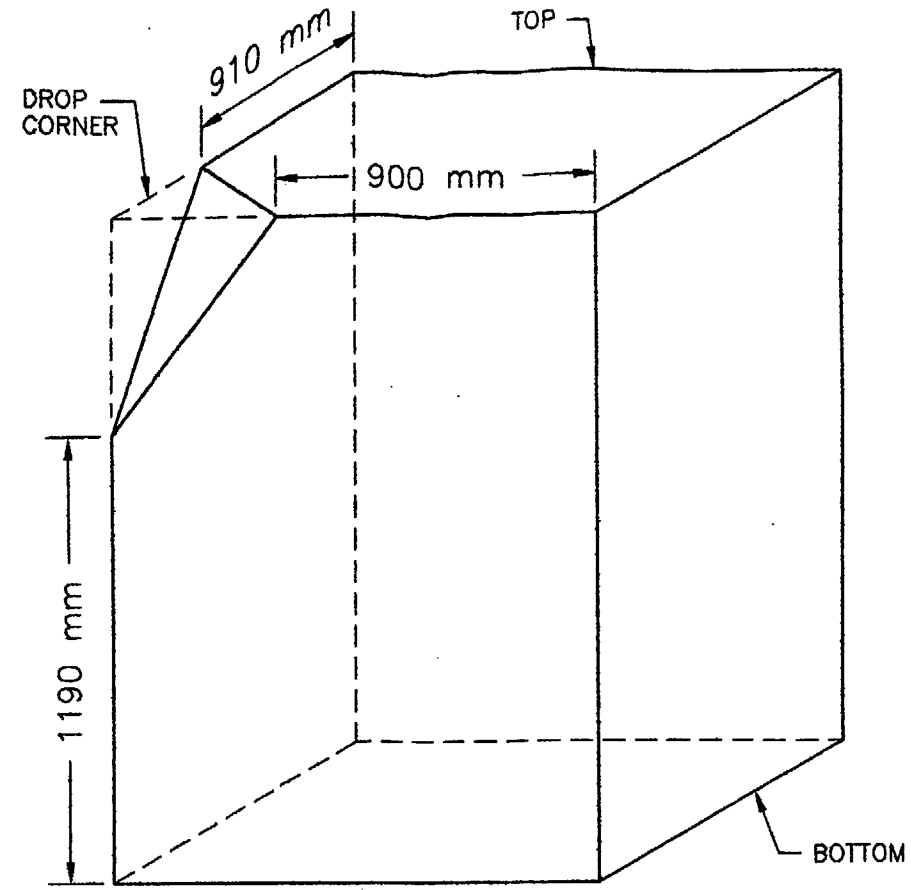


DROP 1 – 30 FT FREE DROP ON BOTTOM

JUNE 11, 1998

PRE-DROP	POST-DROP
A-A – 1444 mm 56 7/8"	A-A – 1424 mm 56 1/16"
B-B – 1440 mm 56 11/16"	B-B – 1418 mm 55 13/16"
C-C – 1442 mm 56 3/4"	C-C – 1418 mm 55 13/16"
D-D – 1441 mm 56 3/4"	D-D – 1420 mm 55 15/16"
TOP	**TOP**
W – 1140 mm 44 7/8"	W – 1135 mm 44 11/16"
X – 1145 mm 45 1/16"	X – 1138 mm 44 13/16"
Y – 1140 mm 44 7/8"	Y – 1136 mm 44 3/4"
Z – 1140 mm 44 7/8"	Z – 1136 mm 44 3/4"
BOTTOM	**BOTTOM**
W – 1141 mm 44 15/16"	W – 1137 mm 44 3/4"
X – 1145 mm 45 1/16"	X – 1135 mm 44 11/16"
Y – 1145 mm 45 1/16"	Y – 1138 mm 44 13/16"
Z – 1140 mm 44 7/8"	Z – 1138 mm 44 13/16"

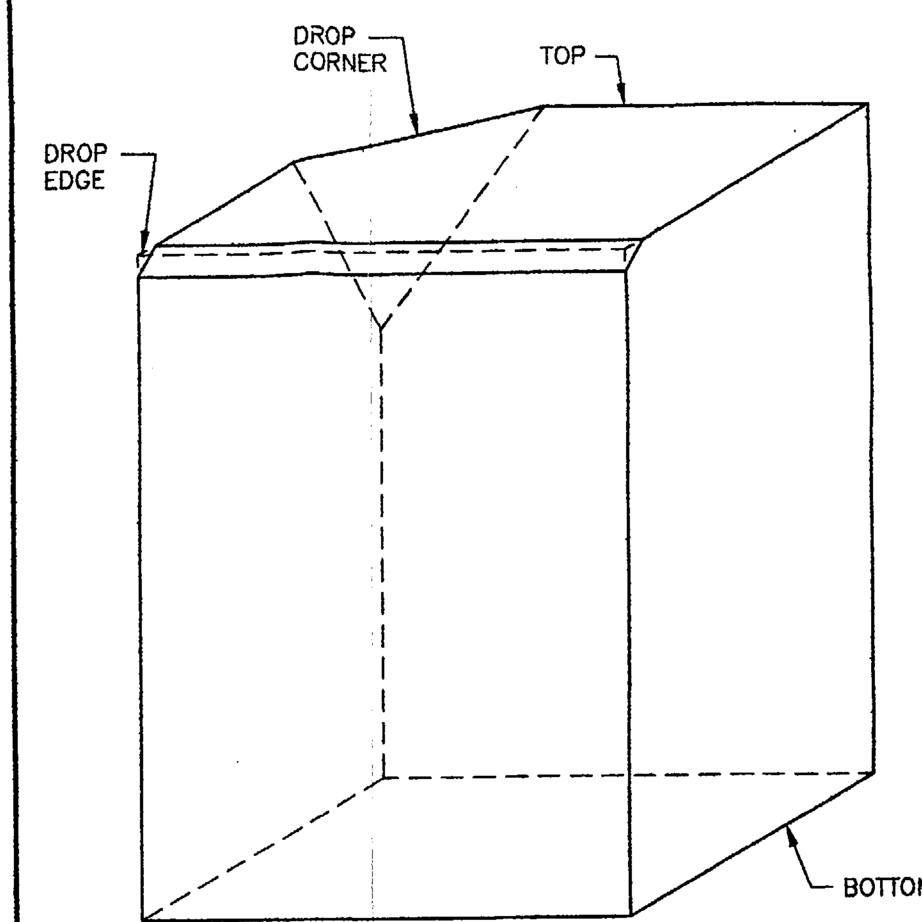
COMMENTS:
EACH SIDE OF THE PACKAGE BULGED APPROXIMATELY 20 TO 40 mm (3/4" TO 1 9/16"). THE HEIGHT OF THE PACKAGE DECREASED APPROXIMATELY 20 TO 30 mm (3/4" TO 1 3/16").



DROP 2 – 30 FT FREE DROP ON CORNER

JUNE 11, 1998

COMMENTS:
DROP CORNER PUSHED IN 125 TO 175 mm (4 15/16" TO 6 7/8")
OUTER SKIN CREASED AND BUCKLED



DROP 3 – 30 FT FREE DROP ON EDGE

JUNE 11, 1998

COMMENTS:
DROP EDGE PUSHED IN 25 TO 55 mm (1" TO 2 3/16")
ANGLE AROUND PERIMETER BENT IN TO CONTACT
WITH PACKAGE LID

THE COLUMBIANA BOILER CO.
COLUMBIANA, OHIO

OP-TU
PROTECTIVE SHIPPING PACKAGE
& TYPE A VESSELS

Checked:	Date: 01/05/2000	Drawing Number
App'd By:	Dr'n By: ARM	OP-TU-DROP
App'd By:	Scale: NONE	REV. / SHEET 1 OF 1

REVISIONS

SECTION THREE THERMAL EVALUATION

TABLE OF CONTENTS

3. *THERMAL EVALUATION*

3.1 Discussion

The Eco-Pak® OP is designed to maintain the temperatures of the storage vessels within specified limits during normal transportation and hypothetical accident conditions. This section presents an evaluation of the thermal performance of the packaging. The thermal tests and analyses performed for this evaluation are designed to:

- Determine the package's thermal limits;
- Determine the maximum and minimum temperatures of the uranium oxide within a loaded storage vessel; and
- Determine the maximum and minimum pressures of the uranium oxide within a loaded storage vessel.

3.1.1 Thermal Source- Specification

The decay heat generated by ≤5.0 weight percent U_{235} enriched uranium oxide is considered insignificant in the thermal evaluation of the package.

3.1.2 Thermal Acceptance Criteria

Thermal design criteria are associated with maintaining containment of the storage vessels during normal conditions of transport and the hypothetical accident conditions. The melting point of UO_2 ranges between 4532 and 5072 degrees Fahrenheit, which are temperatures well beyond those that the storage vessel would be subjected to during either condition. Therefore, the thermal design criteria are limits on the temperature ratings of the storage vessel's materials of construction, which are described below.

3.1.2.1 Minimum Temperature Limit

The minimum temperature limit for the storage vessels is -40^{0}F.

3.1.2.2 Maximum Pressure Limit

The maximum pressure limit for the storage vessels is 169 psig.

3.1.2.3 Maximum Temperature Limit

The maximum temperature limit for the storage vessels is 400^0F. This is based upon the maximum continuous temperature rating for the silicone gasket.

3.1.2.4 Thermal Acceptance Criteria Summary

Minimum Temperature Limit:	-40^0F
Maximum Pressure Limit:	169 psig
Maximum Temperature Limit:	400^0F

3.2 Summary of Thermal Properties of Materials

The thermal properties of materials used in the thermal analyses are listed below. The values are listed as given in the corresponding references.

a. Uranium oxide (Appendix 3.8.1)

Density:	10.5 g/cc (averaged for pellets or powder)
Melting point temperature:	$4532\text{-}5072^0$F ($2500\text{-}2800^0$C)
Specific heat:	0.2635 KJ/Kg^{0}C (between $100\text{-}200^0$C)
Thermal linear expansion:	0.1% (at 100^0C)

b, Steel shot - Plain carbon steel (Ref. 3.7.1, Table TDC, p. 650 and Table F-2, p. 670)

Temperature (F^0)	**Specific Heat** Btu/lbm-^{0}F
70	0.105
100	0.107
150	0.110
200	0.114
250	0.117
300	0.119

c. Insulation (Appendix 2.10.2)

Thermal Conductivity:

Phenolic Foam:	0.013 Btu/hr-ft-^{0}F<k<0.017 Btu/hr-ft-^{0}F at 75^0F
Ceramic Fiber Paper:	0.10 Btu/hr-ft-^{0}F<k<0.11 Btu/hr-ft-^{0}F at 2000^0F
Ceramic Fiber Board:	0.10 Btu/hr-ft-^{0}F<k<0.13 Btu/hr-ft-^{0}F at 1800^0F

d. Vessel shell (Appendix 3.8.1)

Specific Heat: 0.47 KJ/Kg^{0}C

e. Transport Unit surface (Ref. 3.7.2, Table 5-2, Emittance of Various Surfaces)

Analysis used: emissivity = absorptivity = 0.85

3.3 *Technical Specifications of Components*

There are no additional thermal technical specifications for any of the package components.

3.4 *Thermal Evaluation for Normal Conditions of Transport*

3.4.1 Conditions Evaluated

The Eco-Pak® OP is designed to meet the standards specified in 10CFR71, Subpart E when subjected to the Normal Conditions of Transport as specified in 10CFR71.71. Three different conditions are evaluated. The relevant thermal conditions are:

(1) **Heat.** An ambient temperature of 100^{0}F in still air and insolation according to the following table:

Form & location of surface	Total insolation for a 12-hour period (g cal/cm^2)
Flat surfaces transported horizontally: Base	None
Flat surfaces transported horizontally: Other surfaces	800
Flat surfaces not transported horizontally	200
Curved surfaces	400

(2) **Cold.** An ambient temperature of -40^{0}F in still air and shade.

(3) A package must be designed and constructed, and prepared for transport so that in still air at 100^{0}F and in the shade, no accessible surface of a package would have a

temperature exceeding 122^0F in a nonexclusive use shipment, or 185^0F in an exclusive use shipment.

3.4.2 Acceptance Criteria for Normal Conditions of Transport

Generally, the limits on the temperature of the gaskets used in the storage vessels determine the thermal design criteria. The package itself must not degrade during normal transport conditions in such a way as to prevent it from providing protection to the storage vessel in the event of a thermal accident.

The materials of construction of the package are not particularly sensitive to minimal temperature variations (See Section 2.3). Since the package is not air-tight, changes in pressure have no effect on it performance.

The acceptance criteria for the entire packaging under normal conditions of transport are therefore:

	Storage Vessel/UO2	Transport Unit
Minimum Temperature Limit	-40^0F	-40^0F
Maximum Pressure Limit	169 psig	N/A
Maximum Temperature Limit	400^0F	400^0F

None of these limits would be exceeded during normal conditions of transport.

3.4.3 Thermal Model

Calculations assume zero decay heat load and a solar insolation load of 200 cal/12-hr-cm^2 (738.4 Btu/ft^2 over 12 hours) followed by zero solar heat load for 12 hours, repeated indefinitely, on the surface of the package. The heat absorbed by the package over 24 hours is 738.4 + 0 = 738.4 Btu/ft^2. Therefore, the heat absorbed by the package per hour is 30.76 Btu/ft^2. The solar absorptivity of the surface of the package is estimated at 1.0. Ambient temperature is assumed to remain constant at 100^0F. The solar heat load is calculated as:

$$q_{solar} = 30.76 \text{ Btu/hr-ft}^2 \times 1 = 30.76 \text{ Btu/hr-ft}^2$$

Heat is passively rejected to the environment through a combination of natural convection and radiation. The emissivity of the surface of the package is taken to be 1.0.

$h_{total} = h_{conv} + h_{rad}$ (Ref. 3.7.2)

$h_{conv} = h_c A[T_s^4 - T_{amb}^4]$ (for conservative assumption h_c=1 Btu/hr-ft^2)

$h_{rad} = \sigma A \in [T_s^4 - T_{amb}^4]$ (With T in ^{0}R)

The total energy into the package surface must equal the total energy out at steady-state. In the case of constant insolation, this reduces to:

$$q_{solar} = h_{conv} \Delta T + h_{rad}$$

The solution of this equation is T_s = 130.76^{0}F. The average surface temperature is therefore (100+131)/2 =115.38^{0}F.

Due to the low conductivity of the insulating foam and the extremely large thermal inertia of uranium oxide it can be shown that the thermal response of the UO_2 is so slow that it never exceeds the average surface temperature by more than 3.22^{0}F. Thus, the peak UO_2 temperature is 118.60^{0}F. This is shown below:

$$q = (m_{UO2}Cp_{UO2} + m_{st}Cp_{st}) \Delta T \text{ (Ref. 3.7.2)}$$

At quasi-steady state, the maximum difference in temperature between the package outer surface and the UO_2 is:

$$\Delta T = 118.60^0\text{F-1000F} = 18.60^0\text{F}$$

The rate at which the temperature of the UO_2 is changing is 18.60^{0}F/24 hrs = 0.8^{0}F/hr.

3.4.4 Maximum Temperatures

The maximum surface temperature is 130.76^{0}F. The maximum uranium oxide temperature is 118.60^{0}F. These temperatures are well below the limits specified in Section 3.4.2.

3.4.5 Minimum Temperatures

The minimum temperature is -40^{0}F which is also the minimum acceptable temperature.

3.4.6 Maximum Pressure

The maximum pressure occurs when the UO_2 reaches its peak temperature of 118.60^0F. Thus, the maximum pressure of the UO_2 is less than 0.5 psig and less than the acceptable maximum pressure of 169 psig specified in Section 3.4.2.

3.5 Thermal Evaluation for Hypothetical Accident Conditions

3.5.1 Conditions Evaluated

Section 71.73 of 10CFR71 defines the hypothetical accident conditions. The relevant thermal conditions are taken from §71.73(c) and are listed below:

> (4) Thermal. Exposure of the specimen fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent, and in sufficiently quiescent ambient conditions, to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800^0C (1475^0F) for a period of 30 minutes, or any other thermal test that provides the equivalent total heat input to the package and which provides a time averaged environmental temperature of 800^0C. The fuel source must extend horizontally at least 1m (40 in), but may not extend more than 3m (10 ft), beyond any external surface of the specimen, and the specimen must be positioned 1m (40 in) above the surface of the fuel source. [...] Artificial cooling may not be applied after cessation of external heat input, and any combustion of materials of construction, must be allowed to proceed until it terminates naturally.

Section 71.73 requires that the package be subjected to "Free Drop" and "Puncture" tests prior to the thermal testing. The initial temperature of the packaging is that value between -29^0C (-20^0F) and 38^0C (100^0F) which is most unfavorable to the feature under consideration. For this packaging, 100^0F is the most unfavorable starting point for the fire test.

3.5.2 Acceptance Criteria for Hypothetical Accident Conditions

The melting temperature of UO_2 is above 4500^0F, well below the temperatures expected in a diesel fuel fire such as the one required for hypothetical accident condition testing. (See Appendix 3.8.1). Therefore, the thermal design criteria used to determine acceptance are limits on the temperature of the silicone gasketing used to seal the internal closure of the containment cylinder and the storage vessel itself. The gaskets used in the Eco-Pak® OP are 1/4-inch thick 50-70 durometer silicone rubber with a minimum continuous temperature rating of 400^0F.

Therefore, the maximum temperature limit for the storage vessel is 400^0F. The package itself is not required to survive the thermal accident.

Therefore, the acceptance criteria for the uranium oxide within the storage vessel under hypothetical accident conditions are as given below:

	Uranium Oxide
Minimum Temperature Limit	-40^0F
Maximum Pressure Limit	169 psig
Maximum Temperature Limit	400^0F

3.5.3 Thermal Model

3.5.3.1 Analytical Model

The licensing basis for the package, with respect to hypothetical thermal accident conditions, is full scale package testing. This testing program is described in more detail in Appendix 2.10.4, and in the following section. This test program precludes the need for an analytical model of the packaging during the hypothetical thermal accident conditions.

3.5.3.2 Test Model

The hypothetical accident conditions given above in Section 3.5.1 were investigated by performing the specified tests on the actual packaging, where steel shot was substituted for the UO_2.

3.5.4 Package Conditions and Environment

The package was damaged as a result of the drop testing. See Appendices 2.10.4 and 2.10.5 for a complete description of packaging condition prior to and following the thermal test.

The measured ambient temperature during testing was approximately 97^0F. The average wind speed during the first half-hour of testing was 5.1 mph.

The fire was fully engulfing. The package was spaced 40 inches above the surface of the fuel, and no artificial cooling was applied to the package following the fire. The package rested upon a simple support system that was incapable of shielding the package from the fire or cooling the package in any significant way. In order to obtain a fully engulfing fire, the fuel source extended beyond the package between 2 m and 4 m, which exceeds the 10CFR71.73 requirements of 1m to 3m, but results in a more severe thermal environment. The duration of the fire was 31 minutes, and the average measured flame temperature was estimated at 1658^0F.

In summary, the thermal environment to which the packaging was subjected during the test was more severe than the environment required by 10CFR71, §73.73. For the purpose of calculations, it is assumed that the thermal environment created during the tests performed was identical to the environment required. This introduces conservatism into the analysis.

3.5.5 Package Temperatures

The average initial starting temperature of the packaging was 104^0F, higher than the minimum acceptable temperature.

3.5.6 Analysis of Test Data

Based on the readings of the maximum temperature tapes located on the storage vessels, the highest single temperature reading on any portion of the internal packaging was recorded as less than 325^0F with an average temperature calculated at 257^0F. The maximum thermocouple reading was 271^0F with an average calculated temperature of 226^0F. The average temperature of the steel shot contained within the storage vessels was raised to 257^0F from the initial average temperature of 104^0F. The average heat absorption computed for this 153^0F increase was 9,272 kilojoules per vessel. Based on a maximum rated 356.7 pound UO_2 load per vessel and 9,272 kilojoules heat absorption, the maximum temperature of UO_2 would reach 323.6^0F, less than the 400^0F maximum acceptable limit.

3.6 Thermal Evaluation and Conclusions

As demonstrated in hypothetical accident condition testing, the maximum calculated internal package temperature for a lading of UO_2 after exposure to a thirty-minute diesel fire is 323.6^0F, less than the 400^0F considered the maximum acceptable temperature. The minimum temperature is -40^0F. Therefore the performance of the Eco-Pak® OP is considered acceptable both for normal conditions of transport and for hypothetical accident conditions.

3.7 References

3.7.1 1992 ASME Boiler and Pressure Vessel Code, Section II, Part D - Properties, with 1994 Addendum

3.7.2 Frank Kreith, Principles of Heat Transfer, 3rd Edition, 1973

3.8 Appendix

3.8.1 Law Engineering Report of Thermal Evaluation

Appendix 3.8.1

Law Engineering Report of Thermal Evaluation

LAW
ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

August 11, 1998

Eco-Pak Specialty Packaging
125 Iodent Way
Elizabethton, TN 37643

Attention: Ms. Heather Little

Subject: **Report of Thermal Evaluation**
ECO-PAK OP-TU Oxide Transport Unit
Law Engineering Industrial Services Project 10810-8-7008, Phase 08

Dear Ms. Little:

As per your request and as authorized by your Purchase Order Number 4989, Law Engineering Industrial Services (LEIS) is pleased to present this report evaluating the thermal performance of the subject transport unit, referred to as the "ECO-PAK OP-TU Transport Unit" protective shipping package. The transport unit has four storage vessels. The purpose of this evaluation is to determine the solid/liquid condition of uranium dioxide (UO_2) contained in the storage vessel and the maximum pressure limit for the subject storage container, when it is subjected to a 30-minute fire event. This report provides our understanding of the background information, a summary of the thermal test results performed by Southwest Research Institute (SwRI), Dept. of Fire Technology, our analysis method, and our conclusion.

Background Information

Eco-Pak Specialty Packaging provided the following drawings of the "ECO-PAK OP-TU Transport Unit" protective shipping package to LEIS.

DRAWING No.	DESCRIPTION	SHEET NO.	DATE
71497/50	GENERAL ARRANGEMENT ECO-PAK OP-TU OXIDE TRANSPORT UNIT	1 OF 1	7/14/97
71497-1	GENERAL ARRANGEMENT ECO-PAK OP-VA 7" OXIDE VESSEL	1 OF 1	7/10/98

LAW ENGINEERING INDUSTRIAL SERVICES
2801 YORKMONT ROAD, SUITE 200 • CHARLOTTE, NC 28208
P. O. BOX 19667 • CHARLOTTE, NC 28219
(704) 357-8600 • FAX (704) 357-8637

71497-2	GENERAL ARRANGEMENT ECO-PAK OP-VA 8" OXIDE VESSEL	1 OF 1	7/10/98
71497-3	GENERAL ARRANGEMENT ECO-PAK OP-VB 6" OXIDE VESSEL	1 OF 1	7/10/98
71497-4	GENERAL ARRANGEMENT ECO-PAK OP-VB 7" OXIDE VESSEL	1 OF 1	7/10/98
71497-BM	BILL OF MATERIAL ECO-PAK OP-TU OXIDE TRANSPORT UNIT		7/13/98
71497-1-BM	BILL OF MATERIAL ECO-PAK OP-VA 7" OXIDE VESSEL		7/13/98
71497-2-BM	BILL OF MATERIAL ECO-PAK OP-VA 8" OXIDE VESSEL		7/13/98
71497-3-BM	BILL OF MATERIAL ECO-PAK OP-VB 6" OXIDE VESSEL		7/13/98
71497-4-BM	BILL OF MATERIAL ECO-PAK OP-VB 7" OXIDE VESSEL		7/13/98

Please note that there are three different sizes of the storage vessels. The sizes are 6, 7 and 8 inches in diameter. The 8 inches diameter storage vessels were filled with steel shot. The storage vessels are constructed from stainless steel material. The outer box of the transport unit is constructed from carbon steel material. The space between the box and storage vessels is filled with a rigid foam insulation material. The storage vessels are approximately 41 inches in height.

Thermal Test Procedure and Results

Eco-Pak Specialty Packaging provided the information on July 29, 1998 regarding the pool fire test procedure and its results to LEIS. The thermal performance of the subject transport unit was evaluated by conducting an open-pool fire as reported in the SwRI's report. The pool fire test was performed, as described in Title 10 CFR 71.73 (c), (4), at SwRI's remote test facility located in D'Hanis, Texas, approximately 40 miles west of the San Antonio campus. The facility is operated by the Department of Fire Technology and has full utility service and is equipped with a mobile technical support trailer and weather station facility.

Instrumentation requirements for this program were supported with a portable computer and rapid data acquisition equipment. Instrumentation consists of 4 thermocouples used to monitor the time temperature profiles on the surface of the "B" storage vessel during the fire exposure and cool down period. Maximum temperature sensors, installed in 14 places, were also used to monitor the maximum temperature during the test. Please see the attached drawing for the locations of thermocouples and temperature sensors.

The test storage vessels were loaded with a steel shot to simulate a full load of solid or powder UO_2 at atmospheric pressure. As mentioned in the SwRI's report, following the drop tests, the test items were transported to SwRI's Department of Fire Technology for elevated temperature thermal conditioning. Prior to the fire test, the shipping package was placed in SwRI's large-scale horizontal furnace to achieve an equilibrium temperature between 100 to 120 degrees Fahrenheit in the shipping package. The average equilibrium temperature was 104 degrees Fahrenheit. For this packaging, this temperature is considered to be the most unfavorable starting point for the fire test.

Immediately following the elevated temperature thermal soak, the test article was insulated and transported to the remote test site, positioned on the test fixture, and exposed to the specified pool fire conditions for a minimum 30 minute period. The pool fire dimensions were 25 feet x 25 feet. Fuel was supplied to the pool fire pan through a pump during the test at a rate appropriate to maintain a fully engulfed pool fire for 30 minutes.

Thermal Evaluation for Hypothetical Accident Conditions

For the fire test, the package (transport unit) was suspended as indicated in the SwRI's report over a pool of diesel fuel which was ignited and allowed to burn, completely engulfing the test package for approximately 30 minutes. The temperature was monitored for fifteen hours from the beginning of the fire test as shown in the attached time history data. Temperature sensitive labels located on the exterior walls of the inside storage vessels recorded the peak surface temperature encountered at various locations during the test. For the location of thermocouples, please see the attached drawing. This information was provided to LEIS. SwRI Department of Fire Technology provided instrumentation layout, thermocouples, and temperature indicators. Please note that recording of the four thermocouple temperature at various locations was continued even after the end of the 30-minute fire test. SwRI Department. of Fire Technology performed temperature recording. The time and temperature data is attached to this report.

The overall average maximum temperature during the test, indicated by the thermocouples, was 226 degrees Fahrenheit and overall average temperature from the temperature sensors was 257 degrees Fahrenheit. For the conservative approach, we considered 257 degrees Fahrenheit average temperature (higher temperature) of the storage vessel in our thermal analysis. This temperature is less than the melting temperature of UO_2 which is above 4500 degrees Fahrenheit. Because the average flame temperature (1658 degrees Fahrenheit) is below the melting temperature of Uranium Dioxide, a simulated load of Uranium Dioxide is always in the solid or powder phase during a 30-minutes fire test.

Summary of Overpack Thermal Test Results

Storage Vessels Load (Steel Shot)	1420.6 Pounds (four vessels)
Total vessel Weight (Including Load)	2046.8 Pounds
Total Overpack Weight	2348 Pounds
Vessel Max. Temp. Range (Outside Surface)	206 to 271 Degrees Fahrenheit
Average Max. Temperature	226 Degrees Fahrenheit (from thermocouples)
Average Max. Temperature	257 Degrees Fahrenheit (from temperature sensors)
Pre-test holding average temperature	104 Degrees Fahrenheit
Inside Cylinder Pressure	Atmospheric
Total Engulfed Burn Time	30 Minutes

In general, the total heat transferred to the contents of the vessel is dependent on the thermal properties of the transport unit insulation, the temperature difference between the vessel contents and the exterior flame environment, and the heat capacity of the vessel and its contents. LEIS used a one dimensional, electrical analogy, heat transfer analysis to assess each of these factors, as they would affect a vessel containing UO_2. For the case of the steel shot-filled vessel and transport unit under test, a uniform cylinder temperature of 257 degrees Fahrenheit was used in our analysis based on the conservative approach and test results.

Starting with the electrical analogy, for the steel-shot contents of the test vessel, the energy required to uniformly heat the vessel and its contents from 104 degrees to 257 degrees Fahrenheit was determined. The average heat absorption computed for the 153 degree Fahrenheit increase was 9,272 kilojoules per vessel, with average heat flow rate of 5.15 kilojoules per second during the 30 minute test.

Four thermocouples were used to determine the average flame temperature. The flame temperature readings were taken at every minute for approximately 30 minutes. Please refer the attached table for the average flame temperature. The temperature data was provided to LEIS. Please refer to the SwRI's report for more information. Using the average flame temperature of 1658 degrees Fahrenheit, the overall thermal heat transfer co-efficient of the transport unit and its insulation were subsequently calculated.

The thermal properties of uraniun oxide are listed below. In the vessel, containing UO_2 in the solid or powder phase, a temperature increase would be expected until the cylinder reached the UO_2 melting point temperature which is above 4500 degrees Fahrenheit. From the thermal test results, the average steel shot temperature was increased to 257 degrees Fahrenheit. Our evaluation indicates that for the maximum rated 356.7 pound UO_2 load (per vessel) and 9272 kilojoules heat absorption, the temperature of UO_2 would reach 323.6 degrees Fahrenheit. This temperature is well below the melting temperature of UO_2. Therefore the simulated load of UO_2 will stay in the solid or powder phase during 30 minutes of fire test.

Properties of Uranium Dioxide

The following information was taken from the UO_2 reference book

- Density = 10 to 11 gram/cc (Average 10.5 grams/cc for pellets or powder)
- Melting point temperature = 4532 to 5072 degrees Fahrenheit (2500 to 2800 degrees Centigrade)
- Specific heat = 0.2635 KJ/Kg °C (between 100 to 200 degrees Centigrade)
- Thermal linear expansion = 0.1% (at 100 degrees Centigrade)

Based on our review of the temperature test data and the computation discussed above, a properly loaded vessel of UO_2, when contained within a "ECO-PAK OP-TU Transport Unit" protective shipping package, equal to the one tested (8 inches vessel diameter) and subjected to a thirty-minute fire condition represented by the test, would stay in the solid or powder phase. The pressure in the cylinder would increase from an initial atmospheric pressure of 14.7 to 20.11 psia (5.41 psi gage pressure) at the end of a thirty minute fire test.

We calculated the maximum pressure limit for the subject storage vessel. We used American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section VIII, Division 1, as a reference to calculate the pressure.

We assumed the following conditions for our calculations.

- Allowable stress for 316 stainless steel material =18,300 psi 323.6° F
- Weld joint efficiency for the shell = 70%
- For the Silicone gasket factors "m" = 1.0 and minimum design seating stress "y" = 200 psi (same factors for the Silicon "O" ring)

Therefore, it is our opinion that the acceptance criteria given below for the hypothetical accident conditions provided to LEIS by Eco-Pak specialty packaging for the uranium dioxide within the vessel inside of the "ECO-PAK OP-TU Transport Unit" protective shipping package will be met as delineated below.

For Uranium Dioxide

Conditions	Acceptance Criteria	Measured/Calculated Conditions
Minimum Temperature Limit	-40 °F	206 °F
Maximum Pressure Limit (psig)	169 psig	5.41 psig
Maximum Temperature Limit	400 °F	323.6 °F

The properties of UO_2 used in this analysis were obtained from the U.S. Atomic Energy Commission publication; "UO_2 URANIUM DIOXIDE, PROPERTIES AND NUCLEAR APPLICATION" edited by J. Belle (1961) which was provided to us by Eco-Pak specialty packaging. The characteristics corresponding to the, "ECO-PAK OP-TU Transport Unit" protective shipping package was obtained from the drawings supplied to LEIS. If the data contained in this report are known to be incorrect or inappropriate for use in this analysis, please contact us so that we may re-evaluate our calculation accordingly.

Law Engineering Industrial Services appreciates the opportunity to assist you with this project. Please contact this office at 704-357-8600 if you have any questions. We look forward to continuing our working relationship with you on this and future projects.

Sincerely,

LAW ENGINEERING INDUSTRIAL SERVICES

M.N. Parikh

Mike N. Parikh, P.E.
Staff Professional

James W. Page

James W. Page, P.E.
Chief Engineer

Attachment: Temperature Test Data
Time History Temperature Graphs
LEIS Calculation Sheets (with copies of reference pages)
Drawing
Average Flame Temperature Sheet

TEST "ECO-PAK OP-TU Transport Unit" PROTECTIVE SHIPPING PACKAGE *

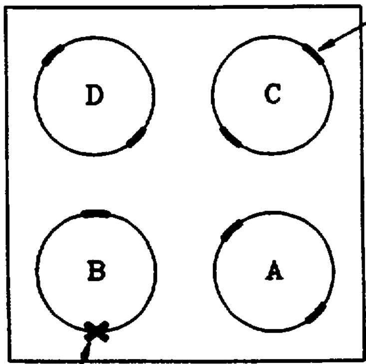
INITIAL AND MAX. TEMPERATURE OF FOUR THERMOCOULPES

THERMOCOULPE # AND LOCATION	INITIAL TEMPERATURE IN °F (ON OD. OF "B" VESSEL)	MAXIMUM TEMPERATURE IN °F (ON OD. OF "B" VESSEL)
TC1, ON VESSEL "B"	122	213
TC2, ON VESSEL "B"	107	206
TC3, ON VESSEL "B"	96	213
TC4, ON VESSEL "B"	91	271

NOTES:

1. FOR LOCATION OF THERMOCOULPLES PLEASE SEE ATTACHED DRAWING.
2. INITIAL TEMPERATURES WERE TAKEN FROM THE BEGINNING OF THE TEST AND MAXIMUM TEMPERATURES WERE TAKEN FROM THE TEMPERATURE GRAPH OVER FIFTEEN HOURS TIME.
3. PRE-TEST HOLDING AVERAGE TEMPERATURE WAS APPROXIMATELY 104 °F
4. INFORMATION PROVIDED TO LEIS BY ECO-PAK, SPECIALTY PACKAGING

ECO-PAK OP-TU OXIDE TRANSPORT UNIT



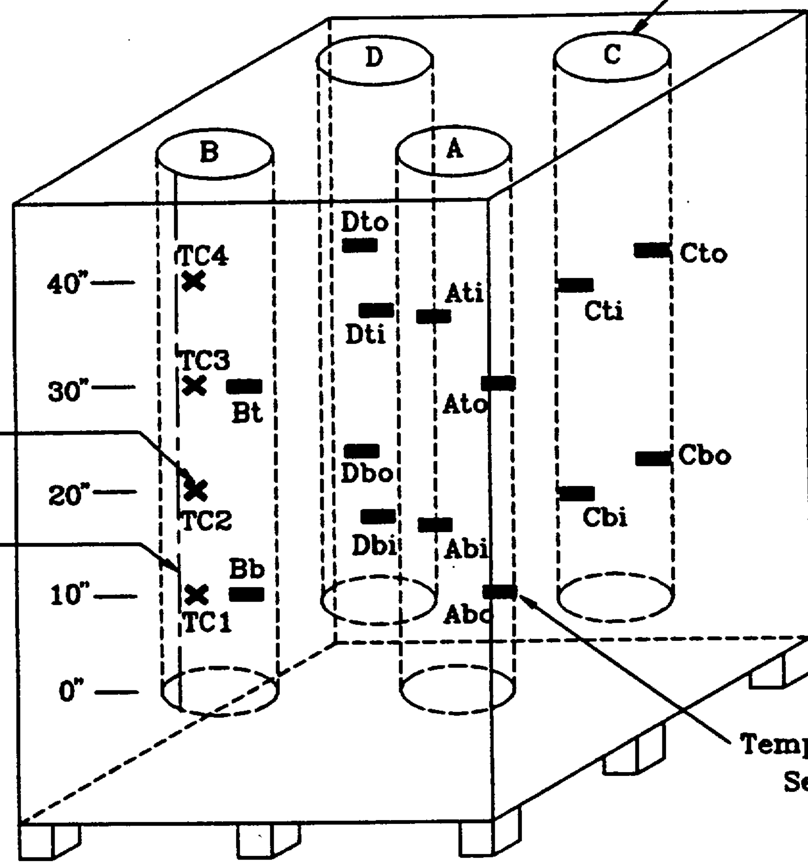


FIGURE: 01

AVG. TEMP. OF CYLINDER (OUTSIDE SURFACE)

SORCE	TEMP. IN °F
TEMP. SENSORS	257
THERMOCOUPLES	226

SENSORS TEMPERATURE

SENSOR LOCATION	APPROXIMATE TEMP. IN °F	*UPPER RANGE TEMP IN °F
Ati	250	275
Ato	200	225
Abi	200	225
Abo	200	225
Bt	300	325
Bb	300	325
Cti	200	225
Cto	300	325
Cbi	200	225
Cbo	250	275
Dti	200	225
Dto	300	325
Dbi	150	175
Dbo	200	225

* USED UPPER SENSOR TEMPERATURE RANGE FOR AVERAGE TEMP. CALCULATIONS

TEMPERATURE SENSOR Abo = TEMP. SENSOR LOCATED ON "A" CYLINDER AT BOTTOM AND AWAY (OUTSIDE) FROM TRANSPORT UNIT CENTER

NOTE: ALL THERMOCOUPLES AND SENSORS ARE MOUNTED ON OUTSIDE SURFACE OF CYLINDERS.

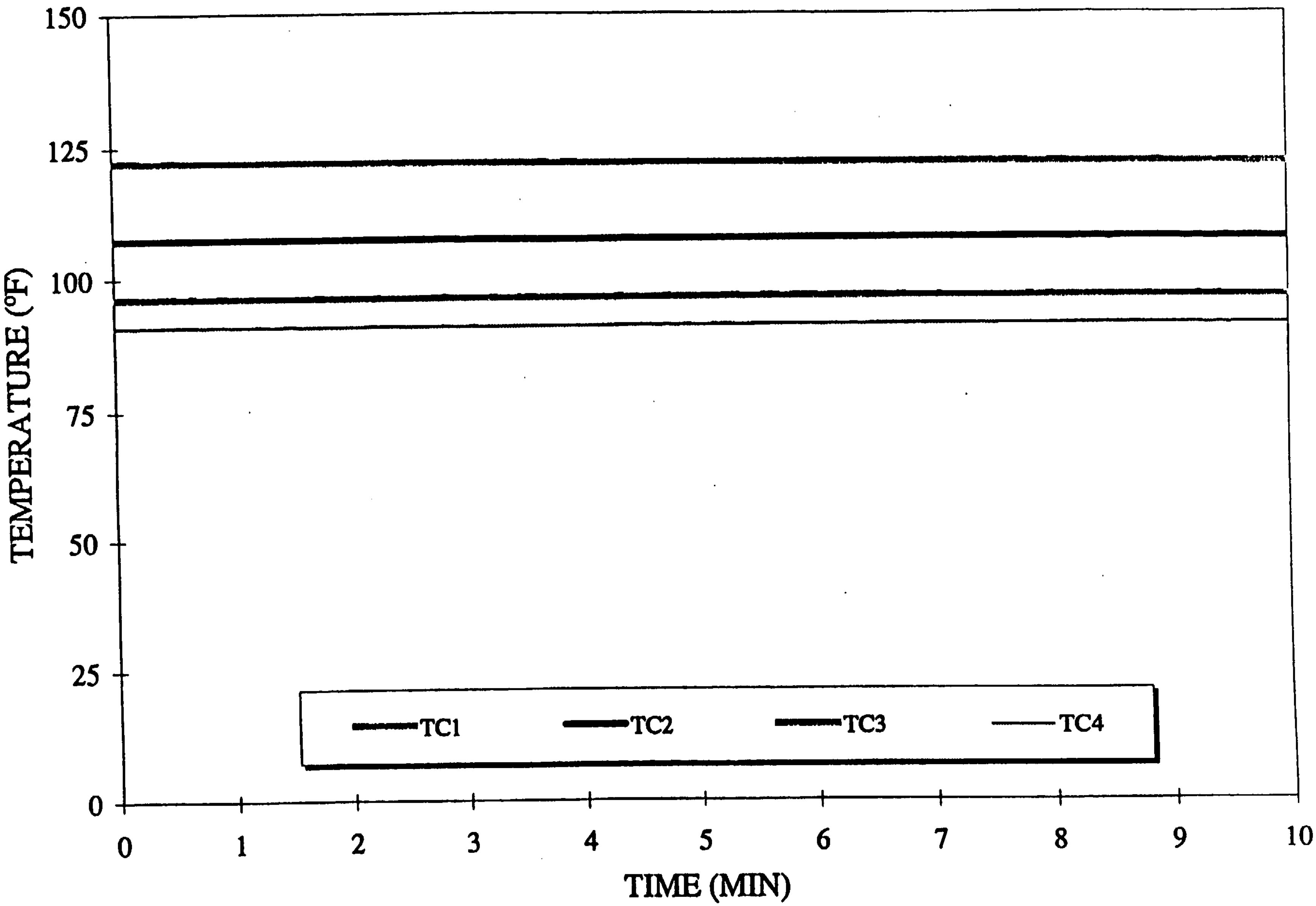
LAW
LAWGIBB GROUP MEMBER
LAW ENGINEERINGINDUSTRIAL SERVICES
CHARLOTTE, NORTH CAROLINA

ECO-PAK SPECIALTY PACKAGING
URANIUM OXIDE TRANSPORT UNIT
THERMAL EVALUATION
ELIZABETHTON, TN 37643

JOB#: 10825-8-7008	FIGURE: PH08-01
DRAWN BY: MNP	SCALE: NTS
APPR'D BY:	DATE: 8-11-98

CLIENT: ECO-PAK SPECIALTY PACKAGING
SwRI PROJECT No.: 01-1680-102b
DATE: 12 JUNE 1998
FILE ID: 163OPMW1.DAT

OPM-1 PRE-TEST DATA
SPECIMEN THERMOCOUPLES



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ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: 163OPMW1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
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0:05	122.2	107.4	96.2	90.9
0:10	122.2	107.4	96.2	90.9
0:15	122.1	107.4	96.2	90.8
0:20	122.1	107.4	96.1	90.9
0:25	122.1	107.4	96.1	90.9
0:30	122.2	107.4	96.2	90.9
0:35	122.1	107.4	96.2	90.9
0:40	122.1	107.4	96.1	90.9
0:45	122.1	107.4	96.2	90.9
0:50	122.1	107.4	96.1	90.8
0:55	122.1	107.4	96.1	90.9
1:00	122.1	107.4	96.2	90.9
1:05	122.1	107.4	96.1	90.8
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1:55	122.1	107.4	96.1	90.8
2:00	122	107.4	96.1	90.8
2:05	122	107.4	96.1	90.8
2:10	122	107.4	96.1	90.8
2:15	122	107.4	96.1	90.9
2:20	122.1	107.4	96.2	90.9
2:25	122	107.4	96.1	90.9
2:30	122	107.4	96.1	90.9
2:35	122	107.4	96.1	90.8
2:40	122	107.4	96.1	90.8
2:45	122	107.4	96.1	90.8
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3:00	122	107.3	96.1	90.8
3:05	122	107.4	96.1	90.8
3:10	122	107.4	96.1	90.9
3:15	122	107.4	96.1	90.8
3:20	122	107.4	96.2	90.8
3:25	122	107.3	96.1	90.8

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: 163OPMW1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

Min. Sec

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
3:30	122	107.4	96.1	90.8
3:35	121.9	107.3	96.2	90.8
3:40	122	107.3	96.2	90.8
3:45	121.9	107.3	96.1	90.8
3:50	121.9	107.3	96.1	90.8
3:55	122	107.3	96.1	90.8
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4:05	121.9	107.3	96.1	90.8
4:10	121.9	107.3	96.1	90.8
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4:35	121.9	107.3	96.1	90.9
4:40	121.9	107.3	96.1	90.9
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4:55	121.9	107.3	96.1	90.8
5:00	121.9	107.3	96.1	90.9
5:05	121.9	107.3	96.1	90.8
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6:35	121.8	107.3	96.2	90.9
6:40	121.8	107.3	96.2	90.9
6:45	121.8	107.3	96.1	90.9
6:50	121.8	107.3	96.2	90.9
6:55	121.8	107.3	96.1	90.9

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: 163OPMW1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
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7:05	121.8	107.3	96.1	90.9
7:10	121.8	107.3	96.2	90.9
7:15	121.8	107.3	96.1	90.9
7:20	121.8	107.3	96.1	90.9
7:25	121.8	107.3	96.1	90.9
7:30	121.8	107.3	96.1	90.9
7:35	121.7	107.3	96.1	90.8
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7:45	121.8	107.3	96.1	90.9
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7:55	121.7	107.3	96.2	90.9
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8:35	121.7	107.3	96.1	90.9
8:40	121.7	107.3	96.1	90.9
8:45	121.7	107.3	96.1	90.9
8:50	121.7	107.3	96.1	90.9
8:55	121.8	107.3	96.2	90.9
9:00	121.7	107.3	96.1	90.9
9:05	121.7	107.3	96.1	90.9
9:10	121.7	107.2	96.1	90.9
9:15	121.7	107.3	96.1	90.9
9:20	121.7	107.2	96.2	90.9
9:25	121.7	107.2	96.1	90.8
9:30	121.7	107.3	96.2	90.9
9:35	121.7	107.2	96.1	90.8
9:40	121.6	107.3	96.1	90.9
9:45	121.6	107.3	96.1	90.9
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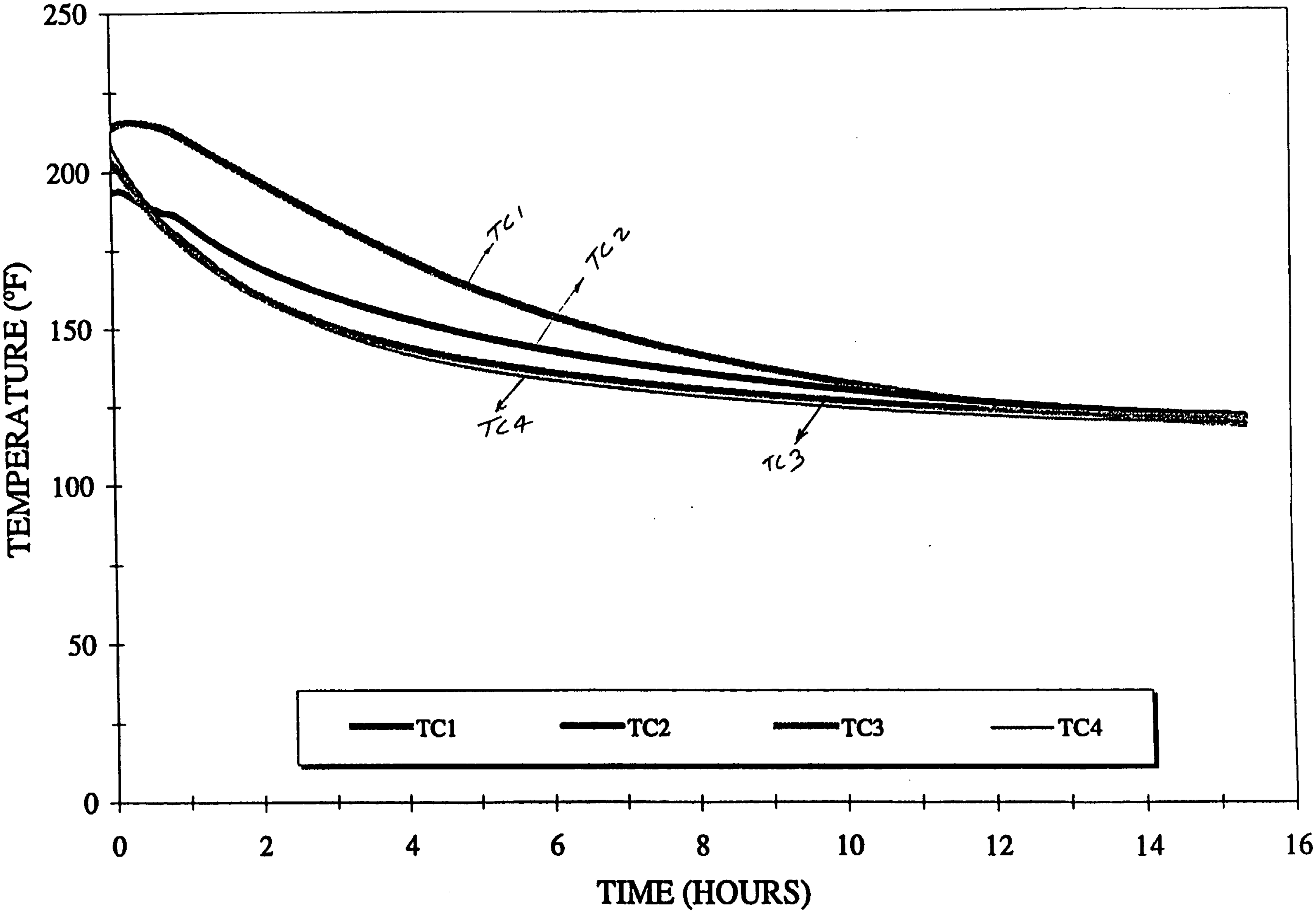
9:55	121.7	107.2	96.1	90.9
10:00	121.6	107.2	96.1	90.8
10:05	121.6	107.2	96.1	90.9

C. (T: ECO-PAK SPECIALTY PACKAGING
SwRI PROJECT No.: 01-1680-102b
DATE: 12 JUNE 1998
FILE ID: 163OPMC1.DAT

OPM-1 COOL DOWN DATA
SPECIMEN THERMOCOUPLES



ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: 163OPMC1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
0:00	214	194	203	209
0:05	215	194	201	205
0:10	216	194	199	202
0:15	216	193	196	198
0:20	216	191	193	195
0:25	215	190	191	193
0:30	215	189	188	190
0:35	215	188	186	187
0:40	214	187	184	185
0:45	213	187	182	183
0:50	213	186	180	182
0:55	212	185	178	180
1:00	210	184	176	178
1:05	209	182	175	177
1:10	208	181	173	175
1:15	207	180	172	174
1:20	206	178	170	172
1:25	205	177	169	170
1:30	204	176	168	169
1:35	203	175	166	167
1:40	201	174	165	166
1:45	200	172	164	165
1:50	199	171	163	163
1:55	198	170	161	162
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2:55	185	161	151	150
3:00	184	160	150	149
3:05	183	159	150	148
3:10	182	159	149	148
3:15	181	158	149	147
3:20	180	158	148	146
3:25	179	157	147	146

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: 163OPMC1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
3:30	178	156	147	145
3:35	177	156	146	145
3:40	176	155	146	144
3:45	175	155	145	143
3:50	174	154	145	143
3:55	173	154	144	142
4:00	172	153	144	142
4:05	171	153	144	141
4:10	170	152	143	141
4:15	170	152	143	140
4:20	169	151	142	140
4:25	168	151	142	140
4:30	167	150	141	139
4:35	166	150	141	139
4:40	165	149	141	138
4:45	164	149	140	138
4:50	164	148	140	138
4:55	163	148	140	137
5:00	162	147	139	137
5:05	161	147	139	136
5:10	161	147	139	136
5:15	160	146	138	136
5:20	159	146	138	136
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5:35	157	145	137	135
5:40	156	144	137	134
5:45	156	144	136	134
5:50	155	143	136	134
5:55	154	143	136	133
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6:35	150	140	134	131
6:40	149	140	134	131
6:45	149	140	133	131
6:50	148	139	133	131
6:55	148	139	133	131

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

[redacted]ATE: 12 JUNE 1998
[redacted]ILE: 163OPMC1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
7:00	147	139	133	130
7:05	146	138	132	130
7:10	146	138	132	130
7:15	145	138	132	130
7:20	145	138	132	129
7:25	144	137	132	129
7:30	144	137	131	129
7:35	143	137	131	129
7:40	143	136	131	129
7:45	143	136	131	128
7:50	142	136	130	128
7:55	142	136	130	128
8:00	141	135	130	128
8:05	141	135	130	128
8:10	140	135	130	127
8:15	140	135	130	127
8:20	139	134	129	127
8:25	139	134	129	127
8:30	139	134	129	127
8:35	138	134	129	127
8:40	138	133	129	126
8:45	137	133	129	126
8:50	137	133	128	126
8:55	137	133	128	126
9:00	136	132	128	126
9:05	136	132	128	126
9:10	136	132	128	125
9:15	135	132	127	125
9:20	135	132	127	125
9:25	134	131	127	125
9:30	134	131	127	125
9:35	134	131	127	125
9:40	133	131	127	125
9:45	133	130	127	124
9:50	133	130	126	124
9:55	132	130	126	124
10:00	132	130	126	124
10:05	132	130	126	124
10:10	131	129	126	124
10:15	131	129	126	124
10:20	131	129	126	123
10:25	130	129	125	123

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: 163OPMC1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
10:30	130	129	125	123
10:35	130	128	125	123
10:40	129	128	125	123
10:45	129	128	125	123
10:50	129	128	125	123
10:55	129	128	125	122
11:00	128	127	124	122
11:05	128	127	124	122
11:10	128	127	124	122
11:15	127	127	124	122
11:20	127	127	124	122
11:25	127	127	124	122
11:30	127	126	124	122
11:35	126	126	124	122
11:40	126	126	124	122
11:45	126	126	124	121
11:50	126	126	123	121
11:55	125	126	123	121
12:00	125	125	123	121
12:05	125	125	123	121
12:10	125	125	123	121
12:15	124	125	123	121
12:20	124	125	123	121
12:25	124	125	123	121
12:30	124	125	123	121
12:35	124	124	122	120
12:40	123	124	122	120
12:45	123	124	122	120
12:50	123	124	122	120
12:55	123	124	122	120
13:00	123	124	122	120
13:05	122	124	122	120
13:10	122	123	122	120
13:15	122	123	122	120
13:20	122	123	122	120
13:25	122	123	122	120
13:30	121	123	122	120
13:35	121	123	121	120
13:40	121	123	121	120
13:45	121	123	121	120
13:50	121	123	121	120
13:55	121	123	121	119

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

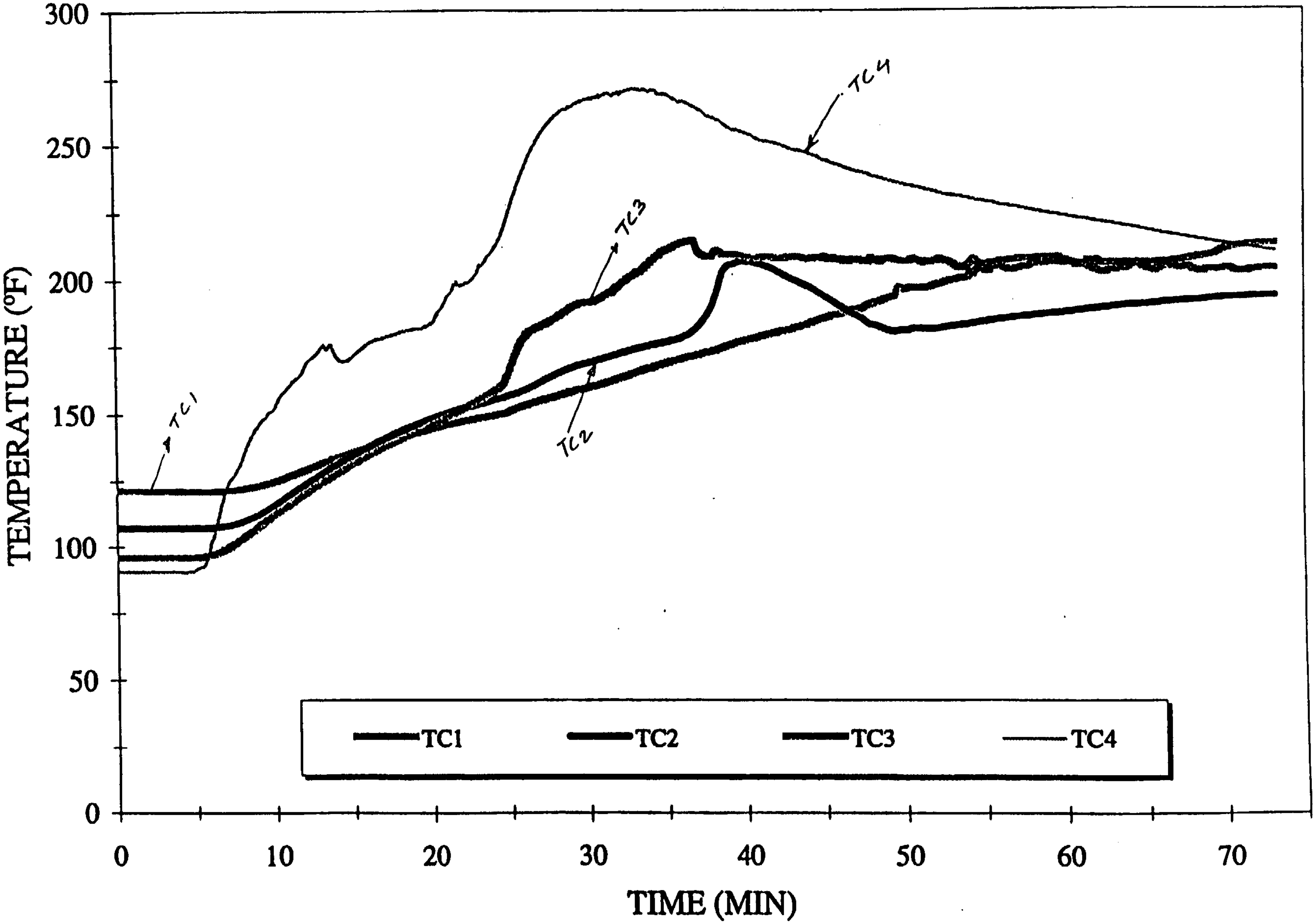
DATE: 12 JUNE 1998
FILE: 163OPMC1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
14:00	120	122	121	119
14:05	120	122	121	119
14:10	120	122	121	119
14:15	120	122	121	119
14:20	120	122	121	119
14:25	120	122	121	119
14:30	120	122	121	119
14:35	119	122	121	119
14:40	119	122	121	119
14:45	119	122	121	119
14:50	119	122	121	119
14:55	119	121	121	119
15:00	119	121	121	119
15:05	119	121	121	119
15:10	119	122	121	119
15:15	118	121	121	119
15:20	118	121	121	119

CL. . . ECO-PAK SPECIALTY PACKAGING
SwRI PROJECT No.: 01-1680-102b
DATE: 12 JUNE 1998
FILE ID: 163OPMT1.DAT

OPM-1 TEST DATA
SPECIMEN THERMOCOUPLES



ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: OPMT1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
0:00	121	107	96	91
0:01	121	107	96	91
0:02	121	107	96	91
0:03	121	107	96	91
0:04	121	107	96	91
0:05	121	107	96	92
0:06	121	107	97	102
0:07	121	108	99	123
0:08	122	110	103	133
0:09	123	112	107	146
0:10	125	116	112	152
0:11	127	120	116	161
0:12	129	124	120	168
0:13	131	128	124	175
0:14	134	131	128	171
0:15	136	135	131	171
0:16	138	138	135	176
0:17	139	141	138	178
0:18	141	143	141	180
0:19	143	146	143	181
0:20	144	148	146	183
0:21	146	150	149	193
0:22	147	152	152	198
0:23	148	153	155	203
0:24	149	155	158	211
0:25	151	157	166	225
0:26	153	159	179	241
0:27	155	162	182	253
0:28	156	164	185	261
0:29	158	167	189	264
0:30	159	168	191	267
0:31	161	170	193	269
0:32	163	172	197	270
0:33	165	174	202	271
0:34	167	175	206	270
0:35	168	176	211	269
0:36	170	178	213	266
0:37	171	182	211	264
0:38	173	190	209	260
0:39	175	205	209	257
0:40	177	206	208	255
0:41	178	205	208	252

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: OPMT1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	TC 1	TC 2	TC 3	TC 4
0:42	179	203	207	250
0:43	181	200	208	248
0:44	183	197	207	247
0:45	185	193	208	244
0:46	186	190	207	242
0:47	188	186	207	240
0:48	190	182	208	239
0:49	192	180	207	237
0:50	196	180	206	235
0:51	196	181	206	234
0:52	197	181	206	233
0:53	199	182	206	231
0:54	200	182	204	230
0:55	205	183	203	229
0:56	206	184	204	228
0:57	207	185	203	227
0:58	207	186	205	226
0:59	208	186	206	224
1:00	207	187	206	223
1:01	205	188	205	222
1:02	206	188	203	221
1:03	206	189	203	220
1:04	206	190	204	219
1:05	206	190	204	218
1:06	206	191	204	217
1:07	206	191	204	216
1:08	208	191	203	215
1:09	208	192	203	214
1:10	211	192	204	213
1:11	212	193	203	212
1:12	213	193	203	211
1:13	213	193	204	210

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: OPMT1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME (h:mm)	FLAME THERMOCOUPLES FTC 1	FTC 2	FTC 3	FTC 4	AVERAGE
0:00	216	129	420	882	412
0:01	977	1243	1857	1136	1303
0:02	1098	1227	2026	1211	1391
0:03	1081	1542	1769	1310	1426 —9
0:04	1197	1449	2298	1564	1627
0:05	1247	1723	1945	1641	1639
0:06	1366	1553	1918	1730	1641
0:07	1259	1518	1996	1506	1570
0:08	1336	1946	2074	1299	1664
0:09	1615	2247	1944	1529	1834
0:10	1614	2051	1928	1336	1732
0:11	1684	2228	1784	1510	1802
0:12	1152	1566	2004	1589	1578
0:13	1406	2049	2073	1372	1725
0:14	1563	2104	1942	1446	1764
0:15	1527	2086	2010	1321	1736
0:16	1625	1960	2062	1350	1749
0:17	1234	1862	1976	1249	1580
0:18	1638	2142	2026	1440	1811
0:19	1222	1911	1972	1309	1603
0:20	1565	2108	2020	1369	1765
0:21	1371	2045	1837	1535	1697
0:22	1278	1951	1704	1895	1707
0:23	1770	2123	1716	1752	1840
0:24	1264	1888	1851	1586	1647
0:25	1352	2043	1954	1517	1717
0:26	1348	1953	1953	1570	1706
0:27	1329	1866	2005	1159	1590
0:28	1175	1749	2039	1428	1598
0:29	1150	1553	1964	1581	1562
0:30	1495	2087	1985	1423	1748 FLM TEMP
0:31	799	1607	1910	684	1250
0:32	328	915	1741	254	809
0:33	198	558	1649	160	641
0:34	162	334	1291	130	479
0:35	128	212	924	120	346
0:36	117	159	686	110	268
0:37	112	135	507	106	215
0:38	106	119	386	108	180
0:39	104	124	312	101	160
0:40	101	131	260	99	148
0:41	99	128	224	98	137

ECO-PAK SPECIALITY PACKAGING
THERMOCOUPLE TEMPERATURES

DATE: 12 JUNE 1998
FILE: OPMT1.DAT

SwRI PROJECT NO: 01-1680-102B
TEST TYPE: 10CFR 71.73(C),(4)

TIME	FLAME THERMOCOUPLES				
(h:mm)	FTC 1	FTC 2	FTC 3	FTC 4	AVERAGE
0:42	99	121	198	98	129
0:43	99	120	178	99	124
0:44	98	120	166	97	120
0:45	97	117	155	96	117
0:46	97	116	149	96	114
0:47	97	108	142	96	111
0:48	97	106	136	96	109
0:49	97	102	131	95	106
0:50	96	103	127	95	105
0:51	96	103	125	95	105
0:52	95	105	122	95	104
0:53	95	106	120	94	104
0:54	95	107	119	95	104
0:55	95	106	119	95	104
0:56	95	104	118	95	103
0:57	95	106	119	94	104
0:58	95	102	117	95	102
0:59	95	103	117	94	102
1:00	94	102	116	94	102
1:01	95	102	115	94	101
1:02	94	100	113	94	100
1:03	94	100	112	94	100
1:04	94	100	111	94	100
1:05	94	99	110	94	99
1:06	94	98	109	94	99
1:07	94	97	108	93	98
1:08	94	98	107	93	98
1:09	93	99	107	93	98
1:10	93	99	107	93	98
1:11	93	97	107	93	98
1:12	93	96	107	93	97
1:13	93	96	105	93	97

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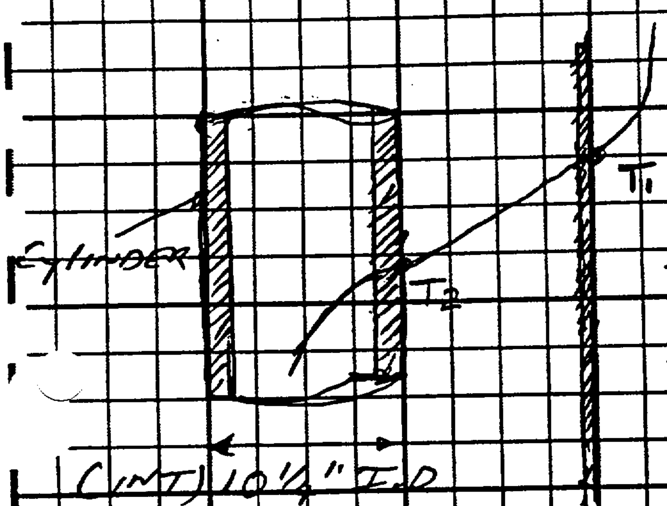
Thermal evaluation OF URANIUM OXIDE (UO_2) OP TRANSPORT UNIT.



(INT) 10 1/4" I.D

(EXT) 12 1/16" O.D

T_1 = OUTSIDE FLAME TEMP. (AVG.)

$\simeq$ 1658 °F

= (903.3 °C)

T_2 = OUTSIDE cylinder wall temp

T_{2P} $\approx$ PRE-HEAT OUTSIDE CYLINDER WALL TEMP

T_{2m} = MAXIMUM AVG. TEMP after 30 MIN. FIRE TEST.

$$T_{2P} = \frac{TC1 + TC2 + TC3 + TC4}{4} = \frac{122 + 107 + 96 + 91}{4}$$

$\simeq$ 104 °F (40 °C)

T_{2m} = 257 °F (FROM SENSORS) (125 °C)

ΔT = TEMP OF CYLINDER INCREASED DUE TO FIRE TEST.

$= T_{2m} - T_{2P} = 125 - 40 = 85\,°C$

$$T_2\ AVG = \frac{T_{2m} + T_{2P}}{2} = \frac{40 + 125}{2} = 82.5\,°C$$

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JOB NAME Eco-Pak
BY MNP DATE 7-29-98
CHECKED BY ______ DATE ______

TOTAL HEAT REQD' (Q1) TO INCRESE THE CYLINDER TEMP FROM 40°C TO 125°C (FROM 104°F TO 257°F)

161.8 Kg / vessel
AS PER H.L MAX RATE 647.2 Kg. wo/ / 4 Vess

ΔT = TEMP INCREASED = 85°C
m = TOTAL MASS
= MASS OF CYLINDER + MASS OF STEEL SHOT

AVG. MASS OF EACH CYLINDER = $\frac{162.8 + 155.2 + 153.4 + 155}{4}$
= 156.6 LB. (71 Kg)

AVG. MASS OF LOAD WT = $\frac{353.2 + 361.6 + 326 + 379.8}{4}$
= 355.15 LBS (161.1 Kg)

AVG. Cylinder + steel shot wt
= 71 + 161.1 = 232.1 Kg (511.7 lbs)

∴ TOTAL HEAT TRANSFR / CYLINDER

$Q = m \cdot C_P (\Delta T)$

C_P = SPECIFIC HEAT OF STEEL = 0.47 KJ/Kg °C

m = 232.1 Kg
ΔT = 85°C

Q = 232.1 (0.47) 85 = 9272 KJ.

Heat Transfer rate = q = $\frac{9272}{30 \times 60}$ = 5.15 KJ/SEC.

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JOB NAME ECO-PAK

BY M.N PARIKH DATE 7-29-98

CHECKED BY ______ DATE ______

From heat transfer rate of flow rate q we can calculate the overall thermal resistance of the transport unit.

$$q_{avg} = \frac{T_1 - T_{2avg}}{\Sigma R}$$

where q_{avg} = heat transfer rate (average)

T_1 = Avg Flame temp during 30 min FIRE TEST = 903.3 °C

T_{2avg} = Avg temp of Cylinder wall during FIRE TEST.

$$T_{2avg} = \frac{T_{2p} + T_{2m}}{2} = \frac{104 + 257}{2} = 180.5 \text{ °F}$$

$$= \frac{40 + 125}{2} = 82.5 \text{ °C}$$

ΣR = overall thermal Resistance

$$\therefore \Sigma R = \frac{T_1 - T_{2avg}}{q} = \frac{903.3 - 82.5}{5.15} = 159 \text{ m}^2\text{ °C/W}$$

FROM overall thermal Resistance we can calculate heat transfer rate at starting & end of the fire test

$$q_{start} = \frac{T_1 - T_{2R}}{\Sigma R} = \frac{903.3 - 40}{159} = 5.43 \text{ KJ/sec}$$

$$q_{end} = \frac{T_1 - T_{2m}}{} = \frac{903.3 - 125}{} = 4.89 \text{ KJ/sec.}$$

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JOB NO. 10810-8-7008 SHEET 4 OF 6

JOB NAME SCO-PAK

BY M.N. PARIKH DATE 7-29-98

CHECKED BY ______ DATE ______

$q_{avg} = \frac{q_{start} + q_{end}}{2} = \frac{5.43 + 4.89}{2} \approx 5.16$ KJ/sec

(Check)

MELTING POINT UO_2 (5.35) 2176°C – 2600°C

Cp = OF UO_2 VARIES: = ~~19.20 + 1.62 × 10^-3 T~~ 0.063 Cal/g °C

DENSITY: 10.5 gm/cc (AVG.

Thermal conductivity: – 0.11 Watt/cm °C @

Varies → density

→ temp.

CAPACITY = 161.8/VESSEL

thermal expansion (Fig-5-8)

Volume of the storage vessel = 7" Ø (ID)

LENGTH = 38 1/8 + 1/2" + 2 1/4"

Tested 8" Ø vessel

= 40 7/8" = 40.875"

Vol = ($\pi/4 D^2 \times L$) = 1573 INCH³ = 25777 Cubic Cm

DENSITY OF UO_2 = 10.0 gm/cc

Wt of UO_2 IN VESSEL = 25777 × 10.5 = ~~257.77~~ 270.65 Kg.

Cylinder is rated up to 161.8 Kg. ∴ FULL = 60%

FOR Powder UO_2 DENSITY = PARA 3.2.1.
URANIUM DIOXIDE
PROPERTIES & NUCLEAR
APPLICATIONS.

~~≈ 10.5 g/cc~~

Silicon – gasket rated 400°F

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MELTING TEMP OF UO_2 IS Approximately 2800°C

TOTAL HEAT TRANSFER DURING 30 MINUTE PERIOD.

$Q = 9272$ KJ

M_{UO_2} = MASS OF URANIUM DIOXIDE = 161.8 Kg

M_{cy} - Avg mass of cylinder = 71 kg

C_p of Cylinder = 0.47 KJ / Kg °C

C_{pUO_2} of UO_2 = 0.2635 KJ/kg °C (200 > T > 100 °C)

0.063 Cal = 0.263592 joule

∴ C_p = 0.063 Cal/g °C

≃ 0.2635 KJ / kg °C

ΔT = TEMP INCREASED DURING 30 MIN. FIRE TEST

$\Delta T = T_F - T_{2P}$

T_F = FINAL TEMP OF SIMULATED UO_2 LOAD

T_{2P} = 40°C

$$Q = \Delta T (M_{cy} \times C_p + M_{UO_2} \times C_{pUO_2})$$

$$9272 = \Delta T (71 \times 0.47 + 161.8 \times 0.2635)$$

$$9272 = \Delta T (76) \quad \therefore \Delta T = 9272/76 \quad 122°C$$

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JOB NO. 10810-8-7008 SHEET 6 OF 6
JOB NAME ECO-PAK
BY M.N. PARIKH. DATE 7-29-98
CHECKED BY ______ DATE ______

FINAL TEMP OF URANIUM OXIDE at the end of 30 MIN. FIRE TEST WOULD BE

$\simeq 40°C + 122°C = 162°C < 2800°C$ (323.6 °F)

∴ SIMULATED LOAD OF UO_2 would stay in solid state.

THERMAL EXPANSION OF SIMILATED URANIUM OXIDE LOAD

$\Delta T = 122°C$

% EXPANSION (LINEAR) $\approx$ 0.1 % = 0.001

V_1 = INITIAL VOL. OF UO_2 LOAD = $\frac{161.8 \times 10^3}{10.5}$ CC = 15409.5 CC = 0.544 ft

V_2 = FINAL VOL. OF " " = $1.001 V_1$

FINAL PRESSURE P_2

$T_1 = 104°F + 490 = $ $T_2 = 323.6°F + 490 = 813.6$

$P_1 = 14.7$ PSI $P_2 = ?$

$V_1 = V_1$ $V_2 = 1.001 V_1$

$$\frac{P_2 V_2}{T_2} = \frac{P_1 V_1}{T_1} \qquad P_2 = P_1 \left(\frac{T_2}{T_1}\right) \times \left(\frac{V_1}{V_2}\right)$$

$$= 14.7 \left(\frac{813.6}{594}\right)\left(\frac{V_1}{1.001 V_1}\right)$$

$= 20.11$ PSIa OR 5.41 PSIg

by the displacement of a fluid that can penetrate all pores and capillaries of a solid down to molecular dimensions are termed real densities. Closed pores, voids completely surrounded by the solid matrix and, thus, inaccessible to any fluid except by diffusion through the solid, are arbitrarily considered as part of the real volume of the material. The helium atom has a small diameter which enables it to penetrate into very fine pores; in addition, there is negligible adsorption of helium on solids at room temperature [8]. Therefore, densities obtained by helium displacement most closely conform to the definition of real densities. Measurements obtained by liquid displacement are usually lower because of incomplete penetration of the pores of the solid by the liquid [8].

Published data on UO_2 densities vary over a wide range (10.0 to 11.0 g/cc), depending on the experimental technique and the method of preparation of the uranium oxide [1, 2, 5, 9, 10]. Some typical results are listed in Table 3.1. The measured densities of UO_2 powders prepared by steam oxidation procedures approach the theoretical 10.96 g/cc [2]. The liquid densities are slightly lower than the helium values, indicating that these powders consist of dense granules (no closed porosity) with varying amounts of small open pores. Low density UO_2 (10.0 to 10.4 g/cc) is obtained from UO_3 and U_3O_8 made by direct pyrolysis of uranyl nitrate hexahydrate crystals [1, 2, 9].

TABLE 3.1—DENSITY OF UO_2 [2]

Method of preparation	O/U	Density (g/cc)	
		Helium	CCl_4*
High-pressure steam oxidation of uranium	1.97	10.92±0.1	10.75
Controlled low-pressure steam oxidation of uranium	2.03	10.85±0.1	10.91
Steam oxidation of uranium from UH_3	2.03	10.98±0.1	10.67
Hydrogen reduction of $UO_3 \cdot 2H_2O$	2.01	10.25±0.05	10.25
Hydrogen reduction of $UO_3 \cdot H_2O$	2.01	10.34±0.05	10.37
Air pyrolysis of $UO_2(NO_3)_2 \cdot 6H_2O$ to UO_3; hydrogen reduction to UO_2**	2.02	10.16±0.05	10.13
Air pyrolysis of $UO_2(NO_3)_2 \cdot 6H_2O$ to U_3O_8; hydrogen reduction to UO_2	2.02	10.03±0.05	9.96
Hydrogen reduction of uranyl oxalate	2.01	10.61±0.2	10.61
Hydrogen reduction of uranium peroxide	2.08	11.00±0.1	10.78
Hydrogen reduction of ammonium hydroxide precipitated diuranate	2.07	11.11±0.2	10.81
Hydrogen reduction of urea precipitated diuranate	2.08	10.74±0.2	10.19

*Precision: ±0.2 percent.
**MCW oxide used in PWR Core 1.

For this type of UO_2, the helium and liquid densities, besides being considerably below the theoretical values, are in close agreement with each other. This suggests that these oxides contain little open porosity but an appreciable amount of closed pores.

In general, the real density of a UO_2 powder preparation depends upon the density of its parent higher oxide ($UO_3 \cdot 2H_2O$, $UO_3 \cdot H_2O$ UO_3, or U_3O_8) [1, 2, 9]. The density is not dependent on the reduction temperature up to 1,200° C [1, 2]. However, heating low density UO_2 above its temperature of preparation can cause an increase in its density [1, 2]. The densities of UO_2 made by CO reduction of U_3O_8 are measurably higher than the densities of UO_2 prepared by H_2 reduction of the same material under similar conditions [1]. For many UO_2 preparations the liquid densities are considerably below the helium values [2]. This is due to the inability of the large liquid molecules to penetrate small microcracks and fissures and indicates that considerable amounts of open porosity are present in these powders.

Grinding low density UO_2 powders does not increase their fluid densities significantly [1, 2, 11]. Comminution processes, in general, are unable to open any of the closed pores. Milling the less abrasive UO_3 produces some increase in its density which is retained upon reduction to UO_2. Uranium dioxide powders with measured densities above the theoretical value have been found to have O/U ratios well above 2.00 [2, 5, 9, 10, 12, 13].

Density is a significant characteristic of both green (as-pressed) and sintered UO_2 bodies. A UO_2 compact contains both open (connected) and closed (unconnected) pores. The total volume can be considered as the sum of the open pore volume, the closed pore volume, and the theoretical UO_2 volume. Techniques have been developed to measure each of these volumes [14–16]. Examples of the relation between density and porosity in sintered UO_2 pellets prepared from MCW and ADU oxides are shown in Figs. 3.1 and 3.2 (see Chap. 7 for a more detailed discussion). At the lower densities, the closed porosity is relatively constant, and the main mode of densification is the decrease in the number of open pores. There is a rise in the closed porosity when the open porosity approaches zero in the higher density range. These curves differ somewhat for bodies prepared from different sources of UO_2 or by different fabrication techniques [14, 16].

3.2.2 Microstructure

The particle shape of UO_2 powders has an important influence on their performance during processing and on the final properties of the sintered product. Particular particle contours may control powder pouring, packing, flow characteristics, and both the as-pressed and sintered density of compacts. In addition, particle shape affects the given in Katz and Rabinowitch [1], was used by Hausner and Mills to calculate the specific heat values given in Table 5.6 [40]. These calculated values are greater than the approximate maximum for the molar heat capacity, $6n$ cal/deg, where n is the total number of atoms in the molecule. Deviations from the law of Dulong and Petit are not unreasonable, however, at high temperatures.

TABLE 5.6—SPECIFIC HEAT OF UO_2 [40]

Temperature (° C)	Specific heat C_p (cal/g-° C)
100	0.063
200	0.067
500	0.074
1,000	0.078
1,500	0.082

5.3.3 Debye Temperature

J. Belle and V. J. Tennery

As discussed in Sect. 5.3.1, at temperatures higher than the Debye characteristic temperature, Θ, the thermal conductivity of dielectric crystals is governed only by the temperature dependence of l, the phonon mean free path. If K (phonon) $=\frac{1}{3}C_v l$ and if it is assumed that heat capacity and phonon velocity remain essentially constant with temperature when $T>\Theta$, K (phonon) is proportional to $1/T$. Tennery used this approximation to estimate the magnitude of the Debye temperature Θ for UO_2 [22]. He obtained a value of about 870° K from a plot of the Kingery, et al., conductivity data versus reciprocal temperature, since the plot becomes reasonably linear above 850° to 870° K [23].

This method of determining the Debye characteristic temperature is, however, not the classical one and is certainly open to question. The Debye temperature can be determined from heat capacity data. Either the T^3 approximation is used near absolute zero, in which the Debye specific heat equation

$$C_v=3R\left[12\frac{T^3}{\theta^3}\int_0^{\theta/T}\frac{x^3dx}{e^x-1}-\frac{3\theta/T}{e^{\theta/T}-1}\right] \qquad \text{Eq. (5.4)}$$

reduces to

$$C_v=\frac{12}{5}\pi^4R\left(\frac{T}{\theta}\right)^3 \text{ for } T\ll\theta \qquad \text{Eq. (5.5)}$$

or the specific heat curve of the compound is matched to the Debye specific heat curve by choosing the proper value for Θ in Eq. (5.4). Jones, et al., determined Θ for UO_2 to be 160° K from their specific heat data below 20° K by using the T^3 approximation [35].

Due to the high specific heat (C_v), it is not possible to match the Debye function to the data on the rising part of the specific heat curve of Jones, et al., to obtain another estimate of Θ [35]. According to the Debye theory, however, at $T=\Theta$, C_v has attained 94 percent of its maximum value. Assuming that the maximum value for the molar specific heat (C_v) of UO_2 is $9R$ (17 cal/deg), it can be seen from the data of Jones, et al., (assuming C_p is equal to C_v), that the Debye temperature is greater than 300° K.[a] Note also that the heat capacity has only attained about 65 percent of its room temperature value at 160° K.

Another estimate of the Debye temperature can be made from the Lindemann approximation in which it is assumed that at the melting point the amplitudes of vibration of the atoms or ions in the solid are approximately equal to their mean distance apart. The maximum Debye frequency ν_m is given by

$$\nu_m\cong 2.8\times10^{12}\sqrt{\frac{T_m}{MV^{2/3}}}$$

where M is molecular weight, V is the molecular volume, and T_m is the melting point in ° K [41]. For UO_2, $\nu_m = 3.22 \times 10^{12}$ sec^{-1} and

$$\theta=\frac{h\nu_m}{k}=154°K,$$

which is surprisingly close to the value found by Jones, et al., from low temperature specific heat data [35].

It may be questionable whether the concept of a single Debye temperature is very meaningful for UO_2, that is, ν_m, the maximum lattice vibrational frequency, cannot be determined by such a simple approximation. The frequency mode distribution for UO_2 must be known in order to determine Θ at a specified temperature. This may be obtained by using the Born-von Karman method for the UO_2 structure although the mathematical complexity of the calculation may be prohibitive [42].

Debye's theory predicts specific heats which seem to fit the data best for diatomic solids in which the ratio of the atomic masses of the two species present does not vary more than 2:1 (such as the alkali halides, CaF_2 and Al_2O_3). Blackman has made a calculation of the specific heat of a linear diatomic lattice and has shown that Θ varies considerably with temperature [43]. As the ratio of the atomic masses increases, the deviation of Θ with temperature becomes more extreme; for a high mass ratio, Θ increases rapidly with temperature but becomes fairly constant at high temperatures. Blackman also cal

[a] Scott reported Θ to be less than 600° K [26].

culated the variation of Θ as a function of temperature for a simple cubic monatomic lattice; in this case, considerable variation of Θ with temperature was also predicted.

For UO_2, where the mass ratio is approximately 15, a considerable variation of Θ with temperature could be expected. If this is the case, the value of Θ determined by Jones, et al., from the T^3 extrapolation below 20° K may be valid only in this temperature range [35].

The distribution of vibrational modes has not been calculated for the fluorite lattice, nor have the expressions been derived which give Θ (T) as a function of the mass ratios. If the electronic specific heat is negligible at elevated temperatures, the derivation of these functions should permit the determination of Θ (T) for UO_2.

5.3.4 Thermal Expansion

H. D. Sheets

Several investigators have reported results of thermal expansion measurements on UO_2 over the temperature range 20° to 1,200° C. Murray and Thackray were the first to report the coefficient of thermal expansion for both sintered UO_2 and sintered nonstoichiometric $UO_{2.13}$ [44]. (It should be noted that since analyses were not reported, the latter oxide may have been reduced at higher temperatures.) In these dilatometric measurements made in a purified argon atmosphere, two heating rates (3½° and 10° C per minute) were used. Results (Fig. 5.8) show that the expansion coefficient increases up to 400° C approximately and remains constant from 400° to 900° C. In this temperature range, the coefficient of thermal expansion is 10×10^{-6}/° C. Schaner* determined the linear thermal expansion of high density UO_2 (about 98 percent theoretical density) to be 10.1×10^{-6}/° C from room temperature to 1,100° C. The measurement was made in vacuum by the autographic optical-lever method. The sample was heated and cooled at 4° C/min and the data from the cooling curve were used to compute the expansion coefficient. The percentage linear expansion between room temperature and various temperatures up to 900° C together with the expansion coefficients over the range 400° to 900° C are given in Table 5.7. Note that bulk density has little effect on the measured thermal expansion.

Other results on sintered UO_2 reported by Burdick and Parker, by Bell and Makin, and by Lambertson and Handwerk are shown in Fig. 5.9; these data agree up to 800° C [45, 46, 47]. (The data of

* B. E. Schaner, unpublished work.

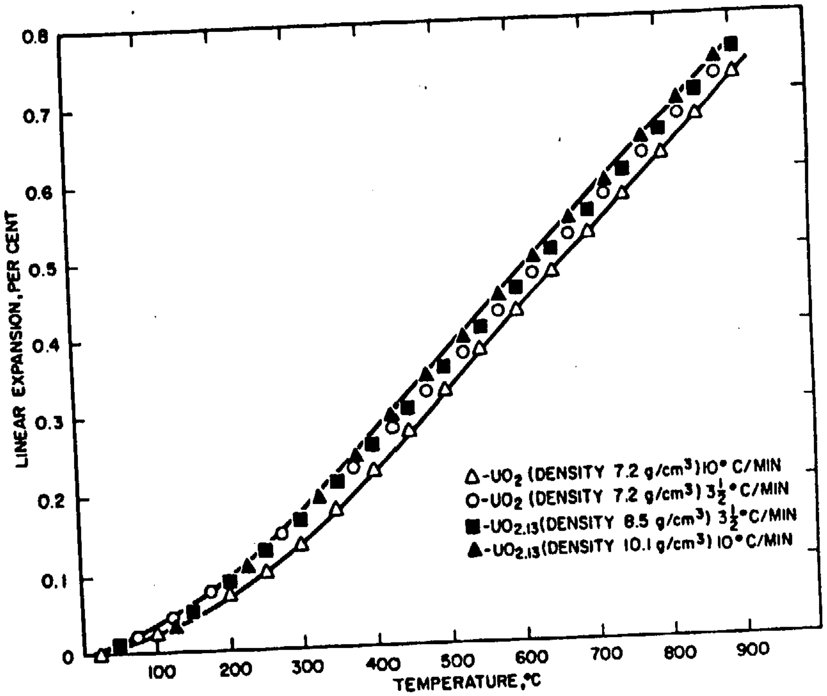

FIGURE 5.8. Thermal Expansion of UO_2.

TABLE 5.7—THERMAL EXPANSION DATA FOR SINTERED UO_2 [4

Specimen	Heating rate	Percentage linear expansion 20°-200° C	20°-400° C	20°-600° C	20°-900° C	Expansion coefficient (400°-900° C)
UO_2, 7.2 g/cm³	10°/min	0.07	0.22	0.42	0.72	10×10^{-6}
UO_2, 7.2 g/cm³	3.5°/min	0.09	0.25	0.44	0.73	9.5×10^{-6}
UO_2, 10.71 g/cm³	4.0°/min					10.1×10^{-6}*
$UO_{2.13}$, 8.54 g/cm³	10°/min	0.08	0.25	0.45	0.75	10×10^{-6}
$UO_{2.13}$, 10.1 g/cm³	3.5°/min	0.08	0.25	0.47	0.78	10.5×10^{-6}

*B. E. Schaner, unpublished work.

Murray and Thackray are shown for comparison.) Burdick and Pa ker fitted their data for the temperature range 27° to 1,260° C to curve of the form

$$y=aT^2+bT+c$$

where

y=percent thermal expansion based on length at 27° C
$a=2.1481\times10^{-7}$
$b=8.4217\times10^{-4}$
$c=-3.0289\times10^{-2}$
T=temperature (° C).

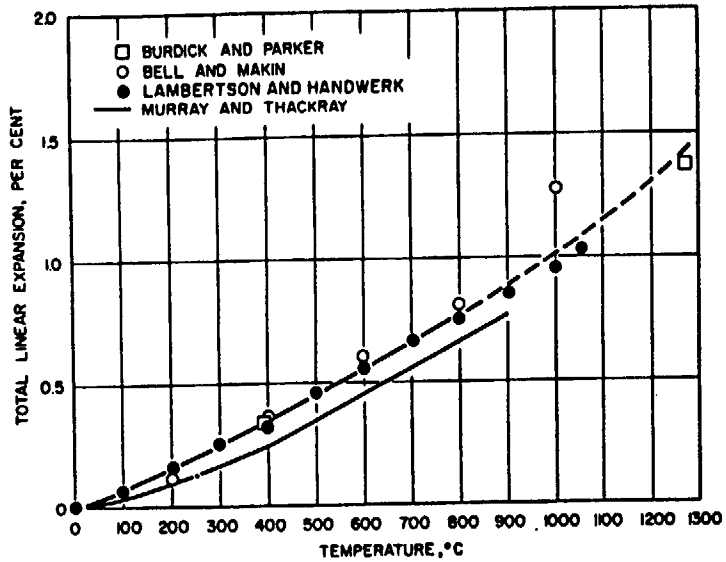

FIGURE 5.9. Thermal Expansion of UO_2.

It should be noted that the experimental thermal expansion data agree in general with values calculated from X-ray parameters (see Sect. 5.2.1).

Recent measurements of Halden, et al., have extended thermal expansion data from the region of 900° to 1,000° C to the melting point of UO_2 [48]. The linear expansion of dense (93 percent of theoretical) UO_2 was found to follow closely the equation

$$l = l_0 (1+6.0\times10^{-6}\, T+2.0\times10^{-9}\, T^2+1.7\times10^{-12}\, T^3)$$

in which T is in ° C. An anomalous expansion was noted in the temperature range of 1,000° to 1,500° C. These results are shown in Fig. 5.10; the data of Bell and Makin and of Murray and Thackray to 1,000° and 900° C, respectively, are shown for comparison [44, 46].

The volume expansion of UO_2 up to the melting point, determined by Halden, et al., is shown in Fig. 5.11 for two types of dense UO_2 specimens [48]. These data were calculated from linear expansion measurements and illustrate the large increase in volume which occurs at temperatures above 2,000° C.

Above 2,450° C excessive vaporization and crystal growth on the surface of the specimens were observed. An attempt was made to explore the region near the melting point by means of a solar furnace, but only qualitative information was obtained. Some preliminary results suggested that the volume change incident on melting was probably less than 3 percent. Note that this compares with an estimate of from 1 to 7 percent obtained from metallographic examina-

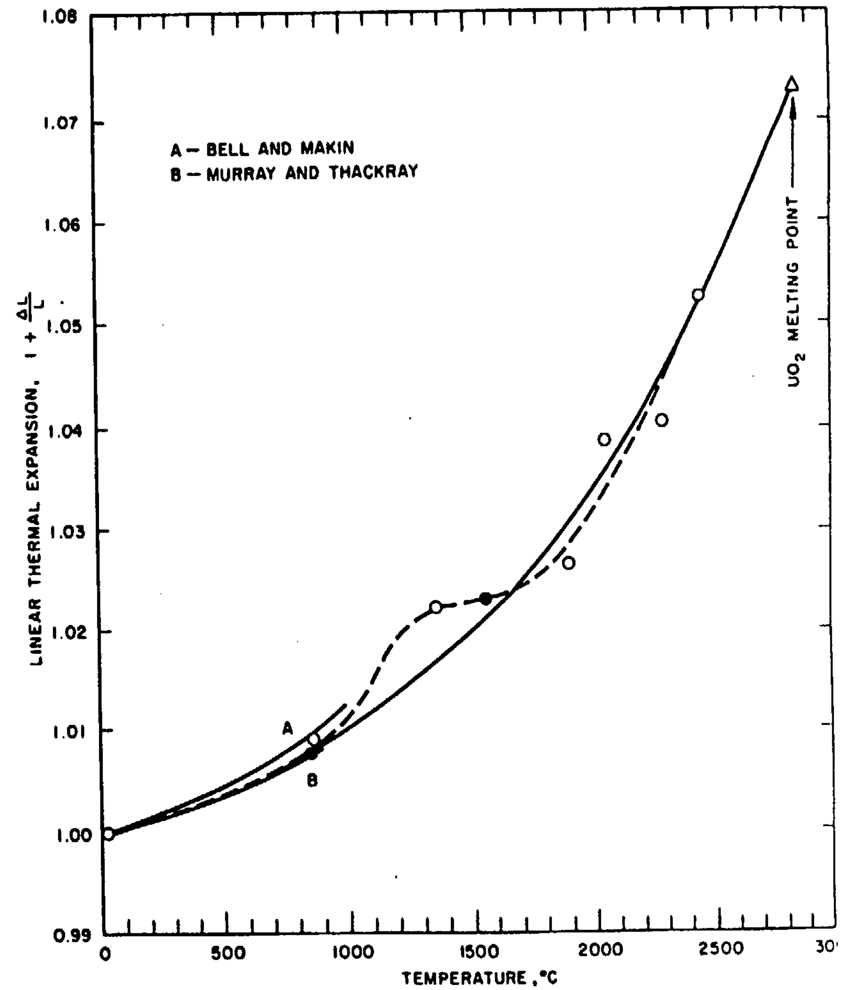

FIGURE 5.10. Linear Thermal Expansion of Dense (10.19 g/cc) UO_2 up Reheating after Initial Heating to 2,000° C [48].

5.3.5 Melting Point

In view of the difficulties involved in measuring and controlli very high temperatures, the effect of small quantities of impurities melting points of oxides, and the rather high vapor pressure of UO_2 elevated temperatures (see Sect. 5.3.6), it is not surprising that wid different values for the melting point have been reported. Some the earlier values of the melting point are those of Ruff and Goec 2,176° C, and Friederick and Sittig, 2,500° to 2,600° C [49, 50].

Lambertson and Handwerk, using specimens heated in a purifi helium atmosphere in a tungsten crucible, reported a melting po of 2,880°±20° C for UO_2 [47]. Spectrographic analysis after m

		FLAME TEMPERATURE DATA					
		Date: July 24, 1998					
		Eco-Pak Specialty Packaging, Project No. 10810-8-7008 Phase 08					
		Flame Temperature					
Thermocouple No.		FTC 1	FTC 2	FTC 3	FTC 4	AVG	
	0 MIN.	216.0	129.0	420.0	882.0	411.8	
	1 MIN.	977.0	1243.0	1857.0	1136.0	1303.3	
	2 MIN.	1098.0	1227.0	2026.0	1211.0	1390.5	
	3 MIN.	1081.0	1542.0	1769.0	1310.0	1425.5	
	4 MIN.	1197.0	1449.0	2298.0	1564.0	1627.0	
	5 MIN.	1247.0	1723.0	1945.0	1641.0	1639.0	
	6 MIN.	1366.0	1553.0	1918.0	1730.0	1641.8	
	7 MIN.	1259.0	1518.0	1996.0	1506.0	1569.8	
	8 MIN.	1336.0	1946.0	2074.0	1299.0	1663.8	
	9 MIN.	1615.0	2247.0	1944.0	1529.0	1833.8	
	10 MIN.	1614.0	2051.0	1928.0	1336.0	1732.3	
	11 MIN.	1684.0	2228.0	1784.0	1510.0	1801.5	
	12 MIN.	1152.0	1566.0	2004.0	1589.0	1577.8	
	13 MIN.	1406.0	2049.0	2073.0	1372.0	1725.0	
	14 MIN.	1563.0	2104.0	1942.0	1446.0	1763.8	
	15 MIN.	1527.0	2086.0	2010.0	1321.0	1736.0	
	16 MIN.	1625.0	1960.0	2062.0	1350.0	1749.3	
	17 MIN.	1234.0	1862.0	1976.0	1249.0	1580.3	
	18 MIN.	1638.0	2142.0	2026.0	1440.0	1811.5	
	19 MIN.	1222.0	1911.0	1972.0	1309.0	1603.5	
	20 MIN.	1565.0	2108.0	2020.0	1369.0	1765.5	
	21 MIN.	1371.0	2045.0	1837.0	1535.0	1697.0	
	22 MIN.	1278.0	1951.0	1704.0	1895.0	1707.0	
	23 MIN.	1770.0	2123.0	1716.0	1752.0	1840.3	
	24 MIN.	1264.0	1888.0	1851.0	1586.0	1647.3	
	25 MIN.	1352.0	2043.0	1954.0	1517.0	1716.5	
	26 MIN.	1348.0	1953.0	1953.0	1570.0	1706.0	
	27 MIN.	1329.0	1866.0	2005.0	1159.0	1589.8	
	28 MIN.	1175.0	1749.0	2039.0	1428.0	1597.8	
	29 MIN	1150.0	1553.0	1964.0	1581.0	1562.0	
	30 MIN	1495.0	2087.0	1985.0	1423.0	1747.5	
TOTAL OF 30		40938.0	55773.0	58632.0	43663.0	49751.5	
	SUM OF FTC1		40938.0				
	SUM OF FTC2		55773.0				
	SUM OF FTC3		58632.0				
	SUM OF FTC4		43663.0				
		TOTAL	199006.0				
		AVG	1658.0				
	AVERAGE FLAME TEMPERATURE = 1658 DEGREES FAHRENHEIT						

SECTION FOUR CONTAINMENT

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4. CONTAINMENT

4.1 Containment Boundary

Containment for the contents of the Eco-Pak® OP Transport Unit is maintained by the storage vessel as described in Appendix 1.3.1.

4.1.1 Containment Vessel

The containment boundary for the Eco-Pak® OP Transport Unit is the internal storage vessel. Containment is maintained as long as there is no structural damage to the storage vessel or its closure which would result in dispersal of contents.

4.1.2 Containment Penetrations

The Eco-Pak® OP storage vessel has no penetrations.

4.1.3 Seals and Welds

The Eco-Pak® OP storage vessel is fabricated, inspected, tested, and maintained in accordance with ESP Drawing No. OP-TU-SAR, Sheets 1, 3 & 4 (Appendix 1.3.2) and with the minimum requirements specified in Sections Seven and Eight of this Safety Analysis Report.

4.1.4 Closure

Each storage vessel in the Eco-Pak® OP is secured by bolting a 5/8" thick stainless steel lid to the vessel with twelve (12) ½" bolts. Each storage vessel lid is also sealed with a 1/4" thick silicone gaskets

4.2 Requirements for Normal Conditions of Transport

4.2.1 Containment of Radioactive Material

The only radioactive materials in UO_2 are isotopes of uranium, primarily ^{235}U which has unlimited A_2 values.

4.2.2 Pressurization of Containment Vessel

The Eco-Pak® OP is not a pressurized package.

4.2.3 Containment Criterion

The UO_2 contained in a storage vessel is effectively triple-sealed, once by the storage vessel itself, twice by the double-flange configuration of the Eco-Pak® OP Transport Unit. However, for purposes of defining the containment criterion, only the inner storage vessel is considered.

The storage vessels of the Eco-Pak® OP are designed to replace the steel pails currently used in the BU-7 and BU(J) type packages for uranium oxide shipments. These packages enclose the lading in non-pressure rated steel pails with a bolted ring closure.

The storage vessels in the Eco-Pak® OP are closed using a gasketed blind flange bolted to an angle ring attached to the top of the storage vessel. The flanges are closed using twelve ½-inch bolts tightened to a prescribed torque of 75 +5/-0 ft-lbs.

Hypothetical accident condition testing showed that this arrangement was sufficient to maintain containment of the enclosed material even under those extreme conditions. Therefore, the bolted-flange closure will provide adequate containment under normal conditions of transport.

4.3 Containment Requirements for Hypothetical Accident Conditions

4.3.1 Fission Gas Products

UO_2 does not contain fission gas products.

4.3.2 Containment of Radioactive Material

Acceptance criteria for meeting the requirements of 10CFR71 are essentially no rupture of the storage vessels and no damage to the sealing mechanisms (bolted-flanged lids with silicone gaskets rated at 400^0F) that would render them inoperative.

4.3.3 Containment Criterion

Full scale compliance testing was performed on the Eco-Pak® OP Transport Unit. This testing is fully described in Sections 2.10.4 and 3.5.

The results of the thermal testing showed that the maximum calculated temperature to be experienced by any of the storage vessels was 323.6^0F, below the 400^0F rating for the gasket.

In addition, upon completion of all tests, the storage vessels were found to have exhibited no damage of any kind nor had the bolted flanges loosened.

5. ***SHIELDING EVALUATION***

Gamma and neutron shielding are not required for storage vessels of UO_2 because the 3/16-inch thick storage vessel walls provide more than adequate shielding for low enriched uranium. However, it is the responsibility of the shipper to assure compliance with 10CFR71.47 regarding radiation standards for each shipment.

SECTION SIX CRITICALITY

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6. CRITICALITY EVALUATION

The Eco-Pak OP Transport Unit is a Type A shipping unit designed for uranium oxide, uranium compounds that have at least two oxygen or other similar atoms, and uranium oxide compounds that have multiple uranium and/or oxygen or other similar atoms in either powder or pellet form[1]. The material may be packaged in plastic containers within the oxide vessel (up to 1307 g. water hydrogen equivalent per Oxide Vessel), with any degree of water or graphite moderation present. It incorporates four double-walled Oxide Vessels placed into four fixed sleeves and enclosed in an outer protective shell. Two vessel sizes are used: an 7 ¾" diameter for UO_2 powder enrichments equal to or less than 4.5 wt% U-235, and a 7" diameter for UO_2 enrichments less than or equal to 5.0 wt% U-235. The 7" diameter vessel is also used for UO_2 pellet enrichments equal to or less than 5.0 wt% U-235. The overall height of both the 7 ¾" and 7" diameter vessels is 42.5". The four vessels are arranged in a square lattice (pitch=22.5") in a rectangular overpack constructed of 11 gauge carbon steel. The volume between the inner and outer shells and the volume between the outer shell and the outer package plates is filled with a fire-retardant phenolic foam with a hydrogen content of 7% by weight and a density of 6 lb/ft^3.

6.1 Discussion and Results

Criticality control of the Eco-Pak OP Transport Unit relies on control of the powder or pellet enrichment, interior vessel diameter and wall thickness, vessel lattice pitch, and number of packagings that may be shipped together. Criticality evaluations are based upon worst case conditions assuming optimum internal moderation by water, plastic (up to the 1307g. water hydrogen equivalent limit per Oxide Vessel), or graphite and optimum interspersed moderation by water, with a conservative vessel lattice pitch of 22.0".

Uranium Dioxide is the most reactive uranium compound used in the commercial industry. Thus, the evaluation of the OP Type A Transport Unit with UO_2 will bound other less reactive uranium compounds without additional analyses. Other uranium compounds that have at least two oxygen or other similar atoms (e.g., flourine, nitrogen, carbon, silicon, and chlorine) are bound by these analyses if the theoretical density of the compound is less than that of uranium dioxide (10.96 g/cc). Uranium oxide compounds that have multiple uranium and/or oxygen or other similar atoms are bound by these analyses if the ratio of the non-fissile atoms to uranium atoms is not less than 2.0 and the density of the compound is less than that of uranium dioxide (10.96 g/cc). Material such as U-metal, U-metal alloys, or uranium hydrites (e.g., UH) are not bound by these analyses and may not be shipped in the OP Type A Transport Unit.

[1] Materials shipped in the OP Type A must meet the following criteria: the ratio of the non-fissile atoms to uranium atoms of the compound is not less than 2.0, and the theoretical density of the compound is less that of uranium dioxide (10.96 g/cc). Material such as U-metal, U-metal alloys, or uranium hydrites (e.g., UH) may not be shipped in the OP Type A Transport Unit.

The uranium compounds that may be shipped in the OP Type A Transport Unit may be packaged under any degree of water moderation, since the package was evaluated for conditions of optimum internal water moderation. Over-moderated or under-moderated conditions would lead to lower multiplication (k_{eff}) values for the OP Type A Transport Unit. Graphite and moderators internal to the package with a hydrogen density less than that of water (11 wt% hydrogen) are bound by the analyses performed. Moderators with a hydrogen density greater than that of water must be excluded.

Uranium compounds may also be packaged in polyethylene containers within the oxide vessel. The total weight of the polyethylene containers must not exceed 1000 g. (2.2 lb.) per oxide vessel (4 vessels per package, for a total maximum polyethylene weight of 4000 g per package). Other plastics may be used, provided the total water hydrogen equivalent content is less than or equal to 1307 g. per Oxide Vessel (5228 g. per package maximum water hydrogen equivalent).

Table 6-1 provides a summary of the results of the criticality evaluation of the Eco-Pak OP Transport Unit. A detailed description of the analytical models and methodology is provided in Section 6-3. All results are less than the conservative administrative Upper Subcritical Limit of 0.95 minus any code bias and uncertainty[2]. Figure 6-1 shows the k_{eff} as a function of the itnernal water moderation H/U_{235} ratio for 4.5 wt% U-235 powder in the 7 ¾" oxide vessel and 5.0 wt% U-235 UO_2 powder in the 7" oxide vessel. Figure 6-2 shows the K_{eff} as function of the water-to-fuel ratio for 5.0 wt% U-235 pellets in the 7" oxide vessel. All curves presented peak below the conservative Upper Subcritical Limit.

To maintain criticality control, the maximum number of Eco-Pak OP Transport Unit packages that may be shipped together is 125. The Transport Index (TI), calculated per 10CFR71.59, is 2.0.

6.2 *Model Specification*

6.2.1 Geometry and Analytical Model

The SCALE43 code with the 44 Group Standard Cross Section Library was used to evaluate K_{eff} of the Eco-Pak OP Transport Unit under all conditions of transport. All evaluations were performed for optimum moderation at 21°C. Input decks for all bounding cases are provided in Appendix 6.5.1.

[2] The k_{eff} used in all cases represents the KENO k_{eff} plus two sigma (sigma was typically on the order of 0.002). The code bias and uncertainty for homogeneous oxides using the 44-group is +0.0032 and 0.0198, respectively, per Reference 6-11. The code bias and uncertainty for heterogeneous oxides using the 44-group is +0.0000 and 0.0125, respectively, per Reference 6-11.

6.2.1.1 Normal Conditions of Transport

The Normal Transport condition postulates a group of 125 Eco-Pak OP Transport Unit packages arranged in the most reactive array with optimum interspersed moderation, optimum internal moderation, and close full reflection by water at the boundaries. For UO_2 powder enrichments less than or equal to 4.5 wt% U-235, a vessel diameter of 7 ¾" is used. For UO_2 powder enrichments less than or equal to 5.0 wt% U-235 and pellet enrichments less than or equal to 5.0 wt% U-235, a vessel diameter of 7.0" is used.

Table 6-2 provides the materials and key dimensions for the Eco-Pak OP Transport Unit [References 6.1 through 6.6]. Figure 6-3 provides a graphical representation of the unit model (one-quarter of a single Eco-Pak OP Transport Unit package) used in the criticality analysis. The packaging consists of four stainless steel vessels in a carbon steel right rectangular prism. The vessels are placed within the rectangular prism on a square lattice with a lattice pitch of 22.5". The overall height of each vessel is 42.5".

The Eco-Pak OP Transport Unit was modeled for both homogeneous powder and heterogeneous pellet loading using the SCALE package [Reference 6-7]. Table 6-2 provides a listing of the materials and dimensions used to model the Eco-Pak OP Transport Unit. Note that the vessel lattice is conservatively modeled at 22.0".

Foam, as a hydrogenous material integral to the packaging, was conservatively modeled as water with a hydrogen density of 75% of the value reported by the manufacturer (7% by weight) for the normal condition of transport as suggested by Reference 6-8. Appendix 6.5.3 contains the calculation of the equivalent water density corresponding to 75% of the hydrogen density reported for the foam.

In order to assure that the package was evaluated for the optimum moderation condition, varying weights and distributions of polyethylene (up to the 1000 g limit) were modeled within the Oxide Vessel to simulate the use of plastic packaging material. Plastics other than polyethylene are bounded by this evaluation if the total weight of the plastic per Oxide Vessel is less than or equal to 1307 grams H_2O hydrogen equivalent. Appendix 6.5.3 contains the calculation of the H_2O hydrogen equivalent weight for the polyethylene containers allowed for the packaging the fissile contents.

A single Eco-Pak OP Transport Unit was analyzed for the normal condition with optimum internal and interspersed moderation and close full reflection by water at the boundaries. A 5x5x5 array of packages was also evaluated. The analyses of the 5x5x5 array assume that the packages are stacked together in the worst case arrangement and with close full reflection on all sides of the stack by water.

Heterogeneous (pellets) packaging requirements were determined with the addition of XSDRN to the sequence used for the homogeneous (powder) packaging. XSDRN provides cell weighted cross sections for modeling of heterogeneous configurations with a homogeneous KENO Va model. Pellets were modeled as spheres, which are more reactive than cylinders (pellets), at the maximum theoretical density (10.95g/cc) for 5.0 wt% enriched UO_2. The sphere diameter and lattice pitch (triangular) were varied to determine the optimum conditions for both parameters. Reference 6-9 suggested that the optimum configuration occurred for a sphere diameter near 1.0 cm for a water-to-fuel ratio near 3.0.

6.2.1.2 Hypothetical Accident Conditions

The hypothetical accident conditions (HAC) postulate a minimum of 48 damaged packages arranged in the most reactive array with optimum interspersed moderation, optimum internal moderation, and close full reflection by water at the boundaries. The foam contained in the packaging was conservatively neglected. The package was modeled using varying weights of polyethylene (up to the 1000 g limit) to simulate the use of plastic packaging material within the oxide vessel. The results of the drop tests reported in Section Two were used as a basis for determining the structural damage to the package under hypothetical accident conditions. The Normal Condition of Transport model described in the previous section was modified to incorporate a conservative 4 degree (6" radial at the bottom) off center shift of all Oxide Vessels. As shown in Figure 6-4, this was accomplished by shifting discrete sections of the model through the axial length of the cylinder. This is a conservative approach, since the modeled shift exceeds the actual shift of the cylinders reported as a result of the drop testing. Three different arrangements of the 50 damaged packages, shown in Figure 6-5, were analyzed to determine the worst case. The 4x4x3 array with 2 additional packages used provides the most reactive credible array of 48 packages. Additional discussion of the arrays is provided in Section 6.3.4. The vessel-to-vessel lattice pitch within each package was maintained at a conservative 22.0". Due to the shift in the cylinders, the vessel-to-vessel lattice pitch between adjacent packages is reduced by 8.0" at the bottom plane of the package. A single damaged Eco-Pak OP Transport Unit was also evaluated for the hypothetical accident conditions previously described. The maximum K_{eff} for all Hypothetical Accident conditions were less than the upper subcritical limit.

6.2.2 Internal Moderation

The UO_2 powder or pellets contained in the Eco-Pak OP Transport Unit is very dry during normal conditions of transport. UO_2 is a ceramic material and is insoluble in water at all temperatures. The Eco-Pak OP Transport Unit is provided with a triple seal at the upper lid. Although it is considered unlikely that water will enter through these barriers, the criticality analysis assumes optimum internal and interspersed moderation for both the normal condition and the hypothetical accident condition.

6.2.2.1 UO_2 Powder

It was assumed that the UO_2 powder contained in the packaging was saturated with water in order to model the most reactive configuration. Figure 6-6 shows the saturation curve for various powder enrichments over a range of H/U-235 ratios. Appendix 6.5.2 provides further data on the UO_2 attributes used in the bounding analysis. The saturation curve represents the most reactive water and UO_2 mixture possible in the vessel. These saturation curves were used in conjunction with References 6-9 and 6-10 to blanket the optimum H/U-235 ratio. Figure 6-7 shows a typical result, demonstrating that there is little variance in the calculated K_{eff} along the saturation curve in the optimum H/U-235 ratio range. The analysis also considered the addition of polyethylene containers within the oxide vessel. The polyethylene was homogenized within the oxide vessels, with varying degrees of water moderation, to determine the optimum condition. The polyethylene was also modeled in a slab at the bottom of the oxide vessel, with varying degrees of UO2 mixed in. As demonstrated by Figures 6-7A and 6-7B, the addition of up to 1000 g. of polyethylene does not increase the multiplication factor. Indeed, in some configurations of the package without polyethylene is bounding.

6.2.2.2 UO_2 Pellets

UO_2 pellets were modeled at their theoretical density with full-interspersed moderation. Water-to-fuel ratios were varied using values of 2.08, 3.08, and 4.10. Values for an infinite mass system were also determined (final monitor) to investigate if the array size was a factor in the optimum sphere and water-to-fuel ratios. For an infinite mass system the maximum k_{eff} ($k_{infinity}$) occurred with a sphere diameter near 1.0-cm in a water-to-fuel ratio of 3.08. For the 5 x 5 x 5 array of packagings using a 7" diameter vessel, the optimum condition was determined to occur with a sphere diameter from 0.9 to 1.1 cm in a water-to-fuel ratio of 3.08. The addition of varying degrees of polyethylene moderation (up to 1000 g.), homogenized and in slab form, was also considered; however, as demonstrated in Figures 6-7A and 6-7B, the analysis of the package without polyethylene yield bounding multiplication factors.

6.2.3 Interspersed Moderation

A range of interspersed moderator (water) densities was used to demonstrate that optimum interspersed moderation was evaluated for the packaging. Figure 6-8 demonstrates that the low interspersed moderation density is the worst case for both normal and accident conditions. Furthermore, the 0.001, 0.0001, and 0.0000 (Bare) moderator densities used in the analyses consistently provided the highest K_{eff}, with little variation. Both homogeneous and heterogeneous package loadings yielded maximum k_{eff} at the low interspersed water moderation densities.

6.2.4 Package Arrays

Several different shipment package array configurations were evaluated in the analyses to determine the most reactive arrangement. The results of the parametric study demonstrated that the 5x5x5 configuration bounds the other arrays as shown in Figure 6-9.

6.3 Criticality Benchmark Experiments

Reference 6-11 documents 303 critical experiments (ranging in enrichment from 0.74 to 10.0 wt% U-235) modeled using the SCALE43 code with the 44 Group Standard Cross Section Library. Of the 303 experiments, 74 were homogeneous solutions and oxides and 229 were heterogeneous oxides and metal lattices. The KENO results for the homogenous and heterogeneous models were grouped and evaluated in Reference 6-11. The bias associated with the homogeneous solution and oxide group reported in Reference 6-11 was +0.0032. The bias associated with the heterogeneous oxides and metal lattices was +0.0000. Since the biases are positive, they are neglected for conservatism. The uncertainty reported for the homogeneous solution and oxide group was 0.0198, and the uncertainty reported for the heterogeneous oxide and metal lattice was 0.0125. Reference 6-11 additionally reports an upper subcritical limit of 0.9775 based on Keff $+2\sigma$ for the homogeneous solution and oxide group and an upper subcritical limit of 0.9844 for the heterogeneous oxide and metal lattice group; however, for conservatism, the upper subcritical limit used in this study is 0.95 minus the bias and uncertainty reported in Reference 6-11.

6.4 References

[6-1] Drawing 71497/50 Rev. 3, "General Arrangement Eco-Pak® OP-TU Oxide Transport Unit."

[6-2] Drawing 71497-2 Rev. 0, "General Arrangement Eco-Pak® OP-VA 8" Oxide Vessel."

[6-3] Drawing 71497-1 Rev. 0, "General Arrangement Eco-Pak® OP-VA 7" Oxide Vessel."

[6-4] Drawing 71497-BM Rev. 0, "Bill of Material Eco-Pak® OP-TU Oxide Transport Unit."

[6-5] Drawing 71497-1-BM Rev. 0, "Bill of Material Eco-Pak® OP-VA 7" Oxide Vessel."

[6-6] Drawing 71497-2-BM Rev. 0, "Bill of Material Eco-Pak® OP-VA 8" Oxide Vessel

[6-7] SCALE 4.3: Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation, NUREG/CR-200, Rev. 4, CCC-545, Radiation Shielding Information Center, Oak Ridge National Laboratory.

[6-8] NUREG/CR-5661, ORNL/TM-11936, "Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages," ORNL, 1997

[6-9] Clark, H.K. "Critical and Safe Masses and dimensions of Lattices of U and UO_2 Rods in Water," DP-1014, DuPont Savannah River Laboratory, Aiken, SC, 1966.

[6-10] United Kingdom Atomic Energy Authority, "Handbook of Criticality Data, Volume 1" AHSB Risely, Warrington, Lancashire, 1965. Figure 1.D.15.

[6-11] Montgomery, Rosemary A. Validation of SCALE-PC for Uranium Systems with Enrichments between 0.72 and 10.0 wt% U-235, MTS985 Rev. 1, 10/99.

6.5 Appendices

6.5.1 SCALE Input Decks for Bounding Cases

6.5.2 UO_2 Saturation Curve Data

6.5.3 Calculation of the Equivalent Water Density for Phenolic Foam and Polyethylene

6.5.4 Benchmarking Analysis - MTS Code Validation (PROPRIETARY)

Table 6-1 Summary of Results

Transport Case	Number of packages in Array	Array Size	Oxide Vessel Diameter	Oxide Form	U-235 Enrichment	Close Water Reflection	Interspersed Moderation (g/cc H_20)	H/U-235 (Water-to-Fuel) Ratio	K_{eff}	σ	$K_{eff} + 2\sigma$	Applicable USL
Normal	125	5x5x5	7-3/4"	Powder	4.50	Yes	0.0001	201	0.9226	0.0018	0.9262	0.9302
Normal	125	5x5x5	7"	Powder	5.00	Yes	0.0000	191	0.8788	0.0018	0.8824	0.9302
Normal	125	5x5x5	7"	Pellet	5.00	Yes	0.0000	(3.08)	0.9045	0.0019	0.9083	0.9375
Hypothetical Accident	50	4x4x3 + 2	7-3/4"	Powder	4.50	Yes	0.0000	213	0.9256	0.0018	0.9291	0.9302
Hypothetical Accident	50	4x4x3 + 2	7"	Powder	5.00	Yes	0.0000	181	0.8738	0.0016	0.8770	0.9302
Hypothetical Accident	50	4x4x3 + 2	7"	Pellet	5.00	Yes	0.0000	(3.08)	0.9038	0.0017	0.9072	0.9375
Normal	1	N/A	7-3/4"	Powder	4.50	Yes	0.0010	240	0.7404	0.0018	0.7440	0.9302
Normal	1	N/A	7"	Powder	5.00	Yes	0.0001	191	0.6843	0.0020	0.6883	0.9302
Normal	1	N/A	7"	Pellet	5.00	Yes	0.0000	(3.08)	0.7027	0.0018	0.7063	0.9375
Hypothetical Accident	1	N/A	7-3/4"	Powder	4.50	Yes	0.0000	240	0.7374	0.0019	0.7412	0.9302
Hypothetical Accident	1	N/A	7"	Powder	5.00	Yes	0.0001	181	0.6823	0.0020	0.6863	0.9302
Hypothetical Accident	1	N/A	7"	Pellet	5.00	Yes	0.001	(3.08)	0.7053	0.0019	0.7091	0.9375

Table 6-2 Eco-Pak OP Transport Unit Dimensions and Materials

Component	Actual Dimension (in)	Actual Dimension (cm)	Modeled Dimension (in)	Modeled Dimension (cm)	Actual material	Modeled material
Radial Direction						
Oxide Vessel Inner Radius	3.875 3.500	9.842 8.890	3.875 3.500	9.842 8.890	UO_2	$UO_2 + H_2O +$ Polypropylene
Vessel Inner wall thickness	3/16	0.47625	3/16	0.47625	SS	SS
Vessel Insulation	0.8130 1.1875	2.06500 3.01625	0.8130 1.1875	2.06500 3.01625	Phenolic Foam	75% Foam (normal) Optimum Water (accident)
Vessel Outer Wall thickness	1/8	0.3175	1/8	0.3175	CS	CS
Air gap	1/8	0.3175	1/8	0.3175	Air	Optimum Water
Vessel Sleeve	1/8	0.3175	1/8	0.3175	CS	CS
Outer Package Plates	1/8	0.3175	1/8	0.3175	CS	CS
Vessel Lattice Pitch	22.500	57.150	22.000	55.880	Phenolic Foam	75% Foam (normal) Optimum Water (accident)
Axial Direction From inside of Vessel Lid						
Vessel Lid	5/8	1.5875	5/8	1.5875	SS	SS
Vessel Lid Gap	1 1/8	2.8575	1 1/8	2.8575	Air	Optimum Water
Vessel Liner Lid	1/2	1.270	1/2	1.270	CS	CS
Encapsulated Plug	1/16	0.15875	1/16	0.15875	CS	CS
Plug Void	5 1/16	12.8588	5 1/16	12.8588	Air	Optimum Water
Outer Lid	1/2	1.270	0.375	0.9525	CS	CS
Outer Package Plates	1/8	0.3175	1/8	0.3175	CS	CS
Axial Direction from inside of Vessel Bottom						
Oxide Vessel Inner Wall	1/2	1.27	1/2	1.27	SS	SS
Vessel Insulation	1.0	2.54	1.0	2.54	Phenolic Foam	75% Foam (normal) Optimum Water (accident)
Oxide Vessel Outer Wall	1/8	0.3175	1/8	0.3175	CS	CS
Neoprene Cushion	1/8	0.3175	1/8	0.3175	Neoprene	Optimum Water
Vessel Sleeve	1/8	0.3175	1/8	0.3175	CS	CS
Plywood Floor	4.0	10.160	4.0	10.160	Plywood	Optimum Water
Outer Package Plates	1/8	0.3175	1/8	0.3175	CS	CS
Package Leg	4.0	10.160	4.0	10.160	CS/Air	OptimumWater

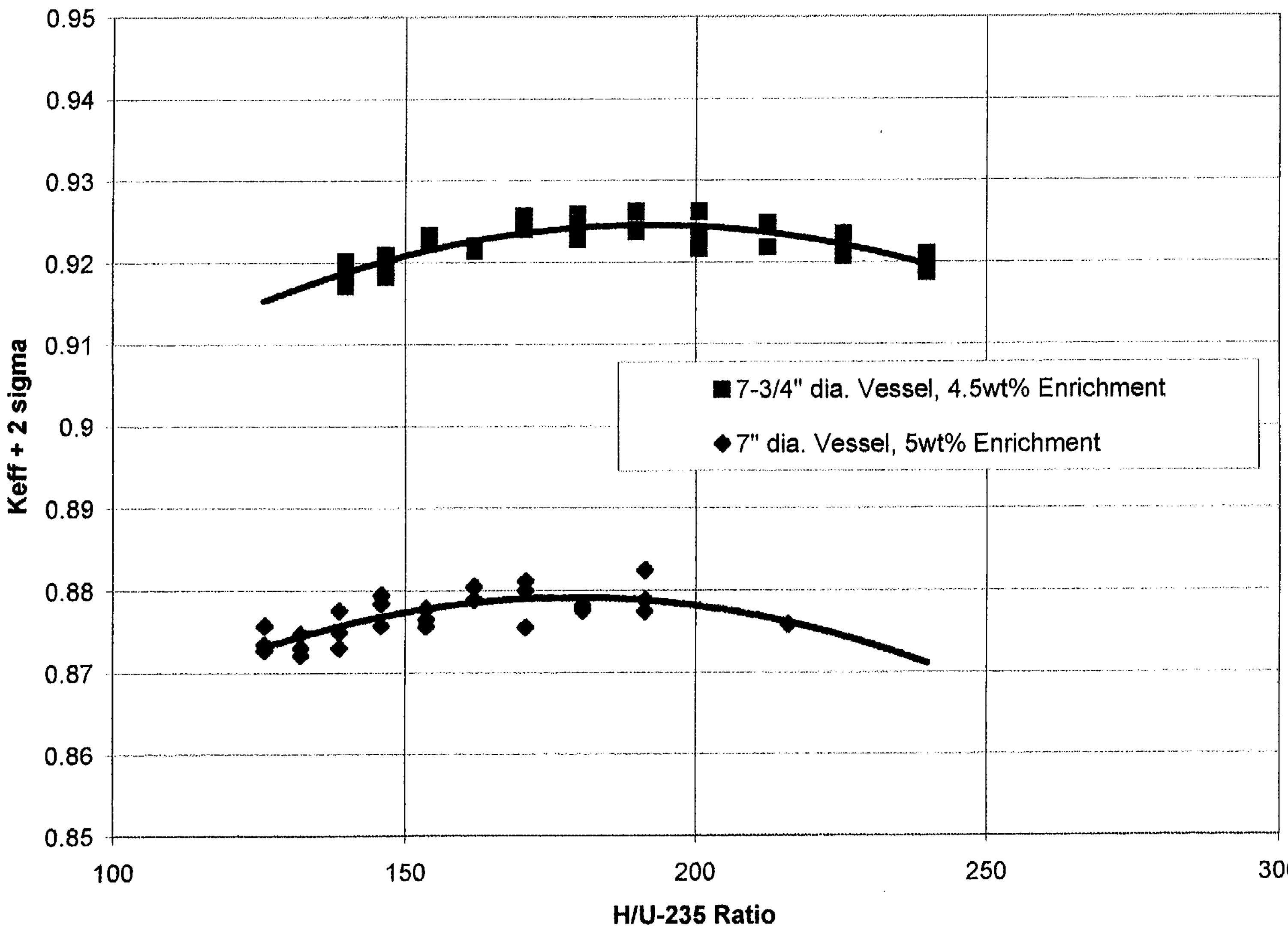


Figure 6-1 Keff + 2σ versus H/U-235 Internal Moderation Ratio for 4.5 wt% U-235 Powder in a 7-3/4" Oxide Vessel and 5.0 wt% U-235 Powder in a 7" diameter Oxide Vessel with Optimum Interspersed Moderation

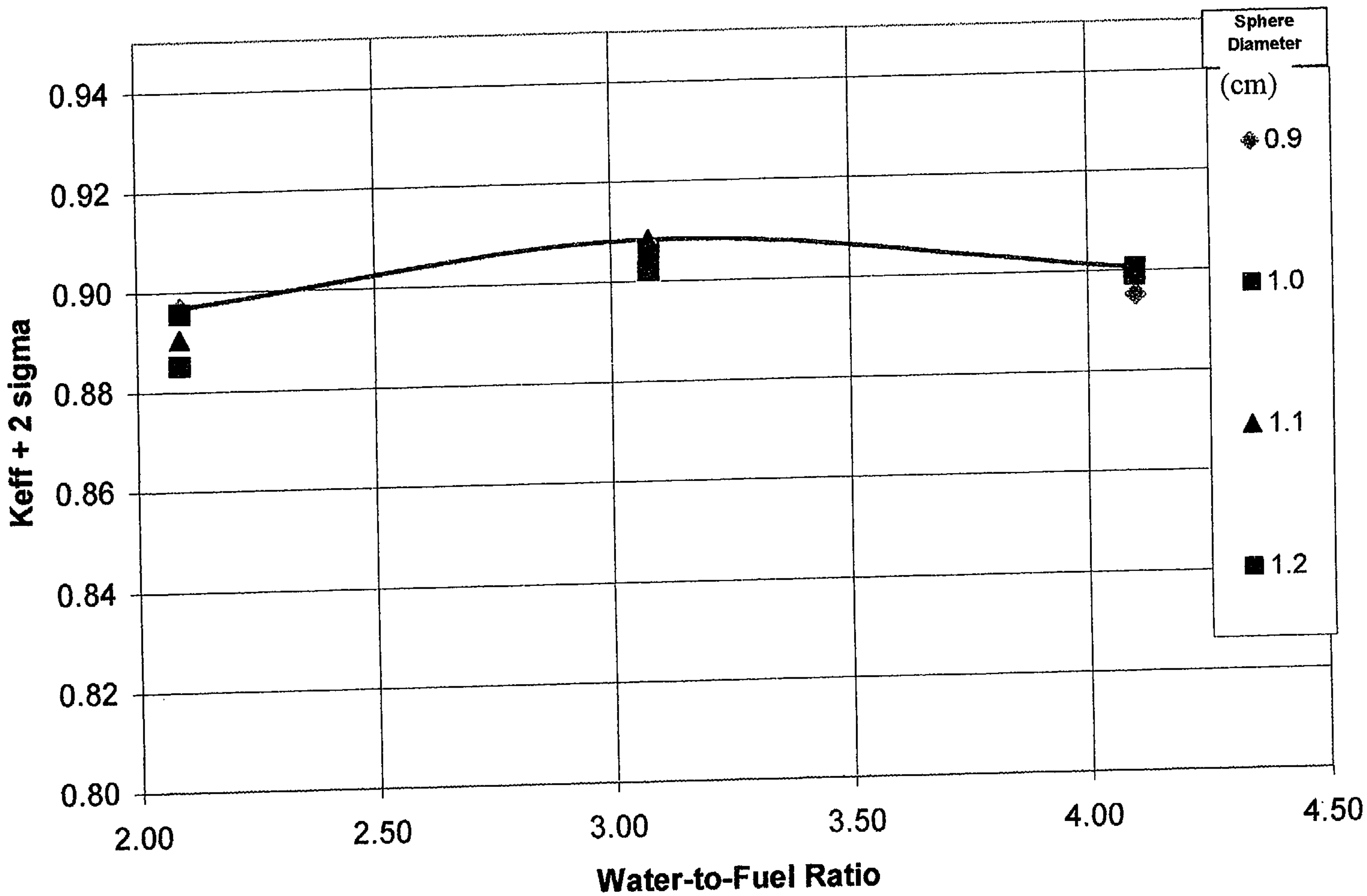
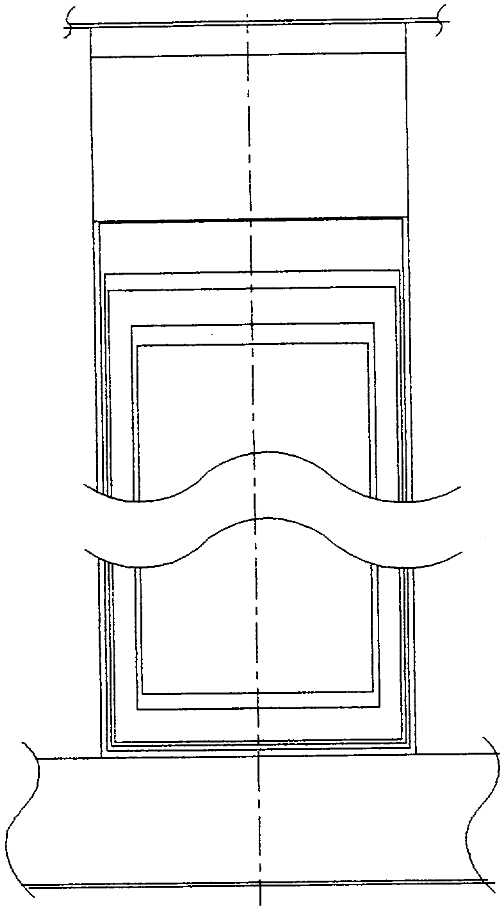


Figure 6-2 Keff versus Water-to-Fuel Ratio for the Optimum Sphere Diameter and Optimum Interspersed Moderation Density at 5.0wt% Pellet Enrichment in the 7" Oxide Vessel



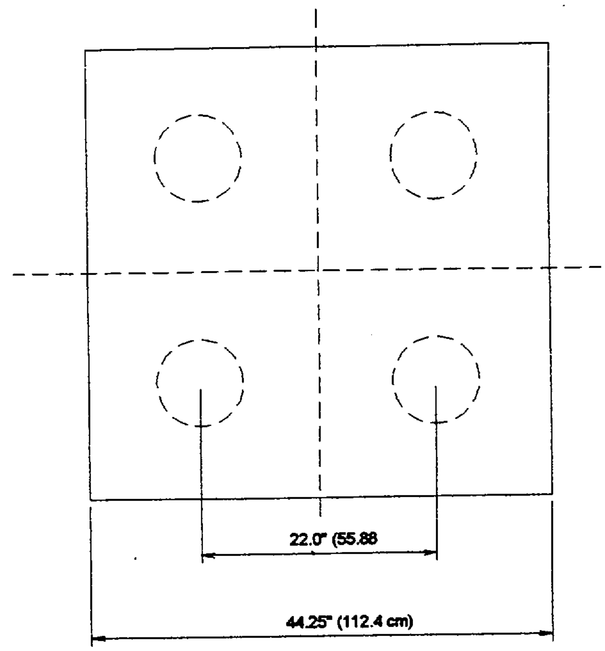


Figure 6-3 KENO Model of the OP Type A Transport Unit for the Normal Condition

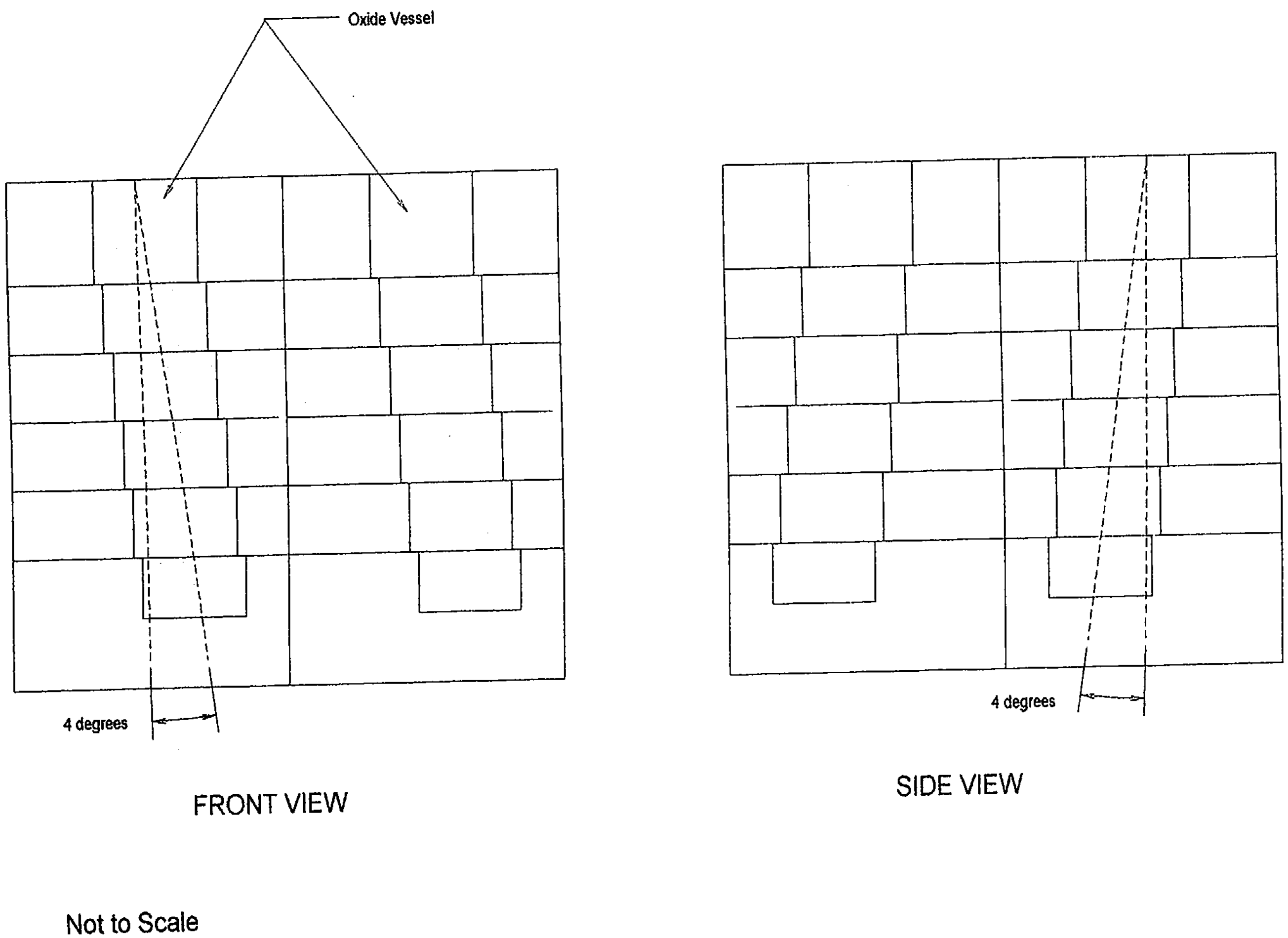
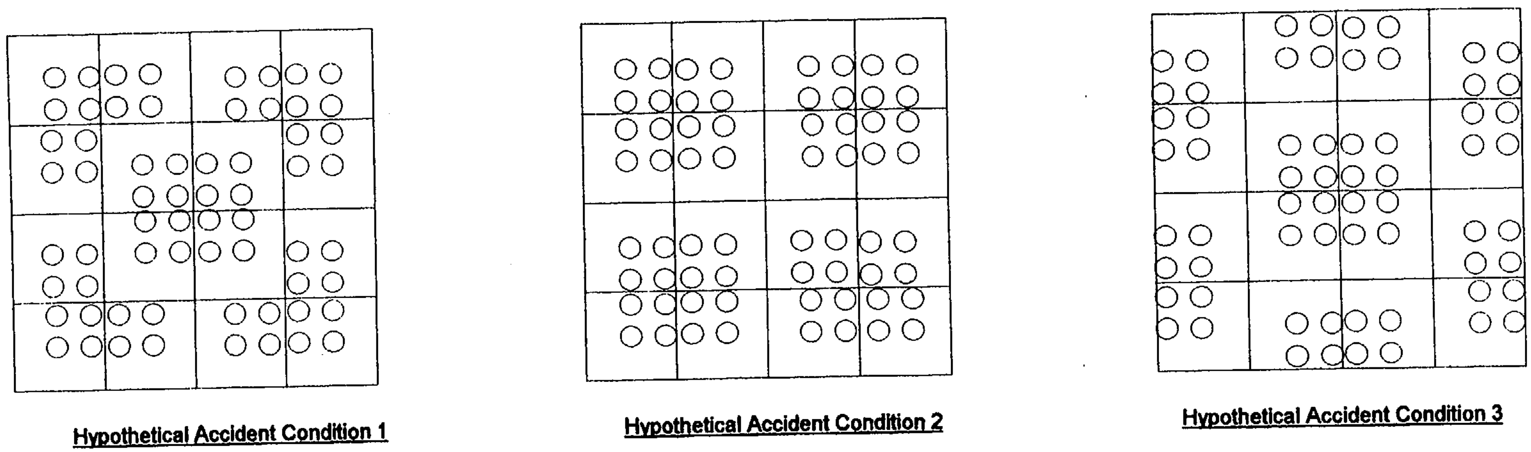


Figure 6-4 Front and Side View of SCALE Model of an Eco-Pak OP Type A Transport Unit with Shifted Oxide Vessels for Hypothetical Accident Conditions



Note: The amount of Oxide Vessel movement has been exaggerated for illustration of the Hypothetical Accident.

Figure 6-5 Arrangement of Packages Analyzed for the Hypothetical Accident Conditions (Shown at the bottom plane of the Oxide Vessels)

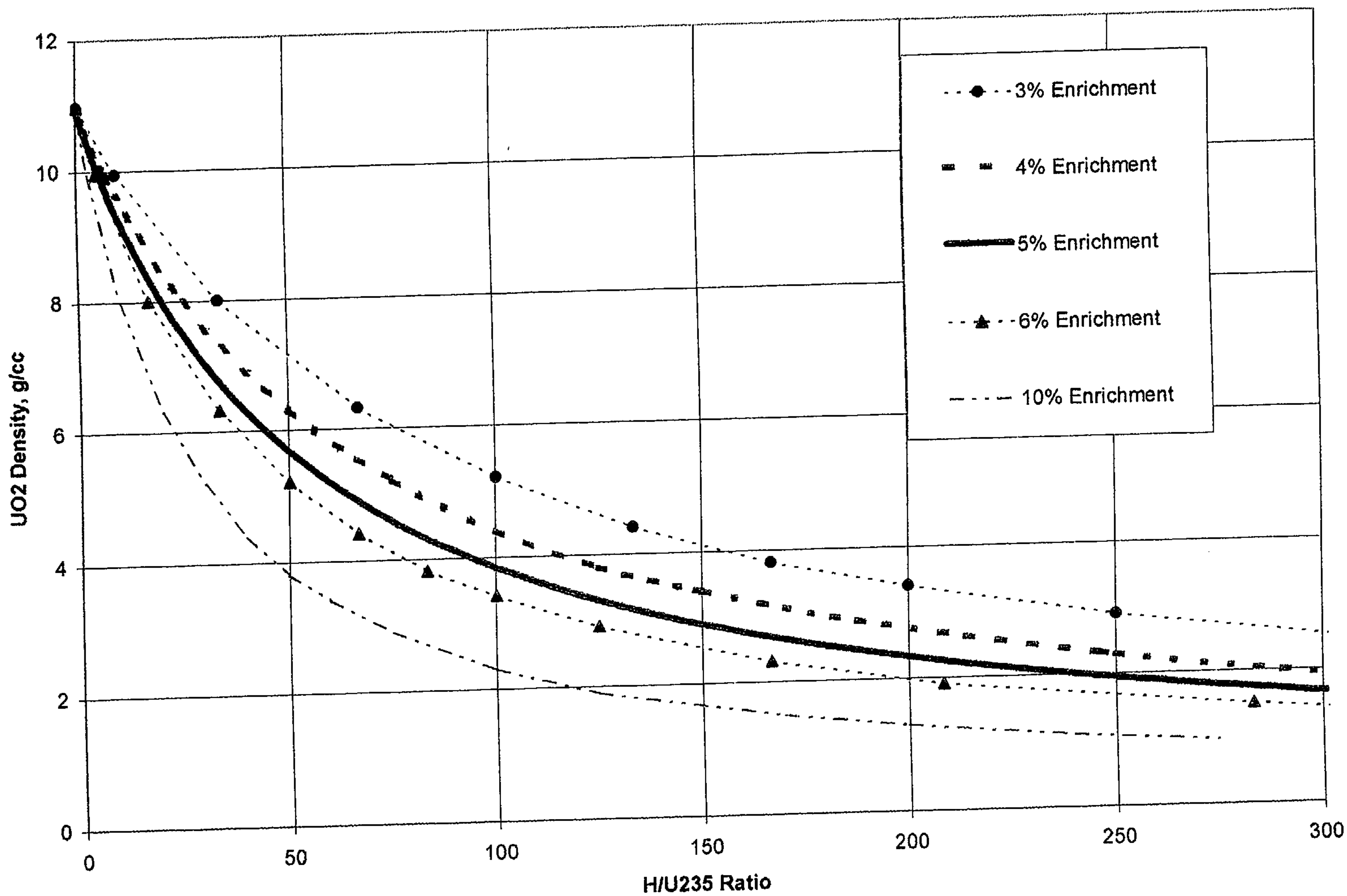


Figure 6-6 Saturated Uranium Oxide Curve for Various U-235 Enrichments

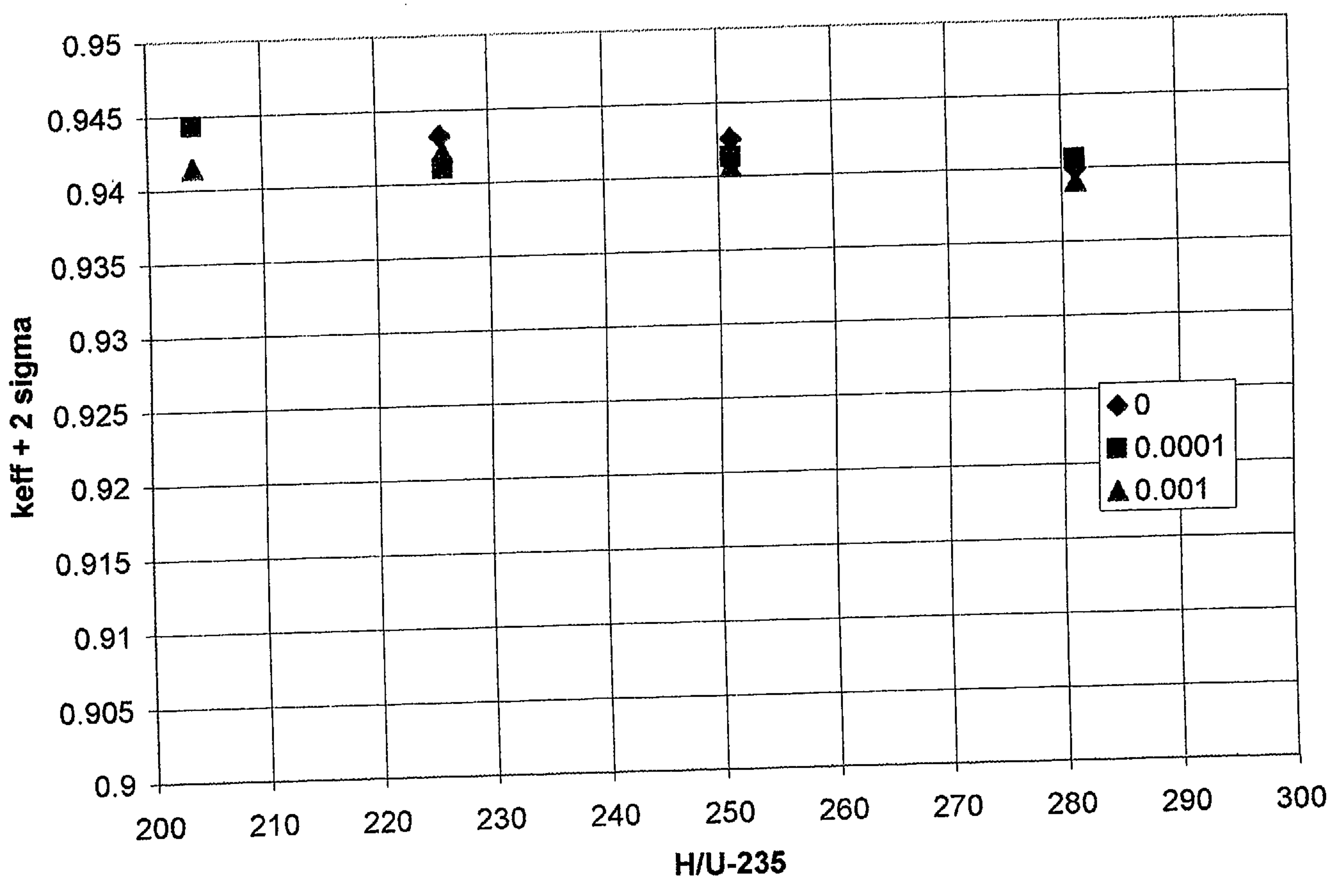


Figure 6-7 K_{eff} versus H/U-235 Ratio, Holding Interspersed Moderation Constant

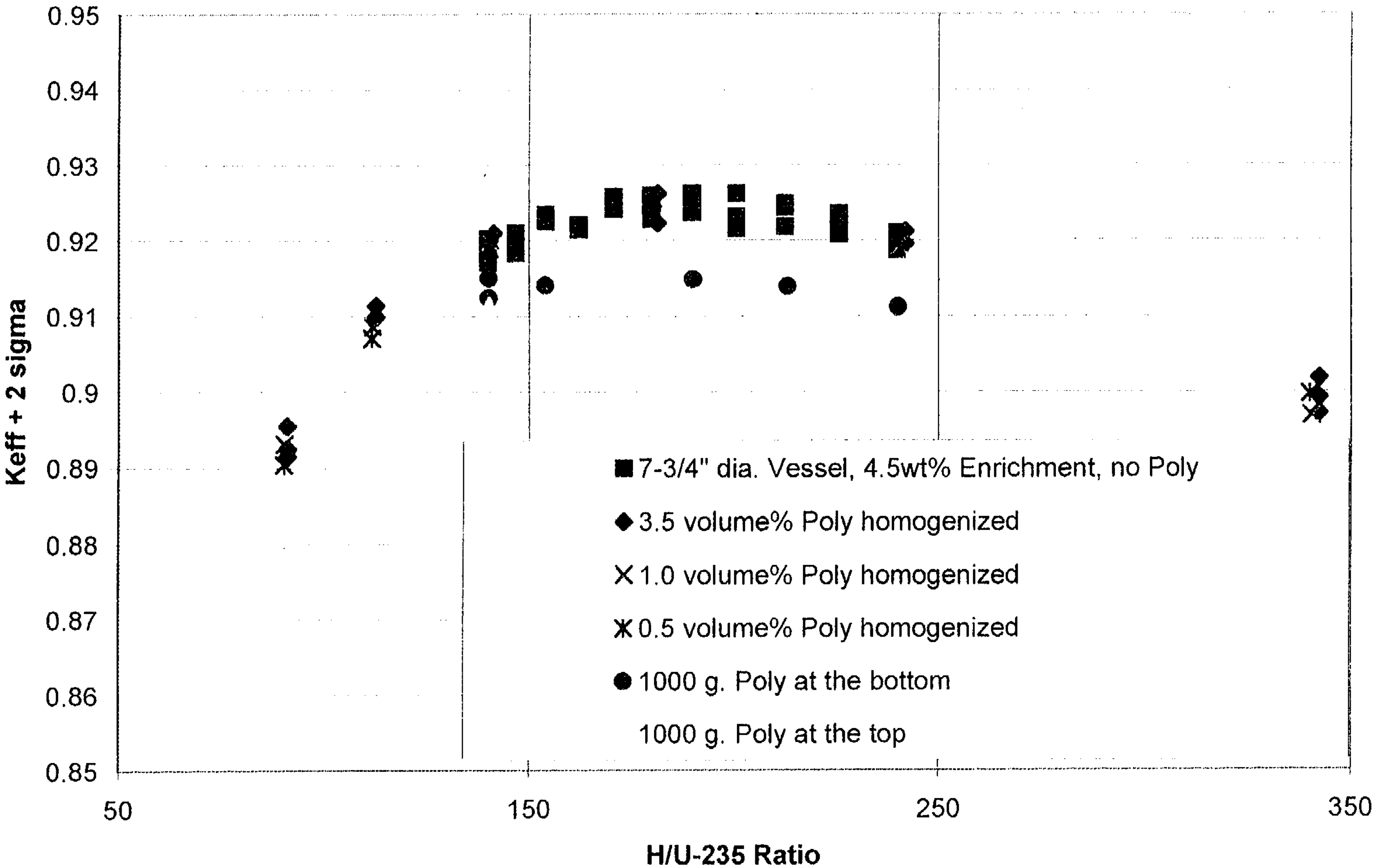


Figure 6-7A Keff as a Function of H/U-235 Ratio for varying Polyethylene content and distribution in the 7-3/4" Oxide Vessel

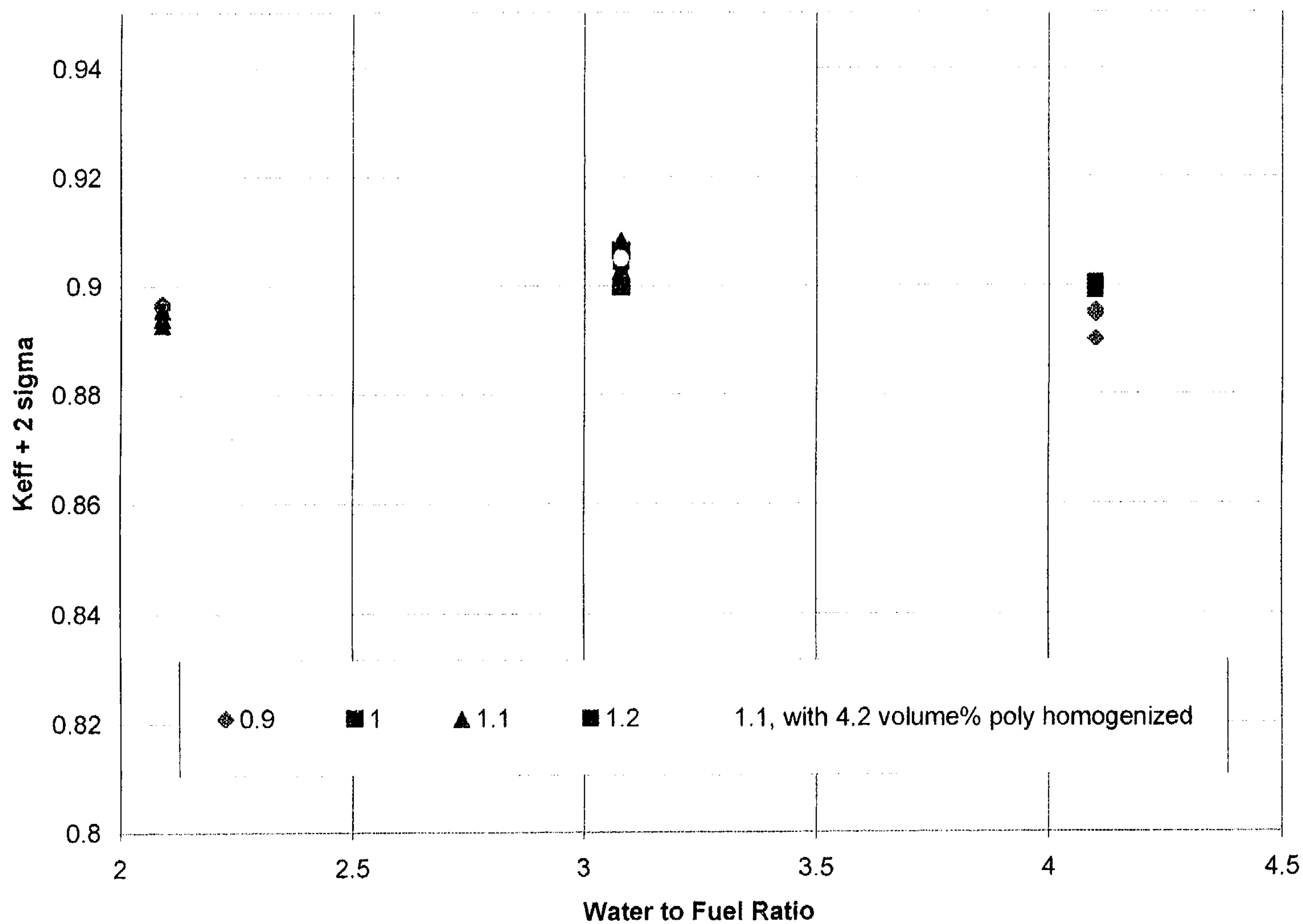


Figure 6-7B Keff as a function of Water-to-Fuel Ratio for the Maximum Polyethylene Content Homogenized with Water Moderation in the 7" Oxide Vessel (5wt% Enriched Pellets)

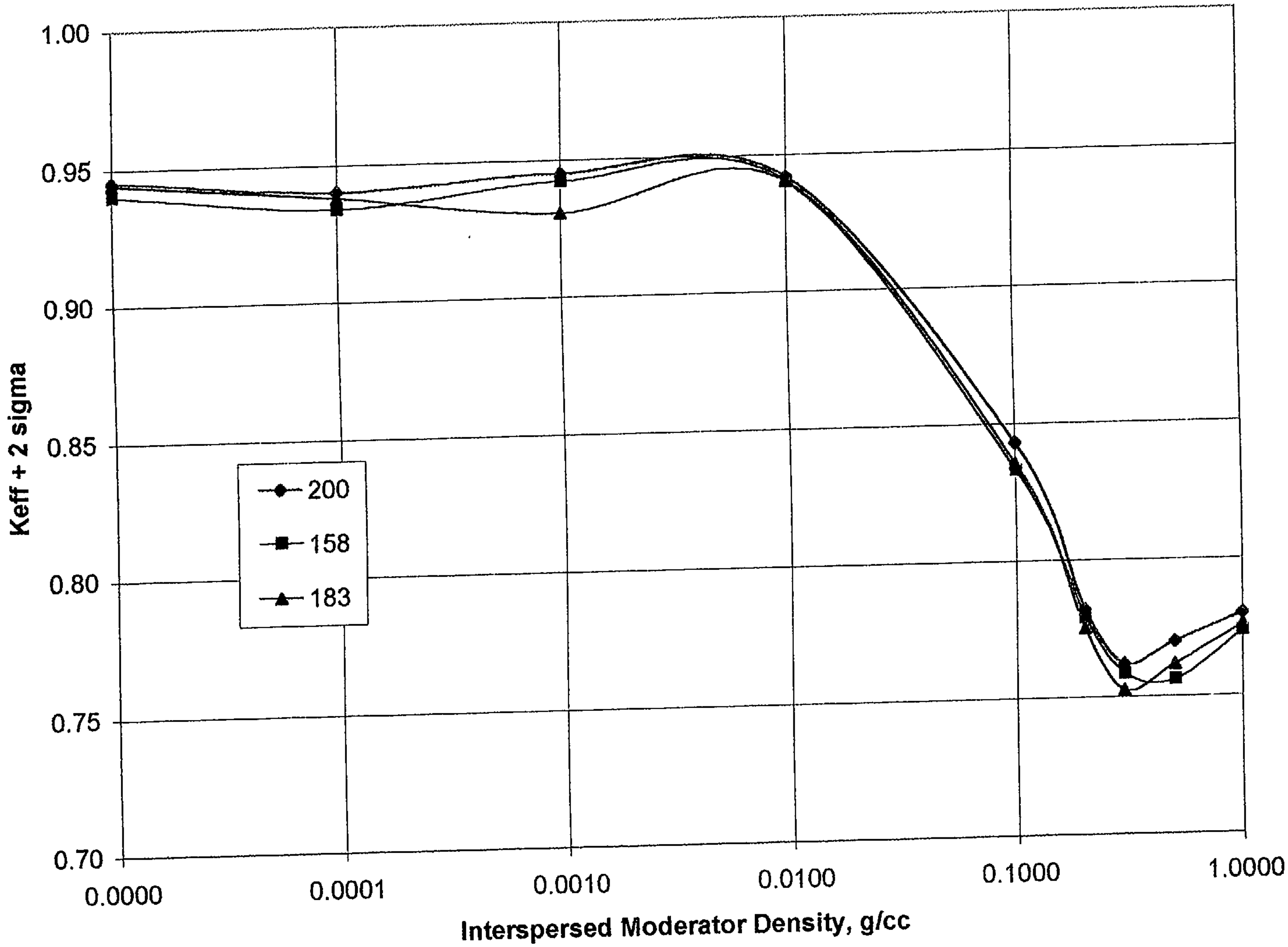


Figure 6-8 K_{eff} as a Function of Interspersed Moderator (water) Density for Various H/U-235 Ratios

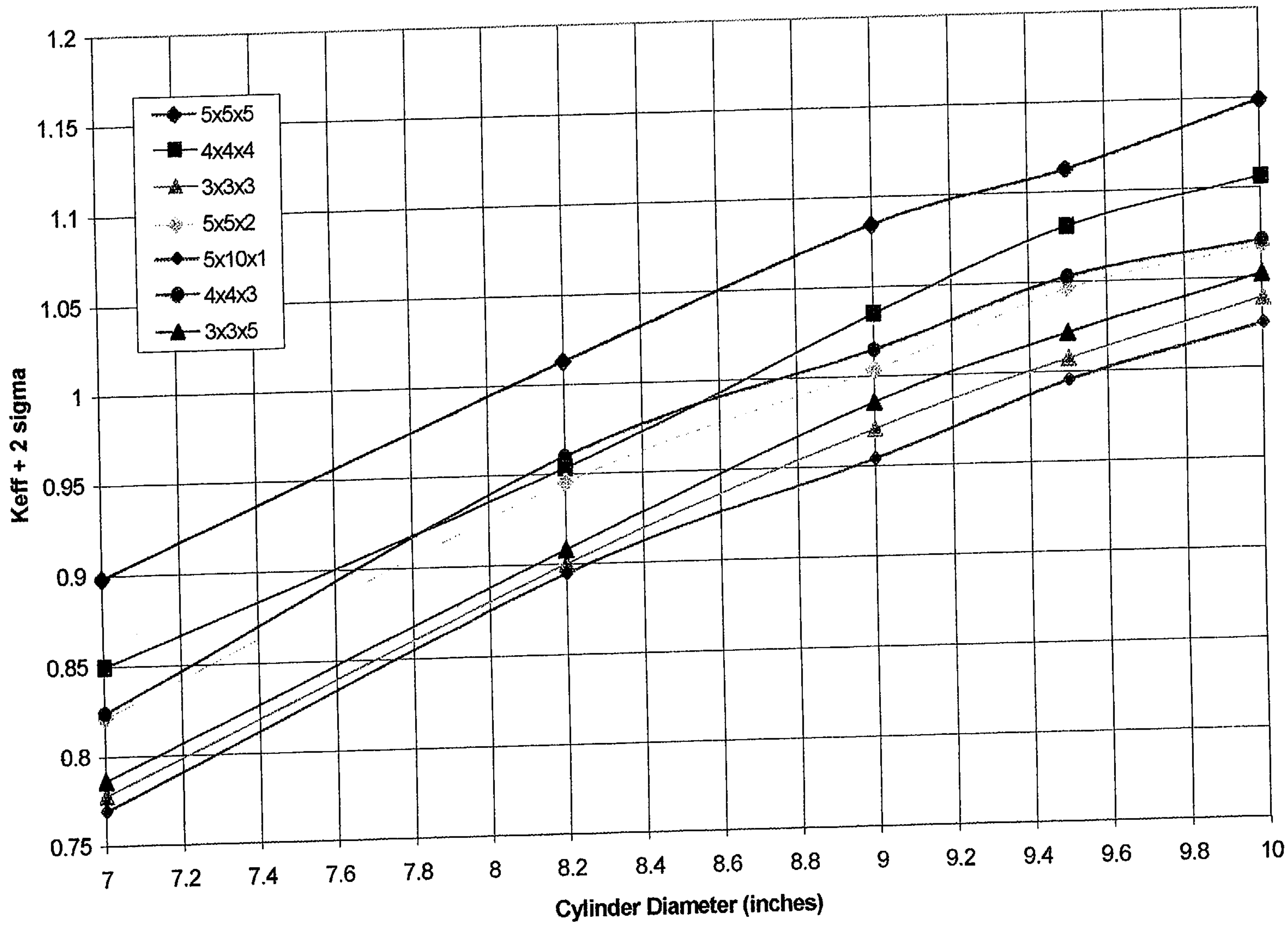


Figure 6-9 5% Enrichment, K_{eff} versus Oxide Vessel Diameter for Various Arrays sizes, holding H/U-235 Ratio and interspersed moderation constan

Appendix 6.5.1

SCALE Input Decks for Bounding Cases

```
=CSAS25
OPTIMUM SATURATED URANIUM OXIDE AND WATER MIXTURE
FULL MODEL OF ECOPAK OXIDE CONTAINER 7-3/4INID Full array
44GR      INFHOM
UO2          1 0.23000 294.00 92235 4.5 92238 95.5 END
H2O          1 0.77000 294.00 END
H2O          2 0.0001 294.00 END
CARBONSTEEL  3 1.0 294.00 END
SS304        4 1.0 294.00 END
H2O          5 1.0 294.00 END
H2O          6 0.030 294.00 END
END COMP
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5
END PARM
READ GEOM
UNIT 1
CYLINDER     1 1  9.84200  104.14000  0.0
REPLICATE    4 1  0.47625  1.58750  1.27000  1
REPLICATE    6 1  2.06500  2.85750  2.54000  1
REPLICATE    3 1  0.31750  1.27000  0.317500  1
REPLICATE    2 1  0.31750  3.96875  0.317500  1
REPLICATE    3 1  0.31750  0.15875  0.63500  1
REPLICATE    2 1  0.00000 12.85875  0.00000  1
REPLICATE    3 1  0.00000  0.95250  0.00000  1
CUBOID       6 1  4P27.94000  128.27000  -15.24000
UNIT 2
ARRAY  1  3*0.0
REPLICATE    3 1  6R0.31750  1
REPLICATE    2 1  5R0 10.16  1
GLOBAL
UNIT 3
ARRAY  2  3*0.0
REPLICATE    5 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=2  NUY=2  NUZ=1  FILL  F1  END FILL
ARA=2  NUX=5  NUY=5  NUZ=5  FILL  F2  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

```
=CSAS25
OPTIMUM SATURATED URANIUM OXIDE AND WATER MIXTURE
FULL MODEL OF ECOPAK OXIDE CONTAINER 8.0INID Full array
44GR      INFHOM
UO2           1 0.25000 294.00 92235 4.5 92238 95.5 END
H2O           1 0.75000 294.00 END
H2O           2 0.001 294.00 END
CARBONSTEEL   3 1.0 294.00 END
SS304         4 1.0 294.00 END
H2O           5 1.0 294.00 END
H2O           6 0.030 294.00 END
END COMP
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5
END PARM
READ GEOM
UNIT 1
CYLINDER     1 1  10.1600  104.14000  0.0
REPLICATE    4 1  0.47625  1.58750  1.27000  1
REPLICATE    6 1  1.74625  2.85750  2.54000  1
REPLICATE    3 1  0.31750  1.27000  0.317500  1
REPLICATE    2 1  0.31750  3.96875  0.317500  1
REPLICATE    3 1  0.31750  0.15875  0.63500  1
REPLICATE    2 1  0.00000 12.85875  0.00000  1
REPLICATE    3 1  0.00000  0.95250  0.00000  1
CUBOID       6 1  4P27.94000  128.27000  -15.24000
UNIT 2
ARRAY  1  3*0.0
REPLICATE    3 1  6R0.31750  1
REPLICATE    2 1  5R0 10.16  1
GLOBAL
UNIT 3
ARRAY  2  3*0.0
REPLICATE    5 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=2  NUY=2  NUZ=1  FILL  F1  END FILL
ARA=2  NUX=5  NUY=5  NUZ=5  FILL  F2  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

```
=CSAS25
OPTIMUM SATURATED URANIUM OXIDE AND WATER MIXTURE
FULL MODEL OF ECOPAK OXIDE CONTAINER 7.0INID Full Model
44GR      INFHOM
UO2            1 0.22000 294.00 92235 5.0 92238 95.0 END
H2O            1 0.78000 294.00 END
H2O            2 0.0001 294.00 END
CARBONSTEEL    3 1.0 294.00 END
SS304          4 1.0 294.00 END
H2O            5 1.0 294.00 END
H2O            6 0.030 294.00 END
END COMP
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5
END PARM
READ GEOM
UNIT 1
CYLINDER    1 1  8.8900  104.14000  0.0
REPLICATE   4 1  0.47625  1.58750  1.27000  1
REPLICATE   6 1  3.01625  2.85750  2.54000  1
REPLICATE   3 1  0.31750  1.27000  0.317500  1
REPLICATE   0 1  0.31750  3.96875  0.317500  1
REPLICATE   3 1  0.31750  0.15875  0.63500  1
REPLICATE   0 1  0.00000 12.85875  0.00000  1
REPLICATE   3 1  0.00000  0.95250  0.00000  1
CUBOID      6 1  4P27.94000  128.27000  -15.24000
UNIT 2
ARRAY  1  3*0.0
REPLICATE   3 1  6R0.31750  1
REPLICATE   0 1  5R0 8.89  1
GLOBAL
UNIT 3
ARRAY  2  3*0.0
REPLICATE   5 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=2  NUY=2  NUZ=1  FILL  F1  END FILL
ARA=2  NUX=5  NUY=5  NUZ=5  FILL  F2  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

```
=CSAS2X
HETEROGENEOUS URANIUM OXIDE @ 5WT% 1.1 DIA./1.589775 LATT.
FULL MODEL OF ECOPAK OXIDE CONTAINER 7.0INID Full array pellet
44GR     LATT
UO2          1 DEN=10.95471 1 294 92235 5.0 92238 95.0 END
H2O          2 1.0 294 END
H2O          3 0.0001 294 END
CARBONSTEEL  4 1.0 294 END
SS304        5 1.0 294 END
H2O          6 1.0 294 END
H2O          7 0.030 294 END
END COMP
SPHTRIANGP  1.589775 1.1 1 2  END
MORE DATA  IIM=500  ICM=500  END MORE
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5 TME=60
END PARM
READ GEOM
UNIT 1
CYLINDER  500 1  8.89000  104.14000  0.0
REPLICATE   5 1  0.47625  1.58750  1.27000  1
REPLICATE   7 1  3.01625  2.85750  2.54000  1
REPLICATE   4 1  0.31750  1.27000  0.317500  1
REPLICATE   0 1  0.31750  3.96875  0.317500  1
REPLICATE   4 1  0.31750  0.15875  0.63500  1
REPLICATE   0 1  0.00000 12.85875  0.00000  1
REPLICATE   4 1  0.00000  0.95250  0.00000  1.
CUBOID      7 1  4P27.94000  128.27000  -15.24000
UNIT 2
ARRAY  1  3*0.0
REPLICATE   4 1  6R0.31750  1
REPLICATE   0 1  5R0 10.16  1
GLOBAL
UNIT 3
ARRAY  2  3*0.0
REPLICATE   6 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=2  NUY=2  NUZ=1  FILL  F1  END FILL
ARA=2  NUX=5  NUY=5  NUZ=5  FILL  F2  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

```
=CSAS25
OPTIMUM SATURATED URANIUM OXIDE AND WATER MIXTURE
FULL MODEL OF ECOPAK OXIDE CONTAINER 7-3/4INID single Package
44GR      INFHOM
UO2           1 0.20000 294.00 92235 4.5 92238 95.5 END
H2O           1 0.80000 294.00 END
H2O           2 0.001 294.00 END
CARBONSTEEL   3 1.0 294.00 END
SS304         4 1.0 294.00 END
H2O           5 1.0 294.00 END
H2O           6 0.030 294.00 END
END COMP
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5
END PARM
READ GEOM
UNIT 1
CYLINDER     1 1  9.84200  104.14000  0.0
REPLICATE    4 1  0.47625  1.58750  1.27000  1
REPLICATE    6 1  2.06500  2.85750  2.54000  1
REPLICATE    3 1  0.31750  1.27000  0.317500  1
REPLICATE    2 1  0.31750  3.96875  0.317500  1
REPLICATE    3 1  0.31750  0.15875  0.63500  1
REPLICATE    2 1  0.00000 12.85875  0.00000  1
REPLICATE    3 1  0.00000  0.95250  0.00000  1
CUBOID       6 1  4P27.94000  128.27000  -15.24000
UNIT 2
ARRAY  1  3*0.0
REPLICATE    3 1  6R0.31750  1
REPLICATE    2 1  5R0 10.16  1
GLOBAL
UNIT 3
ARRAY  2  3*0.0
REPLICATE    5 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=2  NUY=2  NUZ=1  FILL  F1  END FILL
ARA=2  NUX=1  NUY=1  NUZ=1  FILL  F2  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

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=CSAS25
OPTIMUM SATURATED URANIUM OXIDE AND WATER MIXTURE
FULL MODEL OF ECOPAK OXIDE CONTAINER 7.0INID Single Package
44GR      INFHOM
UO2          1 0.22000 294.00 92235 5.0 92238 95.0 END
H2O          1 0.78000 294.00 END
H2O          2 0.0001 294.00 END
CARBONSTEEL  3 1.0 294.00 END
SS304        4 1.0 294.00 END
H2O          5 1.0 294.00 END
H2O          6 0.030 294.00 END
END COMP
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5
END PARM
READ GEOM
UNIT 1
CYLINDER    1 1  8.89000  104.14000  0.0
REPLICATE   4 1  0.47625  1.58750  1.27000  1
REPLICATE   6 1  3.01625  2.85750  2.54000  1
REPLICATE   3 1  0.31750  1.27000  0.317500  1
REPLICATE   2 1  0.31750  3.96875  0.317500  1
REPLICATE   3 1  0.31750  0.15875  0.63500  1
REPLICATE   2 1  0.00000 12.85875  0.00000  1
REPLICATE   3 1  0.00000  0.95250  0.00000  1
CUBOID      6 1  4P27.94000  128.27000  -15.24000
UNIT 2
ARRAY  1  3*0.0
REPLICATE   3 1  6R0.31750  1
REPLICATE   2 1  5R0 10.16  1
GLOBAL
UNIT 3
ARRAY  2  3*0.0
REPLICATE   5 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=2  NUY=2  NUZ=1  FILL  F1  END FILL
ARA=2  NUX=1  NUY=1  NUZ=1  FILL  F2  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

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=CSAS2X
HETEROGENEOUS URANIUM OXIDE @ 5WT% 1.0 DIA./1.44525 LATT.
FULL MODEL OF ECOPAK OXIDE CONTAINER 7.0INID Single Package Pellet
44GR      LATT
UO2            1 DEN=10.95471 1 294 92235 5.0 92238 95.0 END
H2O            2 1.0 294 END
H2O            3 0.001 294 END
CARBONSTEEL    4 1.0 294 END
SS304          5 1.0 294 END
H2O            6 1.0 294 END
H2O            7 0.030 294 END
END COMP
SPHTRIANGP  1.44525 1.0 1 2  END
MORE DATA  IIM=500  ICM=500  END MORE
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5 TME=60
END PARM
READ GEOM
UNIT 1
CYLINDER  500 1  8.89000  104.14000  0.0
REPLICATE   5 1  0.47625  1.58750  1.27000  1
REPLICATE   7 1  3.01625  2.85750  2.54000  1
REPLICATE   4 1  0.31750  1.27000  0.317500  1
REPLICATE   0 1  0.31750  3.96875  0.317500  1
REPLICATE   4 1  0.31750  0.15875  0.63500  1
REPLICATE   0 1  0.00000 12.85875  0.00000  1
REPLICATE   4 1  0.00000  0.95250  0.00000  1
CUBOID      7 1  4P27.94000  128.27000  -15.24000
UNIT 2
ARRAY  1  3*0.0
REPLICATE   4 1  6R0.31750  1
REPLICATE   0 1  5R0 10.16  1
GLOBAL
UNIT 3
ARRAY  2  3*0.0
REPLICATE   6 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=2  NUY=2  NUZ=1  FILL  F1  END FILL
ARA=2  NUX=1  NUY=1  NUZ=1  FILL  F2  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

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=CSAS25
OPTIMUM SATURATED URANIUM OXIDE AND WATER MIXTURE
FULL MODEL OF ECOPAK OXIDE CONTAINER 7-3/4INID HAC2
4 degree cylinder slant
44GR      INFHOM
UO2          1 0.22000 294.00 92235 4.5 92238 95.5 END
H2O          1 0.78000 294.00 END
H2O          2 0.0001 294.00 END
CARBONSTEEL  3 1.0 294.00 END
SS304        4 1.0 294.00 END
H2O          5 1.0 294.00 END
END COMP
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5 TME=60
END PARM
READ GEOM
UNIT 10
CYLINDER     1 1   9.8420 104.1400  86.7833
REPLICATE    4 1  0.47625  1.58750  0.0  1
REPLICATE    0 1  2.06500  2.85750  0.0  1
REPLICATE    3 1  0.31750  1.27000  0.0  1
REPLICATE    0 1  0.31750  3.96875  0.0  1
REPLICATE    3 1  0.31750  0.15875  0.0  1
REPLICATE    0 1  0.00000 12.85875  0.0  1
REPLICATE    3 1  0.00000  0.95250  0.0  1
CUBOID       0 1  27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 11
CYLINDER     1 1  9.8420 86.7833  69.4267
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  2.06500 0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  25.9080 -29.9720 25.9080 -29.9720 86.7833 69.4267
UNIT 12
CYLINDER     1 1  9.8420 69.4267  52.0700
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  2.06500 0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  23.8760 -32.0040 23.8760 -32.0040 69.4267 52.0700
UNIT 13
CYLINDER     1 1  9.8420 52.0700  34.7133
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1 2.06500 0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  21.8440 -34.0360 21.8440 -34.0360 52.0700 34.7133
UNIT 14
CYLINDER     1 1  9.8420 34.7133  17.3567
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  2.06500 0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  19.8120 -36.0680 19.8120 -36.0680 34.7133 17.3567
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UNIT 15
CYLINDER     1 1   9.8420 17.3567  0.0000
REPLICATE    4 1   0.47625  0.0  1.27000  1
REPLICATE    0 1   2.06500 0.0  2.54000  1
REPLICATE    3 1   0.31750  0.0  0.31750  1
REPLICATE    0 1   0.31750  0.0  0.31750  1
REPLICATE    3 1   0.31750  0.0  0.63500  1
CUBOID       0 1   17.7800 -38.1000 17.7800 -38.1000 17.3567 -15.2400
UNIT 20
CYLINDER     1 1   9.8420 104.1400  86.7833
REPLICATE    4 1   0.47625  1.58750  0.0  1
REPLICATE    0 1   2.06500 2.85750  0.0  1
REPLICATE    3 1   0.31750  1.27000  0.0  1
REPLICATE    0 1   0.31750  3.96875  0.0  1
REPLICATE    3 1   0.31750  0.15875  0.0  1
REPLICATE    0 1   0.00000 12.85875  0.0  1
REPLICATE    3 1   0.00000  0.95250  0.0  1
CUBOID       0 1   27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 21
CYLINDER     1 1   9.8420 86.7833  69.4267
REPLICATE    4 1   0.47625  0.0  0.0  1
REPLICATE    0 1 2.06500 0.0  0.0  1
REPLICATE    3 1   0.31750  0.0  0.0  1
REPLICATE    0 1   0.31750  0.0  0.0  1
REPLICATE    3 1   0.31750  0.0  0.0  1
CUBOID       0 1   29.9720 -25.9080 25.9080 -29.9720 86.7833 69.4267
UNIT 22
CYLINDER     1 1   9.8420 69.4267  52.0700
REPLICATE    4 1   0.47625  0.0  0.0  1
REPLICATE    0 1   2.06500 0.0  0.0  1
REPLICATE    3 1   0.31750  0.0  0.0  1
REPLICATE    0 1   0.31750  0.0  0.0  1
REPLICATE    3 1   0.31750  0.0  0.0  1
CUBOID       0 1   32.0040 -23.8760 23.8760 -32.0040 69.4267 52.0700
UNIT 23
CYLINDER     1 1   9.8420 52.0700  34.7133
REPLICATE    4 1   0.47625  0.0  0.0  1
REPLICATE    0 1   2.06500 0.0  0.0  1
REPLICATE    3 1   0.31750  0.0  0.0  1
REPLICATE    0 1   0.31750  0.0  0.0  1
REPLICATE    3 1   0.31750  0.0  0.0  1
CUBOID       0 1   34.0360 -21.8440 21.8440 -34.0360 52.0700 34.7133
UNIT 24
CYLINDER     1 1   9.8420 34.7133  17.3567
REPLICATE    4 1   0.47625  0.0  0.0  1
REPLICATE    0 1 2.06500 0.0  0.0  1
REPLICATE    3 1   0.31750  0.0  0.0  1
REPLICATE    0 1   0.31750  0.0  0.0  1
REPLICATE    3 1   0.31750  0.0  0.0  1
CUBOID       0 1   36.0680 -19.8120 19.8120 -36.0680 34.7133 17.3567
UNIT 25
CYLINDER     1 1   9.8420 17.3567  0.0000
REPLICATE    4 1   0.47625  0.0  1.27000  1
REPLICATE    0 1   2.06500 0.0  2.54000  1
REPLICATE    3 1   0.31750  0.0  0.31750  1
REPLICATE    0 1   0.31750  0.0  0.31750  1
REPLICATE    3 1   0.31750  0.0  0.63500  1
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CUBOID        0 1  38.1000 -17.7800 17.7800 -38.1000 17.3567 -15.2400
UNIT 30
CYLINDER      1 1  9.8420 104.1400  86.7833
REPLICATE     4 1  0.47625  1.58750  0.0  1
REPLICATE     0 1  2.06500 2.85750  0.0  1
REPLICATE     3 1  0.31750  1.27000  0.0  1
REPLICATE     0 1  0.31750  3.96875  0.0  1
REPLICATE     3 1  0.31750  0.15875  0.0  1
REPLICATE     0 1  0.00000 12.85875  0.0  1
REPLICATE     3 1  0.00000  0.95250  0.0  1
CUBOID        0 1  27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 31
CYLINDER      1 1  9.8420 86.7833  69.4267
REPLICATE     4 1  0.47625  0.0  0.0  1
REPLICATE     0 1 2.06500 0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
REPLICATE     0 1  0.31750  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
CUBOID        0 1  29.9720 -25.9080 29.9720 -25.9080 86.7833 69.4267
UNIT 32
CYLINDER      1 1  9.8420 69.4267  52.0700
REPLICATE     4 1  0.47625  0.0  0.0  1
REPLICATE     0 1 2.06500 0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
REPLICATE     0 1  0.31750  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
CUBOID        0 1  32.0040 -23.8760 32.0040 -23.8760 69.4267 52.0700
UNIT 33
CYLINDER      1 1  9.8420 52.0700  34.7133
REPLICATE     4 1  0.47625  0.0  0.0  1
REPLICATE     0 1  2.06500 0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
REPLICATE     0 1  0.31750  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
CUBOID        0 1  34.0360 -21.8440 34.0360 -21.8440 52.0700 34.7133
UNIT 34
CYLINDER      1 1  9.8420 34.7133  17.3567
REPLICATE     4 1  0.47625  0.0  0.0  1
REPLICATE     0 1  2.06500 0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
REPLICATE     0 1  0.31750  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
CUBOID        0 1  36.0680 -19.8120 36.0680 -19.8120 34.7133 17.3567
UNIT 35
CYLINDER      1 1  9.8420 17.3567  0.0000
REPLICATE     4 1  0.47625  0.0  1.27000  1
REPLICATE     0 1 2.06500 0.0  2.54000  1
REPLICATE     3 1  0.31750  0.0  0.31750  1
REPLICATE     0 1  0.31750  0.0  0.31750  1
REPLICATE     3 1  0.31750  0.0  0.63500  1
CUBOID        0 1  38.1000 -17.7800 38.1000 -17.7800 17.3567 -15.2400
UNIT 40
CYLINDER      1 1  9.8420 104.1400  86.7833
REPLICATE     4 1  0.47625  1.58750  0.0  1
REPLICATE     0 1  2.06500 2.85750  0.0  1
REPLICATE     3 1  0.31750  1.27000  0.0  1
REPLICATE     0 1  0.31750  3.96875  0.0  1
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REPLICATE    3 1  0.31750  0.15875  0.0  1
REPLICATE    0 1  0.00000 12.85875  0.0  1
REPLICATE    3 1  0.00000  0.95250  0.0  1
CUBOID       0 1  27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 41
CYLINDER     1 1  9.8420 86.7833  69.4267
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  2.06500 0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  25.9080 -29.9720 29.9720 -25.9080 86.7833 69.4267
UNIT 42
CYLINDER     1 1  9.8420 69.4267  52.0700
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  2.06500 0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  23.8760 -32.0040 32.0040 -23.8760 69.4267 52.0700
UNIT 43
CYLINDER     1 1  9.8420 52.0700  34.7133
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  2.06500 0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  21.8440 -34.0360 34.0360 -21.8440 52.0700 34.7133
UNIT 44
CYLINDER     1 1  9.8420 34.7133  17.3567
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  2.06500 0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  19.8120 -36.0680 36.0680 -19.8120 34.7133 17.3567
UNIT 45
CYLINDER     1 1  9.8420 17.3567  0.0000
REPLICATE    4 1  0.47625  0.0  1.27000  1
REPLICATE    0 1  2.06500 0.0  2.54000  1
REPLICATE    3 1  0.31750  0.0  0.31750  1
REPLICATE    0 1  0.31750  0.0  0.31750  1
REPLICATE    3 1  0.31750  0.0  0.63500  1
CUBOID       0 1  17.7800 -38.1000 38.1000 -17.7800 17.3567 -15.24000
UNIT 5
CUBOID       5 1  17.78 -38.10 38.10 -17.78 128.27000  -15.24000
UNIT 6
ARRAY  1  3*0.0
UNIT 7
ARRAY  2  3*0.0
UNIT 8
ARRAY  3  3*0.0
UNIT 9
ARRAY  4  3*0.0
UNIT 60
ARRAY  5  3*0.0
REPLICATE   3 1  6R0.31750  1
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REPLICATE   0 1  5R0 10.16  1
UNIT 70
ARRAY  6  3*0.0
REPLICATE   3 1  6R0.31750  1
REPLICATE   0 1  5R0 10.16  1
UNIT 80
ARRAY  7  3*0.0
REPLICATE   3 1  6R0.31750  1
REPLICATE   0 1  5R0 10.16  1
UNIT 90
ARRAY  8  3*0.0
REPLICATE   3 1  6R0.31750  1
REPLICATE   0 1  5R0 10.16  1
UNIT 95
ARRAY  9  3*0.0
REPLICATE   5 1  6R0.31750  1
REPLICATE   5 1  5R0 10.16  1
GLOBAL
UNIT 110
ARRAY  10  3*0.0
REPLICATE   5 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=1  NUY=1  NUZ=6  FILL 15 14 13 12 11 10  END FILL
ARA=2  NUX=1  NUY=1  NUZ=6  FILL 25 24 23 22 21 20  END FILL
ARA=3  NUX=1  NUY=1  NUZ=6  FILL 35 34 33 32 31 30  END FILL
ARA=4  NUX=1  NUY=1  NUZ=6  FILL 45 44 43 42 41 40  END FILL
ARA=5  NUX=2  NUY=2  NUZ=1  FILL  F6  END FILL
ARA=6  NUX=2  NUY=2  NUZ=1  FILL  F7  END FILL
ARA=7  NUX=2  NUY=2  NUZ=1  FILL  F8  END FILL
ARA=8  NUX=2  NUY=2  NUZ=1  FILL  F9  END FILL
ARA=9  NUX=2  NUY=2  NUZ=1  FILL  F5  END FILL
ARA=10  NUX=4  NUY=4  NUZ=4  FILL
60 70 60 70 90 60 70 80 60 90 80 70 90 80 90 80
2Q16
95 95 95 95 95 60 95 95 95 95 80 95 95 95 95 95  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
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=CSAS25
OPTIMUM SATURATED URANIUM OXIDE AND WATER MIXTURE
FULL MODEL OF ECOPAK OXIDE CONTAINER 7.0INID HAC2
4 degree cylinder slant
44GR      INFHOM
UO2            1 0.23000 294.00 92235 5.0 92238 95.0 END
H2O            1 0.77000 294.00 END
H2O            2 0.0001 294.00 END
CARBONSTEEL    3 1.0 294.00 END
SS304          4 1.0 294.00 END
H2O            5 1.0 294.00 END
END COMP
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5 TME=60
END PARM
READ GEOM
UNIT 10
CYLINDER     1 1  8.8900  104.1400  86.7833
REPLICATE    4 1  0.47625  1.58750  0.0  1
REPLICATE    0 1  3.01625  2.85750  0.0  1
REPLICATE    3 1  0.31750  1.27000  0.0  1
REPLICATE    0 1  0.31750  3.96875  0.0  1
REPLICATE    3 1  0.31750  0.15875  0.0  1
REPLICATE    0 1  0.00000 12.85875  0.0  1
REPLICATE    3 1  0.00000  0.95250  0.0  1
CUBOID       0 1  27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 11
CYLINDER     1 1  8.8900  86.7833  69.4267
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  25.9080 -29.9720 25.9080 -29.9720 86.7833 69.4267
UNIT 12
CYLINDER     1 1  8.8900  69.4267  52.0700
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  23.8760 -32.0040 23.8760 -32.0040 69.4267 52.0700
UNIT 13
CYLINDER     1 1  8.8900  52.0700  34.7133
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  21.8440 -34.0360 21.8440 -34.0360 52.0700 34.7133
UNIT 14
CYLINDER     1 1  8.8900  34.7133  17.3567
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
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CUBOID        0 1  19.8120 -36.0680 19.8120 -36.0680 34.7133 17.3567
UNIT 15
CYLINDER      1 1  8.8900  17.3567  0.0000
REPLICATE     4 1  0.47625  0.0  1.27000  1
REPLICATE     0 1  3.01625  0.0  2.54000  1
REPLICATE     3 1  0.31750  0.0  0.31750  1
REPLICATE     0 1  0.31750  0.0  0.31750  1
REPLICATE     3 1  0.31750  0.0  0.63500  1
CUBOID        0 1  17.7800 -38.1000 17.7800 -38.1000 17.3567 -15.2400
UNIT 20
CYLINDER      1 1  8.8900  104.1400  86.7833
REPLICATE     4 1  0.47625  1.58750  0.0  1
REPLICATE     0 1  3.01625  2.85750  0.0  1
REPLICATE     3 1  0.31750  1.27000  0.0  1
REPLICATE     0 1  0.31750  3.96875  0.0  1
REPLICATE     3 1  0.31750  0.15875  0.0  1
REPLICATE     0 1  0.00000 12.85875  0.0  1
REPLICATE     3 1  0.00000  0.95250  0.0  1
CUBOID        0 1  27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 21
CYLINDER      1 1  8.8900  86.7833  69.4267
REPLICATE     4 1  0.47625  0.0  0.0  1
REPLICATE     0 1  3.01625  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
REPLICATE     0 1  0.31750  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
CUBOID        0 1  29.9720 -25.9080 25.9080 -29.9720 86.7833 69.4267
UNIT 22
CYLINDER      1 1  8.8900  69.4267  52.0700
REPLICATE     4 1  0.47625  0.0  0.0  1
REPLICATE     0 1  3.01625  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
REPLICATE     0 1  0.31750  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
CUBOID        0 1  32.0040 -23.8760 23.8760 -32.0040 69.4267 52.0700
UNIT 23
CYLINDER      1 1  8.8900  52.0700  34.7133
REPLICATE     4 1  0.47625  0.0  0.0  1
REPLICATE     0 1  3.01625  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
REPLICATE     0 1  0.31750  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
CUBOID        0 1  34.0360 -21.8440 21.8440 -34.0360 52.0700 34.7133
UNIT 24
CYLINDER      1 1  8.8900  34.7133  17.3567
REPLICATE     4 1  0.47625  0.0  0.0  1
REPLICATE     0 1  3.01625  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
REPLICATE     0 1  0.31750  0.0  0.0  1
REPLICATE     3 1  0.31750  0.0  0.0  1
CUBOID        0 1  36.0680 -19.8120 19.8120 -36.0680 34.7133 17.3567
UNIT 25
CYLINDER      1 1  8.8900  17.3567  0.0000
REPLICATE     4 1  0.47625  0.0  1.27000  1
REPLICATE     0 1  3.01625  0.0  2.54000  1
REPLICATE     3 1  0.31750  0.0  0.31750  1
REPLICATE     0 1  0.31750  0.0  0.31750  1
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REPLICATE    3 1   0.31750   0.0   0.63500   1
CUBOID       0 1   38.1000 -17.7800 17.7800 -38.1000 17.3567 -15.2400
UNIT 30
CYLINDER     1 1   8.8900   104.1400   86.7833
REPLICATE    4 1   0.47625   1.58750   0.0   1
REPLICATE    0 1   3.01625   2.85750   0.0   1
REPLICATE    3 1   0.31750   1.27000   0.0   1
REPLICATE    0 1   0.31750   3.96875   0.0   1
REPLICATE    3 1   0.31750   0.15875   0.0   1
REPLICATE    0 1   0.00000 12.85875   0.0   1
REPLICATE    3 1   0.00000   0.95250   0.0   1
CUBOID       0 1   27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 31
CYLINDER     1 1   8.8900   86.7833   69.4267
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   29.9720 -25.9080 29.9720 -25.9080 86.7833 69.4267
UNIT 32
CYLINDER     1 1   8.8900   69.4267   52.0700
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   32.0040 -23.8760 32.0040 -23.8760 69.4267 52.0700
UNIT 33
CYLINDER     1 1   8.8900   52.0700   34.7133
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   34.0360 -21.8440 34.0360 -21.8440 52.0700 34.7133
UNIT 34
CYLINDER     1 1   8.8900   34.7133   17.3567
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   36.0680 -19.8120 36.0680 -19.8120 34.7133 17.3567
UNIT 35
CYLINDER     1 1   8.8900   17.3567   0.0000
REPLICATE    4 1   0.47625   0.0   1.27000   1
REPLICATE    0 1   3.01625   0.0   2.54000   1
REPLICATE    3 1   0.31750   0.0   0.31750   1
REPLICATE    0 1   0.31750   0.0   0.31750   1
REPLICATE    3 1   0.31750   0.0   0.63500   1
CUBOID       0 1   38.1000 -17.7800 38.1000 -17.7800 17.3567 -15.2400
UNIT 40
CYLINDER     1 1   8.8900   104.1400   86.7833
REPLICATE    4 1   0.47625   1.58750   0.0   1
REPLICATE    0 1   3.01625   2.85750   0.0   1
REPLICATE    3 1   0.31750   1.27000   0.0   1
```

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REPLICATE    0 1  0.31750  3.96875  0.0  1
REPLICATE    3 1  0.31750  0.15875  0.0  1
REPLICATE    0 1  0.00000 12.85875  0.0  1
REPLICATE    3 1  0.00000  0.95250  0.0  1
CUBOID       0 1  27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 41
CYLINDER     1 1  8.8900  86.7833  69.4267
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  25.9080 -29.9720 29.9720 -25.9080 86.7833 69.4267
UNIT 42
CYLINDER     1 1  8.8900  69.4267  52.0700
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  23.8760 -32.0040 32.0040 -23.8760 69.4267 52.0700
UNIT 43
CYLINDER     1 1  8.8900  52.0700  34.7133
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  21.8440 -34.0360 34.0360 -21.8440 52.0700 34.7133
UNIT 44
CYLINDER     1 1  8.8900  34.7133  17.3567
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  19.8120 -36.0680 36.0680 -19.8120 34.7133 17.3567
UNIT 45
CYLINDER     1 1  8.8900  17.3567  0.0000
REPLICATE    4 1  0.47625  0.0  1.27000  1
REPLICATE    0 1  3.01625  0.0  2.54000  1
REPLICATE    3 1  0.31750  0.0  0.31750  1
REPLICATE    0 1  0.31750  0.0  0.31750  1
REPLICATE    3 1  0.31750  0.0  0.63500  1
CUBOID       0 1  17.7800 -38.1000 38.1000 -17.7800 17.3567 -15.24000
UNIT 5
CUBOID       5 1  17.78 -38.10 38.10 -17.78 128.27000  -15.24000
UNIT 6
ARRAY  1  3*0.0
UNIT 7
ARRAY  2  3*0.0
UNIT 8
ARRAY  3  3*0.0
UNIT 9
ARRAY  4  3*0.0
UNIT 60
ARRAY  5  3*0.0
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REPLICATE    3 1   6R0.31750  1
REPLICATE    0 1   5R0 10.16  1
UNIT 70
ARRAY  6  3*0.0
REPLICATE    3 1   6R0.31750  1
REPLICATE    0 1   5R0 10.16  1
UNIT 80
ARRAY  7  3*0.0
REPLICATE    3 1   6R0.31750  1
REPLICATE    0 1   5R0 10.16  1
UNIT 90
ARRAY  8  3*0.0
REPLICATE    3 1   6R0.31750  1
REPLICATE    0 1   5R0 10.16  1
UNIT 95
ARRAY  9  3*0.0
REPLICATE    5 1   6R0.31750  1
REPLICATE    5 1   5R0 10.16  1
GLOBAL
UNIT 110
ARRAY  10  3*0.0
REPLICATE    5 1   6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=1  NUY=1  NUZ=6  FILL 15 14 13 12 11 10  END FILL
ARA=2  NUX=1  NUY=1  NUZ=6  FILL 25 24 23 22 21 20  END FILL
ARA=3  NUX=1  NUY=1  NUZ=6  FILL 35 34 33 32 31 30  END FILL
ARA=4  NUX=1  NUY=1  NUZ=6  FILL 45 44 43 42 41 40  END FILL
ARA=5  NUX=2  NUY=2  NUZ=1  FILL  F6  END FILL
ARA=6  NUX=2  NUY=2  NUZ=1  FILL  F7  END FILL
ARA=7  NUX=2  NUY=2  NUZ=1  FILL  F8  END FILL
ARA=8  NUX=2  NUY=2  NUZ=1  FILL  F9  END FILL
ARA=9  NUX=2  NUY=2  NUZ=1  FILL  F5  END FILL
ARA=10  NUX=4  NUY=4  NUZ=4  FILL
60 70 60 70 90 60 70 80 60 90 80 70 90 80 90 80
2Q16
95 95 95 95 95 60 95 95 95 95 80 95 95 95 95 95  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

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=CSAS2x
HETEROGENEOUS URANIUM OXIDE @ 5.0WT% 1.0 DIA./1.44525 LATT.
FULL MODEL OF ECOPAK OXIDE CONTAINER 7.0INID HAC2
4 degree cylinder slant
44GR      LATT
UO2           1 DEN=10.95471 1 294 92235 5.0 92238 95.00 END
H2O           7 1.0 294 END
H2O           2 0.001 294 END
CARBONSTEEL   3 1.0 294 END
SS304         4 1.0 294 END
H2O           5 1.0 294 END
END COMP
SPHTRIANGP  1.44525 1.0 1 7   END
MORE DATA  IIM=500  ICM=500  END MORE
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5 TME=60
END PARM
READ GEOM
UNIT 10
CYLINDER  500 1  8.8900  104.1400  86.7833
REPLICATE   4 1  0.47625  1.58750  0.0  1
REPLICATE   0 1  3.01625  2.85750  0.0  1
REPLICATE   3 1  0.31750  1.27000  0.0  1
REPLICATE   0 1  0.31750  3.96875  0.0  1
REPLICATE   3 1  0.31750  0.15875  0.0  1
REPLICATE   0 1  0.00000 12.85875  0.0  1
REPLICATE   3 1  0.00000  0.95250  0.0  1
CUBOID      0 1  27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 11
CYLINDER  500 1  8.8900  86.7833  69.4267
REPLICATE   4 1  0.47625  0.0  0.0  1
REPLICATE   0 1  3.01625  0.0  0.0  1
REPLICATE   3 1  0.31750  0.0  0.0  1
REPLICATE   0 1  0.31750  0.0  0.0  1
REPLICATE   3 1  0.31750  0.0  0.0  1
CUBOID      0 1  25.9080 -29.9720 25.9080 -29.9720 86.7833 69.4267
UNIT 12
CYLINDER  500 1  8.8900  69.4267  52.0700
REPLICATE   4 1  0.47625  0.0  0.0  1
REPLICATE   0 1  3.01625  0.0  0.0  1
REPLICATE   3 1  0.31750  0.0  0.0  1
REPLICATE   0 1  0.31750  0.0  0.0  1
REPLICATE   3 1  0.31750  0.0  0.0  1
CUBOID      0 1  23.8760 -32.0040 23.8760 -32.0040 69.4267 52.0700
UNIT 13
CYLINDER  500 1  8.8900  52.0700  34.7133
REPLICATE   4 1  0.47625  0.0  0.0  1
REPLICATE   0 1  3.01625  0.0  0.0  1
REPLICATE   3 1  0.31750  0.0  0.0  1
REPLICATE   0 1  0.31750  0.0  0.0  1
REPLICATE   3 1  0.31750  0.0  0.0  1
CUBOID      0 1  21.8440 -34.0360 21.8440 -34.0360 52.0700 34.7133
UNIT 14
CYLINDER  500 1  8.8900  34.7133  17.3567
REPLICATE   4 1  0.47625  0.0  0.0  1
REPLICATE   0 1  3.01625  0.0  0.0  1
REPLICATE   3 1  0.31750  0.0  0.0  1
REPLICATE   0 1  0.31750  0.0  0.0  1
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REPLICATE    3 1   0.31750   0.0    0.0    1
CUBOID       0 1   19.8120 -36.0680 19.8120 -36.0680 34.7133 17.3567
UNIT 15
CYLINDER   500 1   8.8900   17.3567   0.0000
REPLICATE    4 1   0.47625   0.0   1.27000   1
REPLICATE    0 1   3.01625   0.0   2.54000   1
REPLICATE    3 1   0.31750   0.0   0.31750   1
REPLICATE    0 1   0.31750   0.0   0.31750   1
REPLICATE    3 1   0.31750   0.0   0.63500   1
CUBOID       0 1   17.7800 -38.1000 17.7800 -38.1000 17.3567 -15.2400
UNIT 20
CYLINDER   500 1   8.8900   104.1400   86.7833
REPLICATE    4 1   0.47625   1.58750   0.0   1
REPLICATE    0 1   3.01625   2.85750   0.0   1
REPLICATE    3 1   0.31750   1.27000   0.0   1
REPLICATE    0 1   0.31750   3.96875   0.0   1
REPLICATE    3 1   0.31750   0.15875   0.0   1
REPLICATE    0 1   0.00000 12.85875   0.0   1
REPLICATE    3 1   0.00000   0.95250   0.0   1
CUBOID       0 1   27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 21
CYLINDER   500 1   8.8900   86.7833   69.4267
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   29.9720 -25.9080 25.9080 -29.9720 86.7833 69.4267
UNIT 22
CYLINDER   500 1   8.8900   69.4267   52.0700
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   32.0040 -23.8760 23.8760 -32.0040 69.4267 52.0700
UNIT 23
CYLINDER   500 1   8.8900   52.0700   34.7133
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   34.0360 -21.8440 21.8440 -34.0360 52.0700 34.7133
UNIT 24
CYLINDER   500 1   8.8900   34.7133   17.3567
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   36.0680 -19.8120 19.8120 -36.0680 34.7133 17.3567
UNIT 25
CYLINDER   500 1   8.8900   17.3567   0.0000
REPLICATE    4 1   0.47625   0.0   1.27000   1
REPLICATE    0 1   3.01625   0.0   2.54000   1
REPLICATE    3 1   0.31750   0.0   0.31750   1
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REPLICATE    0 1   0.31750   0.0   0.31750   1
REPLICATE    3 1   0.31750   0.0   0.63500   1
CUBOID       0 1   38.1000 -17.7800 17.7800 -38.1000 17.3567 -15.2400
UNIT 30
CYLINDER   500 1   8.8900   104.1400   86.7833
REPLICATE    4 1   0.47625   1.58750   0.0   1
REPLICATE    0 1   3.01625   2.85750   0.0   1
REPLICATE    3 1   0.31750   1.27000   0.0   1
REPLICATE    0 1   0.31750   3.96875   0.0   1
REPLICATE    3 1   0.31750   0.15875   0.0   1
REPLICATE    0 1   0.00000 12.85875   0.0   1
REPLICATE    3 1   0.00000   0.95250   0.0   1
CUBOID       0 1   27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 31
CYLINDER   500 1   8.8900   86.7833   69.4267
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   29.9720 -25.9080 29.9720 -25.9080 86.7833 69.4267
UNIT 32
CYLINDER   500 1   8.8900   69.4267   52.0700
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   32.0040 -23.8760 32.0040 -23.8760 69.4267 52.0700
UNIT 33
CYLINDER   500 1   8.8900   52.0700   34.7133
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   34.0360 -21.8440 34.0360 -21.8440 52.0700 34.7133
UNIT 34
CYLINDER   500 1   8.8900   34.7133   17.3567
REPLICATE    4 1   0.47625   0.0   0.0   1
REPLICATE    0 1   3.01625   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
REPLICATE    0 1   0.31750   0.0   0.0   1
REPLICATE    3 1   0.31750   0.0   0.0   1
CUBOID       0 1   36.0680 -19.8120 36.0680 -19.8120 34.7133 17.3567
UNIT 35
CYLINDER   500 1   8.8900   17.3567   0.0000
REPLICATE    4 1   0.47625   0.0   1.27000   1
REPLICATE    0 1   3.01625   0.0   2.54000   1
REPLICATE    3 1   0.31750   0.0   0.31750   1
REPLICATE    0 1   0.31750   0.0   0.31750   1
REPLICATE    3 1   0.31750   0.0   0.63500   1
CUBOID       0 1   38.1000 -17.7800 38.1000 -17.7800 17.3567 -15.2400
UNIT 40
CYLINDER   500 1   8.8900   104.1400   86.7833
REPLICATE    4 1   0.47625   1.58750   0.0   1
REPLICATE    0 1   3.01625   2.85750   0.0   1
```

```
REPLICATE    3 1  0.31750  1.27000   0.0  1
REPLICATE    0 1  0.31750  3.96875   0.0  1
REPLICATE    3 1  0.31750  0.15875   0.0  1
REPLICATE    0 1  0.00000 12.85875   0.0  1
REPLICATE    3 1  0.00000  0.95250   0.0  1
CUBOID       0 1  27.9400 -27.9400 27.9400 -27.940 128.27 86.7833
UNIT 41
CYLINDER   500 1  8.8900  86.7833  69.4267
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  25.9080 -29.9720 29.9720 -25.9080 86.7833 69.4267
UNIT 42
CYLINDER   500 1  8.8900  69.4267  52.0700
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  23.8760 -32.0040 32.0040 -23.8760 69.4267 52.0700
UNIT 43
CYLINDER   500 1  8.8900  52.0700  34.7133
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  21.8440 -34.0360 34.0360 -21.8440 52.0700 34.7133
UNIT 44
CYLINDER   500 1  8.8900  34.7133  17.3567
REPLICATE    4 1  0.47625  0.0  0.0  1
REPLICATE    0 1  3.01625  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
REPLICATE    0 1  0.31750  0.0  0.0  1
REPLICATE    3 1  0.31750  0.0  0.0  1
CUBOID       0 1  19.8120 -36.0680 36.0680 -19.8120 34.7133 17.3567
UNIT 45
CYLINDER   500 1  8.8900  17.3567  0.0000
REPLICATE    4 1  0.47625  0.0  1.27000  1
REPLICATE    0 1  3.01625  0.0  2.54000  1
REPLICATE    3 1  0.31750  0.0  0.31750  1
REPLICATE    0 1  0.31750  0.0  0.31750  1
REPLICATE    3 1  0.31750  0.0  0.63500  1
CUBOID       0 1  17.7800 -38.1000 38.1000 -17.7800 17.3567 -15.24000
UNIT 5
CUBOID       5 1  17.78 -38.10 38.10 -17.78 128.27000  -15.24000
UNIT 6
ARRAY  1  3*0.0
UNIT 7
ARRAY  2  3*0.0
UNIT 8
ARRAY  3  3*0.0
UNIT 9
ARRAY  4  3*0.0
UNIT 60
```

```
ARRAY  5  3*0.0
REPLICATE   3 1  6R0.31750  1
REPLICATE   0 1  5R0 10.16  1
UNIT 70
ARRAY  6  3*0.0
REPLICATE   3 1  6R0.31750  1
REPLICATE   0 1  5R0 10.16  1
UNIT 80
ARRAY  7  3*0.0
REPLICATE   3 1  6R0.31750  1
REPLICATE   0 1  5R0 10.16  1
UNIT 90
ARRAY  8  3*0.0
REPLICATE   3 1  6R0.31750  1
REPLICATE   0 1  5R0 10.16  1
UNIT 95
ARRAY  9  3*0.0
REPLICATE   5 1  6R0.31750  1
REPLICATE   5 1  5R0 10.16  1
GLOBAL
UNIT 110
ARRAY  10  3*0.0
REPLICATE   5 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=1  NUY=1  NUZ=6  FILL 15 14 13 12 11 10  END FILL
ARA=2  NUX=1  NUY=1  NUZ=6  FILL 25 24 23 22 21 20  END FILL
ARA=3  NUX=1  NUY=1  NUZ=6  FILL 35 34 33 32 31 30  END FILL
ARA=4  NUX=1  NUY=1  NUZ=6  FILL 45 44 43 42 41 40  END FILL
ARA=5  NUX=2  NUY=2  NUZ=1  FILL  F6  END FILL
ARA=6  NUX=2  NUY=2  NUZ=1  FILL  F7  END FILL
ARA=7  NUX=2  NUY=2  NUZ=1  FILL  F8  END FILL
ARA=8  NUX=2  NUY=2  NUZ=1  FILL  F9  END FILL
ARA=9  NUX=2  NUY=2  NUZ=1  FILL  F5  END FILL
ARA=10  NUX=4  NUY=4  NUZ=4  FILL
60 70 60 70 90 60 70 80 60 90 80 70 90 80 90 80
2Q16
95 95 95 95 95 60 95 95 95 95 80 95 95 95 95 95  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

```
=CSAS25
OPTIMUM SATURATED URANIUM OXIDE AND WATER MIXTURE
FULL MODEL OF ECOPAK OXIDE CONTAINER 7-3/4INID single Package accident
Full cylinder shift
44GR      INFHOM
UO2           1 0.2000 294.00 92235 4.5 92238 95.5 END
H2O           1 0.8000 294.00 END
H2O           2 0.001 294.00 END
CARBONSTEEL   3 1.0 294.00 END
SS304         4 1.0 294.00 END
H2O           5 1.0 294.00 END
H2O           6 0.030 294.00 END
END COMP
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5
END PARM
READ GEOM
UNIT 1
CYLINDER     1 1  9.842    104.14000  0.0
REPLICATE    4 1  0.47625  1.58750  1.27000  1
REPLICATE    0 1  2.06500  2.85750  2.54000  1
REPLICATE    3 1  0.31750  1.27000  0.317500  1
REPLICATE    0 1  0.31750  3.96875  0.317500  1
REPLICATE    3 1  0.31750  0.15875  0.63500  1
REPLICATE    0 1  0.00000 12.85875  0.00000  1
REPLICATE    3 1  0.00000  0.95250  0.00000  1
CUBOID       0 1  17.78 -38.10 38.10 -17.78 128.27000  -15.24000
UNIT 2
ARRAY  1  3*0.0
REPLICATE    3 1  6R0.31750  1
REPLICATE    0 1  5R0 10.16  1
GLOBAL
UNIT 3
ARRAY  2  3*0.0
REPLICATE    5 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=2  NUY=2  NUZ=1  FILL  F1  END FILL
ARA=2  NUX=1  NUY=1  NUZ=1  FILL  F2  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

```
=CSAS25
OPTIMUM SATURATED URANIUM OXIDE AND WATER MIXTURE
FULL MODEL OF ECOPAK OXIDE CONTAINER 7.0INID Single Package accident
Full Cylinder Shift
44GR      INFHOM
UO2           1 0.23000 294.00 92235 5.0 92238 95.0 END
H2O           1 0.77000 294.00 END
H2O           2 0.0001 294.00 END
CARBONSTEEL   3 1.0 294.00 END
SS304         4 1.0 294.00 END
H2O           5 1.0 294.00 END
END COMP
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5
END PARM
READ GEOM
UNIT 1
CYLINDER     1 1  8.89000  104.14000  0.0
REPLICATE    4 1  0.47625  1.58750  1.27000  1
REPLICATE    2 1  3.01625  2.85750  2.54000  1
REPLICATE    3 1  0.31750  1.27000  0.317500  1
REPLICATE    2 1  0.31750  3.96875  0.317500  1
REPLICATE    3 1  0.31750  0.15875  0.63500  1
REPLICATE    2 1  0.00000 12.85875  0.00000  1
REPLICATE    3 1  0.00000  0.95250  0.00000  1
CUBOID       2 1  17.78 -38.10 38.10 -17.78  128.27000  -15.24000
UNIT 2
ARRAY  1  3*0.0
REPLICATE    3 1  6R0.31750  1
REPLICATE    2 1  5R0 10.16  1
GLOBAL
UNIT 3
ARRAY  2  3*0.0
REPLICATE    5 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=2  NUY=2  NUZ=1  FILL  F1  END FILL
ARA=2  NUX=1  NUY=1  NUZ=1  FILL  F2  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

```
=CSAS2X
HETEROGENEOUS URANIUM OXIDE @ 5WT% 0.9 DIA./1.301 LATT.
FULL MODEL OF ECOPAK OXIDE CONTAINER 7.0INID  Single Package Pellet HAC
Full cylinder shift
44GR      LATT
UO2           1 DEN=10.95471 1 294 92235 5.0 92238 95.0 END
H2O           2 1.0 294 END
H2O           3 0.001 294 END
CARBONSTEEL   4 1.0 294 END
SS304         5 1.0 294 END
H2O           6 1.0 294 END
H2O           7 0.030 294 END
END COMP
SPHTRIANGP  1.301 0.9 1 2  END
MORE DATA  IIM=500  ICM=500  END MORE
accident
READ PARM  NUB=YES GEN=305 NPG=600 NSK=5 TME=60
END PARM
READ GEOM
UNIT 1
CYLINDER  500 1  8.89000  104.14000  0.0
REPLICATE   5 1  0.47625  1.58750  1.27000  1
REPLICATE   3 1  3.01625  2.85750  2.54000  1
REPLICATE   4 1  0.31750  1.27000  0.317500  1
REPLICATE   3 1  0.31750  3.96875  0.317500  1
REPLICATE   4 1  0.31750  0.15875  0.63500  1
REPLICATE   3 1  0.00000 12.85875  0.00000  1
REPLICATE   4 1  0.00000  0.95250  0.00000  1
CUBOID      3 1  17.78 -38.10 38.10 -17.78 128.27000  -15.24000
UNIT 2
ARRAY  1  3*0.0
REPLICATE   4 1  6R0.31750  1
REPLICATE   3 1  5R0 10.16  1
GLOBAL
UNIT 3
ARRAY  2  3*0.0
REPLICATE   6 1  6R30.48  1
END GEOM
READ ARRAY
ARA=1  NUX=2  NUY=2  NUZ=1  FILL  F1  END FILL
ARA=2  NUX=1  NUY=1  NUZ=1  FILL  F2  END FILL
END ARRAY
READ BOUNDS
ALL=VOID
END BOUNDS
END DATA
END
```

Appendix 6.5.2

UO_2 Saturation Curve Data

Table B-1 Saturation Curve Data for 4.5wt% Enrichment

UO_2 PARAMETERS								NUMBER DENSITY CALCULATIONS			
%UO_2	%H_2O	DUO_2	DU	DH_2O	TD	H/U	H/U235	NDU235	NDU238	NDH	NDO
5.000	95.000	0.548	0.483	0.948	1.496	51.877	1138.911	5.567E-05	1.167E-03	6.341E-02	3.415E-02
10.000	90.000	1.096	0.966	0.898	1.994	24.573	539.484	1.113E-04	2.333E-03	6.007E-02	3.492E-02
15.000	85.000	1.643	1.448	0.848	2.492	15.472	339.675	1.670E-04	3.500E-03	5.673E-02	3.570E-02
20.000	80.000	2.191	1.931	0.799	2.990	10.921	239.771	2.227E-04	4.666E-03	5.340E-02	3.648E-02
25.000	75.000	2.739	2.414	0.749	3.488	8.191	179.828	2.784E-04	5.833E-03	5.006E-02	3.725E-02
30.000	70.000	3.287	2.897	0.699	3.985	6.371	139.866	3.340E-04	7.000E-03	4.672E-02	3.803E-02
35.000	65.000	3.834	3.380	0.649	4.483	5.071	111.322	3.897E-04	8.166E-03	4.338E-02	3.880E-02
40.000	60.000	4.382	3.863	0.599	4.981	4.096	89.914	4.454E-04	9.333E-03	4.005E-02	3.958E-02
45.000	55.000	4.930	4.345	0.549	5.479	3.337	73.263	5.011E-04	1.050E-02	3.671E-02	4.036E-02
50.000	50.000	5.478	4.828	0.499	5.977	2.730	59.943	5.567E-04	1.167E-02	3.337E-02	4.113E-02
55.000	45.000	6.025	5.311	0.449	6.475	2.234	49.044	6.124E-04	1.283E-02	3.004E-02	4.191E-02
60.000	40.000	6.573	5.794	0.399	6.972	1.820	39.962	6.681E-04	1.400E-02	2.670E-02	4.268E-02
65.000	35.000	7.121	6.277	0.349	7.470	1.470	32.277	7.238E-04	1.517E-02	2.336E-02	4.346E-02
70.000	30.000	7.669	6.760	0.299	7.968	1.170	25.690	7.794E-04	1.633E-02	2.002E-02	4.424E-02
75.000	25.000	8.216	7.242	0.250	8.466	0.910	19.981	8.351E-04	1.750E-02	1.669E-02	4.501E-02
80.000	20.000	8.764	7.725	0.200	8.964	0.683	14.986	8.908E-04	1.867E-02	1.335E-02	4.579E-02
85.000	15.000	9.312	8.208	0.150	9.462	0.482	10.578	9.465E-04	1.983E-02	1.001E-02	4.656E-02
90.000	10.000	9.860	8.691	0.100	9.960	0.303	6.660	1.002E-03	2.100E-02	6.674E-03	4.734E-02
95.000	5.000	10.408	9.174	0.050	10.457	0.144	3.155	1.058E-03	2.217E-02	3.337E-03	4.811E-02

Table B-2 Saturation Curve Data for 5.0% Enrichment

UO_2 PARAMETERS								NUMBER DENSITY CALCULATIONS			
$\%UO_2$	$\%H_2O$	DUO_2	DU	DH_2O	TD	H/U	H/U235	NDU235	NDU238	NDH	NDO
5.000	95.000	0.548	0.483	0.948	1.496	51.877	1025.086	6.186E-05	1.160E-03	6.341E-02	3.415E-02
10.000	90.000	1.095	0.966	0.898	1.994	24.573	485.567	1.237E-04	2.321E-03	6.007E-02	3.492E-02
15.000	85.000	1.643	1.448	0.848	2.492	15.472	305.727	1.856E-04	3.481E-03	5.673E-02	3.570E-02
20.000	80.000	2.191	1.931	0.799	2.990	10.921	215.808	2.474E-04	4.642E-03	5.340E-02	3.648E-02
25.000	75.000	2.739	2.414	0.749	3.487	8.191	161.856	3.093E-04	5.802E-03	5.006E-02	3.725E-02
30.000	70.000	3.286	2.897	0.699	3.985	6.371	125.888	3.711E-04	6.962E-03	4.672E-02	3.803E-02
35.000	65.000	3.834	3.380	0.649	4.483	5.071	100.196	4.330E-04	8.123E-03	4.338E-02	3.880E-02
40.000	60.000	4.382	3.862	0.599	4.981	4.096	80.928	4.948E-04	9.283E-03	4.005E-02	3.958E-02
45.000	55.000	4.930	4.345	0.549	5.479	3.337	65.941	5.567E-04	1.044E-02	3.671E-02	4.036E-02
50.000	50.000	5.477	4.828	0.499	5.976	2.730	53.952	6.186E-04	1.160E-02	3.337E-02	4.113E-02
55.000	45.000	6.025	5.311	0.449	6.474	2.234	44.142	6.804E-04	1.276E-02	3.004E-02	4.191E-02
60.000	40.000	6.573	5.794	0.399	6.972	1.820	35.968	7.423E-04	1.392E-02	2.670E-02	4.268E-02
65.000	35.000	7.121	6.276	0.349	7.470	1.470	29.051	8.041E-04	1.509E-02	2.336E-02	4.346E-02
70.000	30.000	7.668	6.759	0.299	7.968	1.170	23.122	8.660E-04	1.625E-02	2.002E-02	4.424E-02
75.000	25.000	8.216	7.242	0.250	8.466	0.910	17.984	9.278E-04	1.741E-02	1.669E-02	4.501E-02
80.000	20.000	8.764	7.725	0.200	8.963	0.683	13.488	9.897E-04	1.857E-02	1.335E-02	4.579E-02
85.000	15.000	9.312	8.208	0.150	9.461	0.482	9.521	1.052E-03	1.973E-02	1.001E-02	4.656E-02
90.000	10.000	9.859	8.690	0.100	9.959	0.303	5.995	1.113E-03	2.089E-02	6.674E-03	4.734E-02
95.000	5.000	10.407	9.173	0.050	10.457	0.144	2.840	1.175E-03	2.205E-02	3.337E-03	4.811E-02

Appendix 6.5.3

Equivalent Water Density for Phenolic Foam

Equivalent Water Density for Phenolic Foam

Under normal conditions of transport, the phenolic foam used in the package was modeled at a reduced hydrogen content of 75% [Reference 8] the content reported by the manufacturer. It was input into the SCALE model as equivalent water. Using a conservative 4 lb/ft^3 (0.064 g/cc) foam density, the equivalent water density was determined by the following method:

*(7 g Hydrogen/ 100 g Foam) * 0.064 g Foam/cc = 0.00448 g Hydrogen/cc Foam.*

Converting to water,

(0.00448 g Hydrogen/cc Foam) / (0.11 g Hydrogen /g water) = 0.0407 g water/cc foam.

*(0.0407 g water/cc foam) * 75% = <u>0.030 g water/cc foam</u>.*

Equivalent Water Density for Polyethylene

Powder and pellets shipped in the OP Package may be packaged in polyethylene containers weighing up to 1000 grams per Oxide Vessel (4000 grams maximum per OP Package). Other plastic materials may be used for pre-packaging, provided that water hydrogen equivalent for the plastic material does not exceed the water hydrogen equivalent of 1000 grams polyethylene hydrogen. The water hydrogen equivalent was determined by the following method:

(1000 g. polyethylene)(0.143818 g hydrogen/ g polyethylene)/(0.11g Hydrogen / g water)
<u>= 1307.4 g water hydrogen equivalent.</u>

SECTION SEVEN OPERATING PROCEDURES

TABLE OF CONTENTS

7. ***OPERATING PROCEDURES***

The Eco-Pak® OP Transport Unit (OP-TU) is loaded and unloaded and the UO_2 storage vessel is filled, inspected, and handled in accordance with standard, in-plant, operating procedures at various enrichment plants and at various nuclear fuel facilities. As a minimum, the specific procedures should include steps described in the subsequent sections.

7.1 Procedures for Loading Package

7.1.1 Receipt and Filling of Storage Vessel

Receipt and filling of the storage vessel shall be performed in accordance with standard in-plant operating procedures.

7.1.2 Storage Vessel Inspection

The user shall inspect the storage vessel in accordance with written procedures prior to insertion into a transport unit to assure the following at a minimum:

a. The contents must be within the limits specified in Section 1.2.3.1.

b. Vessel shell is free from unacceptable discontinuities.

c. Gasket is in place and intact and not in a deteriorated or damaged condition.

d. Vessel lids fit properly with no gaps.

e. Closure bolts are properly adjusted for tight closure and are torqued to 75 +5 -0 ft-lbs.

7.1.3 Transport Unit Inspection

The user shall inspect the OP-TU in accordance with written procedures prior to every outgoing shipment and upon receipt of every incoming shipment to assure the following:

a. Transport unit base and supports are sound with no broken welds or components.

b. Transport unit inner and outer shells are intact and free from unacceptable discontinuities.

c. Inner cylinders are free of debris and standing water and are intact and are not in a deteriorated or damaged condition.

d. Gaskets and storage vessel support pads are in place and intact and are not in a deteriorated or damaged condition.

e. Cover plates and welds are sound and undamaged.

f. Package lids fit properly with no gaps.

g. Closure bolts are properly adjusted for tight closure and are torqued to 75 +5 -0 ft-lbs.

7.1.4 Procedure for Loading the Eco-Pak® OP-TU

a. Complete an inspection report verifying that the steps in Section 7.1.3 have been completed at a minimum.

b. Carefully load the storage vessels into the transport unit. Any Type A storage vessels may be transported in any combination in the OP-TU.

c. Place inner lids on transport unit.

d. Tighten all bolts closures alternating bolts on opposing sides of the inner flanges to the proper torque of 75 +5 -0 ft-lbs..

e. Carefully place outer lids on transport unit.

f. Tighten all bolts closures alternating bolts on opposing sides of the outer flanges to the proper torque of 75 +5 -0 ft-lbs.

g. Install security seals and record their numbers.

h. Complete inspection report.

i. Complete contamination survey in accordance with 10 CFR Part 71.87 (i) and (j).

j. Remove old labels and re-label per applicable regulations.

k. Transport unit surface temperatures must be in accordance with 10 CFR 71.43 (g) at any time during transportation.

7.2 Procedures for Unloading Transport Unit

Unload the OP-TU as follows:

a. Complete receiving report.

b. Remove and record the package seal.

c. Loosen all bolts on outer flanges.

d. Remove the outer flanges from the transport unit.

e. Remove the inner flanges from the transport unit.

f. Remove the storage vessel from the transport unit.

g. Clean any loose debris from OP-TU interior.

h. Close the transport unit prior to storage.

7.3 Preparation of Empty Transport Unit for Transport

Preparation of an empty OP-TU for shipment:

a. Close the transport units.

b. Complete contamination survey in accordance with 10 CFR 71.87 (i) and (j).

c. Remove old labels and re-label per applicable regulations.

SECTION EIGHT ACCEPTANCE TESTS AND MAINTENANCE PROGRAM

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8. ACCEPTANCE AND MAINTENANCE PROGRAMS

This section describes the activities to be performed in compliance with Subpart G of 10CFR71 to assure that the Eco-Pak® OP Transport Unit (OP-TU) conforms to the requirements of this Safety Analysis Report and remains in conformance following loading.

8.1 Acceptance Tests

8.1.1 Acceptance Tests for the Eco-Pak® OP-TU

Each completed transport unit shall be inspected to document compliance with the following drawing requirements:

a. Final dimensions as described below:
   - Cylinder dimensions.
   - Outer package dimensions.
   - Closure bolt locations.
   - Flatness of gasket surface.

b. Installation of gaskets and storage vessel support pads.

c. Lid to body fit.

d. Closure bolt and nut adjustments.

e. Installation of lifting shackles and security seal pads.

f. Final assembled weights.

g. Proper permanent marking and nameplates.

8.1.2 Acceptance Tests for the Storage Vessel

Each completed storage vessel shall be inspected to document compliance with the following drawing requirements:

a. Final dimensions as described below:
   - Inner shell diameter
   - Outer vessel dimensions
   - Closure bolt locations
   - Flatness of gasket surface

b. Installation of gasket

c. Lid-to-body fit

d. Closure bolt and nut adjustments

e. Final assembled weights

f. Proper permanent marking and nameplate

8.2 Maintenance Programs

8.2.1 Maintenance Programs for the Eco-Pak® OP-TU

The user shall establish written procedures for the periodic maintenance and inspection of each Model Eco-Pak® OP-TU requiring the following as a minimum:

8.2.1.1 Pre-shipment

a. Transport unit base and supports are sound with no broken welds or components.

b. Transport unit inner and outer shells are intact and free from unacceptable discontinuities, such as corrosion, pitting, cracks, pinholes and other defects.

c. Inner cylinders are free of debris and standing water and are intact and are not in a deteriorated or damaged condition.

d. Gaskets and storage vessel support pads are in place and intact and are not in a deteriorated or damaged condition.

e. Cover plates and welds are sound and undamaged.

f. Package lids fit properly with no gaps.

g. Closure bolts are properly adjusted for tight closure and are torqued to 75 +5 -0 ft-lbs.

h. Ensure that security seal holes are functional and capable of maintaining their integrity when seals are used.

i. Ensure that the transport units are within the most recent five-year re-certification performed in accordance with Section 8.2.1.3 below.

8.2.1.2 Annually

a. Check that the lifting shackles and closure bolts and supports are sound and free from weld cracks, damage and deterioration.

b. Check that the packaging is free of unacceptable discontinuities, and the inner shells are free of debris and standing water.

c. Check that the flanges are sound and undamaged.

d. Check that gaskets are in place, intact, and not damaged or deteriorated.

8.2.1.3 Every Five Years

The owners are responsible for re-certifying the OP-TU every five years to meet original design specifications. The following inspections shall be performed:

a. Perform all routine inspections stated in Section 8.2.1.1 and 8.2.1.2 stated above.

b. Full visual inspection of all welds for the presence of cracks. Any questionable condition of a weld shall be subject to further examination to assure that no cracks are present. Weld defects shall be repaired.

c. Check the lids and flanges for warpage and/or distortion which could prevent tight closure. Check that the gasket sealing surfaces meet design specifications.

d. Verify that inner and outer surfaces are free of unacceptable discontinuities.

e. Assure that security seal holes are functional and capable of maintaining their integrity when seals are used.

f. Permanently mark the nameplates listing the dates of re-certification, the individual transport unit weights, and the name of the re-certifying company.

g. The transport unit shall receive a full visual inspection for rusting and the presence of corrosion. This inspection shall include assurance that corrosion or other indications have not reduced the skin wall thickness by 10% of the nominal thickness over a six-inch square area. When visual inspection cannot assure sufficient wall thickness, other examinations shall be utilized, such as ultrasonic testing, to assure acceptability.

h. All repairs shall be performed by competent sources. Allowable repairs shall include repairs to welds and base metal as referenced in (h.) above. Repairs that require welding shall be made by welders who are qualified in accordance with Section IX of the ANSI/ASME Boiler and Pressure Vessel Code or Section 5 of ANSI/AWS D1.1. The repair shop shall provide certification of weld procedures and welder qualifications.

8.2.2 Maintenance Program for the Storage Vessel

The user shall establish written procedures for the periodic maintenance and inspection of each storage vessel requiring the following as a minimum:

8.2.2.1 Pre-shipment

a. The contents must be within the limits specified in Section 1.2.3.1.

b. Vessel shell is intact and free from unacceptable discontinuities, such as corrosion, pitting, cracks, pinholes and other defects.

c. Gasket is in place and intact and not in a deteriorated or damag[illegible]ndition.

d. Vessel lids fit properly with no gaps.

e. Closure bolts are properly adjusted for tight closure and are torqued to 75 +5 -0 ft-lbs.

8.2.2.2 Annually

a. Check that the closure bolts are sound and free from damage and deterioration.

b. Check that the vessel is free from unacceptable discontinuities.

c. Check that the flanges are sound and undamaged.

d. Check that gaskets are in place, intact, and not damaged or deteriorated.

8.2.2.3 Every Five Years

a. Perform all routine inspections stated in 8.2.2.1 and 8.2.2.2 above.

b. Full visual inspection of all welds for the presence of cracks. Any questionable condition of a weld shall be subject to further examination to assure that no crack are present. Weld defects shall be repaired.

c. Check the lids and flanges for warpage and/or distortion which could prevent tight closure.

d. Verify that inner and outer surfaces are free from unacceptable discontinuities.

e. Assure that security seal holes are functional and capable of maintaining their integrity when sealed.

f. Permanently mark the nameplates listing the dates of re-certification, the individual storage vessel weights, and the name of the re-certifying company.

g. Each storage vessel shall receive a full visual inspection for rusting and the presence of corrosion. This inspection shall include assurance that corrosion or other indications have not reduced the skin wall thickness by 10% of the nominal thickness over a six-inch square area. When visual inspection cannot assure sufficient wall thickness, other examinations shall be utilized, such as ultrasonic testing, to assure acceptability.

h. All repairs shall be performed by competent sources. Allowable repairs shall include repairs to welds and base metal as referenced in (h.) above. Repairs that require welding shall be made by welders who are qualified in accordance with Section IX of the ANSI/ASME Boiler and Pressure Vessel Code or Section 5 of ANSI/AWS D1.1. The repair shop shall provide certification of weld procedures and welder qualifications.

Appendix 6.5.4

Benchmarking Analysis: MTS Code Validation

(PROPRIETARY)

AFFIDAVIT

I, Rosemary A. Montgomery, Sole Proprietor of Montgomery Technical Services. (MTS), make the following representations that to the best of my knowledge and beliefs:

1. The following document enclosed in the letter (MTS985 Rev. 1), dated October, 1999, which Montgomery Technical Services wishes to have withheld from public disclosure, is:

   Validation of SCALE-PC for Uranium Systems with Enrichments between 0.72 and 10.0 wt% U-235

2. The information contained in the document cited in 1 above has been held in confidence by Montgomery Technical Services in that it is of a privileged and confidential commercial nature.

3. The information contained in the document cited in 1 above is the intellectual property of Montgomery Technical Services and as such is customarily held in confidence by Montgomery Technical Services. This information is submitted to Eco-Pak Specialty Packaging for the purpose of submittal to the Nuclear Regulatory Commission (NRC), in confidence, in response to NRC's request for information pertaining to criticality analyses performed by Montgomery Technical Services for Eco-Pak Specialty Packaging.

4. The information contained in the document cited in 1 above has not been made available to public sources by Montgomery Technical Services, nor has Montgomery Technical Services authorized that it be made available.

5. The public disclosure of the information contained in the document cited in 1 above is likely to cause substantial economic harm to Montgomery Technical Services.

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Rosemary A. Montgomery
Sole Proprietor, Montgomery Technical Services

10-29-99
date

Witnessed by: Notary

10-29-99
date

Expires April 29th 2002