Y/EN-4120

Y-12

OAK RIDGE Y-12 PLANT

MARTIN MARIETTA

Engineering Division
Mechanical Design Department

PACKAGING MATERIALS PROPERTIES DATA

M. S. Walker

JANUARY 1991 .

Prepared for the
Y-12 Plant Program Management
Packaging Group

Prepared by the
Engineering Division
Y-12 Mechanical Design Department
Oak Ridge, Tennessee 37831-8202
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

MANAGED BY
MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Y/EN--4120

DE92 002022

Issue Date: January 1991

PACKAGING MATERIALS PROPERTIES DATA

Prepared for the
Y-12 Plant Program Management
Packaging Group

Prepared by the
Engineering Division
Y-12 Mechanical Design Department
Oak Ridge, Tennessee 37831-8202
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

APPROVALS

Name	Organization	Date
		1-28-91
	Program Management	January 1991
		1-28-91
	Mechanical Engineering	January 1991
		1-28-91
	Mechanical Engineering	January 1991
		2-11-91
	Mechanical Engineering	January 1991
		2-12-91
	Project Engineering	January 1991

Y/EN-4120

Engineering Division
Mechanical Design Department

PACKAGING MATERIALS PROPERTIES DATA

M. S. Walker

JANUARY 1991

Prepared for the
Y-12 Plant Program Management
Packaging Group

Prepared by the
Engineering Division
Y-12 Mechanical Design Department
Oak Ridge, Tennessee 37831-8202
managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-84OR21400

PREFACE

In the process of preparing and reviewing a series of Safety Analysis Reports for Packaging, a need was determined for detailed compression versus deflection data for the energy absorbing materials used in the packages. Data for this property is required for package use at ambient temperature and at -40°C (-40°F). In addition, data was collected and is reported for a temperature of 66°C (150°F) to simulate conditions which may be attained during hot weather shipments where solar heating of the containers may occur.

CONTENTS

Page

1. ABSTRACT 1

2. INTRODUCTION 3

3. DESCRIPTION OF MATERIALS TESTED 3

4. TEST METHODS 4

5. COMPRESSION vs. DEFLECTION CURVES
Celotex, Sample No. 1, Temperature -39.8°F, Perpendicular to Laminations 5
Celotex, Sample No. 2, Temperature -40.7°F, Perpendicular to Laminations 6
Celotex, Sample No. 3, Temperature -40.3°F, Perpendicular to Laminations 7
Celotex, Sample No. 31, Temperature 73.4°F, Perpendicular to Laminations 8
Celotex, Sample No. 5, Temperature 73.4°F, Perpendicular to Laminations 9
Celotex, Sample No. 6, Temperature 73.4°F, Perpendicular to Laminations 10
Celotex, Sample No. 30, Temperature 150.1°F, Perpendicular to Laminations 11
Celotex, Sample No. 8, Temperature 149.5°F, Perpendicular to Laminations 12
Celotex, Sample No. 9, Temperature 150.6°F, Perpendicular to Laminations 13
Celotex, Sample No. 10, Temperature -42.0°F, Parallel to Laminations 14
Celotex, Sample No. 11, Temperature -39.5°F, Parallel to Laminations 15
Celotex, Sample No. 12, Temperature -40.0°F, Parallel to Laminations 16
Celotex, Sample No. 13, Temperature 73.4°F, Parallel to Laminations 17
Celotex, Sample No. 14, Temperature 73.4°F, Parallel to Laminations 18
Celotex, Sample No. 15, Temperature 73.4°F, Parallel to Laminations 19
Celotex, Sample No. 16, Temperature 150.5°F, Parallel to Laminations 20
Celotex, Sample No. 17, Temperature 149.0°F, Parallel to Laminations 21
Celotex, Sample No. 18, Temperature 148.8°F, Parallel to Laminations 22
Plywood, Sample No. 1, Temperature -39.3°F, Perpendicular to Laminations 23
Plywood, Sample No. 2, Temperature -39.7°F, Perpendicular to Laminations 24
Plywood, Sample No. 3, Temperature -40.8°F, Perpendicular to Laminations 25
Plywood, Sample No. 5, Temperature 73.4°F, Perpendicular to Laminations 26
Plywood, Sample No. 6, Temperature 73.4°F, Perpendicular to Laminations 27
Plywood, Sample No. 19, Temperature 73.0°F, Perpendicular to Laminations 28
Plywood, Sample No. 7, Temperature 150.2°F, Perpendicular to Laminations 29
Plywood, Sample No. 8, Temperature 150.3°F, Perpendicular to Laminations 30
Plywood, Sample No. 9, Temperature 150.5°F, Perpendicular to Laminations 31
Plywood, Sample No. 10, Temperature -38.5°F, Parallel to Laminations 32
Plywood, Sample No. 11, Temperature -40.0°F, Parallel to Laminations 33
Plywood, Sample No. 12, Temperature -39.8°F, Parallel to Laminations 34
Plywood, Sample No. 13, Temperature 73.4°F, Parallel to Laminations 35
Plywood, Sample No. 14, Temperature 73.4°F, Parallel to Laminations 36
Plywood, Sample No. 15, Temperature 73.4°F, Parallel to Laminations 37
Plywood, Sample No. 16, Temperature 150.5°F, Parallel to Laminations 38
Plywood, Sample No. 17, Temperature 149.5°F, Parallel to Laminations 39
Plywood, Sample No. 18, Temperature 148.8°F, Parallel to Laminations 40

Page

FP-236 Foam, Sample No. 19, Temperature -40.1°F, Perpendicular to Skin 41
FP-236 Foam, Sample No. 20, Temperature -40.0°F, Perpendicular to Skin 42
FP-236 Foam, Sample No. 21, Temperature -40.8°F, Perpendicular to Skin 43
FP-236 Foam, Sample No. 22, Temperature 72.5°F, Perpendicular to Skin 44
FP-236 Foam, Sample No. 23, Temperature 72.5°F, Perpendicular to Skin 45
FP-236 Foam, Sample No. 24, Temperature 72.5°F, Perpendicular to Skin 46
FP-236 Foam, Sample No. 25, Temperature 150.3°F, Perpendicular to Skin 47
FP-236 Foam, Sample No. 26, Temperature 149.3°F, Perpendicular to Skin 48
FP-236 Foam, Sample No. 27, Temperature 150.2°F, Perpendicular to Skin 49
FP-236 Foam, Sample No. 28, Temperature -40.6°F, Parallel to Skin 50
FP-236 Foam, Sample No. 29, Temperature -41.0°F, Parallel to Skin 51
FP-236 Foam, Sample No. 30, Temperature -40.7°F, Parallel to Skin 52
FP-236 Foam, Sample No. 31, Temperature 72.5°F, Parallel to Skin 53
FP-236 Foam, Sample No. 32, Temperature 72.5°F, Parallel to Skin 54
FP-236 Foam, Sample No. 33, Temperature 72.5°F, Parallel to Skin 55
FP-236 Foam, Sample No. 34, Temperature 150.3°F, Parallel to Skin 56
FP-236 Foam, Sample No. 35, Temperature 150.2°F, Parallel to Skin 57
FP-236 Foam, Sample No. 36, Temperature 149.9°F, Parallel to Skin 58
Monothane, Sample No. 37-1, Temperature -39.5°F, Perpendicular to Skin 59
Monothane, Sample No. 38-2, Temperature -40.3°F, Perpendicular to Skin 60
Monothane, Sample No. 39-3, Temperature -40.0°F, Perpendicular to Skin 61
Monothane, Sample No. 40-4, Temperature 72.0°F, Perpendicular to Skin 62
Monothane, Sample No. 41-5, Temperature 72.0°F, Perpendicular to Skin 63
Monothane, Sample No. 42-6, Temperature 72.0°F, Perpendicular to Skin 64
Monothane, Sample No. 43-7, Temperature 150.2°F, Perpendicular to Skin 65
Monothane, Sample No. 44-8, Temperature 149.6°F, Perpendicular to Skin 66
Monothane, Sample No. 45-9, Temperature 150.0°F, Perpendicular to Skin 67
Monothane, Sample No. 46-10, Temperature -39.5°F, Parallel to Skin 68
Monothane, Sample No. 47-11, Temperature -39.8°F, Parallel to Skin 69
Monothane, Sample No. 48-12, Temperature -39.6°F, Parallel to Skin 70
Monothane, Sample No. 49-13, Temperature 72.5°F, Parallel to Skin 71
Monothane, Sample No. 50-14, Temperature 72.5°F, Parallel to Skin 72
Monothane, Sample No. 51-15, Temperature 72.5°F, Parallel to Skin 73
Monothane, Sample No. 52-16, Temperature 150.1°F, Parallel to Skin 74
Monothane, Sample No. 53-17, Temperature 150.0°F, Parallel to Skin 75
Monothane, Sample No. 54-18, Temperature 150.0°F, Parallel to Skin 76

1. ABSTRACT

Several energy absorbing materials are used in nuclear weapons component shipping containers recently designed for the Y-12 Plant Program Management Packaging Group. As a part of the independent review procedure leading to Certificates of Compliance, the U.S. Department of Energy Technical Safety Review Panels requested compression versus deflection data on these materials. This report is a compilation of that data.

2. INTRODUCTION

Energy absorbing materials are used in nuclear weapons component shipping containers to protect the components shipped and the inner container from damage in both normal and accident conditions. The containers designed for the Y-12 Plant Program Management Packaging Group have been physically tested at full scale in accordance with the applicable regulations, Title 10, Code of Federal Regulations, Part 71. The energy absorbing materials performed satisfactorily in these tests. Safety Analysis Reports for Packing (SARPs) have been prepared for six containers designated DT-18, DT-19, DT-20, DT-21, DT-22, and DT-23. After review by the Department of Energy, Certificates of Compliance have been issued for most of these containers, authorizing their use for shipment of nuclear materials.

As part of the Department of Energy review process, the SARPs are reviewed by a Technical Safety Review Panel (TSRP). Each container may be reviewed several times--once for each content loading. In the process of performing these reviews, members of the TSRP perform independent analyses of the containers. Although the SARPs contain information on the materials of construction, the TSRPs have requested that the Y-12 Plant Program Management Packaging Group perform additional testing of the energy absorbing materials to characterize its behavior in use. Specifically, the TSRPs asked for compression force versus deflection data for use in calculating energy absorbance. They requested that the data be taken at temperatures from -40°C (-40°F), room temperature, and at the maximum temperature anticipated in normal transport. This temperature was estimated to be 66°C (150°F) for purposes of these tests, to simulate the effect of solar heating in a 38°C (100°F) ambient shipping environment. Detailed temperature requirements are delineated in 10 CFR 71.71.

3. DESCRIPTION OF MATERIALS TESTED

Four energy absorbing materials were tested. Two of the materials are used to surround an inner container and protect it from external damage. The other two materials are used inside the inner container to protect it from damage by the content.

The materials used outside the inner container are plywood and Celotex(R). These materials are laminated together to provide the support structure for the inner container. Plywood is used principally to provide load distribution and reinforcement at points where handling causes additional wear and tear. It is also used at the ends of the inner container where sharp corners might penetrate through the Celotex(R) in an accident. The majority of the external energy absorbing material is Celotex(R), which also performs a thermal insulation role.

The Celotex(R) is a cellulosic fiber insulation board which is specified by ASTM C-208, as Roof Insulating Board. An additional requirement limits the acceptable density to 0.256 ± 0.03 g/cm^3 (16 ± 2 lb/ft^3). The material is manufactured in felted layers 12.7 mm (0.5 in.) thick which are laminated at the vendor's factory into sheets up to 50.8 mm (2 in.) thick. The samples for these tests were 50.8 mm (2 in.) cubes cut from factory laminated stock. Compression versus deflection tests were conducted both normal and parallel to these laminations to account for any anisotropic behavior.

The plywood used in these containers is fir plywood of A-C grade. Thicknesses used are 6.35 mm (.25 in.), 12.7 mm (.50 in.), and 19.05 mm (.75 in.). In order to use consistent sample sizes for all materials, 50.8 mm (2 in.) cubes were laminated from 12.7 mm (.50 in.) sheet. The adhesive used for lamination was the same adhesive used to laminate the layers of Celotex(R) and plywood in the actual containers. This adhesive is TYPE W BLACK MAGIC(R) by the Miracle Adhesive Corporation. Compression versus deflection tests were conducted both normal and parallel to the laminations to account for any anisotropic behavior.

The first of the two materials used for energy absorption inside the inner container is FP-236 foam. This is a medium density flexible polyurethane foam. It is made by the reaction of two components in a closed mold. The raw material is manufactured by the Flexible Products Corporation. The foam parts are molded at the Y-12 Plant. Part density is controlled to the range of 0.24-0.29 g/cc (15-18 lb/ft^3) during the molding process. The parts used for these tests were fabricated by molding a 50.8 mm (2 in.) thick sheet of foam, which was then cut up into 50.8 mm (2 in.) cubes. Where the foam contacts the mold surface, a smooth, relatively non-porous, thin skin of material is formed. Each cube has two sides with this skin. Parts on the perimeter of the sheet, where skin is formed on three sides, were discarded. Compression versus deflection tests were conducted both normal and parallel to the mold skin in order to account for any anisotropic behavior.

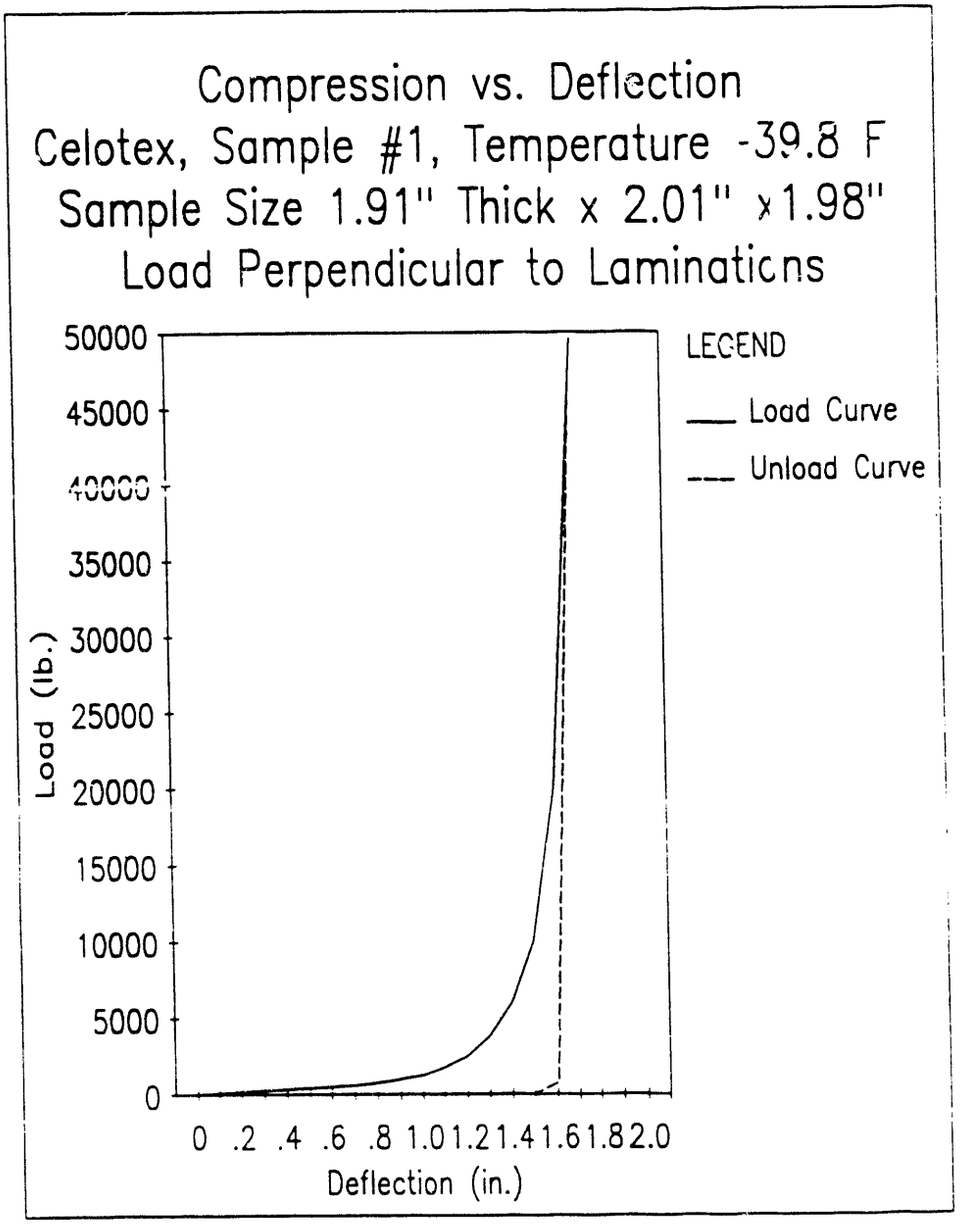
The second material used inside the inner containers is a cast single component solid polyurethane, INDPOL(R) Monothane(R). The resin for this material is manufactured by the SYNAIR Corporation. The parts used in the containers are cast and oven cured at the Y-12 Plant. The material used has a specified Shore A durometer of 40. The samples were manufactured by casting a bar 50.8 mm (2 in.) square by length. This bar was then cut into 50.8 mm (2 in.) cubes for testing. Where the polyurethane is exposed to the air during the oven cure (the top surface of the bar), a dark discolored skin forms. One surface of each cube had this skin. Actual parts cast in molds would have this skin on the top surface as cast. Compression versus deflection tests were conducted both normal and parallel to the skin surface in order to account for any anisotropic behavior.

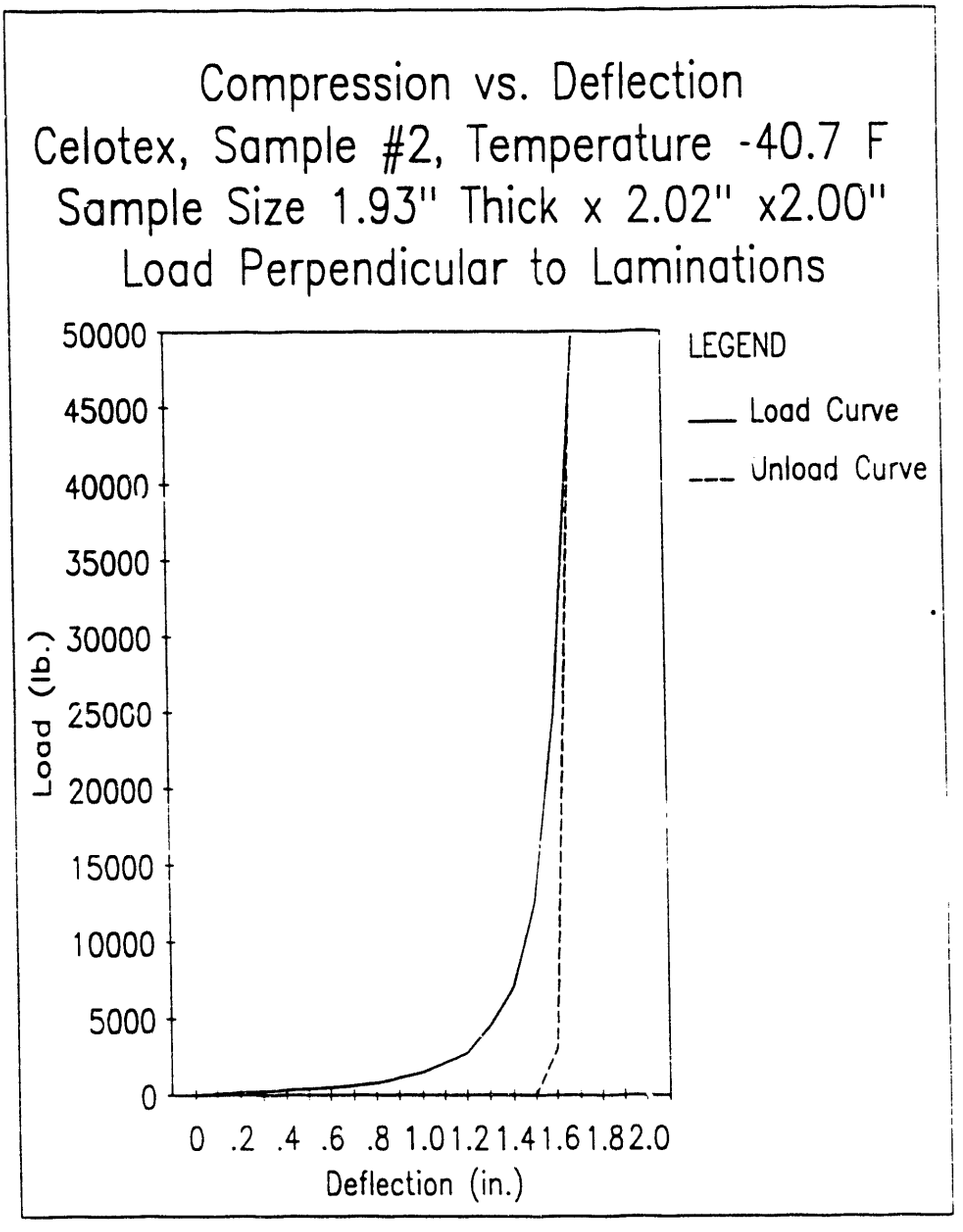
All materials tested were taken from Y-12 Plant production stores. Multiple samples were tested for each material in each orientation and at each temperature. The samples were all taken from one lot of each material.

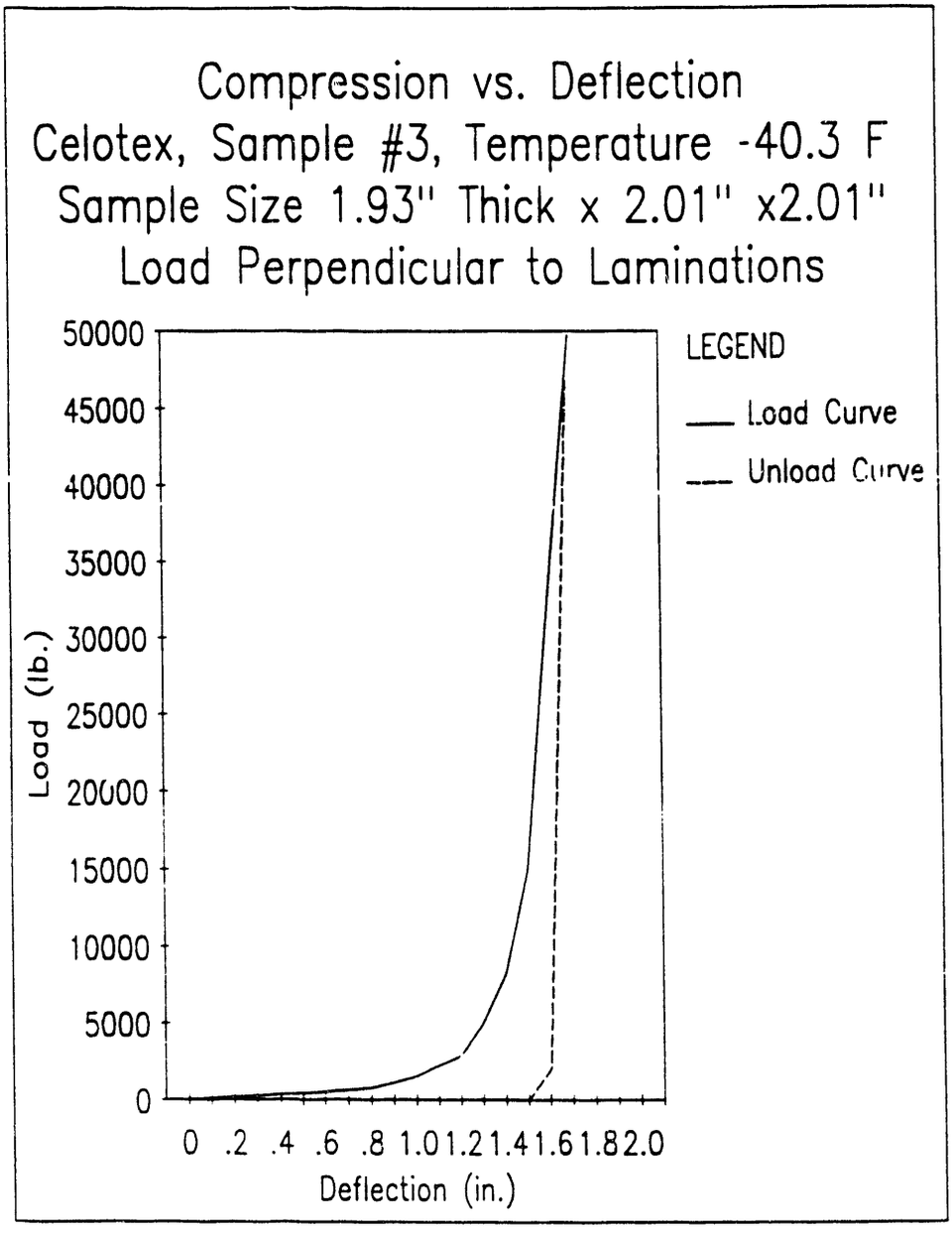
4. TEST METHODS

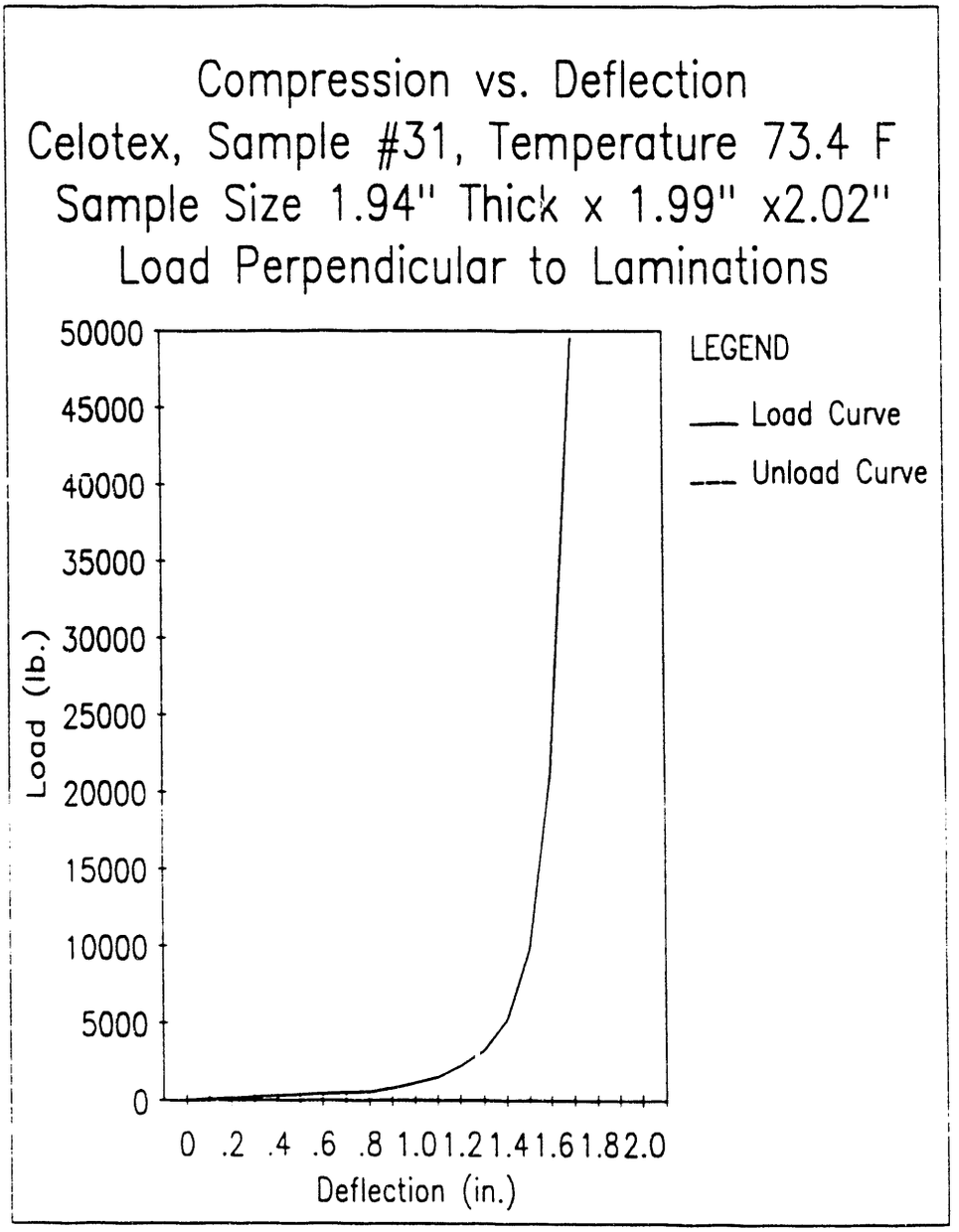
Samples were tested in accordance with ASTM C165, Procedure A. The testing machine was a 55 KIP MTS Tensile Test Machine with Model 880 load frame. This is a closed loop servo hydraulic machine and is equipped with Model 458 electronics. The machine is also equipped with a Thermotron environmental chamber which allows the samples to be tested at reduced and elevated temperatures. When operating at non-ambient temperatures, samples were placed in the chamber and allowed to stabilize before testing. Crosshead speed was set at 0.04 mm/s (0.1 in./min). The samples were compressed to either 90 percent compression, until the material failed to support an increase in compression force, or until the load on the machine reached 222.4 kN (50,000 lb). Sample size was reduced from the ASTM C165, Procedure A, recommendation of 203 mm (8 in.) square to 50.8 mm (2 in.) square in order to achieve higher deformations without exceeding the test machine load capacity. The reduced size is the minimum allowable for the procedure.

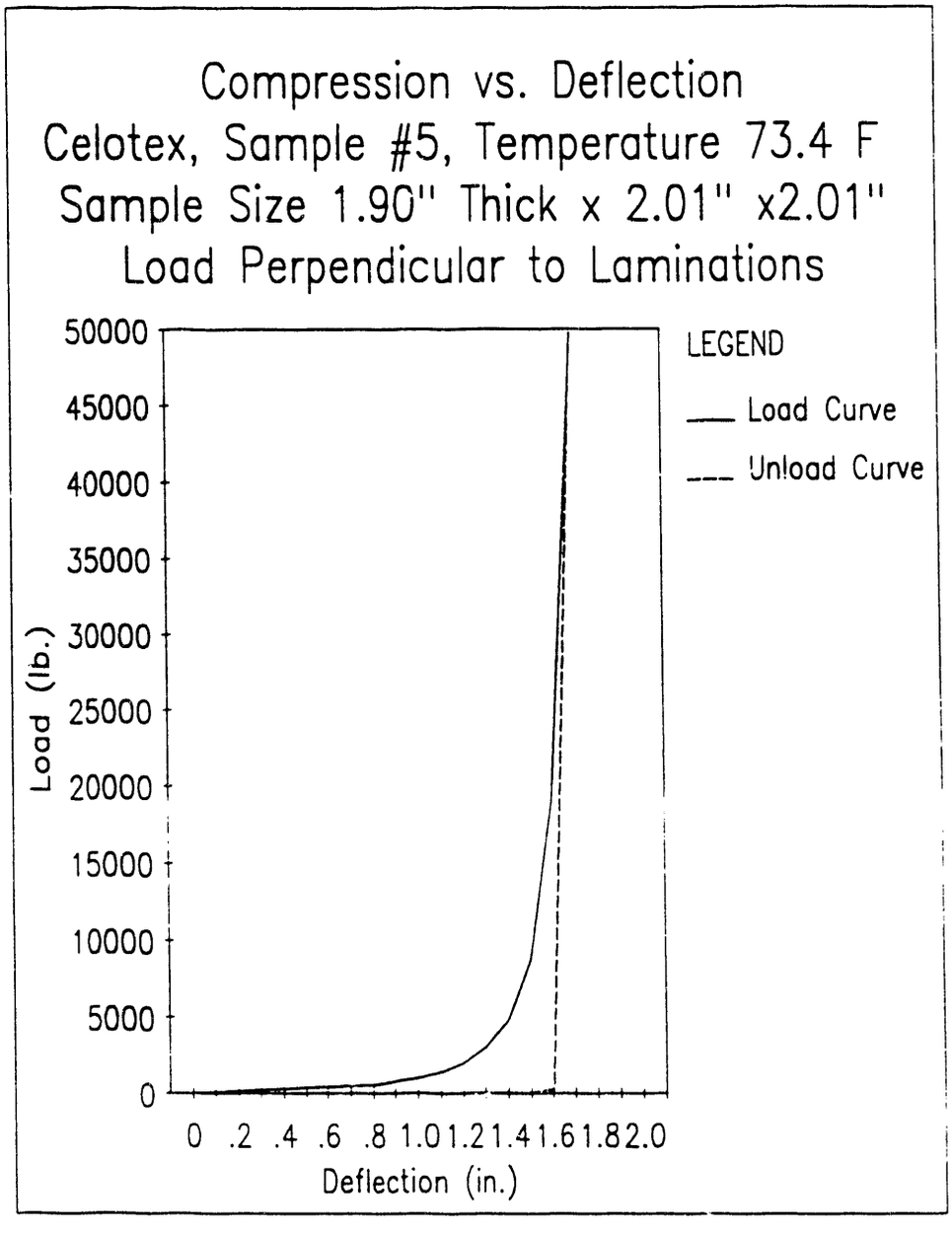
Samples were not laterally constrained during compression. One surface plate was fixed perpendicular to the machine loading axis. The other surface plate was self-aligning, suspended by a spherical bearing. Only the plywood specimens tested normal to the laminations showed significant tendencies to compress nonuniformly. In the tests conducted at 66°C (150°F), the laminations tended to slip at high loads, caused by nonuniform compression. Plywood is not laminated into 50.8 mm (2 in.) thicknesses in the actual containers.

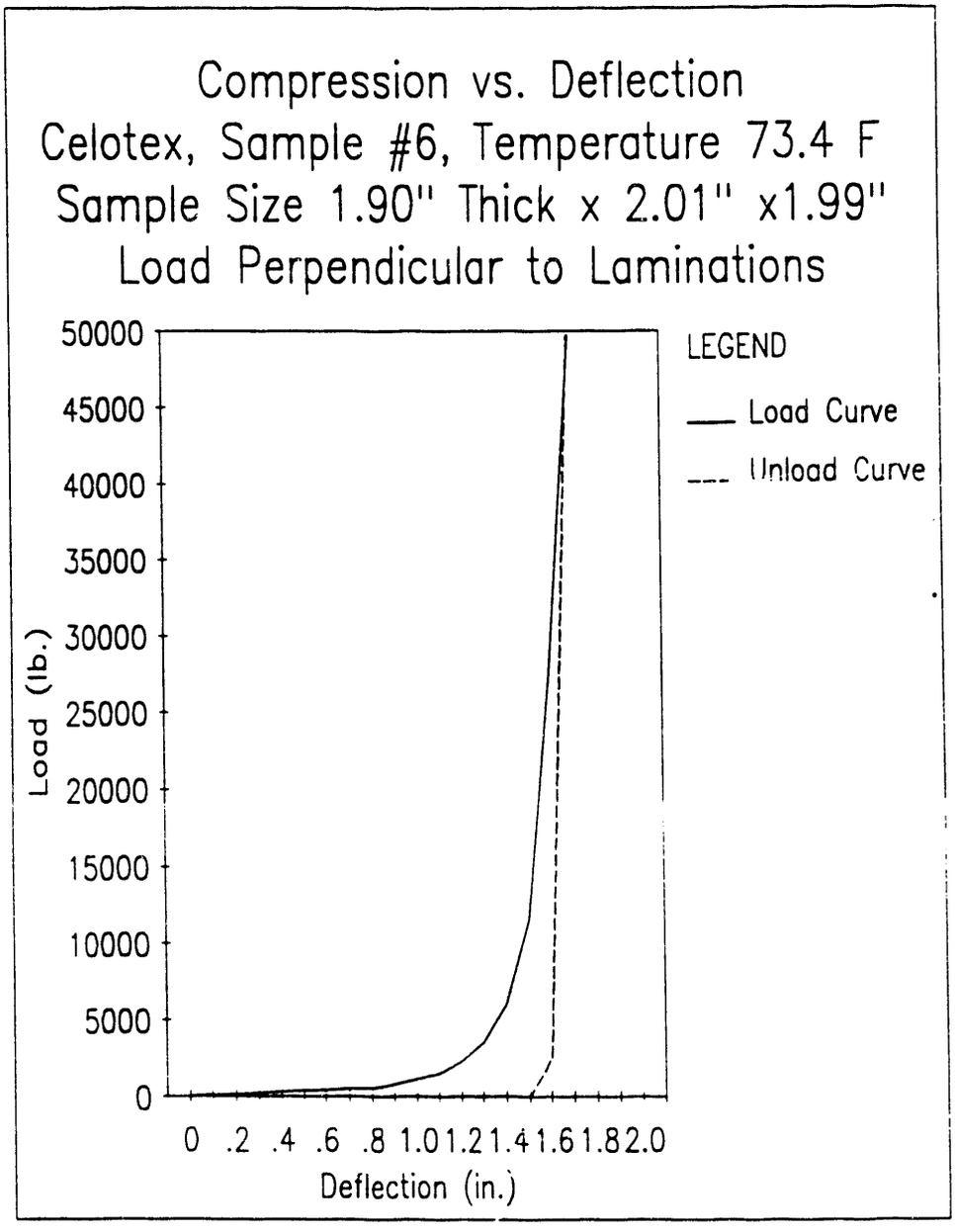

Compression vs. Deflection
Celotex, Sample #1, Temperature -39.8 F
Sample Size 1.91" Thick x 2.01" x 1.98"
Load Perpendicular to Laminations
LEGEND
Load Curve
Unload Curve
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)

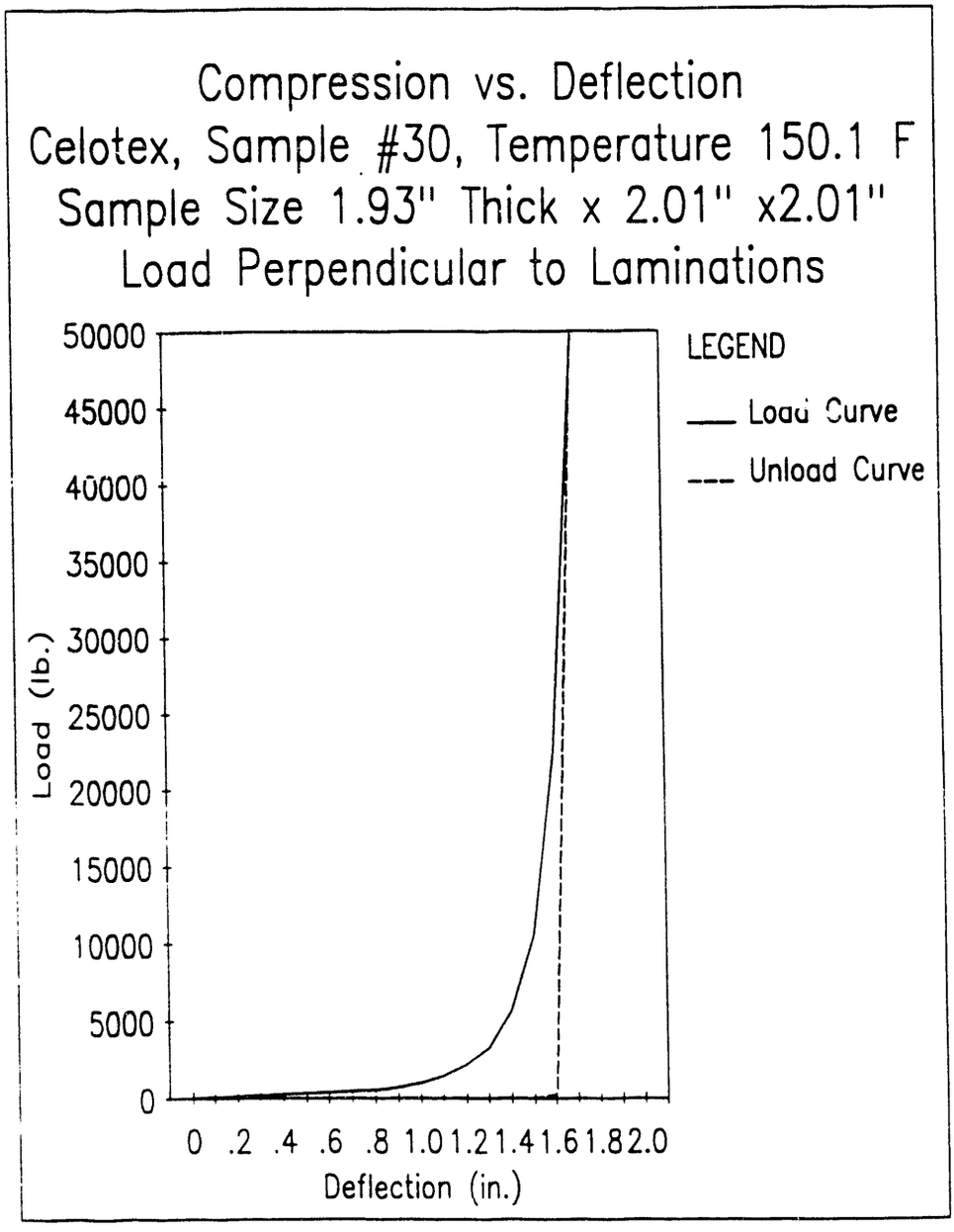

Compression vs. Deflection
Celotex, Sample #2, Temperature -40.7 F
Sample Size 1.93" Thick x 2.02" x2.00"
Load Perpendicular to Laminations
LEGEND
Load Curve
Unload Curve
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)

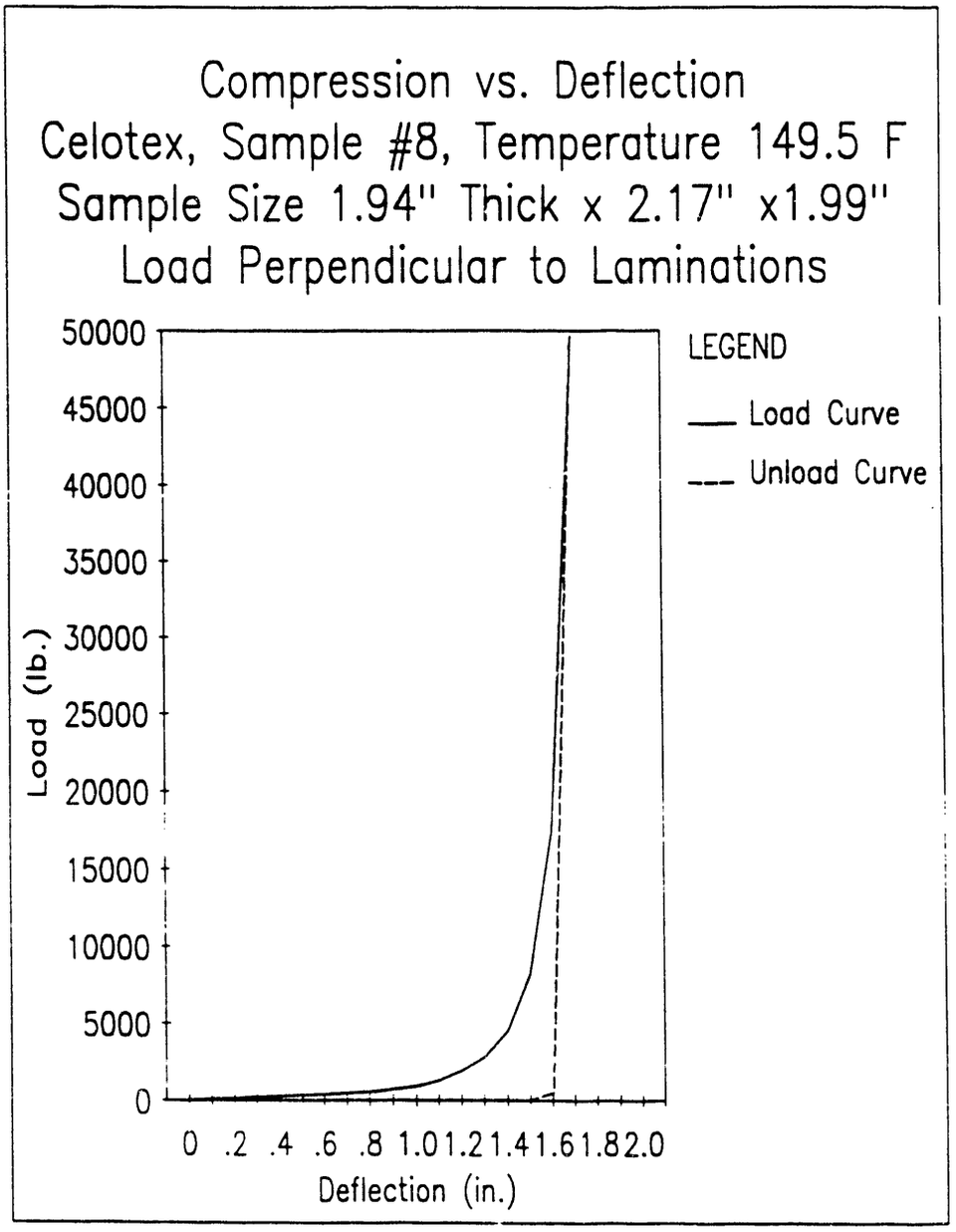

Compression vs. Deflection
Celotex, Sample #3, Temperature -40.3 F
Sample Size 1.93" Thick x 2.01" x2.01"
Load Perpendicular to Laminations
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

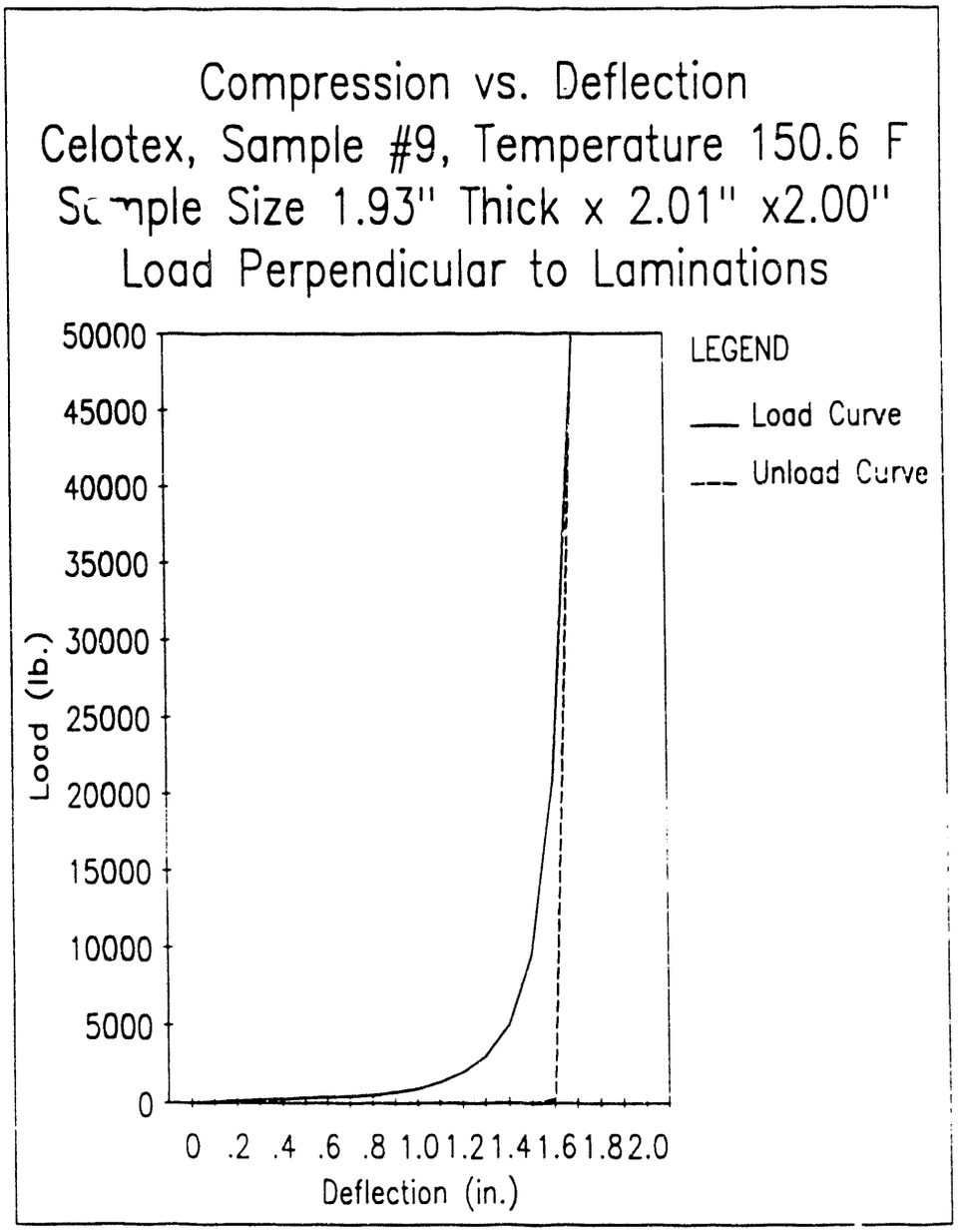

Compression vs. Deflection
Celotex, Sample #31, Temperature 73.4 F
Sample Size 1.94" Thick x 1.99" x2.02"
Load Perpendicular to Laminations
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

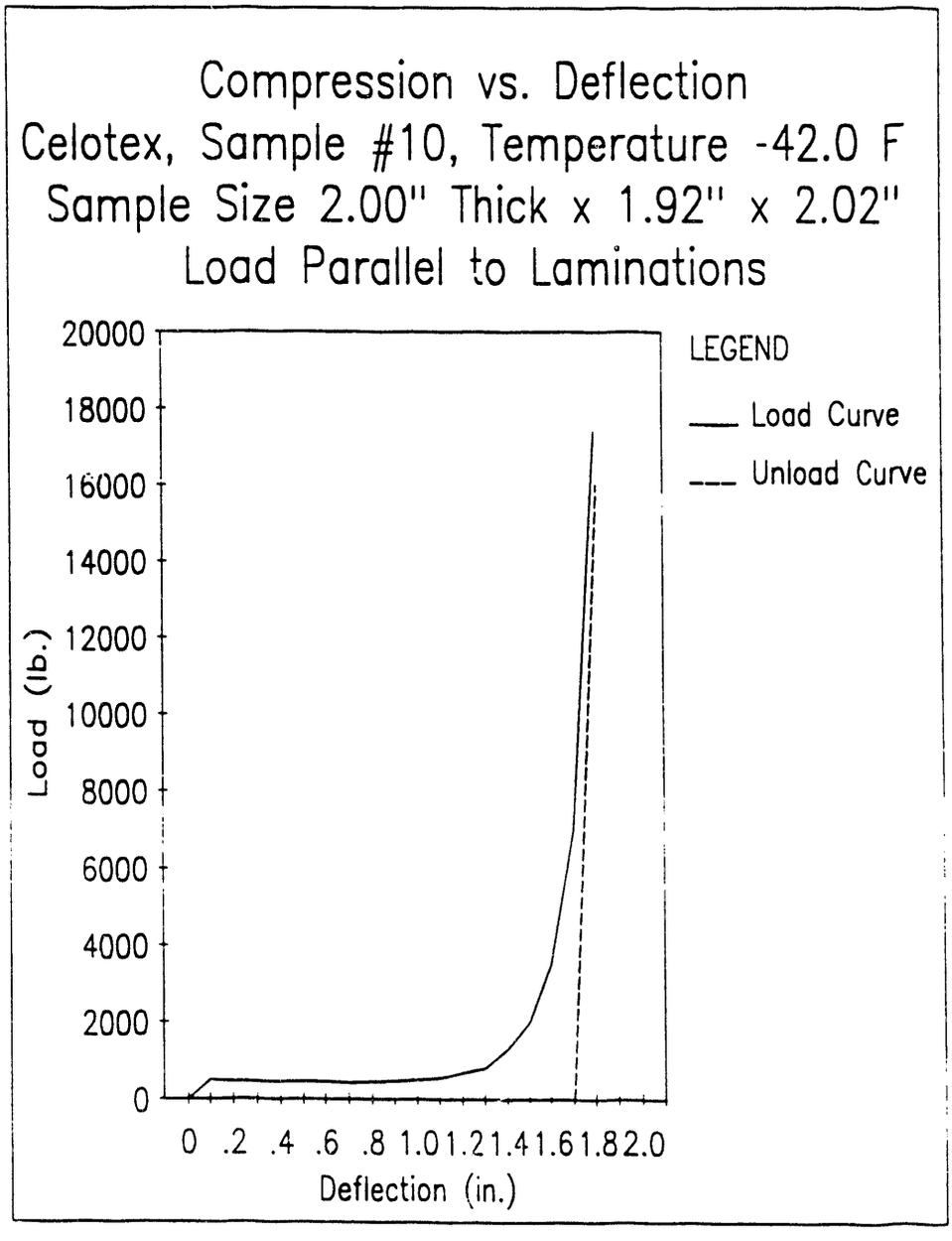

Compression vs. Deflection
Celotex, Sample #5, Temperature 73.4 F
Sample Size 1.90" Thick x 2.01" x2.01"
Load Perpendicular to Laminations
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

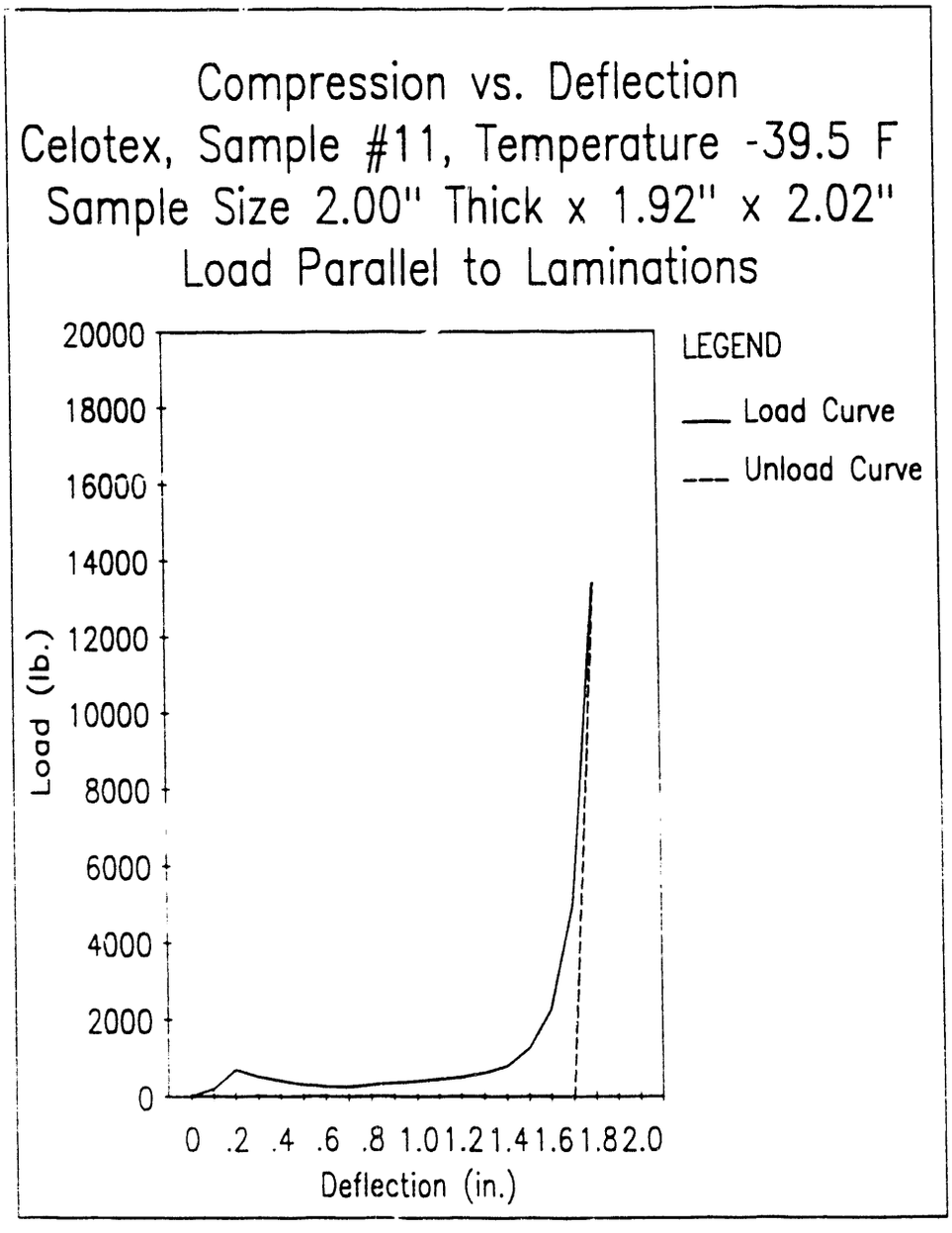

Compression vs. Deflection
Celotex, Sample #6, Temperature 73.4 F
Sample Size 1.90" Thick x 2.01" x1.99"
Load Perpendicular to Laminations
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

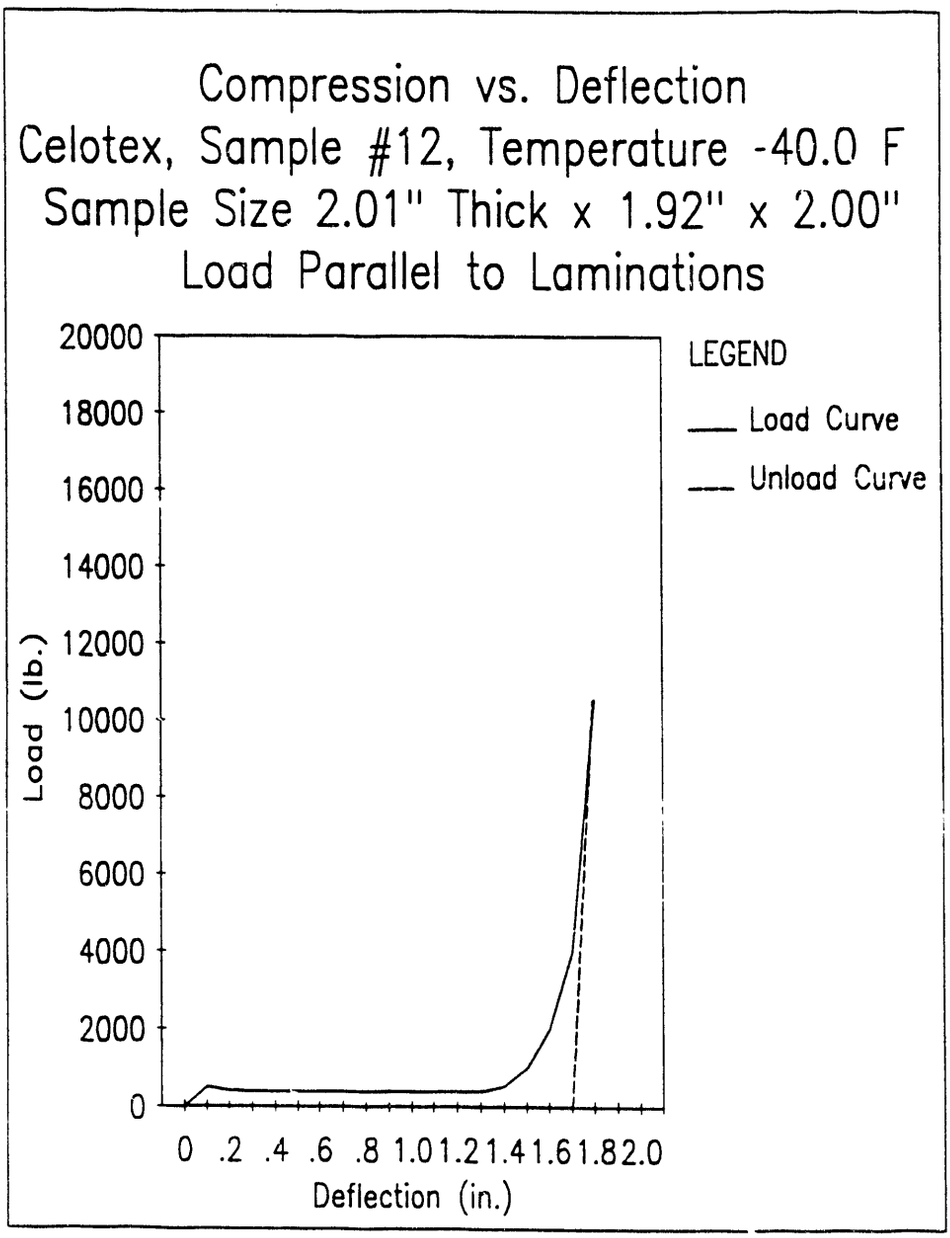

Compression vs. Deflection
Celotex, Sample #30, Temperature 150.1 F
Sample Size 1.93" Thick x 2.01" x2.01"
Load Perpendicular to Laminations
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

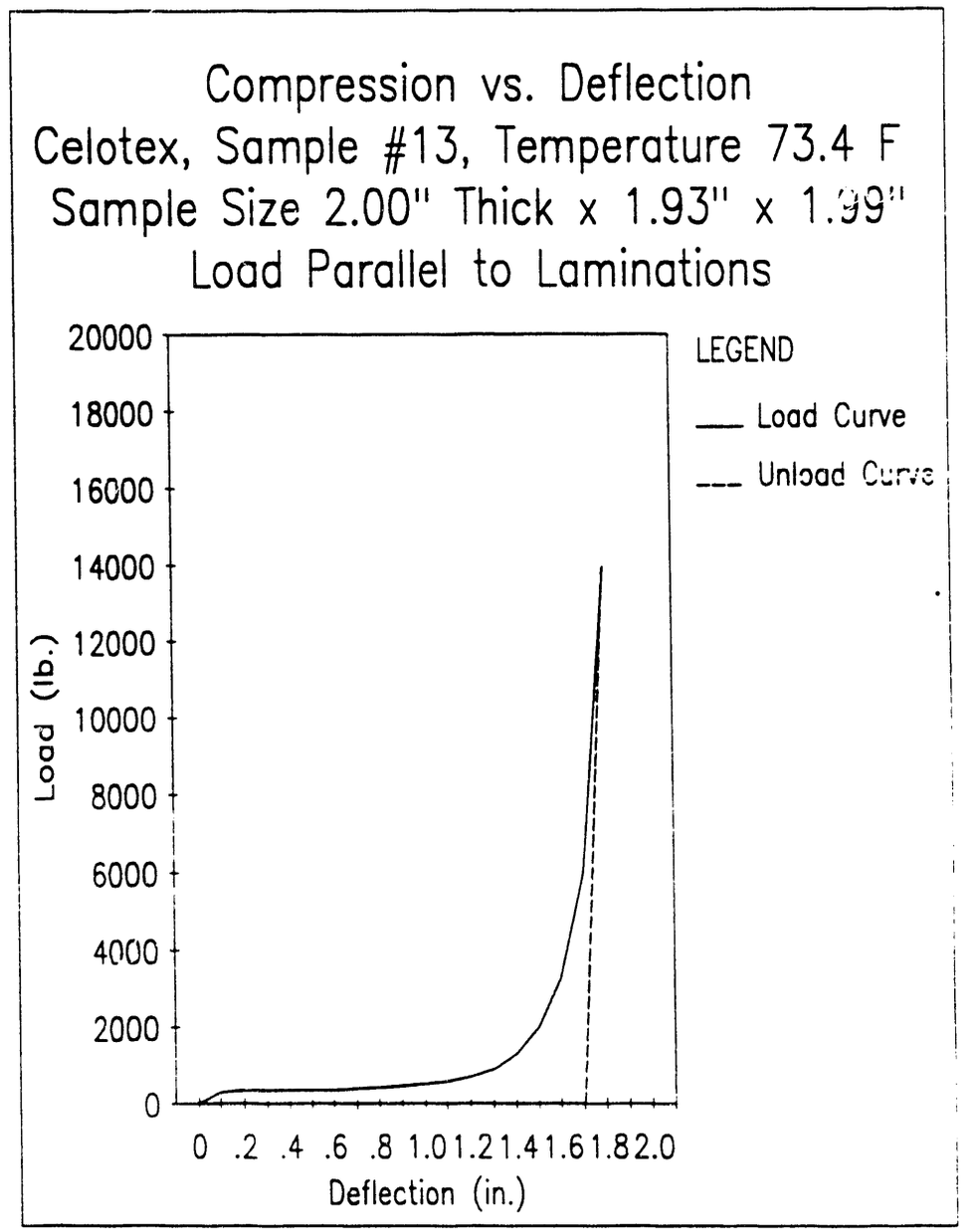

Compression vs. Deflection
Celotex, Sample #8, Temperature 149.5 F
Sample Size 1.94" Thick x 2.17" x1.99"
Load Perpendicular to Laminations
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

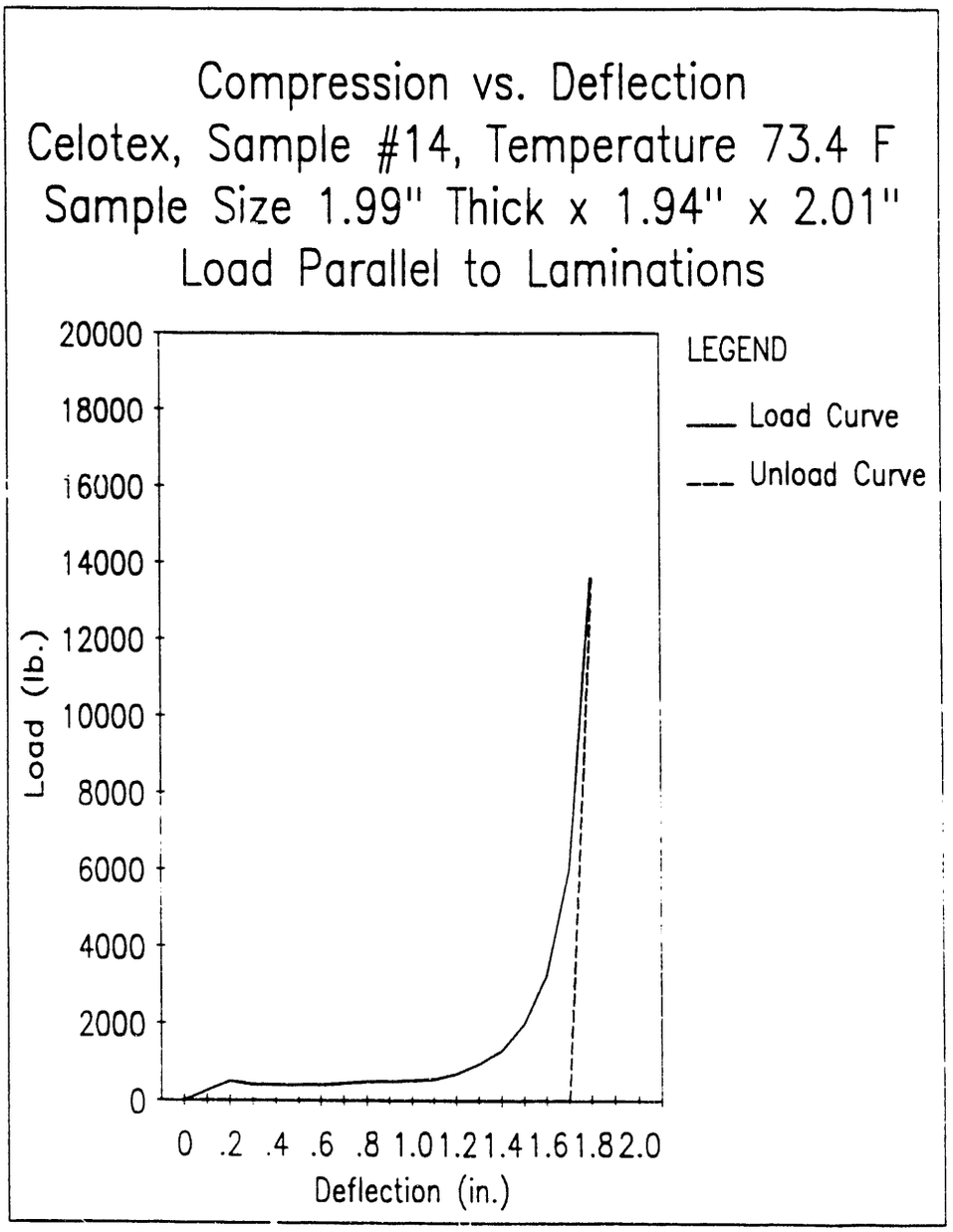

Compression vs. Deflection
Celotex, Sample #9, Temperature 150.6 F
Sample Size 1.93" Thick x 2.01" x2.00"
Load Perpendicular to Laminations
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

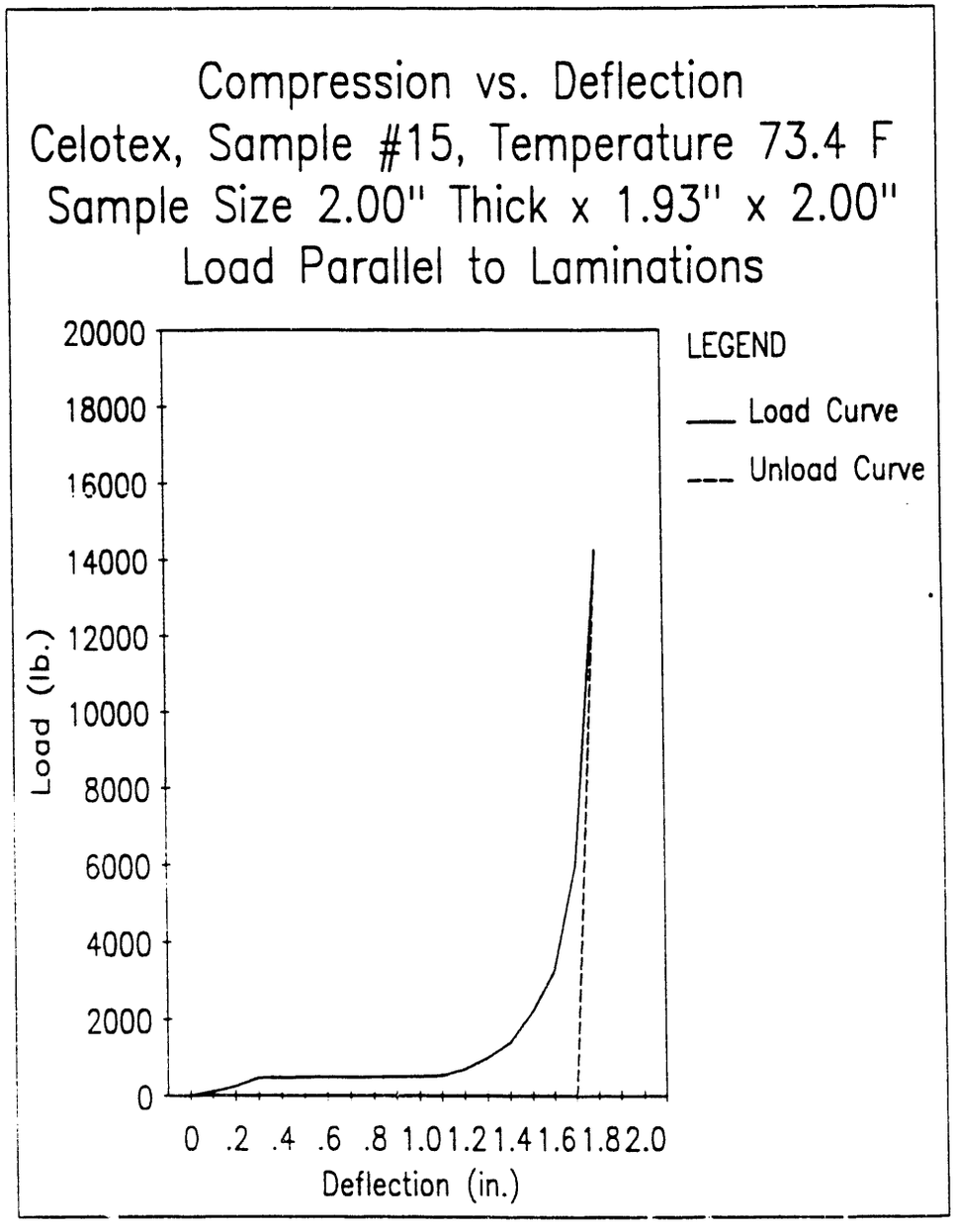

Compression vs. Deflection
Celotex, Sample #10, Temperature -42.0 F
Sample Size 2.00" Thick x 1.92" x 2.02"
Load Parallel to Laminations
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

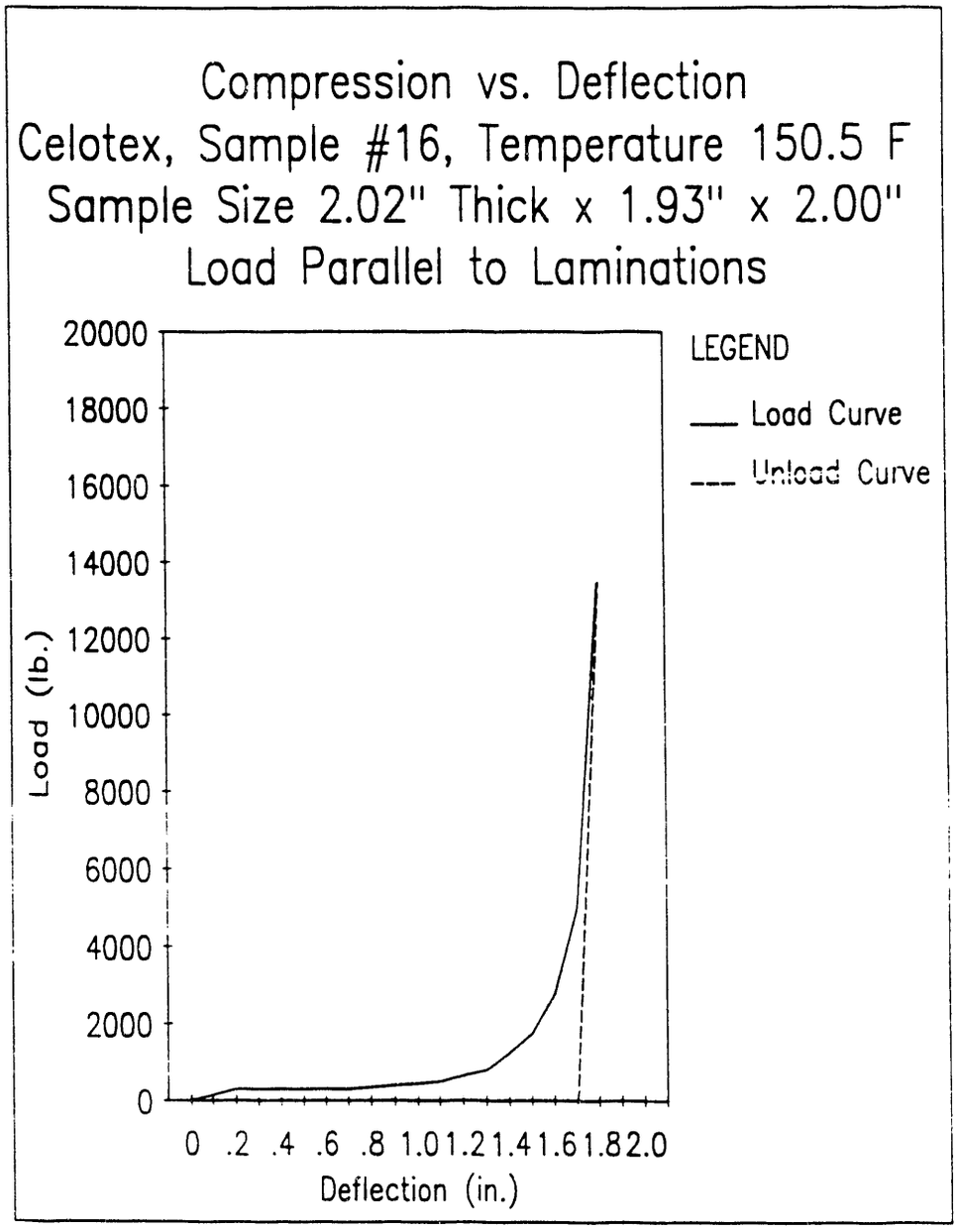

Compression vs. Deflection
Celotex, Sample #11, Temperature -39.5 F
Sample Size 2.00" Thick x 1.92" x 2.02"
Load Parallel to Laminations
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

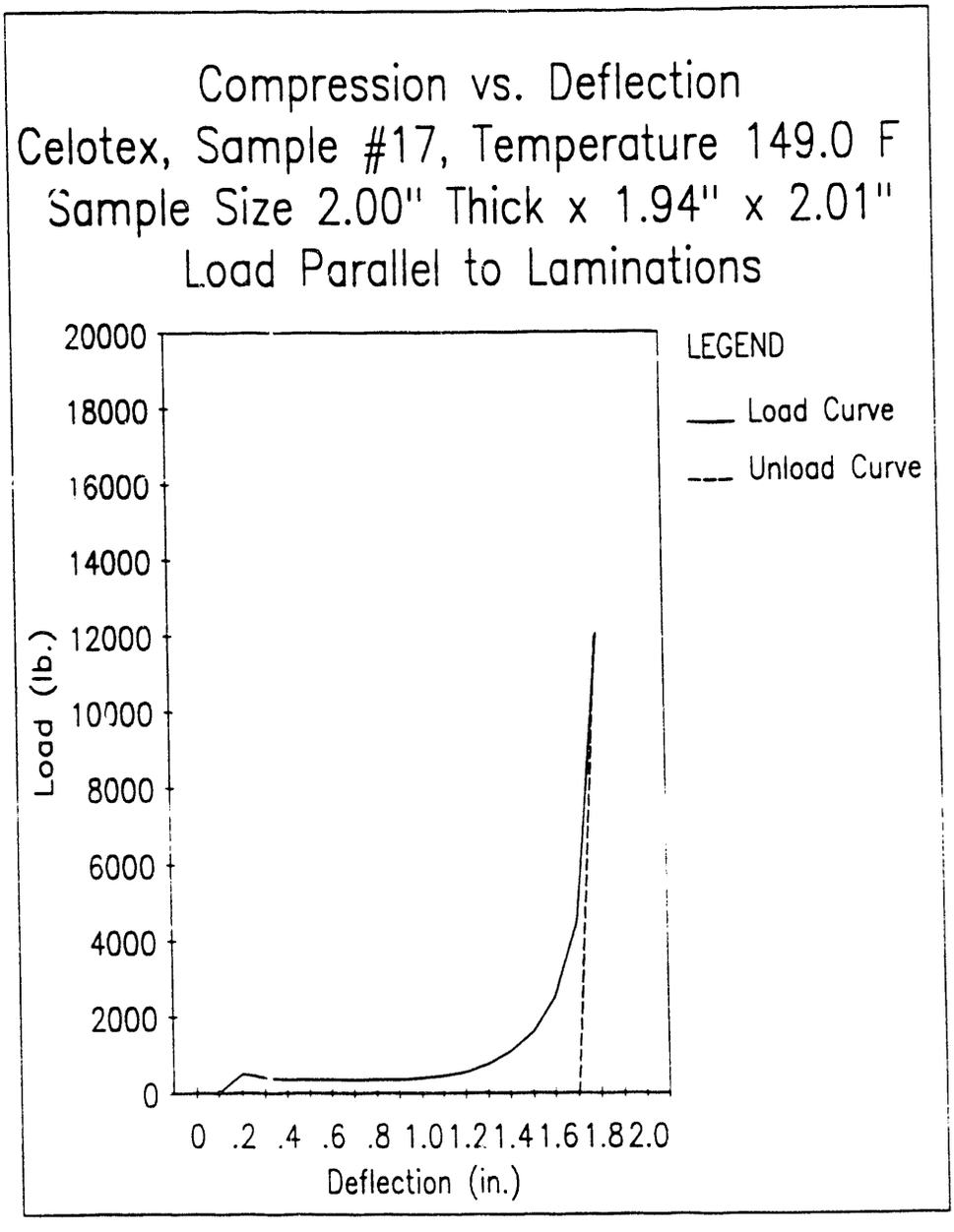

Compression vs. Deflection
Celotex, Sample #12, Temperature -40.0 F
Sample Size 2.01" Thick x 1.92" x 2.00"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

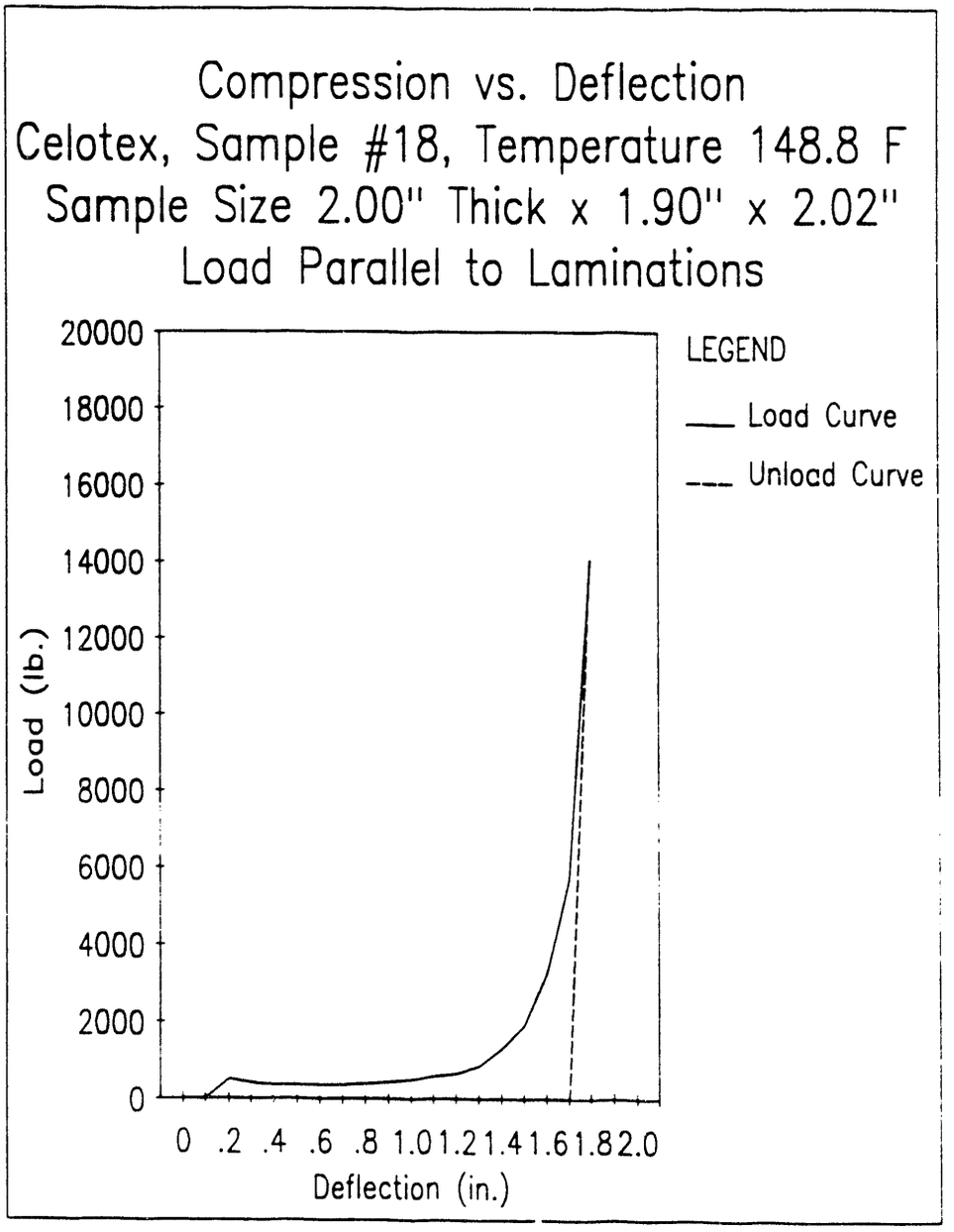

Compression vs. Deflection
Celotex, Sample #13, Temperature 73.4 F
Sample Size 2.00" Thick x 1.93" x 1.99"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

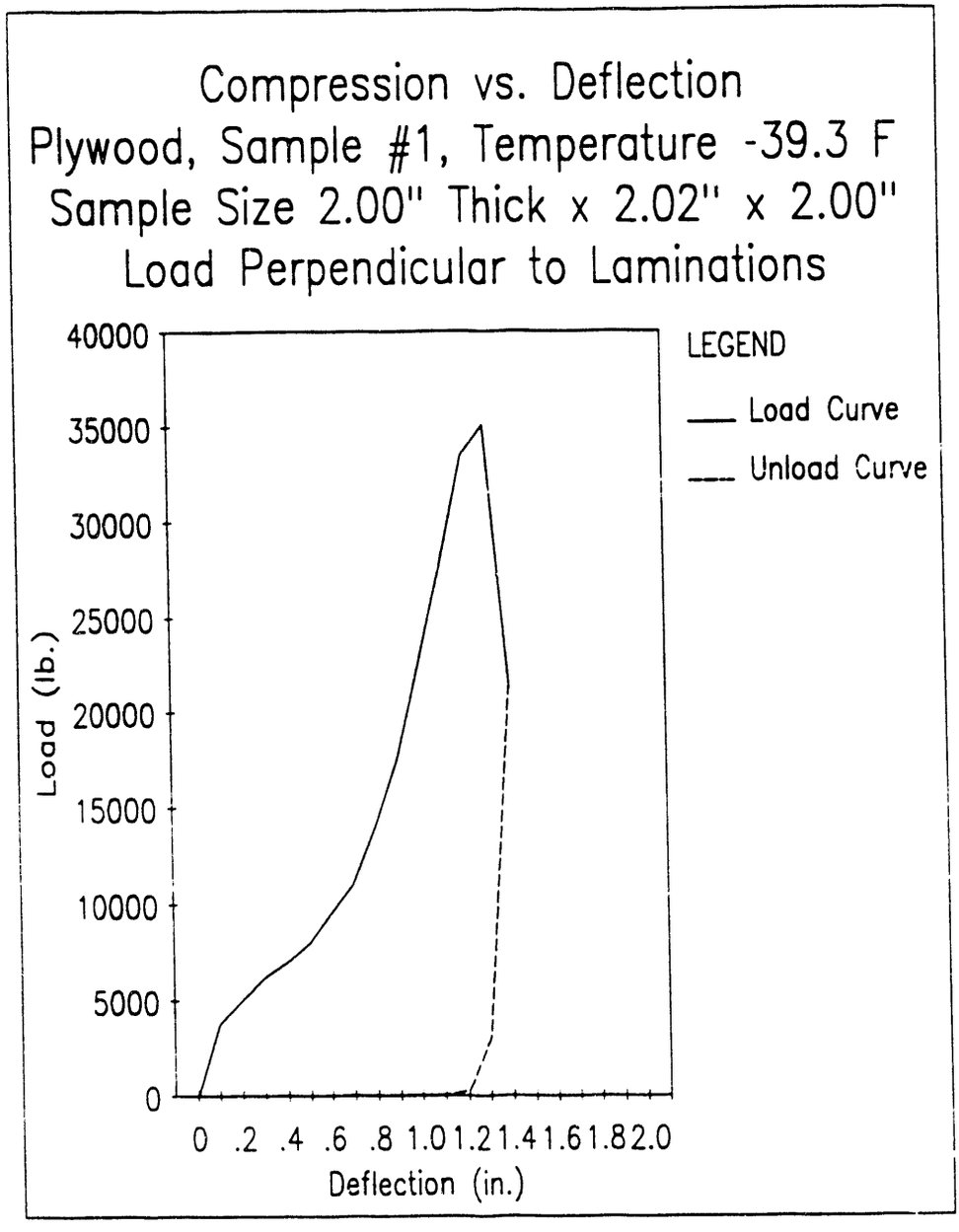

Compression vs. Deflection
Celotex, Sample #14, Temperature 73.4 F
Sample Size 1.99" Thick x 1.94" x 2.01"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

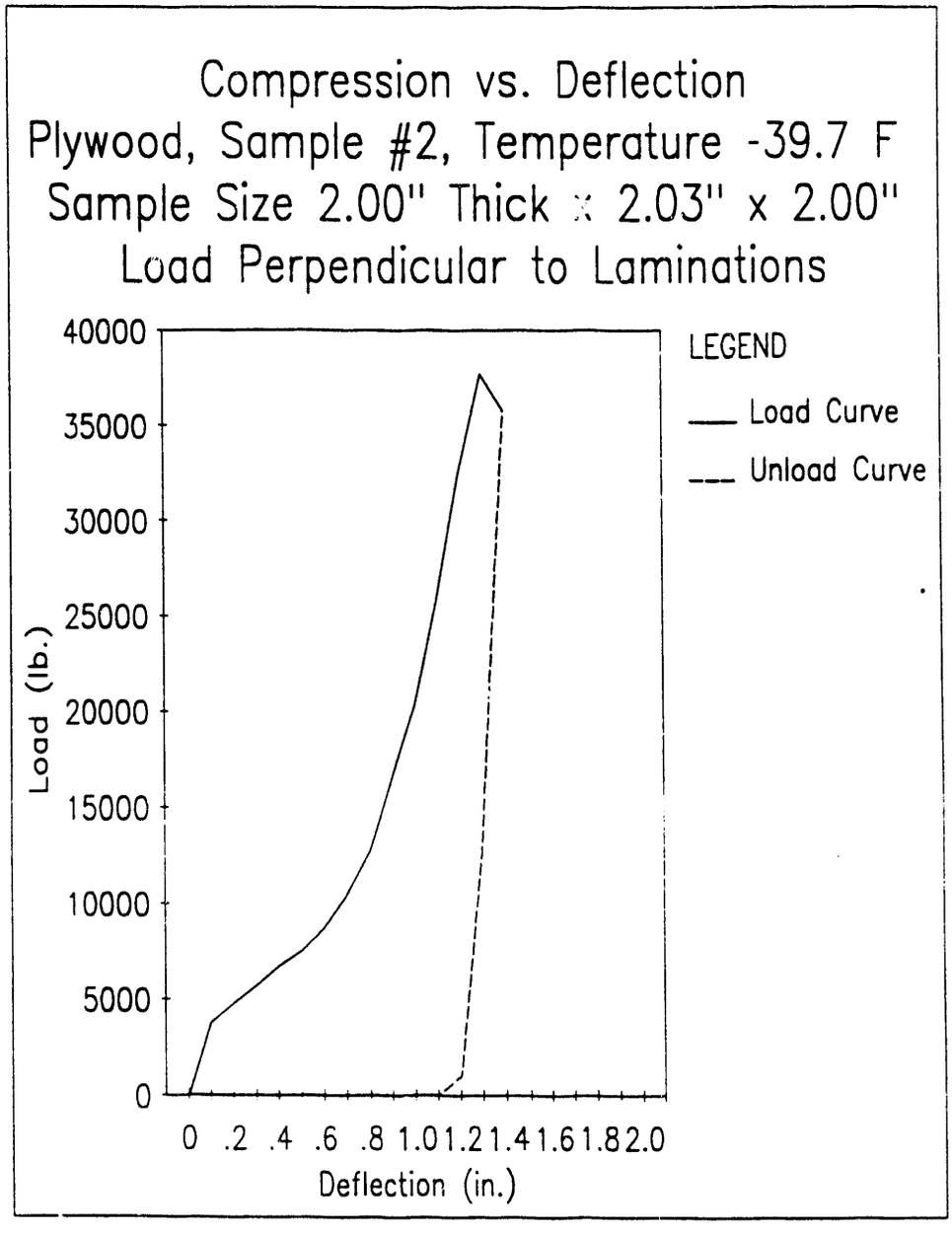

Compression vs. Deflection
Celotex, Sample #15, Temperature 73.4 F
Sample Size 2.00" Thick x 1.93" x 2.00"
Load Parallel to Laminations
LEGEND
Load Curve
Unload Curve
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)

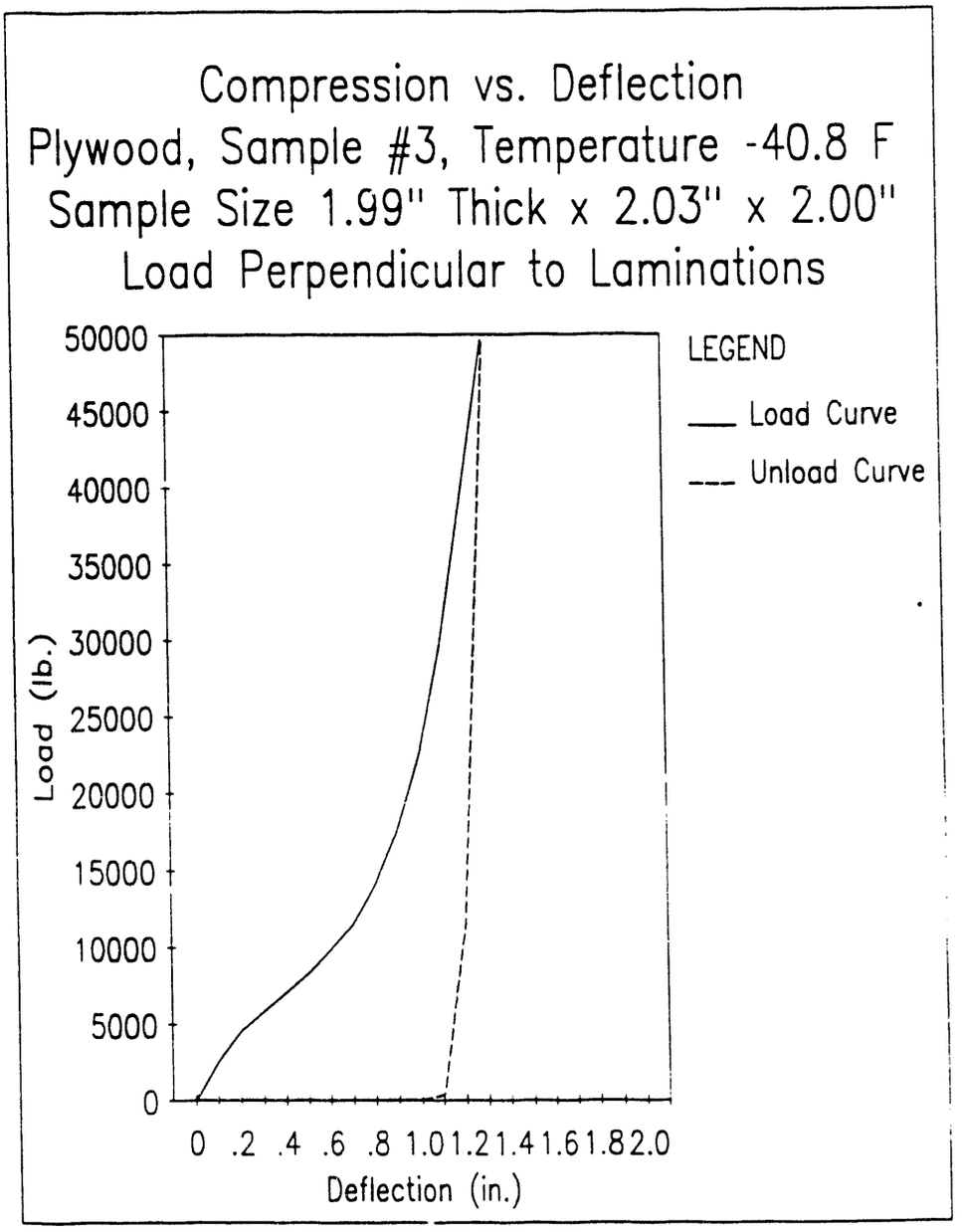

Compression vs. Deflection
Celotex, Sample #16, Temperature 150.5 F
Sample Size 2.02" Thick x 1.93" x 2.00"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

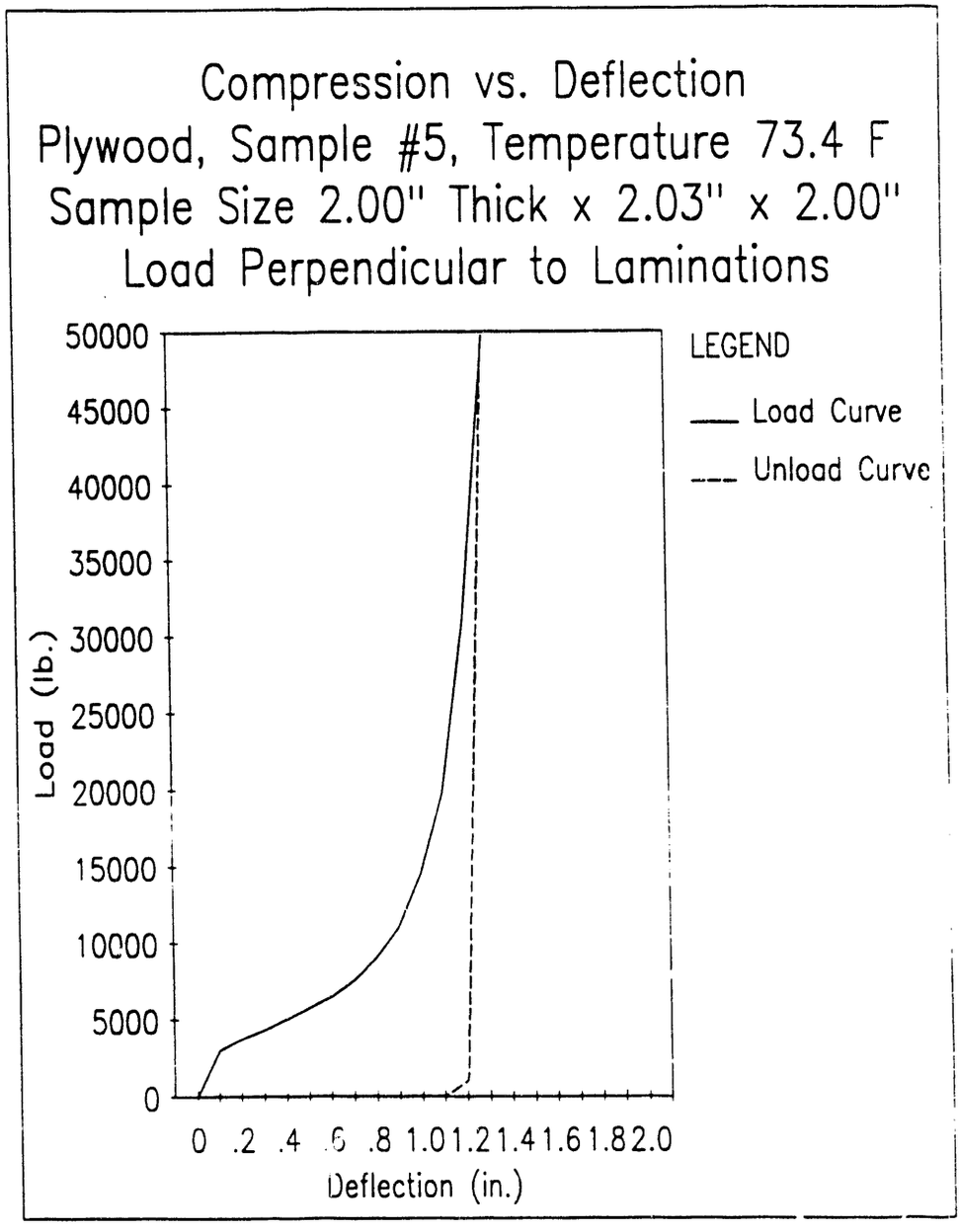

Compression vs. Deflection
Celotex, Sample #17, Temperature 149.0 F
Sample Size 2.00" Thick x 1.94" x 2.01"
Load Parallel to Laminations
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

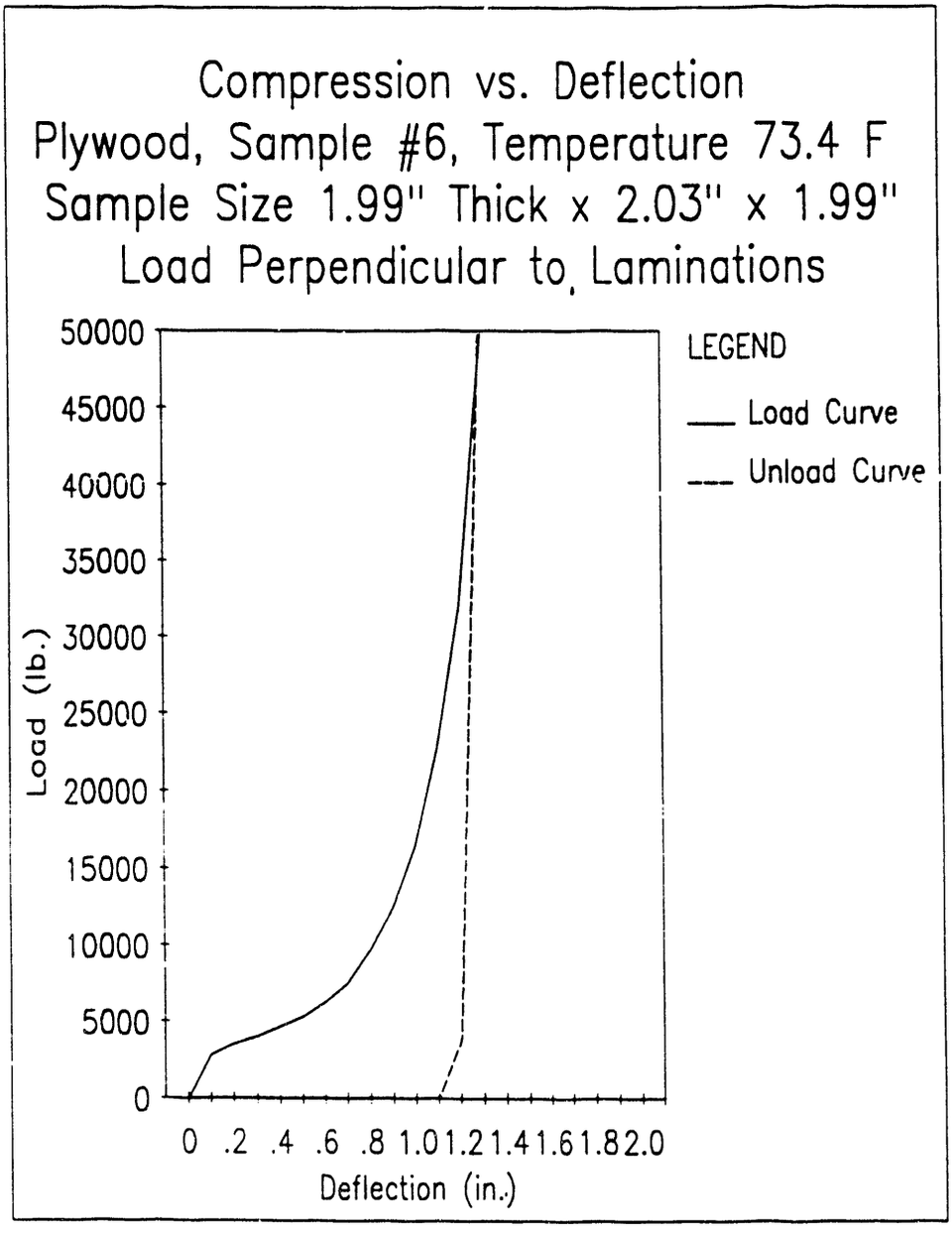

Compression vs. Deflection
Celotex, Sample #18, Temperature 148.8 F
Sample Size 2.00" Thick x 1.90" x 2.02"
Load Parallel to Laminations
LEGEND
Load Curve
Unload Curve
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)

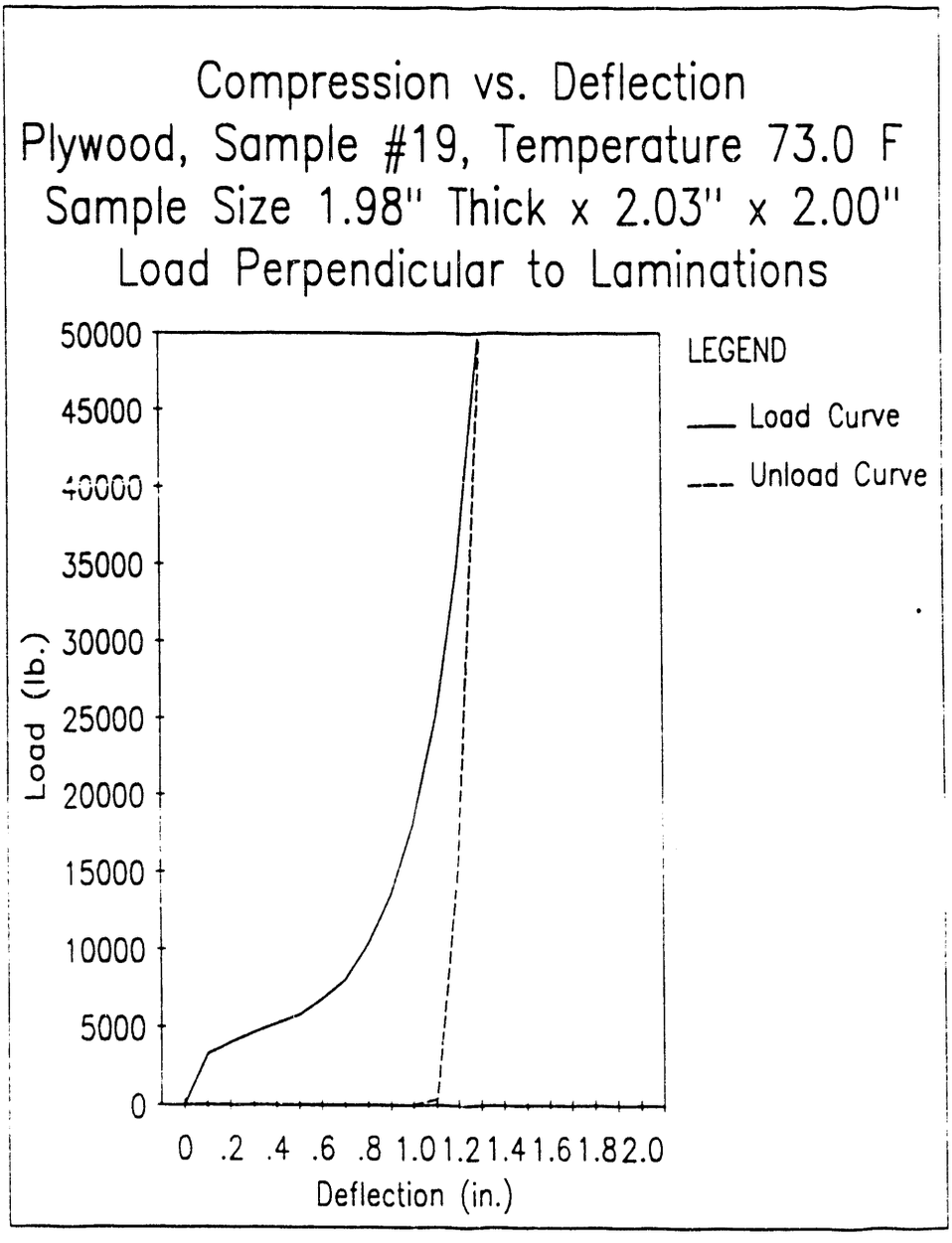

Compression vs. Deflection
Plywood, Sample #1, Temperature -39.3 F
Sample Size 2.00" Thick x 2.02" x 2.00"
Load Perpendicular to Laminations
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

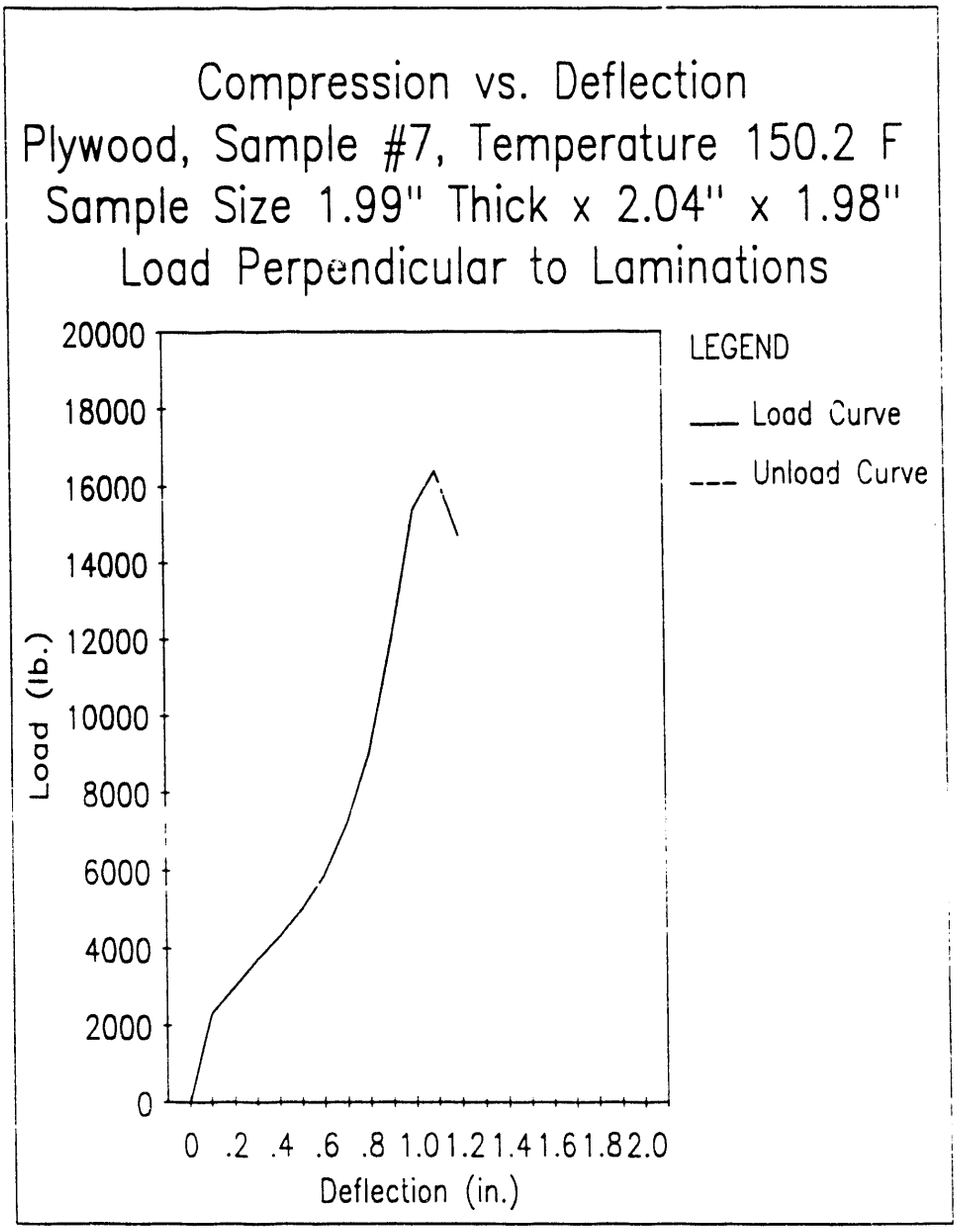

Compression vs. Deflection
Plywood, Sample #2, Temperature -39.7 F
Sample Size 2.00" Thick x 2.03" x 2.00"
Load Perpendicular to Laminations
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

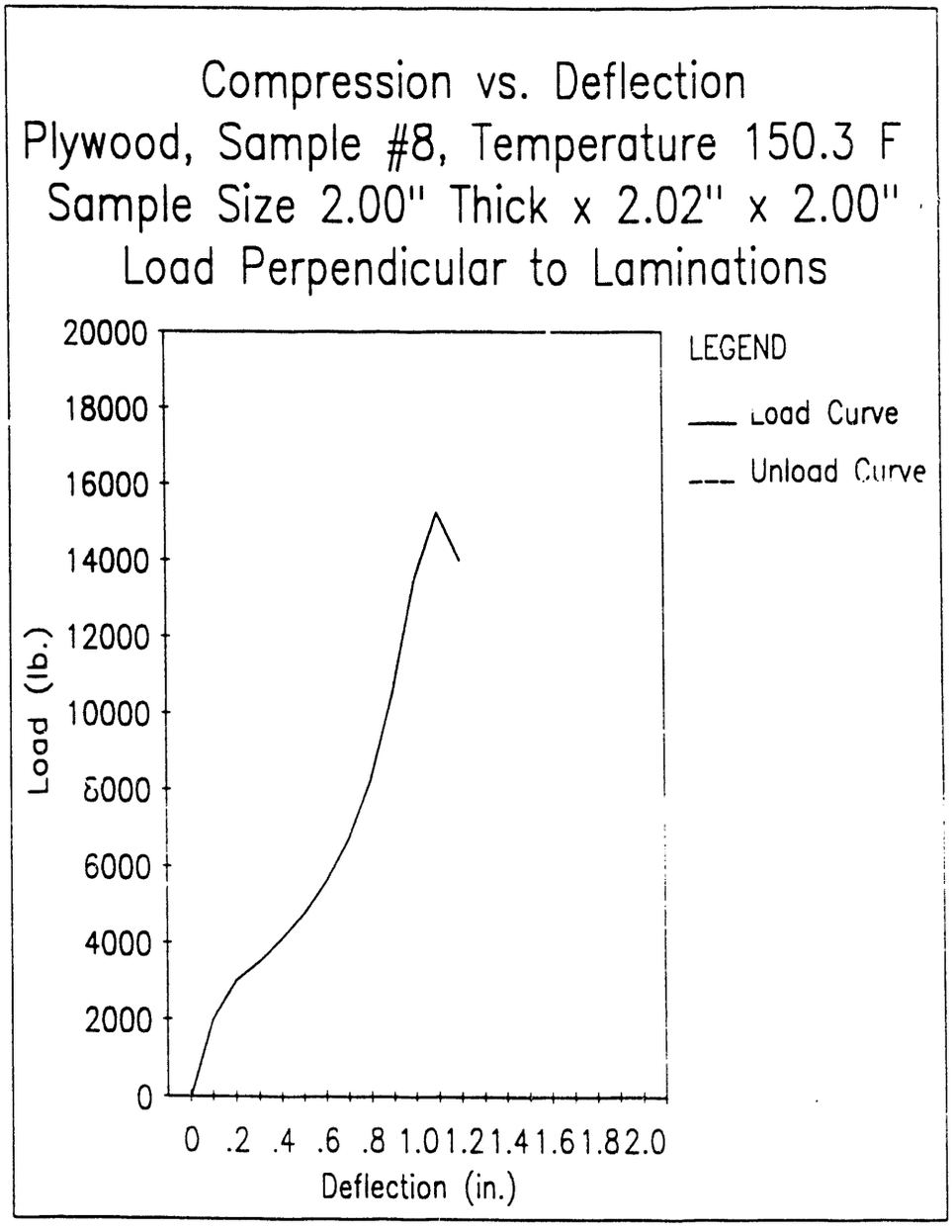

Compression vs. Deflection
Plywood, Sample #3, Temperature -40.8 F
Sample Size 1.99" Thick x 2.03" x 2.00"
Load Perpendicular to Laminations
LEGEND
Load Curve
Unload Curve
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)

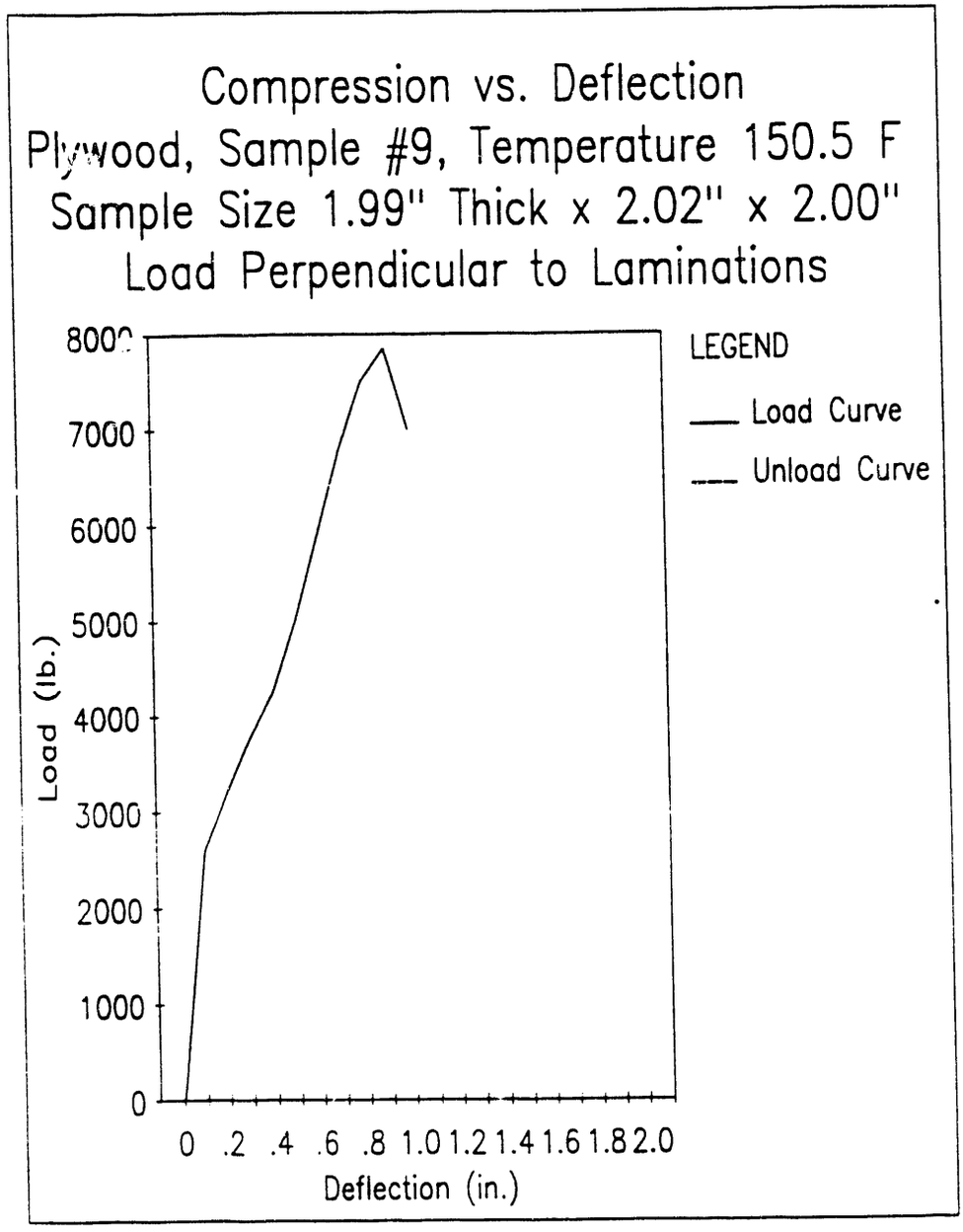

Compression vs. Deflection
Plywood, Sample #5, Temperature 73.4 F
Sample Size 2.00" Thick x 2.03" x 2.00"
Load Perpendicular to Laminations
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

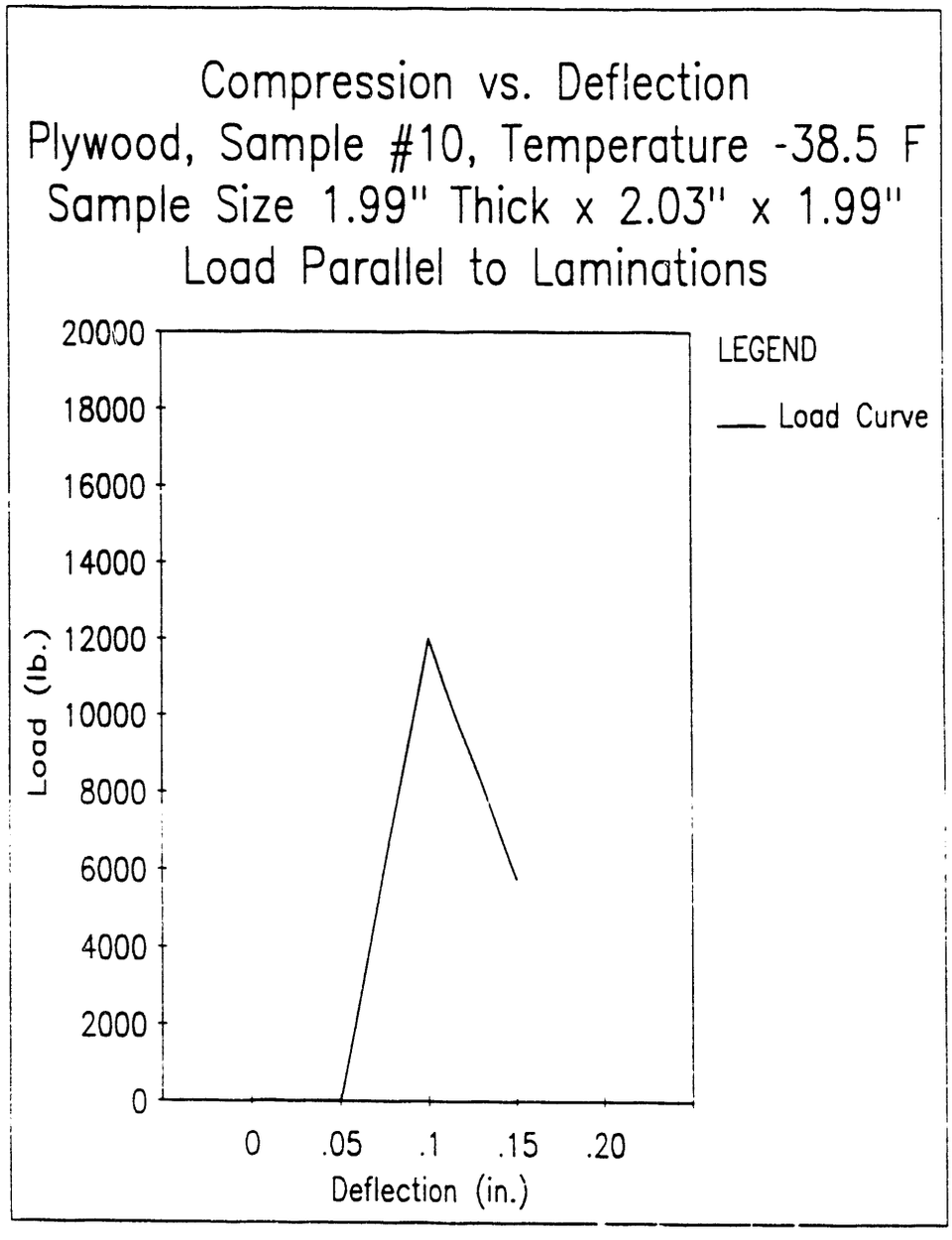

Compression vs. Deflection
Plywood, Sample #6, Temperature 73.4 F
Sample Size 1.99" Thick x 2.03" x 1.99"
Load Perpendicular to Laminations
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

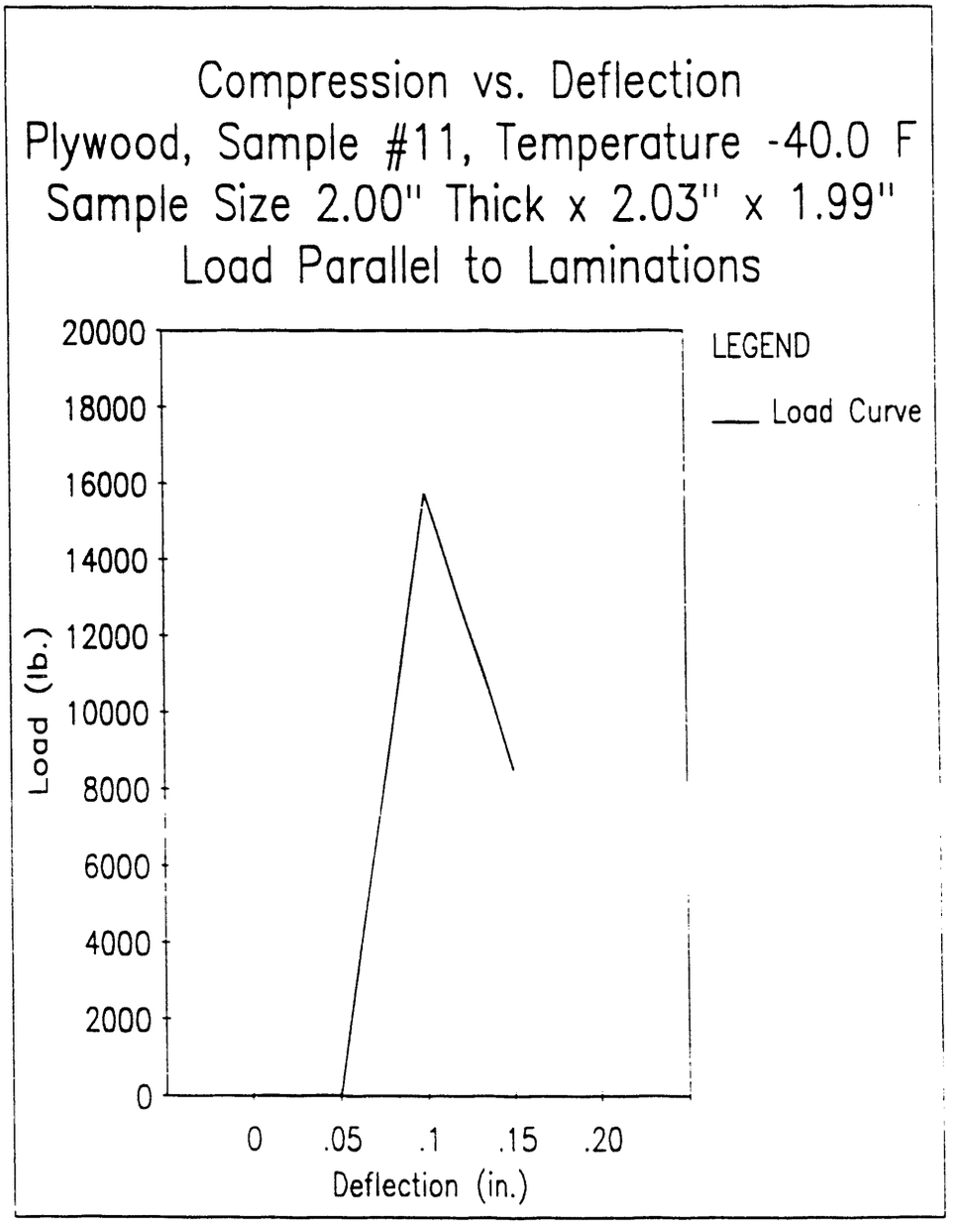

Compression vs. Deflection
Plywood, Sample #19, Temperature 73.0 F
Sample Size 1.98" Thick x 2.03" x 2.00"
Load Perpendicular to Laminations
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

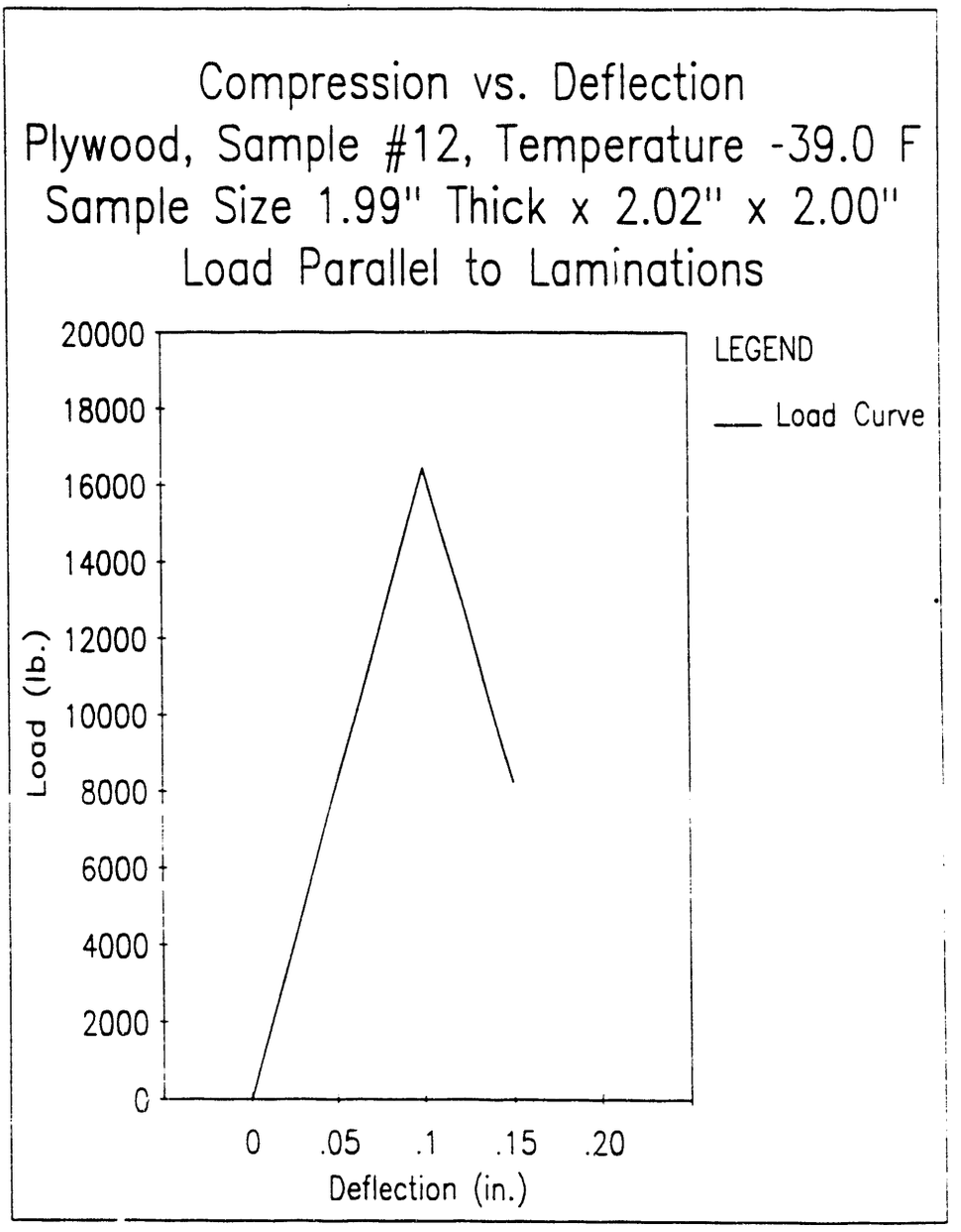

Compression vs. Deflection
Plywood, Sample #7, Temperature 150.2 F
Sample Size 1.99" Thick x 2.04" x 1.98"
Load Perpendicular to Laminations
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

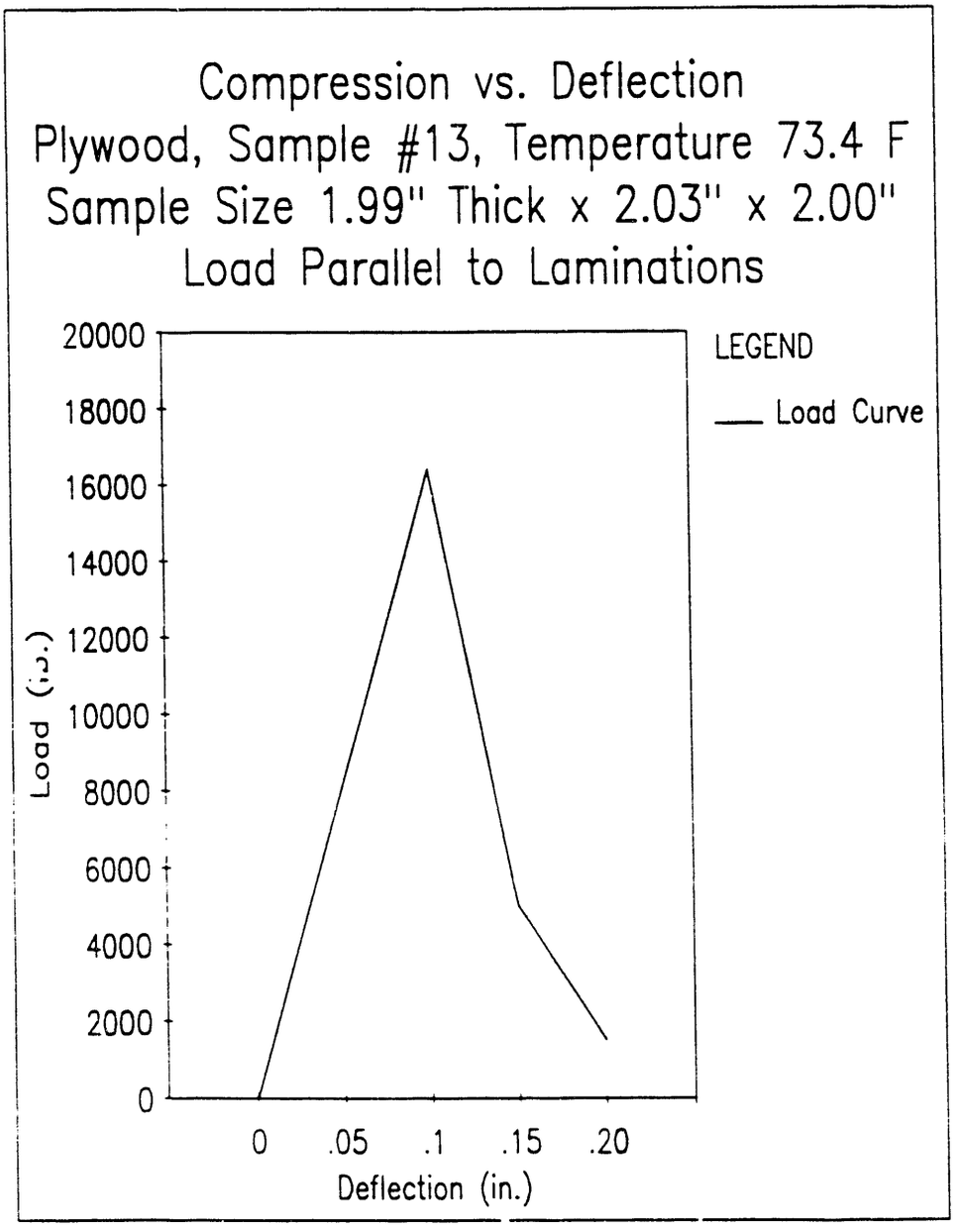

Compression vs. Deflection
Plywood, Sample #8, Temperature 150.3 F
Sample Size 2.00" Thick x 2.02" x 2.00"
Load Perpendicular to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

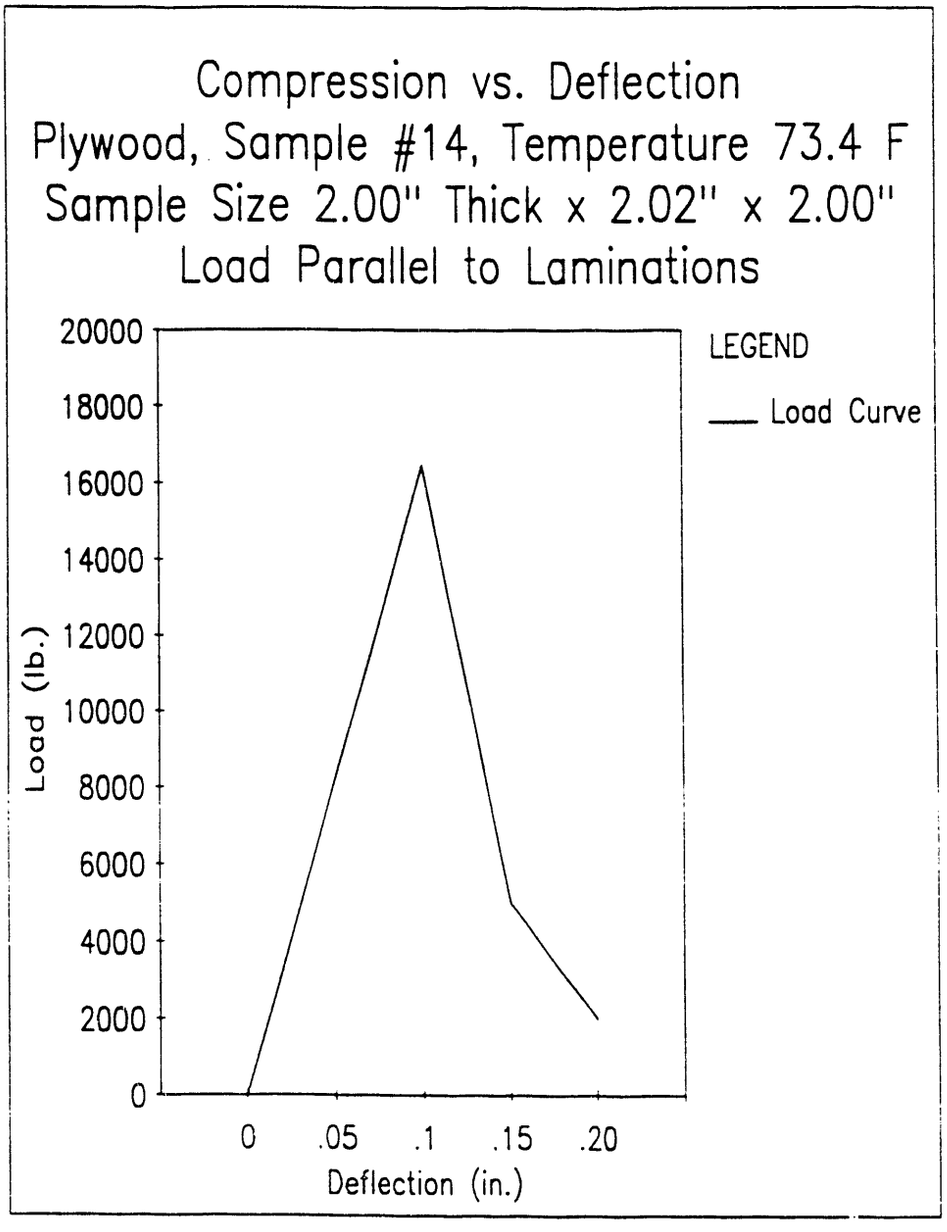

Compression vs. Deflection
Plywood, Sample #9, Temperature 150.5 F
Sample Size 1.99" Thick x 2.02" x 2.00"
Load Perpendicular to Laminations
LEGEND
Load Curve
Unload Curve
Load (lb.)
8000
7000
6000
5000
4000
3000
2000
1000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)

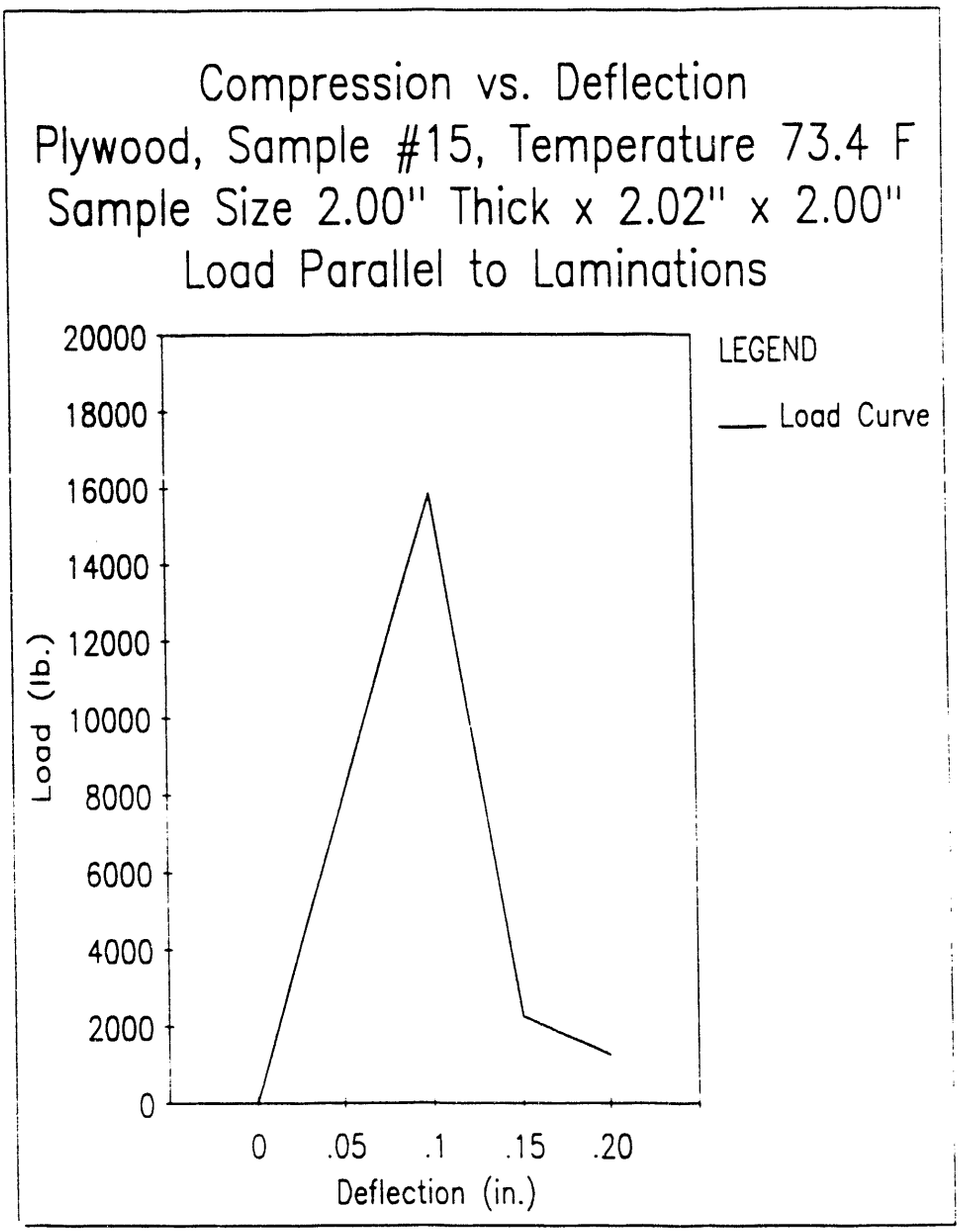

Compression vs. Deflection
Plywood, Sample #10, Temperature -38.5 F
Sample Size 1.99" Thick x 2.03" x 1.99"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0
.05
.1
.15
.20
Deflection (in.)
LEGEND
Load Curve

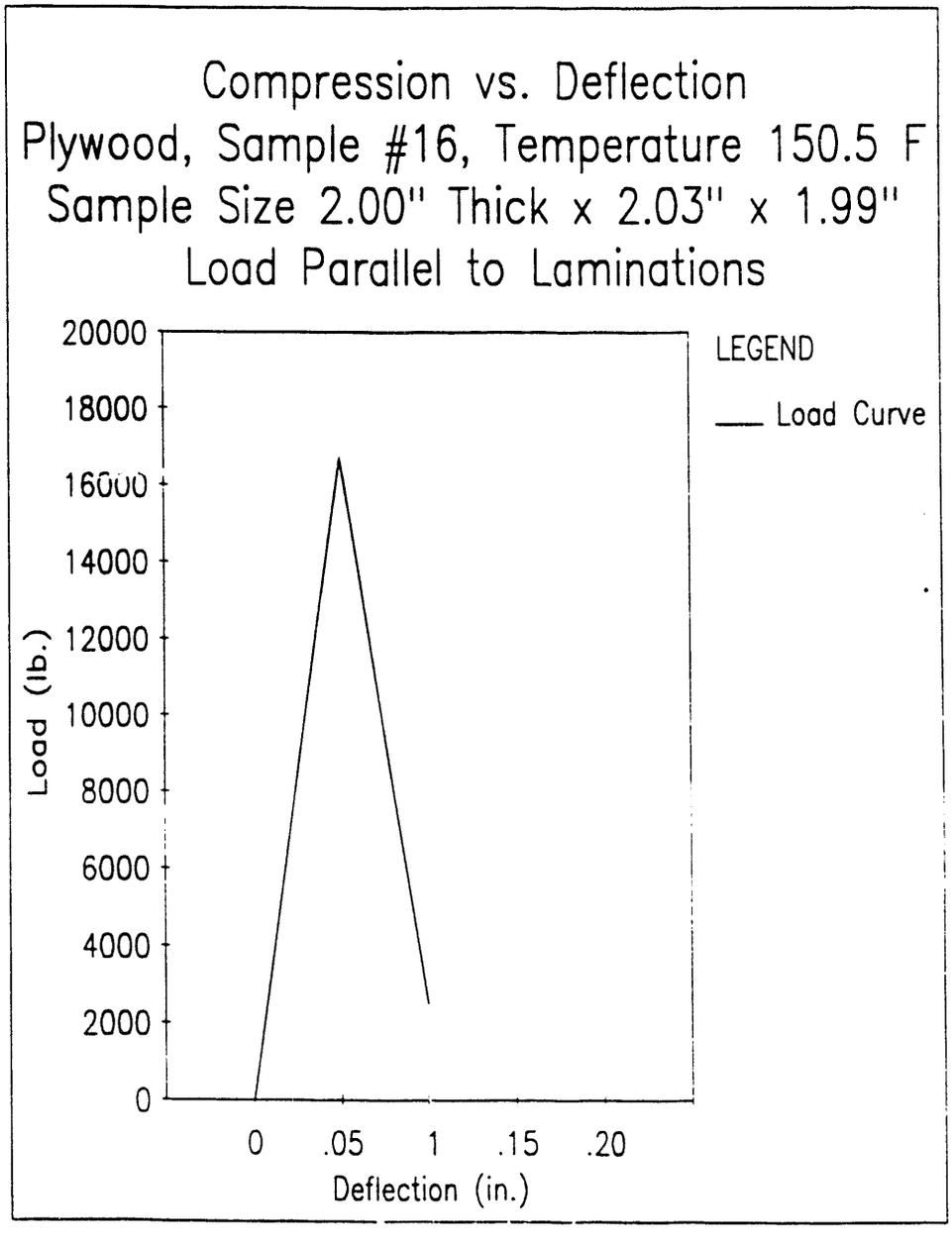

Compression vs. Deflection
Plywood, Sample #11, Temperature -40.0 F
Sample Size 2.00" Thick x 2.03" x 1.99"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0
.05
.1
.15
.20
Deflection (in.)
LEGEND
Load Curve

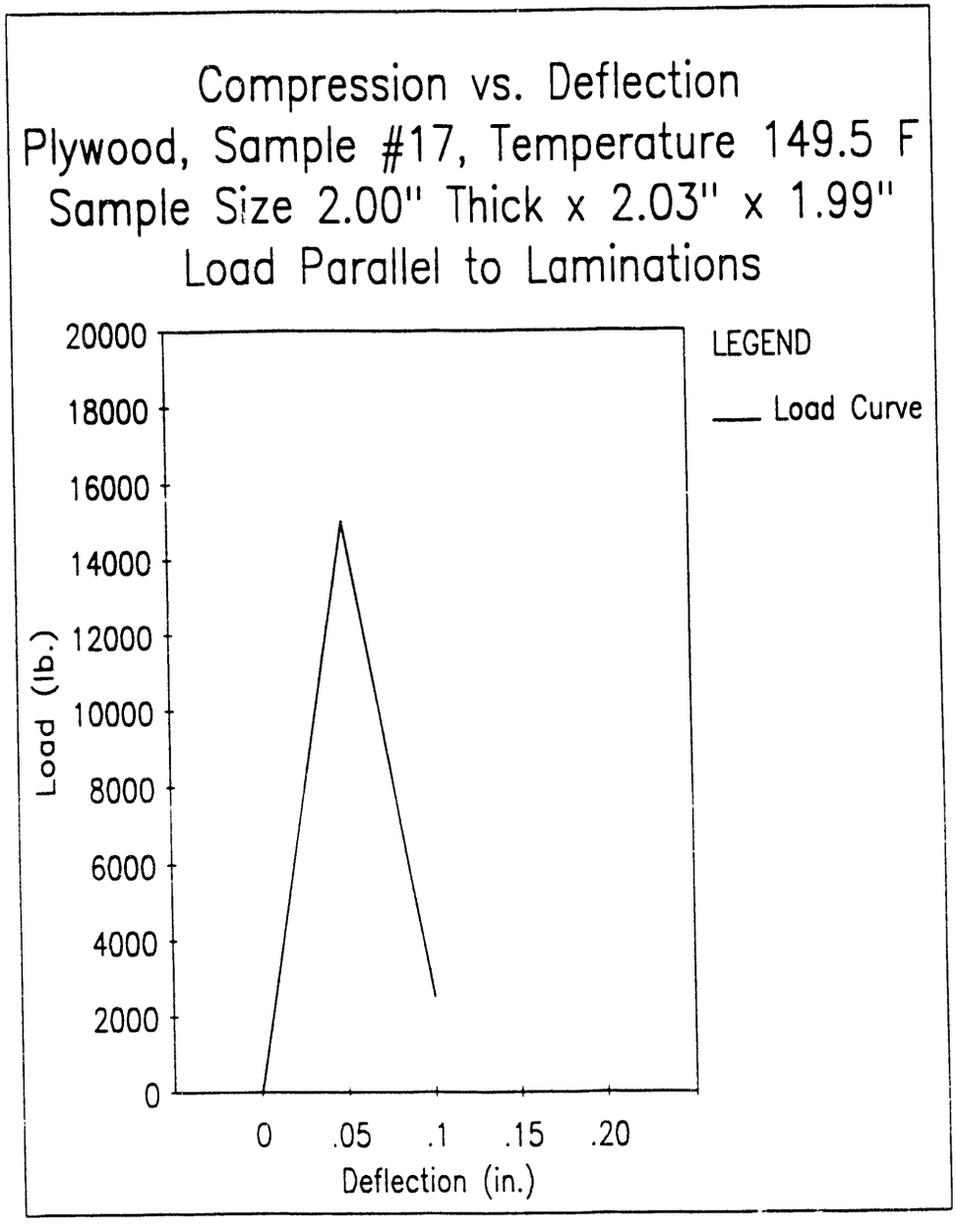

Compression vs. Deflection
Plywood, Sample #12, Temperature -39.0 F
Sample Size 1.99" Thick x 2.02" x 2.00"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0
.05
.1
.15
.20
Deflection (in.)
LEGEND
Load Curve

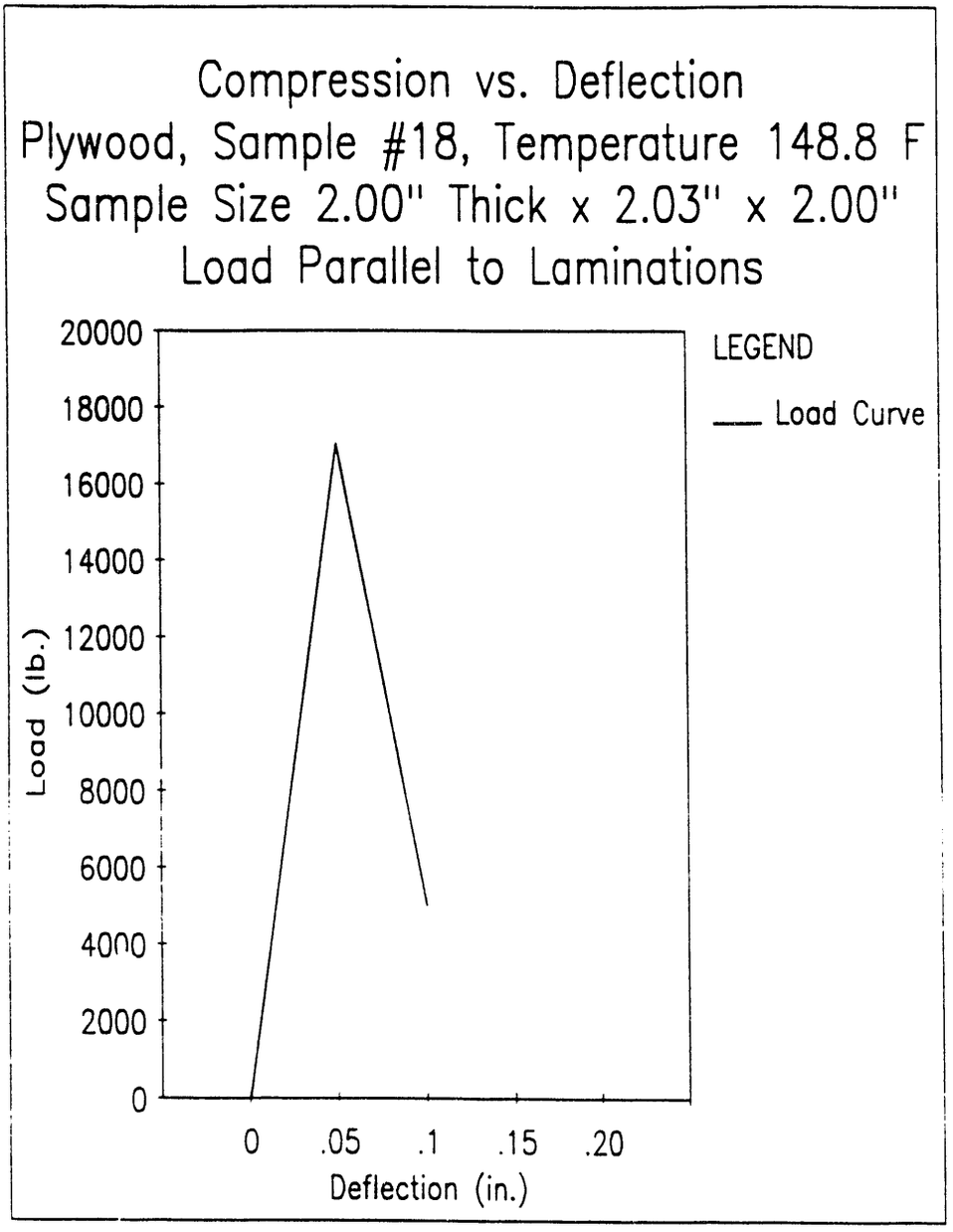

Compression vs. Deflection
Plywood, Sample #13, Temperature 73.4 F
Sample Size 1.99" Thick x 2.03" x 2.00"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0
.05
.1
.15
.20
Deflection (in.)
LEGEND
Load Curve

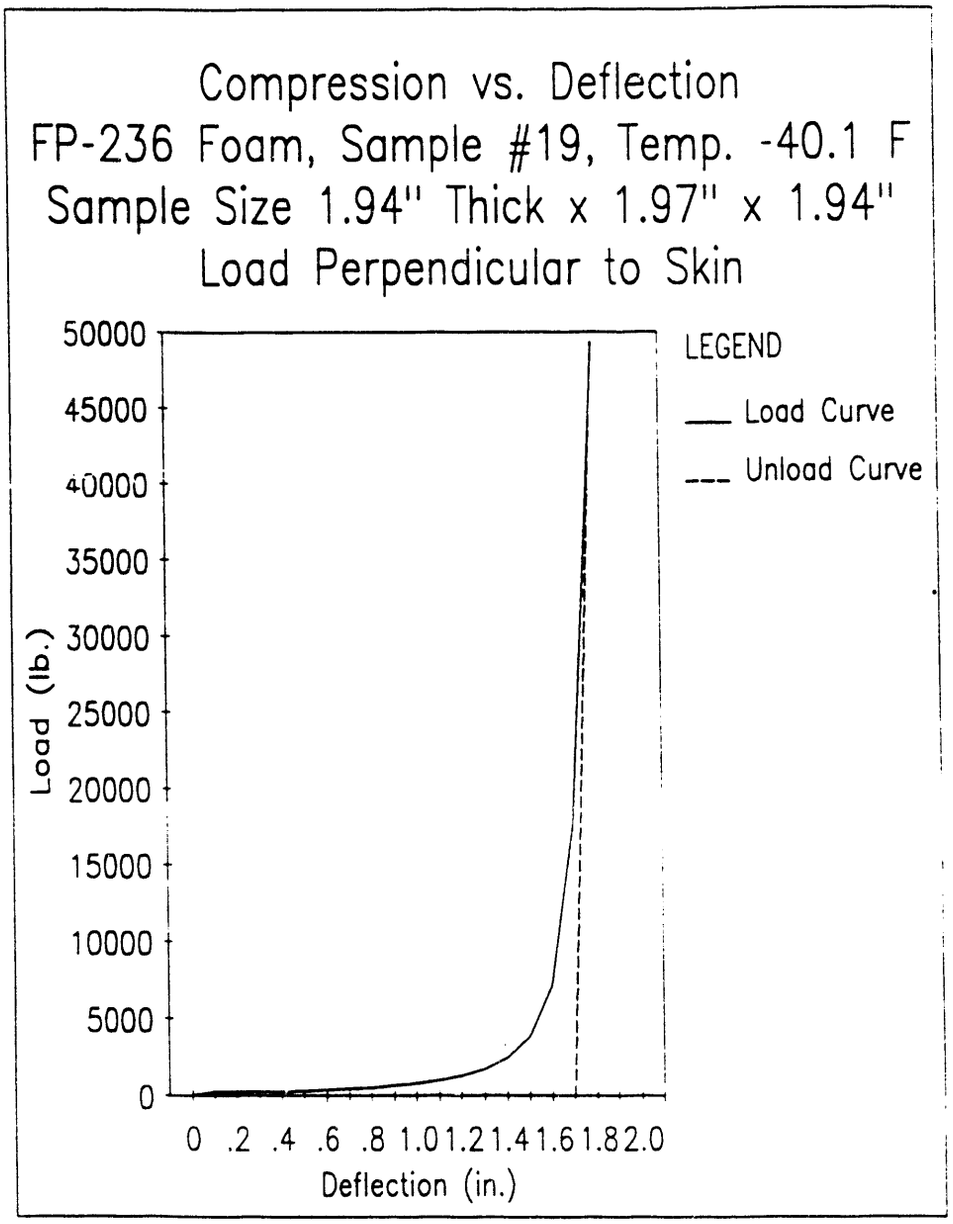

Compression vs. Deflection
Plywood, Sample #14, Temperature 73.4 F
Sample Size 2.00" Thick x 2.02" x 2.00"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0
.05
.1
.15
.20
Deflection (in.)
LEGEND
Load Curve

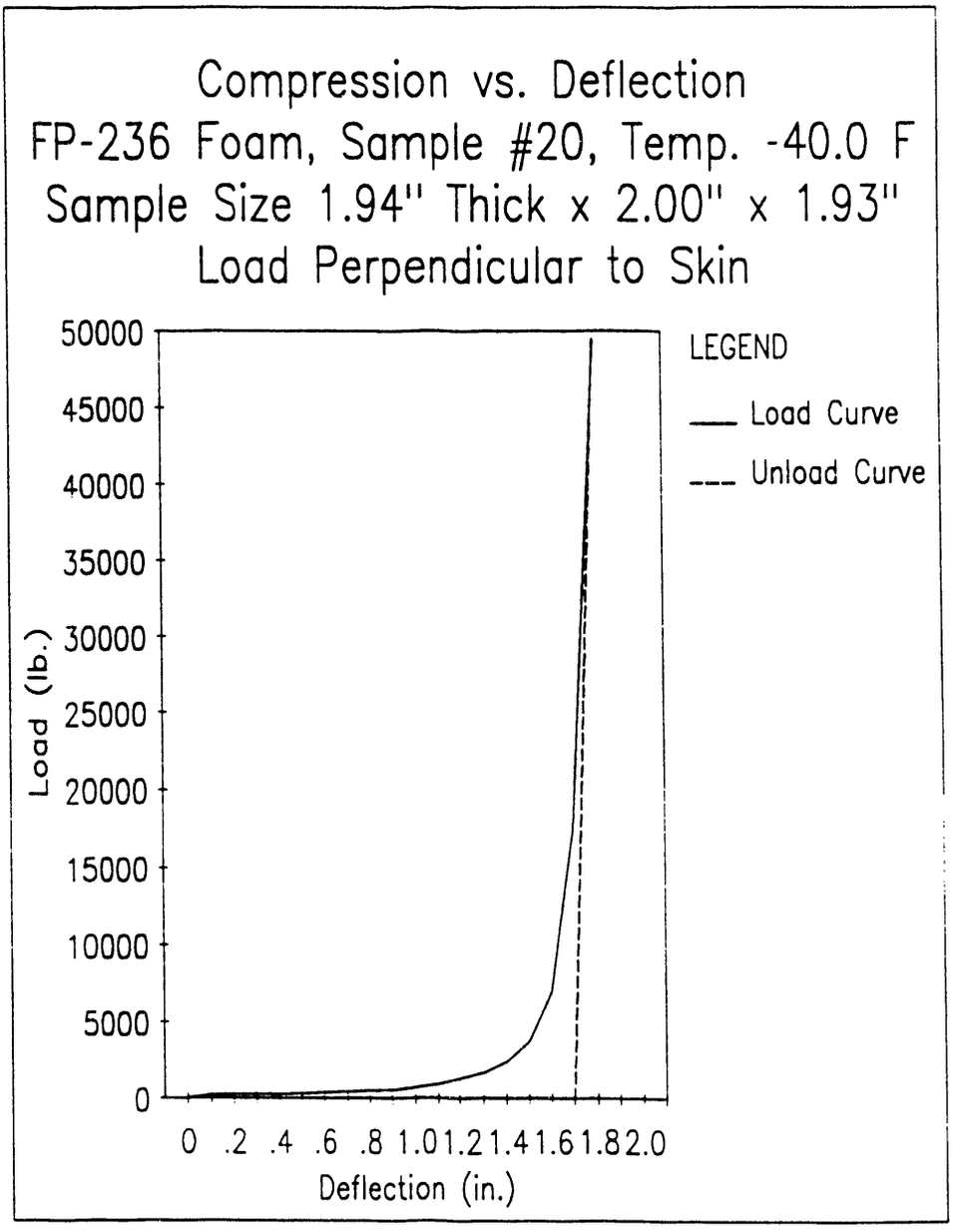

Compression vs. Deflection
Plywood, Sample #15, Temperature 73.4 F
Sample Size 2.00" Thick x 2.02" x 2.00"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0
.05
.1
.15
.20
Deflection (in.)
LEGEND
Load Curve

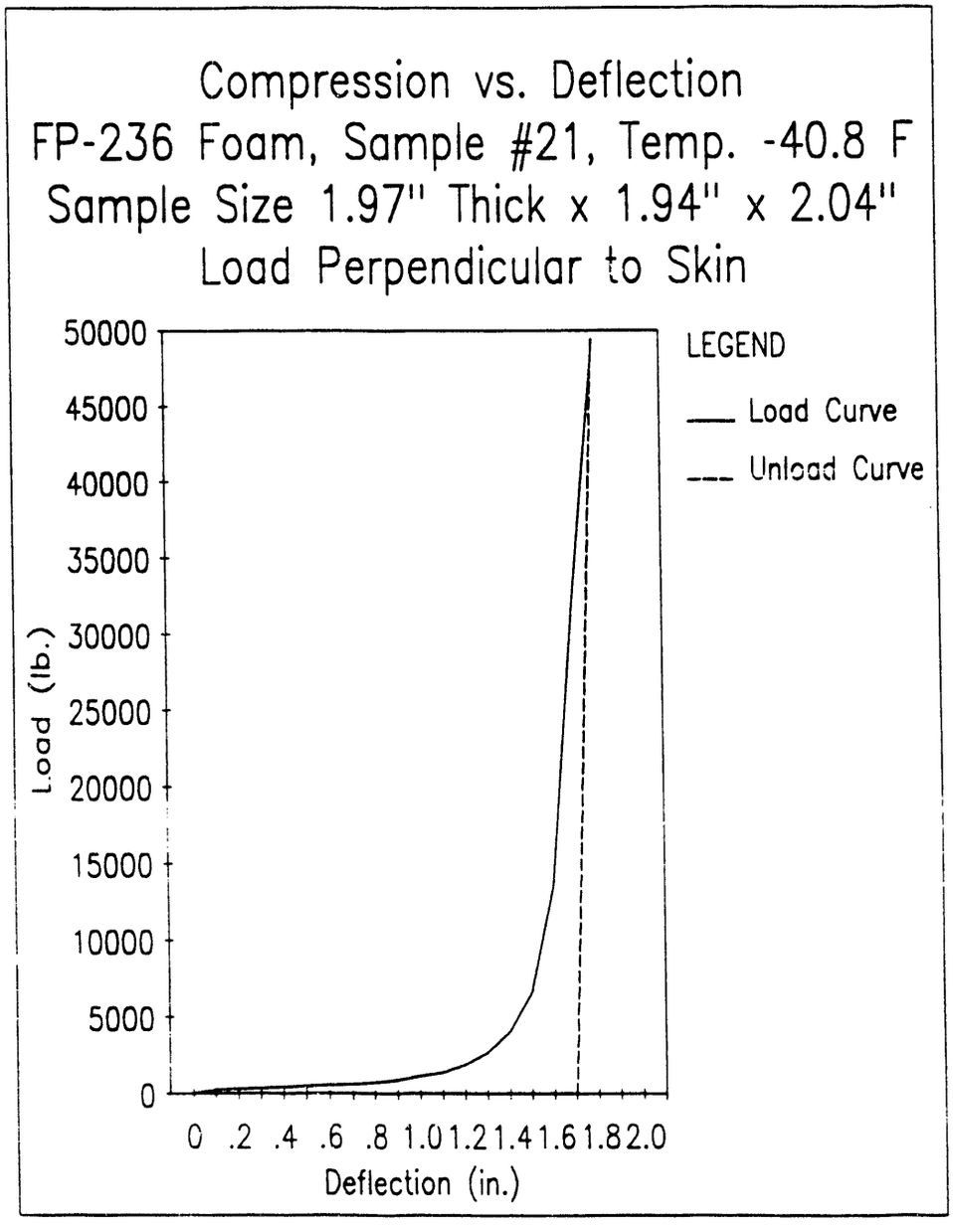

Compression vs. Deflection
Plywood, Sample #16, Temperature 150.5 F
Sample Size 2.00" Thick x 2.03" x 1.99"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0
.05
1
.15
.20
Deflection (in.)
LEGEND
Load Curve

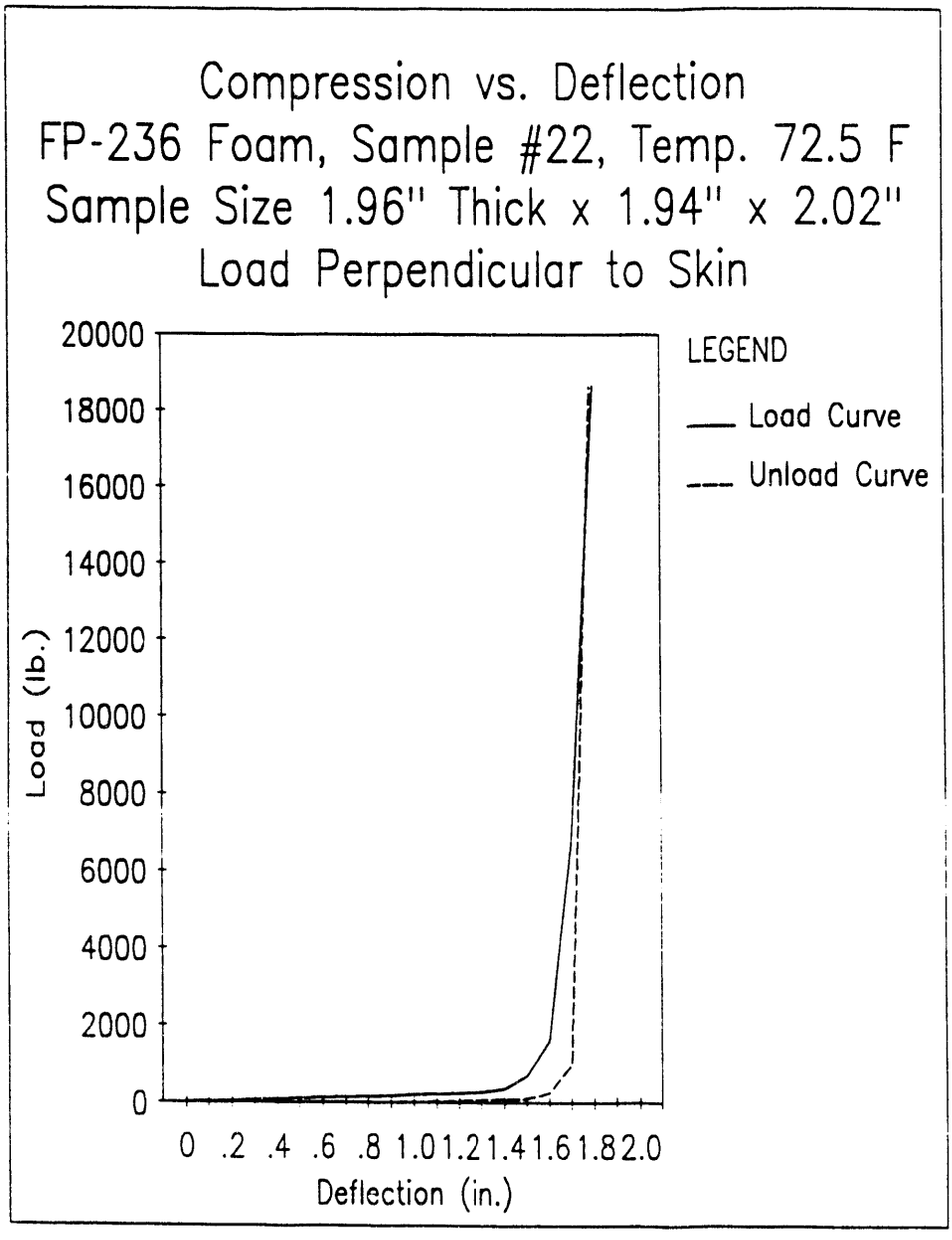

Compression vs. Deflection
Plywood, Sample #17, Temperature 149.5 F
Sample Size 2.00" Thick x 2.03" x 1.99"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0
.05
.1
.15
.20
Deflection (in.)
LEGEND
Load Curve

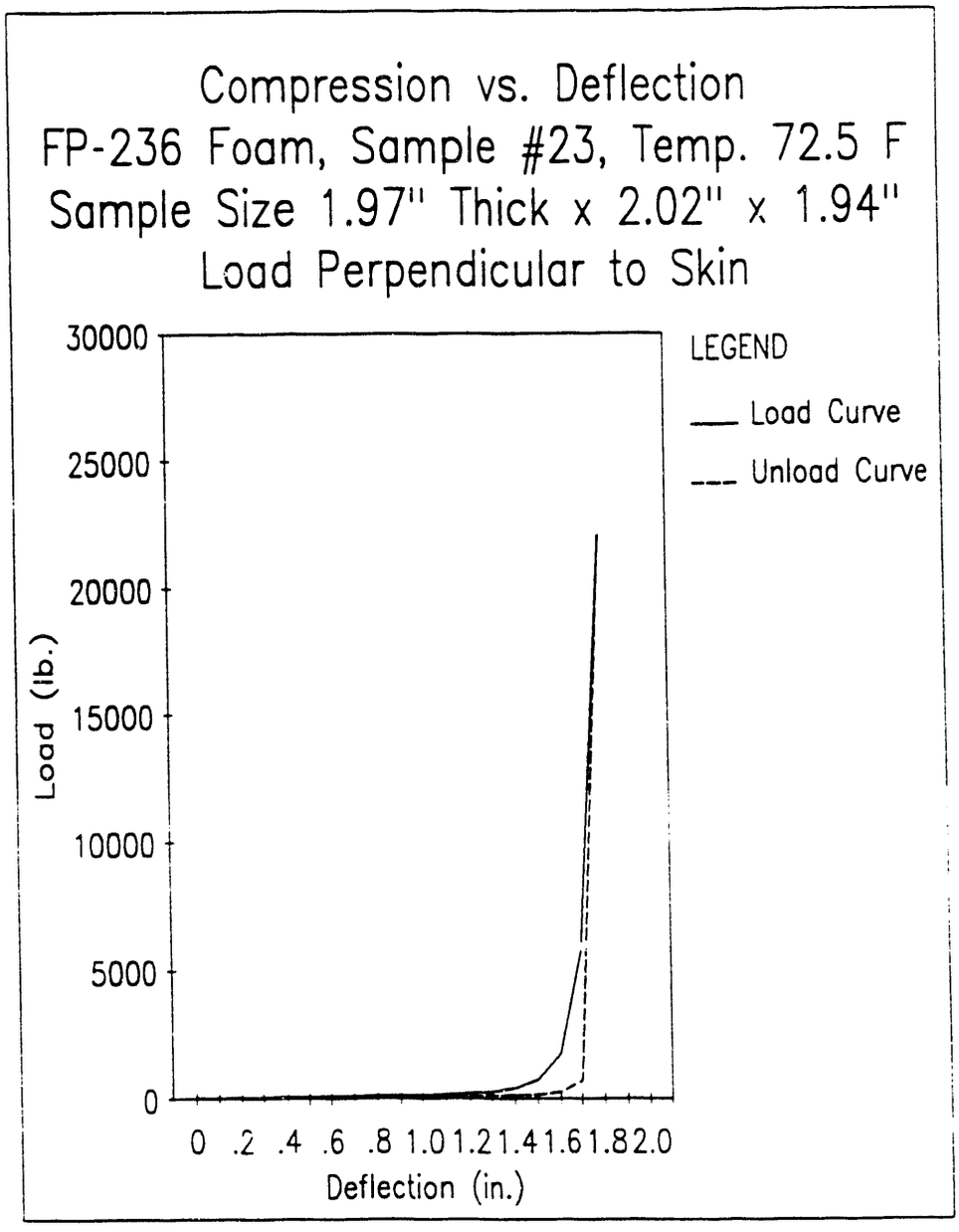

Compression vs. Deflection
Plywood, Sample #18, Temperature 148.8 F
Sample Size 2.00" Thick x 2.03" x 2.00"
Load Parallel to Laminations
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0
.05
.1
.15
.20
Deflection (in.)
LEGEND
Load Curve

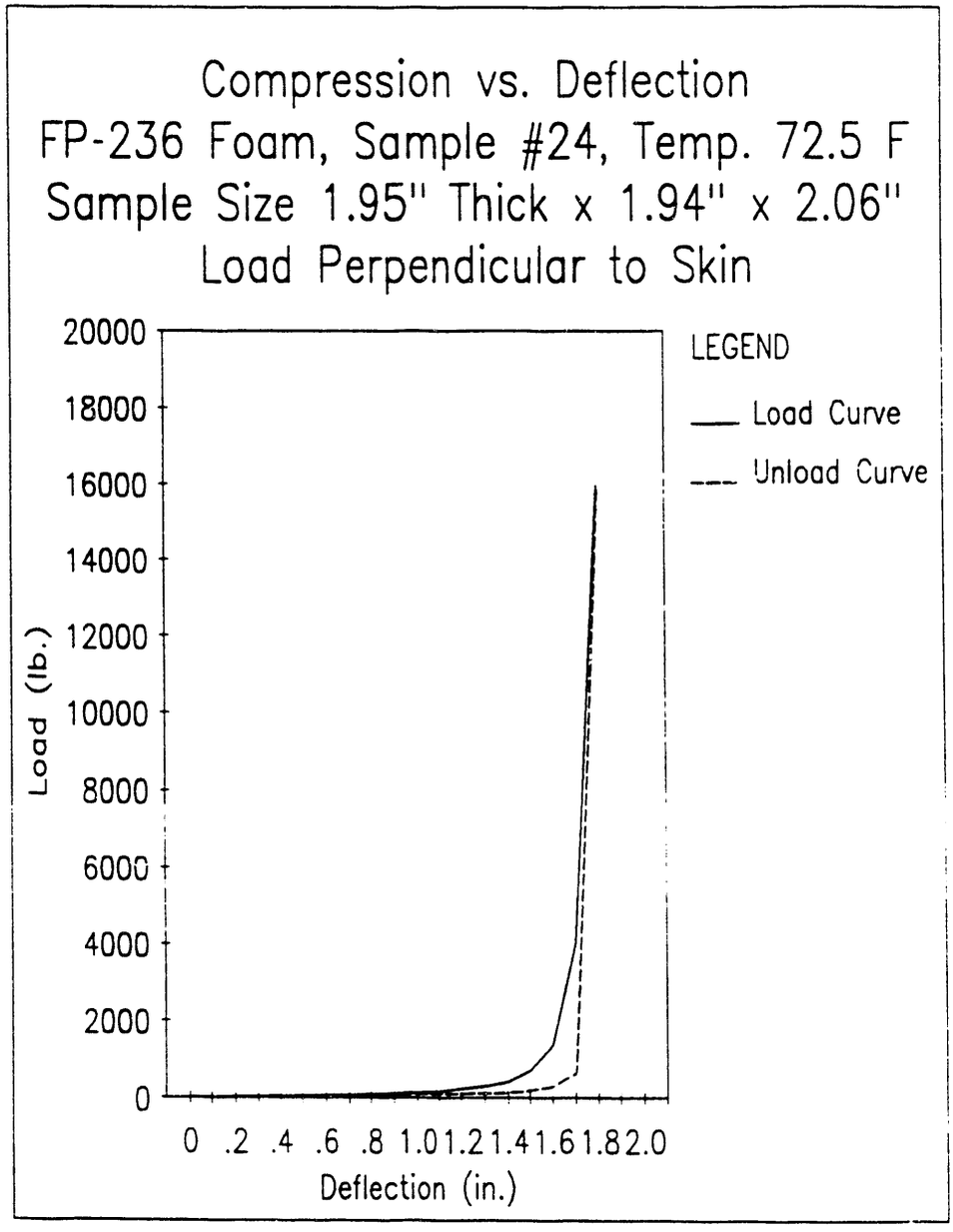

Compression vs. Deflection
FP-236 Foam, Sample #19, Temp. -40.1 F
Sample Size 1.94" Thick x 1.97" x 1.94"
Load Perpendicular to Skin
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

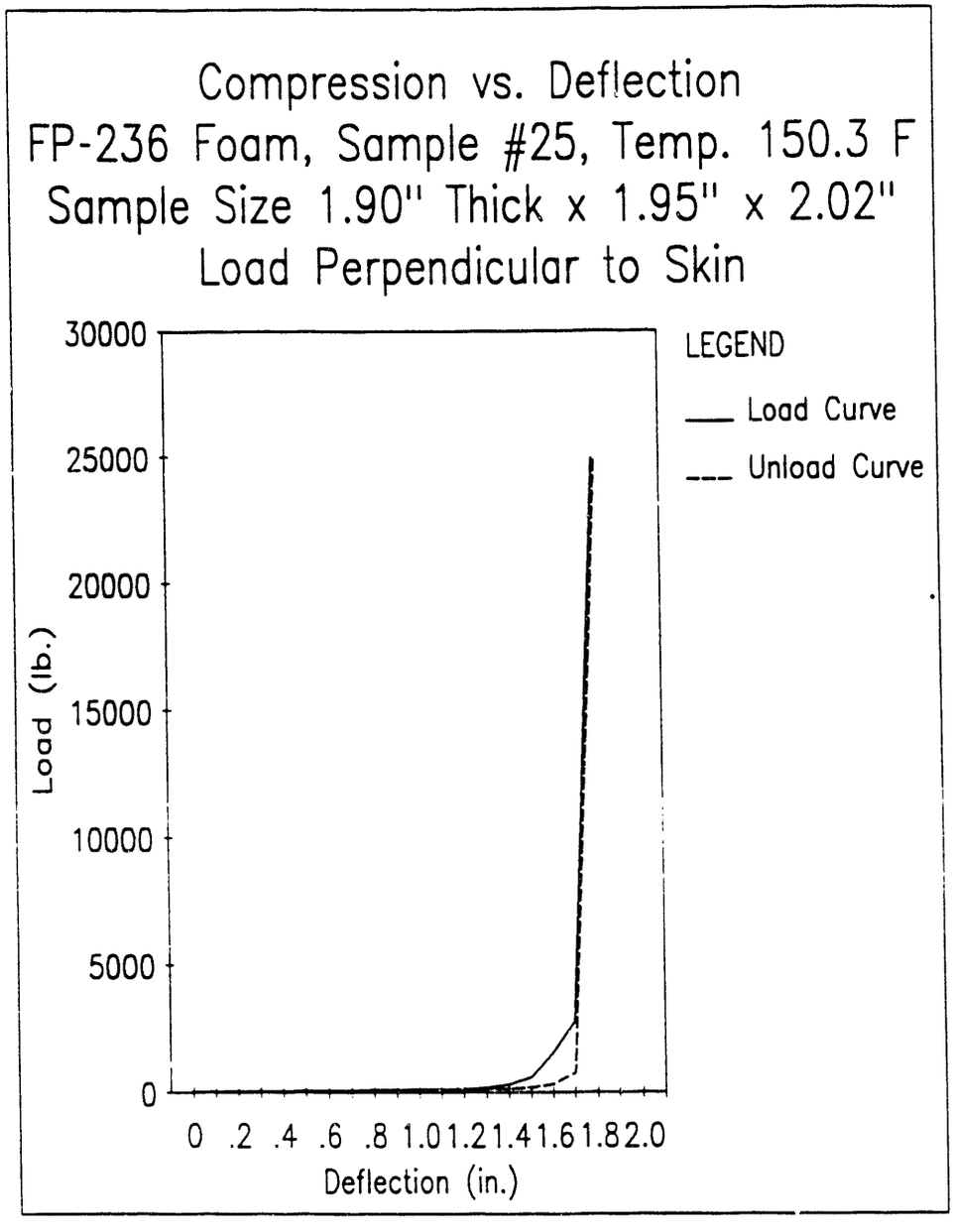

Compression vs. Deflection
FP-236 Foam, Sample #20, Temp. -40.0 F
Sample Size 1.94" Thick x 2.00" x 1.93"
Load Perpendicular to Skin
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

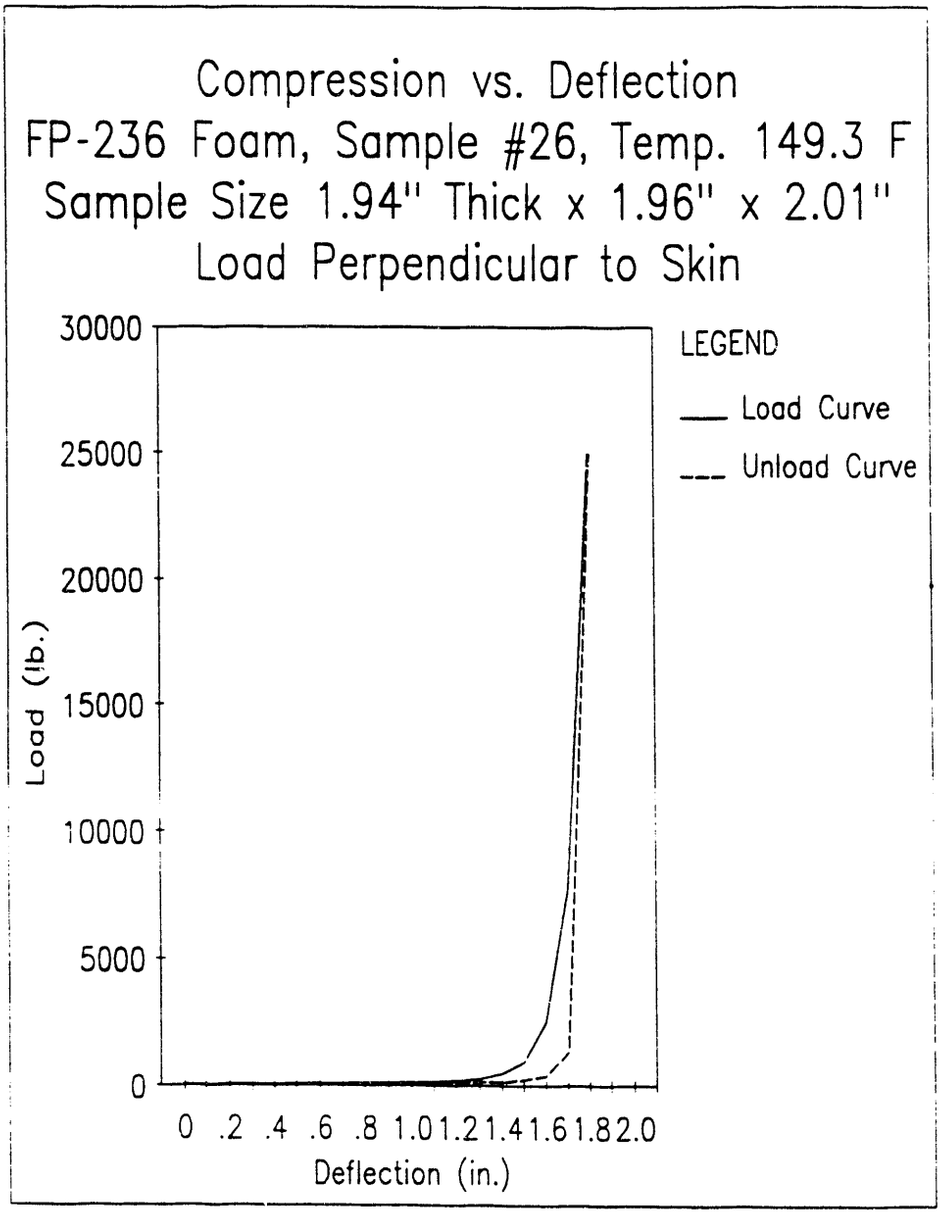

Compression vs. Deflection
FP-236 Foam, Sample #21, Temp. -40.8 F
Sample Size 1.97" Thick x 1.94" x 2.04"
Load Perpendicular to Skin
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

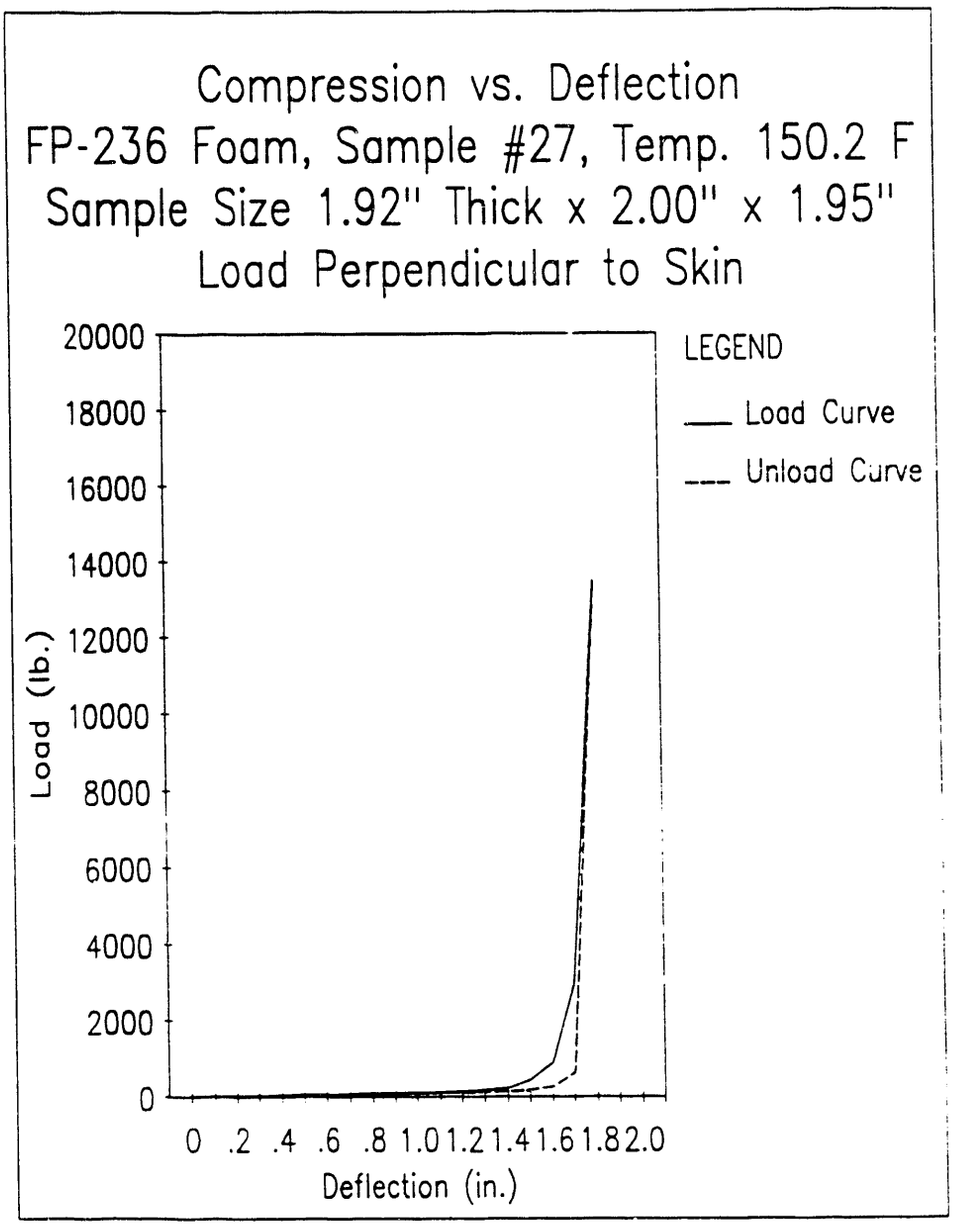

Compression vs. Deflection
FP-236 Foam, Sample #22, Temp. 72.5 F
Sample Size 1.96" Thick x 1.94" x 2.02"
Load Perpendicular to Skin
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

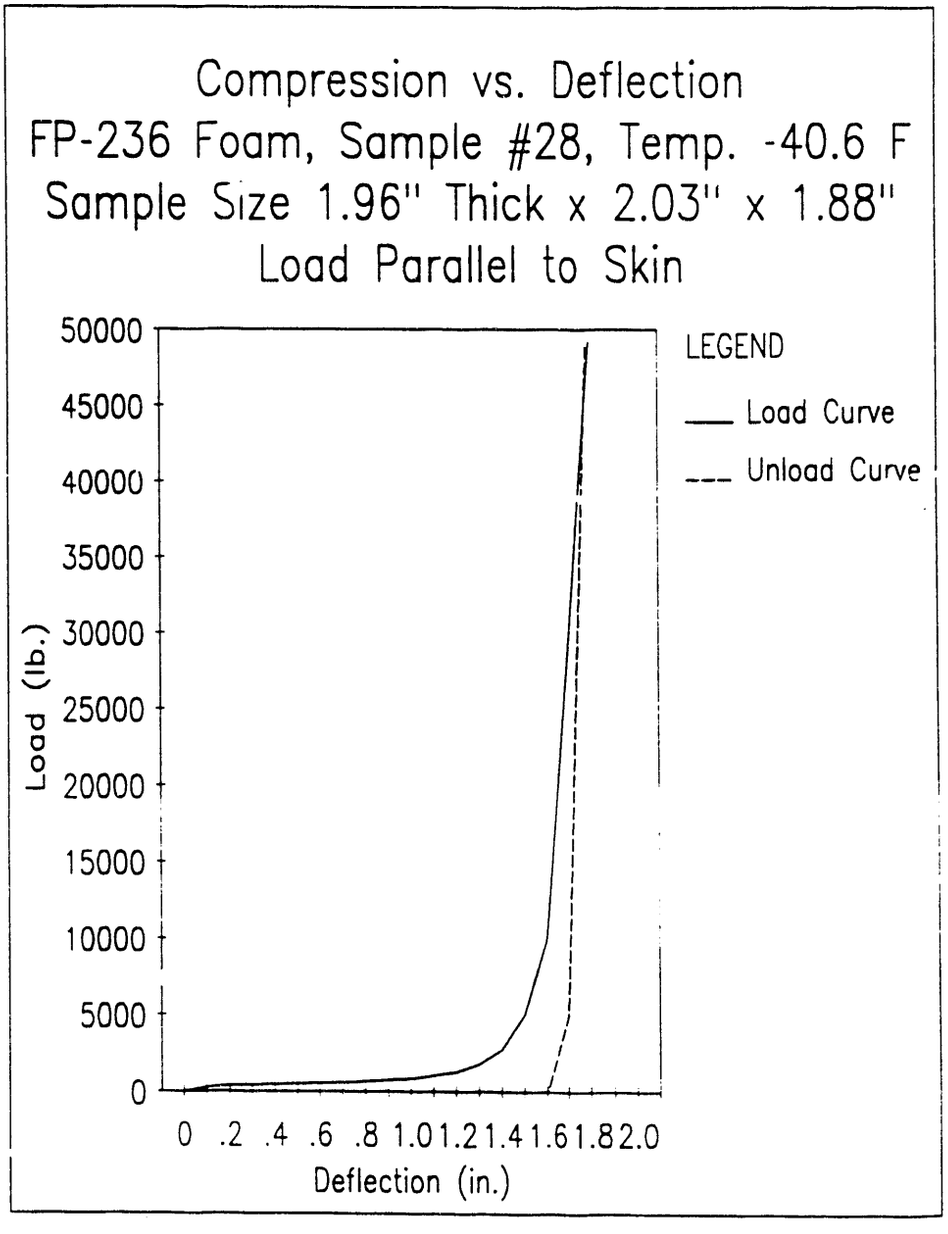

Compression vs. Deflection
FP-236 Foam, Sample #23, Temp. 72.5 F
Sample Size 1.97" Thick x 2.02" x 1.94"
Load Perpendicular to Skin
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

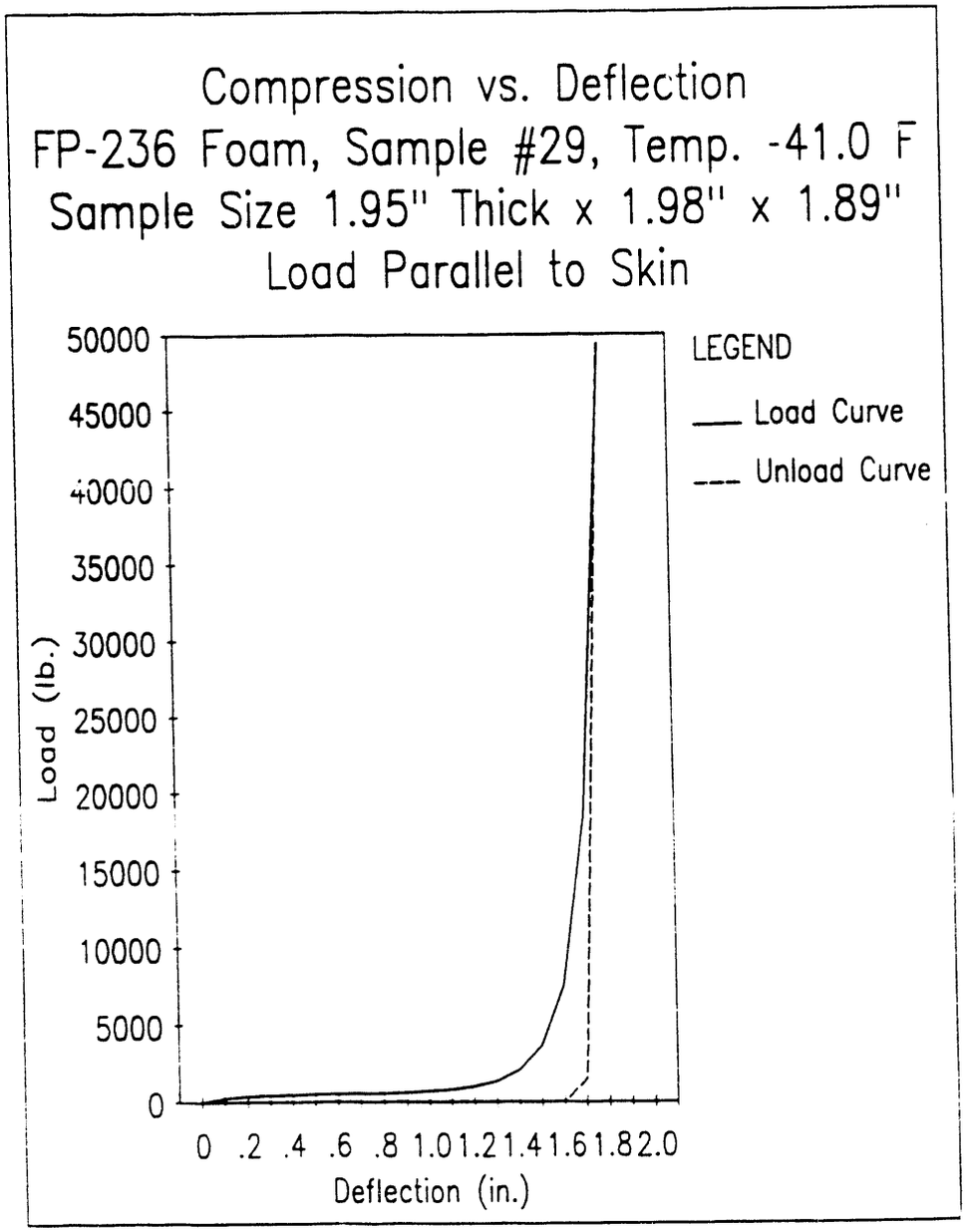

Compression vs. Deflection
FP-236 Foam, Sample #24, Temp. 72.5 F
Sample Size 1.95" Thick x 1.94" x 2.06"
Load Perpendicular to Skin
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

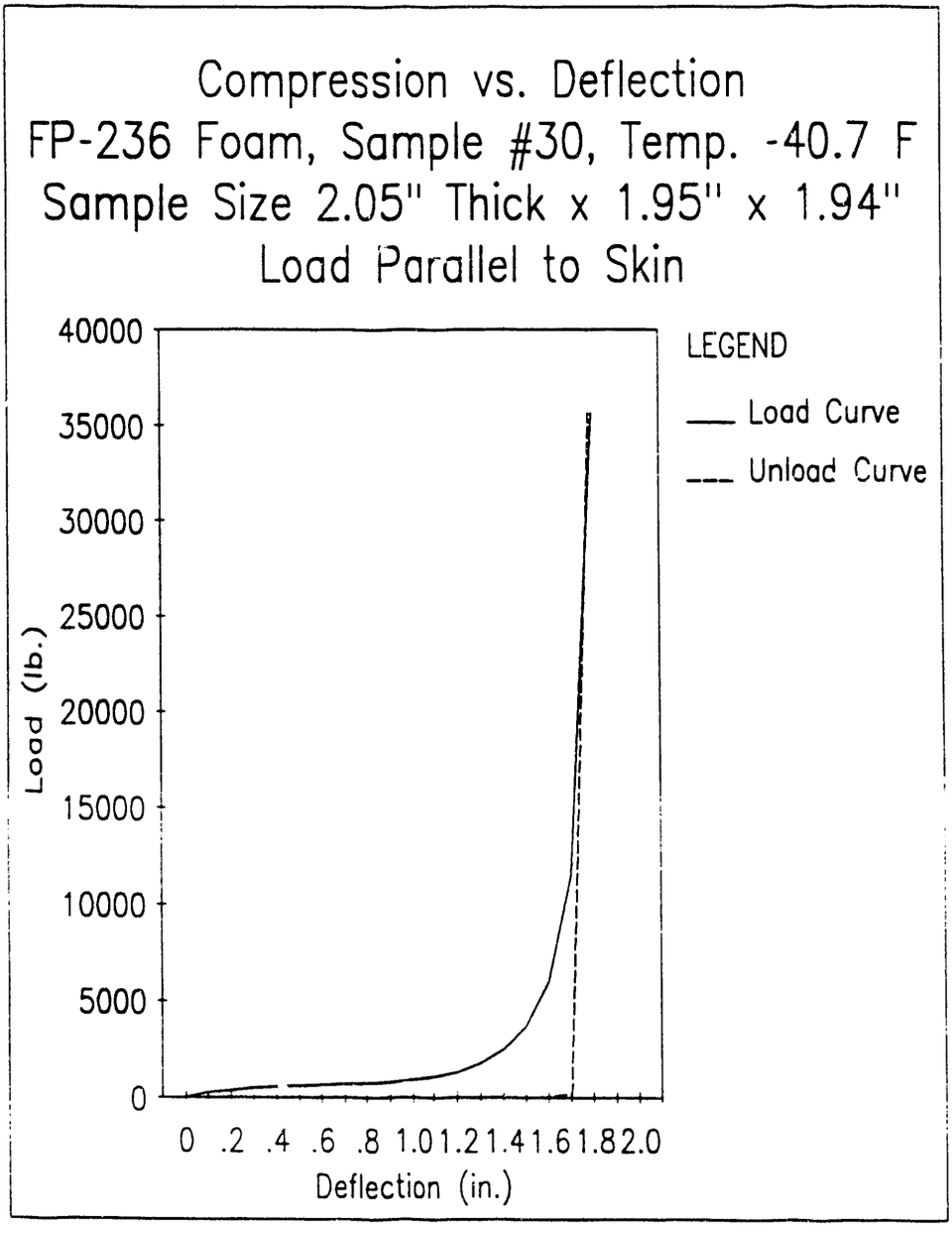

Compression vs. Deflection
FP-236 Foam, Sample #25, Temp. 150.3 F
Sample Size 1.90" Thick x 1.95" x 2.02"
Load Perpendicular to Skin
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

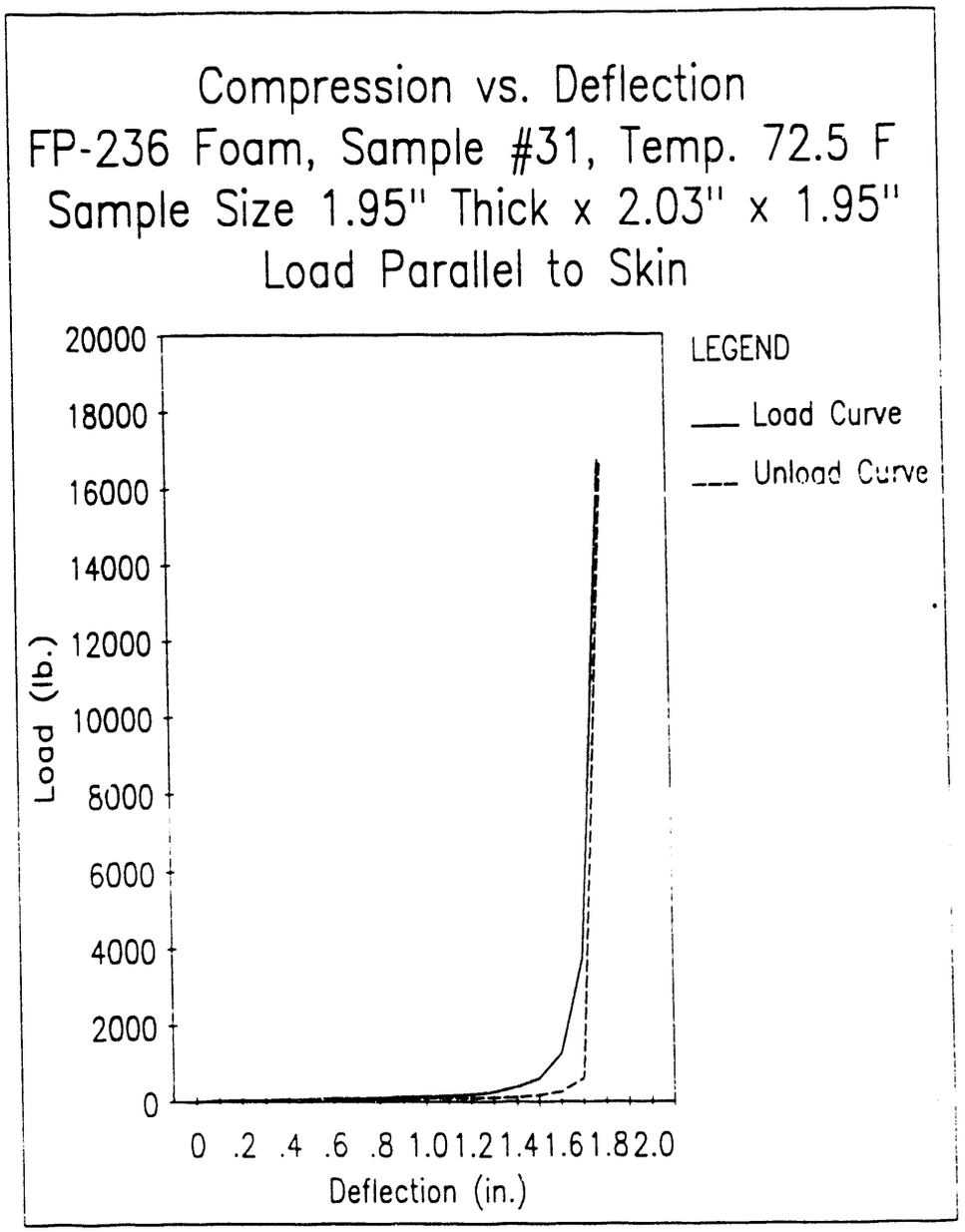

Compression vs. Deflection
FP-236 Foam, Sample #26, Temp. 149.3 F
Sample Size 1.94" Thick x 1.96" x 2.01"
Load Perpendicular to Skin
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

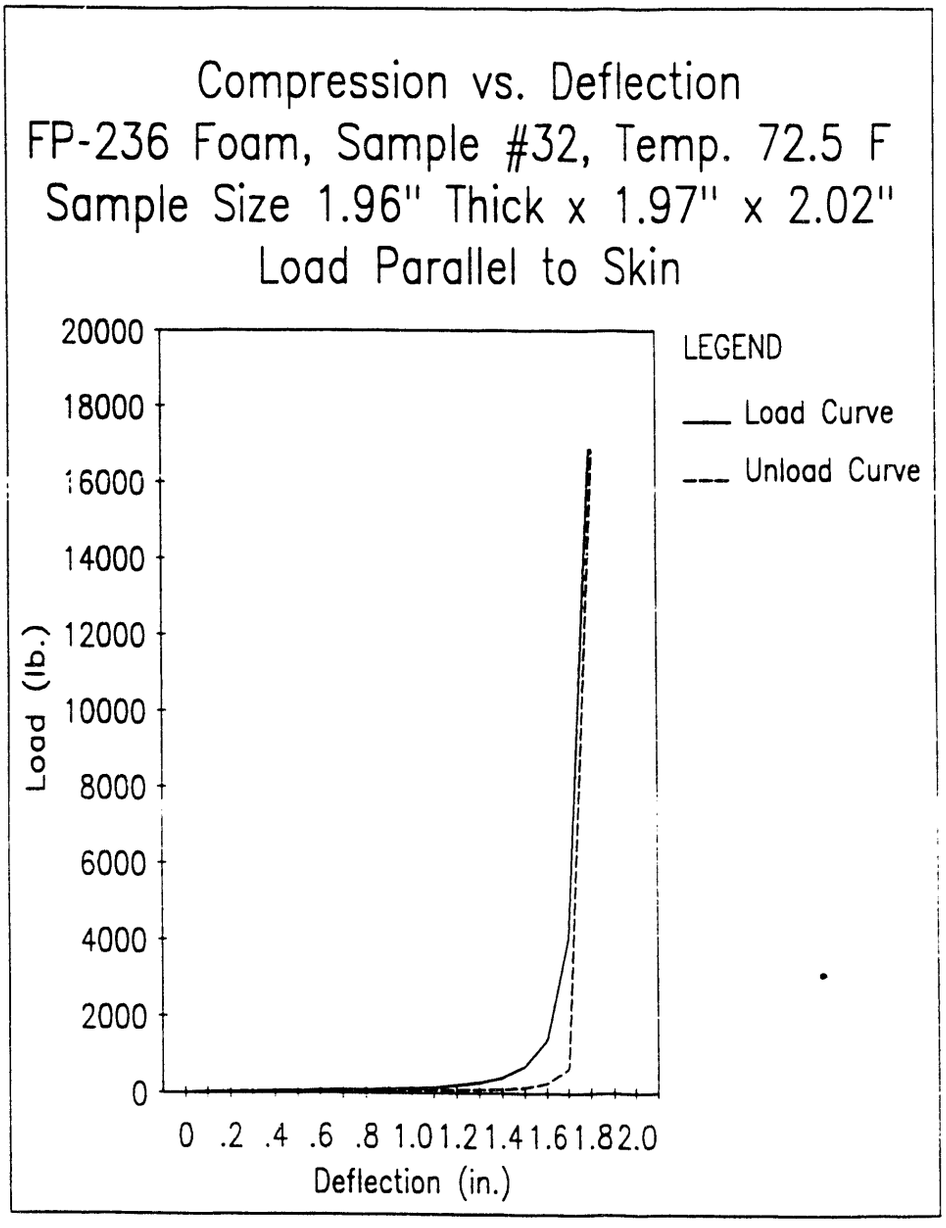

Compression vs. Deflection
FP-236 Foam, Sample #27, Temp. 150.2 F
Sample Size 1.92" Thick x 2.00" x 1.95"
Load Perpendicular to Skin
LEGEND
Load Curve
Unload Curve
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)

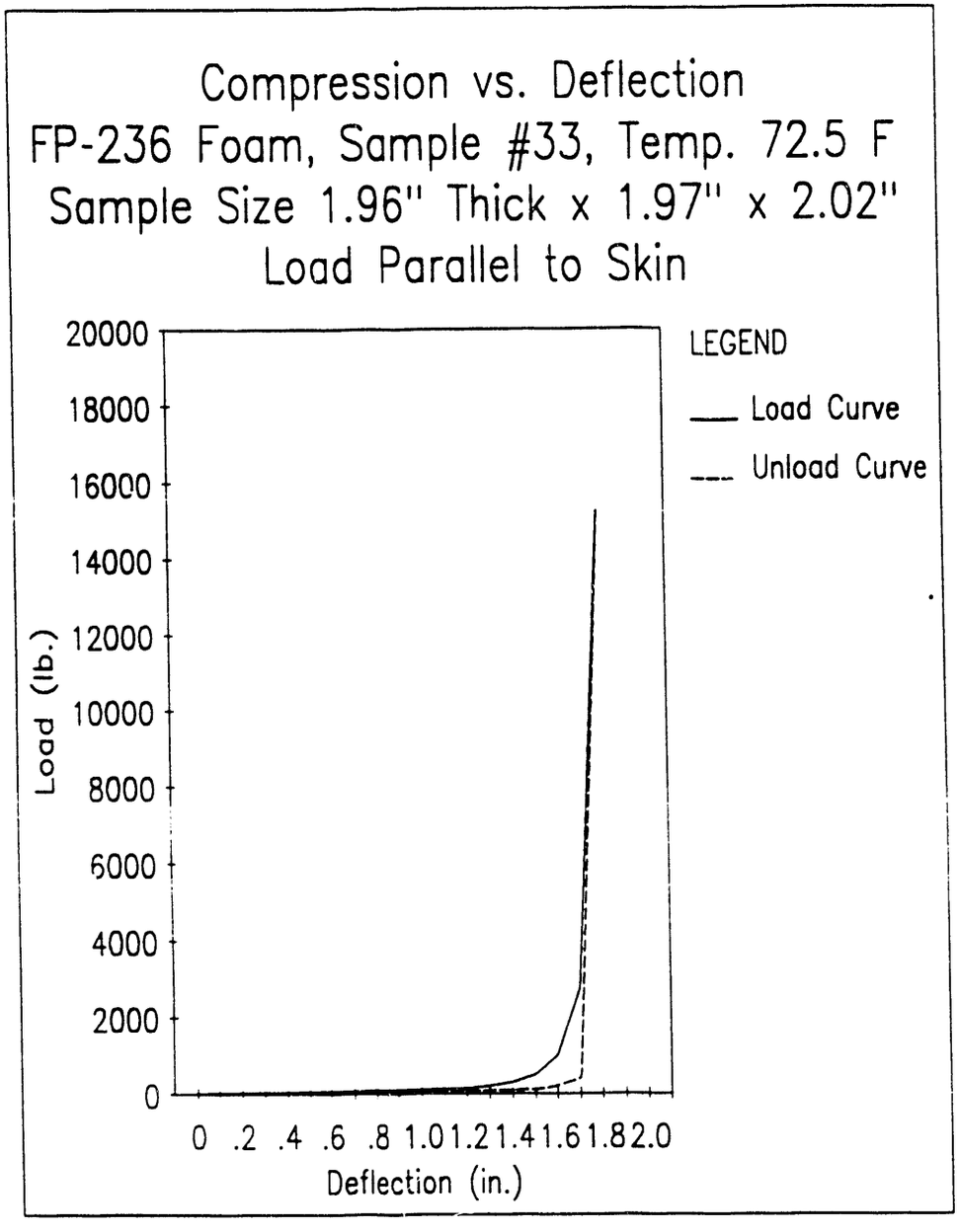

Compression vs. Deflection
FP-236 Foam, Sample #28, Temp. -40.6 F
Sample Size 1.96" Thick x 2.03" x 1.88"
Load Parallel to Skin
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

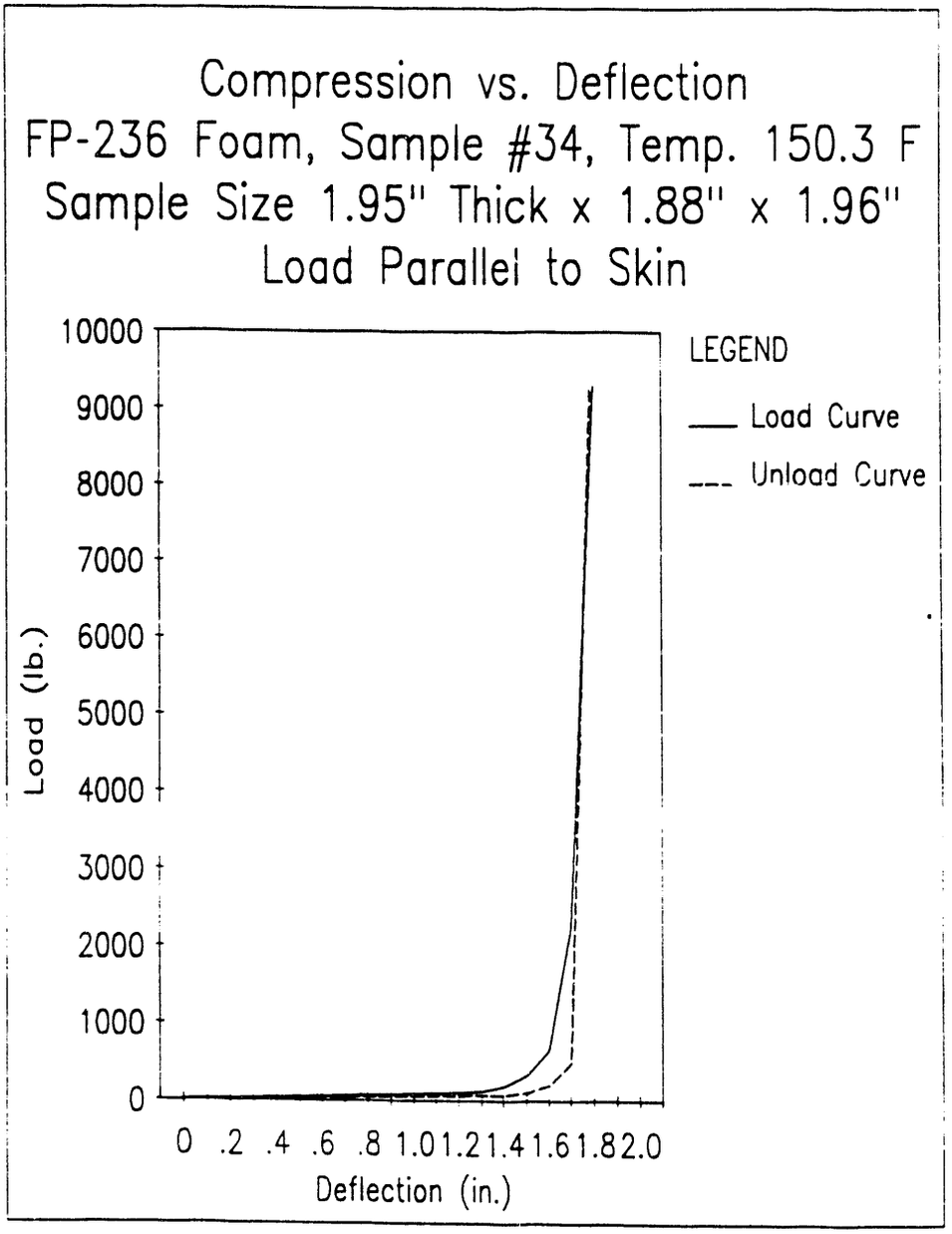

Compression vs. Deflection
FP-236 Foam, Sample #29, Temp. -41.0 F
Sample Size 1.95" Thick x 1.98" x 1.89"
Load Parallel to Skin
LEGEND
Load Curve
Unload Curve
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)

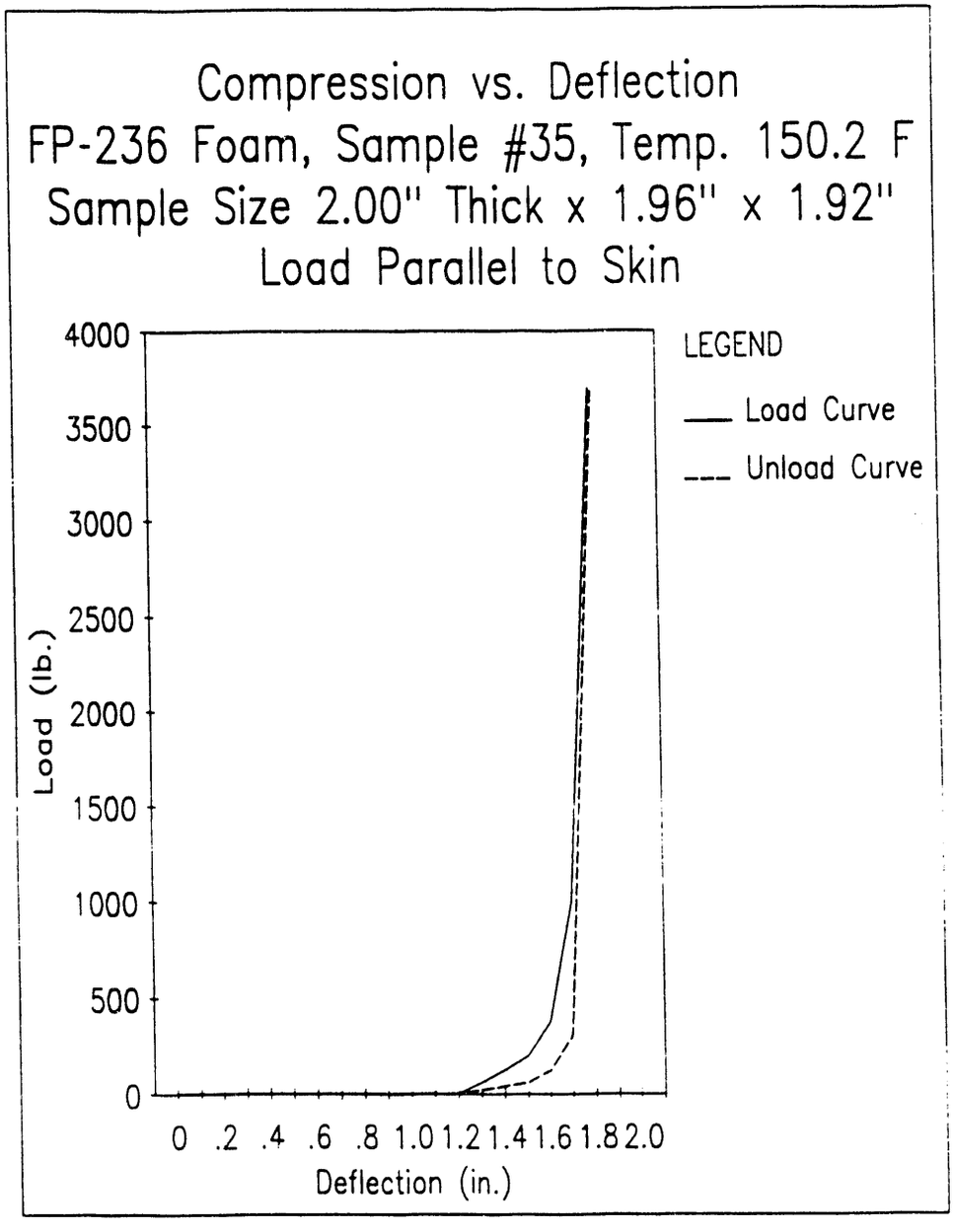

Compression vs. Deflection
FP-236 Foam, Sample #30, Temp. -40.7 F
Sample Size 2.05" Thick x 1.95" x 1.94"
Load Parallel to Skin
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

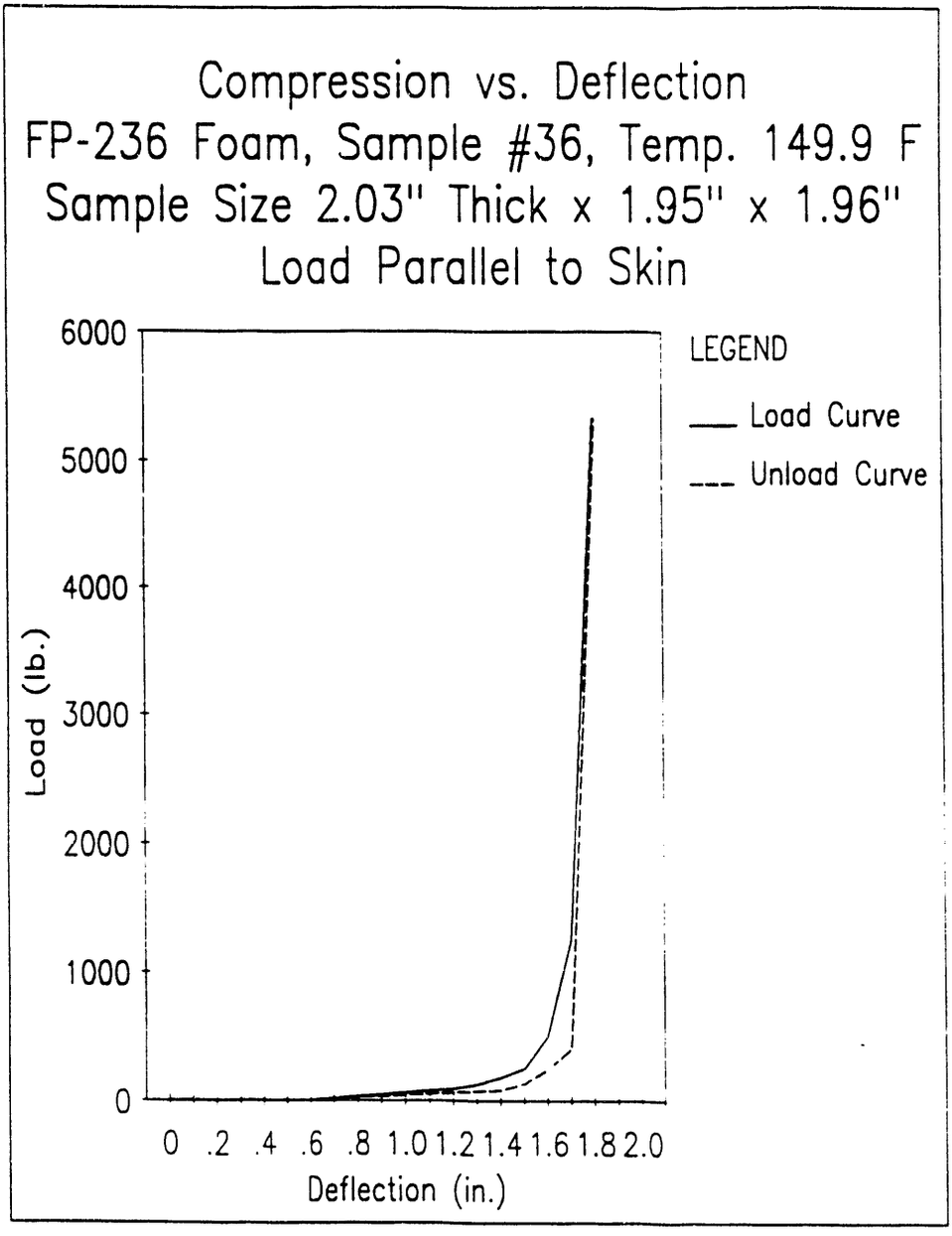

Compression vs. Deflection
FP-236 Foam, Sample #31, Temp. 72.5 F
Sample Size 1.95" Thick x 2.03" x 1.95"
Load Parallel to Skin
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

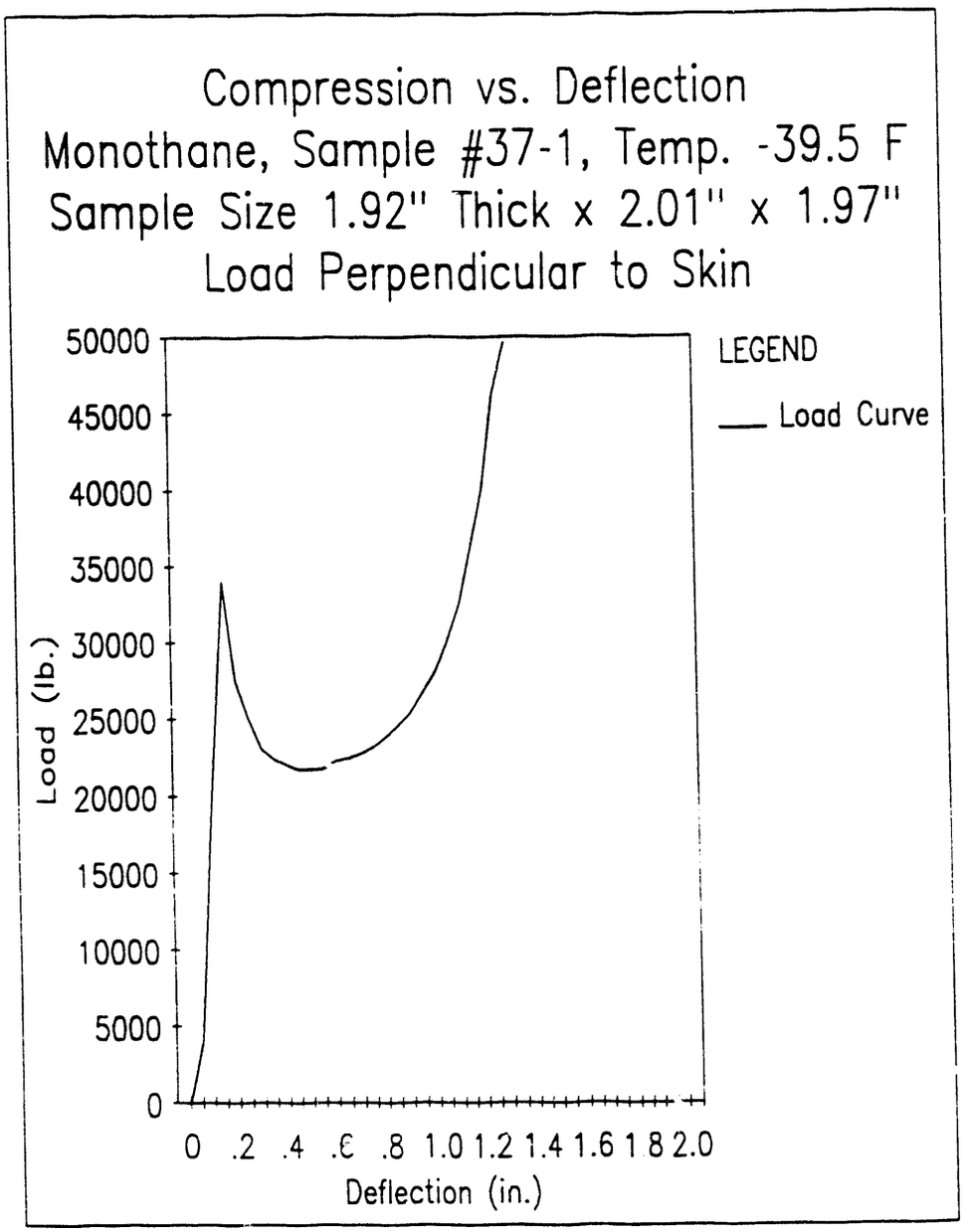

Compression vs. Deflection
FP-236 Foam, Sample #32, Temp. 72.5 F
Sample Size 1.96" Thick x 1.97" x 2.02"
Load Parallel to Skin
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

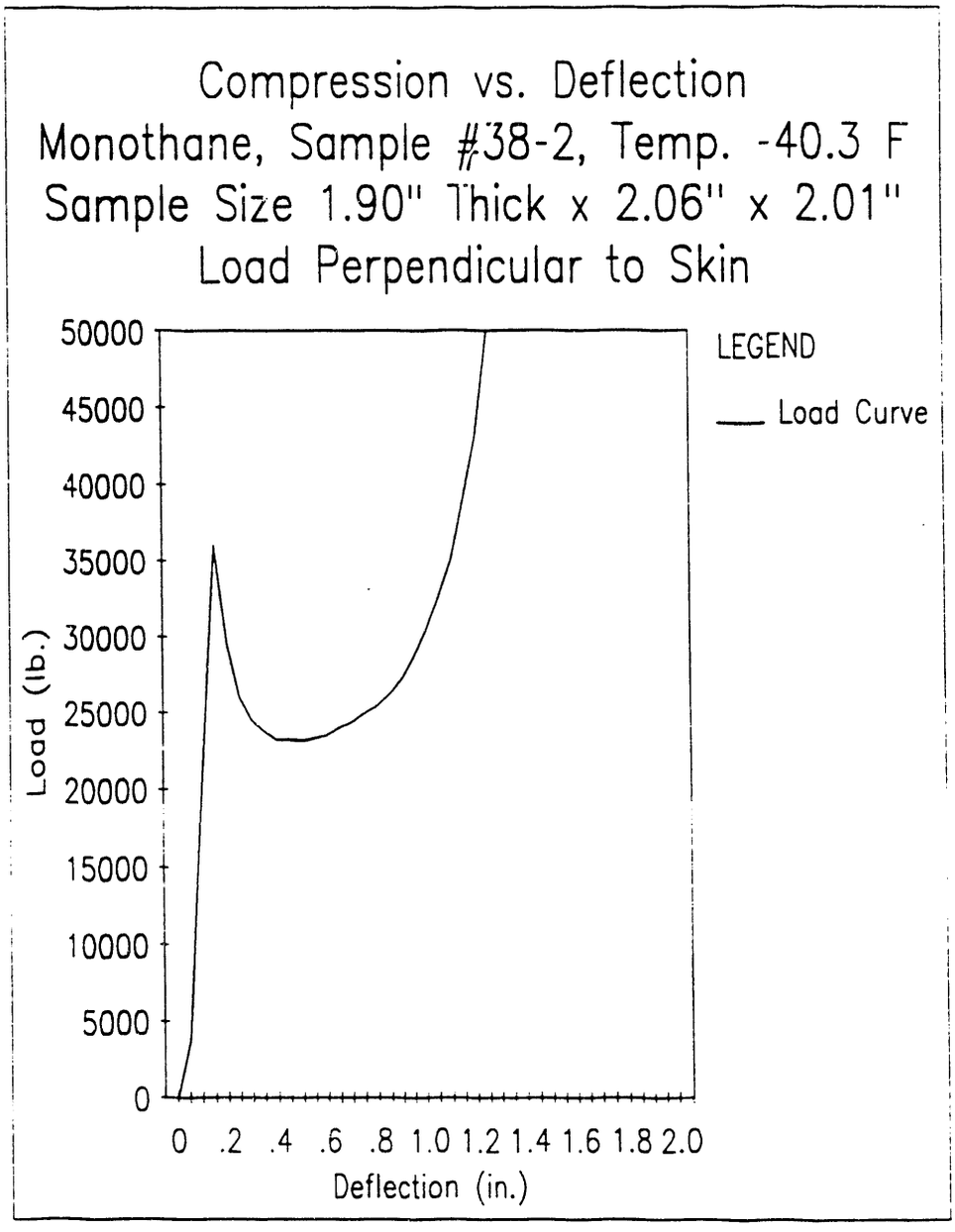

Compression vs. Deflection
FP-236 Foam, Sample #33, Temp. 72.5 F
Sample Size 1.96" Thick x 1.97" x 2.02"
Load Parallel to Skin
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

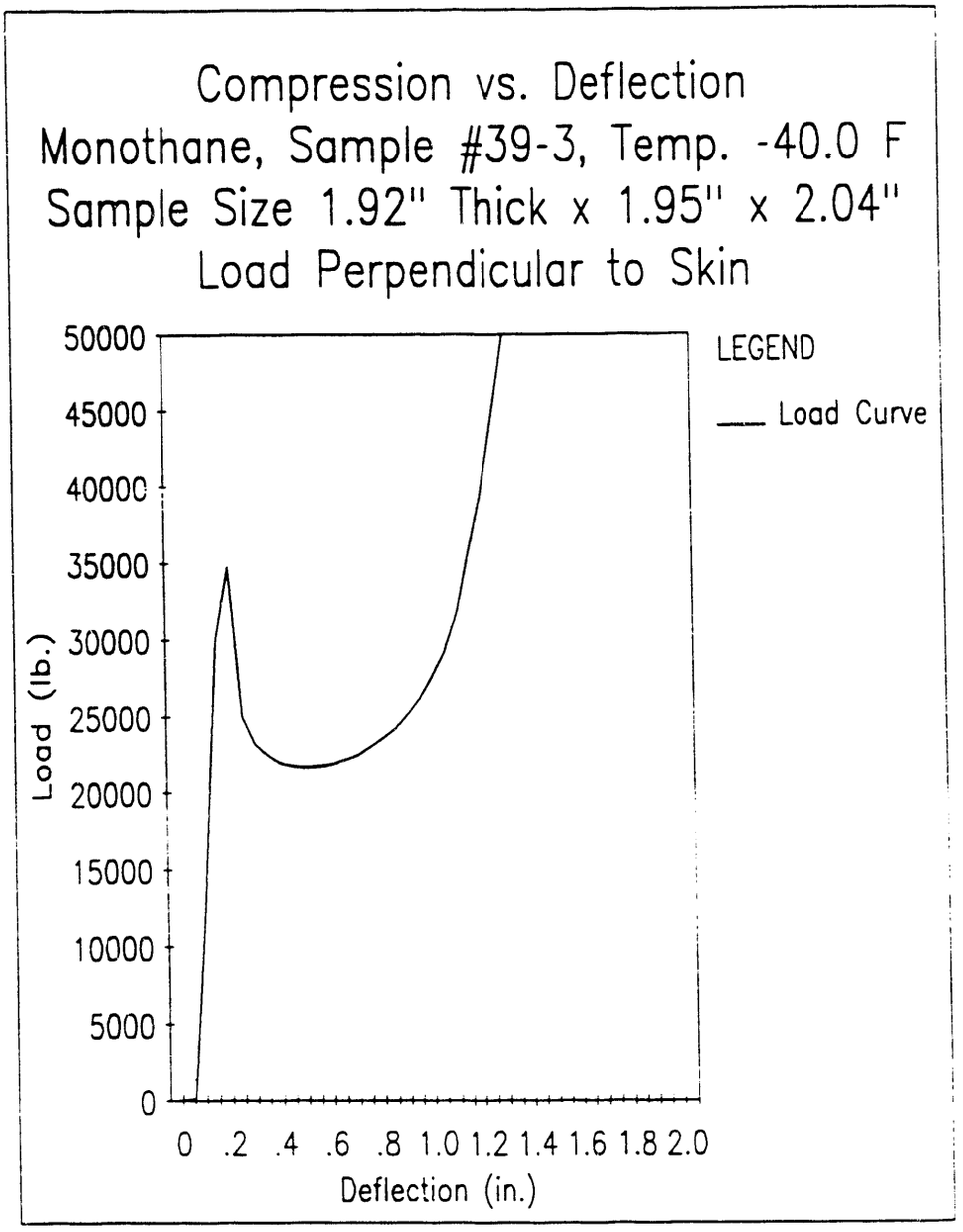

Compression vs. Deflection
FP-236 Foam, Sample #34, Temp. 150.3 F
Sample Size 1.95" Thick x 1.88" x 1.96"
Load Parallel to Skin
Load (lb.)
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

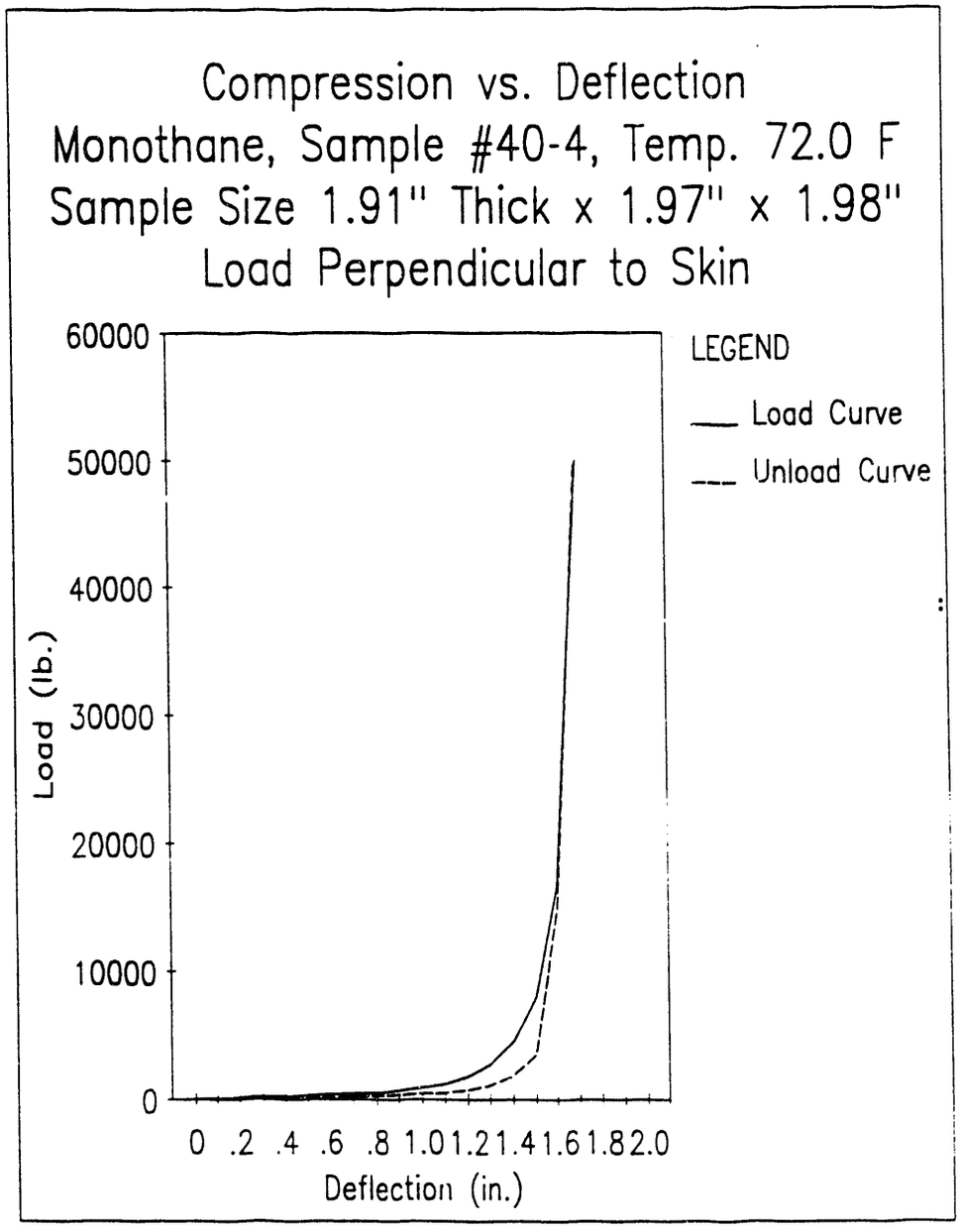

Compression vs. Deflection
FP-236 Foam, Sample #35, Temp. 150.2 F
Sample Size 2.00" Thick x 1.96" x 1.92"
Load Parallel to Skin
4000
3500
3000
2500
2000
1500
1000
500
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

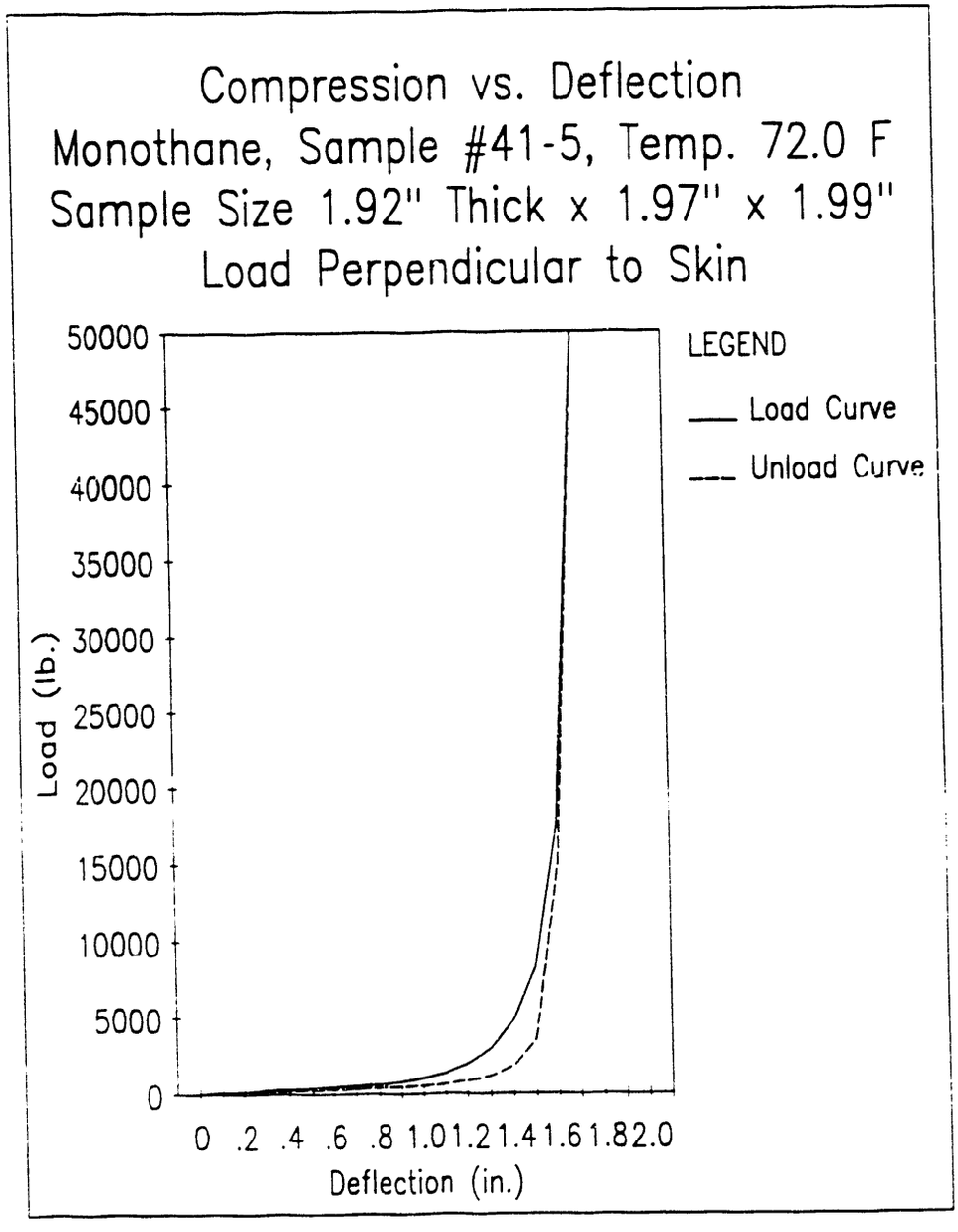

Compression vs. Deflection
FP-236 Foam, Sample #36, Temp. 149.9 F
Sample Size 2.03" Thick x 1.95" x 1.96"
Load Parallel to Skin
6000
5000
4000
3000
2000
1000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

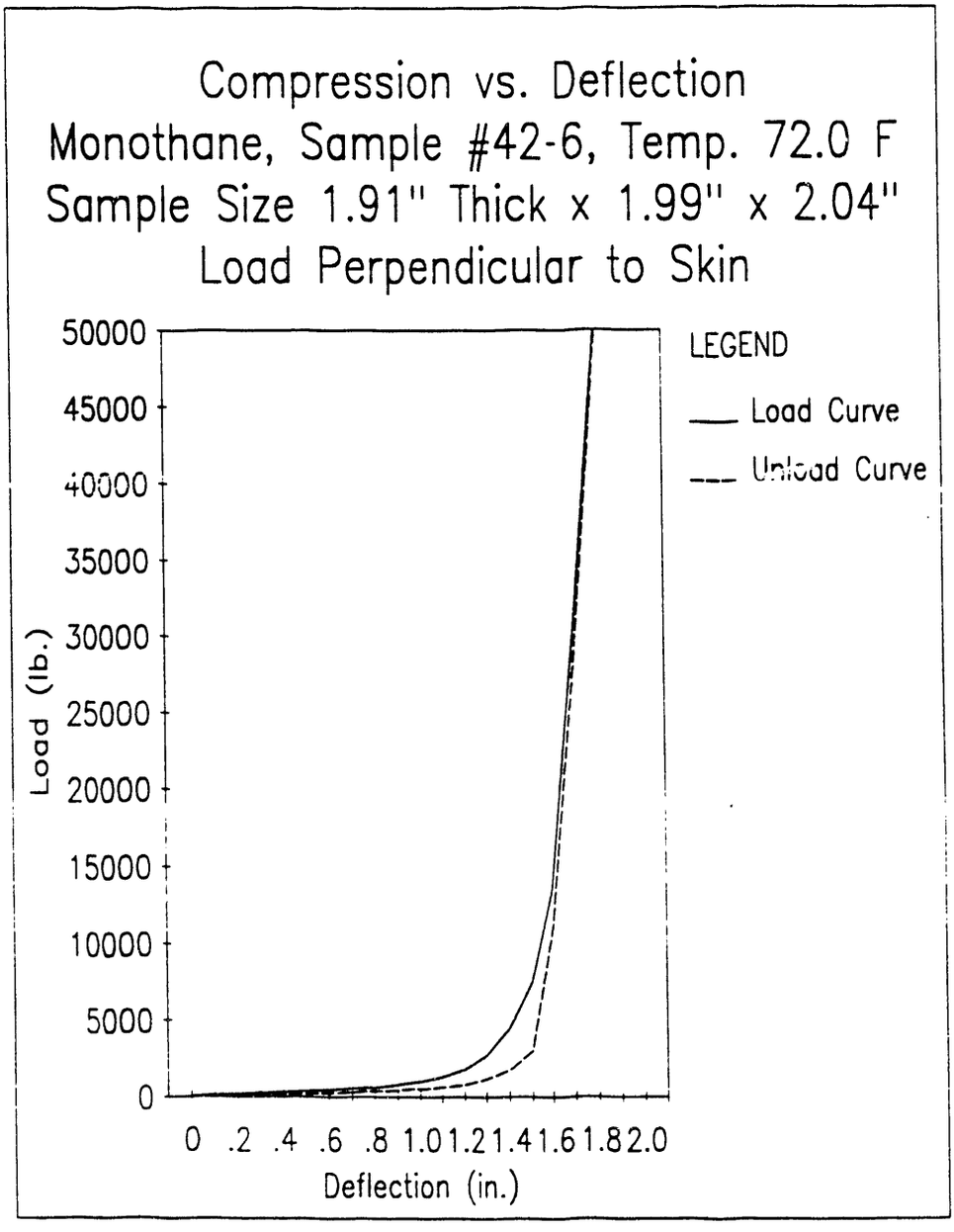

Compression vs. Deflection
Monothane, Sample #37-1, Temp. -39.5 F
Sample Size 1.92" Thick x 2.01" x 1.97"
Load Perpendicular to Skin
LEGEND
Load Curve
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)

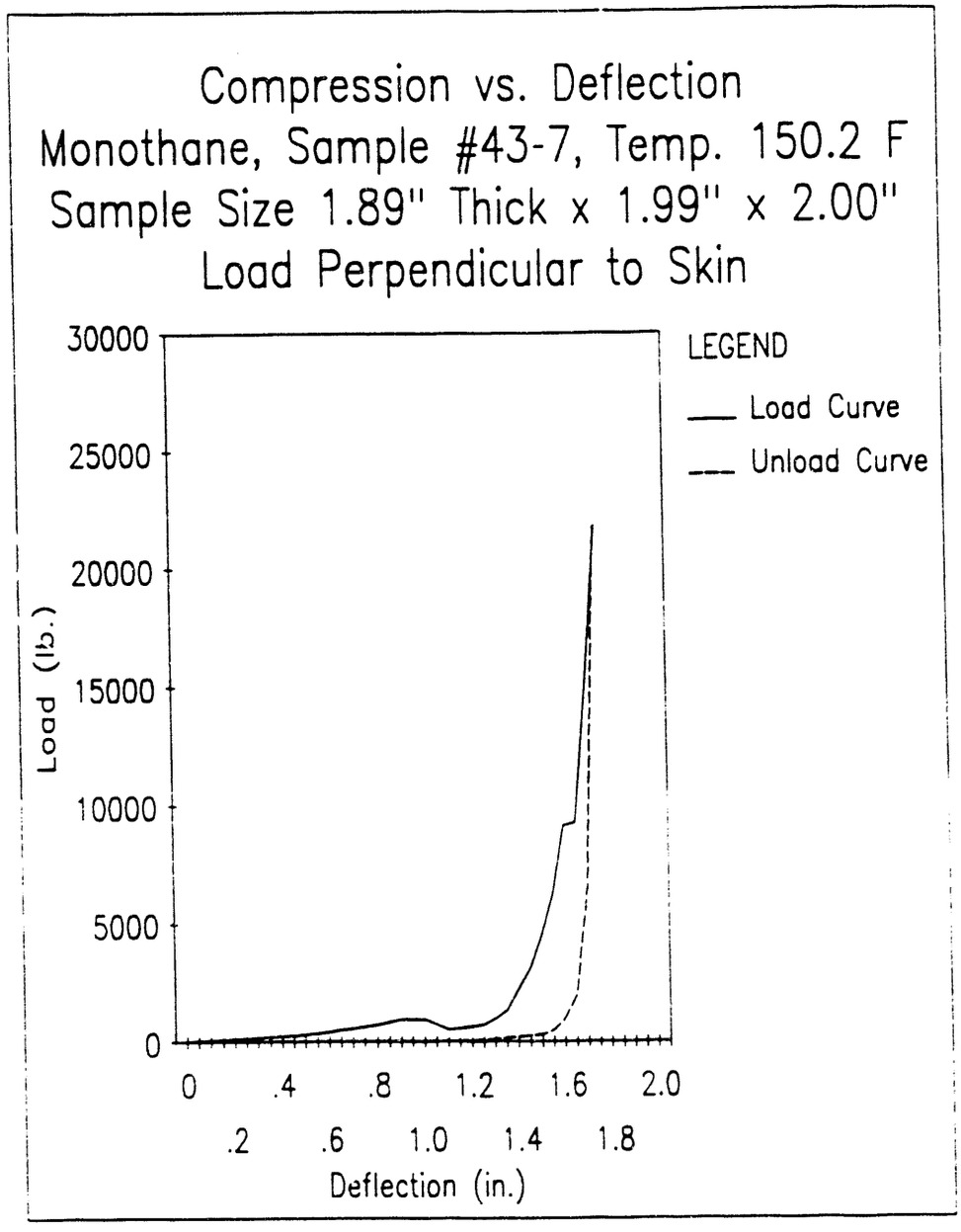

Compression vs. Deflection
Monothane, Sample #38-2, Temp. -40.3 F
Sample Size 1.90" Thick x 2.06" x 2.01"
Load Perpendicular to Skin
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve

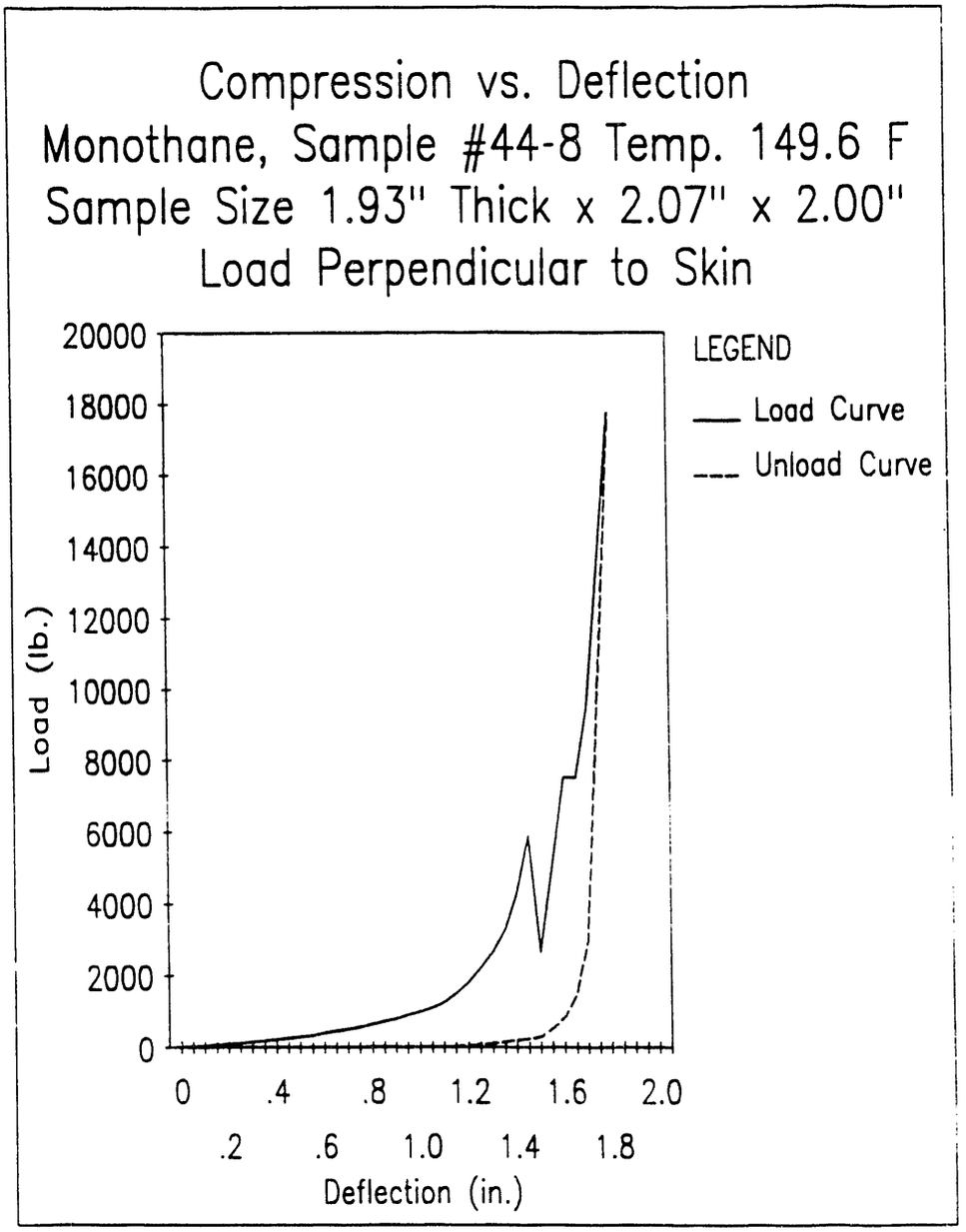

Compression vs. Deflection
Monothane, Sample #39-3, Temp. -40.0 F
Sample Size 1.92" Thick x 1.95" x 2.04"
Load Perpendicular to Skin
LEGEND
Load Curve
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)

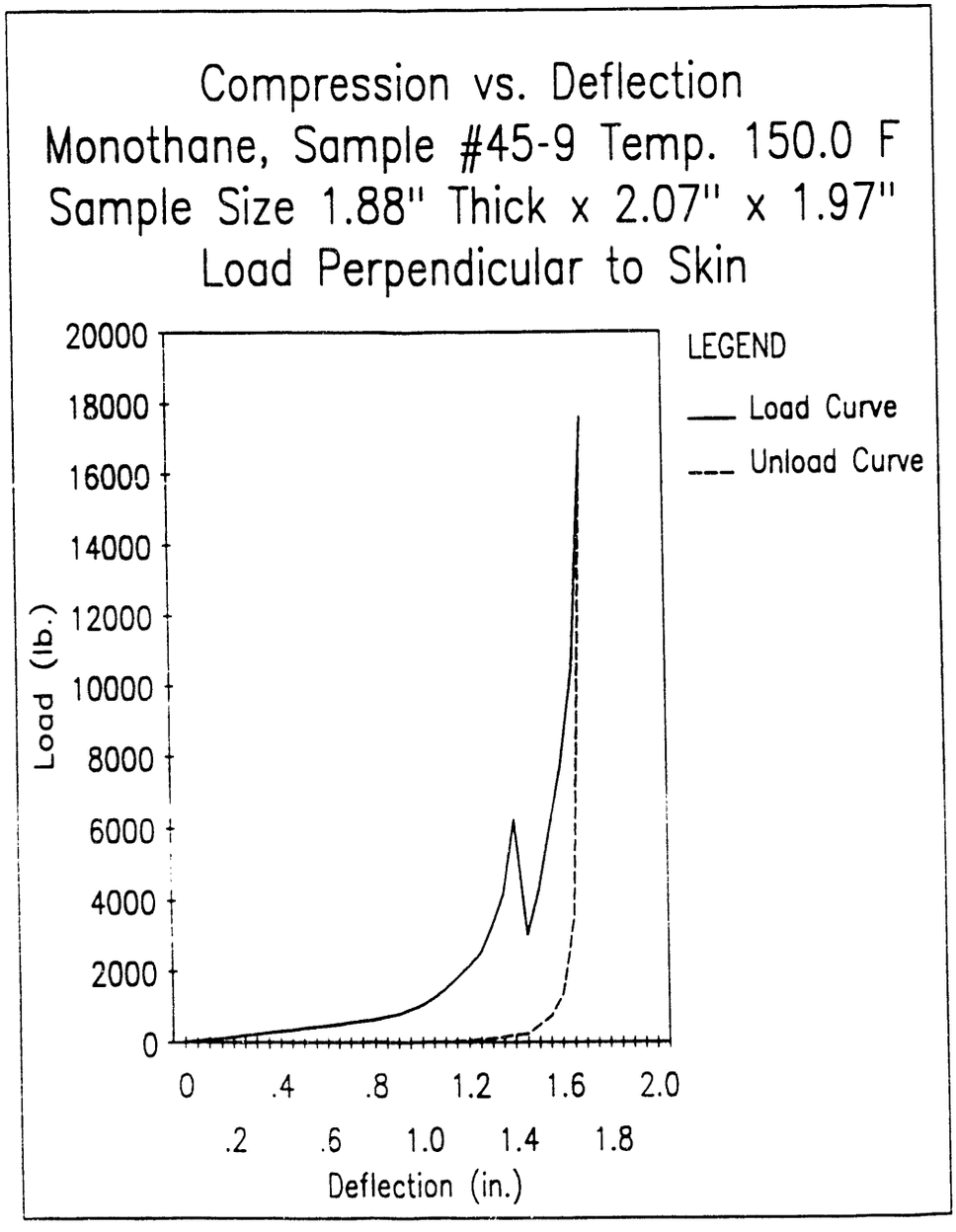

Compression vs. Deflection
Monothane, Sample #40-4, Temp. 72.0 F
Sample Size 1.91" Thick x 1.97" x 1.98"
Load Perpendicular to Skin
60000
50000
40000
30000
20000
10000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

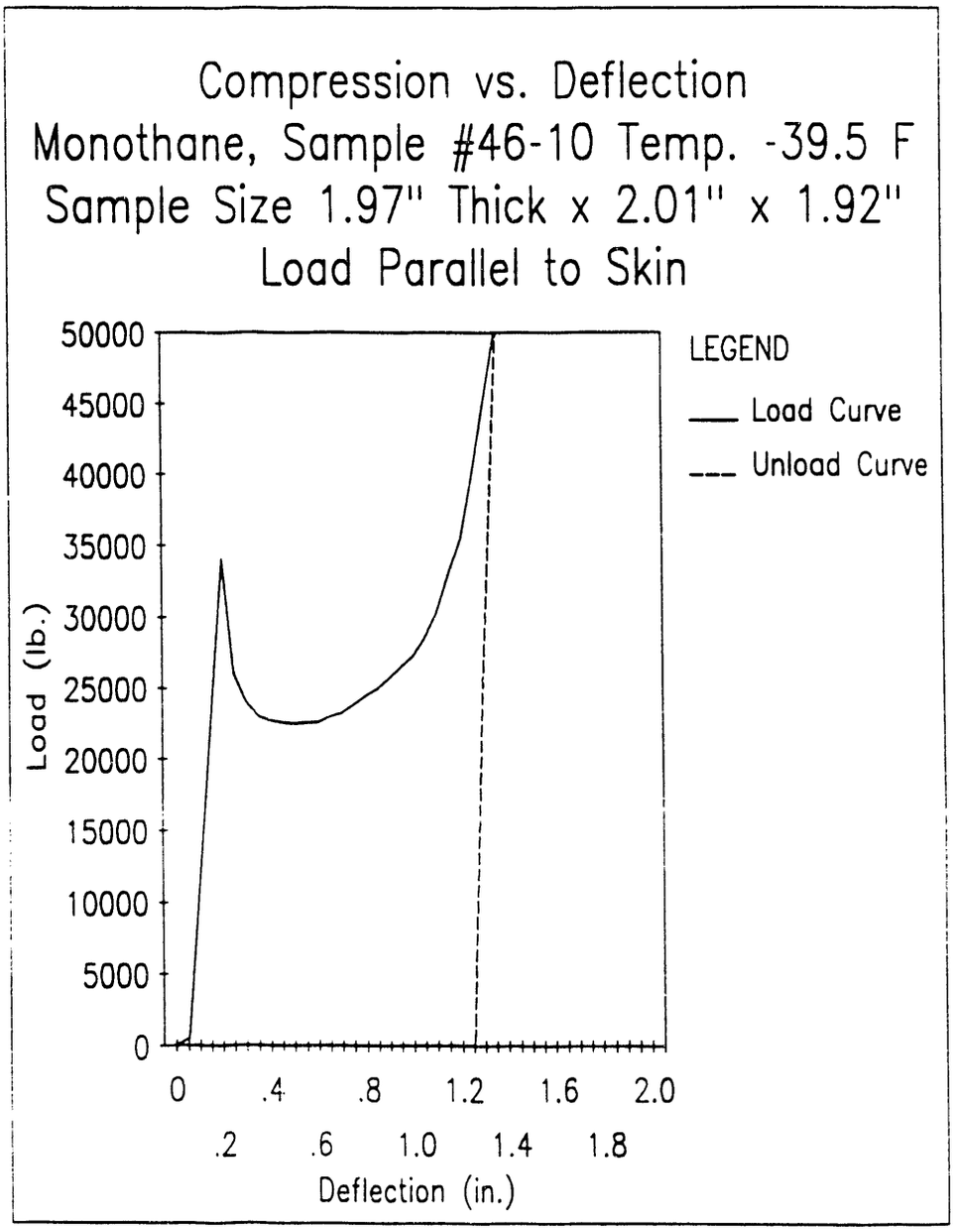

Compression vs. Deflection
Monothane, Sample #41-5, Temp. 72.0 F
Sample Size 1.92" Thick x 1.97" x 1.99"
Load Perpendicular to Skin
LEGEND
Load Curve
Unload Curve
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)

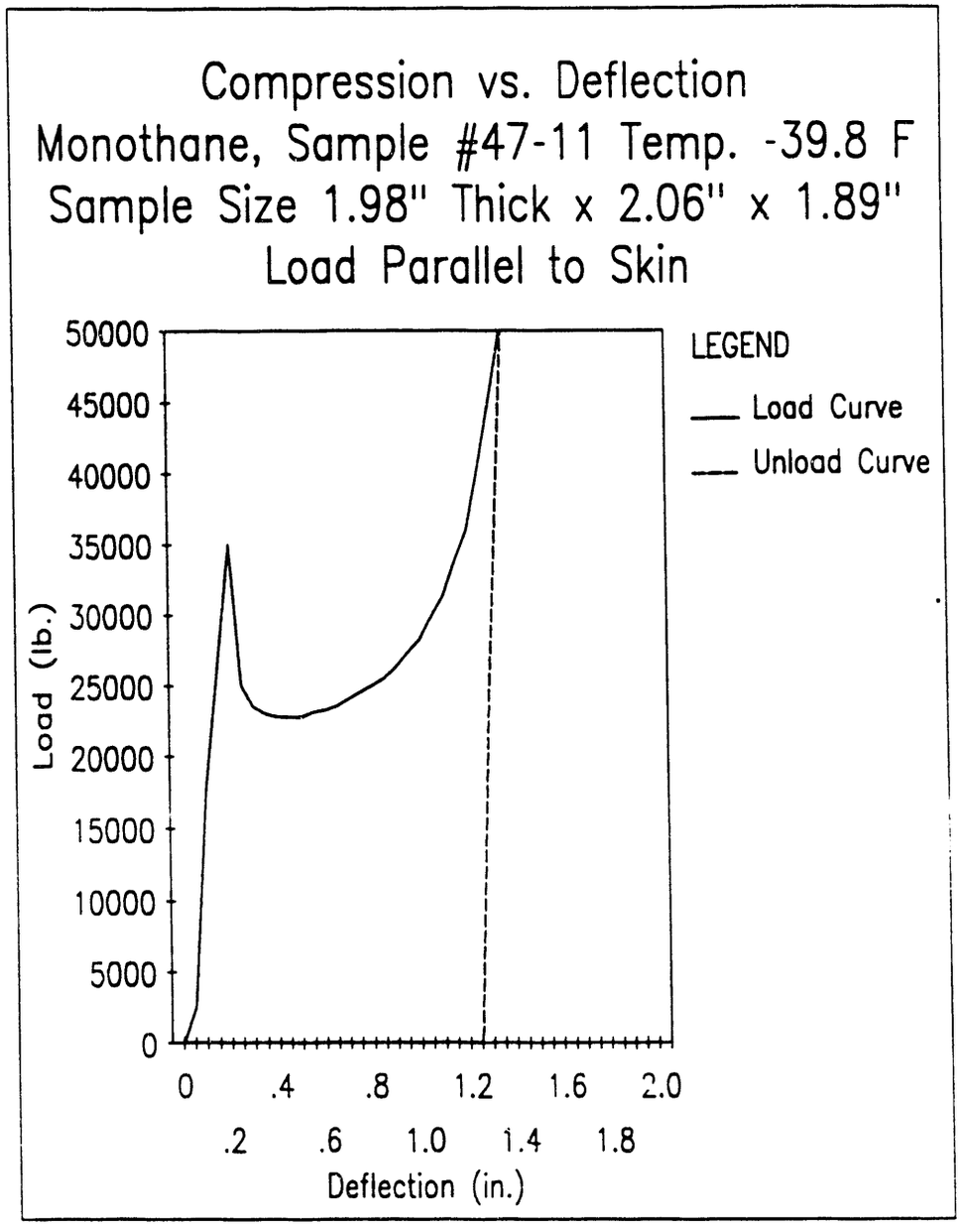

Compression vs. Deflection
Monothane, Sample #42-6, Temp. 72.0 F
Sample Size 1.91" Thick x 1.99" x 2.04"
Load Perpendicular to Skin
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

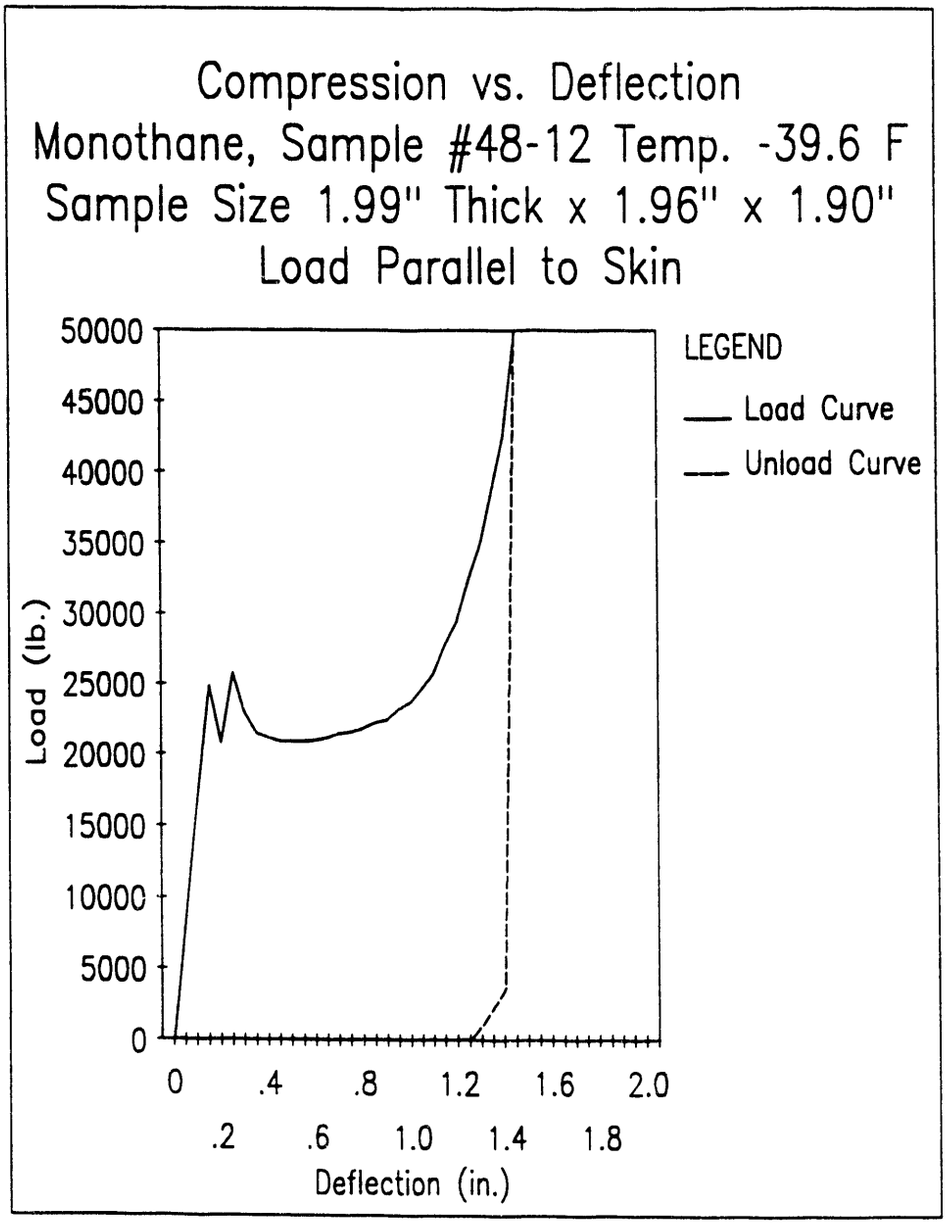

Compression vs. Deflection
Monothane, Sample #43-7, Temp. 150.2 F
Sample Size 1.89" Thick x 1.99" x 2.00"
Load Perpendicular to Skin
LEGEND
Load Curve
Unload Curve
Load (lb.)
30000
25000
20000
15000
10000
5000
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Deflection (in.)

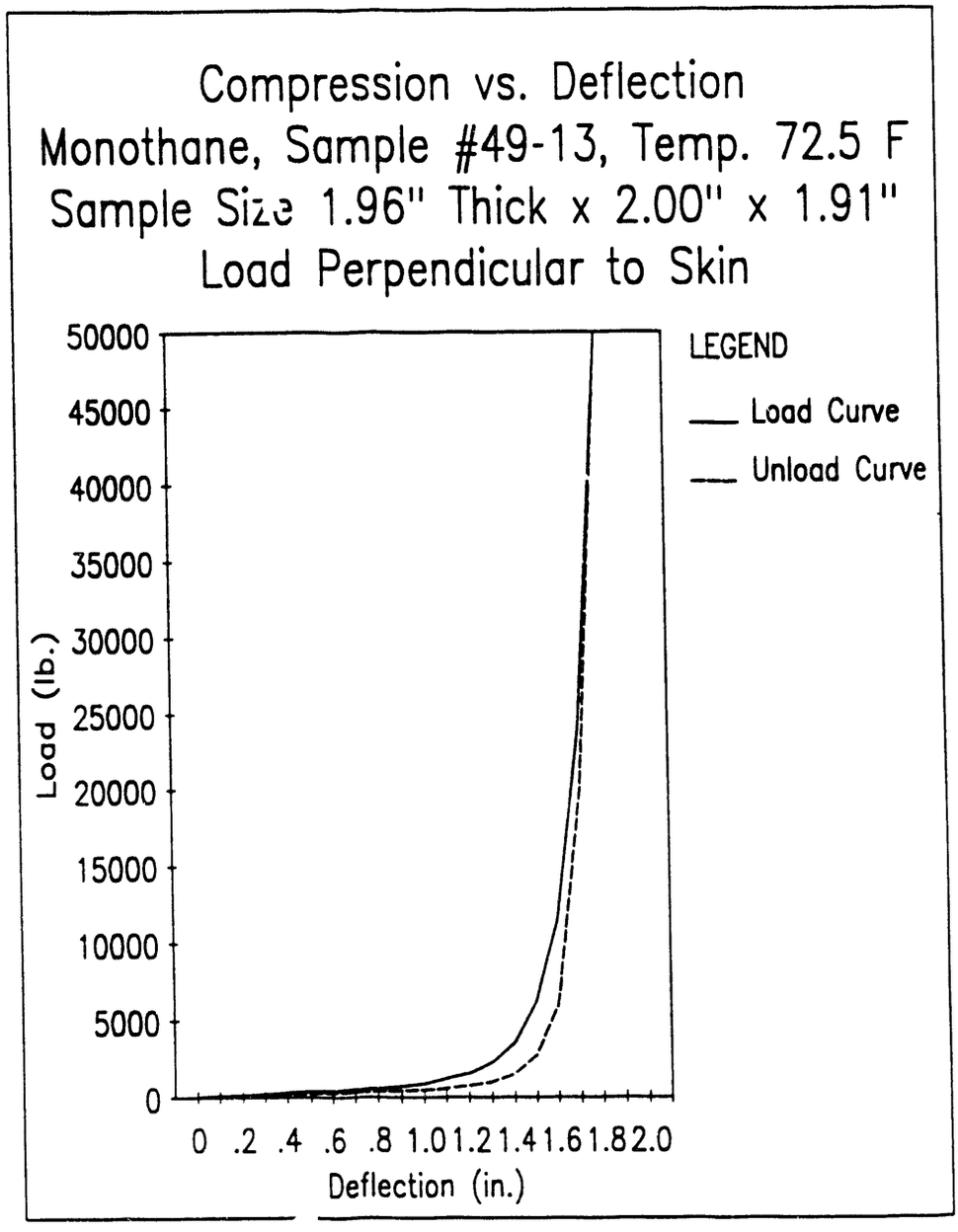

Compression vs. Deflection
Monothane, Sample #44-8 Temp. 149.6 F
Sample Size 1.93" Thick x 2.07" x 2.00"
Load Perpendicular to Skin
LEGEND
Load Curve
Unload Curve
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Deflection (in.)

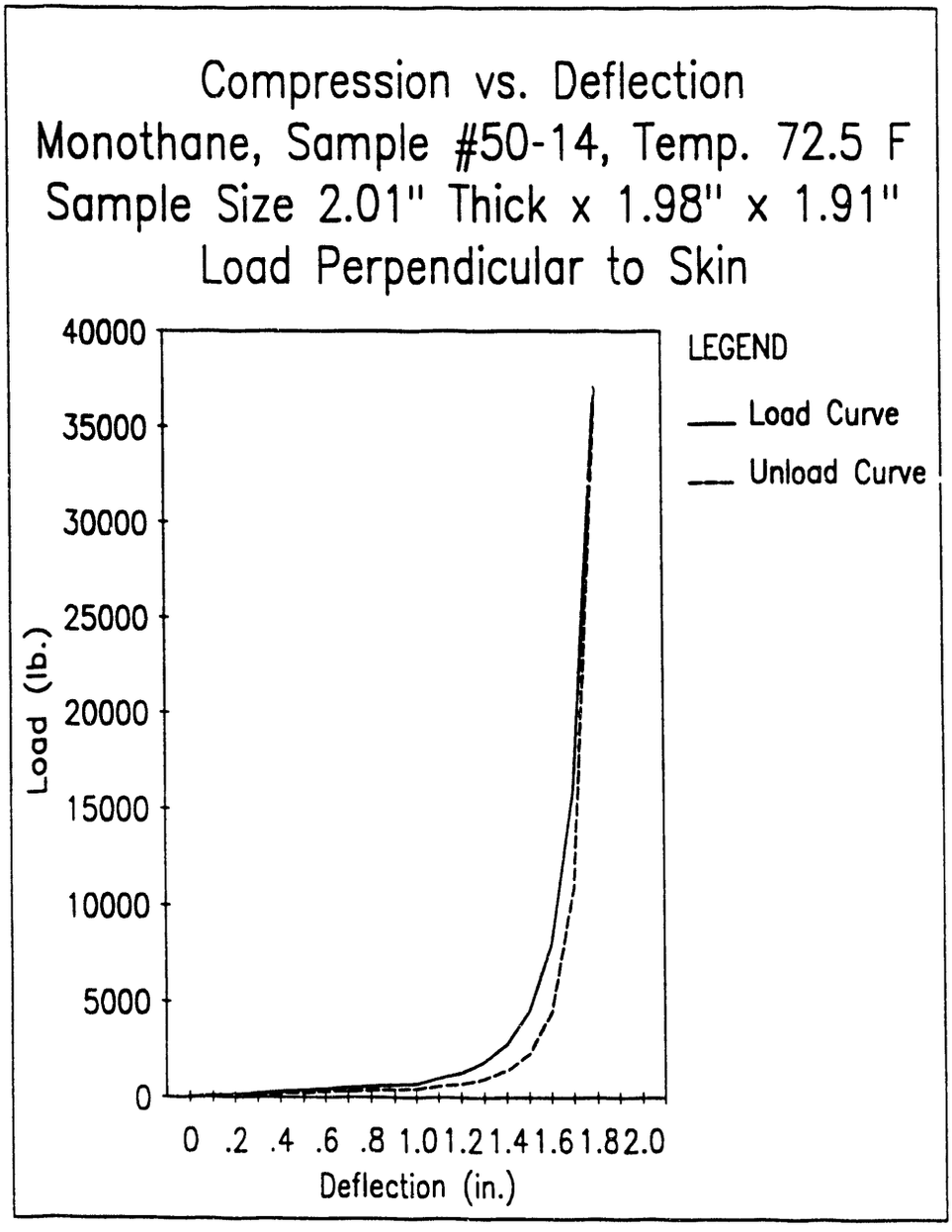

Compression vs. Deflection
Monothane, Sample #45-9 Temp. 150.0 F
Sample Size 1.88" Thick x 2.07" x 1.97"
Load Perpendicular to Skin
LEGEND
Load Curve
Unload Curve
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Deflection (in.)

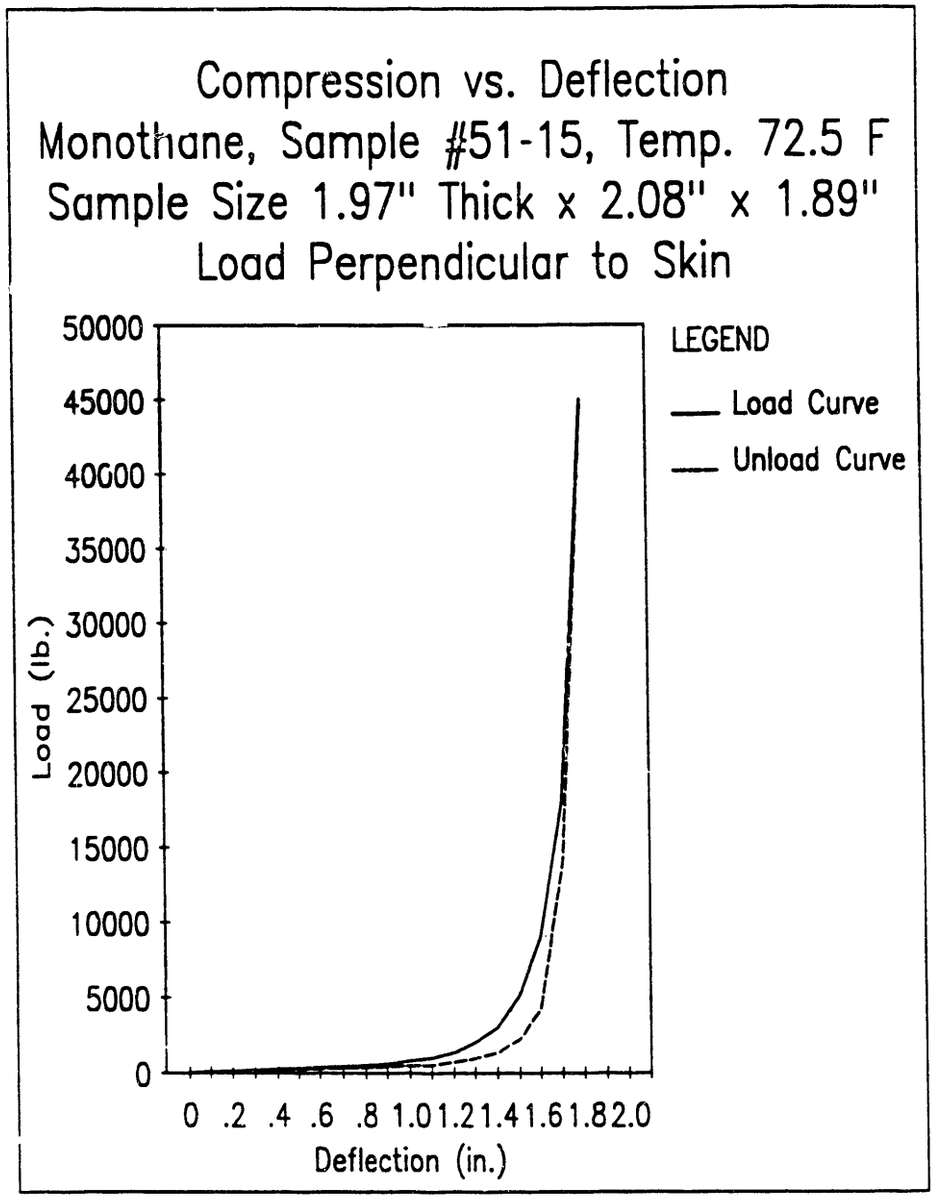

Compression vs. Deflection
Monothane, Sample #46-10 Temp. -39.5 F
Sample Size 1.97" Thick x 2.01" x 1.92"
Load Parallel to Skin
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

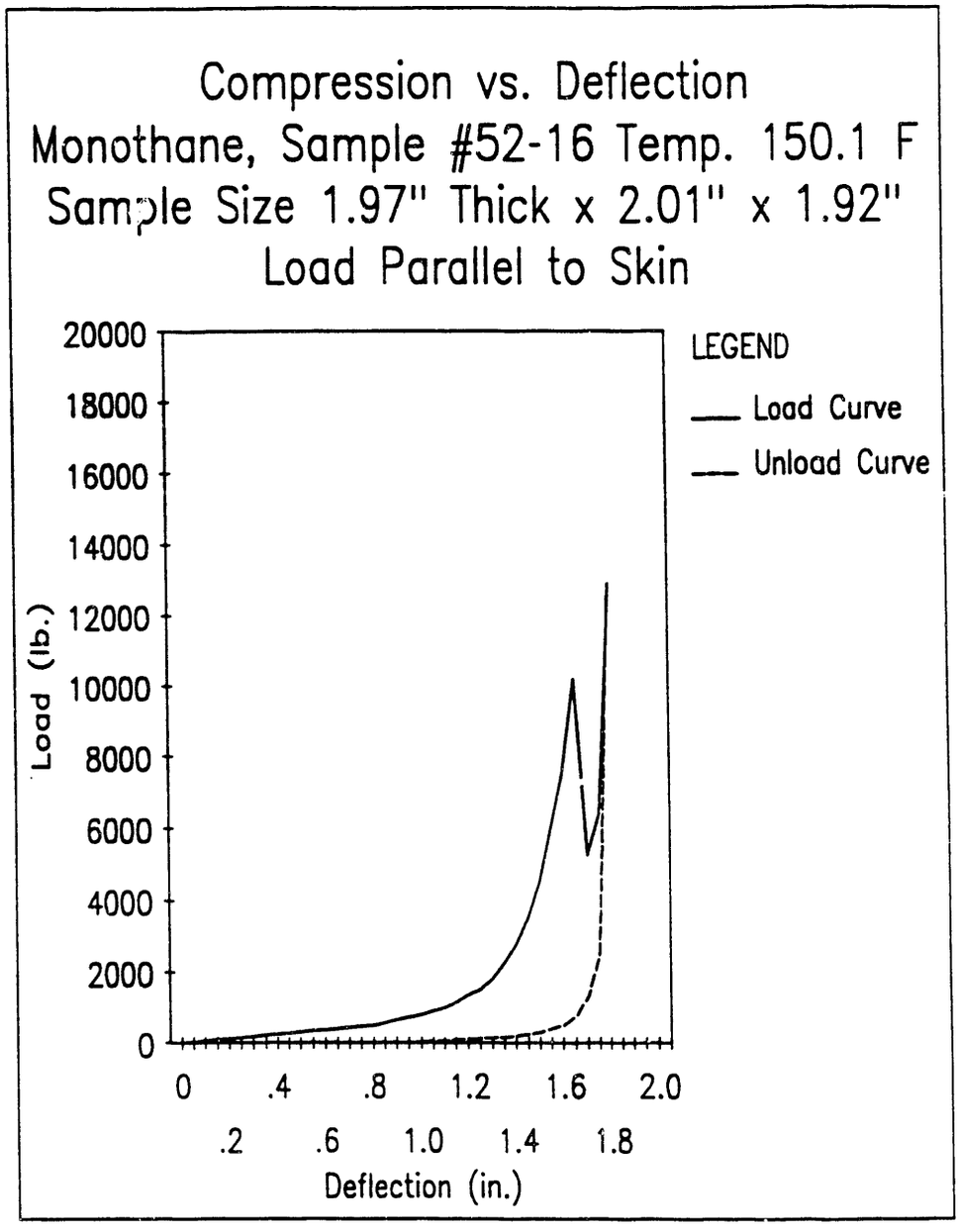

Compression vs. Deflection
Monothane, Sample #47-11 Temp. -39.8 F
Sample Size 1.98" Thick x 2.06" x 1.89"
Load Parallel to Skin
Load (lb.)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

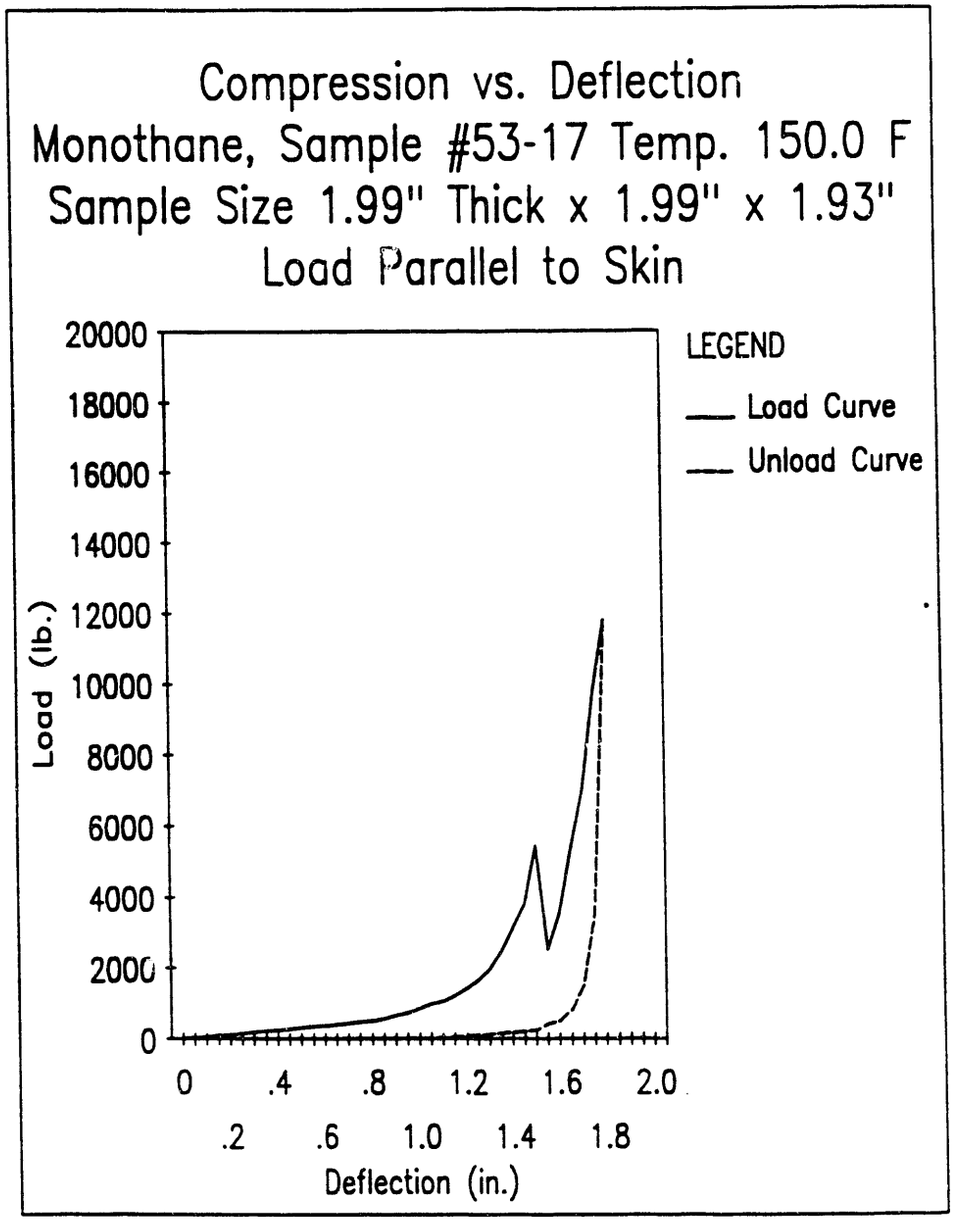

Compression vs. Deflection
Monothane, Sample #48-12 Temp. -39.6 F
Sample Size 1.99" Thick x 1.96" x 1.90"
Load Parallel to Skin
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
LEGEND
Load Curve
Unload Curve
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Deflection (in.)

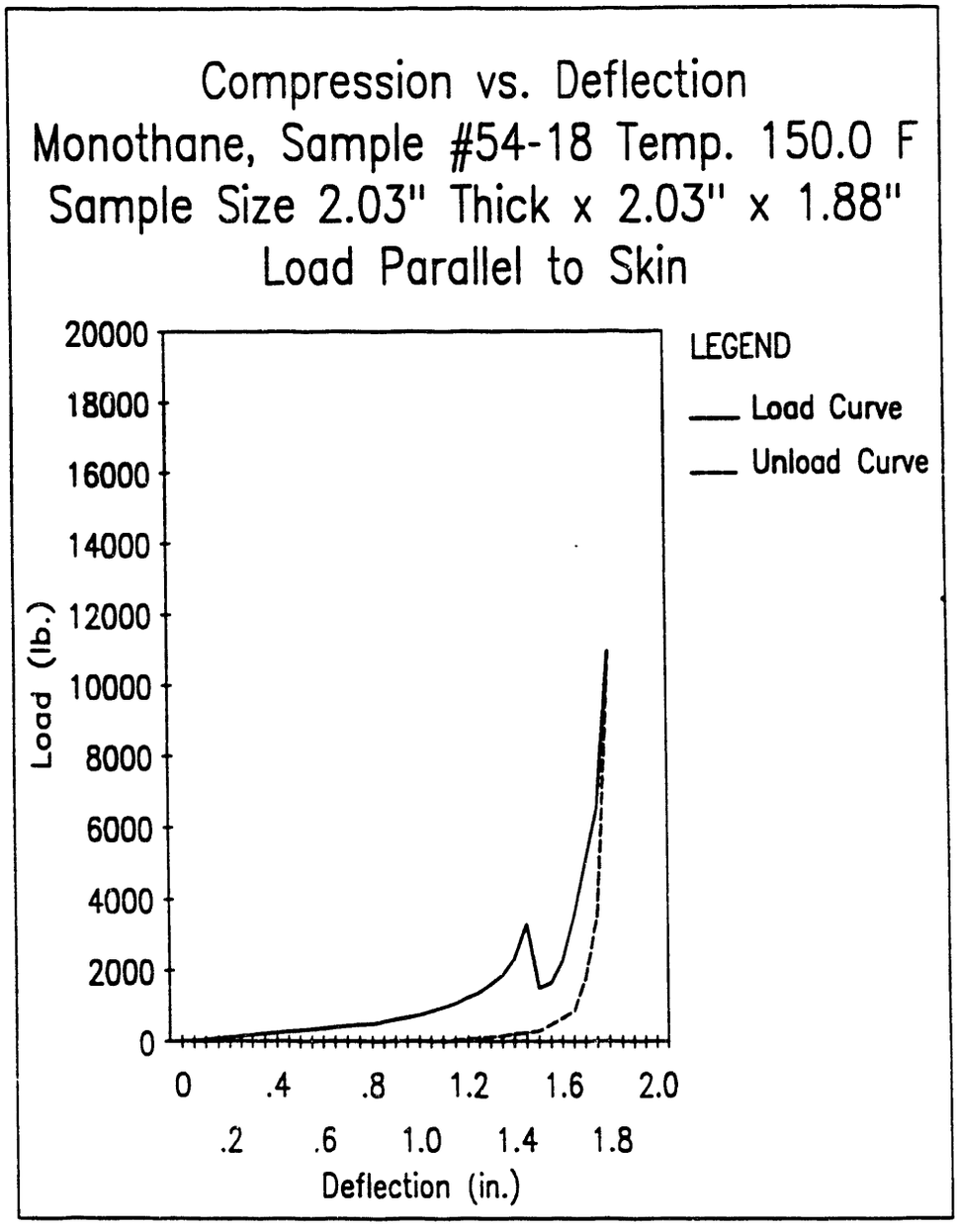

Compression vs. Deflection
Monothane, Sample #49-13, Temp. 72.5 F
Sample Size 1.96" Thick x 2.00" x 1.91"
Load Perpendicular to Skin
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve


Compression vs. Deflection
Monothane, Sample #50-14, Temp. 72.5 F
Sample Size 2.01" Thick x 1.98" x 1.91"
Load Perpendicular to Skin
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve


Compression vs. Deflection
Monothane, Sample #51-15, Temp. 72.5 F
Sample Size 1.97" Thick x 2.08" x 1.89"
Load Perpendicular to Skin
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
Load (lb.)
0 .2 .4 .6 .8 1.0 1.2 1.4 1.6 1.8 2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve


Compression vs. Deflection
Monothane, Sample #52-16 Temp. 150.1 F
Sample Size 1.97" Thick x 2.01" x 1.92"
Load Parallel to Skin
LEGEND
Load Curve
Unload Curve
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Deflection (in.)


Compression vs. Deflection
Monothane, Sample #53-17 Temp. 150.0 F
Sample Size 1.99" Thick x 1.99" x 1.93"
Load Parallel to Skin
LEGEND
Load Curve
Unload Curve
Load (lb.)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Deflection (in.)


Compression vs. Deflection
Monothane, Sample #54-18 Temp. 150.0 F
Sample Size 2.03" Thick x 2.03" x 1.88"
Load Parallel to Skin
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
Load (lb.)
0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
Deflection (in.)
LEGEND
Load Curve
Unload Curve

END

DATE FILMED

12/27/91