SAFETY ANALYSIS REPORT
FOR THE
MODEL ESP-30X PROTECTIVE SHIPPING PACKAGE
FOR 30-INCH UF_6 CYLINDERS

Submitted by:

Eco-Pak Specialty Packaging
Elizabethton, Tennessee 37643

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SECTION ONE GENERAL INFORMATION

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1. GENERAL INFORMATION

This Safety Analysis Report for the Model ESP-30X Protective Shipping Package (PSP) is submitted in support of the Eco-Pak Specialty Packaging request for approval of the subject package and issuance of a Type B 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

Although the ESP-30X Protective Shipping Package basic design is an adaptation of the DOT-21PF1 and 21PF-1B overpack designs in use since the mid-1960's, the ESP-30X package configuration features several significant improvements over previous designs. These improvements have been added to address concerns with the DOT-21PF designs that have arisen over the past few years, specifically protection of the valves on the 30B cylinders transported by the overpacks.

Improvements to the design include increasing inner and outer end plate thicknesses from 14 ga steel to ½" thick steel and increasing inner and outer body shells from 14 ga to 11 ga steel. In addition, wood insulation on the ends of each package has been replaced with rigid, shock-absorbing foam.

Chloride content in earlier phenolic foam formulations has been a concern due to potential corrosion of stainless steel. Insulation used in ESP-30X Protective Shipping Packages is manufactured from a phenolic foam formulation containing virtually no free chlorides; the foam used in ESP-30X Protective Shipping Packages has a less than 200 ppm total chloride content, a level considered acceptable in previous PSP designs.

Testing documented in this Safety Analysis Report was conducted on ESP-30X Protective Shipping Packages manufactured with mild steel. Approval for use of ESP-30X PSP's constructed of mild steel is requested.

1.1 Introduction

The ESP-30X is a Type B, Fissile Class II Package (minimum Transport Index of 5.0) for shipment of Model 30B cylinders of up to 5% enriched UF_6 containing either virgin or recycled uranium. Each cylinder is limited to 5,020 pounds of UF_6 ; for recycled uranium, the package is further limited to not more than 1,150 A_2 quantities of radioactive materials as determined per 10CFR71, Appendix A. The contents of individual elements and radioactive isotopes are further limited as specified in **Section 1.2.3** below to meet the specification requirements of ASTM C-787 for feed materials and ASTM C-996 for UF_6 which has been processed through an enrichment plant.

1.2 Package Description

1.2.1 Packaging

The ESP-30X Protective Shipping Package is an overpack for 30-inch enriched uranium hexafluoride (UF_6) cylinders. The package is a right circular cylinder constructed of two steel shells, i.e. an outer shell 43 inches ID by 96 inches long and an inner shell 30-7/8 inches ID by 82-5/8 inches long. The volume between the shells, including the space between the ½-inch thick end plates of the two shells, is filled with fire-retardant, phenolic foam per ESP Specification ESP-PF-1 **(Appendix 2.10.2)**.

The ESP-30X PSP is fabricated in accordance with Eco-Pak Specialty Packaging Drawing No. ESP-30X, Sheets 1 through 12 **(see Appendix 1.3.1)**; this drawing is complete with dimensions, tolerances, fabrication details, materials list and specifications, weld specifications, gasket and assembly instructions, and inspection and testing requirements.

1.2.1.1 Gross Weights

The gross weights of a loaded ESP-30X are as follows:

Component	Weight (lbs)
ESP-30X Overpack	2,955
30B Cylinder	1,390
UF6 Maximum Load	5,020
Maximum Gross Weight of Loaded Package	**9,365**

1.2.1.2 Materials of Construction

The materials of construction for the ESP-30X are as follows:

Skin	ASTM A569 Carbon Steel
Plates	ASTM A572-50 Carbon Steel
Flat bar and angles	ASTM A36 Carbon Steel
Bolts and nuts	ASTM A193, B7 and A194 2H
Foam	ESP Specification ESP-PF-1 Phenolic Foam
Gasket	Silicone
Lifting Shackles	Forged carbon steel

The 30B cylinder and valve are constructed in accordance with ANSI N14.1.

1.2.1.3 Outer and Inner Protrusions

There are no inner protrusions on the ESP-30X PSP. Outer protrusions on the ESP-30X consist of lifting and tie-down points **(Section 1.2.1.4)** and bolt closures **(Section 1.2.1.7)**.

1.2.1.4 Lifting and Tie down Devices

The bottom half of the package is fitted with ½-inch thick tie-down plates for bolting to the floor of the carrier vehicle with eight 3/4-inch bolts. The bottom half of the package is fitted with four 3/4-inch steel shackles for top lifting. The tare weight of an empty package is nominally 2,955 pounds; the maximum gross weight of the loaded package is 9,365 pounds.

1.2.1.5 Shielding

Shielding is not required for contents of the 30B cylinder.

1.2.1.6 Pressure Relief Systems

There are no pressure relief systems.

1.2.1.7 Closures

A stepped horizontal joint permits the top half of the package to be removed from the base; the horizontal closure joint of each package half is covered with steel and a 5/8" thick silicone gasket seals the joint. The package halves are secured with ten (10) 3/4-inch diameter steel bolts and nuts.

1.2.1.8 Containment

The containment vessel of the package is the Model 30B UF_6 cylinder which must be fabricated, inspected, tested and maintained in accordance with the latest NRC approved revisions of USEC-651 and ANSI Standard No. N14.1 which requires that the cylinder be fabricated in accordance with Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code and be ASME Code "U" stamped.

1.2.2 Operational Features

The ESP-30X package is closed by ten (10) 3/4-inch diameter B-7 bolts and nuts tightened to a specified torque of 150 foot-pounds.

The package is tied-down for transport by bolting to the carrier floor and is interchangeable with earlier overpack designs because the ESP-30X tie-down pattern is identical

with DOT-21PF-1A and DOT-21PF-1B overpacks. The package is lifted by four (4) shackles attached to the lower half of the PSP. The package may also be lifted by fork truck tines under the angle-reinforced bottom of the package.

The closure joint of the package is stepped down to the outside to minimize water in-leakage into the cylinder cavity and provides a metal-to-metal seat on the outboard side such that compression of the inboard gasket is controlled. The gasket is a 5/8-inch thick medium density, closed-cell silicone sponge rubber with a minimum continuous temperature rating of 400°F.

1.2.3 Contents of Packaging

The ESP-30X package is used for the safe transport of uranium hexafluoride enriched in the U^{235} isotope; the UF_6 must be packaged in Model 30B UF_6 cylinders which have been fabricated, inspected, tested and maintained in accordance with the requirements of ANSI N14.1, The package contents are limited to a maximum of 5,020 pounds UF_6 enriched to not more than 5 wt% U^{235}. The UF_6, which may container either virgin or recycled uranium, must meet the requirements of ASTM C-787 for feed materials and ASTM C996 for UF_6 which has been processed through an enrichment plant. In the case of recycled uranium, the package contents must not exceed 1,150 A_2 quantities of radioactive materials as determined per 10CFR71, Appendix A and must not contain more than the following maximum quantities of radionuclides and impurities:

U^{232}	0.005 μg/gU
U^{234}	2000 μg/gU
U^{235}	0.05 g/gU
U^{236}	0.025 g/gU
U^{238}	balance of total uranium content
Pu + Np	Alpha activity not exceeding 3.3 Bq/gU
Tc-99	5 μg/gU
Th^{228}	1.17 X 10^{-3} μg/gU (other U-232 daughters are ignored because of very short half-lives)
Fission Products	4.4 x 105 Mev Bq/d kgU (total contribution from gamma emitting fission products); this results in the following individual maximum activities:

Ru^{106}/Rh^{106}	2095 Bq/gU
Ru^{103}/Rh^{103}	885 Bq/gU
$Ce^{144}/Pr^{144}/Pr^{144*}$	8349 Bq/gU
Sb^{125}	1030 Bq/gU
Cs^{134}	283 Bq/gU

Cs^{137}/Ba^{137}*	778 Bq/gU
Zr^{95}	598 Bq/gU
Nb^{95}	574 Bq/gU

From ASTM C-787, the total concentration of elements that form non-volatile fluorides (including Al, Ba, Be, Bi, Cd, Co, Cr, Cu, Fe, Pb, Li, Mg, Mn, Ni, K, Ag, Na, Sr, Th, Sn, Zn, and Zr) must no exceed 300 μg/gU.

Also, from ASTM C-787, the content of other elements must not exceed the following concentrations in μg/gU:

Sb < 1	As < 3	B < 1	Bi < 5	Cl < 100
Cr < 10	Nb < 1	P < 50	Ru < 1	Si < 100
Ta < 1	Ti < 1	Mo < 1.4	W < 1.4	V < 1.4

1.3 Appendices

1.3.1 Eco-Pak Specialty Packaging Drawing No. ESP-30X, Model ESP-30X Protective Shipping Package

1.3.2 UF_6 30B Cylinder

Appendix 1.3.1

ESP Drawing No. ESP-30X

FIGURE WITHHELD UNDER 10 CFR 2.390

ESP Eco-Pak Specialty Packaging Division of ...

30X
PROTECTIVE SHIPPING PACKAGE

Checked:	Date: 8/97	DRAWING NUMBER 30X-1
Rec'd By:	Dwn By: NTS	
Appr'd By:	Scale: NONE	REV. 1 SHEET 1 of 12

FIGURE WITHHELD UNDER 10 CFR 2.390

ESP Eco-Pak Specialty Packaging Division of ...

30X
PROTECTIVE SHIPPING PACKAGE

Checked:	Date: 8/97	DRAWING NUMBER 30X-2
Appr'd By:	Dr'n By: NTS	
Appr'd By:	Scale: NONE	REV. 1 | SHEET 2 of 12

FIGURE WITHHELD UNDER 10 CFR 2.390

Eco-Pak Specialty Packaging
Division of O&G

30X
PROTECTIVE SHIPPING PACKAGE

Checked:	Date: 1/30/98	DRAWING NUMBER 30X-3
Appr'd By:	Dr'n By: ARM	
Appr'd By:	Scale: NONE	REV. / SHEET 3 of 12

FIGURE WITHHELD UNDER 10 CFR 2.390

ESP Eco-Pak Specialty Packaging Division of CDC

30X
PROTECTIVE SHIPPING PACKAGE

Checked	Date: 8/97	DRAWING NUMBER 30X-4
Appr'd By:	Dr'n By: NTS	
Appr'd By:	Scale: NONE	REV. 1 | SHEET 4 OF 12

FIGURE WITHHELD UNDER 10 CFR 2.390

ESP Eco-Pak Specialty Packaging Division of CDO		
30X PROTECTIVE SHIPPING PACKAGE		
Checked:	Date: 8/97	DRAWING NUMBER 30X-5
Appr'd By:	Dr'n By: NTS	
Appr'd By:	Scale: NONE	REV. 1 SHEET 5 OF 12

FIGURE WITHHELD UNDER 10 CFR 2.390

ESP Eco-Pak Specialty Packaging Division of ...

30X
PROTECTIVE SHIPPING PACKAGE

Checked:	Date: 8/97	DRAWING NUMBER
Appr'd By:	Dwn By: NTS	30X-6
Appr'd By:	Scale: NONE	REV. 1 SHEET 6 OF 12

FIGURE WITHHELD UNDER 10 CFR 2.390

ESP Eco-Pak Specialty Packaging Division of ODC

30X
PROTECTIVE SHIPPING PACKAGE

Checked:	Date: 8/97	DRAWING NUMBER 30X-7
Appr'd By:	Dr'n By: NTS	
Appr'd By:	Scale: NONE	REV. 1	SHEET 7 OF 12

FIGURE WITHHELD UNDER 10 CFR 2.390

ESP Eco-Pak Specialty Packaging Division of GSC

30X
PROTECTIVE SHIPPING PACKAGE

Checked	Date: 8/97	Drawing Number 30X-8
Appr'd By:	Dr'n By: NTS	
Appr'd By:	Scale: NONE	Rev. 1 | Sheet 8 of 12

FIGURE WITHHELD UNDER 10 CFR 2.390

ESP Eco-Pak Specialty Packaging Division of C&D			
30X PROTECTIVE SHIPPING PACKAGE			
Checked	Date 8/97	DRAWING NUMBER 30X-9	
Appr'd By	Dr'n By NTS		
Appr'd By	Scale NONE	REV. 1	SHEET 9 OF 12

FIGURE WITHHELD UNDER 10 CFR 2.390

30X
PROTECTIVE SHIPPING PACKAGE

Checked	Date 8/97	DRAWING NUMBER 30X-10
Appr'd By	Dwn By NTS	
Appr'd By	Scale NONE	REV. 1 / SHEET 10 OF 12

FIGURE WITHHELD UNDER 10 CFR 2.390

ESP Eco-Pak Specialty Packaging Division of C&B

30X
PROTECTIVE SHIPPING PACKAGE

Checked	Date 8/97	DRAWING NUMBER 30X-11
Appr'd By	Dr'n By NTS	
Appr'd By	Scale NONE	REV. 1 / SHEET 11 OF 12

SHOP BILL OF MATERIAL

MARK	NO. OF PCS.	MATERIAL	LENGTH FT	LENGTH INS	REMARKS
	ONE	MODEL NCI-21PF-1 PROTECTIVE SHIPPING PACKAGE			
pa	1	PL 11 GA. x 65 1/2	7	11 5/8	ROLL & BEND
pb	1	PL 11 GA. x 73 3/4	7	11 5/8	ROLL & BEND
pc	2	PL 11 GA. x 8 3/16	7	11 3/8	BEND
pd	2	PL 11 GA. x 7 3/4	7	11 3/8	BEND
pf	2	PL 11 GA. x 8 3/16	3	7	BEND
pg	2	PL 11 GA. x 7 3/4	3	7	BEND
pk	2	PL 1/2 x 23 9/16	3	7 1/8	A572-50
pm	2	PL 1/2 x 19 9/16	3	7 1/8	A572-50
pn	1	PL 11 GA. x 49 15/16	6	10 1/8	ROLL & BEND
ps	2	PL 1/2 x 15 1/4	2	7 1/8	A572-50
pt	1	PL 11 GA. x 49 15/16	6	10 1/8	ROLL & BEND
pw	2	PL 1/2 x 15 5/16	2	7 1/8	A572-50
px	2	PL 1/2 x 5" O.D.			
aa	4	L2 x 2 x 1/4	–	9 3/8	
ab	4	L2 x 2 x 1/4	7	10 1/2	
ac	2	L3 x 3 x 3/8	5	5 11/16	ROLL(ADD FOR ROLLING)
ad	4	L2 x 2 x 1/4	7	3 11/16	
ag	2	L2 x 2 x 1/4	2	11 1/4	
af	2	L3 x 3 x 3/8	5	9 1/8	ROLL(ADD FOR ROLLING)
ah	4	L2 x 2 x 3/8	7	10 3/8	
am	4	L2 1/2 x 2 1/2 x 3/8	–	2 1/4	
an	2	L2 x 2 x 1/4	3	6 7/8	
ap	4	L2 1/2 x 2 1/2 x 3/8	–	2 1/4	
as	6	L2 1/2 x 2 1/2 x 3/8	–	2 1/4	
av	6	L2 1/2 x 2 1/2 x 3/8	–	2 1/4	
ar	2	L2 x 2 x 1/4	2	11 1/4	
at	2	L2 x 2 x 1/4	3	2 11/16	
aw	4	L2 x 2 x 1/4	1	0	
ak	2	L3 x 3 x 3/8	4	8	

SHOP BILL OF MATERIAL

MARK	NO. OF PCS.	MATERIAL	LENGTH FT	LENGTH INS	REMARKS
ba	2	br.1/2 x 6	3	7	
bb	2	br.1/2 x 2 1/8	–	2 5/8	
bc	1	br.1/4 x 3	5	4 1/8	ROLL(ADD FOR ROLLING)
bd	6	br.1/4 x 3	–	7 1/2	BEND
bf	1	br.1/4 x 3	6	0 1/8	ROLL(ADD FOR ROLLING)
bg	12	br.3/8 x1 5/8	–	2 1/4	
bh	4	br.1/4 x 3	–	6 3/8	BEND
bk	6	br.1/4 x 3	–	6 7/8	BEND
bn	4	11 GA. x 4 x 4	–	–	A569
		W/1 3/4Ø HOLE IN CENTER			
bo	4	1/2 x 3Ø (FROM pk & pm)	–	–	A572-50
bm	4	br.1/4 x 3	–	6 11/16	BEND
ca	2	C 7 x 12.25	3	0	A36
ms	10	1/8 x 1 1/2			C/S
		SPRING COTTER PIN			
mx	4	3/4Ø SHACKLE			C/S
		W/ 7/8Ø PIN			
	4	PAD EYE 1/4"SS			
	2	11 GA x 11 x 16			304 S/S
		NAMEPLATE			
	10	3/4Ø UNC-2A HEAVY			A193 GRADE B7
		HEX BOLT x 6 1/2 LONG			(MARKED)
		ANSI B16.2.1			
	10	3/4Ø UNC-2B HEAVY			A194 GRADE 2H
		HEX NUT - ANSI B18.2.2 SF			(MARKED)
	10	3/4Ø LOCK WASHER			C/S
	10	3/4Ø FLAT WASHER			C/S
	4	1Ø WELD COLLAR			COMMERCIAL
	4	1Ø PLASTIC PLUG			COMMERCIAL

SHOP BILL OF MATERIAL

MARK	NO. OF PCS.	MATERIAL	LENGTH FT	LENGTH INS	REMARKS
		UPPER PADS			
	4	NEOPRENE SPONGE			1/2"THK.x6"x9"
		MED. DENSITY, CLOSED CELL			
		LOWER PADS			
	2	NEOPRENE			3/16"THK.x18"x36"
		50 - 60 DUROMETER A			
		GASKET			
	20 FT	SILICONE SPONGE			5/8 THK. x 1 1/2 WIDE
		MED. DENSITY CLOSED CELL			
		RATED FOR CONTINUOUS			
		USE AT 400°F			
		AMERICAN FOAM TECHNOLOGIES			
		PHENOLIC FOAM THERMO-COR II			
		LOW CHLORIDE (200 PPM OR LESS)			
		545 LBS TOTAL			

NOTE:
UNLESS NOTED, ALL STEEL
IS A36 FOR SHAPES & PLATE,
SHEET IS A569.

NOTE:
ITEMS SPECIFIED HEREIN BY TRADE NAME
PROVIDE MINIMUM REQUIREMENTS ONLY;
EQUIVALENT OR BETTER ITEMS MAY BE
SUBSTITUTED.

Rev. No.	Change	Date	By
9			
8			
7			
6			
5			
4			
3			
2	GENERAL REVISIONS	3/19/98	ARM
1	GENERAL REVISIONS	1/29/98	ARM

* REVISIONS *

ESP Eco-Pak Specialty Packaging Division of

30X
PROTECTIVE SHIPPING PACKAGE

Checked:	Date: 8/97	DRAWING NUMBER 30X-12
Appr'd By:	Dr'n By: NTS	
Appr'd By:	Scale: NONE	REV. 1 — SHEET 12 OF 12

Appendix 1.3.2

UF_6 30B Cylinder

FIGURE WITHHELD UNDER 10 CFR 2.390

THE COLUMBIANA BOILER CO. COLUMBIANA, OHIO		
UF_6 CYLINDER – MODEL 30B		
Checked	Date 5/22/97	DRAWING NUMBER 52471-R2
Appr'd By	Dr'n By ARM	
Appr'd By	Scale AS NOTED	REV. / SHEET 1 OF 1

SECTION TWO STRUCTURAL EVALUATION

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2. *STRUCTURAL EVALUATION*

2.1 Structural Design

2.1.1 Discussion

The ESP-30X PSP described in this report is a cylindrical overpack similar in dimension and design to the DOT-21PF-1B packages used since the 1960's. The DOT-21PF-1B was designed to safely transport a 30B cylinder filled with UF_6. In recent years, similar overpacks manufactured with various modifications have been extensively tested, particularly in relation to the overpack's ability to successfully protect the cylinder valve on the cylinder inside the overpack when subjected to the one-meter puncture test with the center-of-gravity over and in vertical alignment with the valve and target piston.

Recent testing using a valve protection device (VPD) has shown that the device provides sufficient protection to prevent damage to the valve in such testing. The ESP-30X is designed to provide equally sufficient protection without the use of the VPD.

The ESP-30X design is described in Eco-Pak Specialty Packaging Drawing No. ESP-30X, Sheets 1 through 12 **(see Appendix 1.3.1)**. The ESP-30X features several modifications of the DOT-21PF-1B design that are intended to render the package capable of providing increased protection of the cylinder valve. These modifications include:

1. The thickness of the inner and outer ends plates has been increased from 14 ga (2.1 mm) sheet metal to ½" (12.7 mm) plate.

2. The inner and outer shell material has been increased from 14 ga (2.1 mm) sheet metal to 11 ga (3.0 mm) sheet metal.

3. The space between the inner and outer shells is filled with Specification ESP-PF-1 phenolic foam **(see Appendix 2.10.2)**, replacing all wood components and Specification SP-9 phenolic foam.

2.1.2 Design Criteria

The ESP-30X was designed to meet all of the performance requirements of 10CFR71, Subpart E. The primary containment vessel is the Model 30B UF_6 cylinder, such that the performance requirements specified in 10CFR71, Subpart E are satisfied when the cylinder containment vessel is protected, under both normal and hypothetical accident conditions, from unacceptable impact damage, from failure of package components due to cold (-40°F), from accidental or inadvertent opening of the package, or from over-pressurization due to over-heating.

For normal conditions of transport, compliance of the ESP-30X is demonstrated through the evaluation described in **Section 2.6** below.

Compliance of the ESP-30X 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 ESP-30X package, its cylinder and its UF_6 contents are tabulated below. Centers of gravity are determined from the geometric center of the package with vertical distances (y) shown as positive for centers of gravity above the center line Longitudinal distances (x) are shown as positive for centers of gravity nearer the plug end of the cylinder and negative for centers of gravity nearer the valve end of the cylinder (see **Figure 2.1-1** below).

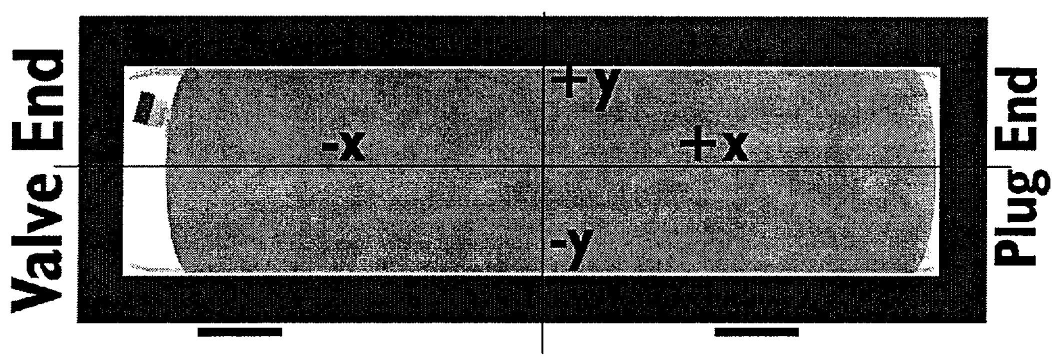


Figure 2.1-1

Component	**Maximum Weight**	**x**	**Wx**	**y**	**Wy**
Overpack	2955 lbs	0.0	0	-0.7	-1596
30B Cylinder	1390 lbs	0.5	700	0.0	0
Maximum UF6 Load (Content)	5020 lbs	2.3	11546	-4.9	-24598
Gross Package Weight	9365 lbs	1.4	12246	-3.0	-26194

2.3 Mechanical Properties of Materials

2.3.1 Metal Properties

Property/Material	A36 Angle	A36 Flat bar	A572-50	A-193B7
Min Yield Strength (psi x 1,000)	36	36	50	105
Min Tensile Strength (psi x 1,000)	58-80	58-80	65	125
Elongation in 2" (%)	21	23	21	16 (4D)

NOTE: Minimum Yield Strength in shear is calculated at 75% of the Minimum Yield Strength in tension.

2.3.2 Insulation Properties

Property/Material	ESP-PF-1 Foam
Closed cell content (%)	85
Density (lb/cu-ft)	9.5-12.5
Thermal Conductivity (Btu/hr sq-ft ^{0}F/in)	.20-.32

2.3.3 References

(1) ASME Boiler & Pressure Vessel Code (1974 Ed), Section VIII, Table UHA-23.
(2) Perry's Chemical Engineers' Handbook (4th Ed), Table 23.5.

2.4 General Standards for All Packages

The ESP-30X package 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 package and its Model 30B cylinder provide complete containment under Normal Conditions of Transport, the cylinder valve is well protected against accidental or unauthorized operation, and there is no pressure relief valve nor any provision for continuous venting. Since there is essentially no source of internal heat (i.e., decay heat is negligible as shown in **Appendix 2.10.1**), the external surfaces will not exceed 38°C in still air in the shade at 38°C. Other General Standard provisions are also met as described below:

2.4.1 Minimum Package Size

The ESP-30X easily exceeds the minimum package size requirements.

2.4.2 Tamper proof Feature

The ESP-30X features two locations for installing tamper indicating devices, typically individually-numbered seals, which would disclose any unauthorized entry into the package.

2.4.3 Positive Closure

The ESP-30X is closed with ten (10) 3/4-inch B-7 bolts.

2.4.4 Chemical and Galvanic Reactions

2.4.4.1 Carbon Steel Construction

The ESP-30X is constructed of carbon steel and there is no contact with stainless steel, therefore no chemical, galvanic or other reaction should take place between metals in the package.

The ESP-PF-1 foam used in the ESP-30X is a low chloride foam which should cause no corrosion in the carbon steel. As additional protection all surfaces which come in contact with the foam are coated with an epoxy primer.

Painting of exterior surfaces is recommended to provide protection from corrosion resulting from road salts, ocean spray and normal wear and tear.

Dry UF_6 , as contained in the Model 30B cylinder, has been shown to be essentially non-corrosive to the steel cylinder.

2.4.4.2 ESP-PF-1

The ESP-30X utilizes ESP-PF-1 phenolic foam which is composed of a phenolic resin mixture and a mild acid catalyst. A chemical analysis to verify that the ESP-PF-1 foam will not

lead to corrosion of the carbon steel was conducted and the results compared to an accelerated corrosion test of carbon and stainless steel using 400 ppm and 1% ferric chloride solution in October 1995 **(Appendix 2.10.3).**

The testing facility concluded that the ESP-PF-1 foam should not cause significant corrosion of carbon steel material during accelerated corrosion testing. The ESP-PF-1 foam contains less than 200 ppm chloride content, well below the acceptable level.

2.5 Lifting and Tie-down Devices

The ESP-30X package can be lifted by fork-truck tines in which case it is supported on angle reinforcements under its belly. 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.

The bottom half of the package is fitted with ½-inch thick tie-down bases for bolting to the floor of the carrier vehicle. These bases are identical to those used in the original DOT-21PF-1B design and are bolted down in the same manner as the original design. As shown in **Section 2.5.2**, this tie-down system meets the requirements of 10CFR71.45(b) and was designed to ultimately fail at the bolt holes so as not to damage any structural part of the package.

2.5.1 Lifting Devices

The ESP-30X package is lifted using four shackles (3/4-inch stock diameter, 7/8-inch pin diameter, steel) on the bottom half of the overpack. The working load limit for the 3/4-inch shackles is 13,000 pounds. The safety factor is:

SF=(4*13,000)/9365 = 5.6

2.5.2 Tiedown Devices

The ESP-30X package is tied down to the carrier vehicle at eight bolted locations in the foot plate by using 3/4-inch A-193 B-7 bolts.

Longitudinal Load at 10 g = 10 x 9,365 lb = 93,650 lb

Transverse Load at 5 g = 5 x 9,365 lb = 46,825 lb

Combined Horizontal Load = $(10^2 + 5^2)^{½}$ x 9,365 = 104,704 lb

Shearing Stress on the 8 bolts:

$$S = \frac{104{,}704 \times 4}{8 \times 0.75^2 \times 3.1} = 29{,}640 \text{ psi}$$

With the package loaded sideways on a carrier, the 10 g longitudinal load creates a coupling moment through the center of gravity placing a vertical load (V_t) on 4 bolts on one side of the package to counteract the moment; the 5 g transverse load creates a similar vertical load (V_t) on 4 bolts on one end of the package as follows:

V_t = 10 x 9,365 lb x 22"/40" = 51,508 lb

V_t = 5 x 9,365 lb x 22"/58" = 17,761 lb

The maximum total vertical load on a bolt (V) due to the forces calculated above plus that due to a 2g vertical load is:

V= (2 x 9,365/8) + (51,508/4) + (17,761/4) = 19,659 lb/bolt

The maximum tensile strength on a bolt is:

$$S = \frac{19{,}659 \ lb}{0.75^2 \times 3.14/4} = 44{,}521 \text{ lb}$$

Shear stress under the bolt head is:

$$S = \frac{19{,}659 \ lb}{1.25'' \times 3.14 \times 0.5''} = 10{,}017 \text{ psi}$$

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°F with no insolation and no decay heat results in a package with a uniform temperature of -40°F. An ambient temperature of -40°F will not have an adverse effect on the ESP-30X. The ductility of the steel in the overpack is not seriously

affected by temperatures in this range.

The UF_6 cylinder is fabricated in accordance with ANSI N14.1 which specifies materials suitable for use at -40°F.

At very low temperatures the internal pressure of the cylinder will be close to zero absolute. Structurally, this is equivalent to in external pressure of one atmosphere or 14.7 psia. Under ANSI N14.1, the 30B cylinder is designed for an external pressure of 25 psig.

2.6.3 Reduced External Pressure

The internal pressure of a filled 30B cylinder will range from 0 to 14.7 psia (corresponding to UF_6 temperatures of 0°F to 130°F, respectively). A reduced external pressure of 3.5 psia will result in a net internal pressure of 3.5 psig. This pressure is significantly less than the design internal pressure of the 30B cylinder (200 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 cylinder cavity pressure of 0 psia). The cylinder is designed for an external pressure of 25 psig as specified in ANSI N14.1.

2.6.5 Vibration

Vibration incident to transport has no measurable effect on the ESP-30X package. Neoprene pads on the inner surface of the overpack firmly hold the UF_6 cylinders to prevent movement during transport. The bolted overpack 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 ESP-30X package. A welded steel jacket totally encloses the foam insulation in the ESP-30X package and there are no penetrations other than the vents which are sealed and closed. The package top and bottom halves join at a closure joint which is stepped down to the outside with a soft gasket on the inboard side to keep water out of the cylinder cavity.

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 overpack, 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 cylinder 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 30B cylinder is required to meet shielding requirements. Additionally no criticality concerns exist since, as shown in **Section Six**, criticality is maintained without the overpacks.

2.6.8 Corner Drop

Not applicable to the ESP-30X package.

2.6.9 Compression

The minimum vertical projected area of the phenolic foam in the ESP-30X is:

$$(43.5 \text{ in}) (82.625 \text{ in}) = 3{,}594 \text{ in}^2$$

Five times the weight of the package is:

$$(5) (9{,}365 \text{ lbs}) = 46{,}825 \text{ lbs}$$

This is equivalent to a pressure of:

$$46{,}825 \text{ lbs} / 3{,}594 \text{ in}^2 = 13.03 \text{ psi}$$

This pressure is less than the minimum compressive strength of the foam which is 388 psi. This assumption neglects the presence of the 30B cylinder and the steel shells of the overpack.

$$\text{M.S.} = (388/13.03) - 1 = 28.8$$

2.6.10 Penetration

Dropping a 13 pound rod as described in 10CFR71 will have a negligible effect on the 11 gauge (0.1196") steel walls of the ESP-30X overpack. Penetration drop damage reported in the first safety analysis report performed on a DOT-21PF-1 style overpack (K-1686, "Protective Shipping Packages for 30 Inch Diameter UF_6 Cylinders") showed that a drop test performed with a 13-pound, 1-1/4" diameter steel rod dropped 4 feet onto the shell of a DOT-21PF-1 prototype

caused a "barely discernable" indentation in the thin walled 16 gage (0.0598") steel. Since the thickness of the walls of the ESP-30X are nearly four times greater than the thickness of the walls of the test model of the DOT-21PF-1 prototype, it is concluded that negligible damage would be expected to the ESP-30X overpack due to the penetration test.

2.6.11 Conclusion

As shown in **Section Six**, calculations of criticality for the packagings are not dependent on the use of overpacks. Therefore, damage from free drop tests which might result in change to the package overall dimensions would not affect concerns with criticality. Additionally, since the 30B cylinder provides necessary shielding for the lading, any local change in the overpack dimensions will not result in a decrease in the shielding 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 ESP-30X overpack can easily meet.

The analyses presented in **Section 2.6** show that normal loads will not result in any significant structural damage of the ESP-30X package and the containment function of the 30B cylinder will be maintained.

2.7 Hypothetical Accident Conditions

The history of overpack testing of the DOT-21PF-1 class of overpacks is extensive and well documented (Safety Analysis Report for the NCI-21PF-1 Protective Shipping Package, Rev. 2, March 1997, Appendix 2.10.6 Submitted by Nuclear Containers, Inc.). Based on previous testing, it has been determined that two orientations, 13.5° (±1°) from vertical and 60° (±1°) from vertical could result in damage to the valve, either by allowing the cylinder skirt to bend and impact the valve, allowing the overpack inside wall to impact the valve or by allowing the overpack to open. These impacts were only evident on packages with damaged cylinder skirts due to previous drop testing. Subsequent testing has shown that the use of a valve protection device prevents this type of impact. Based on these tests, it was determined that both the 13.5° from vertical and 60° from vertical orientations would be considered in evaluating the ESP-30X package for the tests required in 10CFR71 hypothetical accident testing.

In addition, tests were conducted on samples of the basic materials used in the manufacture of ESP-30X overpacks to determine the effect of different temperatures on their physical characteristics. Metal samples were subjected to Charpy "V" impact tests (see **Appendix 2.10.4**) and ESP-PF-1 foam insulation samples (See **Appendix 2.10.5**) were analyzed at three temperature ranges: +100°F, 67-74°F and -20°F. Although the physical characteristics of the foam samples were essentially unaffected by the different temperatures, metal samples tested at the -20°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°F

prior to drop tests.

Two full-scale representative ESP-30X overpacks containing 30B cylinders with simulated loads were subjected to testing. One ESP-30X overpack (Test Article #1) was subjected to the sequence of drop and puncture tests in the 13.5° (±1°) from vertical orientation. A second ESP-30X overpack (Test Article #2) was subjected to a 60° (±1°) from vertical 30' free drop with the package rotated 5° over the closure bolts. Impact occurred on the plug end of the package with an accelerated secondary impact on the valve end of the overpack. This same overpack was then subjected to a 40" puncture test with impact from the puncture ram occurring directly on the center bolt on the closure plane. A fire test was then conducted on the package determined to have the most damage. (See **Appendix 2.10.6** for criteria used in evaluating damage.) Following the fire test, a comparable hydrostatic test was performed for the 3 foot immersion test. An assessment of immersing the package 50 feet in water was also performed.

A detailed test program is provided as **Appendix 2.10.8**.

Test Program Summary

The first step of the testing program was the preparation of the 30B cylinders. **(Appendix 2.10.7)** The cylinder skirts were bent approximately 1 inch toward the valve location and repaired. This was done to simulate the worst damage expected to be seen by the cylinder skirts during normal handling. After repair, the cylinders were loaded with steel shot to a weight simulating the maximum load of UF_6 to be transported in the packages. The cylinder valves were installed and the cylinders were leak tested for normal conditions by both a 100 psi soap bubble test and helium mass spectrometer test.

The cylinders were fitted with several different temperature measuring devices and then loaded into the overpacks. The overpacks were secured following the torque sequence described in **Section 7**.

The packages were then cooled to a temperature of at least -20°F in a cooling chamber.

Test Article #1 was removed from the cooling chamber with a recorded insulation temperature of -23°F. It was subjected to a 30 foot free drop at 13.5° (±1°) from vertical center of gravity over the valve. This drop was followed by a 40 inch puncture test in the same orientation. External damage was recorded, but the package was not opened. Test Article #1 was returned to the cooling chamber.

Test Article #2 was removed from the cooling chamber with a recorded insulation temperature of -30°F and subjected to a 30 foot free drop at 60° (±1°) from vertical with initial impact occurring on the closure on the plug end of the overpack (rotated 5° from center) and accelerated secondary impact on the valve end of the overpack. This drop was followed by a 40 inch puncture test directly over the center bolt on the closure plane.

Based on criteria outlined in **Appendix 2.10.6**, Test Article #1 was determined to have suffered the most damage. This package was then removed from the cooling chamber with an insulation temperature of -30°F and subjected to a final 40" puncture test with the longitudinal axis of the package horizontal and the seam between the upper and lower halves of the package at 45°.

Test Article #2 was opened and the 30B cylinder removed. The cylinder was helium leak tested and then subjected to a hydrostatic test at 19 psig (equivalent to the 3 foot immersion test of 10CFR71.73). No leaks were detected.

Test Article #1 was warmed to 100°F in preparation for the 30 minute fire test. The package was then subjected to a 30 minute fully engulfing diesel fuel fire.

After Test Article #1 cooled following the fire, the overpack was opened and the 30B cylinder removed. The cylinder was subjected to a soap bubble leak test and a helium mass spectrometer leak test, then a hydrostatic test at 19 psig (equivalent to the 3 foot immersion test of 10CFR71.73) was performed. No leaks were detected.

The results of the tests and analyses demonstrate that the ESP-30X overpack effectively protects the 30B cylinder from damage. Test reports are provided in **Appendix 2.10.8 and Appendix 2.10.9.**.

2.7.1 ESP-30X Test Article #1

2.7.1.1 Free Drop

A full-scale ESP-30X overpack was used for the 10CFR71 hypothetical accident compliance testing. The test was performed at an angle of 14° from vertical in the center of gravity over the valve orientation, within the 13.5° (±1°) parameters established for the test. The test setup for this 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. The insulation temperature of the overpack was recorded to be -23°F at the time of the first drop test.

After being removed from the cooling chamber, the package was positioned at 14° from vertical and raised 30 feet as measured from the lowest position on the package. The package was rotated so that the impact would be into the valve location.

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 **Appendix 2.10.8** and **Appendix 2.10.9** for photos). Damage is summarized in **Section 2.7.7**. The package was not opened after the 30 foot drop, but was subjected to the 40 inch puncture drop test.

2.7.1.2 Puncture

The puncture ram was a 6" diameter x 16" high mild steel bar welded onto a 2" thick steel plate bolted to the steel plate of the target pad. The test setup for the 13.5° orientation puncture test is shown in **Figure 2.7-3**.

The package was positioned at an orientation of 13.5° from vertical, then raised 40 inches above the puncture bar as measured from the impact point on the package. The package was rotated so that the puncture would be into the valve location.

External deformation data was recorded and documented with both video and still photography. (See **Appendix 2.10.8** for photos). Damage is summarized in **Section 2.7.7**. The package was not opened after the puncture drop, but was returned to the cooling chamber to await evaluation following the series of drop tests on ESP-30X Test Article #2.

2.7.2 ESP-30X Test Article #2

2.7.2.1 Free Drop

A second full-scale ESP-30X overpack was used for the 10CFR71 hypothetical accident compliance testing. The test was performed at an angle of 60° from vertical with impact occurring on the closure (rotated 5° from center) on the plug end of the overpack. The test setup for the 60° orientation drop test is shown in **Figure 2.7-4**.

The 30 foot drop test was performed at low temperature to evaluate the adequacy of the package to perform under reduced temperature. The insulation temperature of Test Article #2 was recorded at -30°F just prior to removal for testing.

After being removed from the cooling chamber, the package was positioned at 60° from vertical (as described above) and raised 30 feet as measured from the lowest position on the package.

The package was dropped onto the target pad. External deformation data was recorded and documented with both video and still photography. (See **Appendix 2.10.8** for photos). Damage is summarized in **Section 2.7.7**. The package was not opened after the 30 foot drop, but was subjected to the 40 inch puncture drop test.

2.7.2.2 Puncture

The test setup for the closure puncture test is shown in **Figure 2.7-5**.

The package was positioned parallel to the ground with the center bolt on the closure plane over the puncture bar, then raised 40 inches above the bar as measured from the impact point on the package.

External deformation data was recorded and documented with both video and still photography. (See **Appendix 2.10.8** for photos). Damage is summarized in **Section 2.7.7**. The package was not opened after the puncture drop, but was held for comparison with ESP-30X Test Article #1 to determine which overpack would be subjected to additional testing.

2.7.3 Side Puncture

According to criteria outlined in **Appendix 2.10.6**, ESP-30X Test Article #1 was determined to have suffered the most damage. The insulation temperature of the package was -30°F at the time of its removal from the cooling chamber.

The test setup for the side puncture test is shown in **Figure 2.7-6**. The package was positioned 40 inches above the puncture bar with the side parallel to the ground and the seam between the top and bottom halves of the overpack at 45°.

External deformation data was recorded and documented with both video and still photography. (See **Appendix 2.10.8** and **Appendix 2.10.9** for photos). Damage is summarized in **Section 2.7.7**. The package was not opened after the puncture drop, but was placed in a warming oven in preparation for the thermal testing.

2.7.4 Thermal

Both cylinders had been instrumented with thermocouples and maximum temperature sensors prior to being loaded into the overpacks. Fourteen thermocouples were installed on the cylinders and an additional six thermocouples were used to monitor the temperature of the fire. The maximum temperature sensors had a range of 150°F - 300°F and were in the form of irreversible self-adhesive temperature tapes with heat sensitive indicators sealed under transparent heat resistant windows.

The thermocouples consisted of 20 ga, type K, Chrome-Alumel grounded junctions with magnesium oxide insulation and Inconel 600 sheath. A hole was drilled in the end of the overpack opposite the valve to serve as a conduit for the thermocouple wires. The hole was packed with insulation and a metal cover was installed over the thermocouple leads to protect them from secondary impacts during the drop testing.

Test Article #1 had been heated to 100°F 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 2.7-7 and 2.7-8** illustrate the fire test configuration. No. 2 diesel fuel was floated on water within the 25' x 25' fuel pan.

The fire was totally engulfing and lasted for 31 minutes. The package was left on the test stand for 24 hours and allowed to cool before moving.

Thermocouple data was obtained both during the fire and during the cool down period. Photographs (**Appendix 2.10.8 and Appendix 2.10.9**) and video of the thermal test were taken. The package was opened for inspection and leak testing (see **Section 2.7.7**).

2.7.5 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 not enter the 30B cylinder following the hypothetical accident conditions.

All seals on the 30B cylinder and in the valve are metal. The valve threads are tinned with solder and then threaded into the cylinder. The tinning material is typically extruded from the threads during the valve installation process. There are no elastomeric seals or gaskets on the cylinder or valve, so any leakage path into the cylinder would be basically identical to a leakage path out of the cylinder.

This being the case, an equivalent hydrostatic test was performed instead of performing a water immersion test. The test pressure is calculated assuming the internal pressure of the cylinder is zero absolute. Therefore, the test pressure is:

$$
\begin{aligned}
P_{\text{Hydro Test}} &= P_{atm} + P_{9.8ft} + \Delta P_{\text{internal pressure}} \\
&= 14.7 \text{ psia} + 4.24 \text{ psia} + 14.7 \text{ psia} \\
&= 33.6 \text{ psia} \\
&= 19 \text{ psig}
\end{aligned}
$$

After completion of all drop and thermal testing, the 30B cylinder was filled with blue-tinted water to 19 psig. (Tinted water would facilitate leak detection since any leakage would contrast against the white painted cylinder. Checks for leakage were made at the valve periodically over an eight hour period and results of the hydrostatic test were recorded. These

results are presented in **Section 2.7.7**.

2.7.6 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). For an undamaged filled 30B cylinder , the internal pressure could be 0 psia and the equivalent external pressure would be 39.3 psig.

The maximum allowable working pressure on the cylinder is 135 psig and, therefore, the 30B cylinder will not be adversely affected by the water pressure.

2.7.7 Summary of Damage and Test Results

Damage from the full compliance testing has been documented through photographs (**Appendix 2.10.8 and Appendix 2.10.9**) and video.

External Overpack Damage

The overpack damage following the 30 foot drop is represented in **Figure 2.7-9.**

The overpack damage following the 40 inch puncture test is represented in **Figure 2.7-10.**

The overpack damage following the side puncture test is represented in **Figure 2.7-11.**

The damage following the 30 minute fire is shown in photographs provided in **Appendix 2.10.8 and Appendix 2.10.9.**

Cylinder Damage

Prior to drop testing, the original dimensions of the cylinder valve in relation to the cylinder skirt were measured. (See **Figure 2.7-12.**)

After the cylinder was removed from the overpack, readings of the irreversible maximum temperature tapes and the temperature paints were recorded. The dimensions of the cylinder valve in relation to the cylinder skirt were re-measured and noted. The locations where measurements were taken and their final values are represented in **Figure 2.7-13**.

Leak Testing

The 30B cylinder had been subjected to leak testing prior to full scale compliance testing to verify that the package met the normal conditions containment criteria discussed in **Section 4**.

The cylinder was pressurized to 100 psig with air and a soap bubble test performed. The pressure was held for 15 minutes. The soap film was applied to the valve threads, stem, packing nut, and cap. No air leaks were detected. Following the soap bubble test, the package was evacuated for a helium leak test. No leaks greater that 1 x 10^{-7} std cc/sec were detected.

After the cylinder was removed from the overpack, it was again subjected to the same air and helium leak test described above. The bubble test at 100 psig did not indicate any leakage. No leaks greater that 1 x 10^{-7} std cc/sec were detected using the helium mass spectrometer method.

Following the leak testing, the steel shot was removed from the cylinder using the bottom plug and the 19 psig hydrostatic test was performed. No water leakage from the cylinder was detected during a period of 8 hours.

2.7.8 Conclusion

Based on the results of the tests, the ESP-30X overpack will absorb the required energy and successfully protect the cylinder and cylinder valve 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:

Damage was obviously insufficient to allow contact between the cylinder valve and either the cylinder skirt or the overpack wall;

The 30B cylinder remained leak tight after accident testing; and

The ESP-30X overpack provided sufficient thermal protection to prevent the temperature of the contents of the 30B cylinder to reach the triple point of UF_6.

Therefore, the ESP-30X overpack will provide adequate protection to the 30B cylinder against the hypothetical accident conditions of 10CFR71.73.

Figure 2.7-1
ESP-30X Package Testing Program

Proc. #	Action (Proceed if Successful)	Decision
1	Bend and Repair 30B Cylinder Skirts	
2	Fill 30B Cylinders with Steel Shot	
3	Install 30B Cylinder Valves	
4	Perform 100 psig Soap Bubble Tests (ANSI N14.1), Note Results	If leak is detected, return to Procedure 3
5	Evacuate Cylinders & Perform Helium Mass Spectrometer Leak Tests, Note Results	If leak >1E-07, return to Procedure 3
6	Load Cylinders into Overpacks	
7	Place Overpacks into Cold Storage to at least -20°F	
8	Remove Test Article #1 from Cold Storage	
9	Perform 30 foot Free Drop, 13.5° from Vertical Orientation on Test Article #1	
10	Record Damage and Measure Crush Area	
11	Perform 40 inch Puncture Drop, 13.5° from Vertical Orientation on Test Article #1	
12	Record Damage and Measure Crush Area	
13	Perform 30 foot Free Drop, 60° from Vertical Orientation on Test Article #2	
14	Record Damage and Measure Crush Area	
15	Perform 40 inch Puncture Drop on closure on Test Article #2	
16	Record Damage and Measure Crush Area	
17	Evaluate Which Overpack Suffered Most Damage	Overpack Suffering Most Damage is Chosen for Additional Testing
18	Perform 40 inch Puncture Drop on Test Article side	
19	Record Damage and Measure Crush Area	
20	Open Test Article Not Subject to Further Testing and Conduct Leak Test on Cylinder	
21	Warm Overpack to 100°F	

22	Perform 30 minute Fire Test	
23	Cool Package	
24	Record External Damage from Fire Test	
25	Open Package	
26	Record Damage	
27	Remove Cylinder from Overpack	
28	Pressurize Cylinder to 100 psig and Perform Soap Bubble Leak Test, Note Results	
29	Evacuate Cylinder and Perform Helium Mass Spectrometer Leak Test, Note Results	
30	Remove Steel Shot	
31	Perform 19 psig Hydrostatic Test, Note Results	
	TESTING COMPLETE	

Figure 2.7-2
ESP-30X Package Test Article #1
Free Drop Orientation

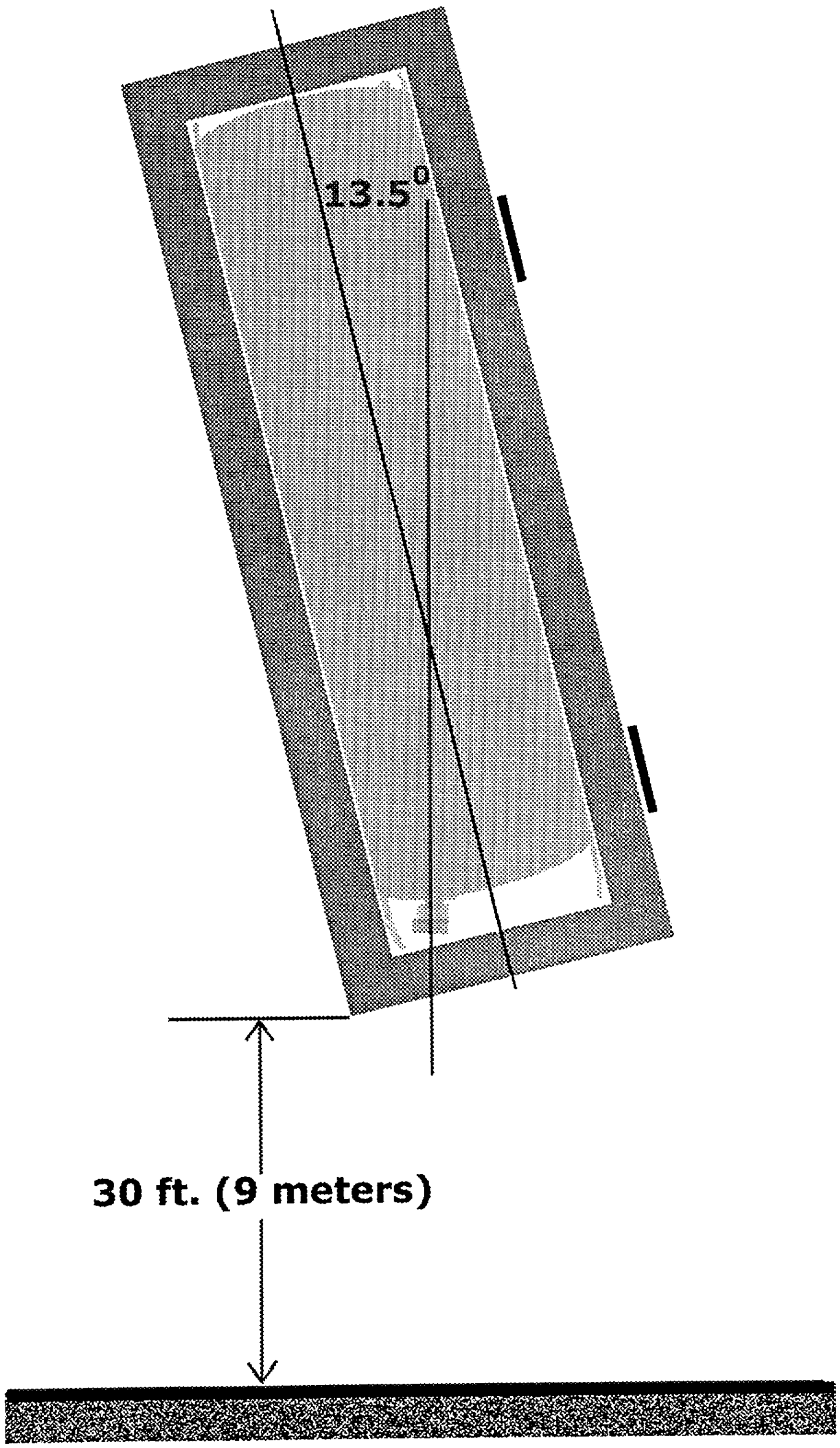


Figure 2.7-3
ESP-30X Package Test Article #1
Puncture Drop Orientation

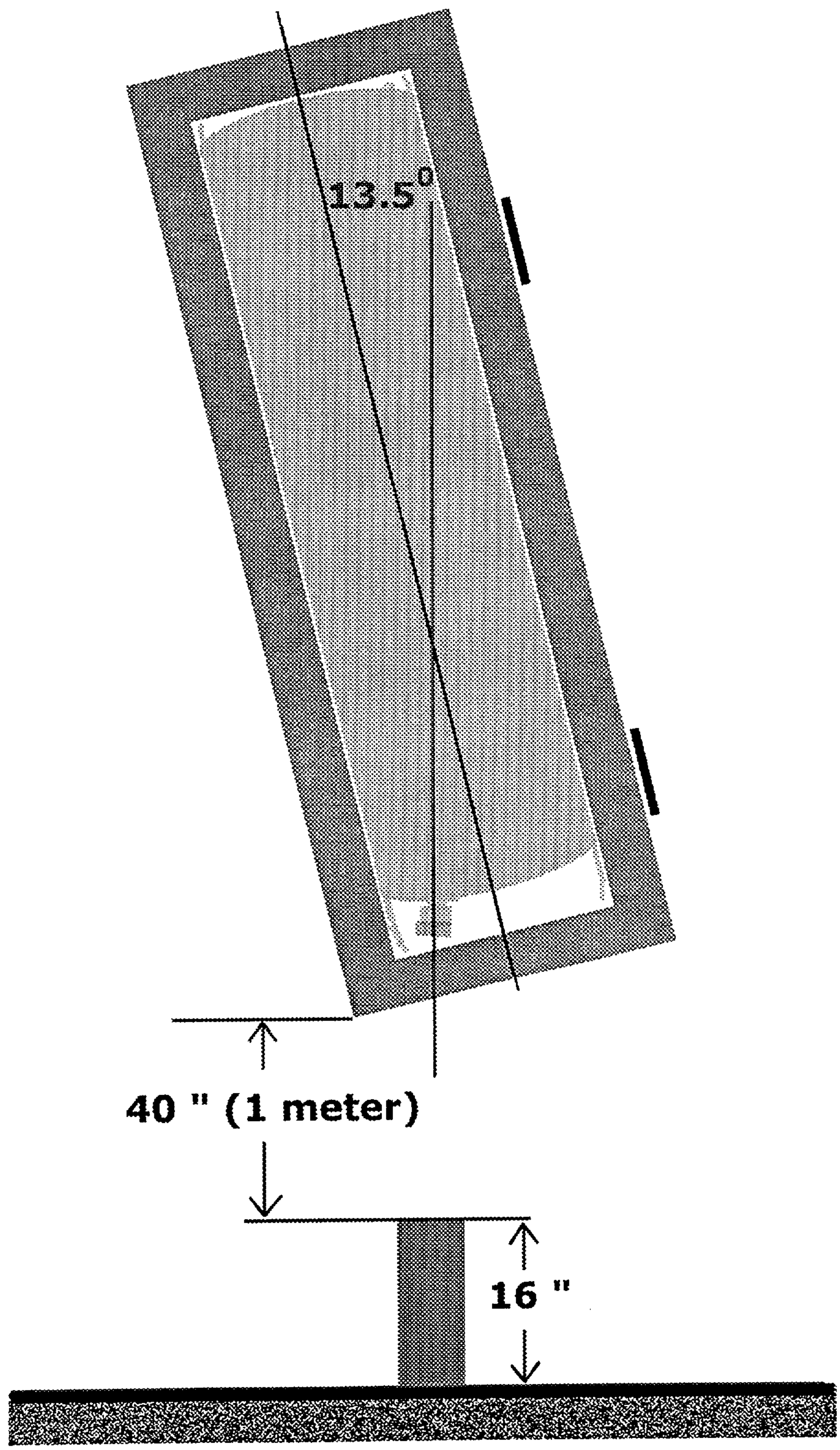


Figure 2.7-4
ESP-30X Package Test Article #2
Free Drop Orientation

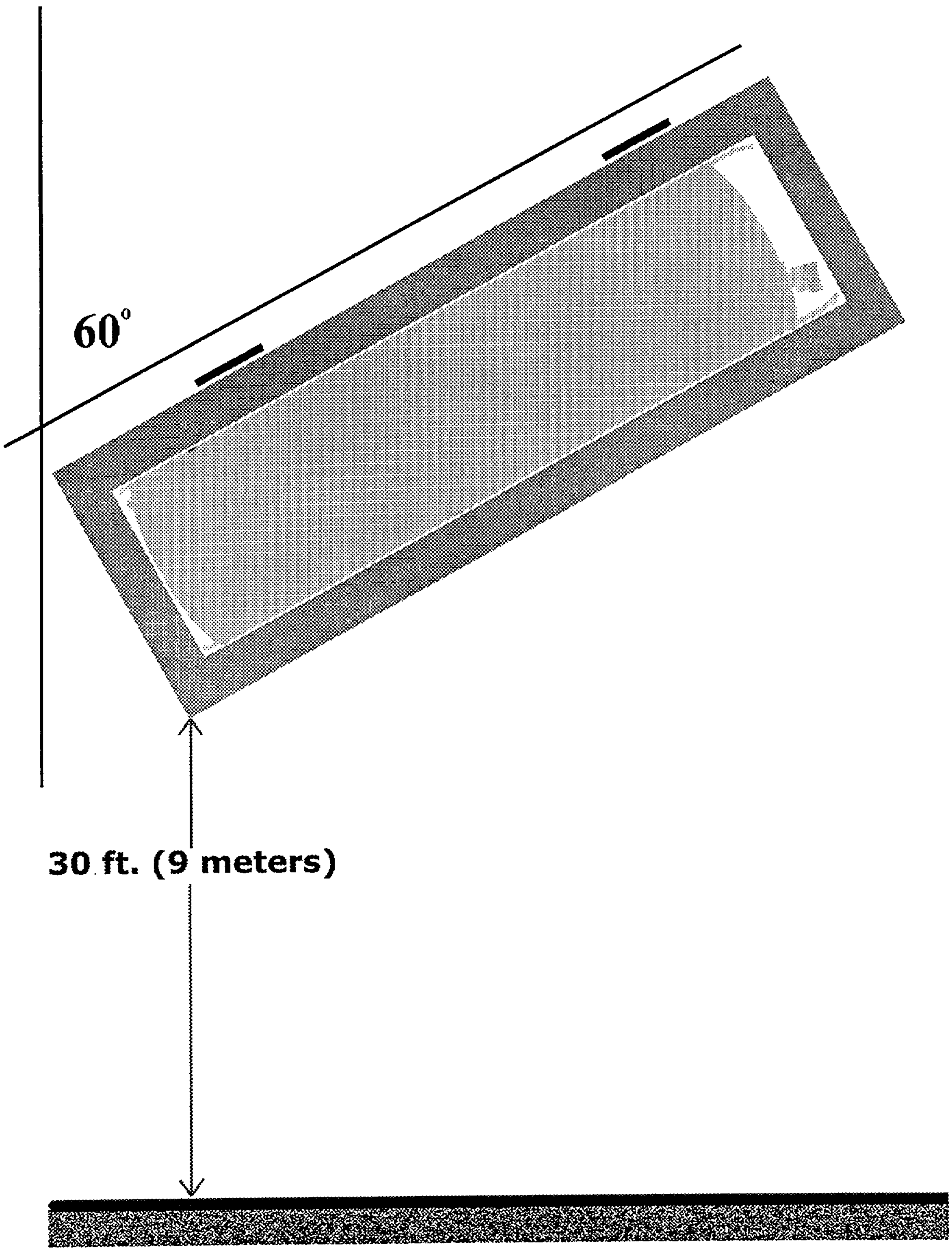


Figure 2.7-5
ESP-30X Package Test Article #2
Puncture Drop Orientation

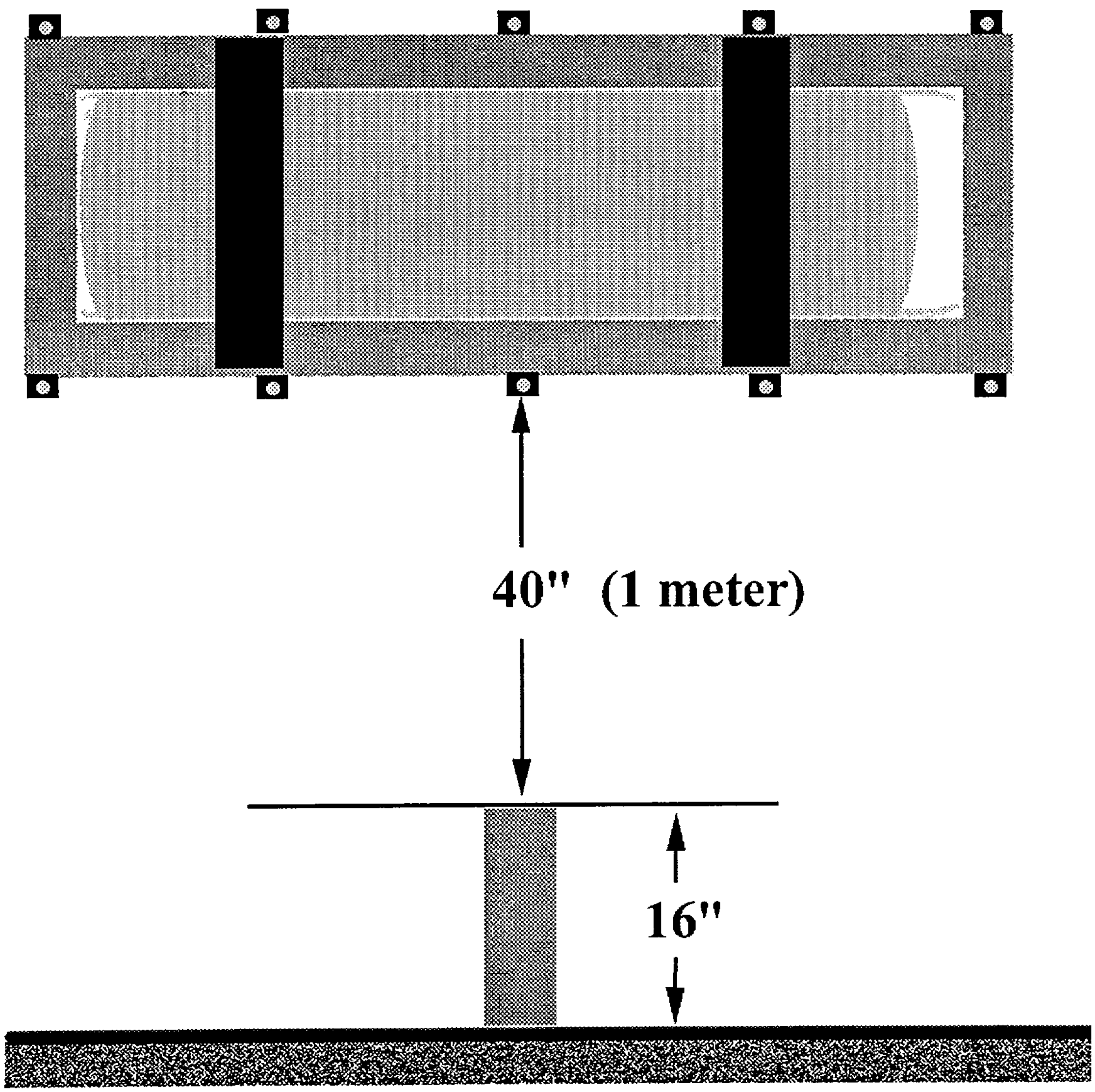


Figure 2.7-6
ESP-30X Package Test Article #1
Side Drop Orientation

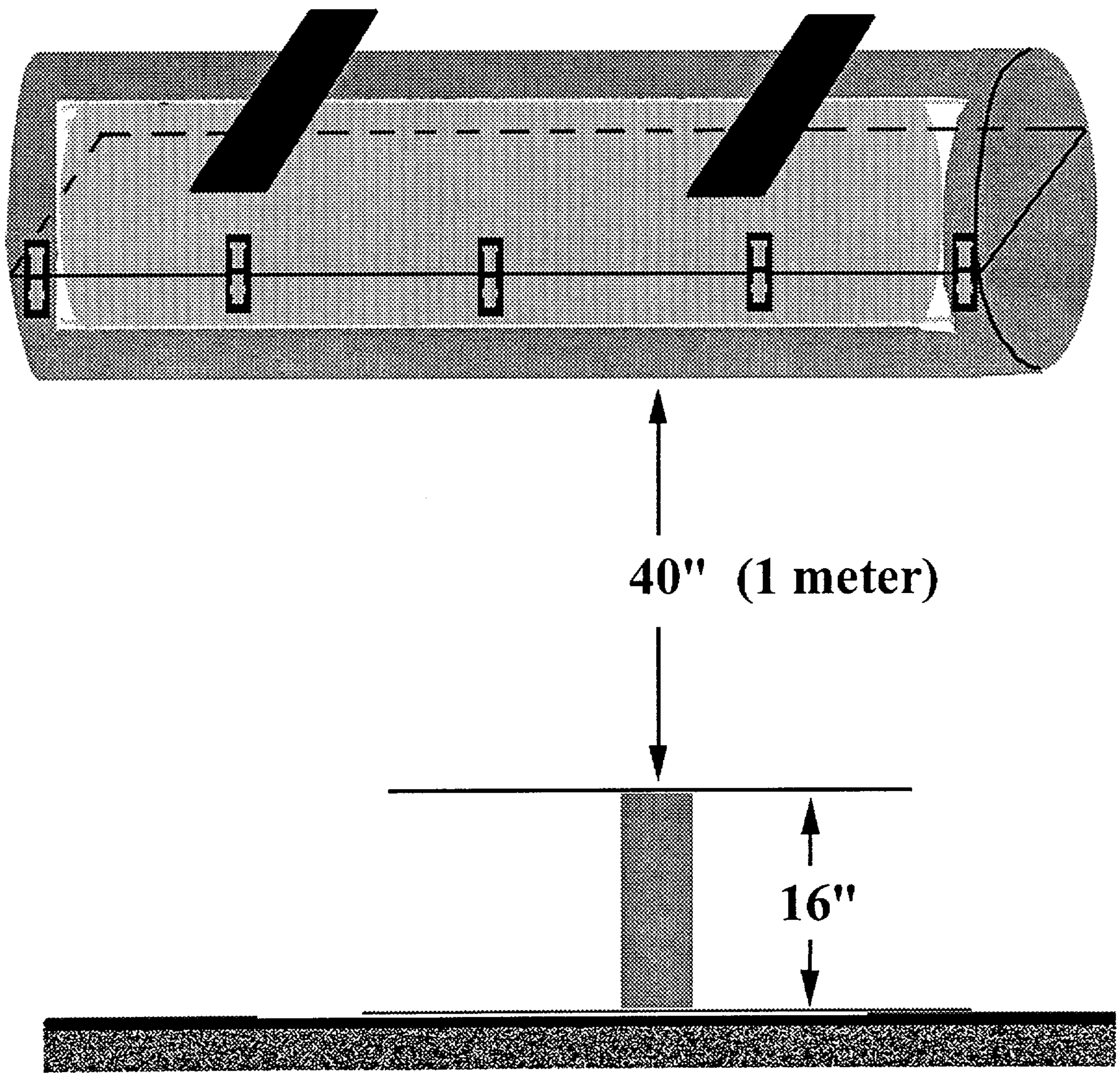


Figure 2.7-7
ESP-30X Package
Thermal Test Fuel Pan Setup (Side View)

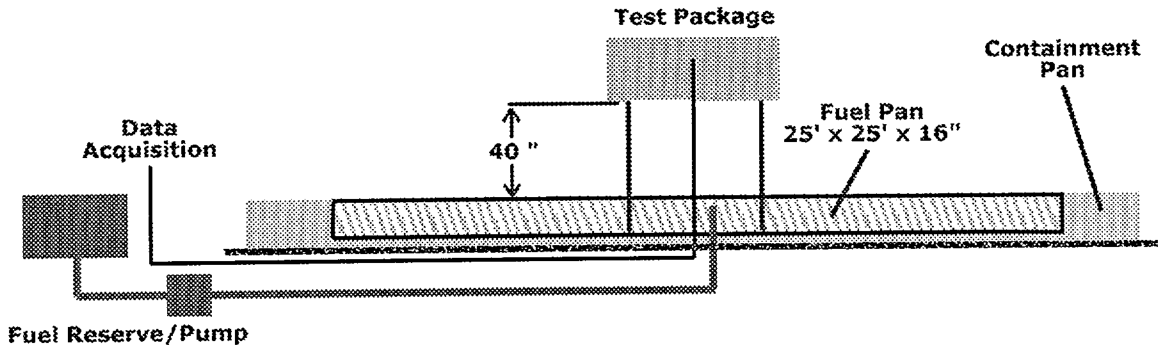


Figure 2.7-8
ESP-30X Package
Thermal Test Fuel Pan Setup (Top View)

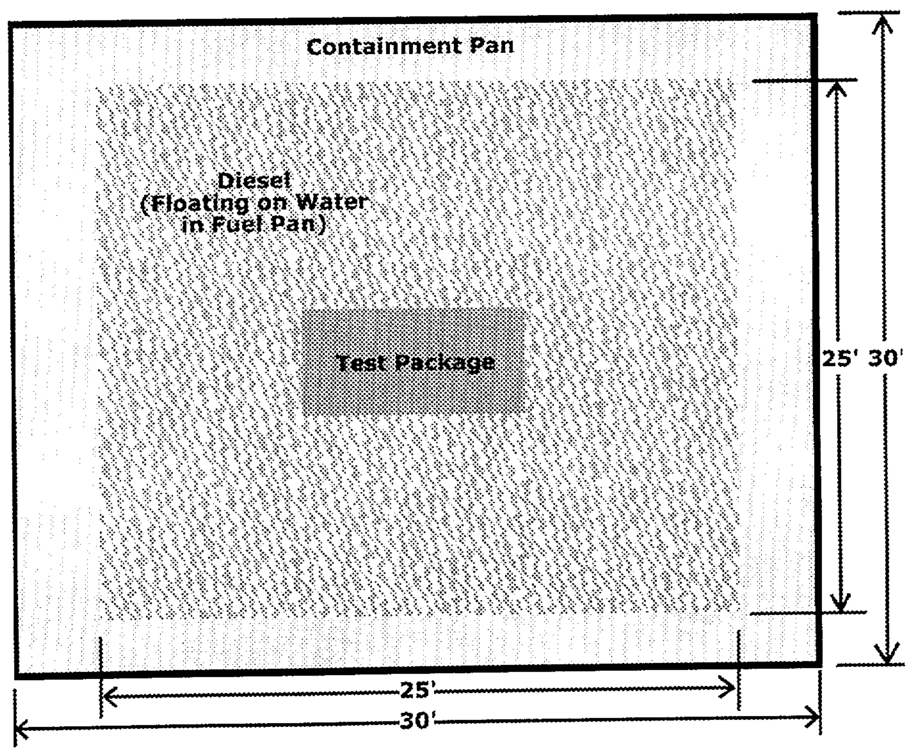


Figure 2.7-9
ESP-30X Package Test Article #1
Damage Following Free Drop Test

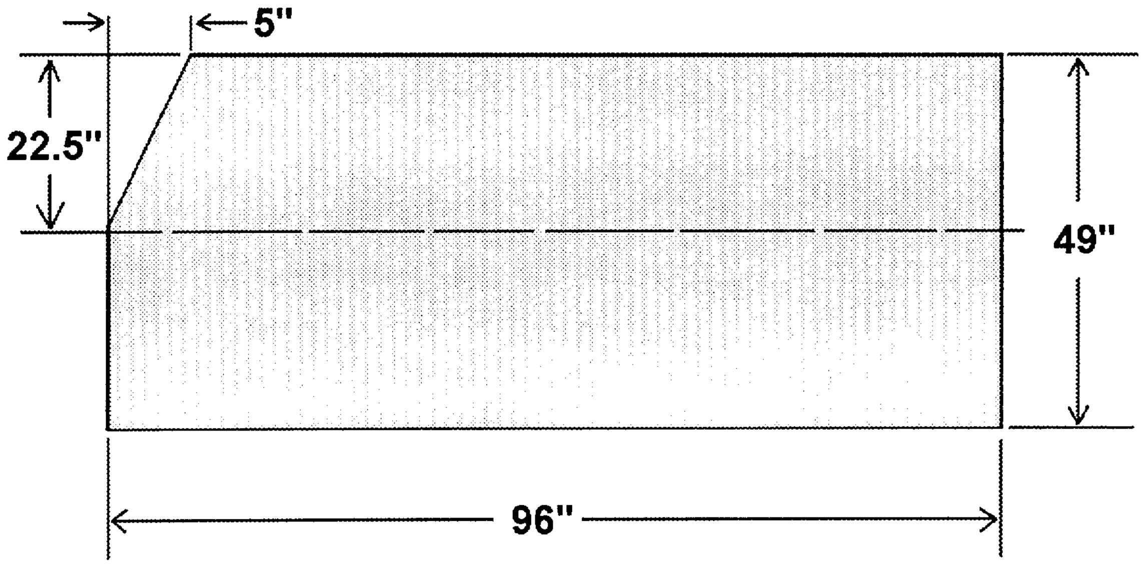


Figure 2.7-10
ESP-30X Package Test Article #1
Damage Following Puncture Drop Test

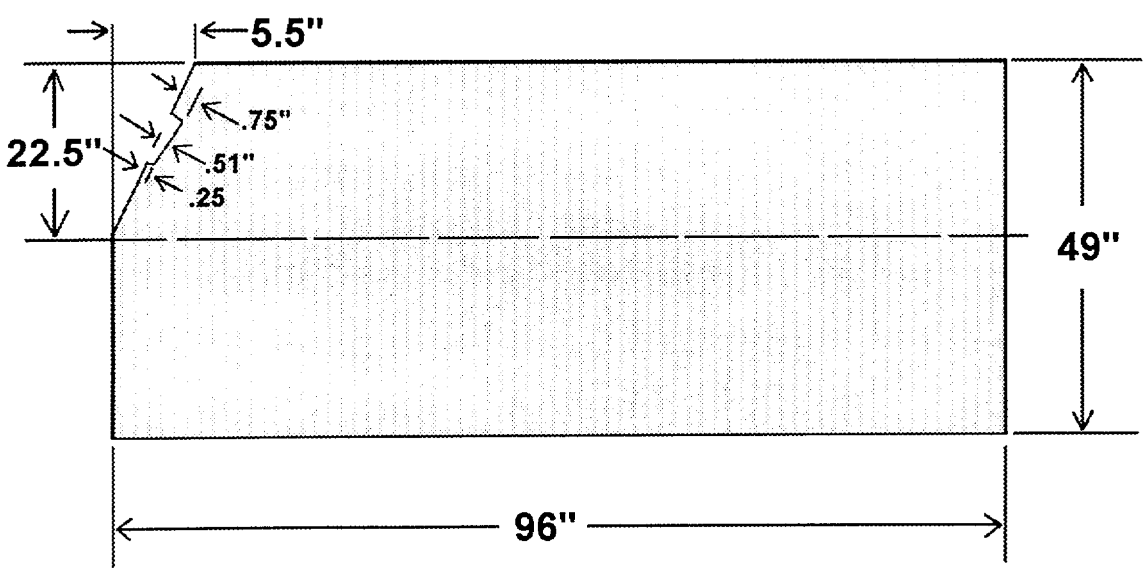


Figure 2.7-11
ESP-30X Package Test Article #1
Damage Following Side Puncture Drop Test

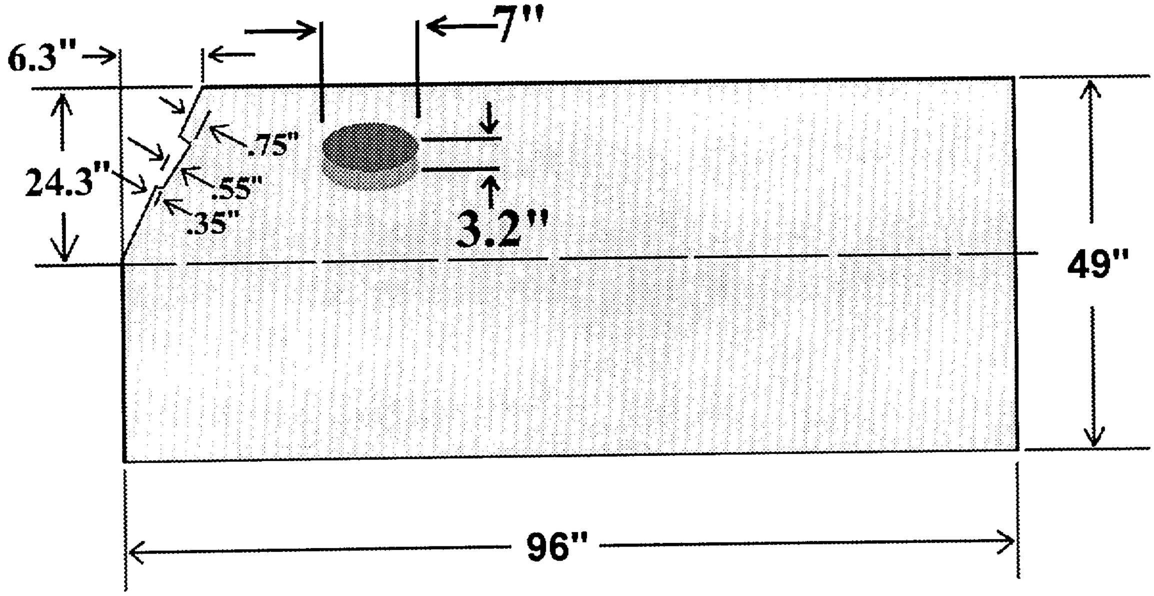
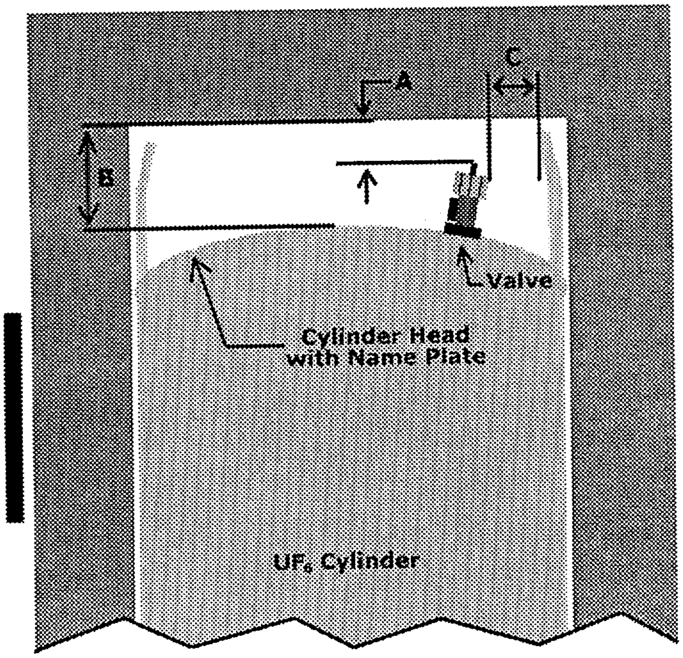


Figure 2.7-12
ESP-30X Package Test Article #1
Valve Placement Measurements Before Testing

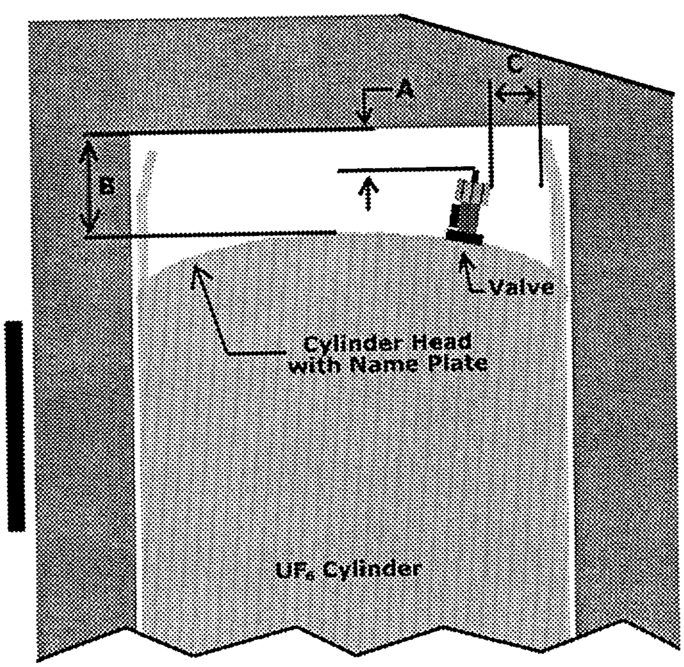


A = .9”

B = 5.3”

C = 2.3”

Figure 2.7-13
ESP-30X Package Test Article #1
Valve Placement Measurements After Testing



A = .9”

B = 5.3”

C = 2.3”

2.8 Special Form

Special form material as defined in 10CFR71 is not applicable to the ESP-30X.

2.9 Fuel Rods

This section is not applicable to the ESP-30X.

2.10 Appendices

2.10.1	Determination of Decay Heat for UF_6 Cylinder Containing Typical Recycled Uranium
2.10.2	Material and Equipment Specification of Phenolic Foam
2.10.3	Chemical and Galvanic Reactions Analysis
2.10.4	Law Engineering Report on Charpy "V" Impact Tests
2.10.5	Law Engineering Report on ESP-PF-1 Foam Characteristics
2.10.6	Criteria for Overpack Damage Evaluation
2.10.7	30B Cylinder Chime Deformation Procedure
2.10.8	Compliance Testing of the ESP-30X Package
2.10.9	Southwest Research Institute Performance Evaluation of UF_6 Shipping Containers Under Hypothetical Accident Conditions

Appendix 2.10.1

Determination of Decay Heat for UF_6 Cylinder Containing Typical Recycled Uranium

If we assume the maximum 1,150 A_2 values per cylinder at an average of 0.1 Ci/A_2 and an average disintegration energy of 5 Mev/d, the corresponding decay heat load in the cylinder is calculated as follows:

1,150 A_2/cyl x 0.1 Ci/A2 = 115 Ci/cyl

$$1.33 \text{ x } 1014 \text{ d/hr/Ci x } \frac{5 \ Mev/d}{6.58 \ x \ 10^{15} \ Btu/Mev} = 0.10 \text{ Btu/hr/Ci}$$

0.10 Btu/hr/Ci x 115 Ci/cyl = 12 Btu/hr per cyl.

Compared with the solar heat loads under Normal Conditions of Transport (see **Section 3.4**) and the larger heat loads under Hypothetical Accident Thermal Conditions, a decay heat load of 12 Btu/hr per cylinder is insignificant.

Appendix 2.10.2

Material and Equipment Specification of ESP-PF-1 Phenolic Foam

ECO-PAK SPECIALTY PACKAGING
ELIZABETHTON, TN

SPECIFICATION NO.: ESP-PF-1

PROCEDURE TYPE: MATERIAL AND EQUIPMENT SPECIFICATION

DESCRIPTION: ESP-PF-1 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	8/15/97	ALL	ORIGINAL
1	5/1/98	2	TECHNICAL ADJUSTMENTS

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APPROVALS

QA MANAGER	CBC EXEC VP OF MANUFACTURING OPERATIONS	ESP PRESIDENT

Eco-Pak Specialty Packaging
Material and Equipment Specification
ESP-PF-1
Fire Resistant Phenolic Foam

SCOPE

This specification shall cover the material requirements for the installation fire resistant phenolic foam with a density range of 8.0-10.0 lbs/ft^3 for the Eco-Pak® PG-1 chemical tank and a density range of 9.5-12.5 lbs/ft^3 for the ESP-30X overpack.

BASIC PHYSICAL PROPERTIES

The phenolic foam shall meet the basic physical properties as listed below.

Compressive Strength

Testing was performed in accordance with ASTM D-1621-94, *Compressive Properties of Rigid Cellular Plastics*. Testing performed on samples with a minimum density of 9.5 lbs/ft^3 for the ESP-30X overpack have a minimum compressive strength of 388 psi, and testing performed on samples with a minimum density of 8.0 lbs/ft^3 for the Eco-Pak® PG-1 have a minimum compressive strength of 165 psi (Attachment 1).

Thermal Conductivity

Based on testing performed on samples ranging in density from 5-20 lbs/ft^3 in June 1995 as described in Attachment 2, the thermal conductivity of the foam ranges from 0.20 to 0.32 Btu-in/hr-ft^2-°F at 75°F. Testing was performed in accordance with ASTM C-518, *Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus*.

Chloride Content

An independent laboratory will provide chloride analysis for each batch of the phenolic resin manufactured. The chloride content of the phenolic resin must be less than 200 ppm. The phenolic foam must also have a chloride content of less than 200 ppm. A random sample of the foam will undergo a chloride analysis on a yearly basis. Initial chloride analysis testing on this phenolic foam shows 42 ppm total chlorides and 40 ppm leachable chlorides (Attachment 3).

STORAGE REQUIREMENTS

Resin Mixture

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 receipt.

Catalysts

1. Store in airtight storage containers.
2. Maximum shelf life at ambient temperature is six months from date of receipt.

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

Receptacles

Receptacles shall be braced as necessary to prevent distortion by the foam and should have vent holes to provide gas relief and prevent voids in the finished foam. The opening used to install the phenolic foam must have a 1.5" minimum diameter.

Temperatures

1. Receptacles shall be at room temperature, but not less than 60°F.
2. The resin mixture shall be at a maximum temperature of 65°F prior to mixing.
3. The catalysts shall be at ambient temperature prior to mixing.
4. The mixed foam shall be at a maximum temperature of 92°F prior to installation.
5. The air temperature shall not be less than 60°F.

OPERATING PROCEDURES

See SOP 6.10.

QUALITY ASSURANCE

Production

Prior to production of each product utilizing this 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 installed in each package is that which is required by dividing the difference in package weight before and after the

foaming operation by the volume of the foam cavity.

Records

A foaming record (Attachment 4) must be completed for foaming operations 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. Thermal conductivity report
3. Initial chloride analysis for samples of the phenolic resin and foam
4. Foaming Record

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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 06
April 28, 1998

High Density Samples

Direction 1

SAMPLE ID+	MASS (lbs)	VOLUME (ft^3)	DENSITY (lbs/ft^3)	PEAK LOAD(lbs)	AREA (in^2)	COMPRESSIVE STRENGTH(psi)
1A	0.0468	0.0048	9.78	1813.95	4.11	441.71
2A	0.0449	0.0047	9.66	1777.32	4.00	444.33
3A	0.0467	0.0048	9.63	1826.16	4.17	438.15

Direction 2

SAMPLE ID+	MASS (lbs)	VOLUME (ft^3)	DENSITY (lbs/ft^3)	PEAK LOAD(lbs)	AREA (in^2)	COMPRESSIVE STRENGTH(psi)
1B	0.0435	0.0045	9.65	1505.65	3.88	388.02
2B	0.0438	0.0045	9.83	1544.57	3.85	401.51
3B	0.0440	0.0046	9.65	1520.15	3.91	388.45

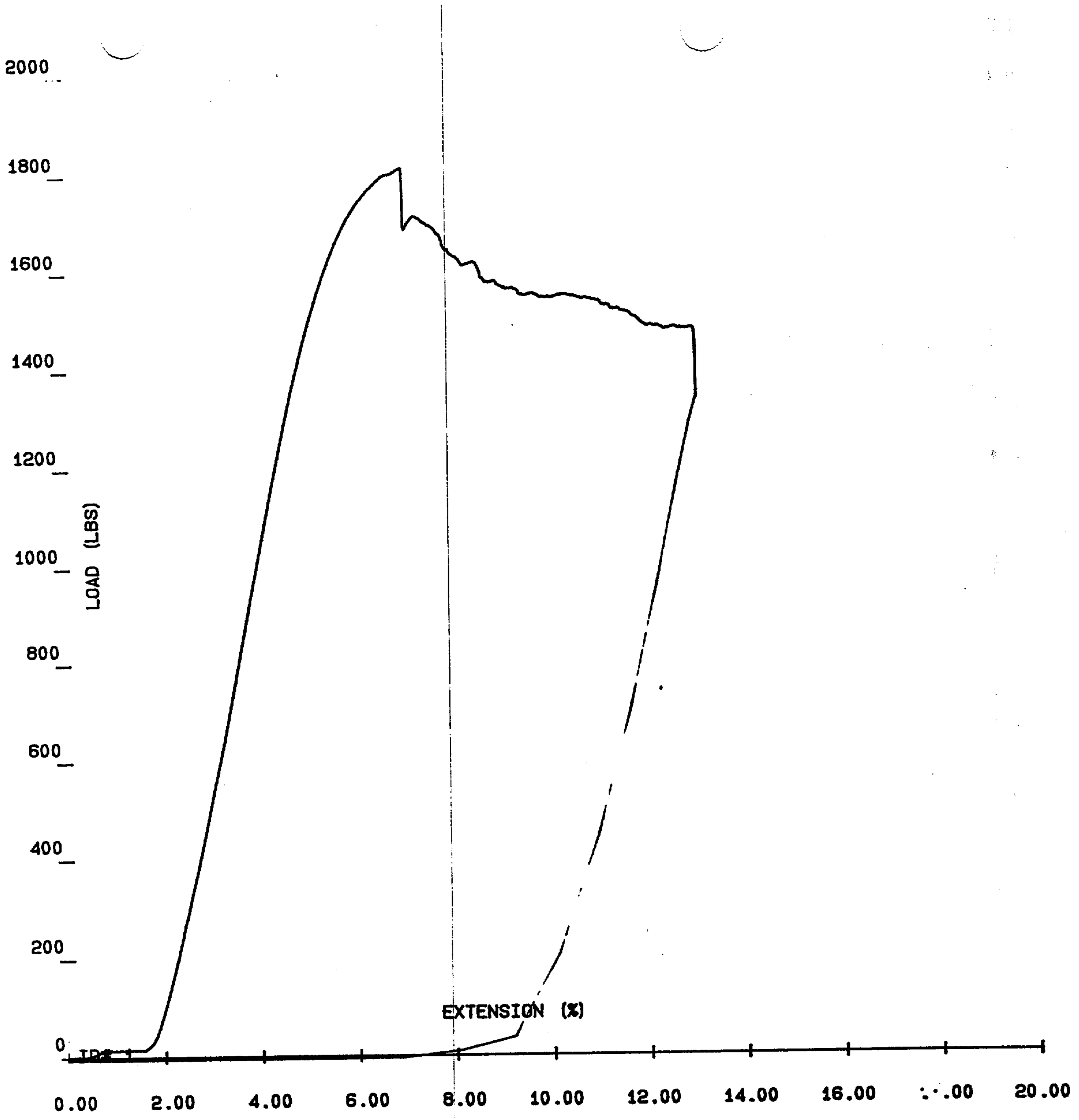
Rate = 0.200in/min
Preload = 1.00 lbs

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

Respectfully submitted,

Lakshman Santanam
Charlotte Technical Center Manager

SAMPLE 1
1A



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SAMPLE I.D
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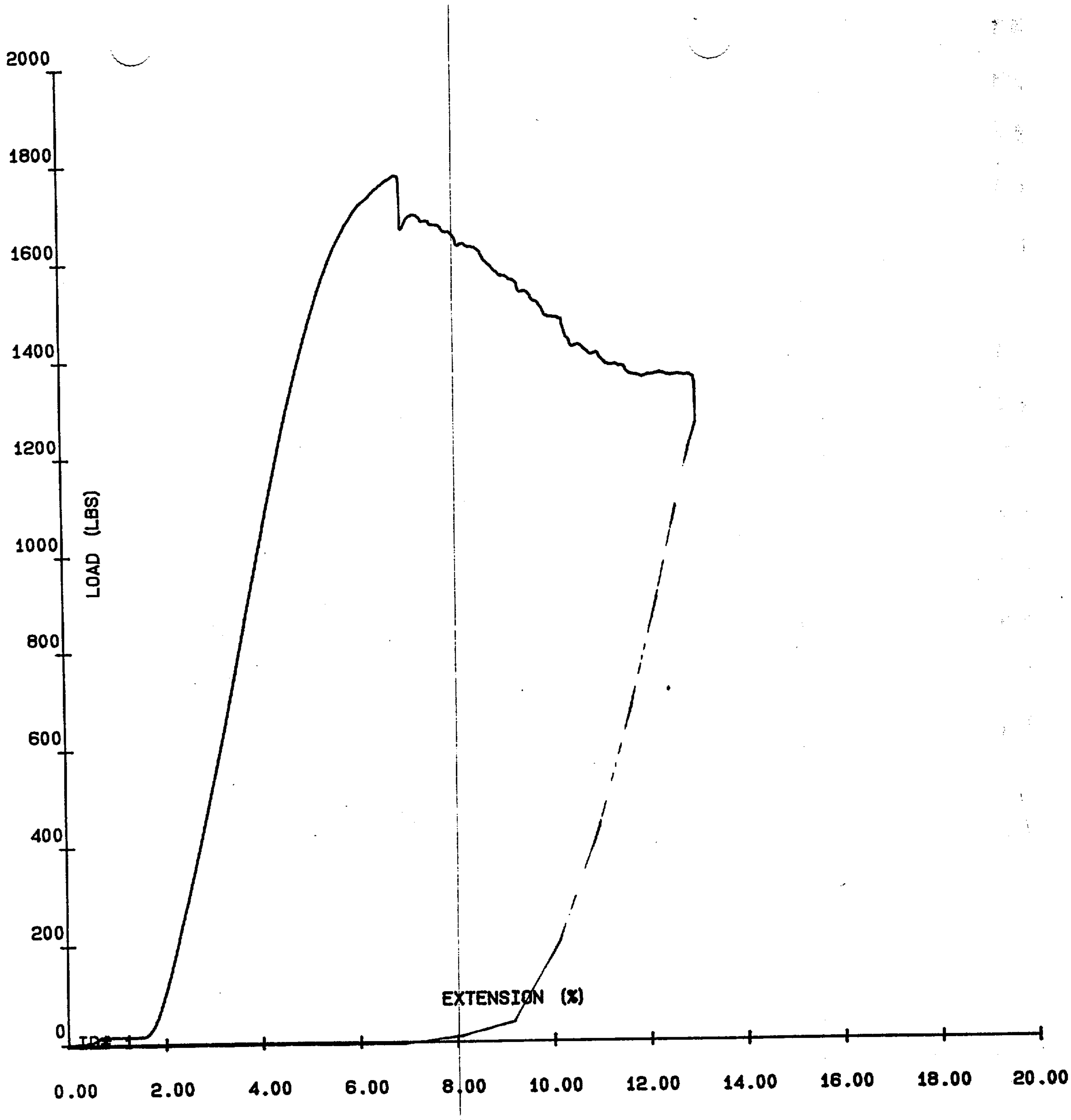
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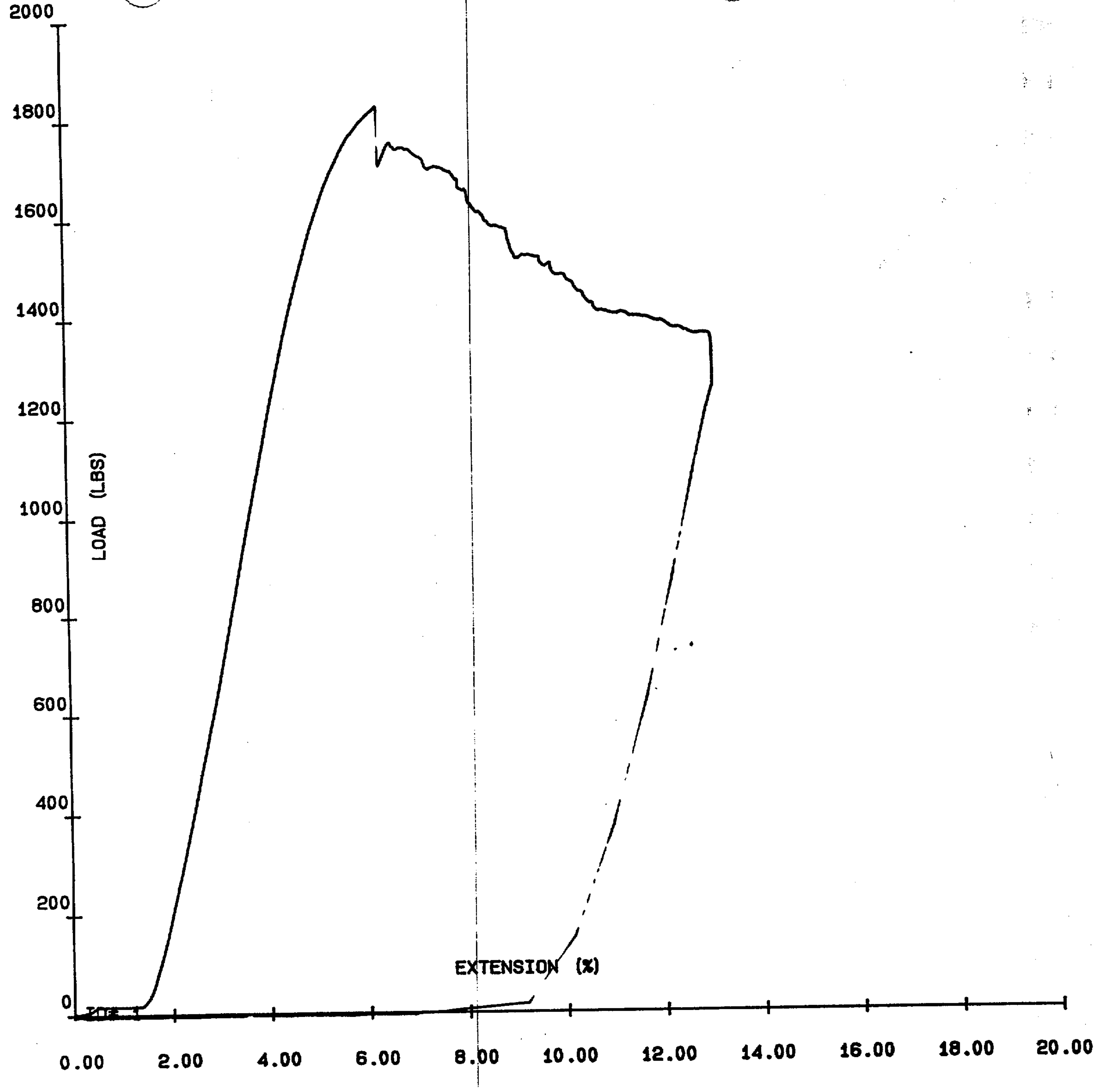

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SAMPLE
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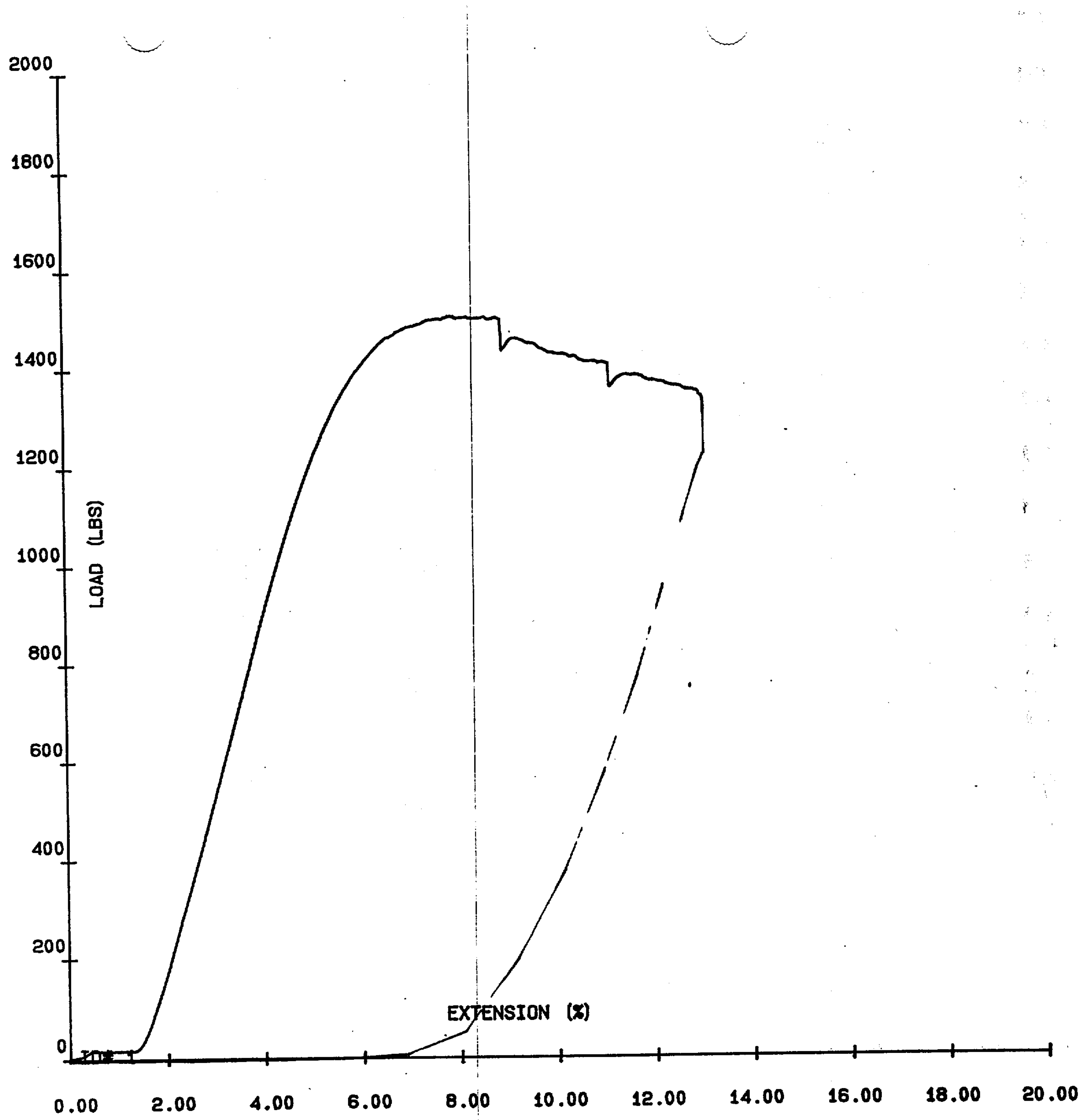
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5 AE I.D.
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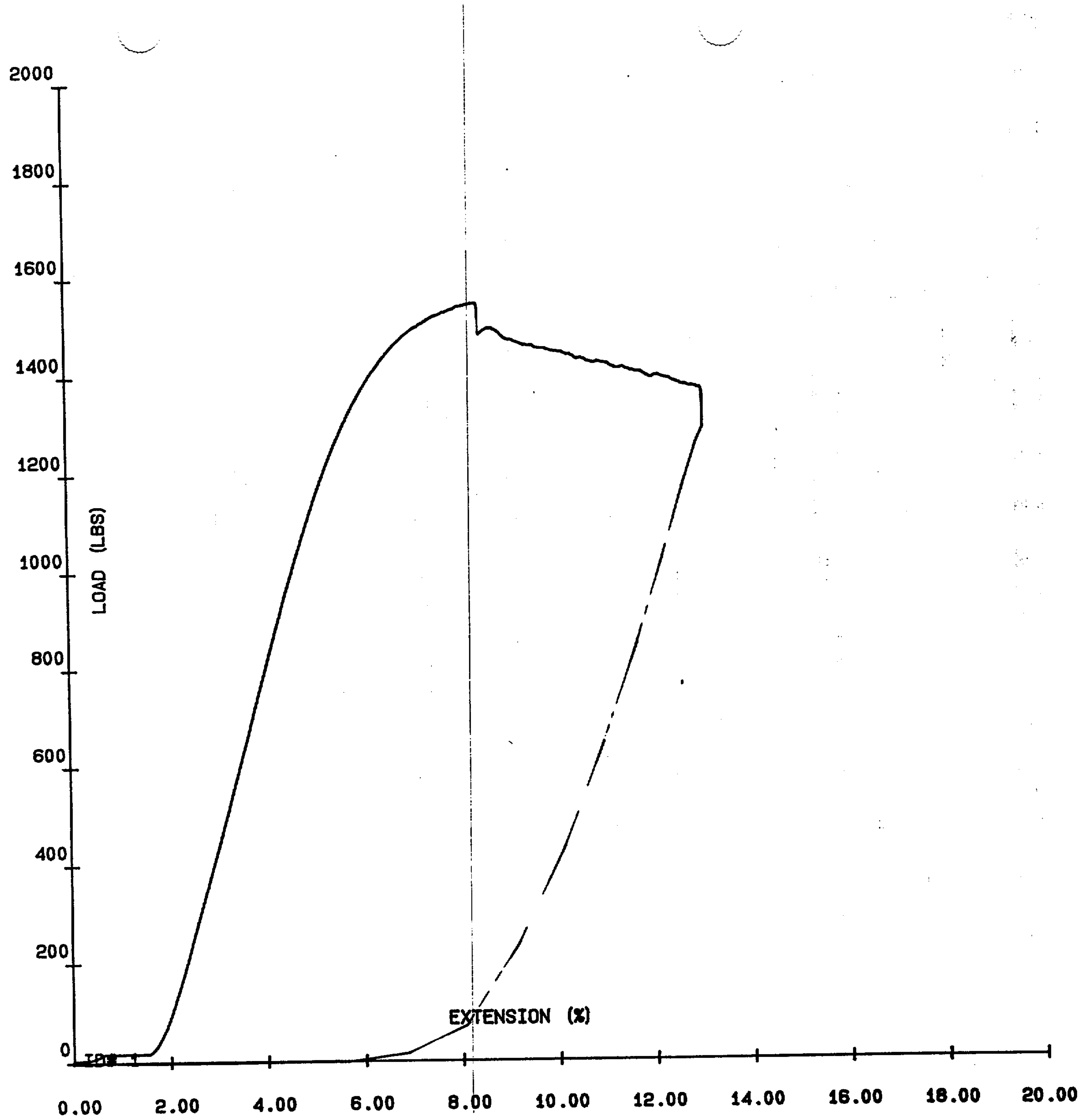

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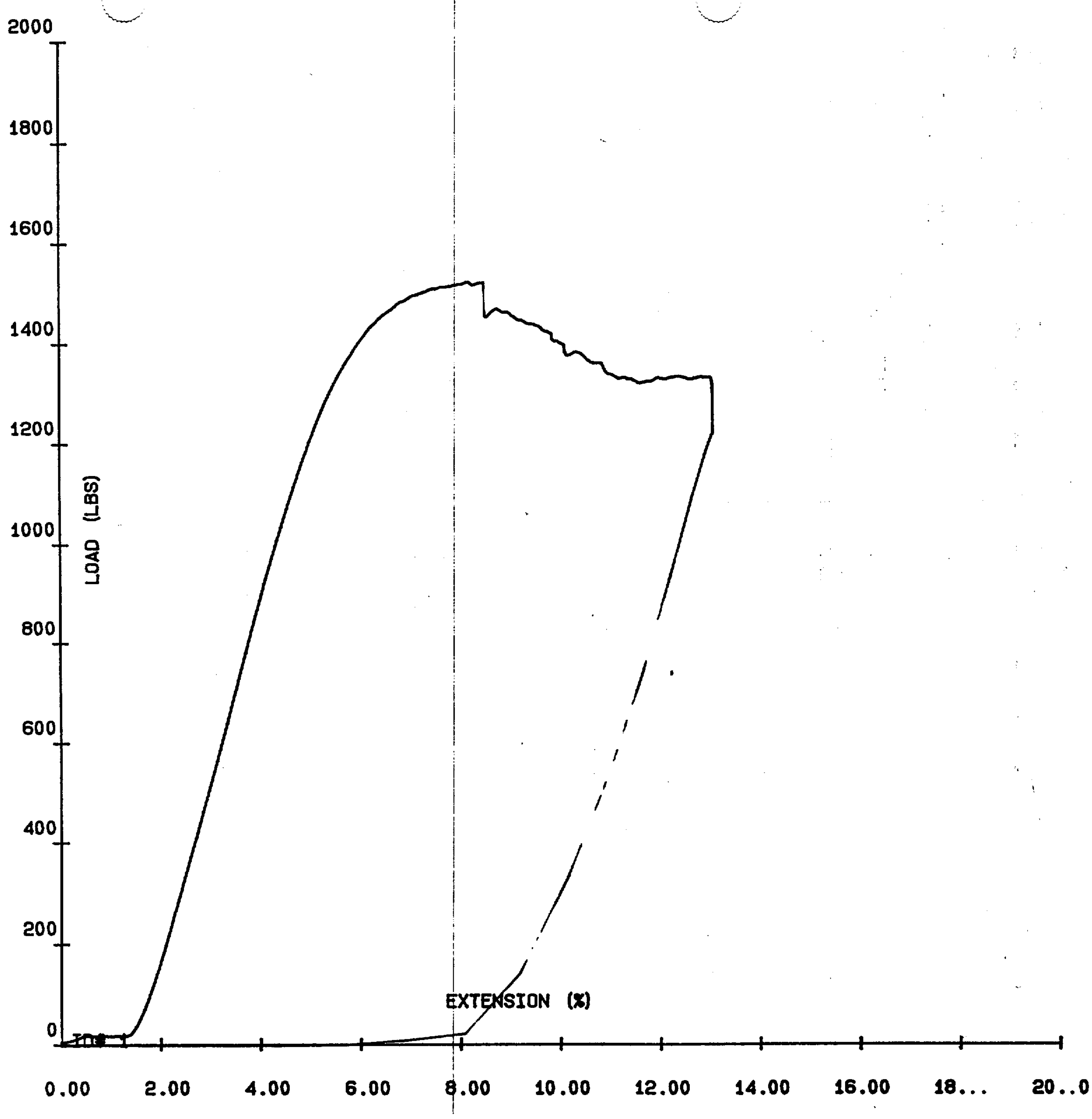

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PHONE 704-357-8600 •FAX 704-357-8637

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

High 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	S	0.0372	0.0047	7.97	896.67	4.00	223.94
100°F	T	0.0376	0.0047	8.00	855.46	4.00	213.67
100°F	U	0.0384	0.0048	7.98	806.62	4.16	193.84
74°F	V	0.0384	0.0048	8.00	971.46	4.13	235.41
74°F	W	0.0380	0.0048	8.00	931.00	4.09	227.47
74°F	X	0.0384	0.0048	8.00	1000.46	4.11	243.66
-20°F	Y	0.0384	0.0047	8.12	1026.40	4.09	250.83
-20°F	Z	0.0376	0.0047	8.00	929.49	4.09	227.15
-20°F	AA	0.0394	0.0048	8.21	1072.19	4.15	258.11

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

Respectfully submitted,

Lakshman Santanam
Charlotte Technical Center Manager

LAW ENGINEERING INDUSTRIAL SERVICES
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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

High Density Samples (Direction 2)

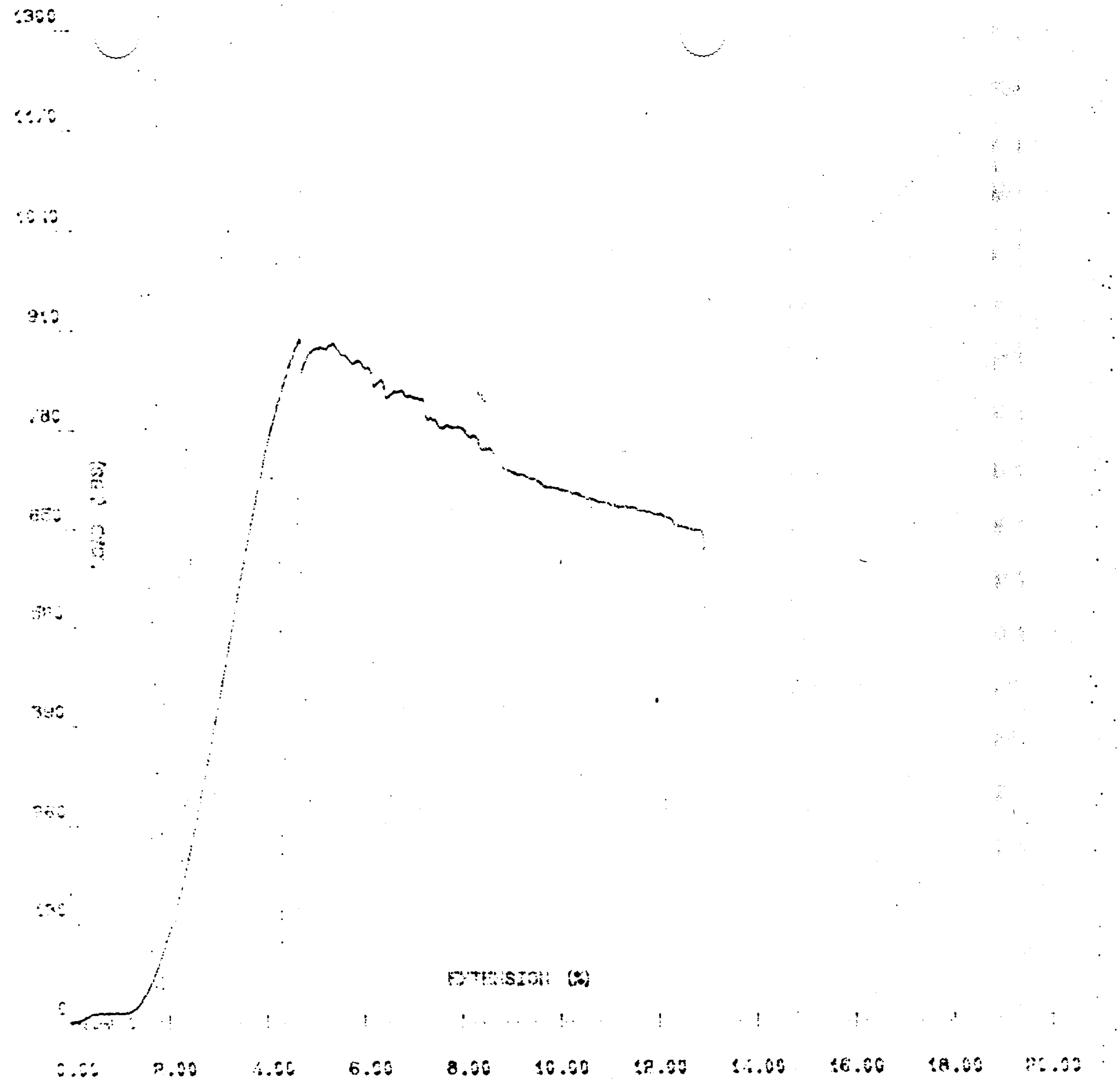
TEST TEMP.	SAMPLE ID+	MASS (lbs)	VOLUME (ft^3)	DENSITY (lbs/ft^3)	PEAK LOAD(lbs)	AREA (in^2)	COMPRESSIVE STRENGTH(psi)
100°F	BB	0.0390	0.0049	8.04	645.60	4.01	160.86
100°F	CC	0.0388	0.0047	8.20	659.34	3.91	168.75
100°F	DD	0.0374	0.0048	7.82	591.42	4.03	146.88
74°F	EE	0.0382	0.0048	7.93	652.47	3.99	163.66
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

100% HIGH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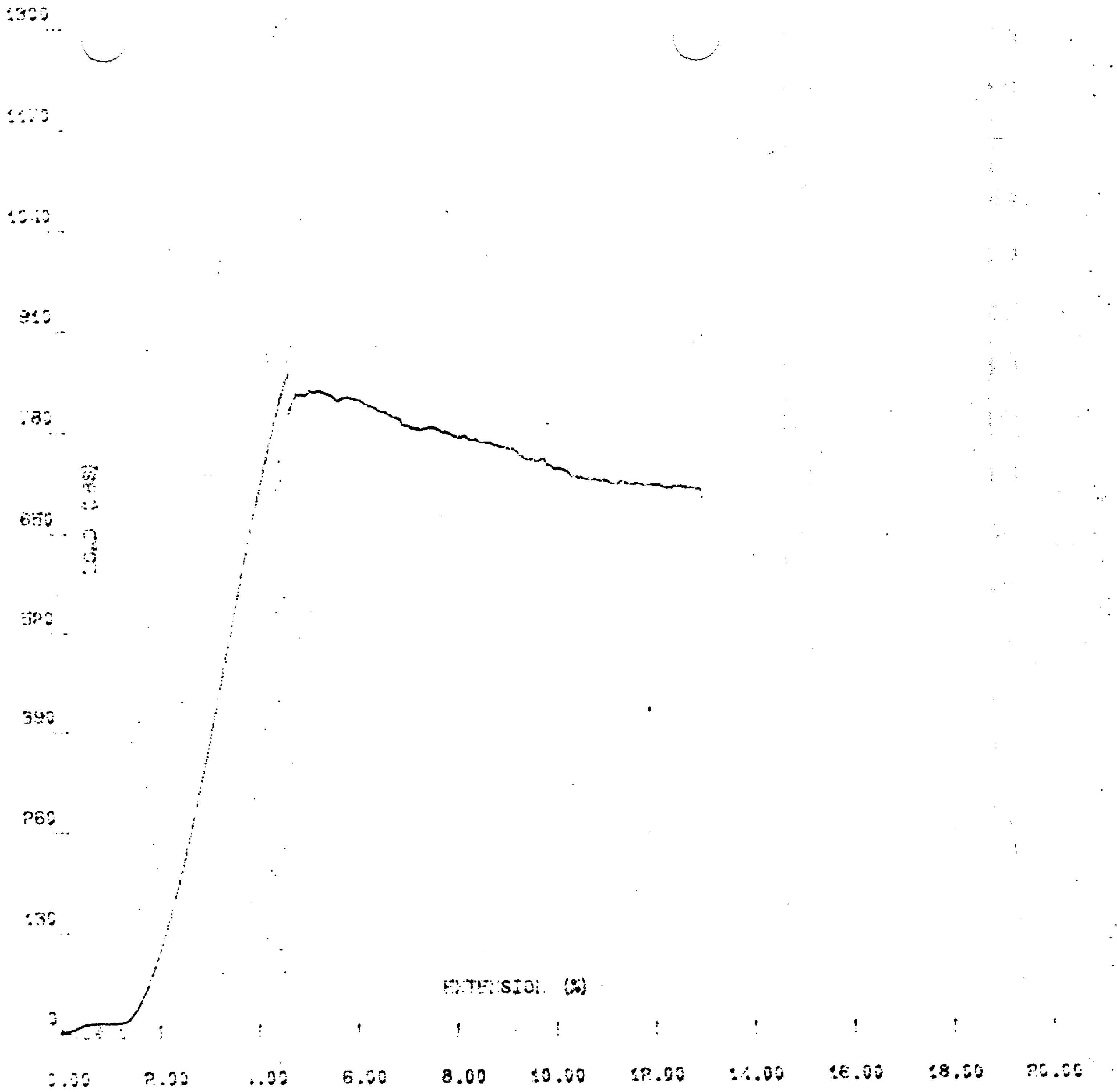
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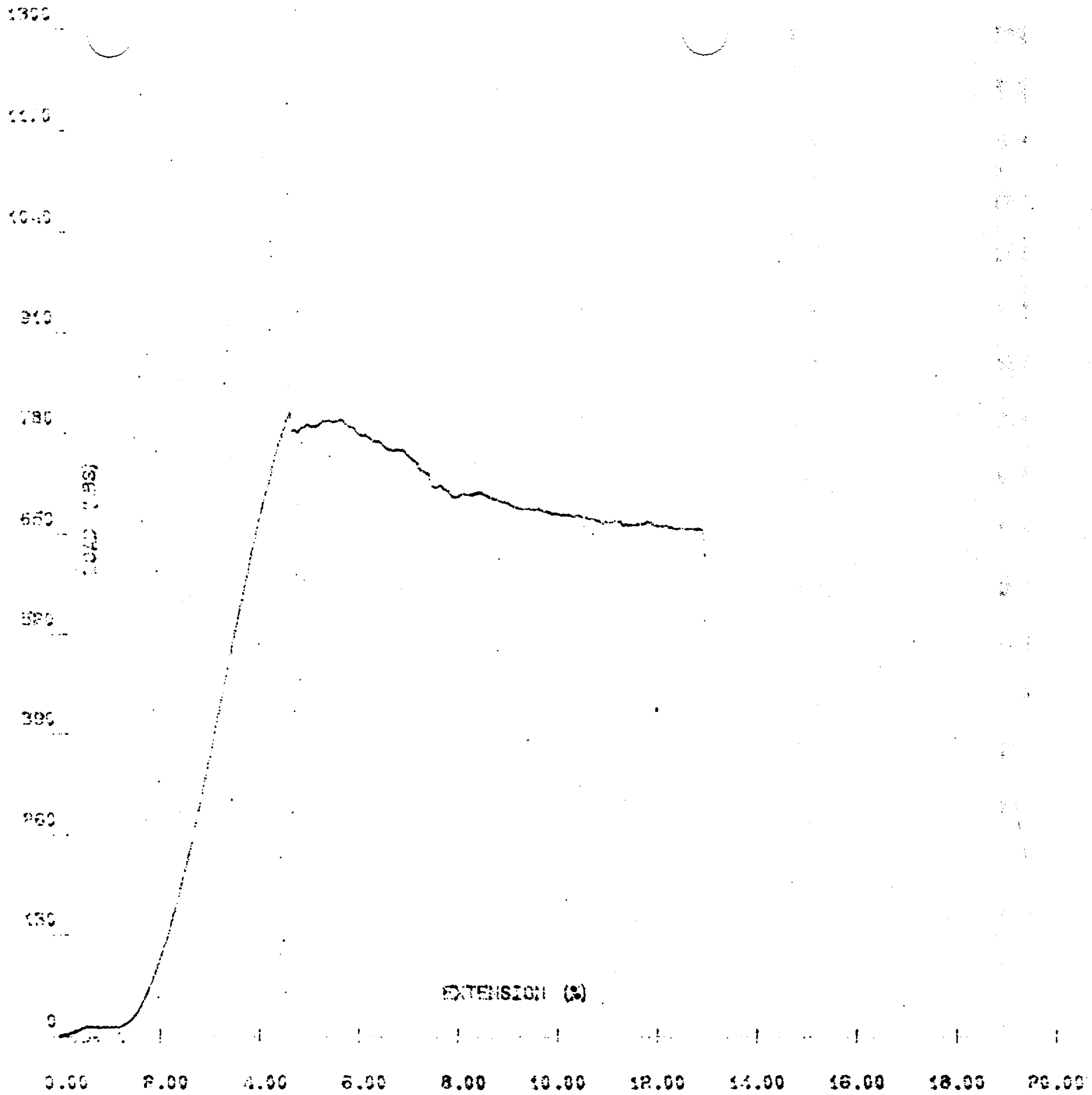
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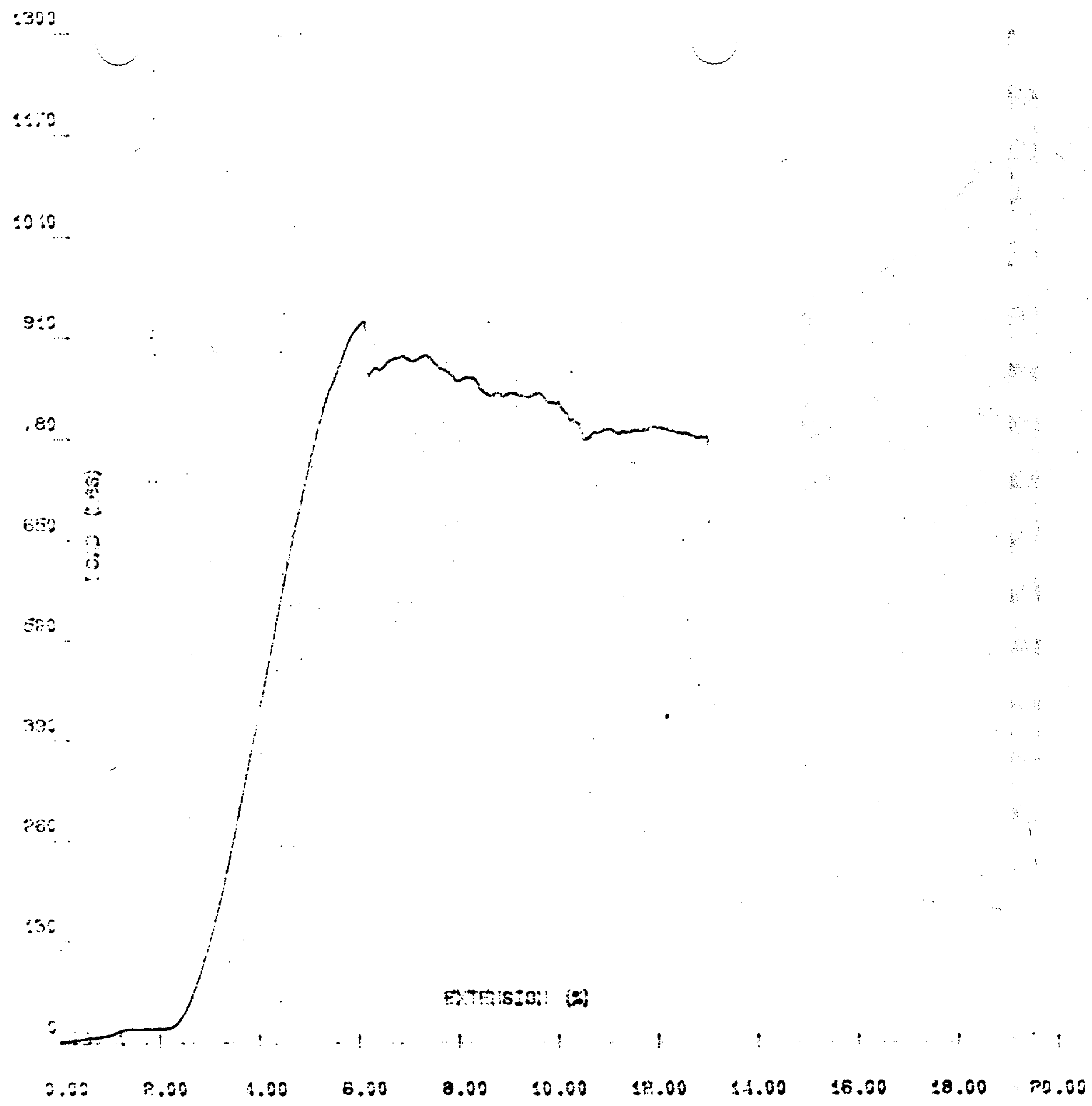

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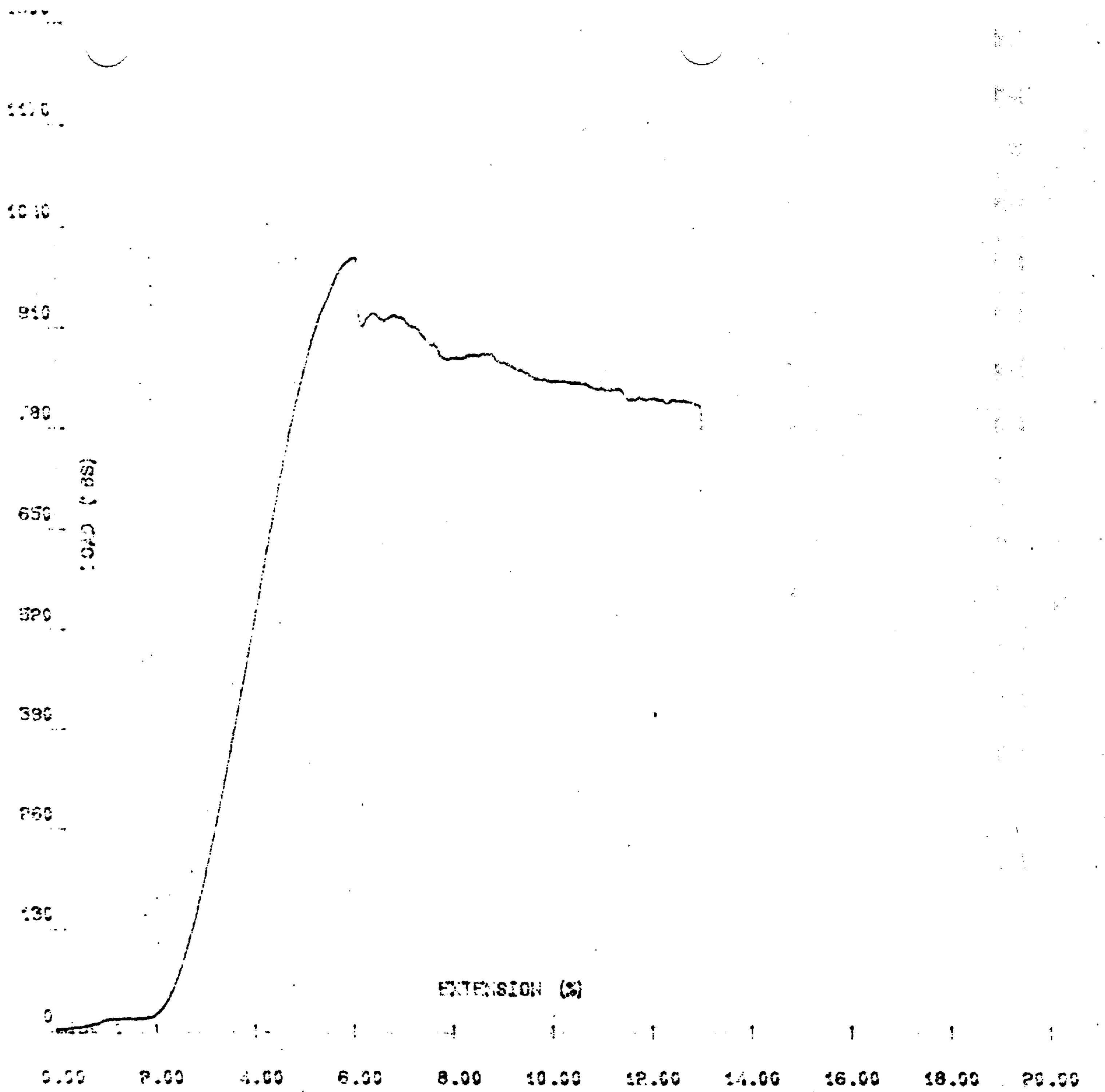
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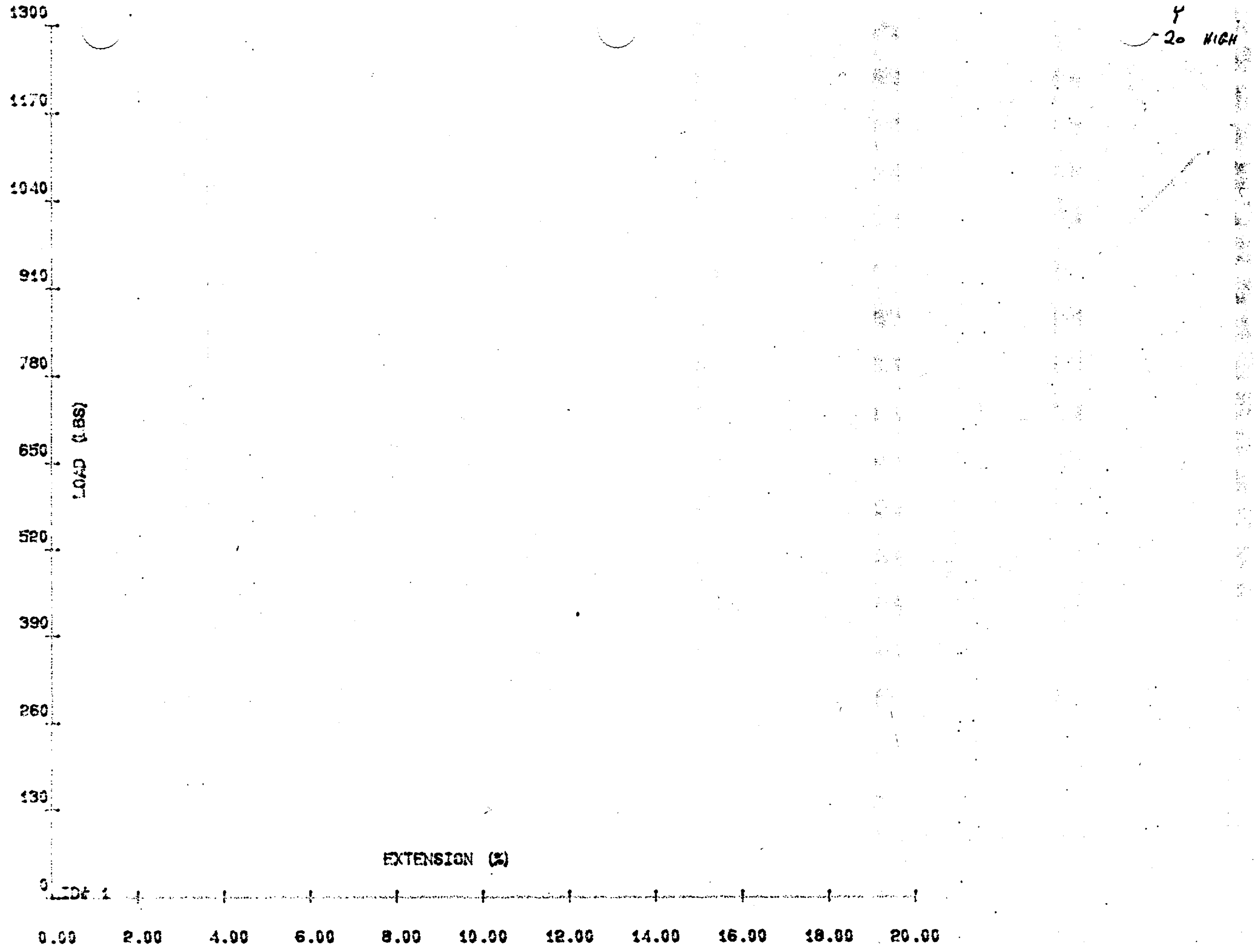

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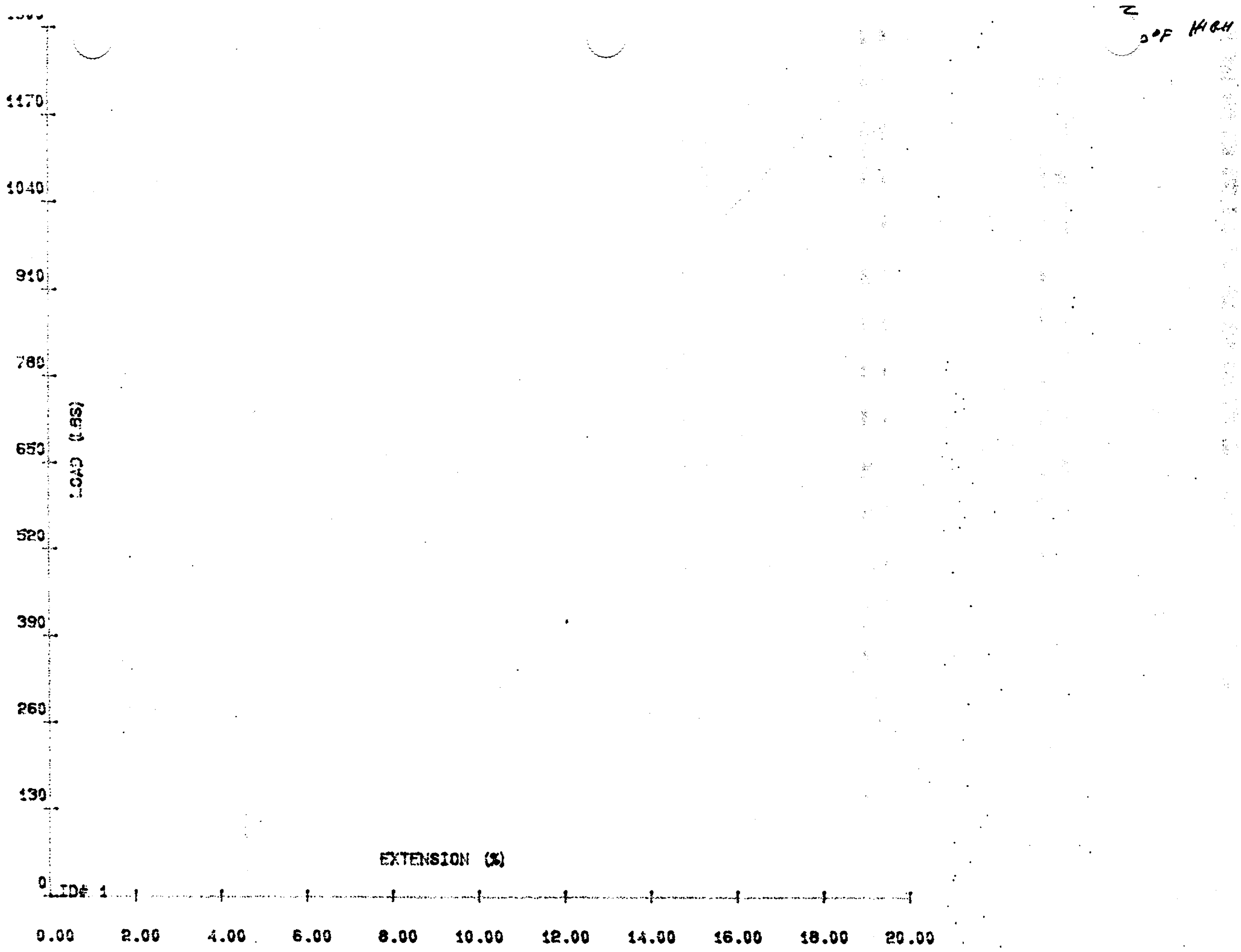

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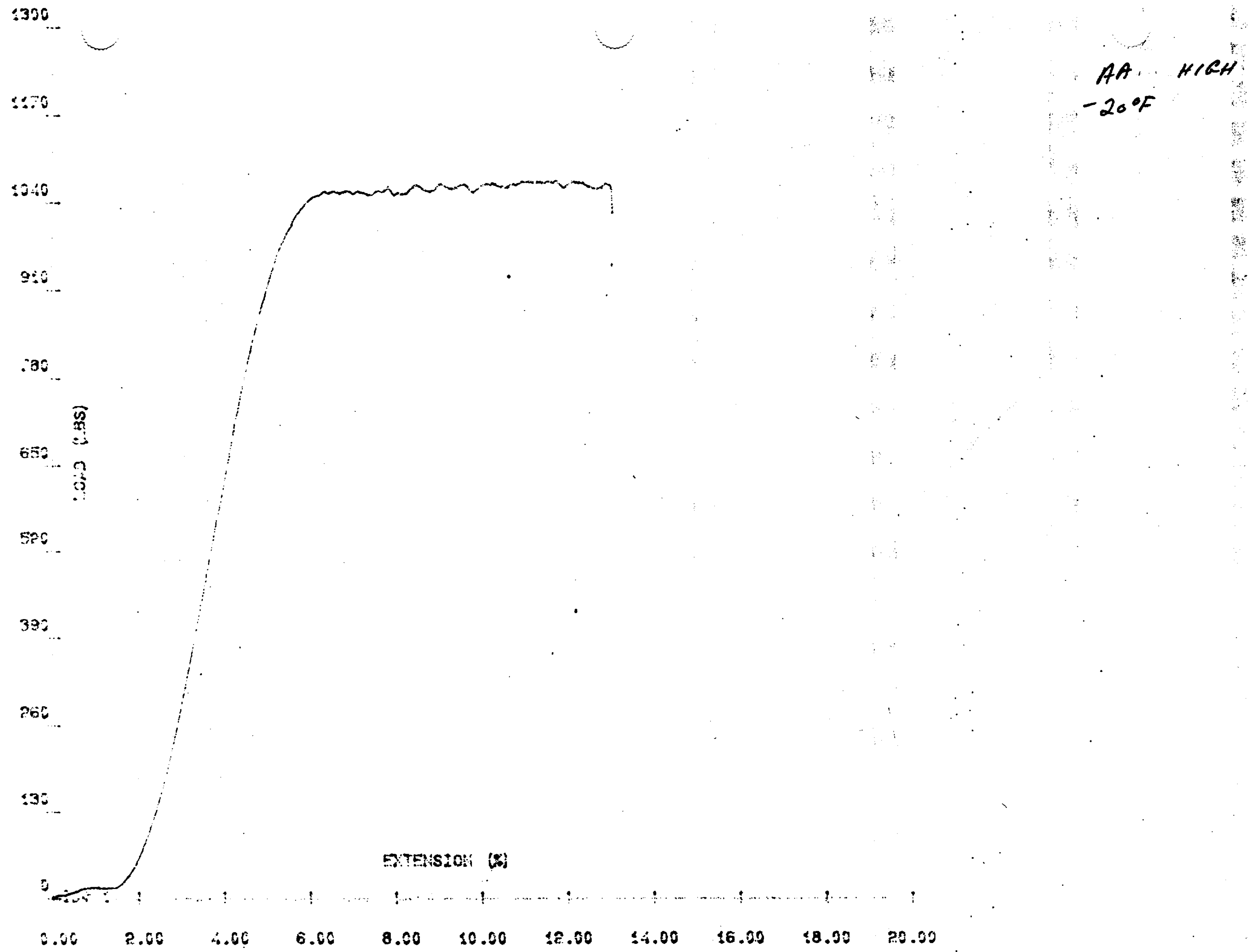

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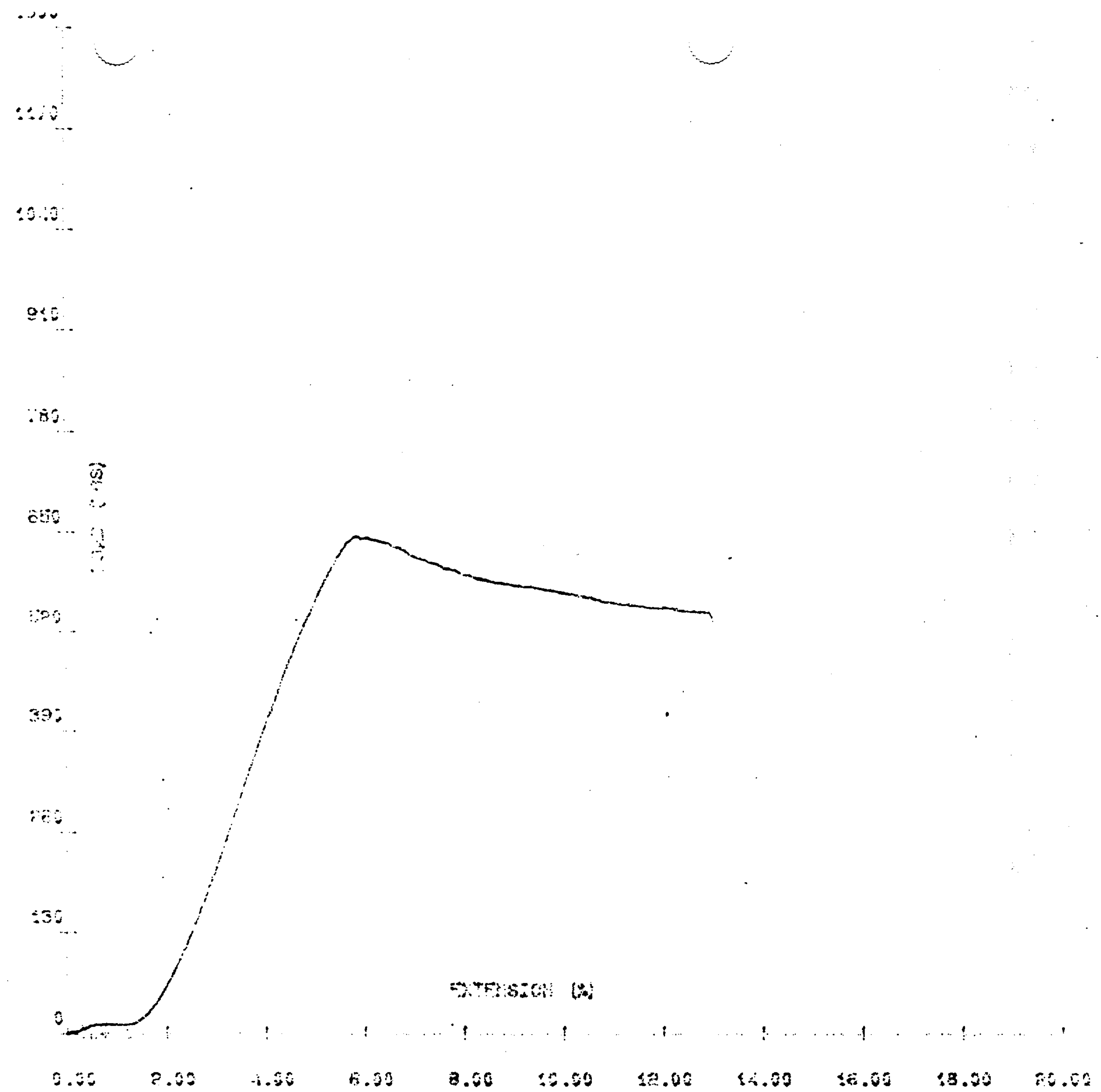

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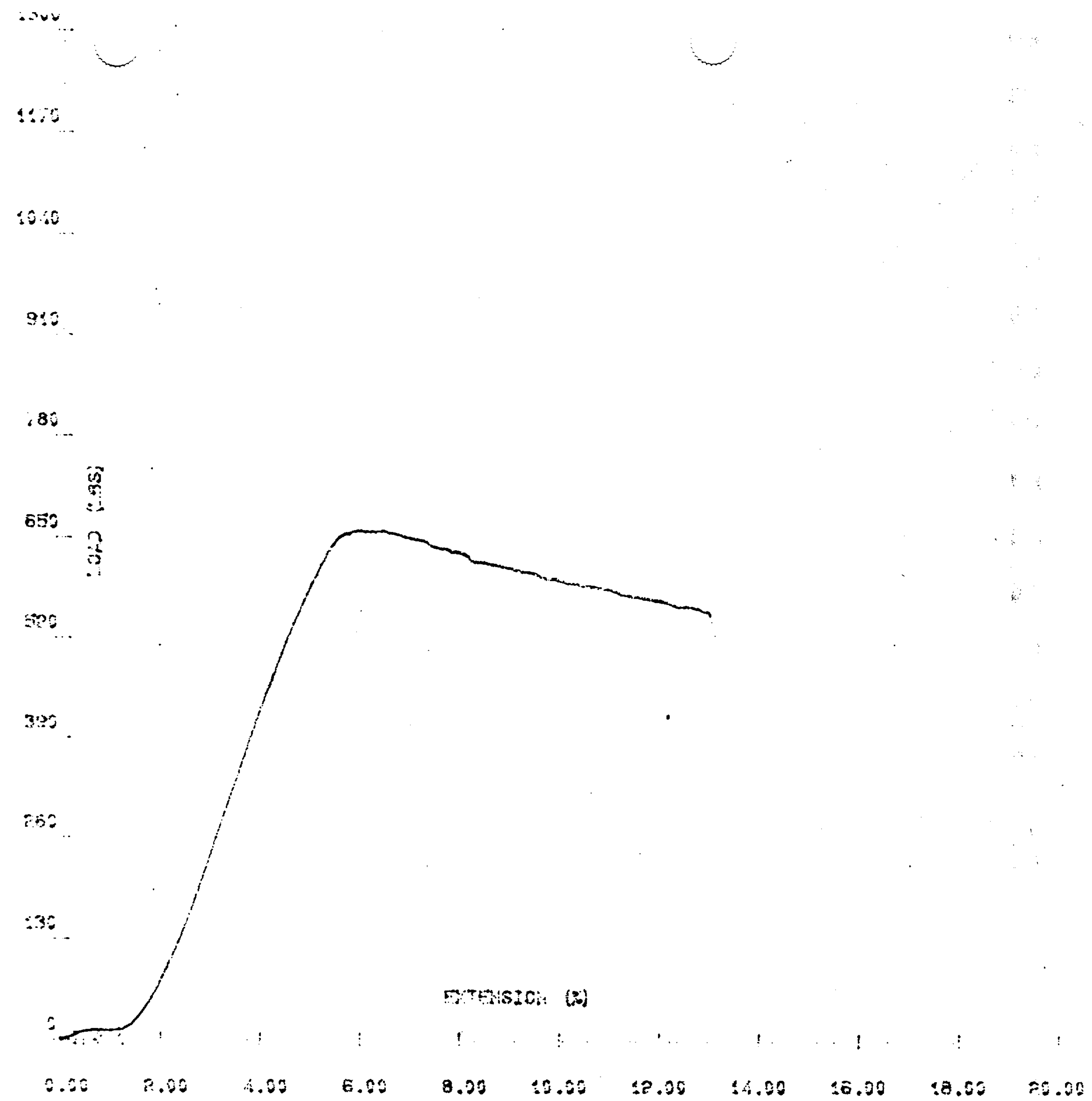

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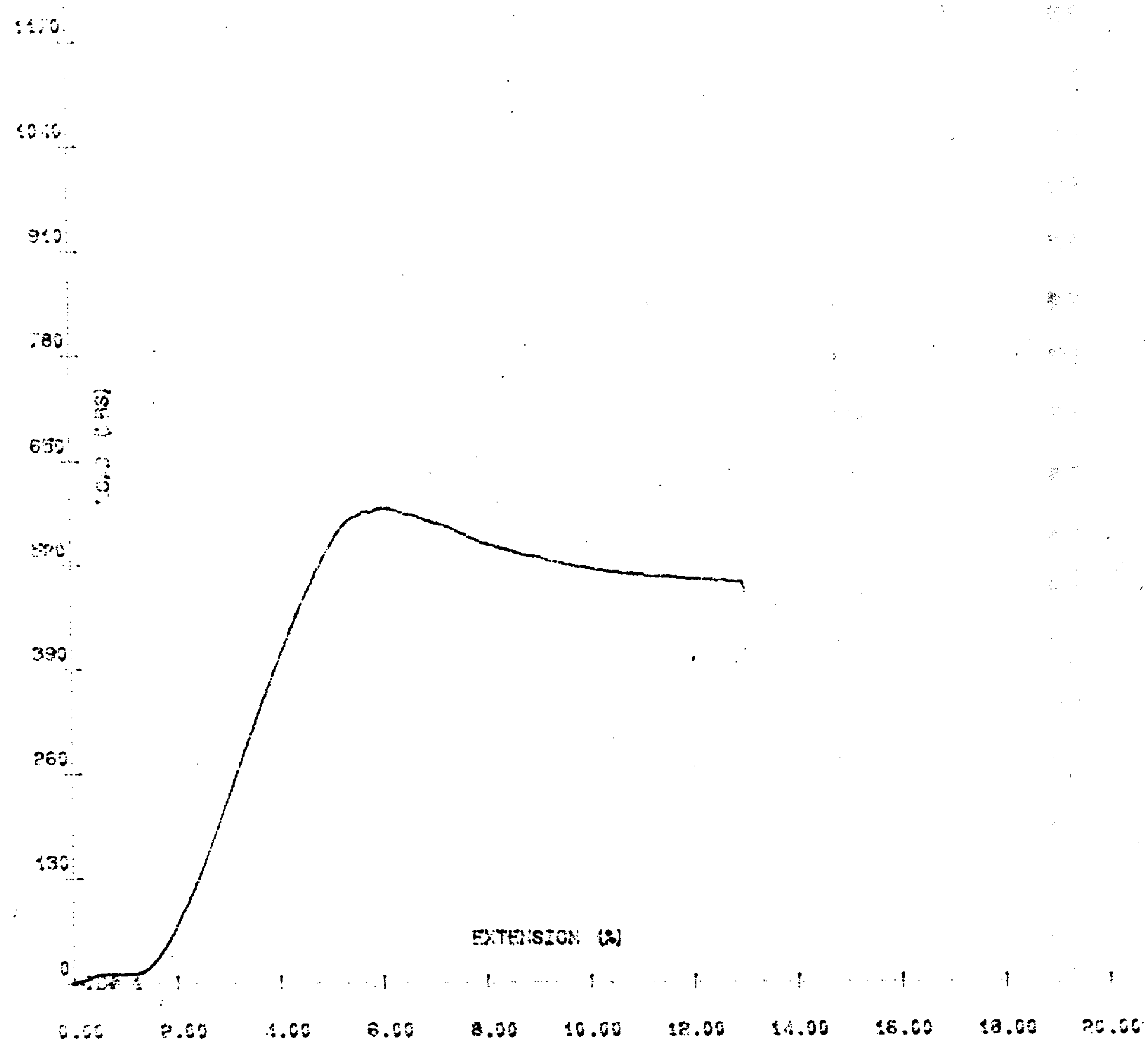

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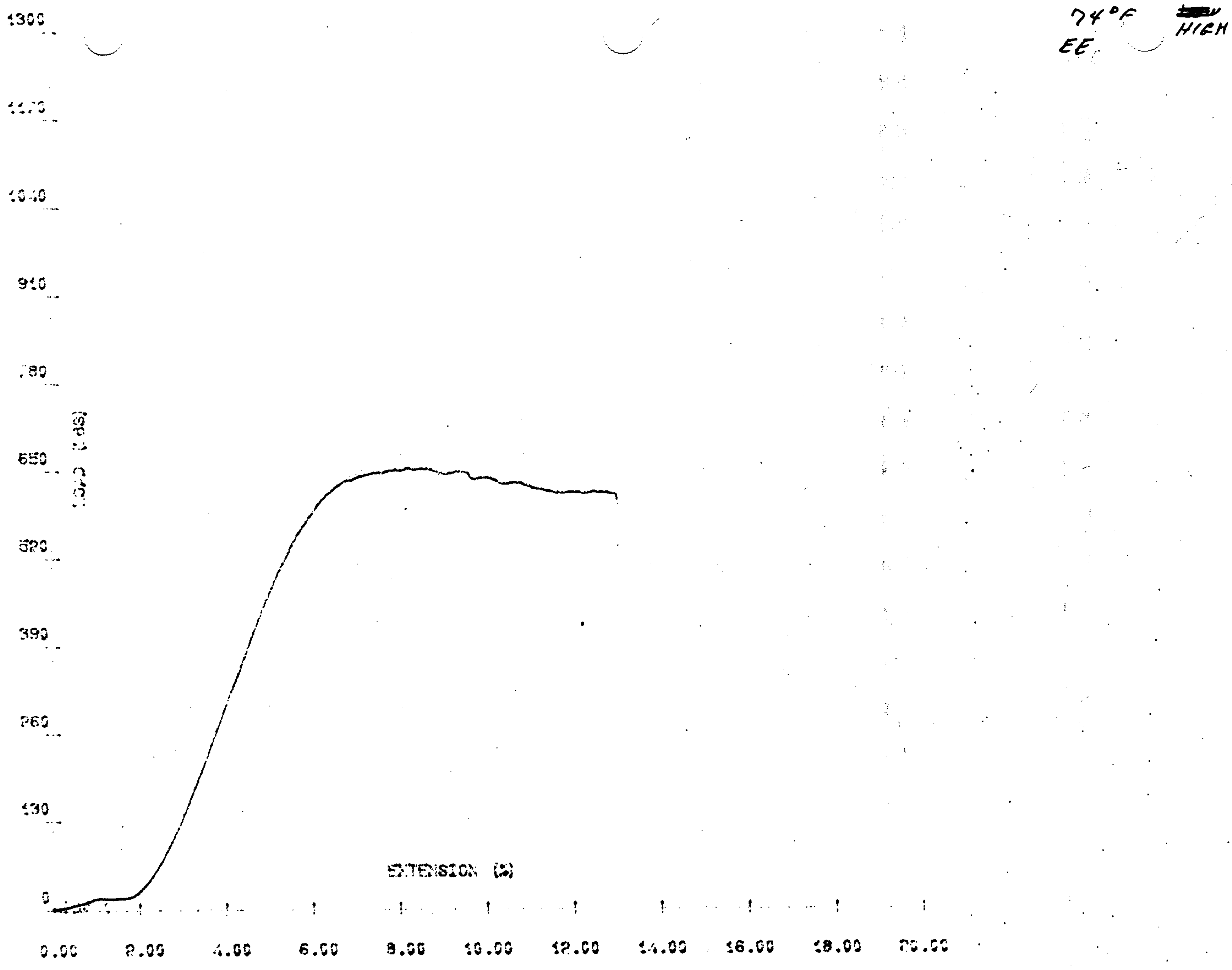
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74°F HIGH
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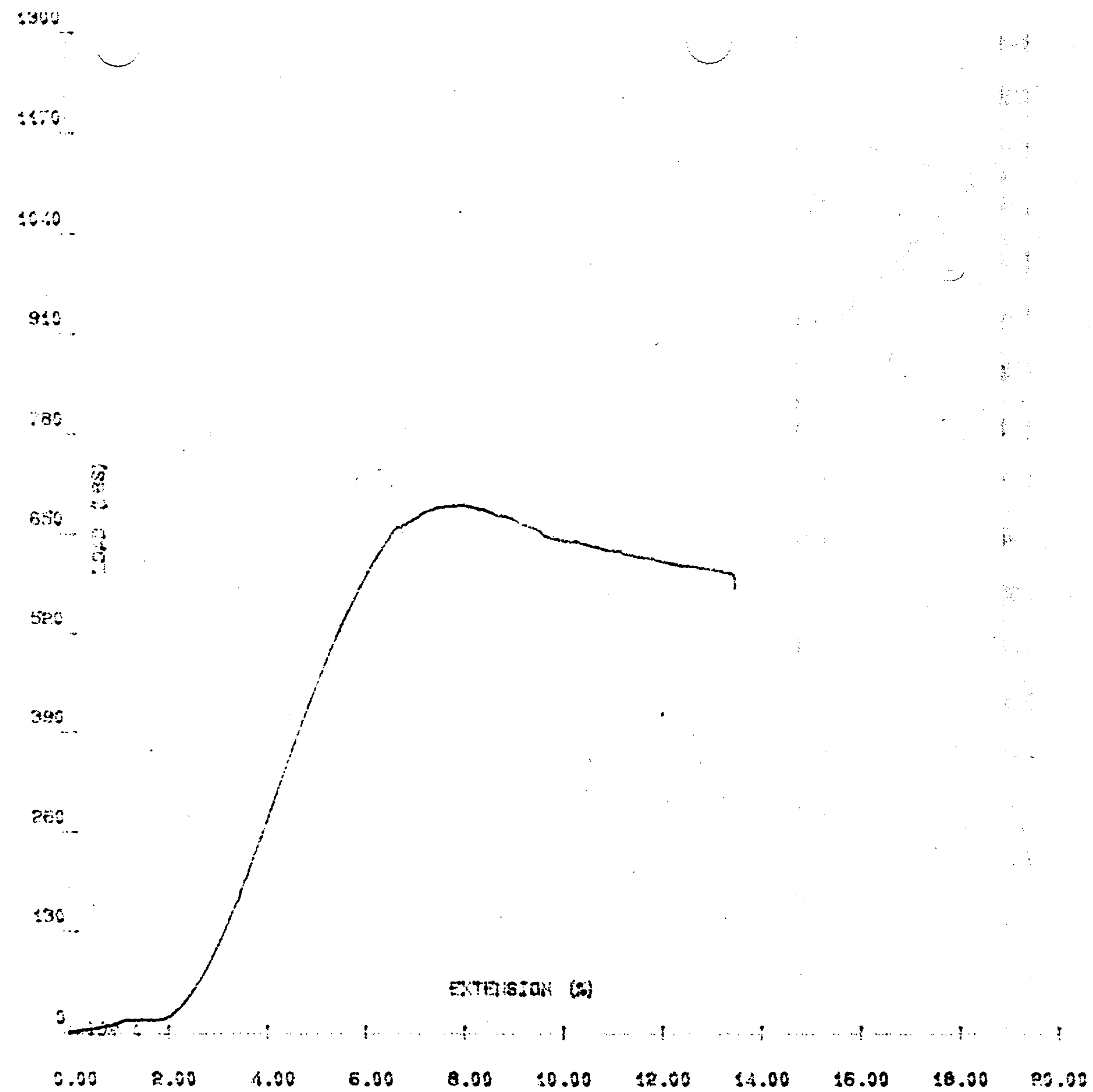

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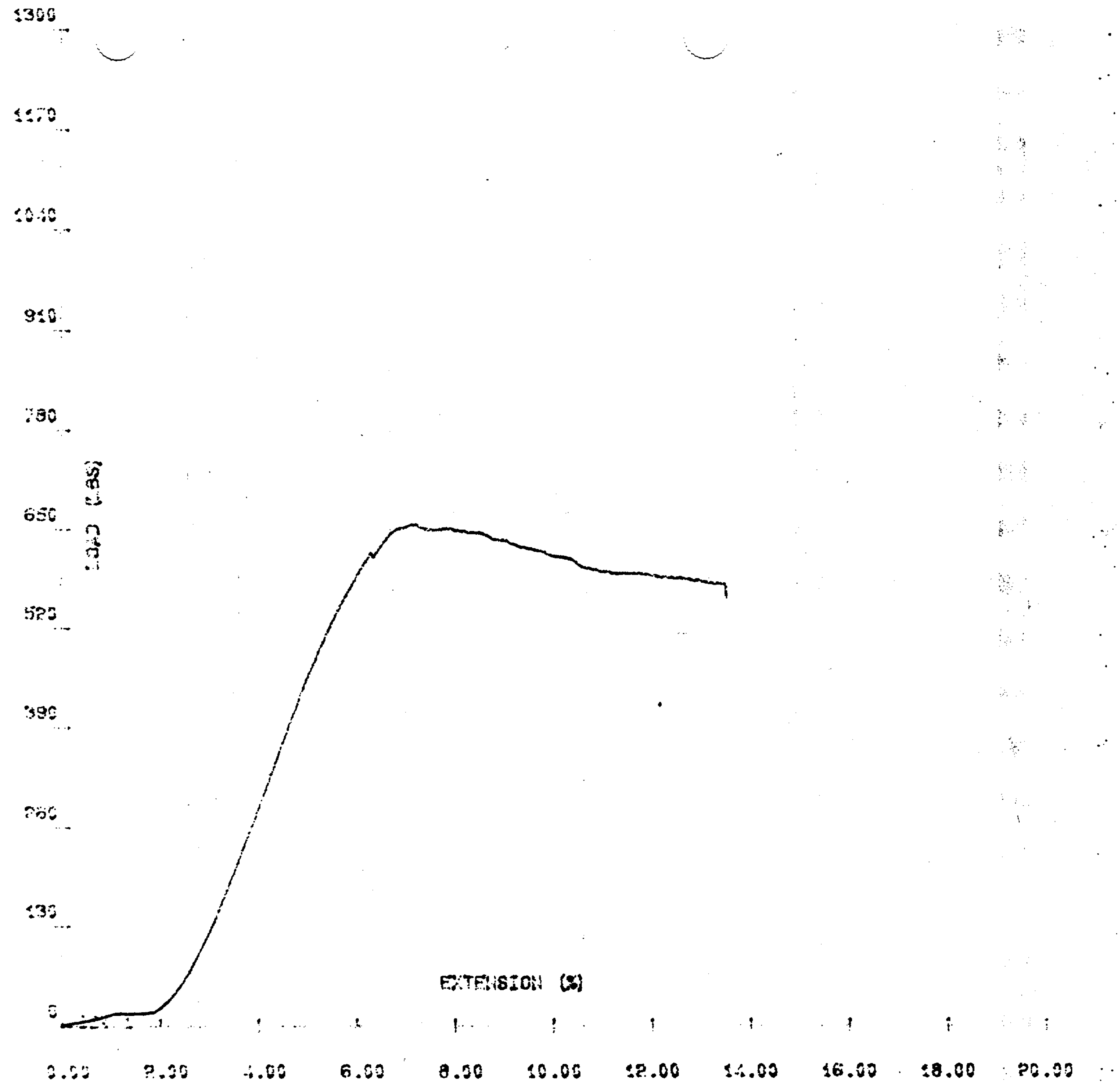

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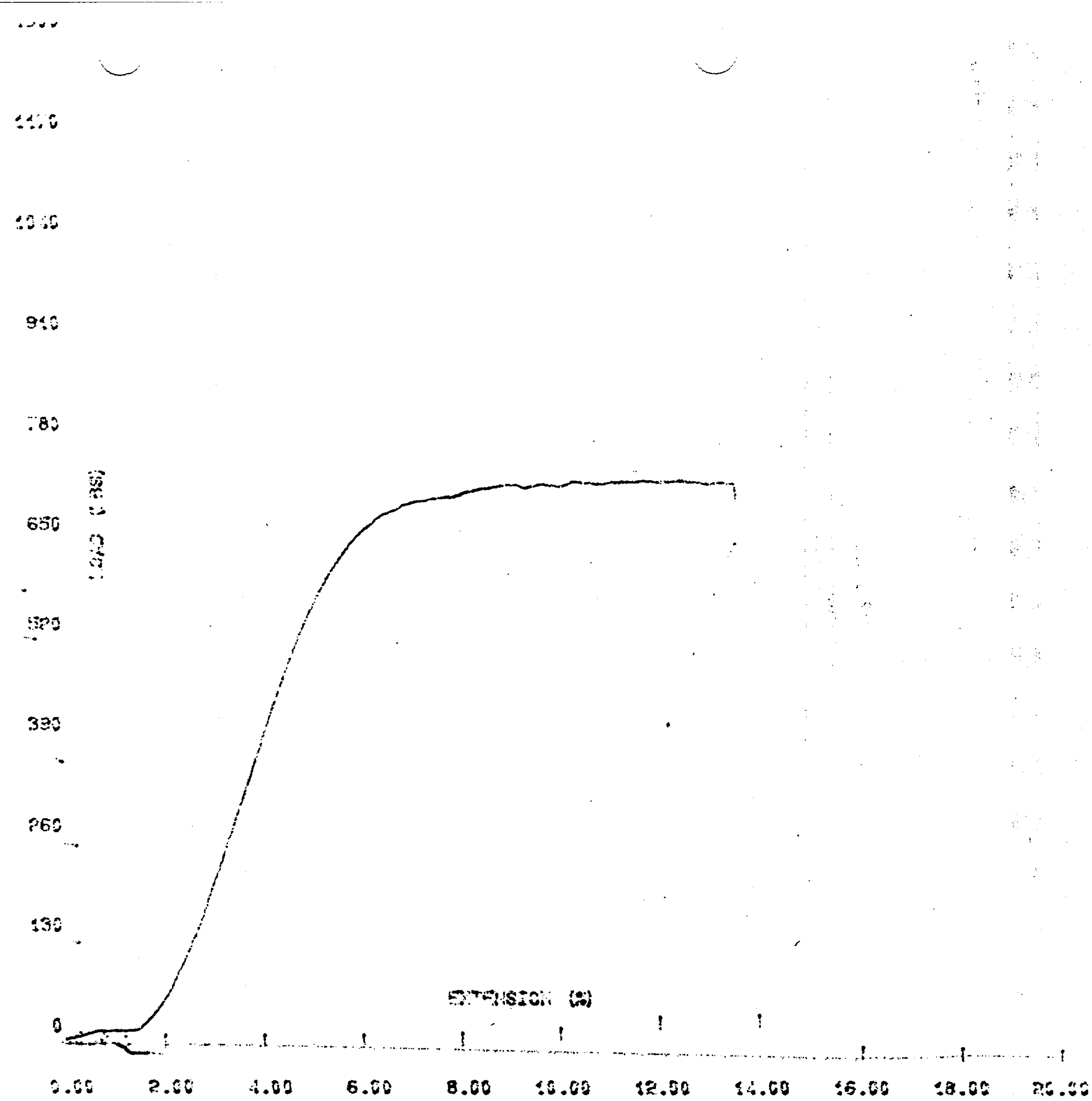

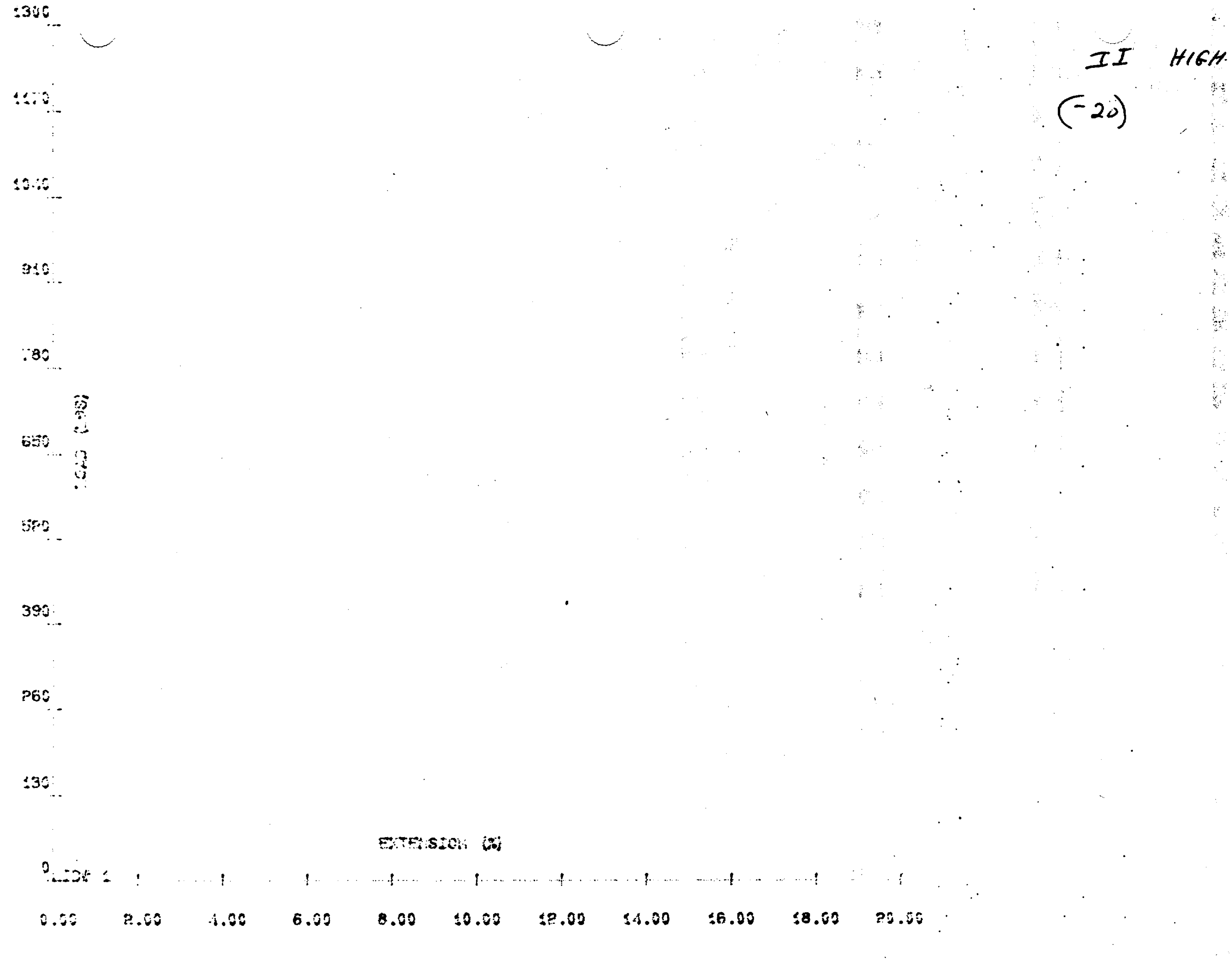
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Approx (-20) HIGH
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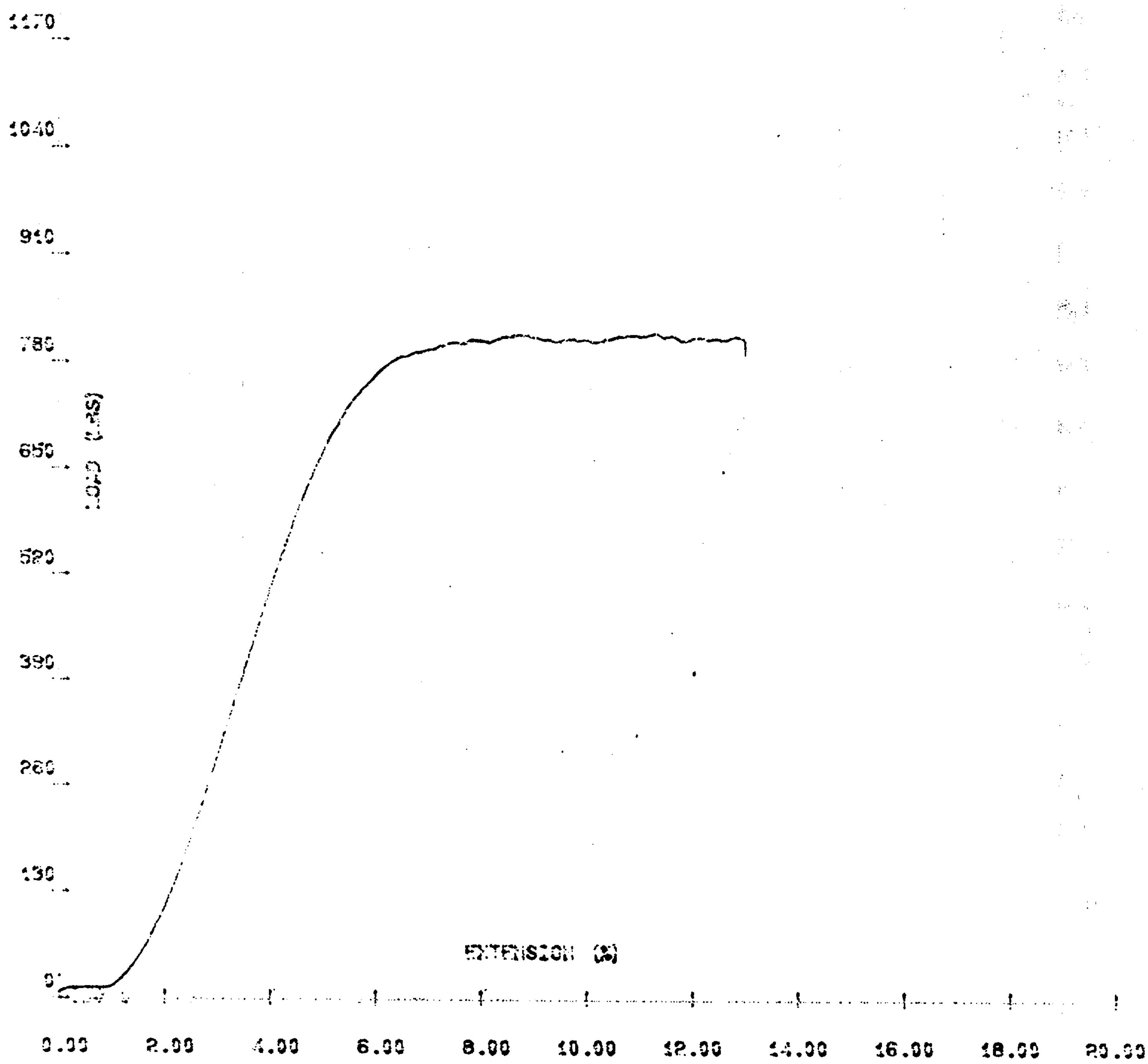

American Foam Technologies
ROUTE 1, BOX 408A, Ronceverte, WV 24970
PHONE: (304) 647-4539 FAX: 647-4125

June 5, 1998

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

Subject: Thermal Conductivity Testing on Thermo-Cor II Phenolic Foam

Dear Heather,

Thermal conductivity testing in accordance with ASTM C518, *Standard Test Method for Steady-State Heat Flux Measurements and Thermal Transmission Properties by Means of the Heat Flow Meter Apparatus,* was performed in June 1995 by Instant Foam Inc. a NVLAP Lab on our Thermo-Cor II phenolic foam. I have enclosed part of a test report from Insta Foam, which includes samples with densities of 5, 7 and 20 lbs/ft3. The thermal conductivity range was reported as 0.20-0.32 Btu-in/hr-sqft deg. F.

Regards,

Samuel L. Rader
President, AFT

Auther:
Jess Garcia/Gina Pietrzyk
Chemists

Approved:
Robert Braun
R&D Lab Manager

Date: June 30, 1995

Report: 499

Title: Report on Physical Testing* of Balsa 7 PCF Phenolic Foam
(Lab Book# n/a; ADR 95-037)

Circ: Gary Grunauer, Lola Jones, Bill Mullally, Debbie.Schutter, Dale Slaboszewski

Key Words: Physical Testing
Balsa 7 PCF Phenolic Foam
American Foam Technologies, Inc/ Jiffy Foam
ADR 95-037

1 . IFTM-05 Flexural Strength (ASTM C203)

Parallel	113 psi
Perpendicular	256 psi

2. IFTM-10 Thermal Conductivity(ASTM C518)

	BTU in / ft^2 Hr °F
Nominal 1 Inch	0.221

**

NVLAP®

Accredited by the department of commerce, national voluntary laboratory accreditation program for 14 test methods for thermal insulation.

* Test data refers only to items tested
** NVLAP or any government agency cannot claim product endorsement.

TEST DATA DONE – JUNE 1995

	5 PCF	7 PCF	20 PCF
FLEXURAL (ASTM C203)	72.9	0.2	886
THERMAL CONDUCTIVITY (ASTM C518)	0.22	0.20	0.32
WT & SHAPE CHANGES (ASTM D756)			
% VOL 140F 24HRS	–1.55	–1.27	–1.16
% WT 140F 24 HRS	–2.05	–1.90	–5.53
% VOL 140F 6 DAYS	–2.96	–2.66	–2.42
%WT 140F 6 DAYS	–4.67	–6.07	–9.04
% VOL 176F 24 HRS –40F/24 176F/24HRS, –40F/24 HRS RECON	–0.37	–0.26	–0.07
% WT 176F 24 HRS –40F/24 176F/24HRS, –40F/24 HRS RECON	–0.79	–0.5	–2.05
COMPRESSIVE (ASTM D1621	103.5	241	802
BURN RATE (MIL F–83671,4.5.3.8)	0.25	0.26	0.25
RESPONSE TO THERMAL/HEATING AGING (ASTM D2126)			
% VOL CHG –40F,2WKS	0.18	0.23	0.72
% VOL CHG –100F,2WKS	–0.01	0.19	0.29
% VOL CHG 158F,2WKS	–3.89	–5.68	–3.61
% VOL CHG 212F,2WKS	–4.84	–4.44	–4.16
% VOL CHG 100F,100%RH,2WKS	–0.27	0.17	–0.19
% VOL CHG 158F,100%RH,2WKS	0.66	0.93	0.75
WATER ABSORPTION (ASTM D2856)			
AV % VOL WATER ABS	15.9	7.3	5.4
AV LBS/FTS AREA ABS	1.12	0.63	0.21
TENSILE STRENGTH (ASTM D1624)			
PARALLEL	68.2	103.5	686.5
PARALLEL MODULUS	4153	5772	13965
PERPEN	33.5	87.3	375
PERPEN MODULUS	1890	4320	11119
SHEAR STRENGTH (ASTM C273)			
PAR	30.5	46	
PAR MOD	517	663	
PER	26.1	51.7	
PER MOD	567	995	
TUMBLING FRIABILITY (ASTM C421)	35.6	24.2	2.6
FEDERAL TEST NO. 101 WATER ABSORPTION	169.5	121.5	34.5

LAW ENGINEERING I( )USTRIAL 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

Date: May 8, 1998

Client P.O. No.: To follow
Material: Reported as Submitted Samples of Foam and Phenolic Resin
Lot No.: Reported as Batch # GP 5034 Resin
Date Tested: Completed May 8, 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
5-4-98-1RCe1	19	17	<15	6.74	Resin Sample
5-4-98-2FCe1	42	40	<15	7.72	Foam Sample

Reviewed by:
Lakshman Santanam
Technical Center Manager

Respectfully submitted,
LAW ENGINEERING INDUSTRIAL SERVICES

Larry Coble, Technical Leader

Eco-Pak Specialty Packaging
Foaming Record
for the ESP-PF-1 Phenolic Foam Insulation

Serial No.____________________ Date____________________

Materials	IFI Spec. No.	Manufacturer	Lot or Batch No.
Phenolic Resin	THERMO-COR 2	American Foam Technologies	
Reaction Agent	Polymeric MDI	Dow Chemical Company	
Catalyst	Phenyl Sulfonic Acid	Capital Resin Corporation	

CONTAINER WEIGHTS (LBS)

TOP POUR:

Weight Before Foaming________________

Weight After Foaming________________

Top Foam Weight________________

BOTTOM POUR:

Weight Before Foaming________________

Weight After Foaming________________

Bottom Foam Weight________________

TOTAL FOAM WEIGHT:____________________________

Operator____

Inspected by QA____

Appendix 2.10.3

Chemical and Galvanic Reactions Analysis

LAW
ENGINEERING AND ENVIRONMENTAL SERVICES, INC.

May 11, 1998

Ms. Heather Little
Eco-Pak Specialty Packaging
125 Iodent Way, Suite B
Elizabethton, TN 37643

Subject: **Reactivity of American Polyplastics Thermo-Cor II phenolic foam with Carbon Stainless Steel**
Eco-Pak Specialty Packaging
Elizabethton, TN
LEIS Project 10810-7008

Dear Ms. Little:

In accordance with your request, Law Engineering Industrial Services (LEIS) has performed a chemical analysis of a foam sample identified as American Polyplastics Thermo-Cor II phenolic foam. Test results are attached to this letter. The results indicate that the sample has 40 parts per million (ppm) of leachable chlorides. We were requested to provide an opinion as to the reactivity of this foam with carbon and stainless steel materials during accelerated corrosion testing.

LEIS has performed accelerated corrosion testing of carbon and stainless steel materials in contact with phenolic foam in ferric chloride solutions of concentrations of 400 ppm and 1%. The tests were performed in general accordance with ASTM G48 ad at a temperature of 122F. For a detailed description of the tests performed and the results, please refer to our reports dated October 6, 1995. From these tests, we conclude that chloride concentrations of 400 ppm or 1% should not significantly affect carbon or stainless steel material and that a twenty year service like could be expected.

It is therefore our opinion that American Polyplastics Thermo-Cor II foam of the same composition as the one referenced in this letter should not cause significant corrosion of carbon and stainless steel material during accelerated corrosion testing. This opinion is based on the higher chloride concentrations employed in our previously mentioned corrosion testing with no adverse effects.

LEIS appreciates the opportunity to provide engineering services to Eco-Pak Specialty Packaging. If we can be of further assistance, please do not hesitate to call.

Sincerely,
LAW ENGINEERING INDUSTRIAL SERVICES

Lakshman Santanam
Technical Center Manager
NACE Certificated as Corrosion Specialist

James W. Page, P.E.
Corporate Consultant
Chief Engineer

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2801 YORKMONT ROAD, SUITE 200 • CHARLOTTE, NC 28208
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Reviewed by:
Lakshman Santanam
Technical Center Manager

Respectfully submitted,
LAW ENGINEERING INDUSTRIAL SERVICES

Larry Coble, Technical Leader

LAW ENGINEERING
INDUSTRIAL SERVICES
A DIVISION OF LAW ENGINEERING, INC.

CORROSION EVALUATION OF STAINLESS STEEL SAMPLES

400 ppm FERRIC CHLORIDE SOLUTION

PREPARED FOR

NUCLEAR CONTAINERS, INCORPORATED

LAW ENGINEERING INDUSTRIAL SERVICES PROJECT 10832-5-0807

October 6, 1995

LAW
ENGINEERING AND ENVIRONMENTAL SERVICES

October 6, 1995

Mr. William M. Arnold
Nuclear Containers, Incorporated
Route 9 Box 2237
Elizabethton, Tennessee 37643

Subject: **Report of Corrosion Evaluation of Stainless Steel Samples**
400 ppm Ferric Chloride Solution
Nuclear Containers, Incorporated
Elizabethton, Tennessee
Law Engineering Industrial Services Project 10832-5-0807

Dear Mr. Arnold:

As authorized by your purchase order number 5577-A dated February 20, 1995 and in general accordance with our proposal 2521ME5 dated February 7, 1995, Law Engineering Industrial Services has completed short term 400 ppm ferric chloride solution corrosion tests to predict long term behavior of stainless steel material. This report contains project background information, summary of calculations for equivalent temperature and times for accelerated corrosion testing, test results and conclusions relevant to the purpose of our work.

PROJECT BACKGROUND INFORMATION

Nuclear Containers, Incorporated (NCI) manufactures AISI 304 stainless steel shipping containers for transport of nuclear materials. The packages consist of an inner chamber and an outer 14 gauge stainless steel sheet with a phenolic foam between them. In the past, hydrochloric acid was added to the foam to reduce its alkalinity. Since October 1991, this practice has been discontinued. Instead, oxalic acid is used as an additive to reduce the alkalinity of the foam. Laboratory analysis of two foam samples obtained from packages manufactured prior to 1991 indicate chloride contents to be 1,825 and 211 ppm, respectively. At present, the chloride content in the foam is typically less than 100 ppm and does not exceed 200 ppm. Since 1991 the stainless steel surfaces in contact with the foam have been coated with an epoxy primer (DP40 manufactured by PPG Industries, Incorporated). DP401 also manufactured by PPG Industries has been used as a catalyst.

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A DIVISION OF LAW ENGINEERING, INC.
2801 YORKMONT ROAD, SUITE 200 • CHARLOTTE, NC 28208
P. O. BOX 19667 • CHARLOTTE, NC 28219
(704) 357-8600 • (800) 672-6601 • FAX (704) 357-8637
ONE OF THE LAW COMPANIES

October 6, 1995

Mr. William M. Arnold
Nuclear Containers, Incorporated
Route 9 Box 2237
Elizabethton, Tennessee 37643

Subject: **Report of Corrosion Evaluation of Stainless Steel Samples**
400 ppm Ferric Chloride Solution
Nuclear Containers, Incorporated
Elizabethton, Tennessee
Law Engineering Industrial Services Project 10832-5-0807

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Mixing and application practices as recommended by the manufacturer have been followed. The minimum wet film thickness of the primer is 4 mils (approximately 1.5 mils dry film thickness).

Law Engineering Industrial Services was informed that a twenty year service life for these containers was desired. We were requested to determine the deleterious effects of the chloride in the foam, if any, to the stainless steel material over the twenty year service life of the containers.

METHODOLOGY

The methodology utilized by us consisted of designing short term corrosion tests to predict long term behavior. Calculations were performed to determine the test temperature and duration. Samples of bare stainless steel, stainless steel coated with primer, stainless steel coated with primer containing a scribe, bare stainless steel with foam attached and stainless steel coated with primer and foam attached were subjected to a 30 day 400 ppm ferric chloride solution at 50°C. The following pages describe how we arrived at the test temperature and duration. The corrosion tests were performed in conjunction with Dr. Bryan A. Chin, Professor and Chairman of the Materials Engineering Program at Auburn University, Alabama.

EQUIVALENT TEMPERATURE AND TIMES FOR ACCELERATED TESTING

SUMMARY

The following sections describe the results of a study to determine accelerated corrosion test conditions (temperature and time) that could be used to predict the performance of stainless steel material subjected to 20 years of ambient temperature exposure at specific sites in the United States. Five sites were specified for investigation in this study: Richland, WA; Haematite, MO; Columbia, SC; Wilmington, NC; and Portsmouth OH. Twenty year climatological data was obtained for these sites and incorporated into kinetic equations describing the relationship of temperature and time on corrosion rates. From these studies equivalent, elevated temperatures were obtained for test times of 1.0, 1.5, 2.0 and 3.0 months. The results indicate that an accelerated corrosion test temperature of 107°F for 1 month is equivalent to 20 years of exposure at the worst site (Columbia, SC).

A total immersion 400 ppm ferric chloride test was conducted following ASTM specifications G48-76 and G46-76. The test temperature was 122°F (50°C) for 1 month. Five types of specimens were included in the tests:

1. Bare stainless steel metal
2. Stainless steel metal coated with epoxy primer
3. Stainless steel metal coated with epoxy primer containing a scribe mark (to simulate a defect in the coating)
4. Bare stainless steel with foam attached
5. Stainless steel coated with primer and foam attached

LITERATURE SEARCHED

An extensive search was made of both books and scientific articles. Emphasis was placed on locating articles relating to pitting corrosion in stainless steels in chloride environments and determining the environmental effects on the corrosion rates.

ENVIRONMENTAL DATA SEARCH

Climatological data for the cities under investigation were obtained from the National Oceanic and Atmospheric Administration. Temperature histories for a twenty year period were used in the calculations (1974 through 1993). Exact temperature histories were available for the cities of Wilmington, NC, and Columbia, SC. The temperature histories for Portsmouth, OH; Richland, WA; and Haematite, MO were assumed to be close to the nearest cities in these states namely, Columbus, OH; Walla Walla, WA; and St. Louis, MO respectively.

DETERMINATION OF ACCELERATED TEST CONDITIONS

Experiments have been previously conducted that describe the temperature-time dependence of the pitting corrosion current for stainless steels. We utilized both the temperature time relationships and materials coefficients derived by these investigators in our calculations. The literature indicates a linear time dependence of the current density in pitting corrosion for a chromium-nickel (18-8) steel alloy in a 0.03 MKCI and 0.5 $MKNO_3$ environment. Assuming this linear time dependence for our system, the current density can be described by,

$$J = A_t t$$

Where J is the current density, A_t is a material constant ad t is the test time. Also, the temperature dependence of the current density is given by,

$$J = A_j e^{(E_{Aj}/RT)}$$

Where A_j is a temperature dependent materials constant, E_{Aj} is the activation energy for the pitting process, R is the gas constant, and T is the absolute temperature in K. The total current density is therefore,

$$J_{tot} = A\, t\, e^{(E_{Aj}/RT)}$$

Since A is a material constant that is unknown, a new parameter J^1 was used in the calculations. J^1 was defined by,

$$J^1 = J_{tot} / A = t\, e^{(E_{Aj}/RT)}$$

Monthly average temperatures were used instead of daily temperatures to simplify the calculations. Thus the combined effect of pitting corrosion in 20 years is given by the equation:

$$J^1_{20\,yrs} = J^1_1 + J^1_2 + J^1_3 + J^1_4 + \ldots\ldots\ldots\ldots + J^1_{240}$$

Thus, the combined effect of pitting corrosion for 20 years would include summing the corrosion effect at each month average temperature for 240 months. A further simplification was made, by averaging the monthly temperatures for January, February, etc. over a 20 year period. The result was multiplied by 20 to simulate 20 years since the temperature behavior is cyclic at any given location.

The required temperature , T_{eq}, to complete a simulation of the above effect in **x** months was then determined from the equation.

$$J^1_{20\,yrs} = x\, e^{(E_{Aj}/RT_{eq})}$$

The value of E_{Aj} was experimentally determined by previous investigators to be -266,000 **J/(mole K)** and the value of **R** was taken to be 8.3144 **J/(mole K)**.

RESULTS

Table 1 shows the test temperatures that were obtained as a result of the above described methodology. It shows the calculated equivalent test temperatures as a function of the location site and the planned duration of the test.

As a result of this study it can be concluded that:

- One month elevated test temperatures required to simulate 20 years of ambient temperature exposure for pitting corrosion have been determined.
- Depending upon site specific ambient temperatures obtained from the National Oceanic and Atmospheric Administration, the equivalent test temperatures for one month elevated temperature pitting corrosion tests range from 98°F to 107°F.

FERRIC CHLORIDE SOLUTION PITTING CORROSION TESTS

SUMMARY OF RESULTS

Ferric chloride corrosion tests were performed in accordance with ASTM G48. Specimens were exposed at 50°C for 30 days and evaluated for weight loss, pitting, blisters and loss of adhesion. Hardness measurements were taken to help evaluate subsurface corrosion effects. Evaluations were conducted in accordance to ASTM specifications G48-76, G46-76 and D1654-79a. Table 2 gives a summary of material performance.

SCOPE

Ferric chloride corrosion tests were performed in accordance with ASTM G48 to evaluate the pitting resistance of the following materials: stainless steel, stainless steel coated with primer (DP-40), stainless steel coated with primer and scribed, stainless steel with foam attached and stainless steel with primer and foam attached. The test provided information on the relative resistance of the stainless steel and the performance of the primer in corrosive environments.

TEST PROCEDURE

Ferric Chloride Bath Preparation

A 400 ppm by weight ferric chloride solution was made using distilled water and $FeCl_3 \cdot 6H_2O$. The solution was filtered through filter paper to remove any insoluble particles. Two baths of 1500 ml each were prepared. The specimens in the baths are shown in Table 3. The baths were maintained at 50°C and the test was conducted for 30 days.

Test Set-Up

The corrosion baths were set-up as shown in Figure 1. The bath temperature was monitored using a thermometer and a thermocouple connected to a chart recorder. Figure 2 shows the chart recorder readout showing a constant temperature of 50°C. In addition a thermometer was used to monitor the temperature of the solution. The temperature was continuously monitored over the 30 day test duration. Figure 3a shows a close up of the sample loading in the bath. ASTM specification G48 glass cradles were used to support the samples at a 45° angle. Figure 3b shows how the stainless steel/foam samples were loaded. The solution was constantly stirred using a magnetic stirrer.

SPECIMEN PREPARATION

As Received Material

Stainless steel plates that were provided were sheared into 1 x 2 inch recommended standard size specimens. The specimen edges were ground to remove any rough edges. Figure 4a shows the stainless steel specimens.

Primer Coated Specimens

Stainless steel standard size 1 x 2 inch specimens were coated with the DP-40 primer using an air gun operating at 40 psi. The coated specimens were air dried for over 72 hours until completely dry. Specimen surfaces were cleaned with acetone to remove any grease or dirt prior to coating. Figure 5a shows the primed stainless steel specimens.

Primer Coated Specimens-Inscribed

Standard size specimens of primer coated stainless steel were inscribed on both sides. The scribe was made using a tungsten carbide cutting tool in accordance with ASTM D1654. The scribes made on both sides of the specimens were in opposite directions to each other. The specimens were used to test adhesion of the coating at the scribe mark when exposed to corrosive environments. Figures 6a, b show both sides of the scribed stainless steel specimens.

Stainless Steel/Foam Specimens

Large sections of the stainless steel/foam material (as provided) were cut into standard specimens of 1 x 2-inch using a band saw. The foam was held together with the stainless steel using rubber bands. The rubber bands were treated in boiling water to remove any water soluble elements prior to actual testing of specimens. The stainless steel/foam specimens are shown in Figures 7a and 8a.

SPECIMEN EVALUATION

Photographic Examination

All test specimens were photographed to record visual changes induced by the test. The specimens were cleaned using running water and acetone to remove corrosion products. The following is a listing of all the specimens photographed in the post test condition:

- Figure 4b - Stainless Steel
- Figure 5b - Stainless Steel+Primer
- Figures 6c,d - Stainless Steel+Primer (Inscribed)
- Figures 7b,c - Stainless Steel/Foam (2UP)
- Figures 8b,c - Stainless Steel/Foam (4P)

A few coated specimens were stripped of the coating to examine the surface underneath. Acetone was used to remove the coating from the specimens. The following is a listing of the specimens that were stripped:

- Figure 5c - Stainless Steel+Primer
- Figure 6e,f - Stainless Steel+Primer (Inscribed)

The colors of the bath solution are shown in Figures 9a, b. Color change indicated the buildup of corrosion products

Specimen Weight Evaluation

All specimens were weighed prior to testing and were weighed again after the 30 day testing period. The specimens were totally dried prior to weighing. Table 4 shows the weight changes for the various specimens.

Pitting Evaluation

All the uncoated specimens and the stripped specimens were examined for pitting. Standard procedures defined by ASTM G48 and G46 were used. However, no pitting was visually observed on any of the specimens. Table 5 shows the details of the measurements.

Blister Evaluation of Coated Specimens

All coated specimens were examined for blisters on the surface. The 10 largest blisters were examined and reported. Table 6 shows the details of the evaluation. The coated specimens which were inscribed were examined for by loss of adhesion. This is reported in Table 7 as the distance from the scribe over which the coating has failed. No loss of adhesion was observed along the scribe.

Performance Based on Surface Area Affected

All bare and coated specimens were evaluated based on the overall performance. A plastic grid was used to determine the percentage of affected area in all of the samples. All uncoated specimens were evaluated for area covered by pitting. Coated samples were evaluated for blister area coverage. Table 8 shows the overall performance of the specimens. Inscribed specimens were not evaluated using this method, but by measuring the distance of creapage in accordance with ASTM D1654 as given in Table 7.

Hardness Measurements

Table 9 shows the hardness measurements made on the specimens after the corrosion test. Changes in surface hardness indicate subsurface corrosion effects. No significant hardness changes were observed in the specimens.

CONCLUSIONS

The 400 ppm ferric chloride corrosion test resulted in the following conclusions:

- Stainless steel (bare) specimens did not show visible pitting and a weight loss of 0.002% was recorded.
- Stainless steel primer coated specimens showed blister attack of coating, but the metal surface was not attacked and a weight loss of 0.009% was recorded.
- Stainless steel coated and inscribed specimens showed a good adhesion of coating, metal surface underneath was not attacked and a weight loss of 0.008% was recorded.
- Stainless steel/foam specimens recorded a weight loss of 0.05%.
- Stainless steel + primer/foam specimens recorded a weight loss of 0.05%.
- No significant hardness changes were noted in the specimens.
- Based on the test data, it is our opinion that a 400 ppm chloride content in the foam will not significantly pit or corrode the stainless steel material over a twenty year service life.

Law Engineering Industrial Services appreciates the opportunity of working with you on this project. If you have any questions concerning this report please contact the writer at (704)-357-8600.

Sincerely,
LAW ENGINEERING INDUSTRIAL SERVICES

Lakshman Santanam
Laboratory Manager
NACE Certified Corrosion Specialist

Hussein M. Sadek
Managing Principal

LS/HMS:mh

Attachments 1 and 2

ATTACHMENT 1

Table 1: Pitting Corrosion Test Temperatures for Different Locations

LOCATION	TEST DURATION (mo.)	TEST TEMP. (°F)
Wilmington, NC	1	105.79
	1.5	103.15
	2	101.30
	3	98.70
Portsmouth (Columbus), OH	1	98.85
	1.5	96.27
	2	94.47
	3	91.93
Richland (Walla Walla), WA	1	98.73
	1.5	96.16
	2	94.35
	3	91.83
Columbia, SC	1	106.90
	1.5	104.25
	2	102.39
	3	99.97
Haematite (St. Louis), MO	1	103.89
	1.5	101.28
	2	99.43
	3	96.86

Table 2. Summary of Corrosion Test Results

(Note Hardness changes indicate subsurface corrosion, not a change in mechanical properties.)

SPECIMEN MATERIAL	30 DAY 400 ppm FERRIC CHLORIDE @ 50°C
Stainless Steel	No visible pitting and 0.002% weight loss.
Stainless Steel+Primer	30% of coating area attacked by blisters, coating protects from pitting, negligible hardness change and 0.009% weight loss.
Stainless Steel+Primer (Inscribed)	40% of coating area attacked by blisters, good coating adhesion at scribe, coating protects from pitting, negligible hardness change and 0.008% weight loss.
Stainless Steel/Foam (2UP)	No visible pitting, 0.05% weight loss, negligible hardness change.
Stainless Steel+Primer/Foam (4p)	No visible pitting, 0.05% weight loss, negligible hardness change.

Table 3. Specimens in the Corrosion Bath

FERRIC CHLORIDE BATH	SPECIMEN	SPECIMEN NO.
Bath - 1	Stainless Steel	SS-A, SS-B
	Stainless Steel +Primer	SSP-A, SSP-B
	Stainless Steel +Primer (Inscribed)	SSPI-A, SSPI-B
Bath - 2	Stainless Steel/Foam	2UP-A, 2UP-B
	Stainless Steel +Primer/Foam	4P-A, 4P-B

Table 4. Corrosion Induced Weight Loss

SPECIMEN MATERIAL	SPECIMEN NO.	SPECIMEN WEIGHT LOSS (mg/mm^2)
Stainless Steel	SS-A	1.44×10^{-4}
	SS-B	1.05×10^{-4}
Stainless Steel+Epoxy Primer	SSP-A	1.99×10^{-4}
	SSP-B	8.19×10^{-4}
Stainless Steel+Primer (Inscribed Specimen)	SSPI-A	3.45×10^{-4}
	SSPI-B	5.86×10^{-4}
Stainless Steel/Foam (As received)	2UP-A	2.56×10^{-3}
	2UP-B	3.3×10^{-3}
Stainless Steel+Primer/Foam	4P-A	5.29×10^{-3}
	4P-B	1.11×10^{-3}

Table 5. Corrosion Induced Pitting

SPECIMEN MATERIAL	SPECIMEN NO.	AVERAGE PIT SIZE (mm^2) 10 EACH SIDE	PIT DEPTH (mm) (MAX/AVG.) 10 EACH SIDE	PIT DENSITY ($PITS/m^2$)
Stainless Steel	SS-A	None		
	SS-B	None		
Stainless Steel + Epoxy Primer	SSP-A			
	SSP-B	Primer None	Removed	
Stainless Steel+Primer (Inscribed Specimen)	SSPI-A			
	SSPI-B	Primer None	Removed	
Stainless Steel /Foam (As is)	2UP-A	None		
O-Open Side	2UP-B	None		
F-Foam Side	4P-A	None		
	4P-B	None		

Table 6. Corrosion Induced Blistering of Coated Specimens

SPECIMEN MATERIAL	SPECIMEN NO.	BLISTER DIAMETER (mm) (AVERAGE SIZE)	BLISTER DENSITY (BLISTERS/m^2)
Stainless Steel + Epoxy Primer	SSP-A	1, .25, .5, .5, .38, .38, .64, .5, .38, .25, .5 **(0.53)**	259,975
	SSP-B	1.65, 1.4, 1, 1, 1, .5, .5, .38, .64, .25 **(1.28)**	273,056
Stainless Steel +Primer (Inscribed Specimen)	SSPI-A	.5, .38, .64, .25, .38, .25, .5, .38, .25, .5 **(0.4)**	359,240
	SSPI-B	.25, .25, .38, .38, .5, .5, .25, .25, .25, .38, .25 **(0.37)**	331,034

Table 7. Corrosion Induced Primer Adhesion Loss at Scribe

SPECIMEN MATERIAL	SPECIMEN NO.	CREAPAGE FROM SCRIBE/MEAN (mm)
Stainless Steel +Primer (Inscribed Specimen)	SSPI-A	0.25, 0.25, 0.25, 0.25, 0.25 **(0.25)**
	SSPI-B	0.25, 0.25, 0.25, 0.25, 0.25 **(0.25)**

Table 8. Overall Surface Attack of Uncoated and Coated Specimens

SPECIMEN MATERIAL	SPECIMEN NO.	% AREA AFFECTED-PITS, BLISTER
Stainless Steel	SS-A	0
	SS-B	0
Stainless Steel+Epoxy Primer	SSP-A	28
	SSP-B	31
Stainless Steel+Epoxy Primer (Inscribed Specimen)	SSPI-A	41
	SSPI-B	38
Stainless Steel/Foam (As Received)	2UP-A	0
	2UP-B	0
Stainless Steel +Primer/Foam	4P-A	0
	4P-B	0

Table 9. Specimen Hardness in Post Test Condition

SPECIMEN MATERIAL	SPECIMEN NO.	SPECIMEN HARDNESS/MEAN (POST CORROSION TEST)
Stainless Steel	SS-A	74, 73, 72.5, 75, 75 (R_B)/73.9
	SS-B	72.5, 71 70, 71, 71 (R_B)/71.1
Stainless Steel+Epoxy Primer	SSP-A	
	SSP-B	74, 73, 73, 74.5, 74 (R_B)/73.7
Stainless Steel+Epoxy Primer (Inscribed Specimen)	SSPI-A	
	SSPI-B	74.5, 74, 75.5, 74.5, 75 (R_B)/74.7
Stainless Steel/Foam (As Received)	2UP-A	58, 58, 62, 63, 50.5 (R_B)/58.3
	2UP-B	57, 56, 62, 52, 53 (R_B)/56
Stainless Steel +Primer/Foam	4P-A	69.5, 76, 79, 73, 69 (R_B)/73.3
	4P-B	54.5, 56, 53.5, 52, 48 (R_B)/52.8
Stainless Steel (Pretest Condition)		71, 73, 73, 72, 73 (R_B)/72.4
Stainless Steel/Foam 2UP/4P (Thickness = 1/16") (Pretest)		51, 56.5, 56.5, 62, 50 (R_B)/55.2
Stainless Steel/Foam 2UP/4P (Thickness = 0.076") (Pretest)		71.5, 82, 77.5, 81, 79(R_B)/78.2

ATTACHMENT 2

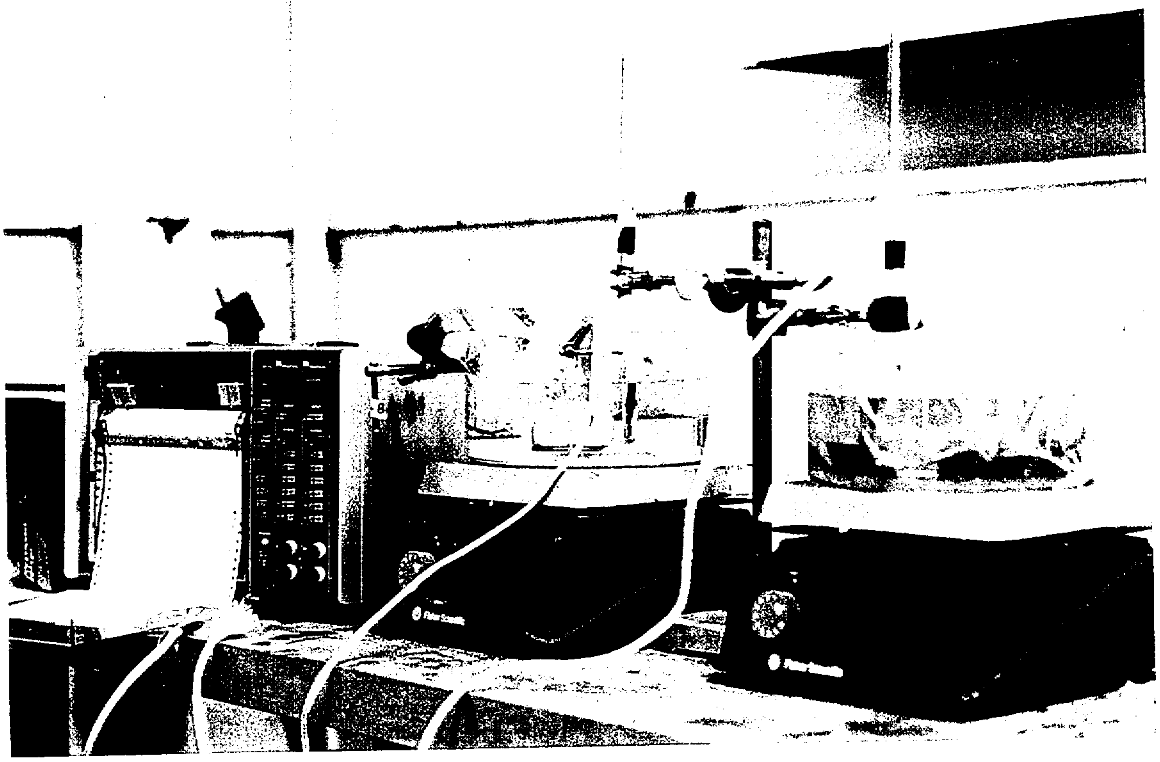

Figure 1. 400 ppm ferric chloride corrosion bath setup.

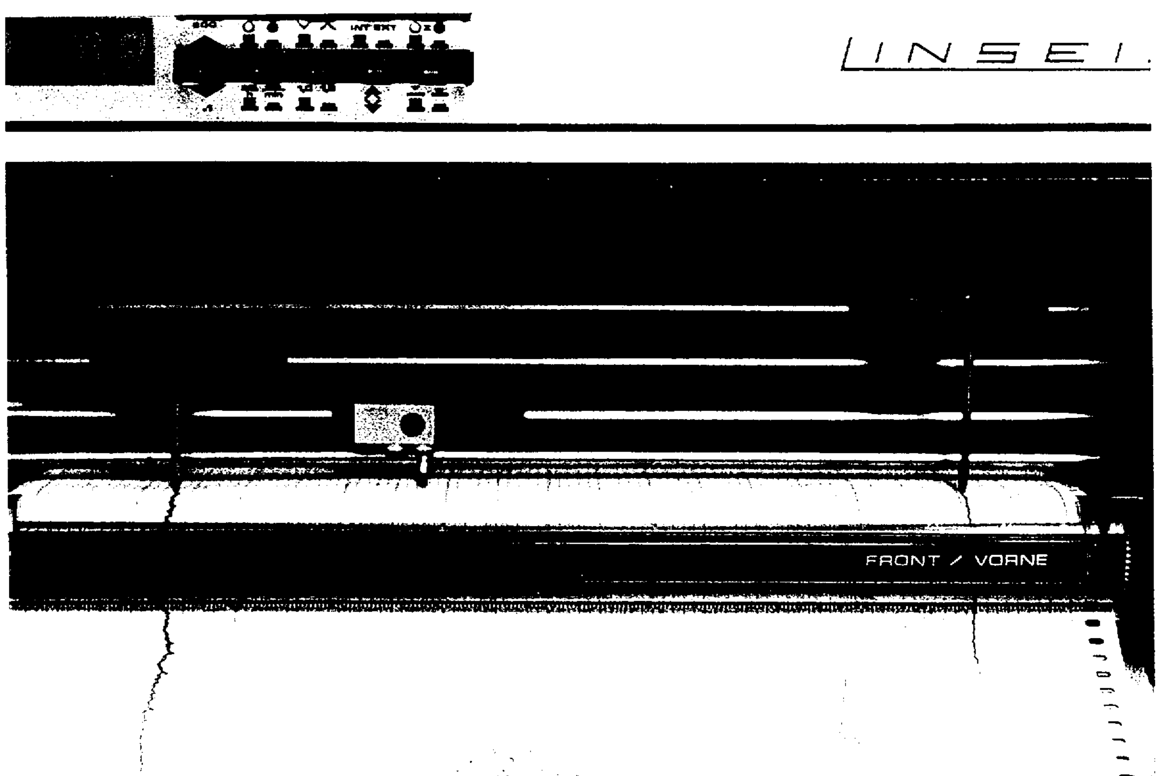

Figure 2. Readout from chart recorder indicating constant bath temperature

Figure 3a. Close-up showing specimen loading in the bath.

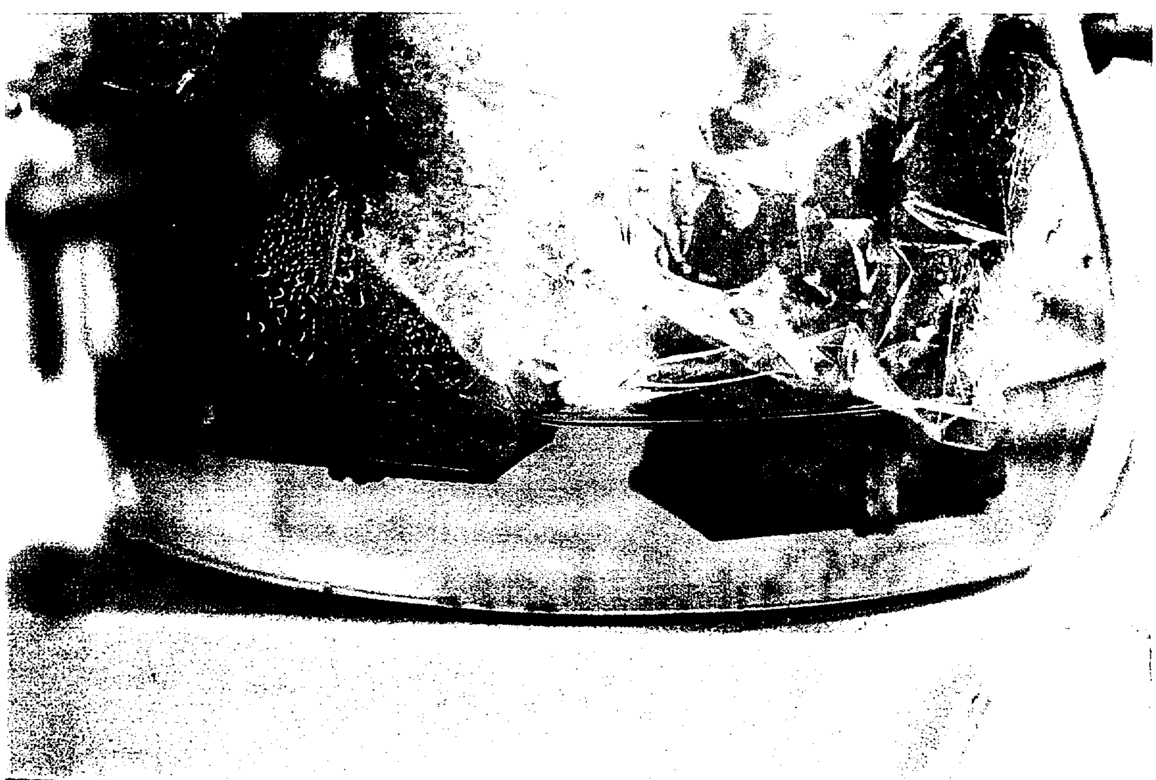

Figure 3b. Close-up showing foam/stainless steel specimen loading.

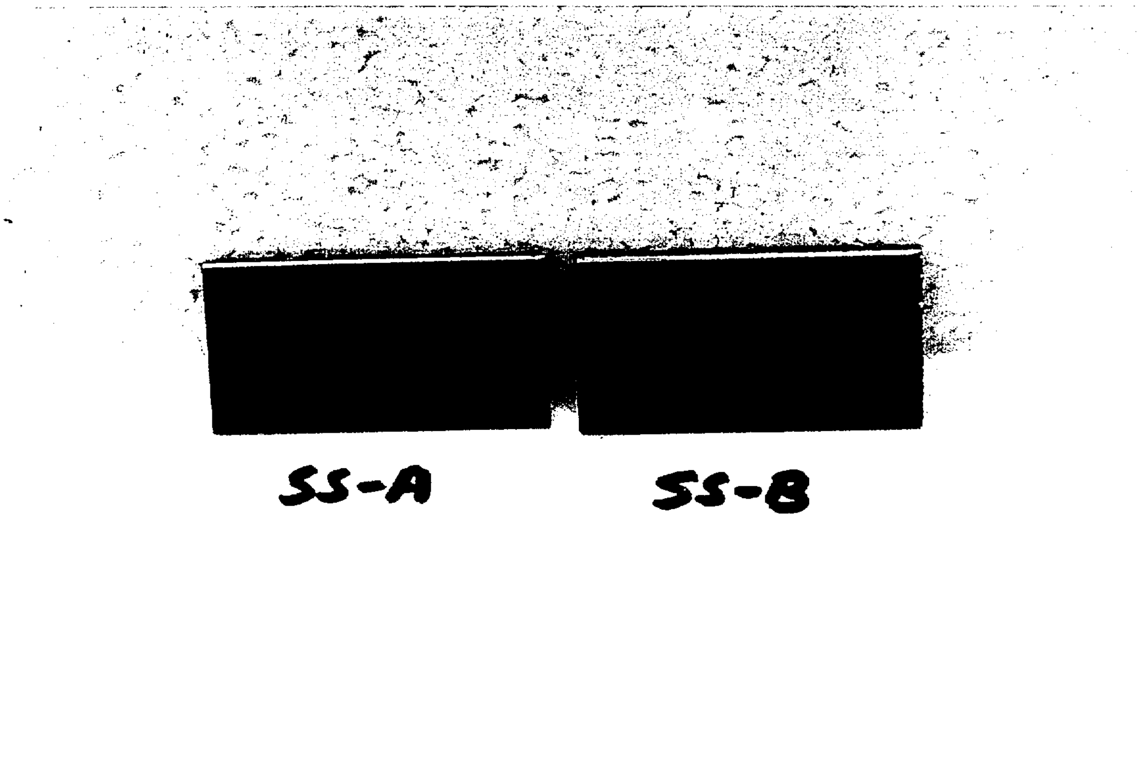

Figure 4a. Stainless steel specimens (SS-A, SS-B) in pretest condition.

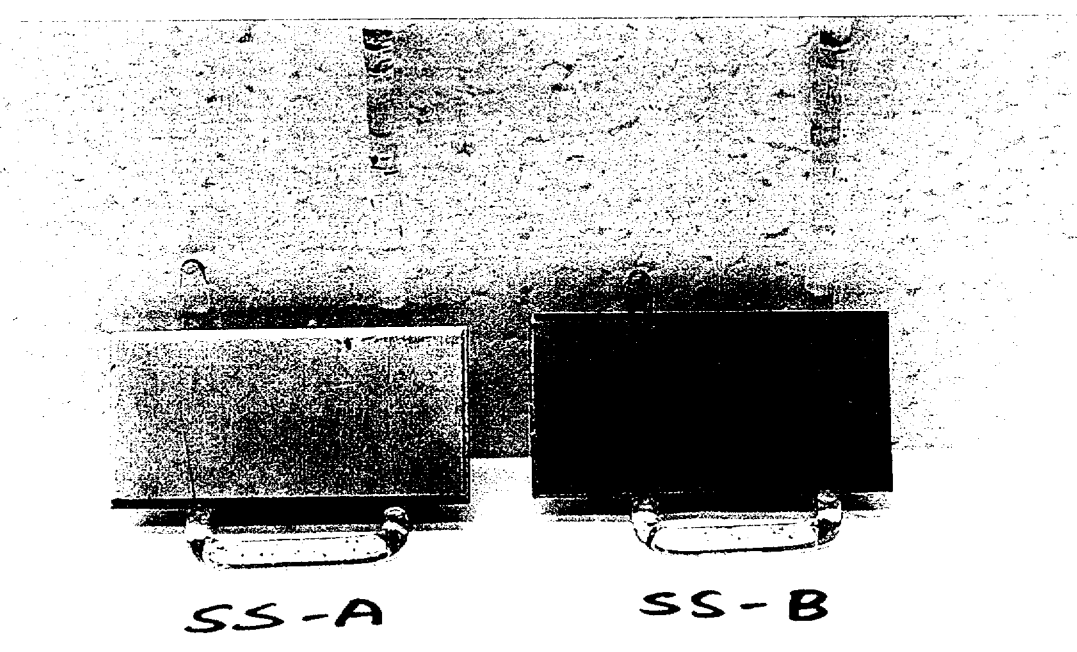

Figure 4b. Stainless steel specimens (SS-A, SS-B) in post-test condition.

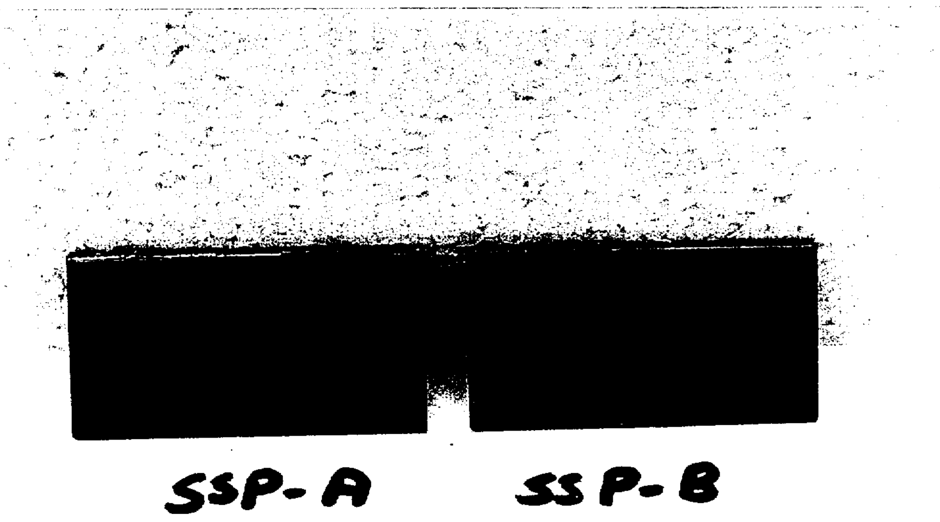

Figure 5a. Stainless steel specimens coated with primer (SSP-A, SSP-B) in pretest condition.

Figure 5b. Stainless steel specimens coated with primer (SSP-A, SSP-B) in post-test condition.

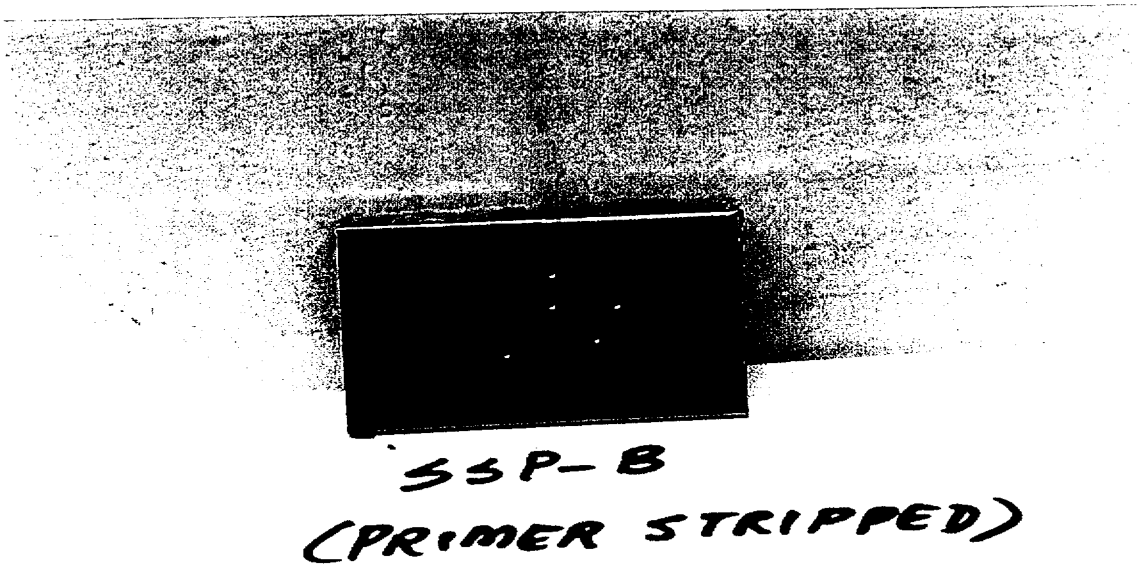

Figure 5c. Stainless steel specimen primer coated (SSP-B) showing after coating was stripped in post-test condition.

Figure 6a. Stainless steel primer coated and inscribed (SSPI-A, SSPI-B) in the pretest condition. (Top Side).

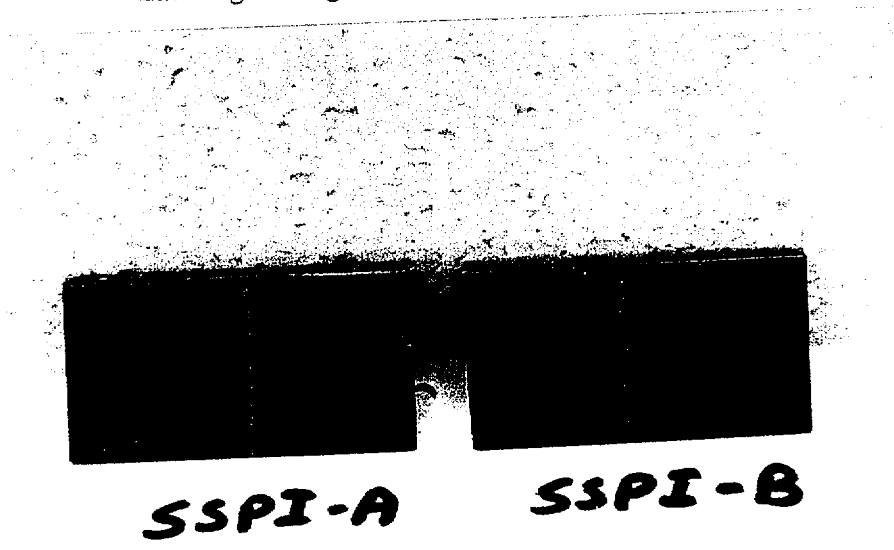

Figure 6b. Stainless steel primer coated and inscribed (SSPI-A, SSPI-B) in the pretest condition. (Bottom Side)

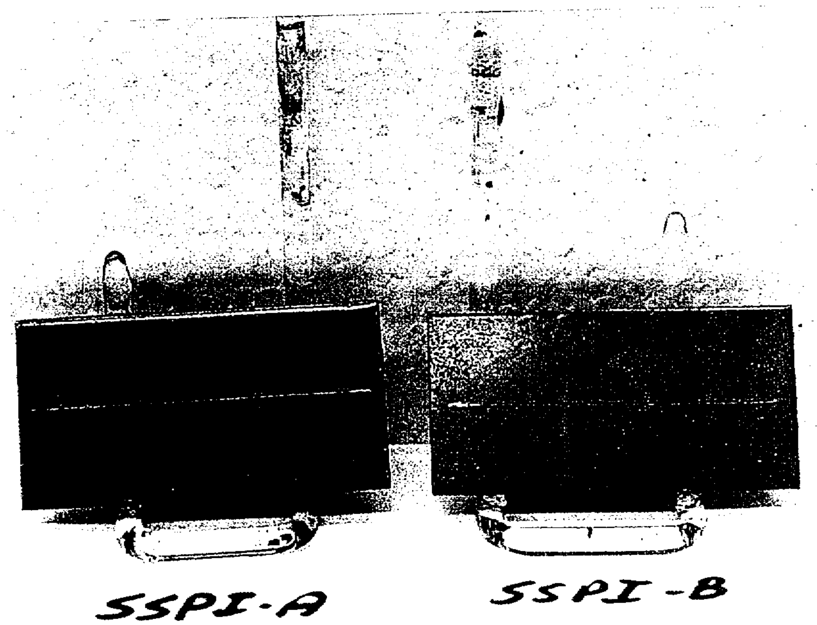

Figure 6c. Stainless steel primer coated and inscribed (SSPI-A, SSPI-B) in the post-test condition. (Top Side).

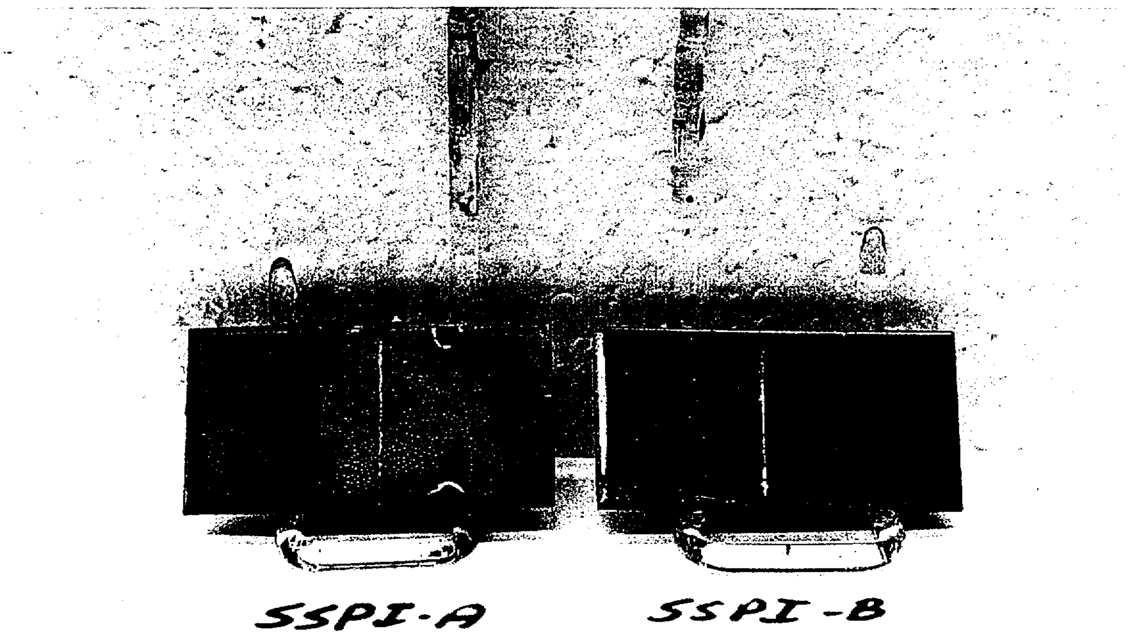

Figure 6d. Stainless steel primer coated and inscribed (SSPI-A, SSPI-B) in the post-test condition. (Bottom Side)

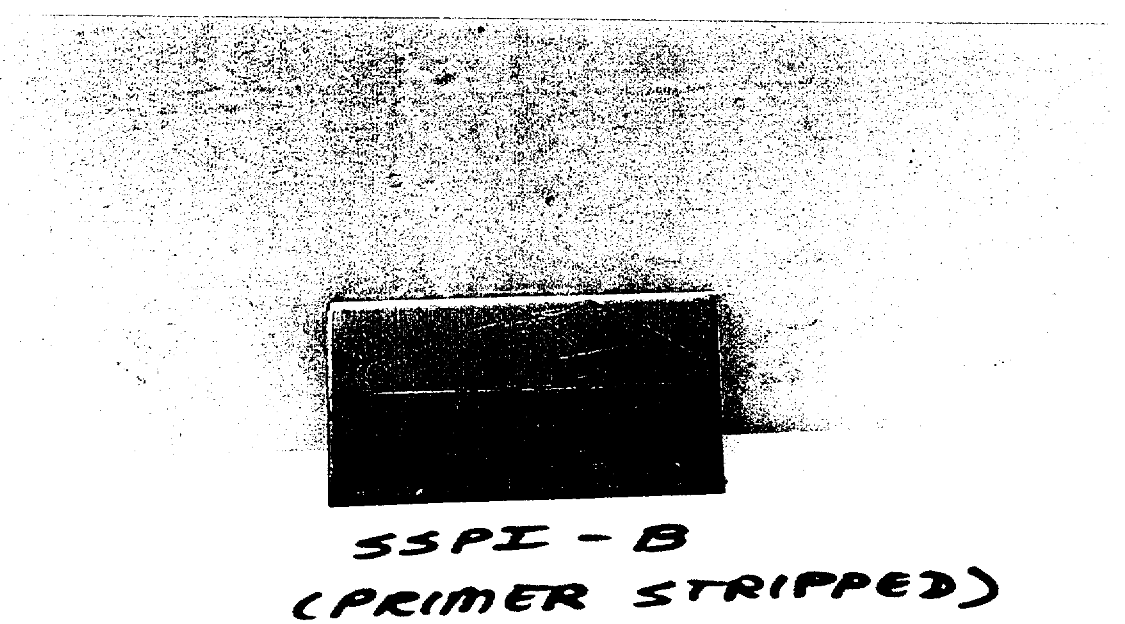

Figure 6e. Stainless steel primer coated and inscribed (SSPI-B)shown after the coating was stripped in the post-test condition. (Top Side).

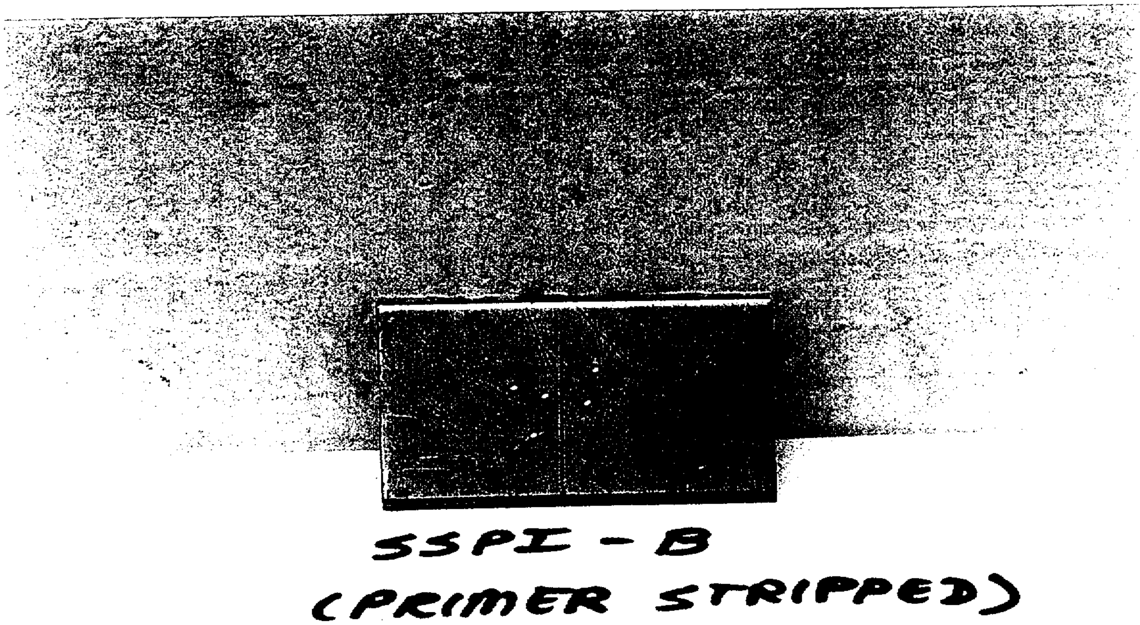

Figure 6f. Stainless steel primer coated and inscribed (SSPI-B) shown after the coating was stripped in the post-test condition. (Bottom Side)

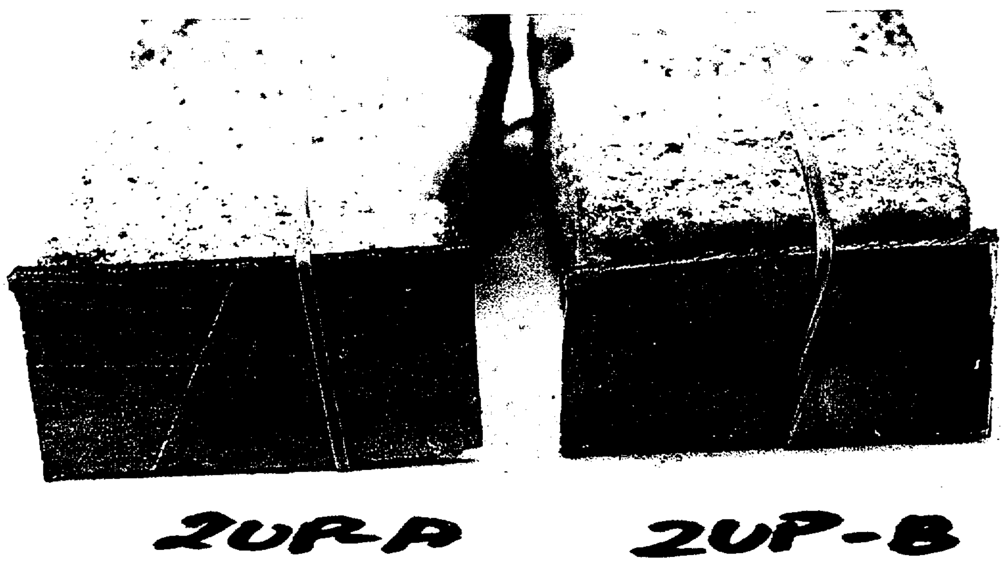

Figure 7a. Stainless steel/foam specimens (2UP-A, 2UP-B) in pretest condition.

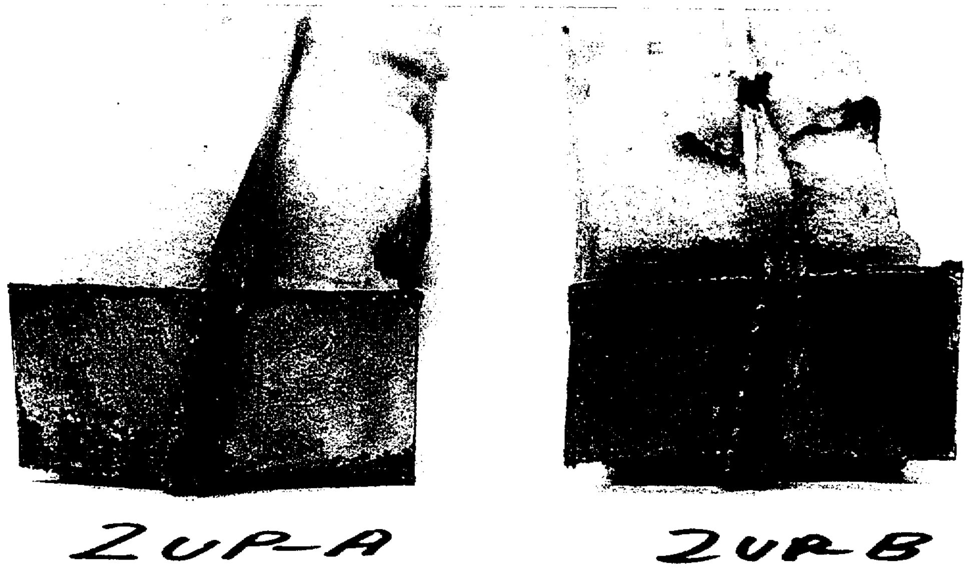

Figure 7b. Stainless steel/foam specimens (2UP-A, 2UP-B) in post-test condition.

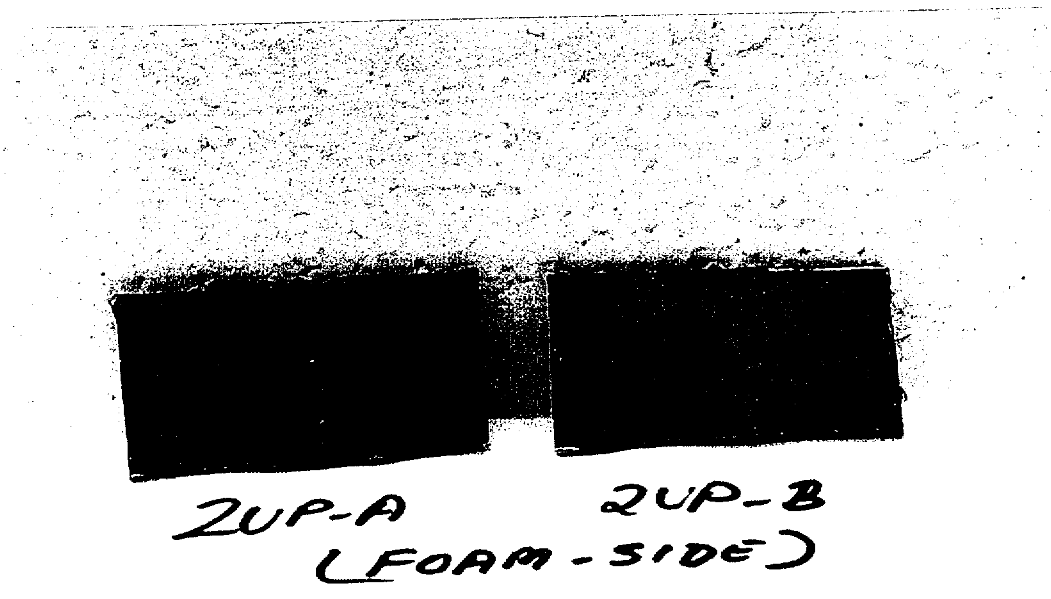

Figure 7c. Stainless steel/foam specimens (2UP-A, 2UP-B) in post-test condition. (Showing the side facing the foam)

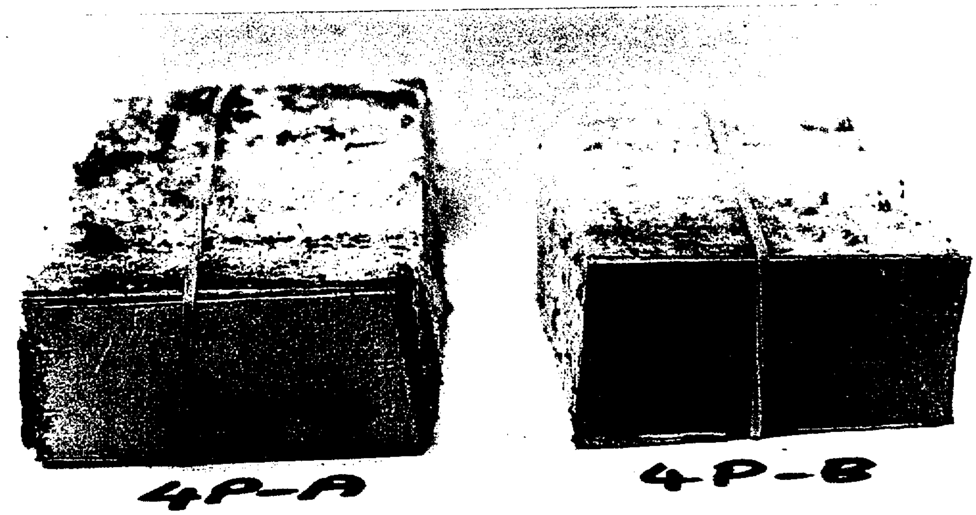

Figure 8a. Stainless steel/foam specimens (4P-A, 4P-B) in pretest condition.

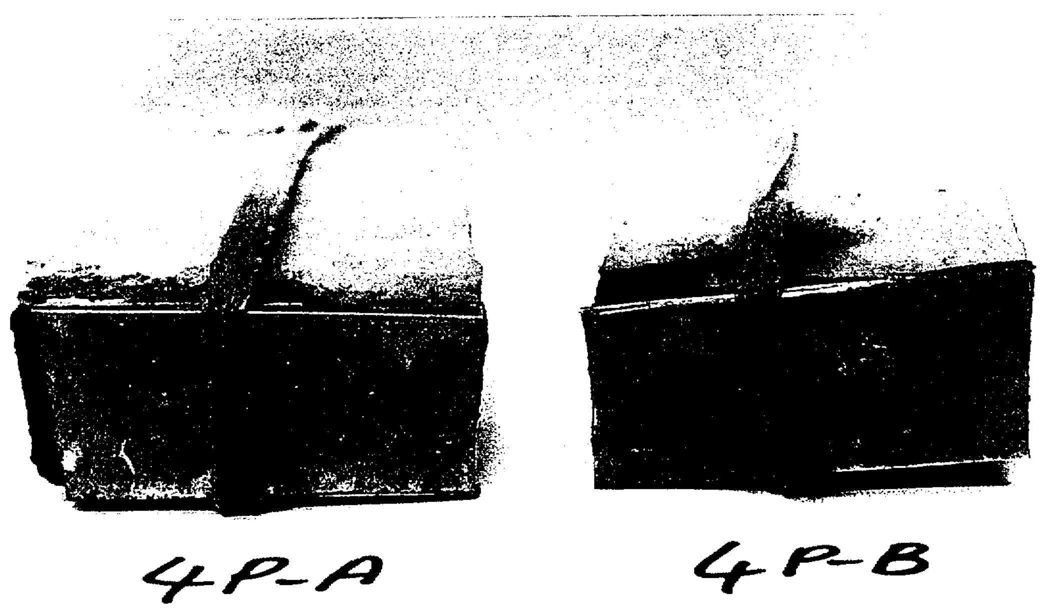

Figure 8b. Stainless steel/foam specimens (4P-A, 4P-B) in post-test condition

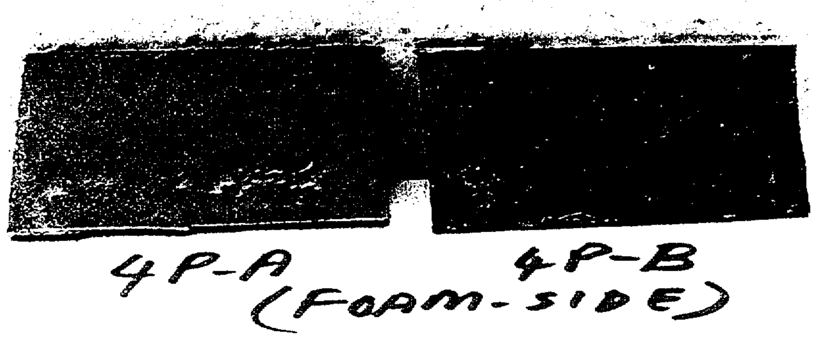

Figure 8c. Stainless steel/foam specimens (4P-A, 4P-B) in pretest condition. (Showing the side facing the foam)

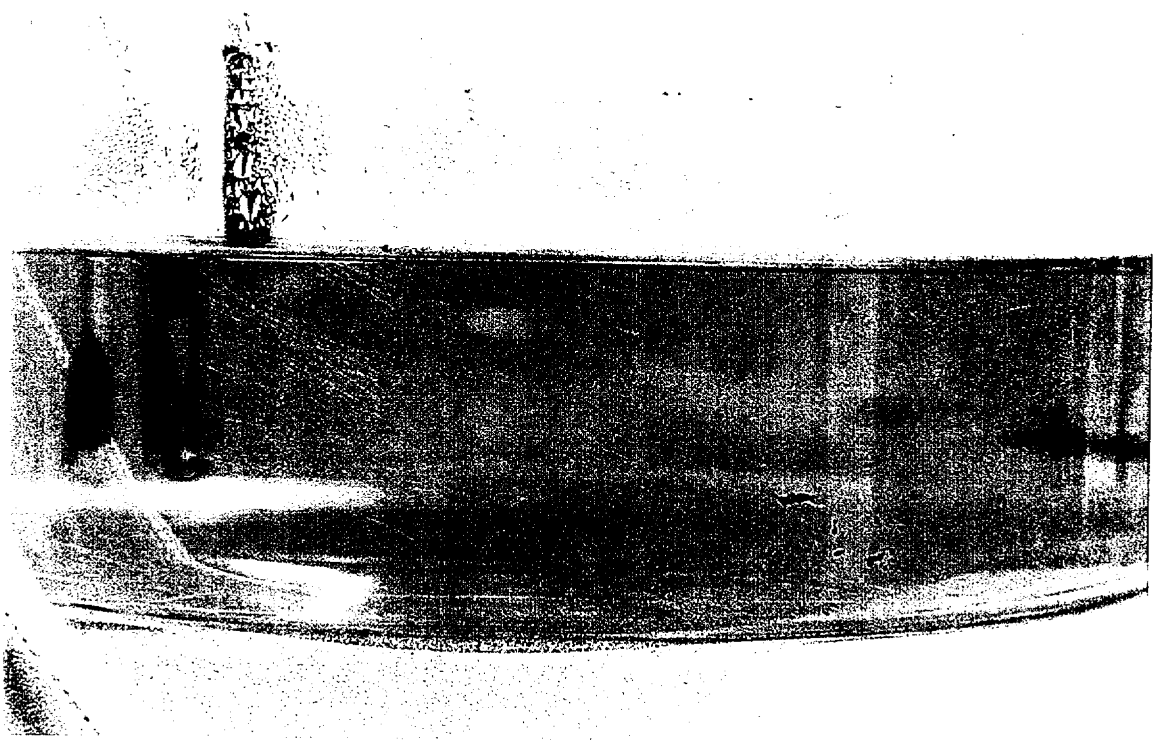

Figure 9a. Color of the bath-1 solution. (Containing SS, SSP and SSPI specimens)

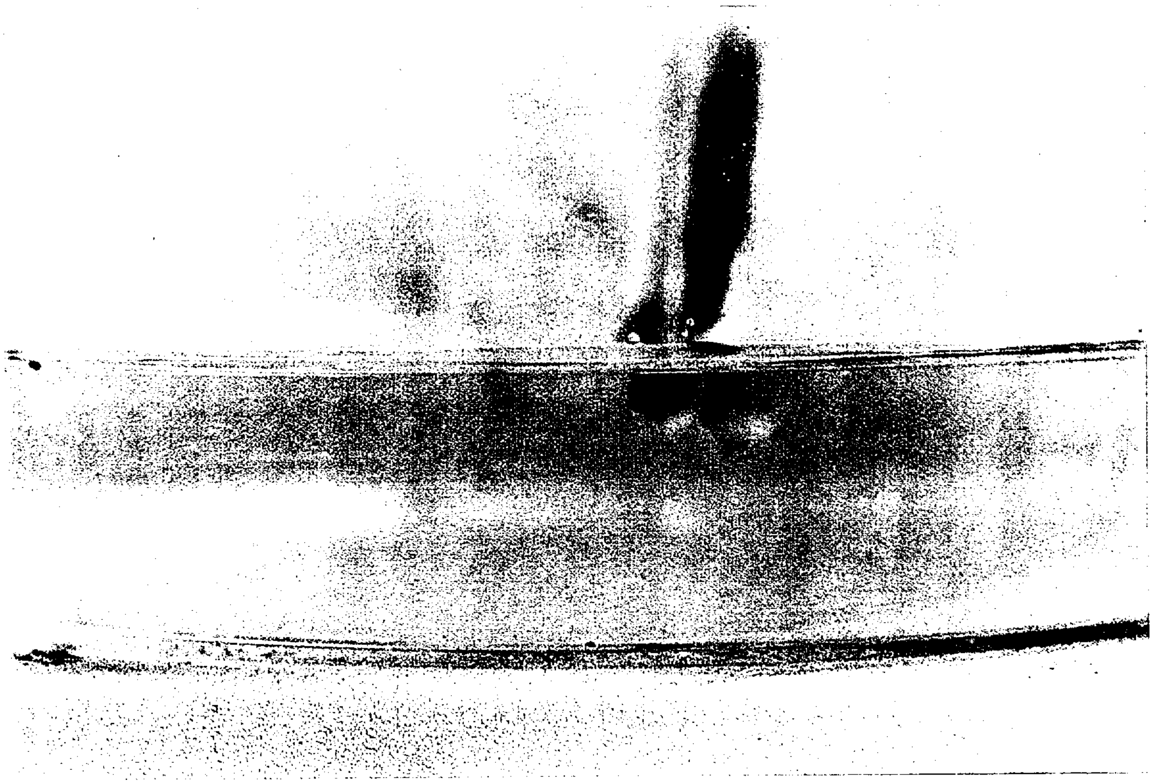

Figure 9b. Color of the bath-2 solution. (Containing 2UP and 4P Specimens)

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A DIVISION OF LAW ENGINEERING, 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

REPORT OF MICROSCOPIC EXAMINATION

Client: NUCLEAR CONTAINERS, INC.
c/o Law Engr. Indus. Svcs.
P.O. Box 19667
Charlotte, NC 28219
Attn: Mr. L. Santanam

Project: General
Office: LEIS Charlotte
Lab No.: 10832-5-0807

Date: October 20, 1995

Client P.O. No.: Not Reported
Material: Reported as Submitted Samples from 400ppm Ferric Chloride Corrosion Test, ID (See Below)
Heat/Lot No.: Not Reported
Date Tested: Completed October 20, 1995
Procedure: In accordance with Client's Instructions and ASTM E-3-80(86)

TEST RESULTS

LEIS Piece No.	Results	Comments
10-11-95-SS-A	Photomicrograph - Side 1	See Photo*
10-11-95-SS-B	Photomicrograph - Side 1	See Photo*
0-11-95-SSP-A	Photomicrograph - Side 1	See Photo*
10-11-95-SSP-B	Photomicrograph - Side 2	See Photo*
10-11-95-SSPI-A	Photomicrograph - Side 2	See Photo*
10-11-95-SSPI-B	Photomicrograph - Side 2	See Photo*
10-11-95-2UP-A	Photomicrograph - Side 1	See Photo*
10-11-95-2UP-B	Photomicrograph - Side 2	See Photo*
10-11-95-4P-A	Photomicrograph - Side 1	See Photo*
10-11-95-4P-B	Photomicrograph - Side 1	See Photo*

*Cross Section

Attachment: Photomicrograph (10 Etched)

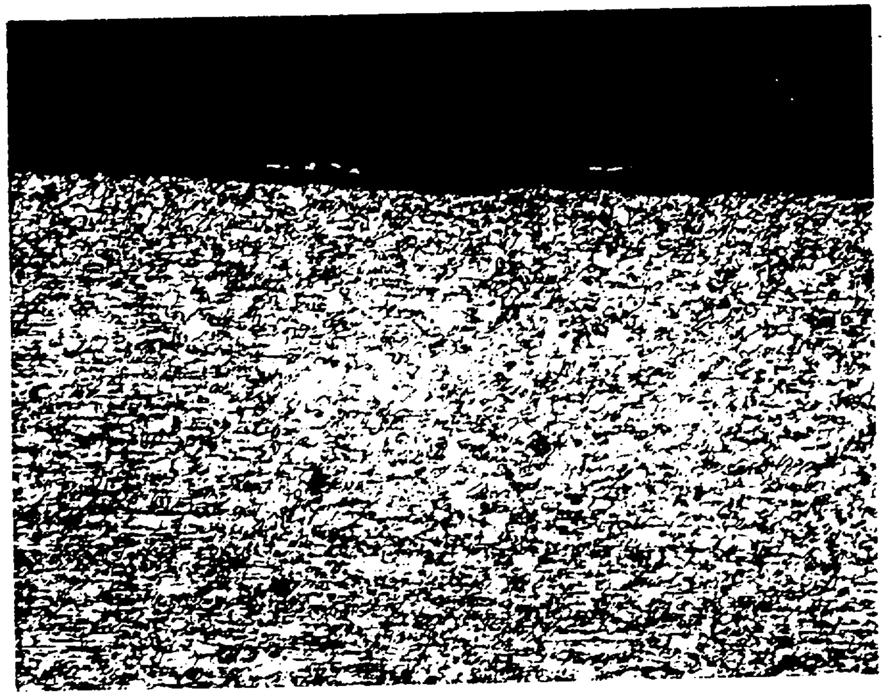
Reviewed by: L. Santanam
Lakshman Santanam
Laboratory Manager

Respectfully Submitted,
LAW ENGINEERING INDUSTRIAL SERVICES

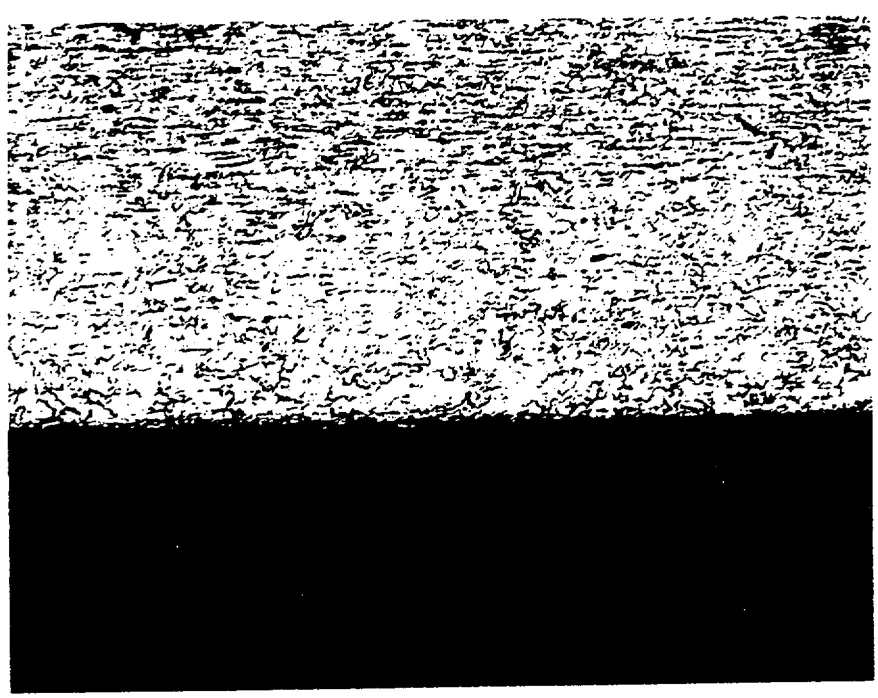
Larry E. Coble, Metals Lab Supervisor

NUCLEAR CONTAINERS, INC.
c/o Law Engr. Indus. Svcs.
Charlotte, NC
LEIS Lab No. 10832-5-0807
October 20, 1995

Piece No. 10-11-95-SSP-A 100X Etched



Piece No. 10-11-95-SSP-B 100X Etched



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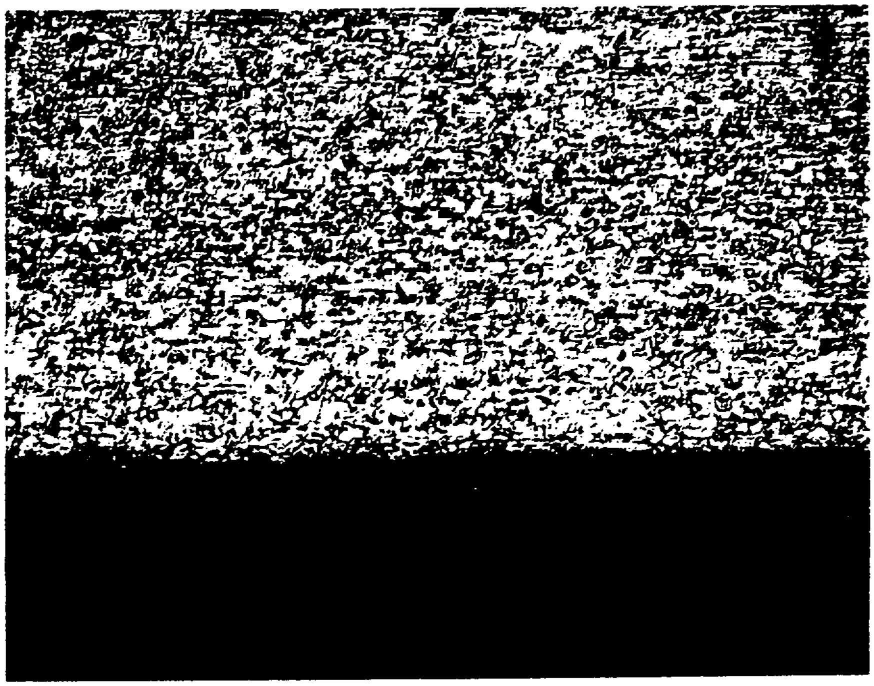
Charlotte, NC
LEIS Lab No. 10832-5-0807
October 20, 1995

Piece No. 10-11-95-SSPI-A 100X Etched



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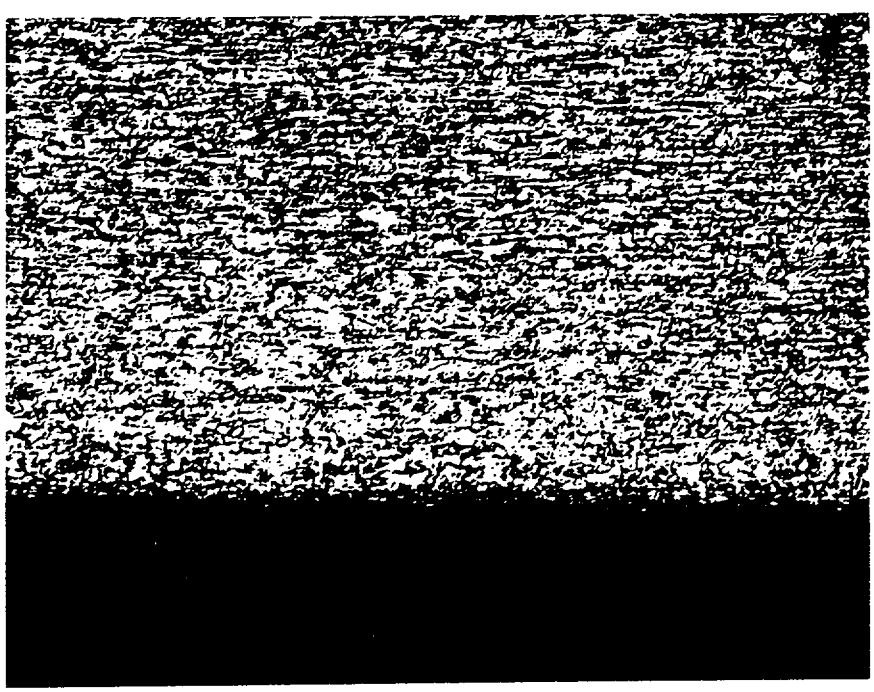

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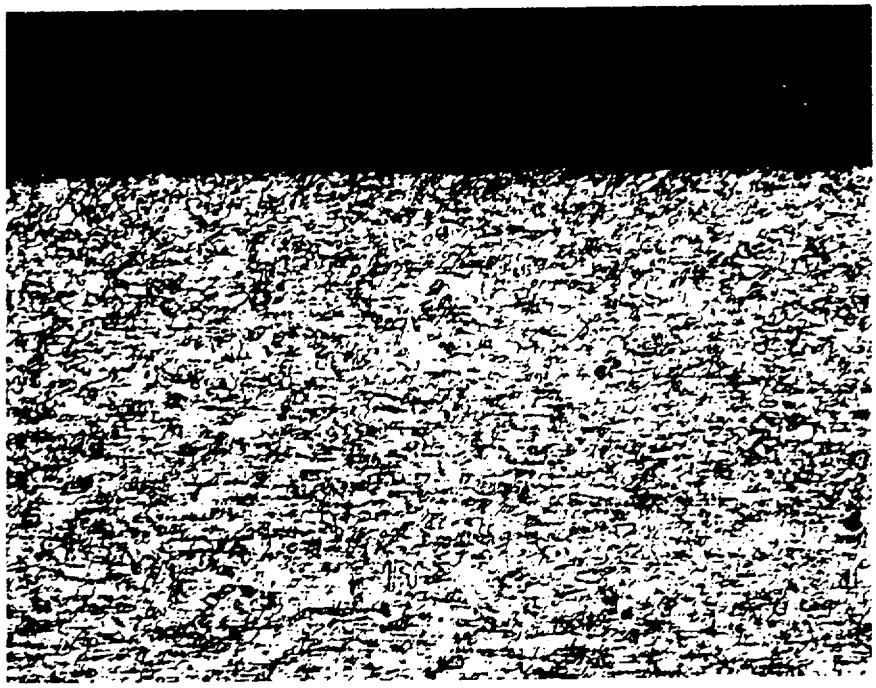
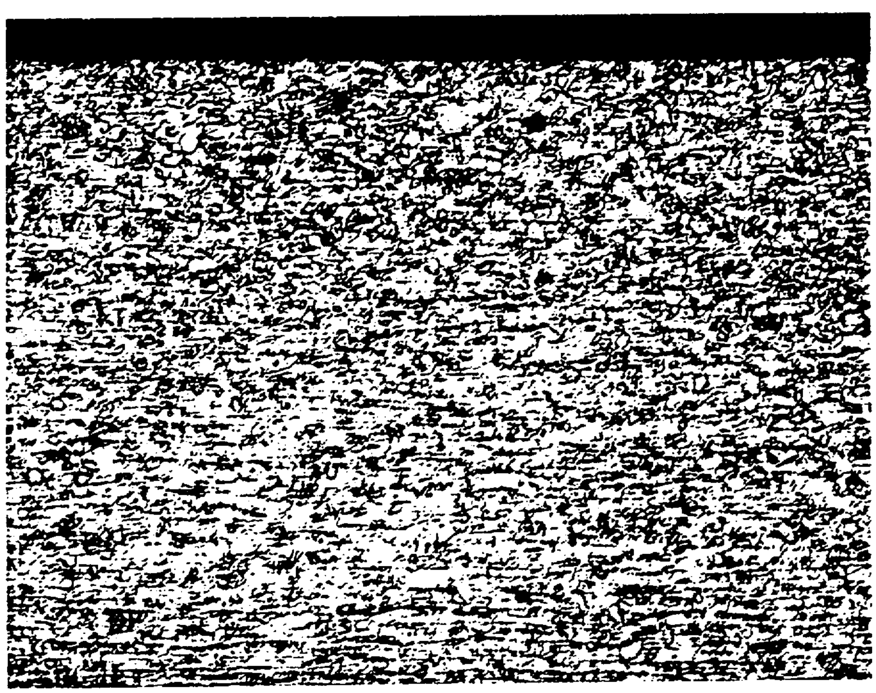
Charlotte, NC
LEIS Lab No. 10832-5-0807
October 20, 1995

Piece No. 10-11-95-SS-A 100X Etched



Piece No. 10-11-95-SS-B 100X Etched



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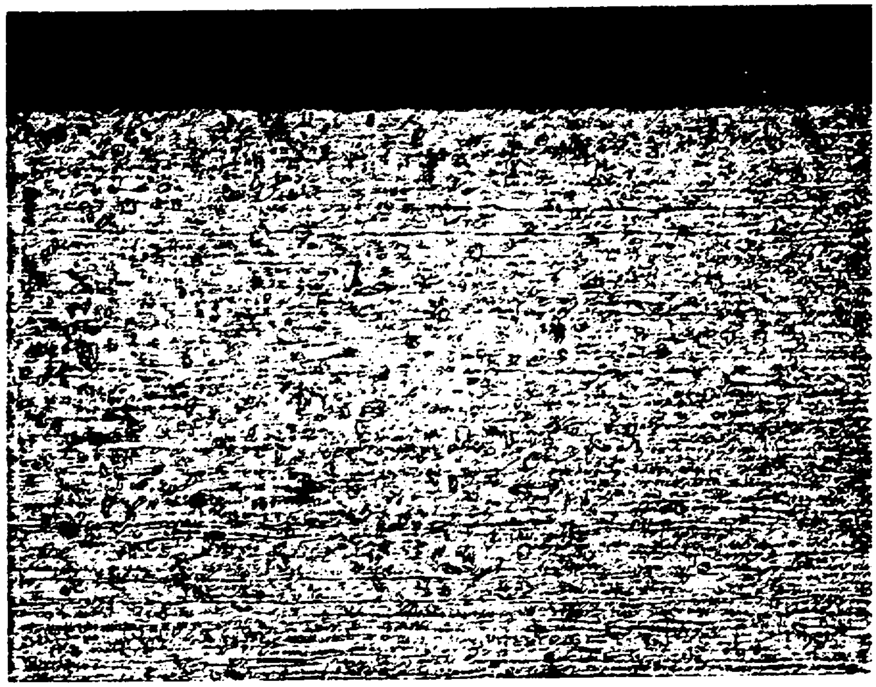
LEIS Lab No. 10832-5-0807
October 20, 1995

Piece No. 10-11-95-2UP-A 100X Etched



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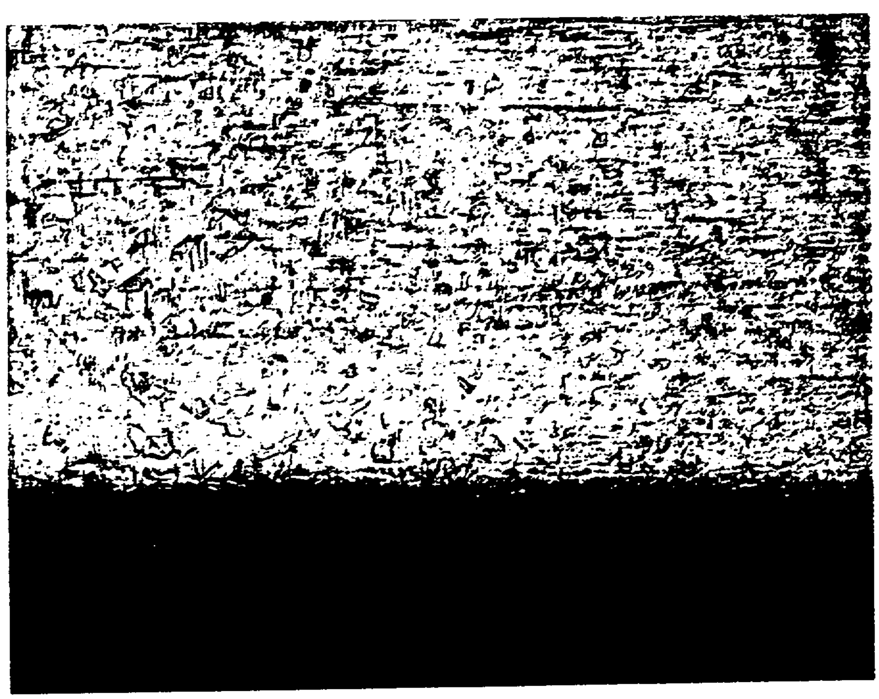

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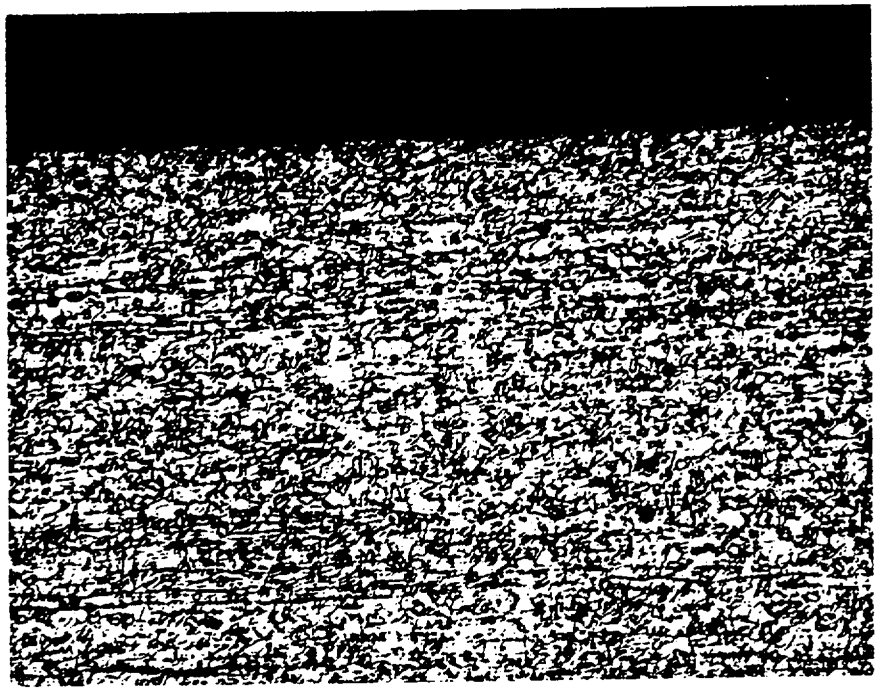
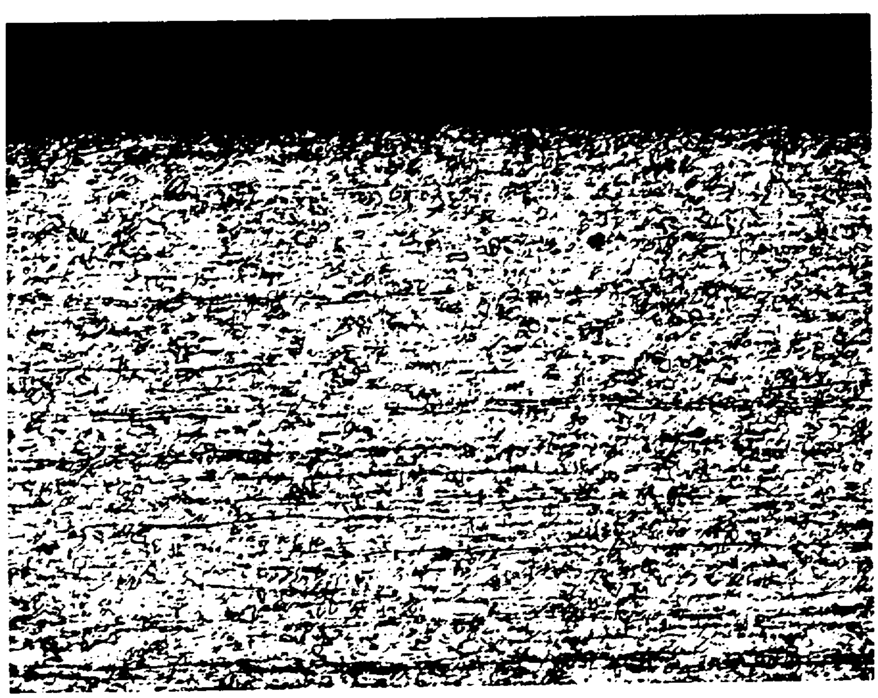
Charlotte, NC
LEIS Lab No. 10832-5-0807
October 20, 1995

Piece No. 10-11-95-4P-A 100X Etched



Piece No. 10-11-95-4P-B 100X Etched



Appendix 2.10.4

Law Engineering Report on Charpy "V" Impact Tests

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
·27-98-1CB1	125	0.092	*	+100°F
-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

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 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

Leis ece No.	Impact Strength (ft. lbs.)	Lateral Expansion (in.)	Percent Shear (%)	Comments
-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 Coble, Technical Leader

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 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 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
-27-98-3CB1	20	0.048	50	+100°F
2-27-98-3CB2	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	"

Respectfully Submitted,
LAW ENGINEERING INDUSTRIALS SERVICES

Reviewed By:
Lakshman Santanam
Technical Center Manager

Larry Coble, Technical Leader

Appendix 2.10.5

Law Engineering Report on ESP-PF-1 Foam Characteristics

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 04
March 18, 1998

High 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	S	0.0372	0.0047	7.97	896.67	4.00	223.94
100°F	T	0.0376	0.0047	8.00	855.46	4.00	213.67
100°F	U	0.0384	0.0048	7.98	806.62	4.16	193.84
74°F	V	0.0384	0.0048	8.00	971.46	4.13	235.41
74°F	W	0.0380	0.0048	8.00	931.00	4.09	227.47
74°F	X	0.0384	0.0048	8.00	1000.46	4.11	243.66
-20°F	Y	0.0384	0.0047	8.12	1026.40	4.09	250.83
-20°F	Z	0.0376	0.0047	8.00	929.49	4.09	227.15
-20°F	AA	0.0394	0.0048	8.21	1072.19	4.15	258.11

+ 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.
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 04
March 18, 1998

High Density Samples
(Direction 2)

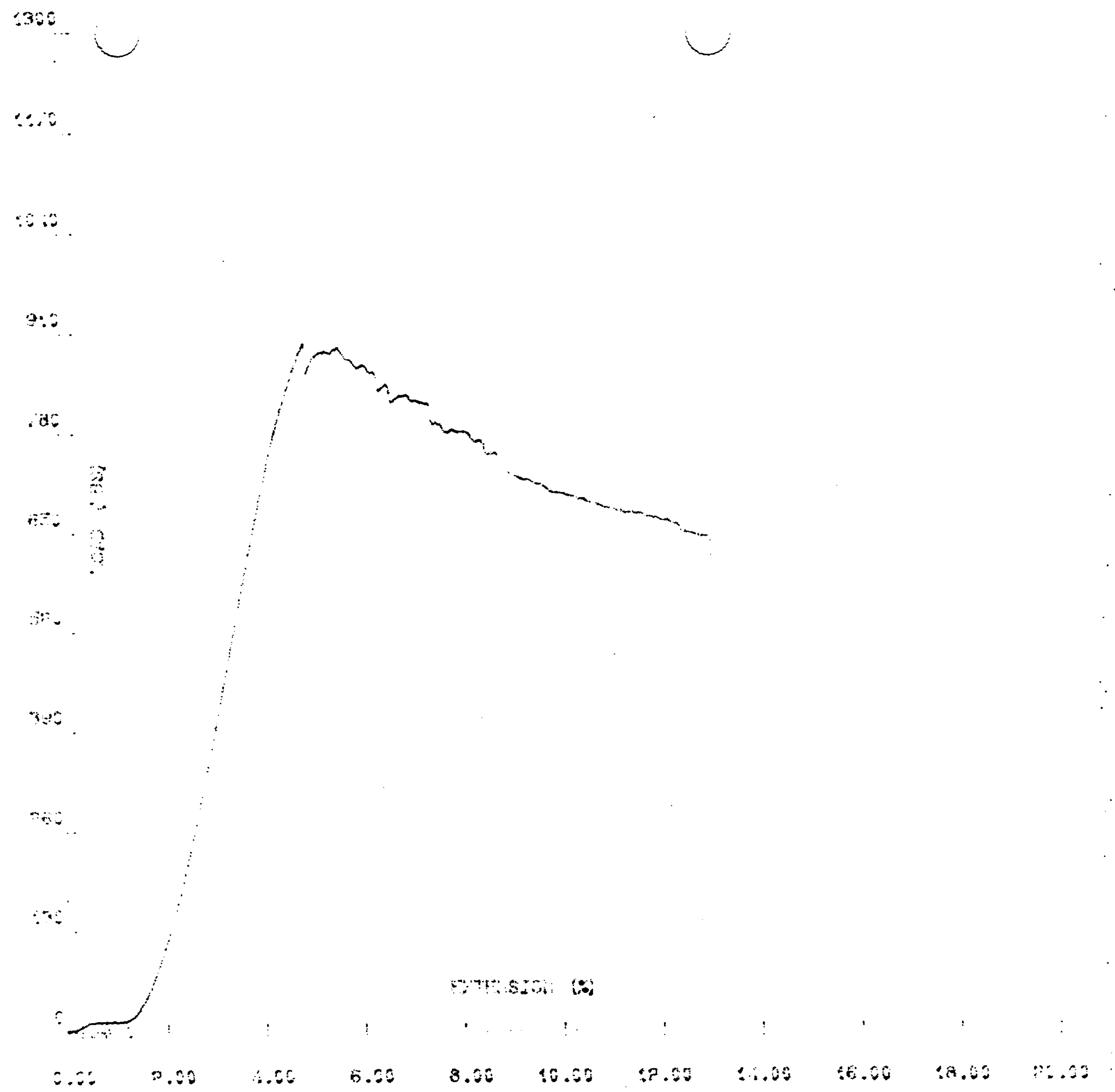
TEST TEMP.	SAMPLE ID+	MASS (lbs)	VOLUME (ft^3)	DENSITY (lbs/ft^3)	PEAK LOAD(lbs)	AREA (in^2)	COMPRESSIVE STRENGTH(psi)
100°F	BB	0.0390	0.0049	8.04	645.60	4.01	160.86
100°F	CC	0.0388	0.0047	8.20	659.34	3.91	168.75
100°F	DD	0.0374	0.0048	7.82	591.42	4.03	146.88
74°F	EE	0.0382	0.0048	7.93	652.47	3.99	163.66
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

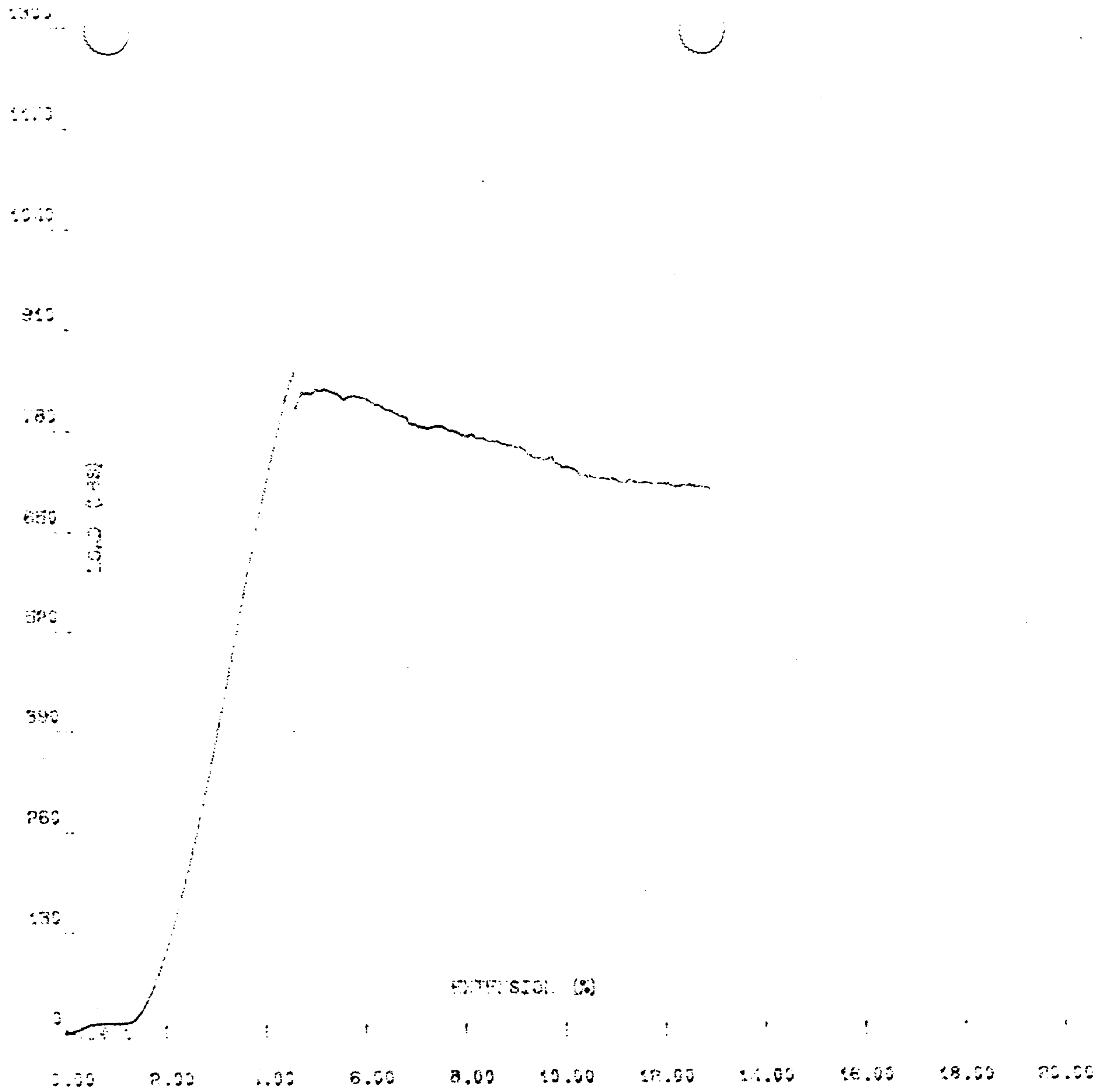
Respectfully submitted,

Lakshman Santanam
Charlotte Technical Center Manager

S 100%
HIGH



100°F
HIGH



LOAD (LBS)
EXTENSION (%)
0
130
260
390
520
650
780
910
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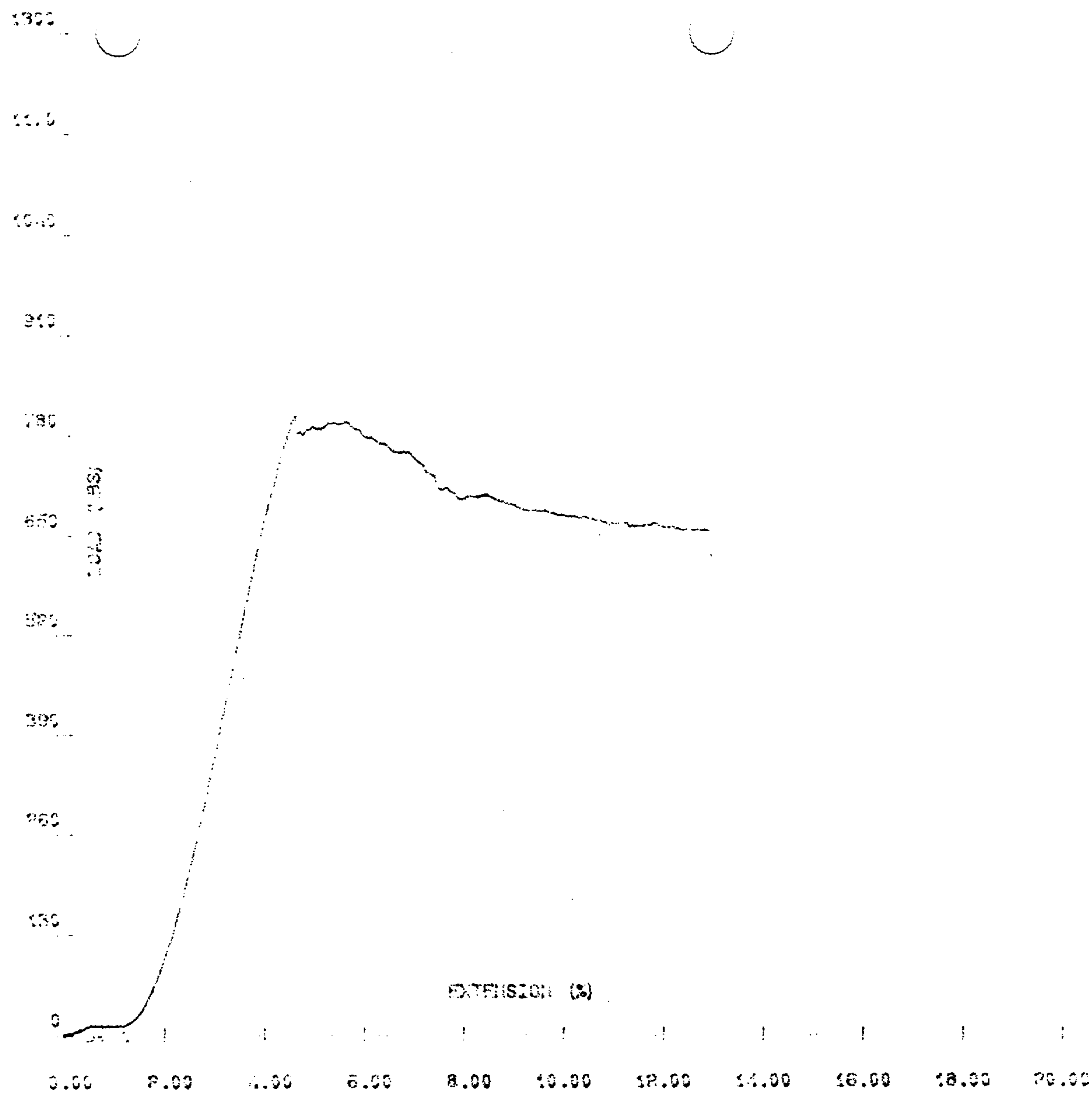
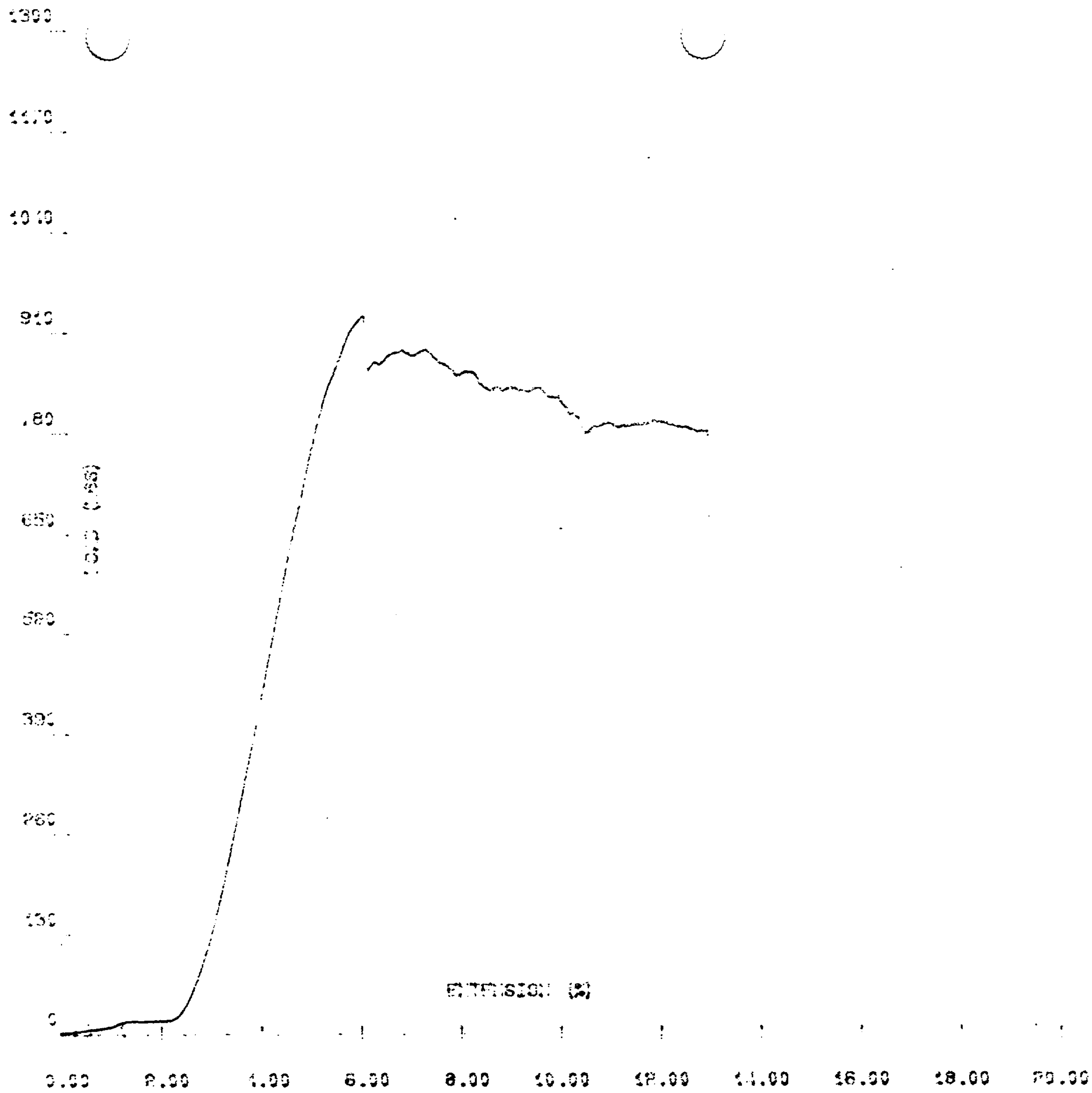
2.00
6.00
8.00
10.00
12.00
16.00
18.00
20.00

U 100°F
HIGH



74°F HIGH
W



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1170
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910
780
650
520
390
260
130
0
0.00
2.00
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6.00
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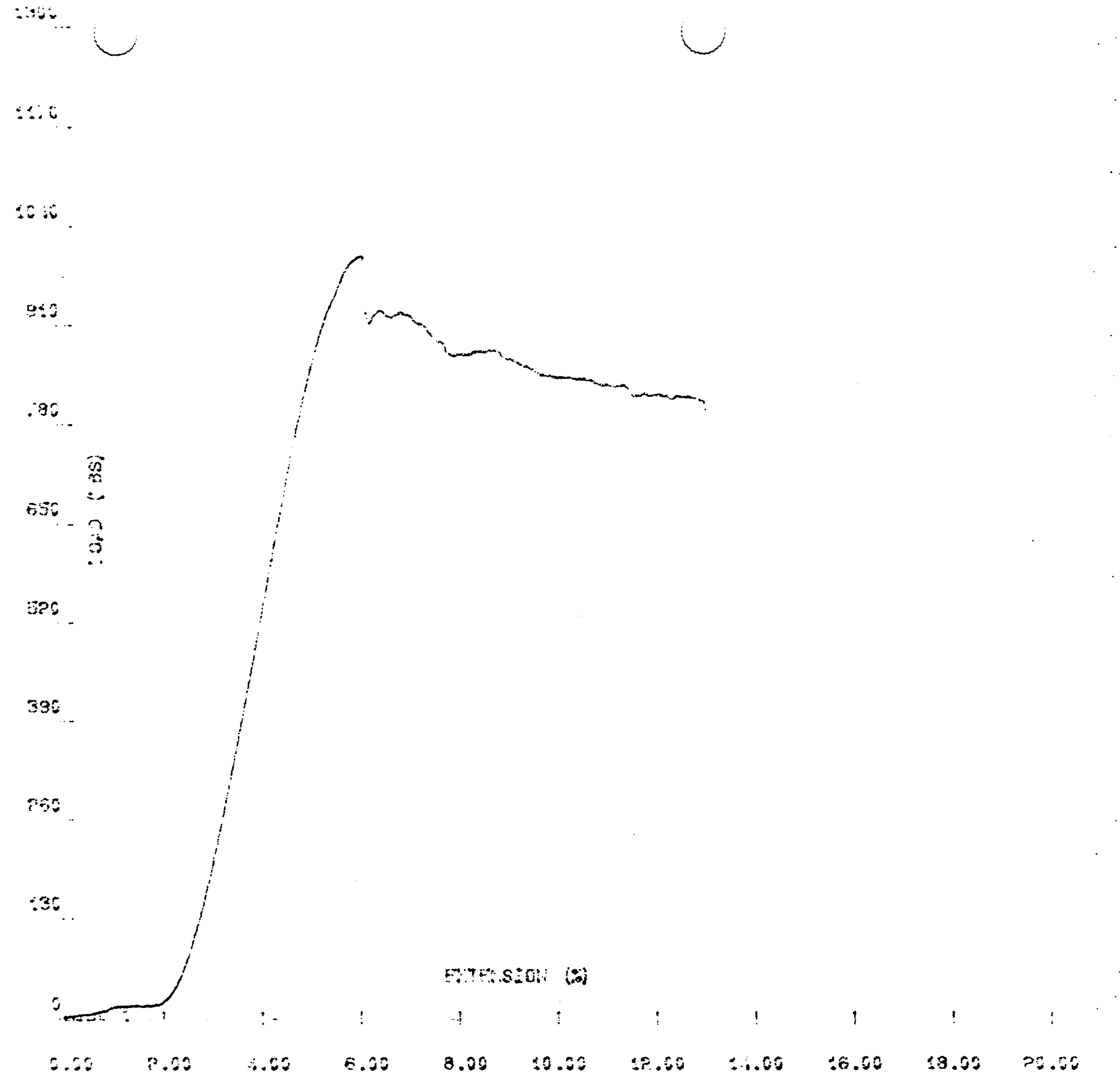
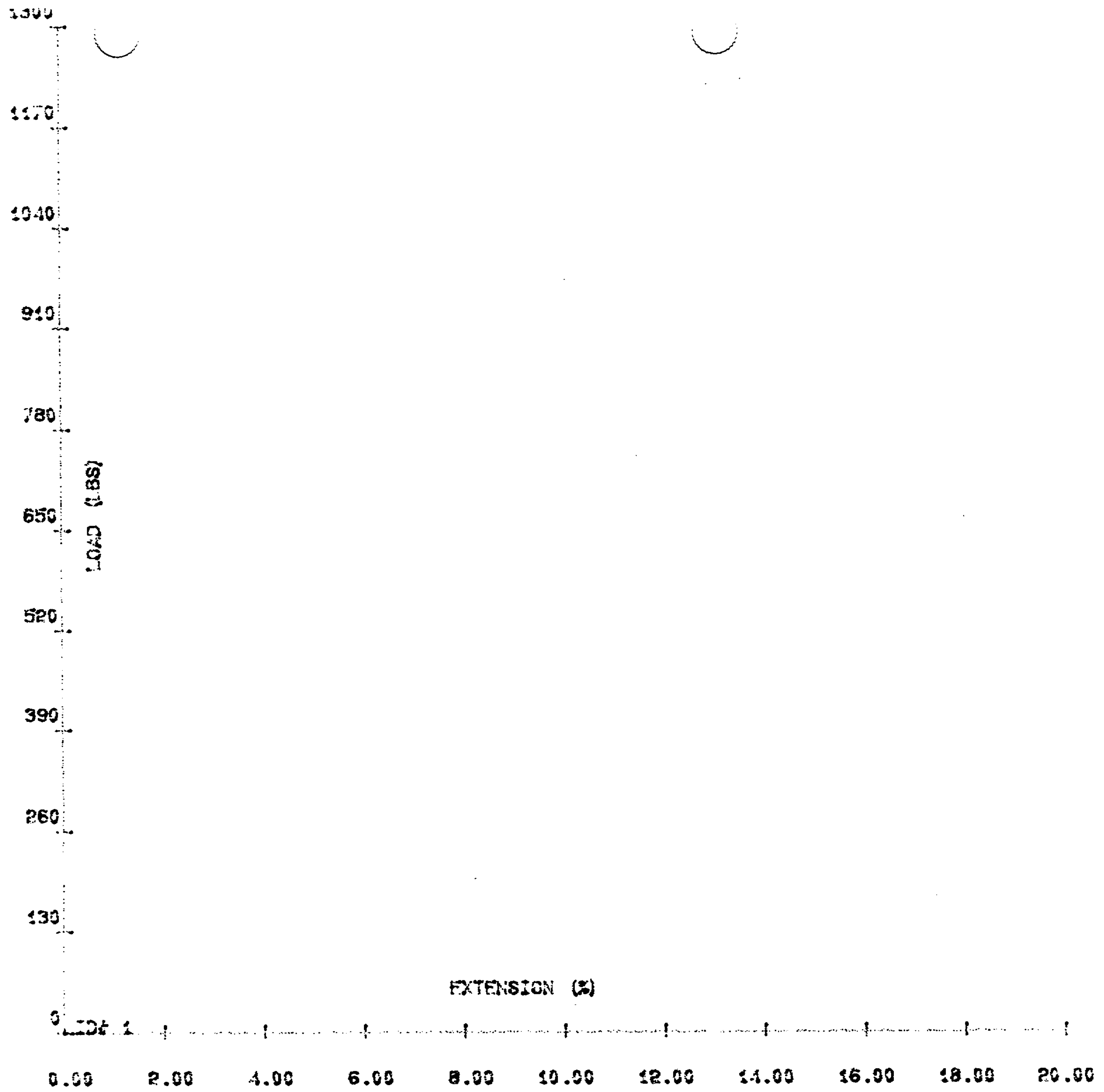
10.00
12.00
14.00
16.00
18.00
20.00
EXTENSION (%)


EXTENSION (%)

Y
20 HIGH



LOAD (LBS)
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1170
1040
910
780
650
520
390
260
130
0
EXTENSION (%)
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2.00
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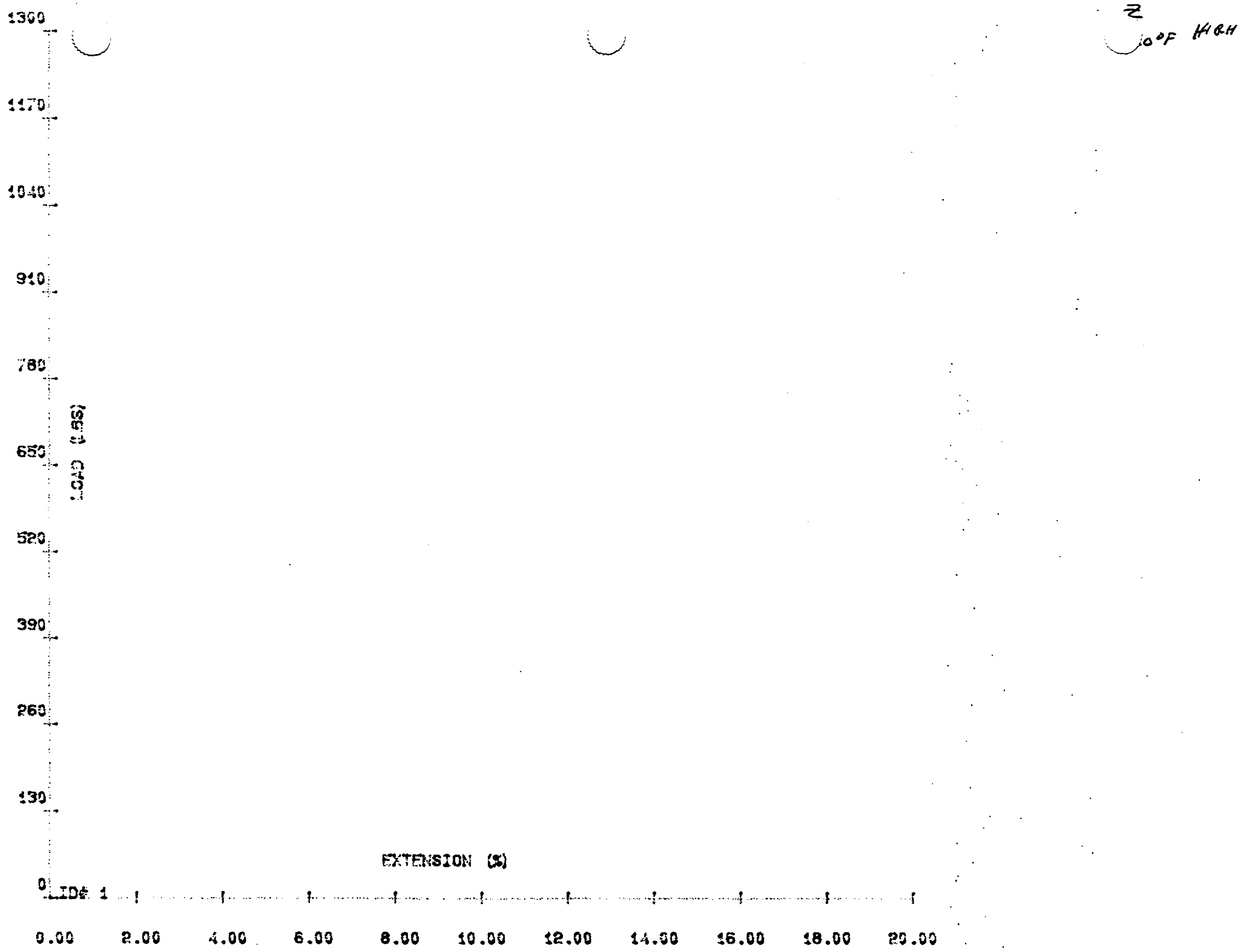
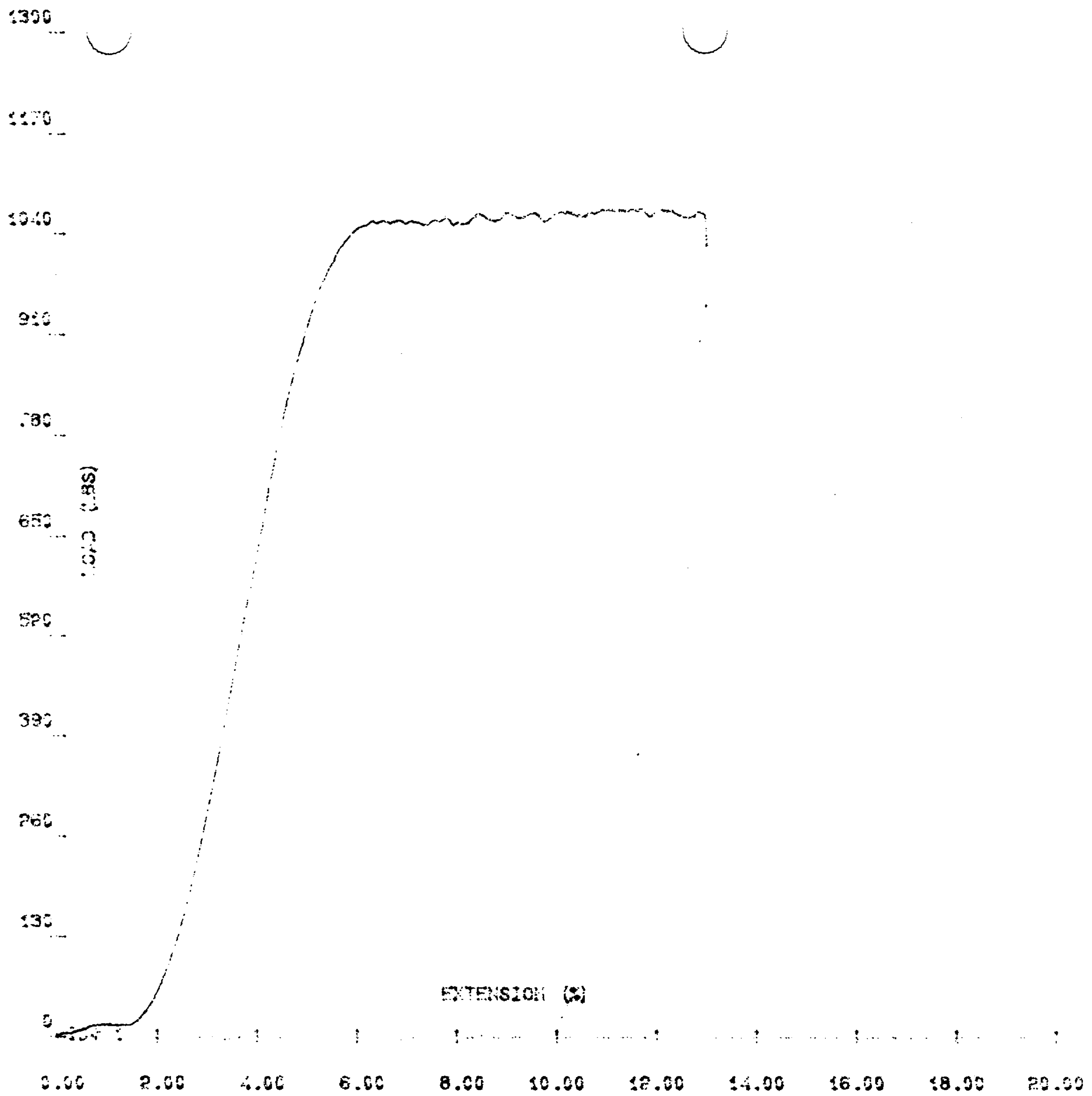
16.00
18.00
20.00

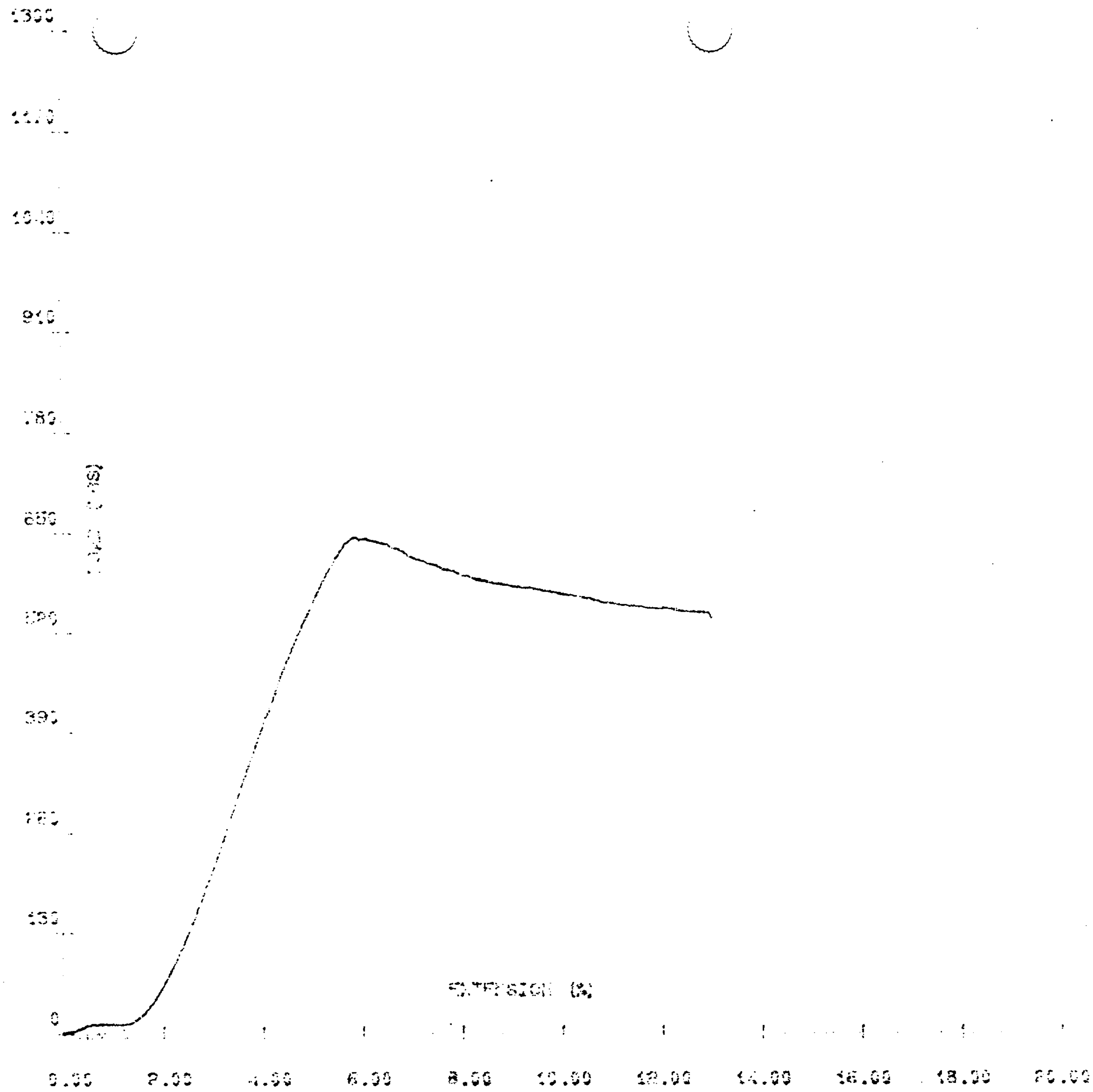

1300
1170
1040
910
780
650
520
390
260
130
0
LOAD (LBS)
EXTENSION (%)
LID# 1
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
HIGH

AA HIGH
-20°F

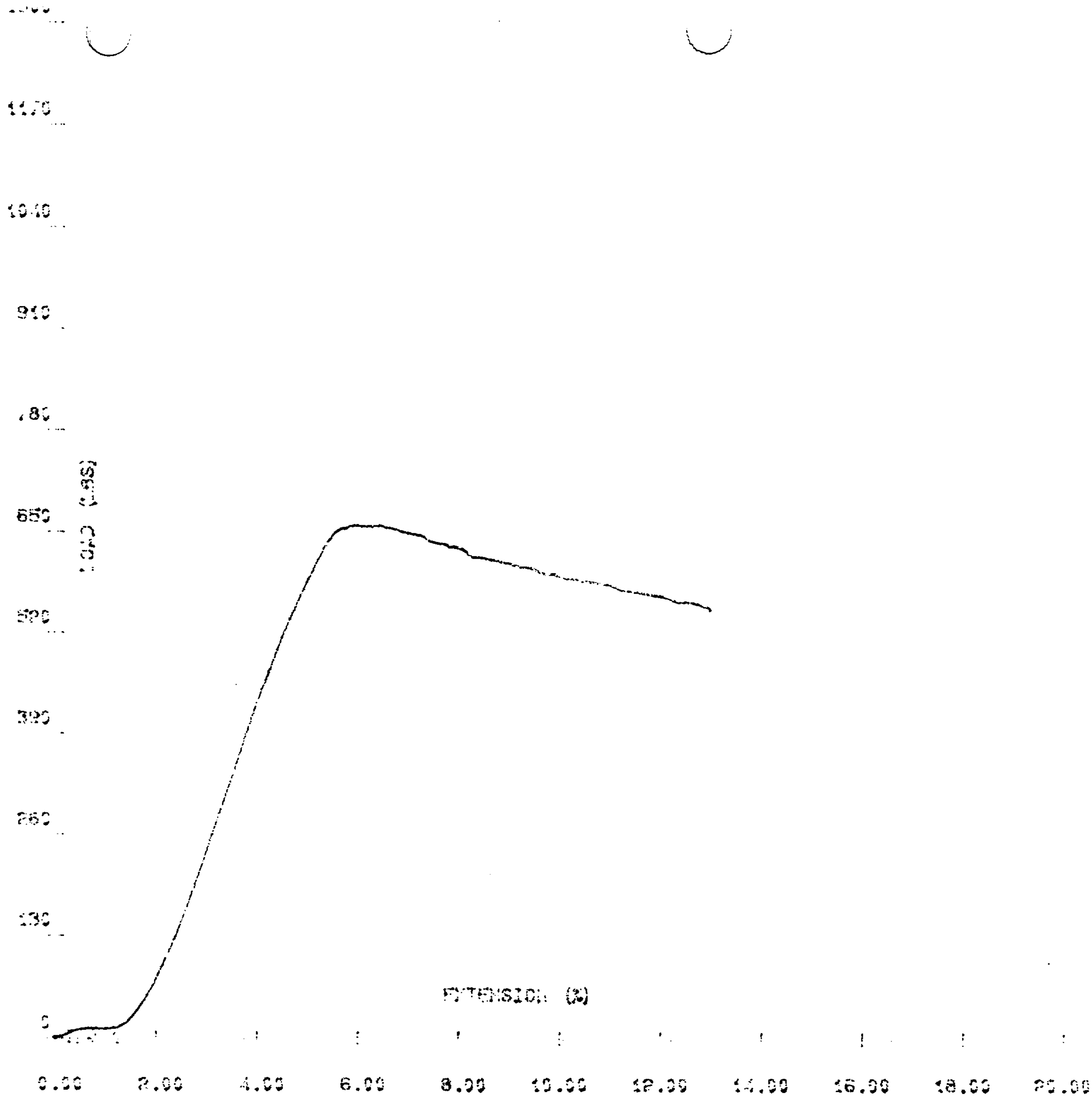


1300
1170
1040
910
780
650
520
390
260
130
0
LOAD (LBS)
EXTENSION (%)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

BD
100°F
HIGH

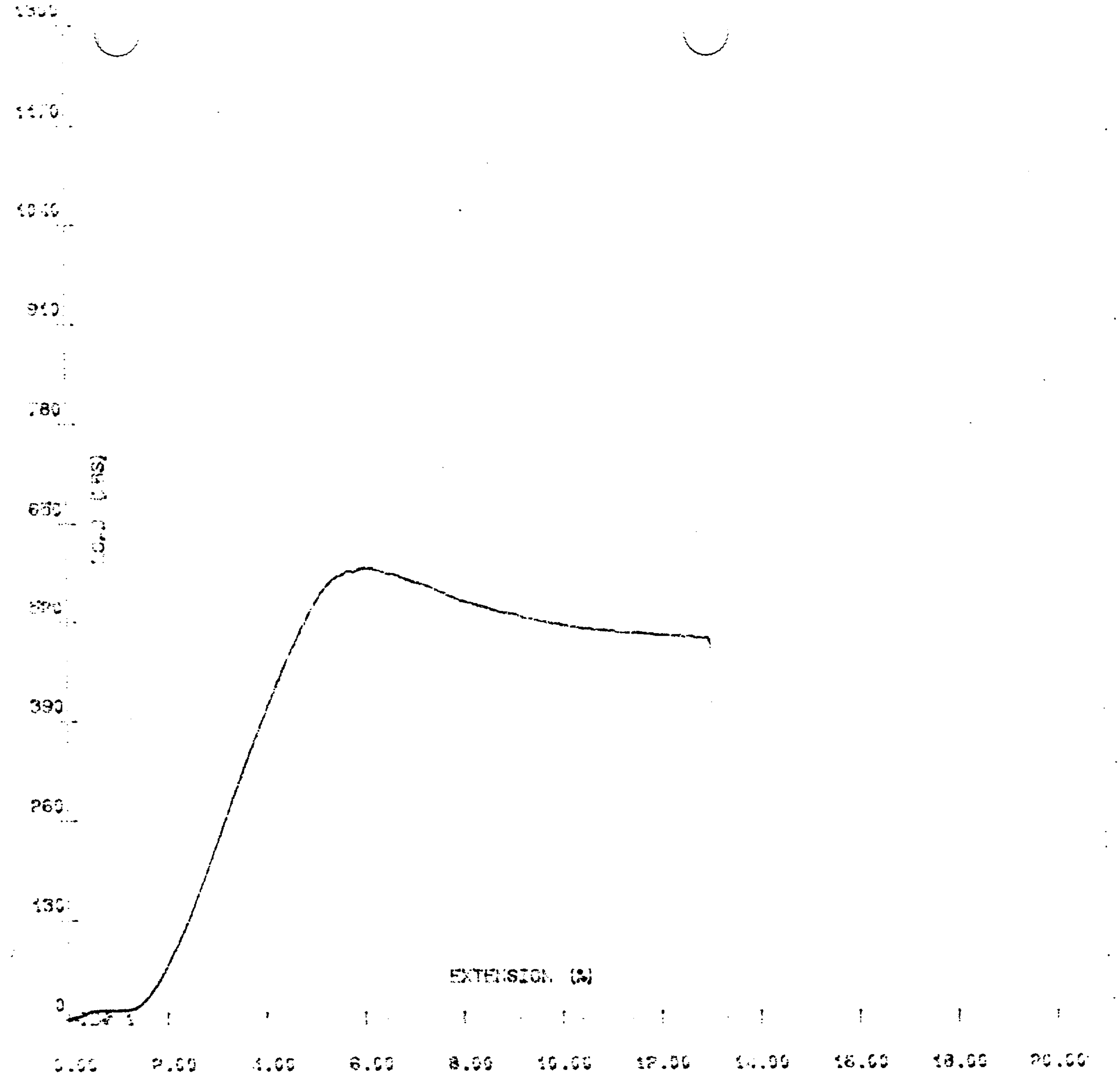


1300
910
780
650
520
390
130
0
EXTENSION (%)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00


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

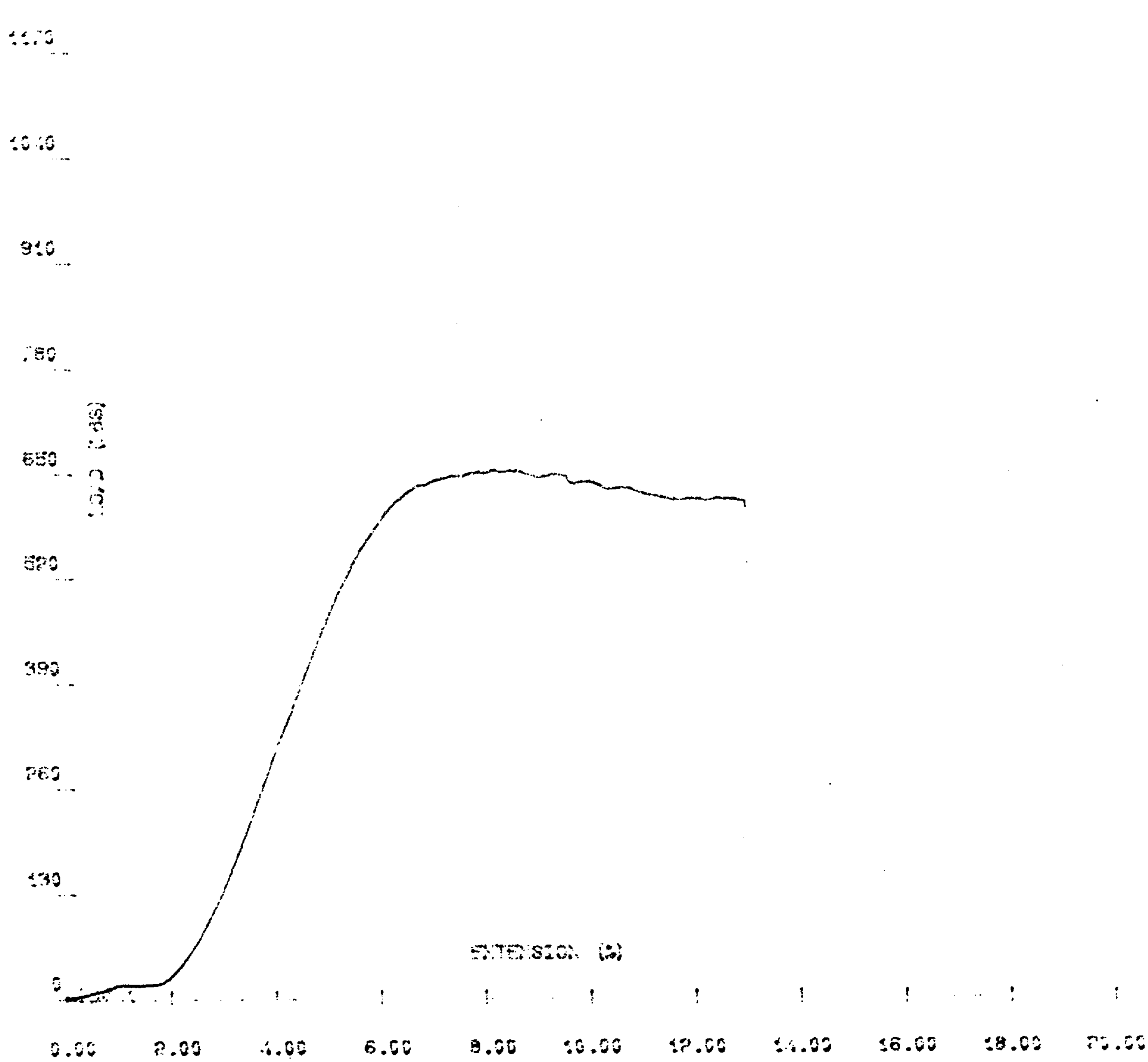
C
700°F
HIGH

UD
100°F
HIGH

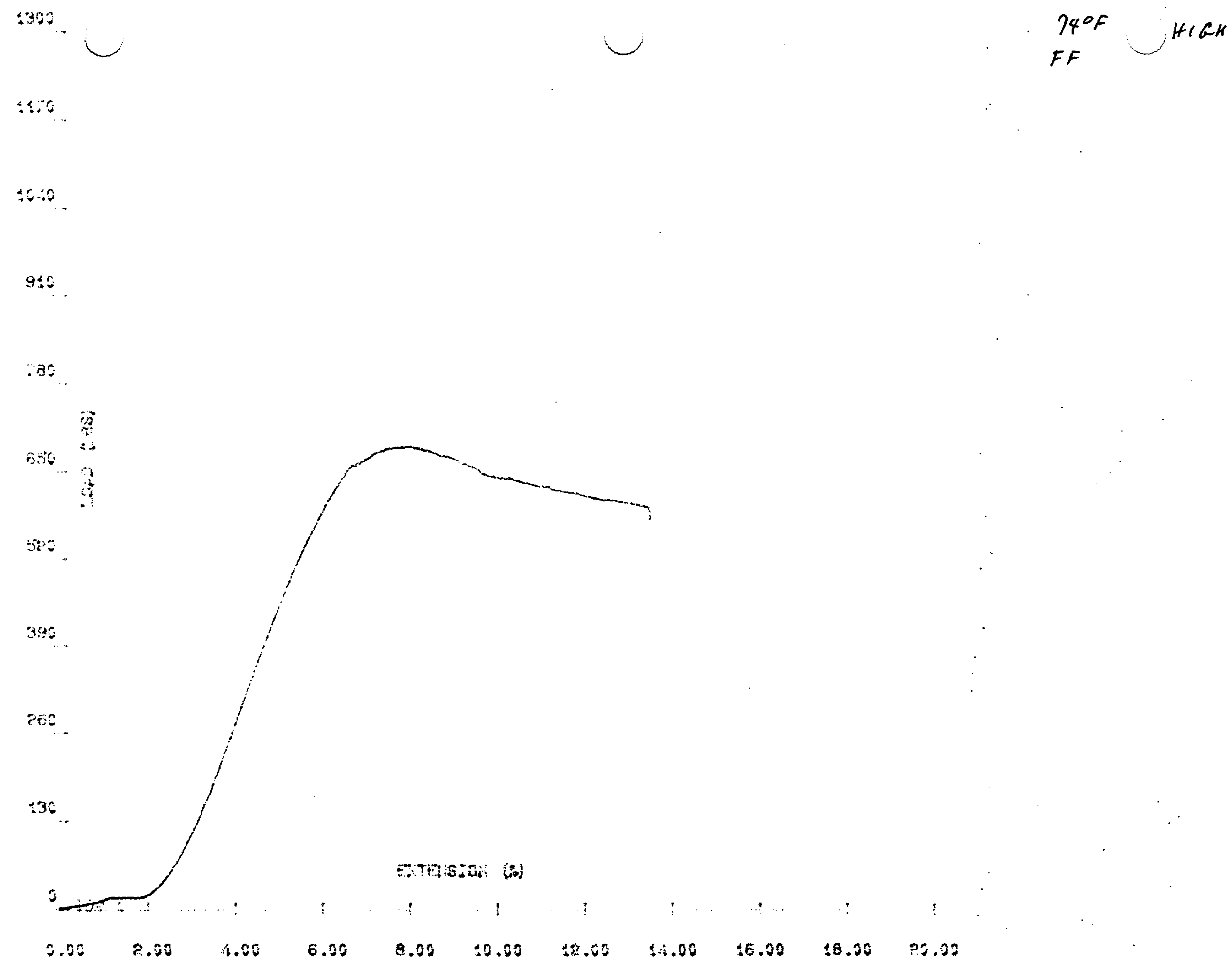


1300
1170
1040
910
780
650
520
390
260
130
0
EXTENSION (%)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

74°F HIGH
EE

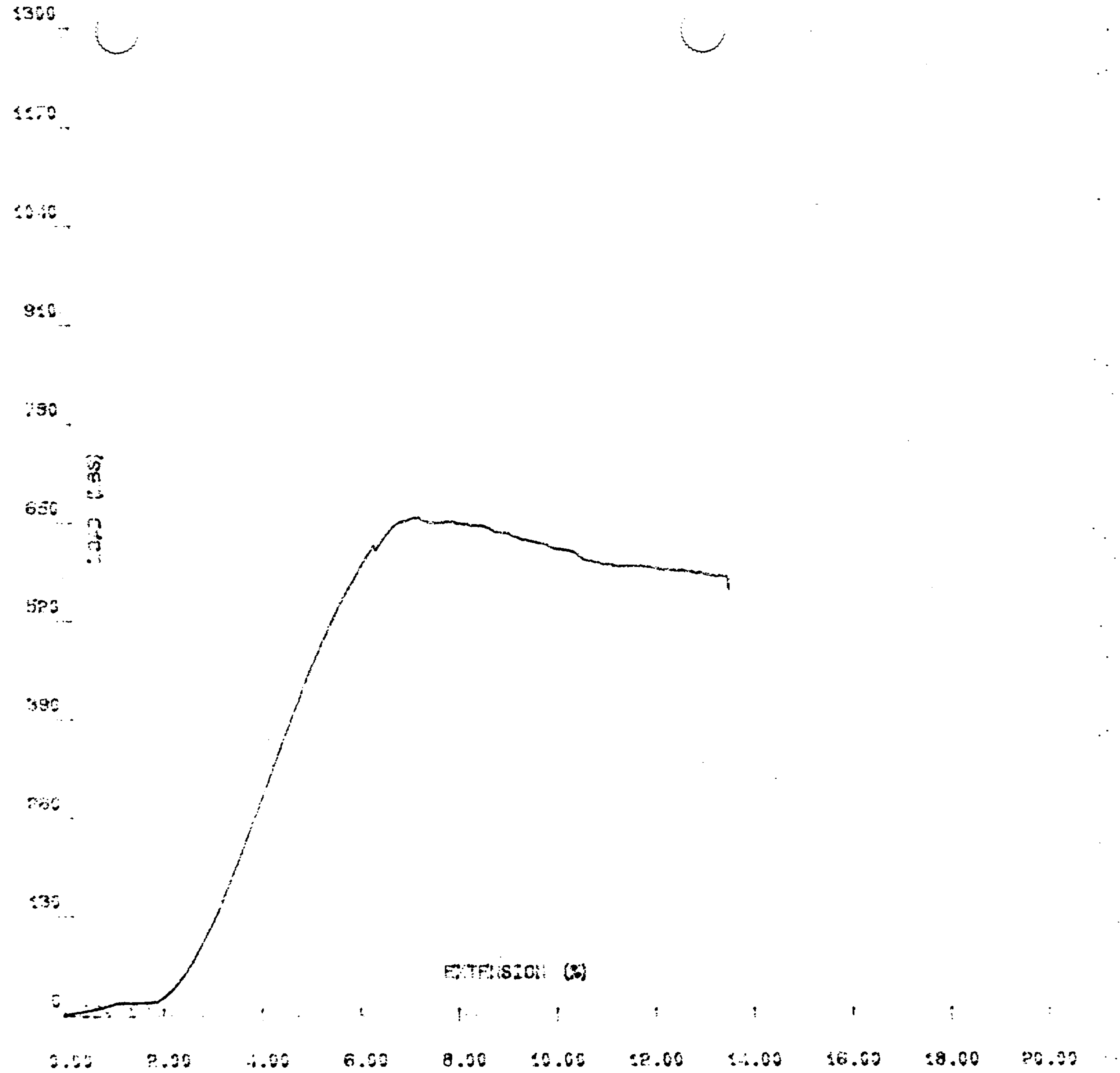


1300
1040
910
780
650
520
390
260
130
0
EXTENSION (%)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00



74°F
FF
HIGH
LOAD (LBS)
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

74°F HIGH
GG

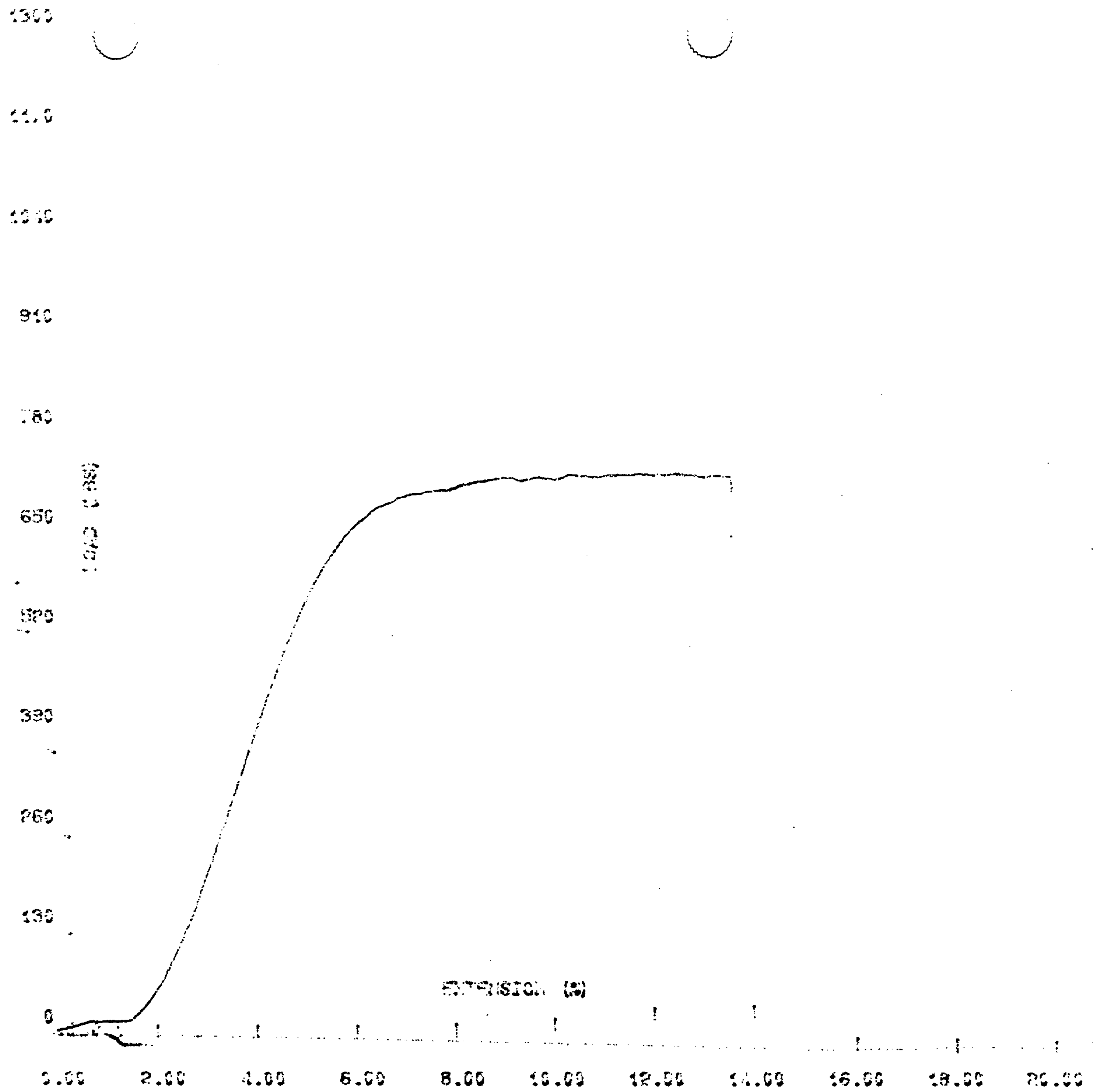


LOAD (LBS)
EXTENSION (%)
0
130
260
390
520
650
780
910
1040
1170
1300
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

H H HIGH

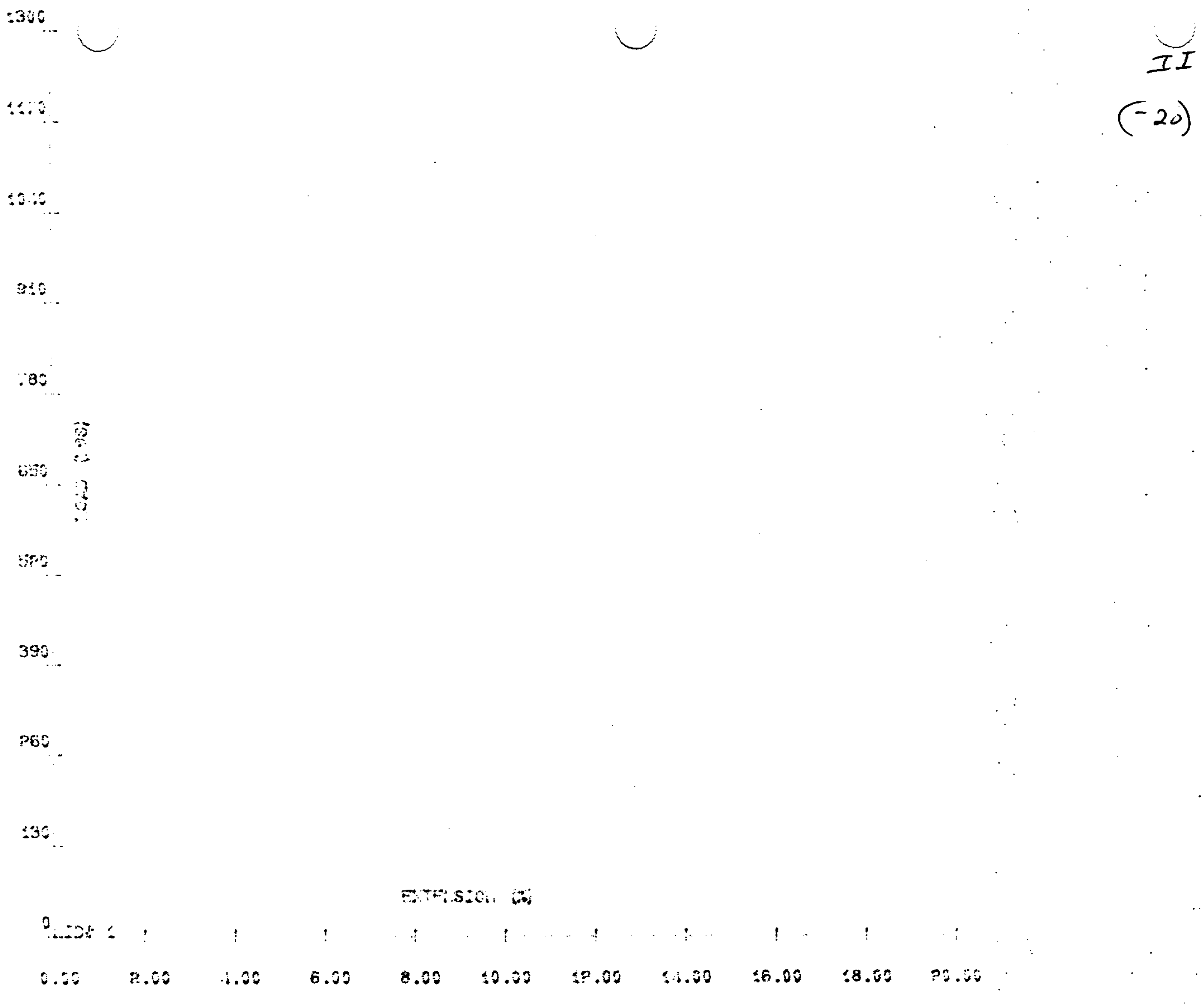
D

Approx -9 °F



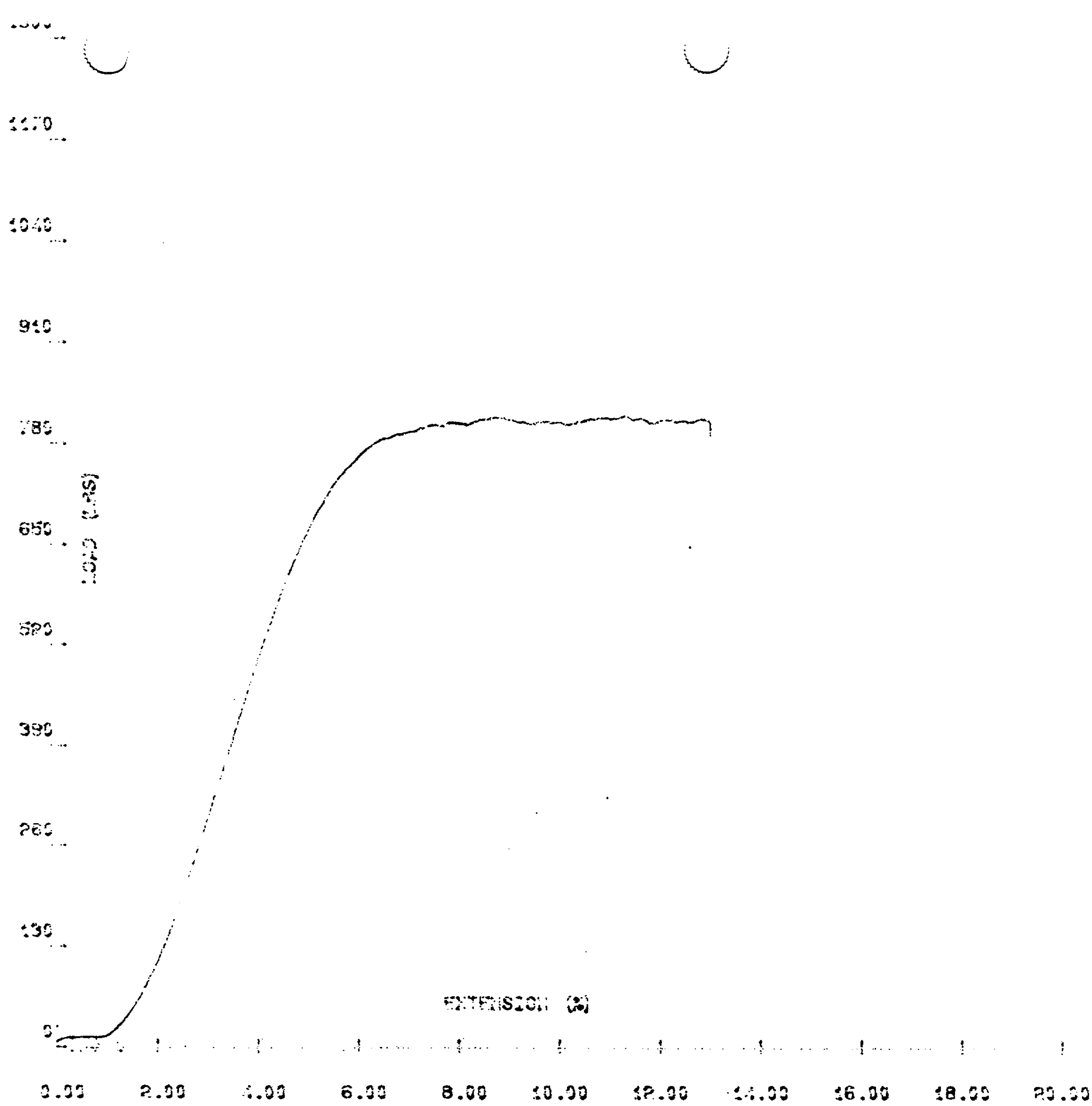
II HIGH

(-20)



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

Approx (-'s) HIGH
JJ



Appendix 2.10.6

Criteria for Overpack Damage Evaluation

ECO-PAK SPECIALTY PACKAGING
ELIZABETHTON, TN

PROCEDURE TYPE: STANDARD OPERATING PROCEDURE

PROCEDURE NO: SOP 2.4

DESCRIPTION: DESIGN PROCEDURE FOR DETERMINING THE MOST DAMAGED PACKAGE PRIOR TO FIRE TESTING

This page is a record of revisions to this procedure. Each time a revision is made, only the revised pages are reissued. Remarks indicate a brief description of the revision and are not a part of the procedure.

REVISION	AFFECTED DATE	PAGE (s)	REMARKS
0	03/09/98	ALL	ORIGINAL

Uncontrolled Copy

APPROVALS

0			
REV	CBC EXEC VP OF COMMERCIAL OPERATIONS	QA MANAGER	ESP PRESIDENT

Procedure Type	Procedure No.	Description
Standard Operating Procedure	SOP 2.4	Design Procedure for Determining the Most Damaged Package prior to Fire Testing

1.0 **PURPOSE**

The purpose of this procedure is to provide the steps necessary for determining a package has the most detrimental damage for a fire test when performing hypothetical accident conditions testing on two or more packages.

2.0 **SCOPE**

The scope of this procedure is to provide the worst case fire test during hypothetical accident conditions in accordance with Title 10 CFR 71.73(c)(4).

3.0 **TEST ARTICLES**

3.1 **The test articles will generally consist of a package and a load, either enclosed or loose.**

4.0 **HYPOTHETICAL ACCIDENT CONDITIONS**

4.1 **The design process of a package includes either comparative analysis, engineering calculations or compliance testing to comply with the requirements of 10CFR71. Hypothetical Accident Conditions is compliance testing for packaging under worst case conditions. These conditions include drop, crush & puncture testing, a thermal test, and immersion testing.**

4.2 **This procedure determines which package of 2 or more tested is in the worst condition after the drop, crush & puncture testing for the thermal (fire) test.**

5.0 **EVALUATION PROCEDURE**

5.1 **Complete drop, crush & puncture testing as required.**

5.2 **Record gross deformation data for each package.**

5.3 **If a package has broken a seal providing a clear passage to the load, then that package shall be fire tested.**

5.4 **If there are no breached packages, then the package that is determined to have done the most damage to the load shall be fire tested.**

Appendix 2.10.7

30B Cylinder Chime Deformation Procedure

30B Cylinder Chime Deformation Procedure
(for test purposes only)

Purpose: The purpose of this procedure is to bend the 30B cylinder chime area adjacent to the cylinder valve at least one inch toward the valve, and then repair the chime back to its original position.

Scope: This procedure is conducted to create a worst case situation when conducting hypothetical accident conditions testing on an overpack for the 30B UF6 cylinder per Title 10 CFR 71.73.

Procedure: Follow the steps below:

1. Measure and record the inner diameter of the cylinder chime directly in line with the cylinder valve location at the 12:00 position.

2. Measure and record the inner diameter of the cylinder chime 15 degrees in both directions from the measurement in Step 1, and mark that area.

3. Heat the marked area of the cylinder chime until it becomes cherry red.

4. Using a hydraulic jack in any design, deform the heated area at least one inch toward the valve position and allow to cool.

5. Repeat Steps 1 & 2 to verify that the chime has been bent at least one inch. If not, repeat Steps 3 & 4 until in the correct position.

6. To repair the chime, heat the deformed area again to cherry red, and use the hydraulic jack to move it back into its original position.

7. Repeat Steps 1, 2 & 6 until the inner diameters are what they were prior to this procedure.

References:

1. Title 10 CFR 71.73

2. Test Report 04-8196-Report No 2, Certification Testing of Valve Protection Devices for UF6 Packages, Section 6.4.1, E.M. Dornes and D.J. Pomerening, Southwest Research Institute, February 1997.

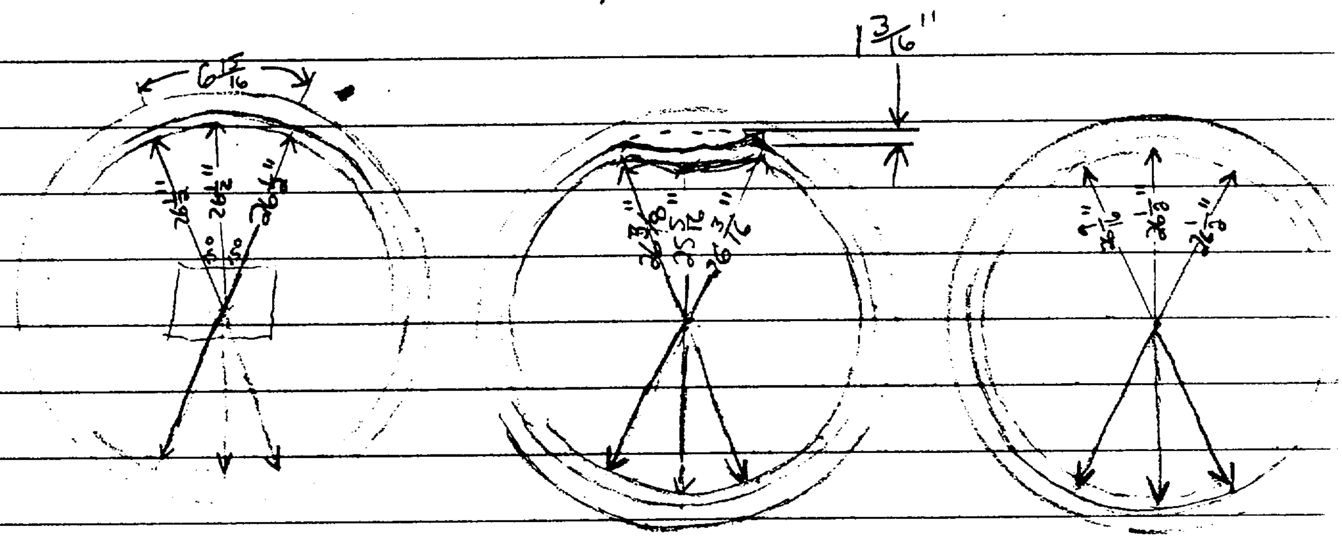
2/26/98 JOB# 1812

30 B's 2 tanks

Chime Deformation (Per 6.4.1 Test item Preparation)

Tank #1 X-ray #

X-ray #
1871-2
pt of
edge-ok
[initials]
2/26/98



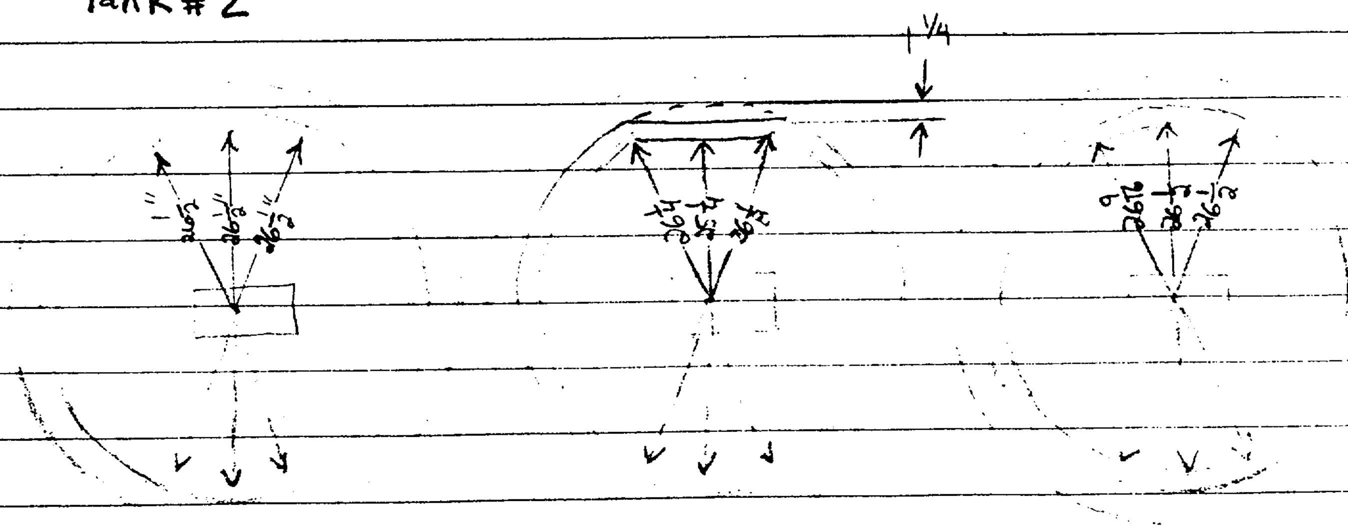
Before

After Deformation
(Heated & used Jack to deform, Then Measured)

Repaired Deformation
(Heated & Jack Back in Place & measured)

Tank #2

X-ray #
1871-7



Appendix 2.10.8

Compliance Testing of the ESP-30X Package

TABLE OF CONTENTS

LIST OF PHOTOS

APPENDIX 2.10.8
COMPLIANCE TESTING OF THE ESP-30X PACKAGE

2.10.8.1 Introduction

This section describes the compliance testing performed on ESP-30X overpacks loaded with 30B cylinders. Drop orientations for testing were chosen based on indications of potential for worst damage from previous testing of overpacks (see **Section 2.7 "Hypothetical Accident Conditions"**). Conclusions arrived based on these tests are also provided in **Section 2.7**.

Temperatures of the packages were reduced to approximately -20°F to maximize the g loading during testing.

ESP-30X Test Article #1 was tested in 30 foot free drop and 40 inch puncture drop tests in the 13.5° from vertical orientation.

ESP-30X Test Article #2 was tested in a 30 foot free drop in the 60° from vertical orientation with impact occurring on the closure (rotated 5° from center) on the plug end of the overpack with accelerated secondary impact on the valve end. It was also subjected to a 40 inch puncture drop test with impact on the center bolt in the closure plane.

The package which exhibited the most damage from drop testing (determined using procedures described in **Appendix 2.10.6)** was used in subsequent puncture drop and fire tests.

Packages were leak tested and hydrostatically tested after completion of the tests.

2.10.8.2 Test Articles

Each test article consisted of a UF_6 30B cylinder, loaded with metal shot to simulated a standard load, and an ESP-30X overpack as described in **Appendix 1.3.1**.

<u>30B Cylinder</u>

Representative 30B cylinders which had the valve-end skirts bent and repaired as described in **Section 2.10.7** were used in the testing. The empty cylinder for Test Article #1 weighed 1364 pounds. The empty cylinder for Test Article #2 weighed 1359 pounds.

<u>ESP-30X Overpack</u>

The ESP-30X overpacks were prototypes built expressly for testing. The overpacks were built according to the drawings supplied in **Appendix 1.3.1** and procedures outlined throughout this

SAR. The overpacks were examined prior to testing and no significant damage was identified. The overpack for Test Article #1 weighed 2953 pounds empty. The overpack for Test Article #2 weighed 2938 pounds empty.

2.10.8.3 Test Facility

Drop Pad

The drop pad was an existing facility that was specifically designed for this type of testing. It is shown in **Appendix 2.10.9, Figure 1a**. 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 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 (See **Appendix 2.10.8, Photo 2.10.8p-1**) was in an open air site adjacent to the test facility. The system was mounted on a mast to place the instrumentation above the immediate local terrain..

Cooling Chamber

A chamber built expressly for this test series provided low temperature conditioning of the test package. The facility (See **Appendix 2.10.8, Photo 2.10.8p-2**) 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 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 35 mm still photography and normal speed video. Two shooting angles were used. Two cameras were used at each location for backup. One camera was kept at a wide angle and the other was set to get a close-up of the impact area.

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 **Figure 2.7-7 and Figure 2.7-8**). 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. (**Appendix 2.10.9, Figure F-5)**

Fire Test Stand

A welded steel stand was centered in the fire test pans to support the package during the fire. 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. (**Appendix 2.10.9, Figure F-6)**

2.10.8.4 Test Equipment and Calibration

All inspection and test equipment was calibrated in accordance with nationally recognized

standards. Calibration documentation is outlined in **Appendix 2.10.9.**

2.10.8.5 Test Description

Remove the 30B Cylinder Valves

The valves were removed from the cylinders.

Bend 30B Cylinder Skirts

Each cylinder skirt in the region of the valve was bent inward to simulate damage which might occur during cylinder use using a hydraulic jack.

The skirt in the region of the valve was heated to approximately 700°F. A load was applied with the hydraulic jack to bend the region a minimum of 1". Once the bending was completed, the cylinder skirt was re-heated and the bent portions of the skirt were straightened as well as possible to bring the cylinder skirt back to its original configuration. The straightening was also done using a hydraulic jack. (See **Appendix 2.10.7.**)

Fill the 30B Cylinder and Replace the Valve

Small diameter (< 1/16 inch) steel shot used for the simulated load. A minimum of 5047 pounds of steel shot were loaded into each cylinder. The steel filled a volume of approximately 18 ft^3 of the total internal volume of 26 ft^3, allowing for movement of the steel shot during handling and testing. The small size and odd shape of the steel shot provided a minimal restriction of the flow of helium from the valve location to the port location.

After the cylinders were loaded, 1-inch 30B cylinder valves were installed using standard procedures. The threads in the boss were cleaned with a tap and the first five threads on the valve were chased with a die. After hand threading, the valves were tightened to a minimum torque of 300 ft-lbs using a special tool fabricated for this purpose. (**Appendix 2.10.8, Photo 2.10.8p-3**).

Normal Conditions Leak Testing

A bubble leak test was performed on the valve cap, valve stem, valve packing nut and the valve seat of each cylinder with a cylinder internal pressure of 100 psig nitrogen or air. The internal pressure was held for a period of 15 minutes, and no bubbles were permitted.

The cylinders were evacuated and helium was introduced around the valve cap, valve stem, valve packing nut and the valve seat of each for a period of at least 2 minutes for the helium mass spectrometer test. The acceptance criterion was an air leakage rate of less than 1×10^{-7} std

cc/sec.

If either of these leakage tests were not successful, the valves were removed, and new valves were installed until the leak tests were performed successfully.

Prepare the 30B Cylinders and the ESP-30X Overpacks

30B Cylinders: Thermocouples and heat sensitive tapes were attached to the cylinders. Fourteen thermocouples were installed on each cylinder, and an additional six thermocouples were used to monitor the temperature of the fire. The heat sensitive tapes had a range of 150-300°F and were in the form of irreversible self-adhesive temperature monitors consisting of heat sensitive indicators sealed under transparent heat resistant windows.

All thermocouples consisted of 20 gage, type K, Chromel-Alumel grounded junctions with magnesium oxide insulation and Inconel 600 sheath. A ½" x 1" x 1/8" weld pad was attached to the sheath for welding to the cylinder (**Appendix 2.10.8, Photo 2.10.8p-4**).

ESP-30X Overpacks: The cylinders were placed horizontally into the bottom halves of the overpacks and seals were inspected to ensure that no debris was present. A 1" hole was drilled in the end of each overpack opposite the valve to serve as a conduit for the thermocouple wires. The holes were packed with insulation. Metal covers were installed over the thermocouple leads to protect them from secondary impacts during the drop testing.

Load Cylinders into Overpacks and Cooling of Overpacks

The 30B cylinders were loaded into the overpacks with the valves in the 12 o'clock position (**Appendix 2.10.8, Photos 2.10.8p-5** and **2.10.8p-6**).

The test articles were installed in the cooling chamber for conditioning to -20°F. The overpacks were closed prior to placement in the cooling chamber to prevent additional moisture from entering them.

Remove Test Article #1 from Storage

Test Article #1 was removed from the cooling chamber and quickly oriented for the drop testing. The location of the valve was marked on the external surface of the overpack. The temperature of the test article was measured using the thermocouple attached to the cylinder skirt.

Perform 30 ft Free Drops and Record Damages

Test Article #1 was positioned at an orientation of 14° from vertical with the package center of gravity over the valve. 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 on 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 overpack was observed and deformation data was recorded. Color photographs of the extent of damage were taken. The overpack was not opened, but was placed into the cooling chamber until the 40 inch puncture test could be performed.

Perform 40 inch Puncture Tests and Record Damages

Test Article #1 was positioned at in orientation of 13.5° from vertical with the location of the valve positioned 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 lowest point on 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 overpack was observed and deformation data was recorded. Color photographs of the extent of damage were taken. The overpack was not opened but was returned to the cooling chamber to await evaluation and comparison with Test Article #2.

Remove Test Article #2 from Storage

Test Article #2 was removed from the cooling chamber and quickly oriented for the drop testing. The temperature of the test article was measured using the thermocouple attached to the cylinder skirt.

Perform 30 ft Free Drops and Record Damages

Test Article #2 was positioned at an orientation of 60° from vertical with the impact point on the closure (rotated 5° from center) on the plug end 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 on 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 overpack was observed and deformation data was recorded. Color photographs of the extent of damage were taken. The overpack was not opened, but was placed into the cooling chamber until the 40 inch puncture test could be performed.

Perform 40 inch Puncture Tests and Record Damages

Test Article #2 was positioned parallel to the ground with the center bolt in the closure plane positioned 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 lowest point on 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 overpack was observed and deformation data was recorded. Color photographs of the extent of damage were taken. The overpack was not opened.

Evaluation of Test Articles

Following drops on both test articles, Test Article #1 was determined to have suffered the most damage.

Puncture Drop on Side

Test Article #1 was removed from the cooling chamber and lifted to a height of 40 inches, again determined by using a 40 inch line with a plumb bob attached to the lowest point on the package. The package was positioned 40 inches above the puncture bar with the side parallel to the ground and the seam between the top and bottom halves of the overpack at 45°. 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 overpack was observed and deformation data was recorded. Color photographs of the extent of damage were taken. The overpack was not opened but was placed in a furnace in preparation for the thermal test.

Open Test Article #2 and Record Internal Damage

Test Article #2 was opened for post-test inspection first. The cylinder was removed and measurements were taken.

Leak Testing of Test Article #2

Once the package was opened and the cylinder was removed from the overpack, the following leak tests were performed on the 30B cylinder:

A bubble leak test was performed on the valve cap, valve stem, valve packing nut and the valve seat with a cylinder internal pressure of 100 psig nitrogen. The internal pressure was held for a period of 15 minutes. Any indication of bubbles were noted.

The cylinder was evacuated and a helium mass spectrometer test was performed by introducing helium around the valve cap, valve stem, valve packing nut and the valve seat for a period of at least 2 minutes. If no leakage was indicated then this leak test was ended. If leakage was indicated, the valve was bagged and continuously sprayed with helium. The helium leak indicator was monitored until the readings stabilized. Both the indicated leak rate and the time to stabilization were recorded.

After the helium leak test, the cylinder was emptied through the bottom plug and a 19 psig hydrostatic test was performed. The cylinder with the valve in the 6 o'clock position was filled with tap water and a blue dying agent. The pressure in the cylinder was increased to 19 psig and held for a minimum of eight hours. The valve cap, valve stem, valve packing nut and the valve seat were checked periodically for any indication or water leakage from the cylinder.

Warm Test Package to 100°F

Test Article #1 was installed in a furnace and a nominal temperature of 100°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 tie down bases 40 inches from the fuel source. The thermocouple wires were connected with instrumentation leads. Both the thermocouple wires and instrumentation leads were protected in an insulated pipe to the instrumentation trailer where the temperature of the cylinder and the fire were recorded.

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 (**Appendix 2.10.8, Photo 2.10.8p-22**). Six thermocouples were placed around the perimeter of the test article to monitor the fire temperature.

The result was a fire area slightly greater than that specified in the regulations on the sides of the

package, but within the regulations for the ends of the package.

The standing diesel fuel was lit with a torch and the ESP-30X package was subjected to a 30 minute fully engulfing fuel/air fire. **(Appendix 2.10.8, Photo 2.10.8p-23)**

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.

Leak Testing of Test Article #1

Once the package was opened and the cylinder was removed from the overpack, the following leak tests were performed on the 30B cylinder:

A bubble leak test was performed on the valve cap, valve stem, valve packing nut and the valve seat with a cylinder internal pressure of 100 psig nitrogen. The internal pressure was held for a period of 15 minutes. Any indication of bubbles was noted.

The cylinder was evacuated and a helium mass spectrometer test was performed by introducing helium around the valve cap, valve stem, valve packing nut and the valve seat for a period of at least 2 minutes. If no leakage was indicated then this leak test was ended. If leakage was indicated, the valve was bagged and continuously sprayed with helium. The helium leak indicator was monitored until the readings stabilized. Both the indicated leak rate and the time to stabilization were recorded.

After the helium leak test, the cylinder was emptied through the bottom plug and a 19 psig hydrostatic test was performed. The cylinder with the valve in the 6 o'clock position was filled with tap water and a blue dying agent. The pressure in the cylinder was increased to 19 psig and held for a minimum of eight hours. The valve cap, valve stem, valve packing nut and the valve seat were checked periodically for any indication or water leakage from the cylinder.

2.10.8.6 Summary and Results of Tests

Testing was conducted at Southwest Research Institute (SwRI), San Antonio, Texas in accordance with written test procedures. The complete test report compiled by SwRI is included as **Appendix 2.10.9.**

Test Article #1 (overpack temperature was -23 °F) was positioned at an orientation of 14° from vertical, and raised 30 feet as measured from the lowest position on the overpack. The overpack was rotated so that the impact would be into the valve location. **(Appendix 2.10.8, Photo 2.10.8p-7)** The weight of the test package was 9,369 lbs. No closures broke or loosened.

No tears or breaks in the overpack were observed. **Figure 2.7-6** illustrates the overpack deformation from the 30 foot drop test.. (**Appendix 2.10.8, Photo 2.10.8p-8 and Photo 2.10.8p-9**).

Following the 30 foot drop test, the test article was positioned at an orientation of 13.5° from vertical, and raised 40 inches above the puncture ram as measured from the impact target on the overpack. (**Appendix 2.10.8, Photo 2.10.8p-10**) The overpack was rotated so that the puncture would be into the valve location. The overpack deformed at the puncture location. All closures remained intact and the punch did not expose any foam. Photographs were taken, measurements made, and the overpack was placed in the cooling chamber to await comparison with Test Article #2. **Figure 2.7-10** illustrates the overpack deformation from the 40 inch puncture test (**Appendix 2.10.8, Photo 2.10.8p-11 and Photo 2.10.8p-12**).

Test Article #2 was positioned at an orientation of 60° from vertical with the impact point on the closure (rotated 5° from center) on the plug end, and raised 30 feet as measured from the lowest position on the overpack. (**Appendix 2.10.8, Photo 2.10.8p-13**) The weight of the test package was 9,350 lbs. No closures broke or loosened.

No tears or breaks in the overpack were observed. **Appendix 2.10.8, Photos 2.10.8p-14 and 2.10.8p-15** illustrate the overpack deformation from the 30 foot drop test..

Following the 30 foot drop test, the test article was positioned parallel to the test pad with the center bolt in the closure plane directly over the puncture ram. It was raised 40 inches above the puncture ram as measured from the impact target on the overpack. (**Appendix 2.10.8, Photo 2.10.8p-16**) The overpack deformed at the puncture location. All closures remained intact. Photographs were taken, measurements made, and the overpack was compared with Test Article #1 for evaluation. **Appendix 2.10.8, Photo 2.10.8p-17 and Photo 2.10.8p-18** illustrate damage from the 40" puncture drop test.

Test Article #1 was evaluated to have suffered the most damage. It was removed from the cooling chamber and positioned 40 inches above the puncture bar with the side parallel to the ground and the seam between the top and bottom halves of the overpack at 45°. (**Appendix 2.10.8, Photo 2.10.8p-19**)

The overpack deformed at the puncture location. All closures remained intact. External deformation data was recorded and documented with both video and still photography. **Figure 2.7-11** illustrates the overpack deformation from the 40 inch puncture test (**Appendix 2.10.8, Photo 2.10.8p-20 and Photo 2.10.8p-21**).

The package was not opened after the puncture drop, but was placed in a warming oven in preparation for the thermal testing.

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. (**Appendix 2.10.8, Photo 2.10.8p-22**).

A fire area slightly greater than that specified in the regulations on the sides of the package was achieved, but it fell within the regulations for the ends of the package.

Wind speed and direction were continuously monitored prior to the fire. Steady wind speeds of 4 mph with gusts up to 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 cylinder temperature immediately prior to the test was approximately 99°F.

The standing diesel fuel was lit with a torch. The test package was subjected to a 30 minute fully engulfing fuel/air fire (**Appendix 2.10.8, Photo 2.10.8p-23 and Photo 2.10.8p-24**)

The package was left on the test stand and its temperature was continuously monitored for the duration of the night. It was moved from the fire facility the following morning. (**Appendix 2.10.8, Photo 2.10.8p-25**)

The locations of the thermocouples and the temperature tapes on the cylinder are illustrated in **Appendix 2.10.9, Figure 9-10 and Figure 9-11**, which provides the maximum temperatures indicated from both thermocouples and temperature tapes.

Plots of the temperature data versus time for the cylinder and the fire are provided in **Appendix 2.10.9, Figures 9-2** through **9-5**.

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 seam between the two halves of the overpack did not open significantly as a result of the fire testing. There was minimal buckling of the overpack outer skin.

The overpack was opened carefully for post test inspection. (**Appendix 2.10.8, Photo 2.10.8p-26 and Photo 2.10.8p-27**).

Deformation measurements of the cylinder were taken.

A soap bubble test was conducted. The cylinder was pressurized to 100 psig with air and this pressure was held for 15 minutes. Soap film was applied to the valve threads, stem, packing nut, and cap. No leaks were detected on the valve area.

The cylinder was evacuated for helium testing. No leaks greater than 1×10^{-7} std cc/sec were detected.

For the hydrostatic testing, the majority of the steel shot was removed from the cylinder through

the port plug. The 19 psig hydrostatic test was performed. No water leakage was detected.

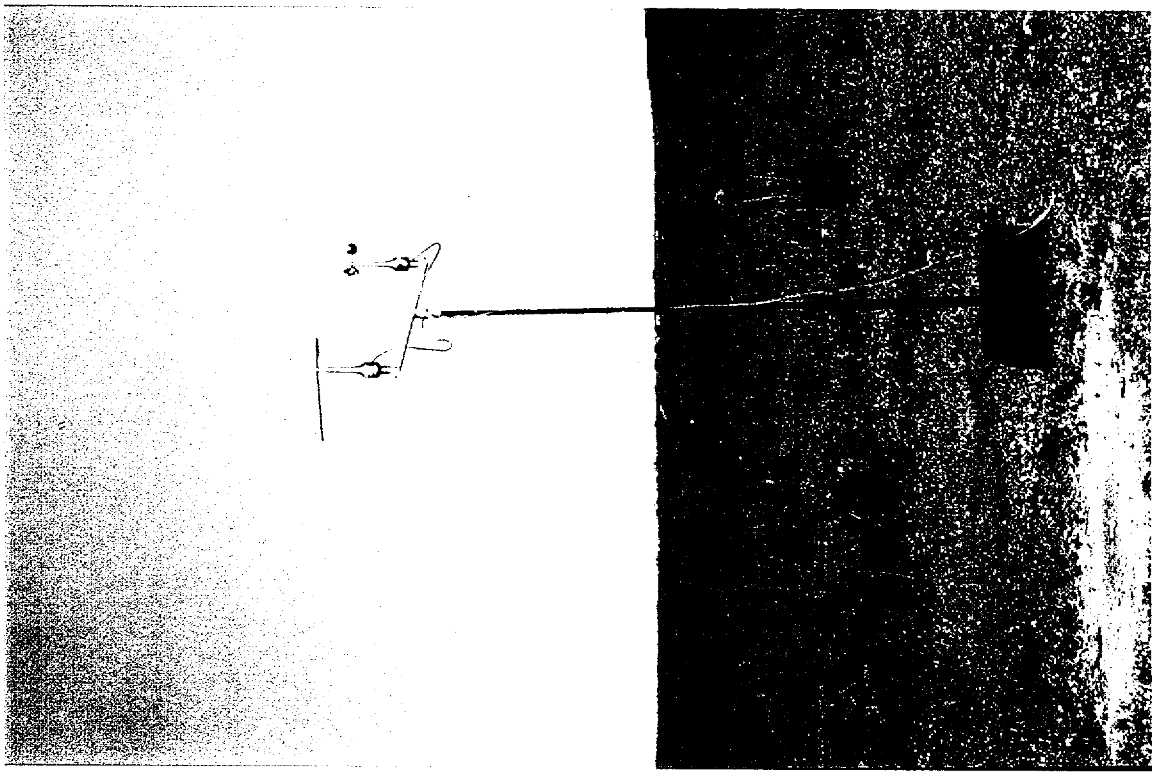
2.10.8.7 Conclusion

The compliance testing of the ESP-30X packaging resulted in the following:

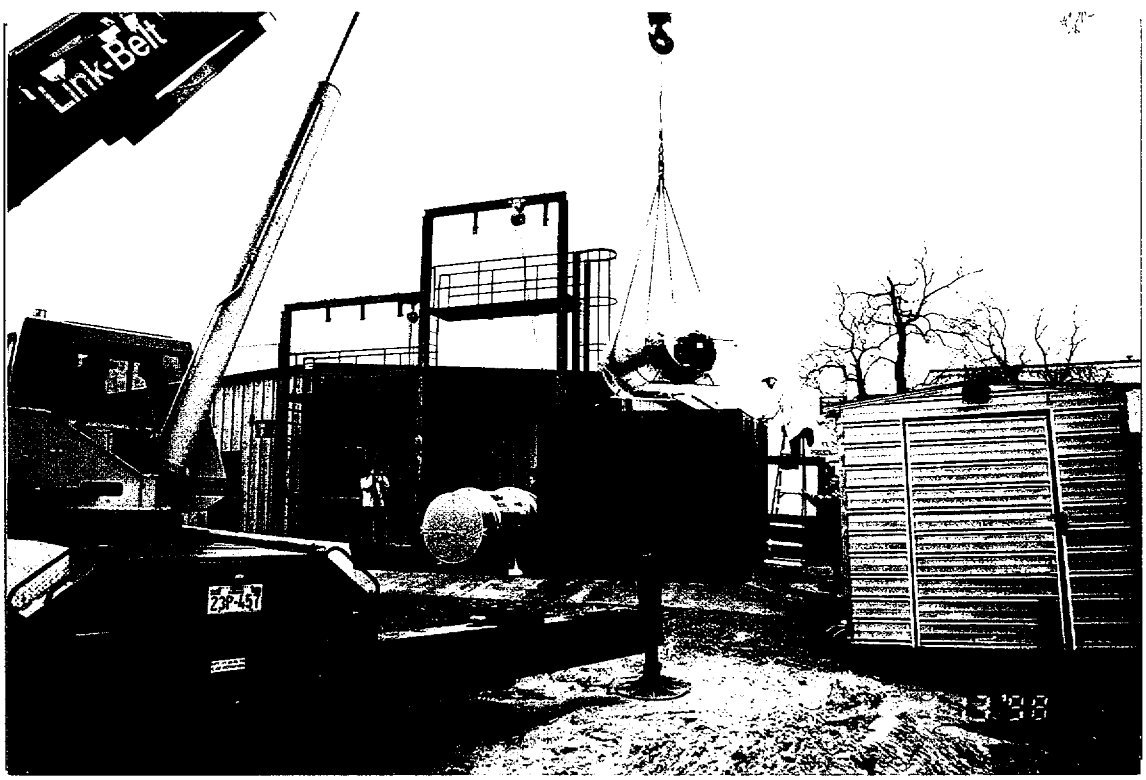
- The ESP-30X overpack successfully protected the valve on the 30B cylinder throughout the test series.

- Pre-Test and Post-Test measurements shown in **Figures 2.7-12 & 13** indicate that deflection of the cylinder skirt was not sufficient to allow contact with the 30B cylinder valve.

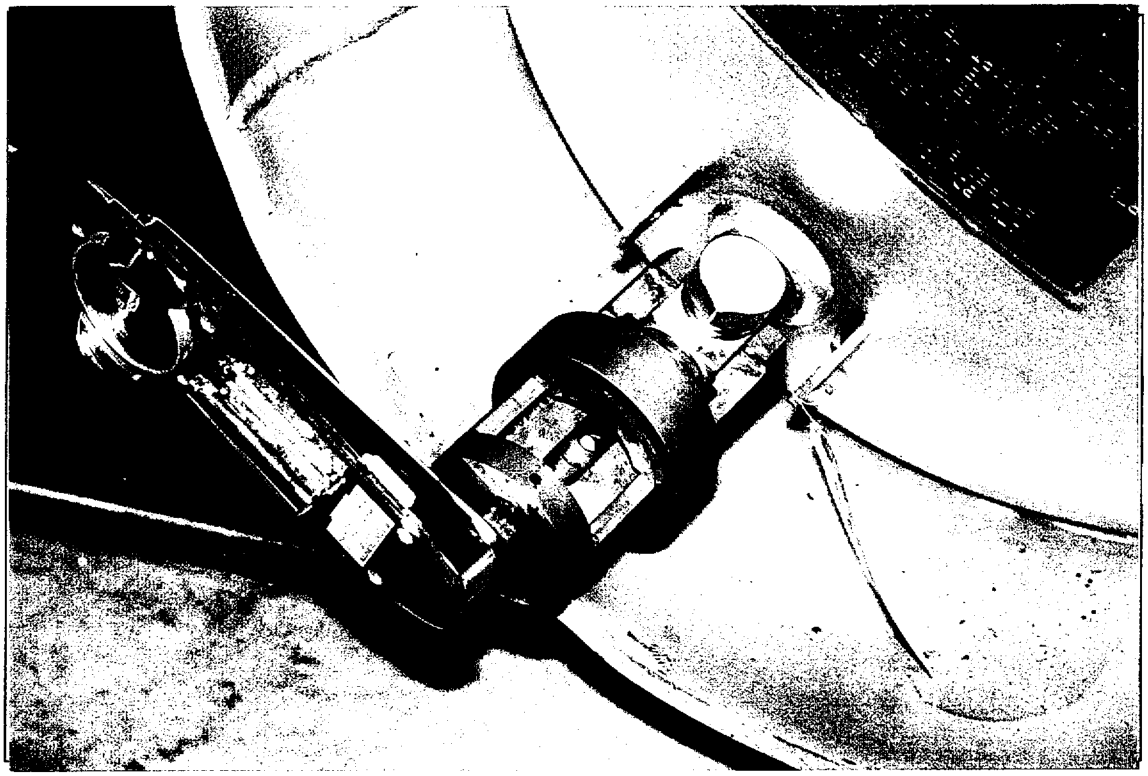
2.10.8p-1 Wind Speed and Direction Instrumentation



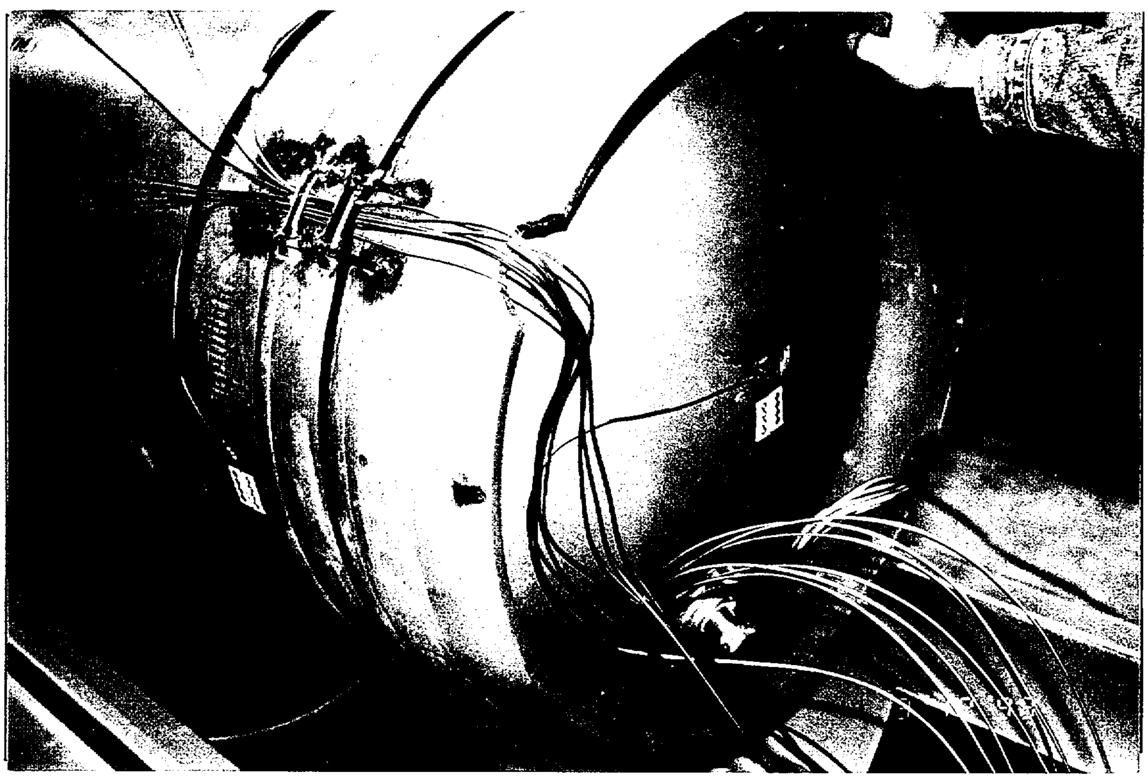
2.10.8p-2 Cooling Chamber



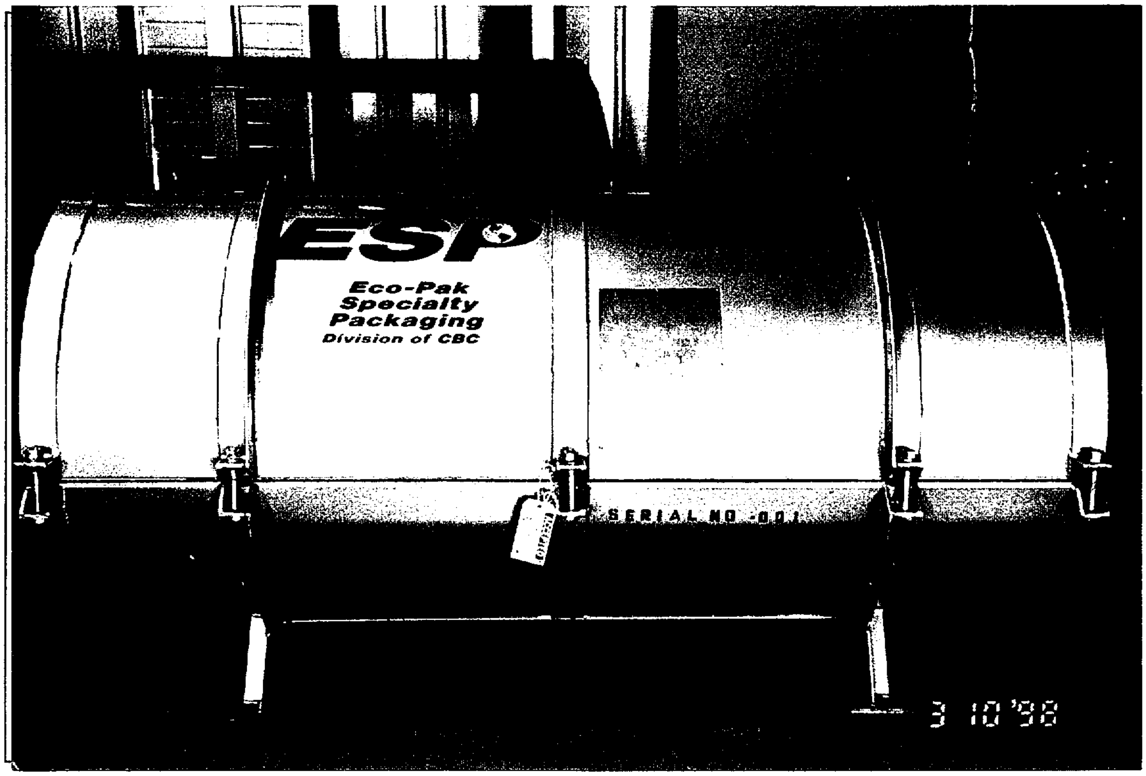
2.10.8p-3 Valve Installation Tool



2.10.8p-4 Cylinder with Temperature Indicated Instrumentation

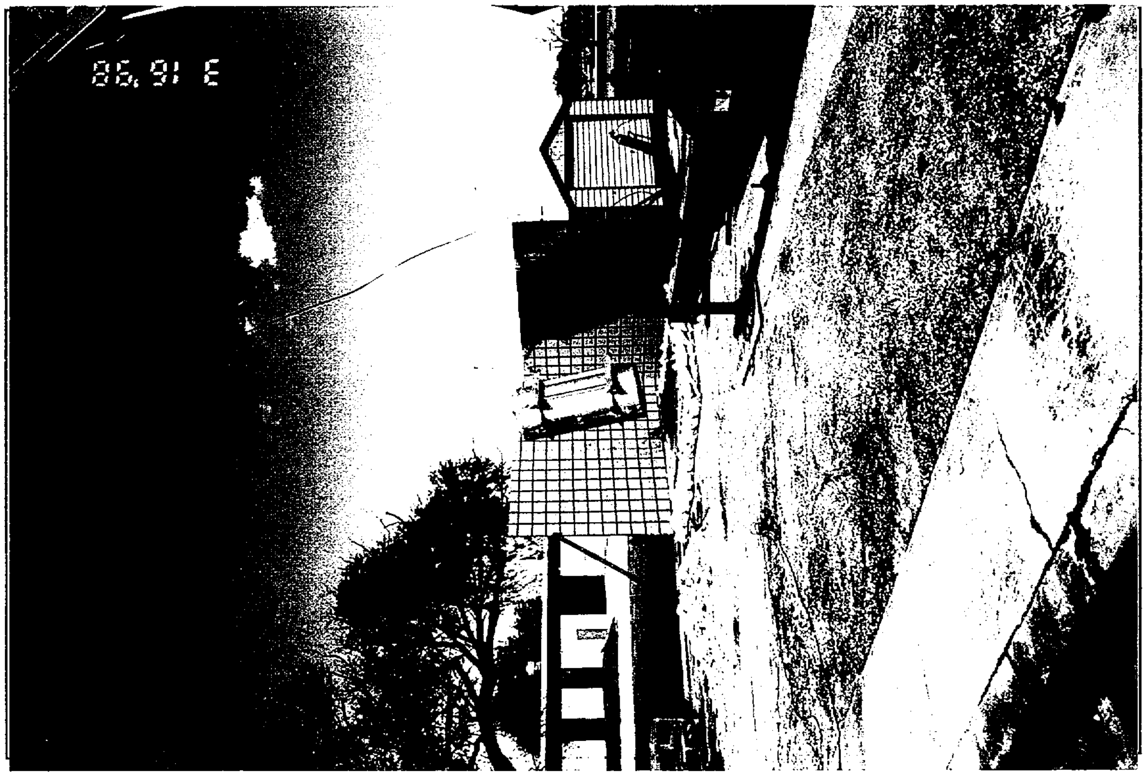


2.10.8p-5 ESP-30X Overpack



2.10.8p-6 Loading the Cylinder into the ESP-30X Overpack

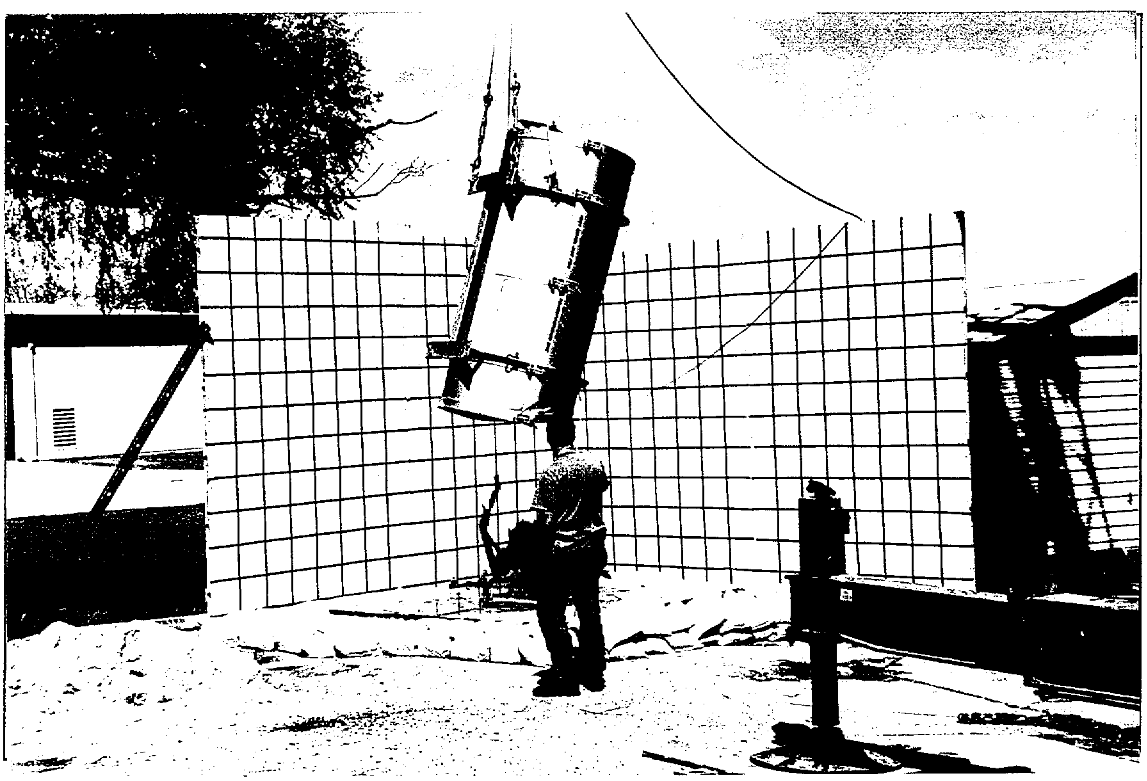
2.10.8p-7 ESP-30X Test Article #1 - 30 Foot Free Drop



2.10.8p-8 ESP-30X Test Article #1 Damage Following 30 Foot Free Drop

2.10.8p-9 ESP-30X Test Article #1 Damage Following 30 Foot Free Drop

2.10.8p-10 ESP-30X Test Article #1 40 Inch Puncture Drop



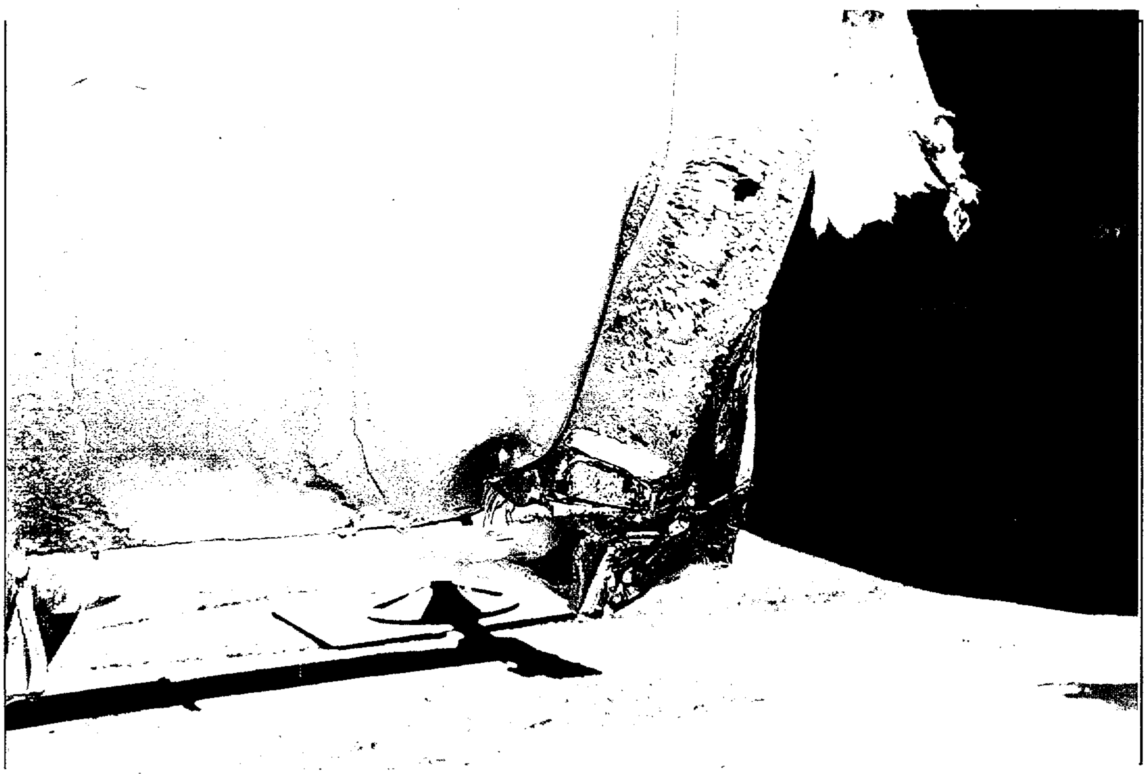
2.10.8p-11 ESP-30X Test Article #1 Damage After 40 Inch Puncture Drop

2.10.8p-12 ESP-30X Test Article #1 Damage After 40 Inch Puncture Drop

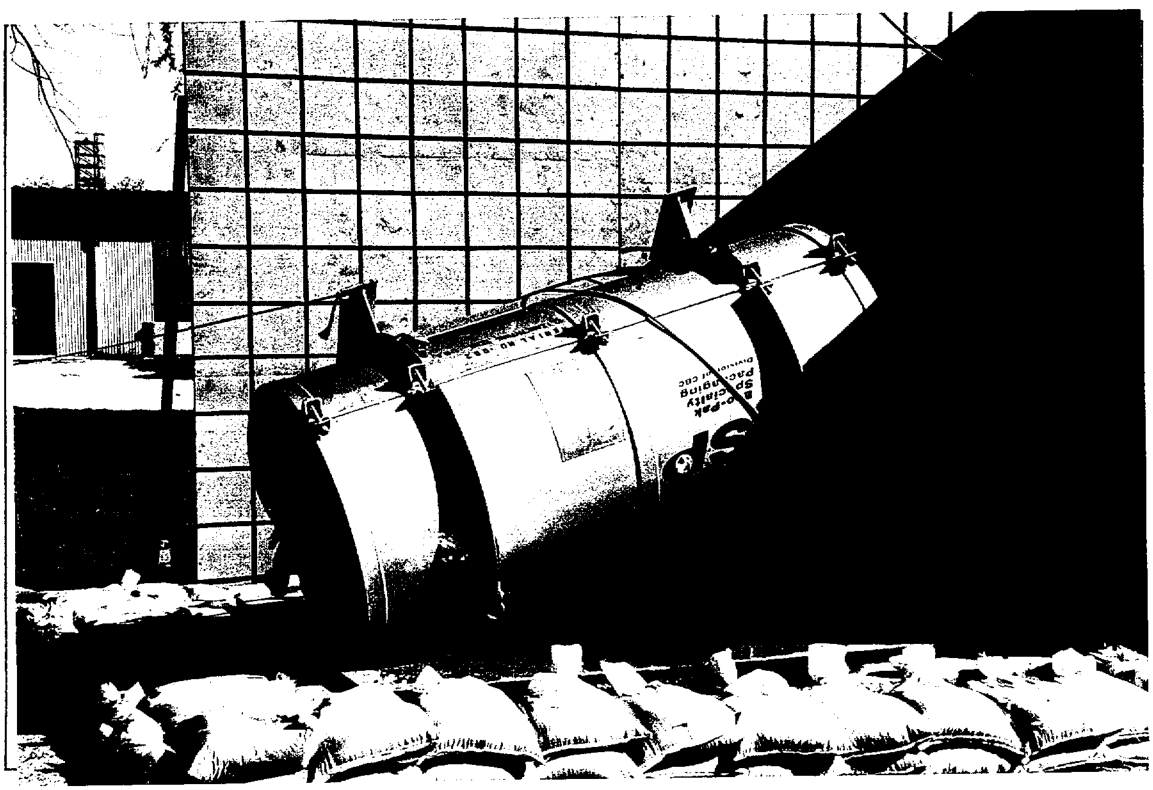
2.10.8p-13 ESP-30X Test Article #2 - 30 Foot Free Drop

2.10.8p-14 ESP-30X Test Article #2 Damage Following 30 Foot Free Drop

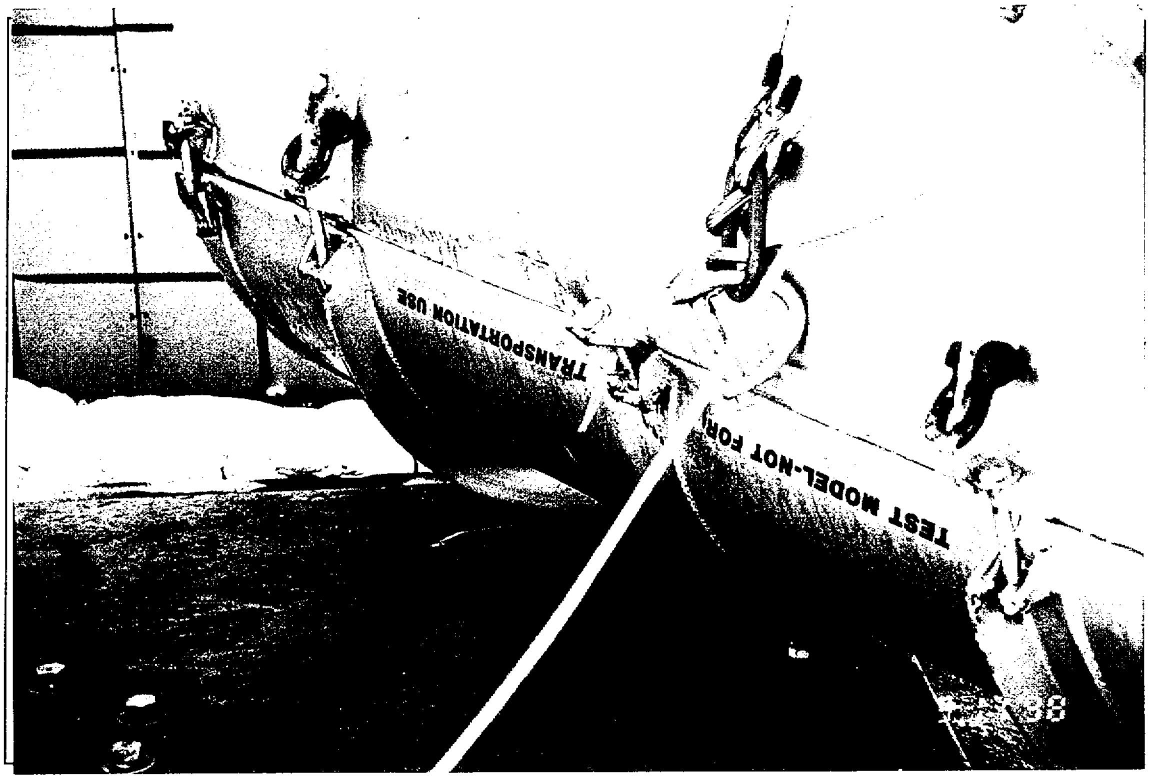
2.10.8p-15 ESP-30X Test Article #2 Damage Following 30 Foot Free Drop



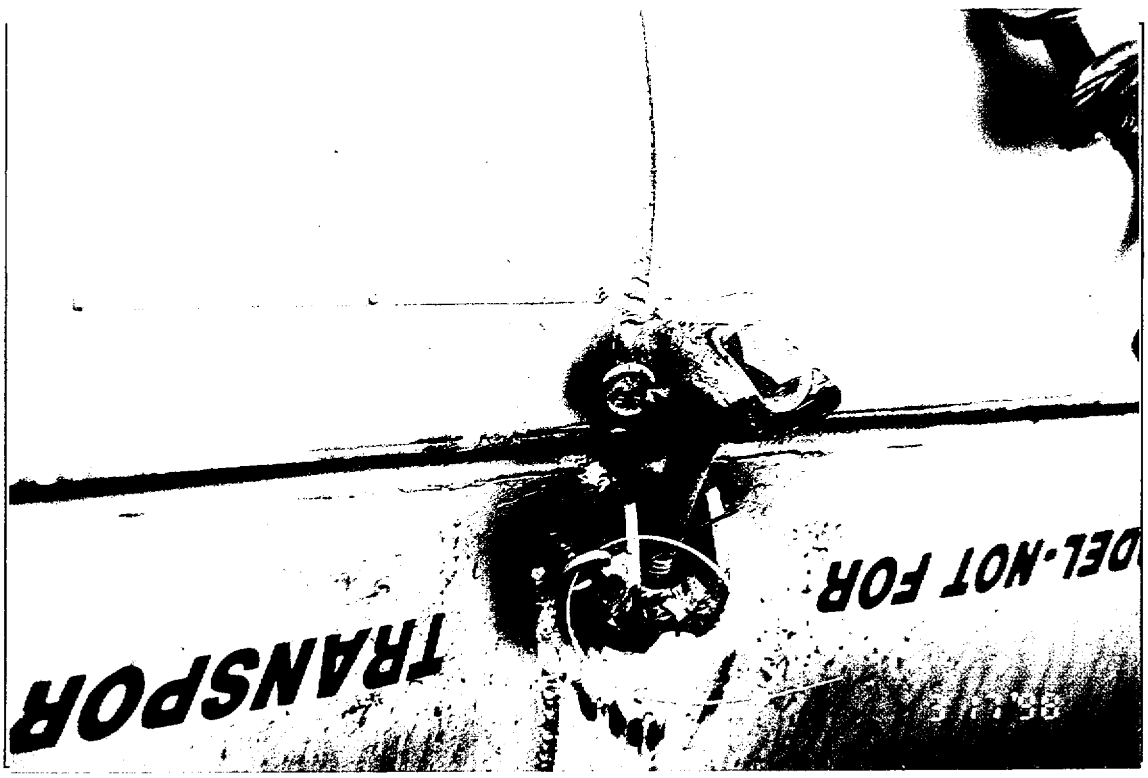
2.10.8p-16 ESP-30X Test Article #2 - 40 Inch Puncture Drop



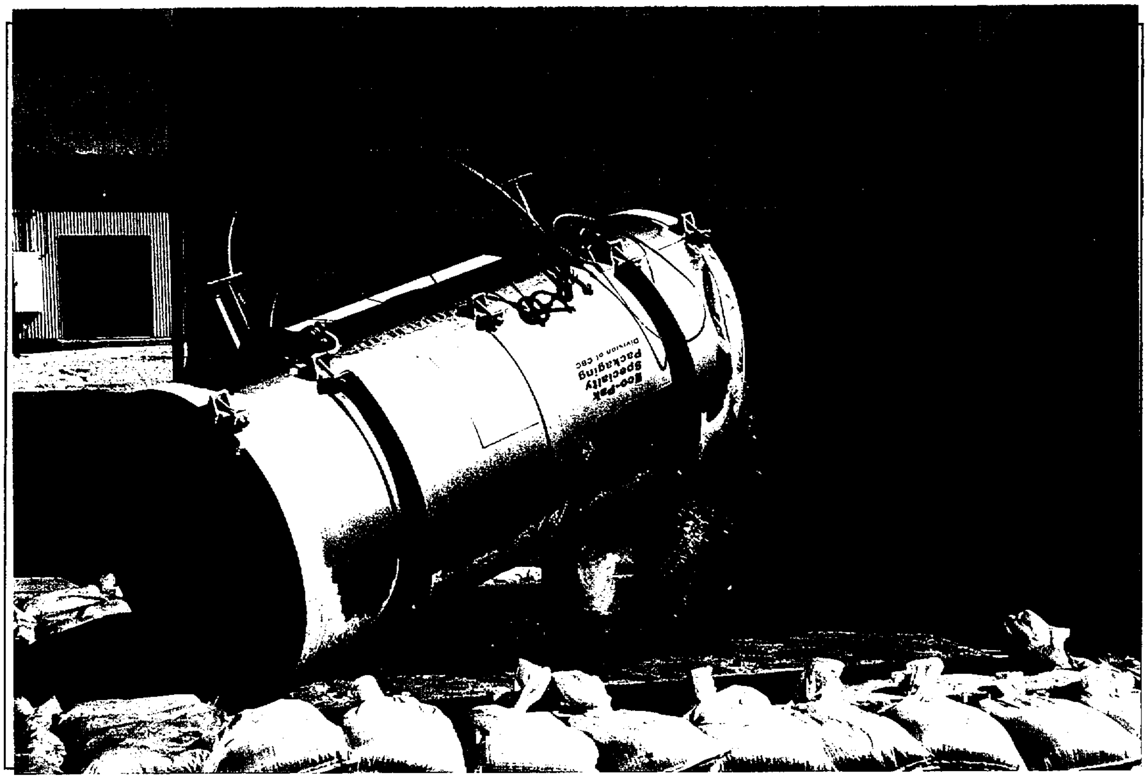
2.10.8p-17 ESP-30X Test Article #2 Damage After 40 Inch Puncture Drop



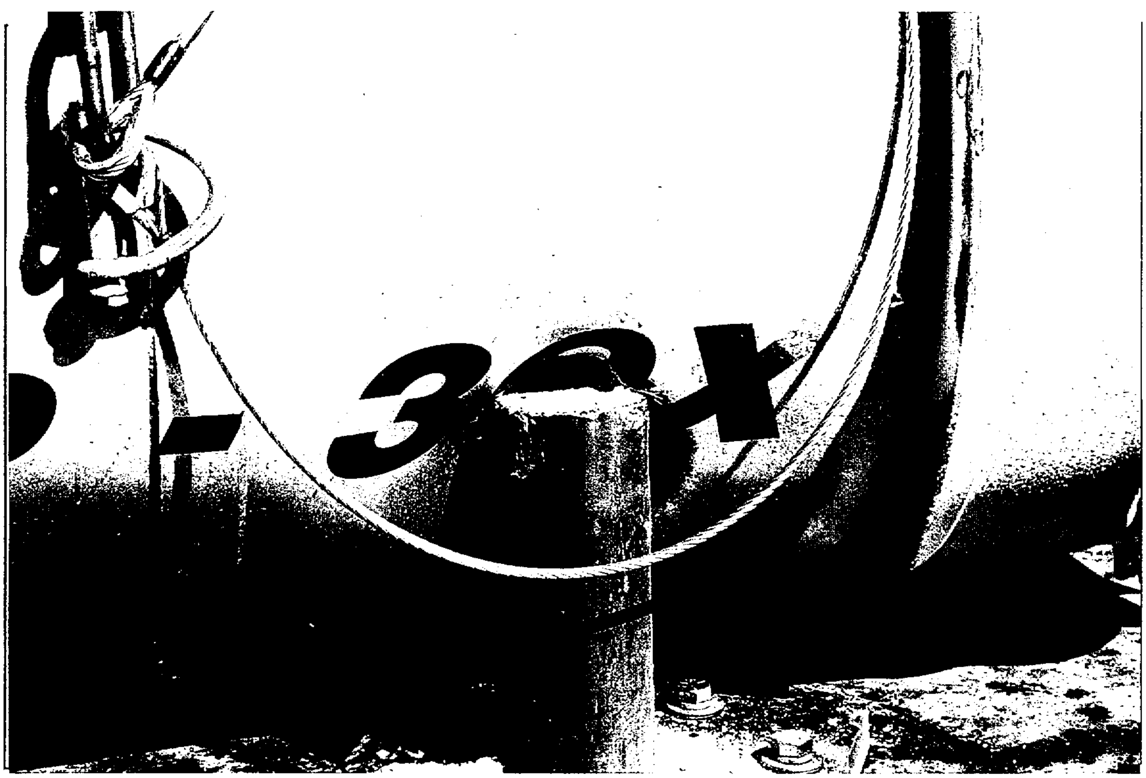
2.10.8p-18 ESP-30X Test Article #2 Damage After 40 Inch Puncture Drop



2.10.8p-19 ESP-30X Test Article #1 - 40 Inch Side Puncture Drop

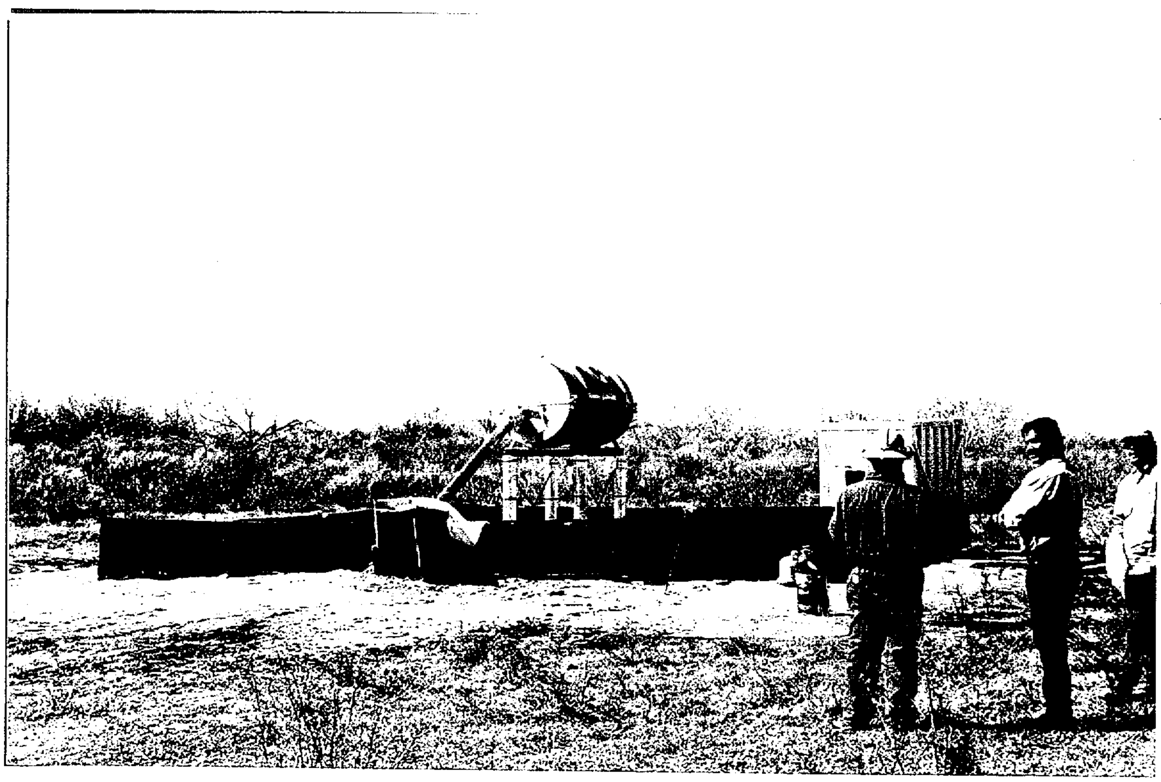


2.10.8p-20 ESP-30X Test Article #1 Damage After 40 Inch Side Puncture Drop



2.10.8p-21 ESP-30X Test Article #1 Damage After 40 Inch Side Puncture Drop

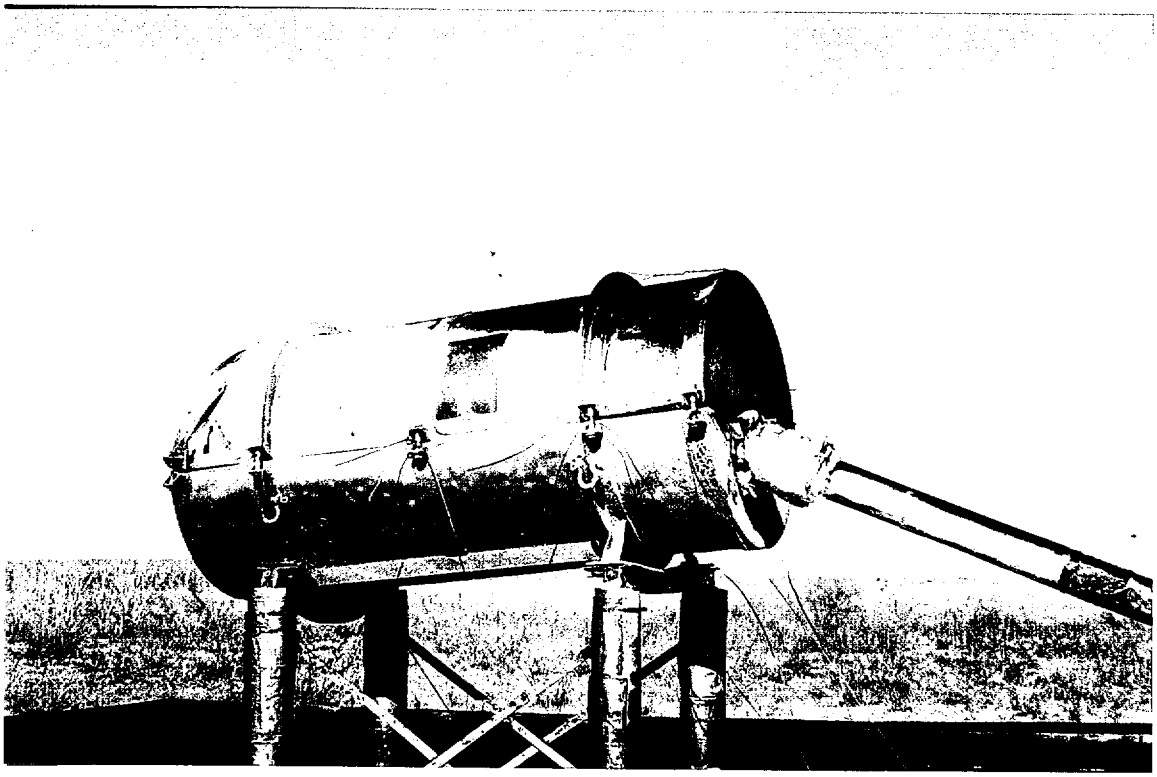
2.10.8p-22 ESP-30X Test Article #1 - Preparing for Fire Testing



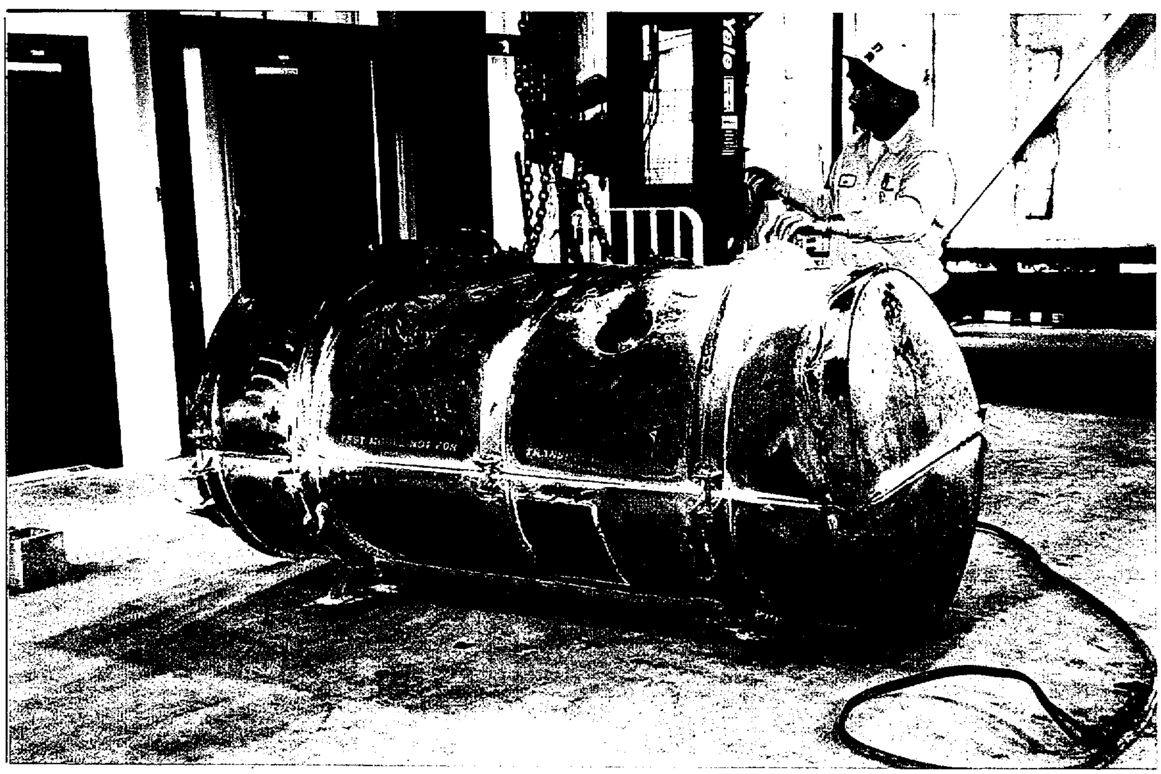
2.10.8p-23 ESP-30X Test Article #1 - Fully Engulfed

2.10.8p-24 ESP-30X Test Article #1 - Fire Complete

2.10.8p-25 ESP-30X Test Article #1 - Package Condition After Cooldown



2.10.8p-26 ESP-30X Test Article #1 - Opening the Package After Fire Test



2.10.8p-27 ESP-30X Test Article #1 - Cylinder Valve After Tests