Appendix 2.10.1

Center of Gravity Report

LAW

LAWGIBB Group Member

June 8, 1999

Eco-Pak Specialty Packaging
107 Meadowview Farms Drive
Jonesborough, TN 37659

Attention: Ms. Heather Little

Subject: **Center of Gravity of Eco-Pak Liqui-Rad-250**
Law Engineering and Environmental Services Project 10810-9-7003, Phase 10

Dear Ms. Little:

Per your request and as authorized by signing our annual proposal acceptance sheet, Law Engineering and Environmental Services (LEES) has completed engineering analysis of the "ECO-PAK LIQUI-RAD-250" shipping container box. The purpose of this analysis was to find the center of gravity of the container and to calculate the container position angles with respect to the drop test configurations in accordance with Title CFR Part 71.73 (Hypothetical Accident Conditions) provided to us by Eco-Pak.

Two drawings are attached with this letter as described below:

SHEET 1 of 2: POSITION OF THE CONTAINER BOX WHEN TOP EDGE "A-A" IS ALIGNED WITH THE CENTER OF GRAVITY.
Top edge "A-A" is shown in the drawing.

SHEET 2 OF 2: POSITION OF THE CONTAINER BOX WHEN A CORNER "A" IS ALIGNED WITH THE CENTER OF GRAVITY.
Corner "A" is shown in the drawing.

The container volume is approximately 270 gallons and the container is designed for a liquid volume of 250 gallons. Therefore, the container is approximately 93% full at its rated load. Please note that we calculated the center of gravity (C.G.) considering the container was at 100% of its rated load and standing on its legs. Because the container is almost full at its rated load, we assumed the container C.G. location would not change when the container rotated to the desired positions for the drop test.

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

Our calculations indicate that the C.G. of the container is at 36.59 inches from the base of the legs of the container. Further more, an angle of 52.44° with the horizontal would align the top edge "A-A" with the C.G. and an angle of 42.60° with the horizontal would align the corner "A" with the C.G.

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

Sincerely,

LAW ENGINEERING AND ENVIRONMENTAL SERVICES

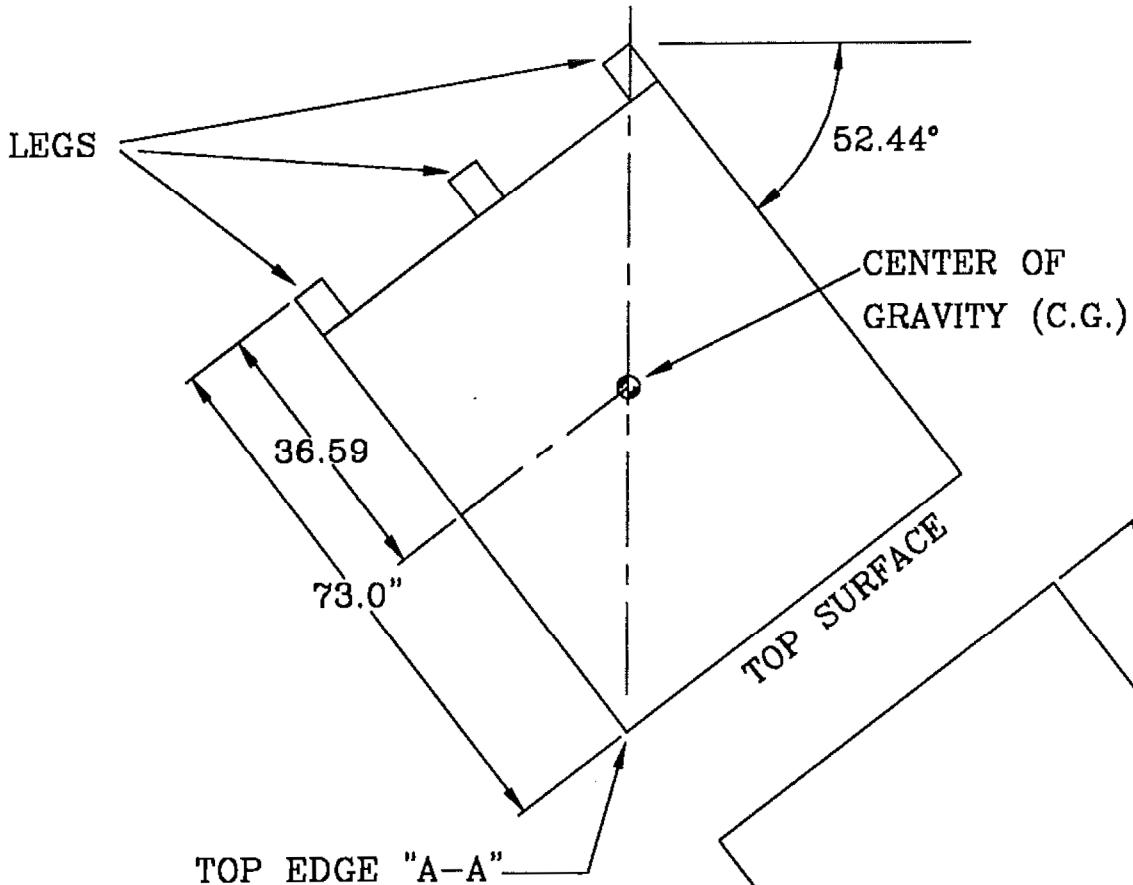
M. N. Parikh

Mike N. Parikh, P.E.
Senior Professional

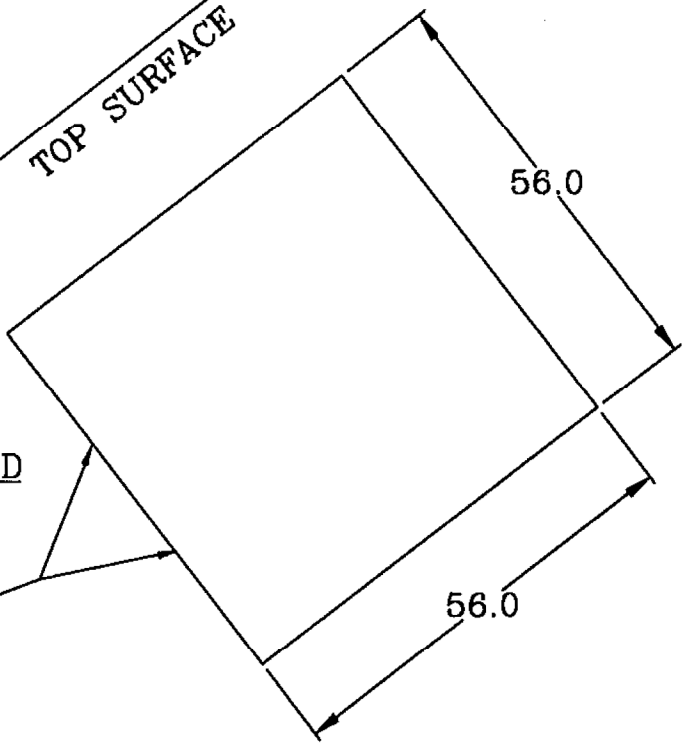
Lakshman Santanam, P.E.
Technical Center Manager

Attachment: Sheet 1 and 2 (2 Sets)

DROP TEST



POSITION OF THE CONTAINER BOX WHEN TOP EDGE "A–A" IS ALIGNED WITH THE CENTER OF GRAVITY



TOP SURFACE VIEW

(DIMENSIONS ARE IN INCHES)

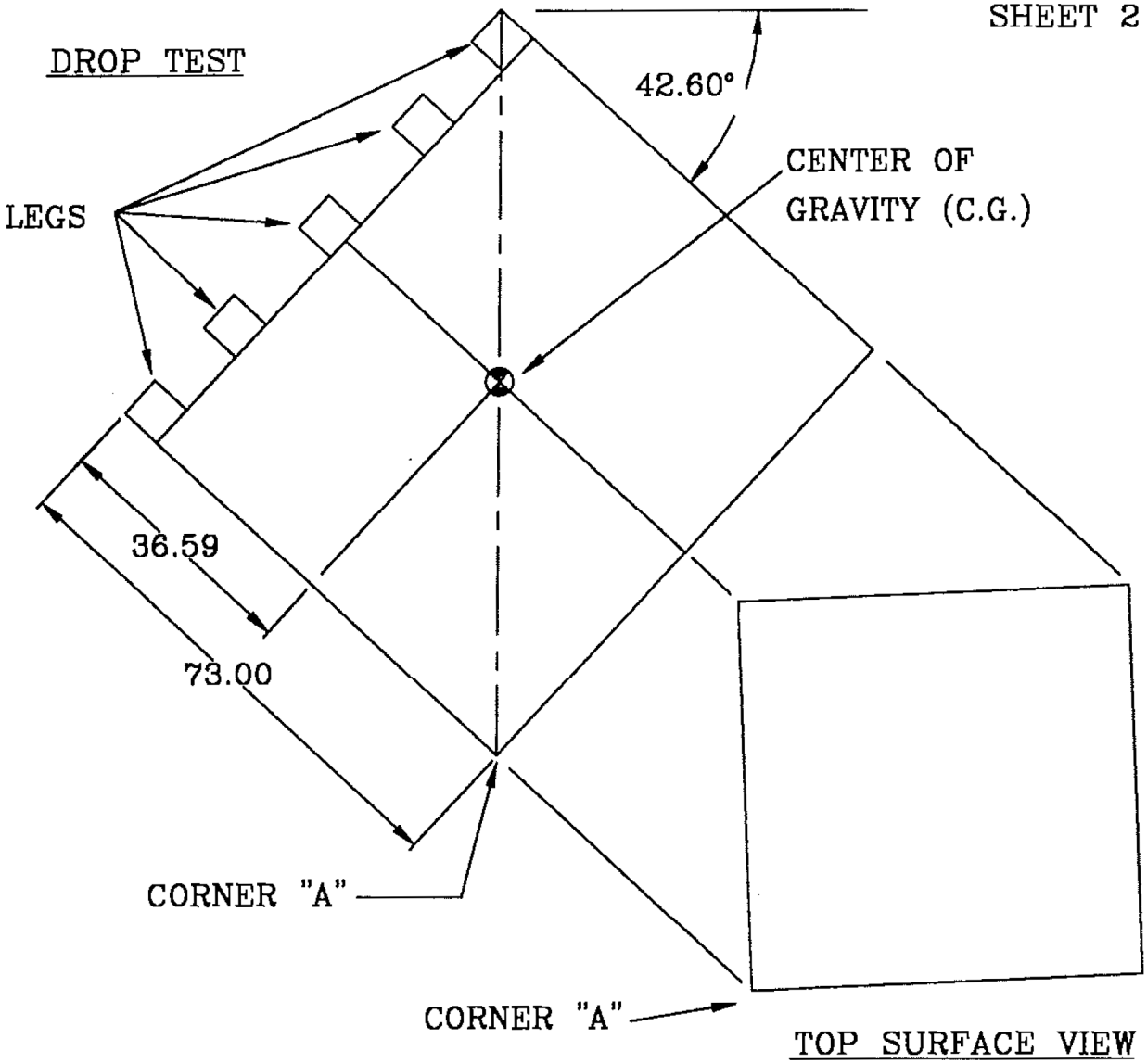
NOTES:
1. APPROX. CONTAINER WT 5440 LBS. (INCLUDING 250 GALLONS OF LIQUID)
2. WE ASSUMED THE C.G. OF THE BOX LOCATED ON THE CENTER LINE OF THE BOX.
3. WE CALCULATED C.G. OF THE BOX WHEN IT STANDS ON ITS LEGS.
4. ASSUMED DENSITIES AS FOLLOWS,
   C/S OR S/S 490 PCF
   (PCF = POUNDS PER CUBIC FEET)
   DURABOARD 8 PCF
   FIBERFRAX PAPER/INSULATION 8 PCF
   SALT WATER 1.2 grm/cc
   CAPACITY = 250 GALLONS
5. WELD MATERIAL WEIGHT IS SMALL AND THEREFORE IT IS NEGLECTED.
6. REF. ECO-PAK DRAWING # 11898/250

LAW ENGINEERING
AND ENVIRONMENTAL SERVICES
CHARLOTTE, NORTH CAROLINA

ESP– PAK LIQUI–RAD–250
ECO–PAK SPECIALITY PACKING
ELIZABETHTON, TN.

JOB# 10810-9-7003 PH 10	FIG: 1 OF 2
DRAWN BY: MNP	SCALE: NTS
APPR'D BY:	DATE: 6-8-99

DROP TEST



TOP SURFACE VIEW

POSITION OF THE CONTAINER BOX WHEN CORNER "A" IS ALIGNED WITH THE CENTER OF GRAVITY

NOTES:

1. APPROX. CONTAINER WT 5440 LBS. (INCLUDING 250 GALLONS OF LIQUID)
2. WE ASSUMED THE C.G. OF THE BOX LOCATED ON THE CENTER LINE OF THE BOX.
3. WE CALCULATED C.G. OF THE BOX WHEN IT STANDS ON ITS LEGS.
4. ASSUMED DENSITIES AS FOLLOWS,
   C/S OR S/S 490 PCF
   (PCF = POUNDS PER CUBIC FEET)
   DURABOARD 8 PCF
   FIBERFRAX PAPER/INSULATION 8 PCF
   SALT WATER 1.2 grm/cc
   CAPACITY = 250 GALLONS
5. WELD MATERIAL WEIGHT IS SMALL AND THEREFORE IT IS NEGLECTED.
6. REF. ECO-PAK DRAWING # 11898/250

(DIMENSIONS ARE IN INCHES)

LAW ENGINEERING AND ENVIRONMENTAL SERVICES CHARLOTTE, NORTH CAROLINA	
ESP- PAK LIQUI-RAD-250 ECO-PAK SPECIALITY PACKING ELIZABETHTON, TN.	
JOB# 10810-9-7003 PH 10	FIG: 2 OF 2
DRAWN BY: MNP	SCALE: NTS
APPR'D BY:	DATE: 6-8-99

Appendix 2.10.2

Material Performance Testing to Determine Worst Case Drop Test Conditions

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
Page 1 of 1
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 ce No.	Impact Strength (ft. lbs.)	Lateral Expansion (in.)	Percent Shear (%)	Comments
7-98-1CB1	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.

Reviewed By:
Lakshman Santanam
Technical Center Manager

Respectfully Submitted,
LAW ENGINEERING INDUSTRIALS SERVICES

Larry Cable, Technical Leader

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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

·is :ce No.	Impact Strength (ft. lbs.)	Lateral Expansion (in.)	Percent Shear (%)	Comments
2-27-98-2CB1	111	0.080	25	+100°F
2-27-98-2CB2	110	0.075	30	"
2-27-98-2CB3	116	0.082	25	"
2-27-98-2CB4	116	0.078	80	+67°F
2-27-98-2CB5	109	0.074	75	"
2-27-98-2CB6	121	0.076	70	"
2-27-98-2CB7	111	0.037	25	-20°F
2-27-98-2CB8	110	0.033	25	"
2-27-98-2CB9	112	0.030	25	"

Respectfully Submitted,
LAW ENGINEERING INDUSTRIALS SERVICES

Reviewed By:
Lakshman Santanam
Technical Center Manager

Larry Goble, Technical Leader

LAW ENGINEERING INDUSTRIAL SERVICES
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PHONE 704-357-8600 •FAX 704-357-8637

REPORT OF CHARPY "V" IMPACT TESTING

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

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

Date: March 13, 1998

Client P.O. No.: Not Reported
Material: Reported as 6" Square X 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 ece No.	Impact Strength (ft. lbs.)	Lateral Expansion (in.)	Percent Shear (%)	Comments
7-98-3CB1	20	0.048	50	+100°F
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

LAW ENGINEERING INDUSTRIAL SERVICES

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

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P.O. BOX 19667 • CHARLOTTE, N.C. 28219-9667

PHONE 704-357-8600 •FAX 704-357-8637

ECO-PAK SPECIALTY PACKAGING

Laboratory Testing, ASTM D 1621-94

Law Engineering Industrial Services Project 10810-8-7008 Phase 04

March 18, 1998

Low Density Samples
(Direction 1)

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

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

Respectfully submitted,

Lakshman Santanam
Charlotte Technical Center Manager

LAW ENGINEERING INDUSTRIAL SERVICES

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

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

Low Density Samples
(Direction 2)

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

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

Respectfully submitted,

Lakshman Santanam
Charlotte Technical Center Manager

Appendix 2.10.3

Chemical and Galvanic Reactions Analysis

LAW

LAWGIBB Group Member

January 18, 2000

Mr. William M. Arnold
EcoPak Specialty Packaging
The Columbiana Boiler Company
200 West Railroad Street
Columbiana, Ohio 44408

Subject: **Material Reactivity**
LEES Project 10810-9-7003, Phase 17

Dear Mr. Arnold:

This letter is written in response to your request for Law Engineering & Environmental Services (LEES) to provide our opinion regarding chemical, galvanic or other corrosive reactions among or between several components. Specifically, the components are:

1. Stainless Steel and Sherwin Williams Epoxy Primer
2. Stainless Steel and Duraboard
3. Stainless Steel and Fiberfrax Fiber Paper
4. Carbon Steel and Sherwin Williams Epoxy Primer
5. Carbon Steel and Duraboard
6. Carbon Steel and Fiberfrax Fiber Paper

LEES completed accelerated corrosion testing of carbon steel and stainless steel samples in various configurations. Humid atmosphere primer adhesion and ferric chloride corrosion tests were performed at an elevated temperature. Please refer to our reports dated August 18, 1999, August 26, 1999 and September 2, 1999 (LEES Project 10810-9-7003, Phase 03) for detailed test results. We were provided with a copy of the Product Data Sheet and Material Safety Data Sheet for Epoxy Primer manufactured by Sherwin Williams Company.

LAW Engineering and Environmental Services, Inc.
2801 Yorkmont Road • Charlotte, NC 28208
704-357-8600 • Fax. 704-357-8638

Based on the results of the laboratory accelerated corrosion testing and review of the product sheet and MSDS for the primer, it is our opinion that no significant effects due to chemical, galvanic or other corrosion reactions among or between the duraboard, fiber paper and primer applied to the metal should occur. Our test results indicated that adhesion of the primer to the metal was important from a corrosion standpoint. In cases where the primer adhered to the metal, corrosion was greatly reduced.

We appreciate the opportunity to provide our services on this project. Please contact us if you have nay questions or need additional information.

Sincerely,

LAW ENGINEERING & ENVIRONMENTAL SERVICES

Lakshman Santanam, P.E.
Director of Projects
Assistant Vice President

Hussein M. Sadek, PMP
Corporate Consultant
Assistant Vice President

Appendix 2.10.4

Southwest Research Institute Hypothetical Accident Testing of Uranyl Nitrate Shipping Containers per Title 10CFR Part 71.73

SOUTHWEST RESEARCH INSTITUTE™

6220 CULEBRA ROAD • POST OFFICE DRAWER 28510 • SAN ANTONIO, TEXAS 78228-0510, USA • (210) 684-5111 • WWW.SWRI.ORG
CHEMISTRY AND CHEMICAL ENGINEERING DIVISION
DEPARTMENT OF FIRE TECHNOLOGY
WWW.FIRE.SWRI.ORG
FAX (210) 522-3377

August 21, 2001

Mr. Tom Dougherty
Chairman
Columbiana Boiler Company (CBC)
4580 E. 71st Street
Cleveland, Ohio 44125
Phone No. 216/271-6100
Fax No. 216/271-5403
E-mail: DCPARTNERS@AOL.COM

Subject: Pool Fire Exposure Conditions of 10 CFR Part 71.73

Ref: SwRI Final Report No. 01-02759, "Hypothetical Accident Testing of Uranyl Nitrate Shipping Containers per Title 10 CFR Part 71.73," Eco-Pak Liqui-Rad 250®

ENGINEERING EVALUATION (Consisting of 7 Pages)

Dear Mr. Dougherty:

This letter and attachments are provided in accordance with your request to address the Nuclear Regulatory Commission's (NRC's) request for additional information (RAI) concerning the pool fire exposure conditions during the above-reference test program.

As you know, 10 CFR Part 71.73, *Section (4) Thermal* states:

> "Exposure of the specimen, fully engulfed, except for a simple support system, in a hydrocarbon fuel/air fire of sufficient extent, and in sufficiently quiescent ambient conditions, to provide an average emissivity coefficient of at least 0.9, with an average flame temperature of at least 800°C (1475°F) for a period of 30 minutes, or any other thermal test that provides the equivalent total heat input to the package and which provides a time averaged environmental temperature of 800°C. The fuel source must extend horizontally at least 1 m (40 in.), but may not extend more than 3 m (10 ft), beyond any external surface of the specimen, aud the specimen must be positioned 1 m (40 in.) above the surface of the fuel source. For purposes of calculation, the surface absorptivity coefficient must be either that value which the package may be expected to possess if exposed to the fire specified or 0.8, whichever is greater; and the convective coefficient must be that value which may be demonstrated to exist if the package were exposed to the fire specified. Artificial cooling may not be applied after cessation of external heat input, and any combustion of materials construction, must be allowed to proceed until it terminates naturally."

The pool fire exposure test conducted September 22, 1999, on the Eco-Pak Liqui-Rad 250® shipping container met the intent of the hypothetical fire exposure conditions specified in 10 CFR 71.73.

The Eco-Pak Liqui-Rad 250® shipping container was exposed to a diesel fuel pool fire which reached temperatures in excess of 2000°F with a maximum temperature over 2400°F (see Figure 1). Figure 2 presents the average flame temperature for the four flame thermocouples (TC's) located on the north, south, east and west side of the shipping container. The integrated area beneath the time temperature curve for the period of 2 to 32 min yields an average flame temperature of approximately 1400°F. Calculation of the weighted average flame temperature yields 1500°F. Omitting the East TC, which was affected by wind conditions, yields an average flame temperature of 1533°F for the 30-min period.

The wind direction and velocity plots are shown in Figures 3 and 4. These plots show the trend that increased wind velocity from the East caused flame displacement from the East TC and reduced temperature readings. Note that the size of the pool fire and the position of the test article are fixed by the test procedure. Increasing the size of the pool fire would reduce the effect of wind on the flame temperature. It is important to note that 10 CFR 71.73 does not specify where the flame temperatures should be measured. Relocating the flame TC's as little as 6 in. lower into the flame plume would minimize the effect of wind on the flame temperature measurements aud yield much higher average flame temperature readings. Note that it would still be the same fire exposure but you would have higher temperature readings.

I hope this information is sufficient for your immediate needs. If I may be of further assistance, please contact me at (210) 522-3716, or by fax (210) 522-3377, or e-mail at JGriffith@swri.org.

Sincerely,

James R. Griffith, Jr.

STATE OF TEXAS
JAMES R. GRIFFITH, JR.
77757
REGISTERED
PROFESSIONAL ENGINEER

James R. Griffith, Jr., P.E., FPE
Manager
Fire Resistauce Section

Approved by:

Alex B. Wenzel

Alex B. Wenzel
Director
Department of Fire Technology

ABW/jgm

Attachment A: Figures 1 – 4

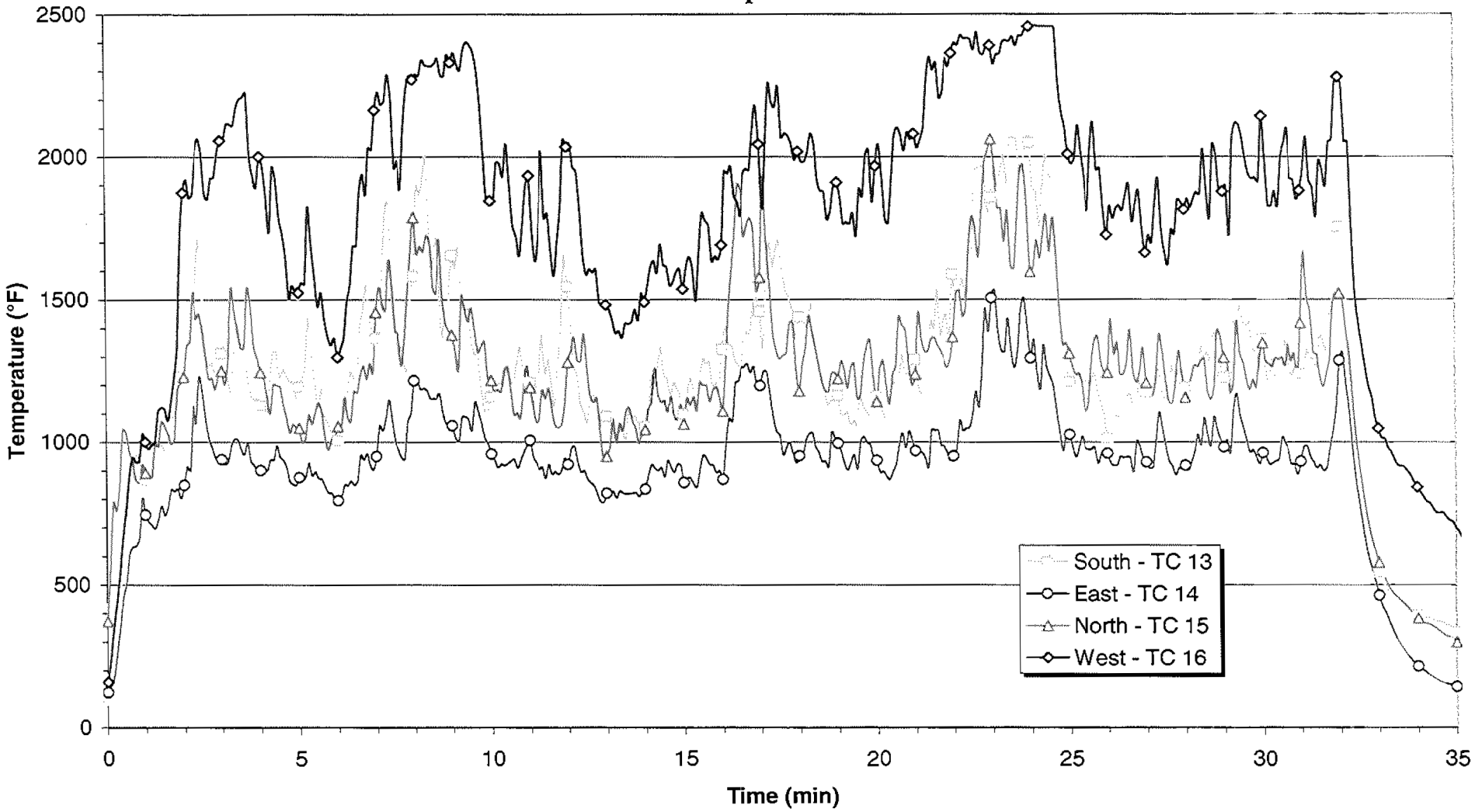
Columbiana Boiler Company
SwRI Project No. 01.02759
August 21, 2001

ATTACHMENT A

Consisting of 4 Pages

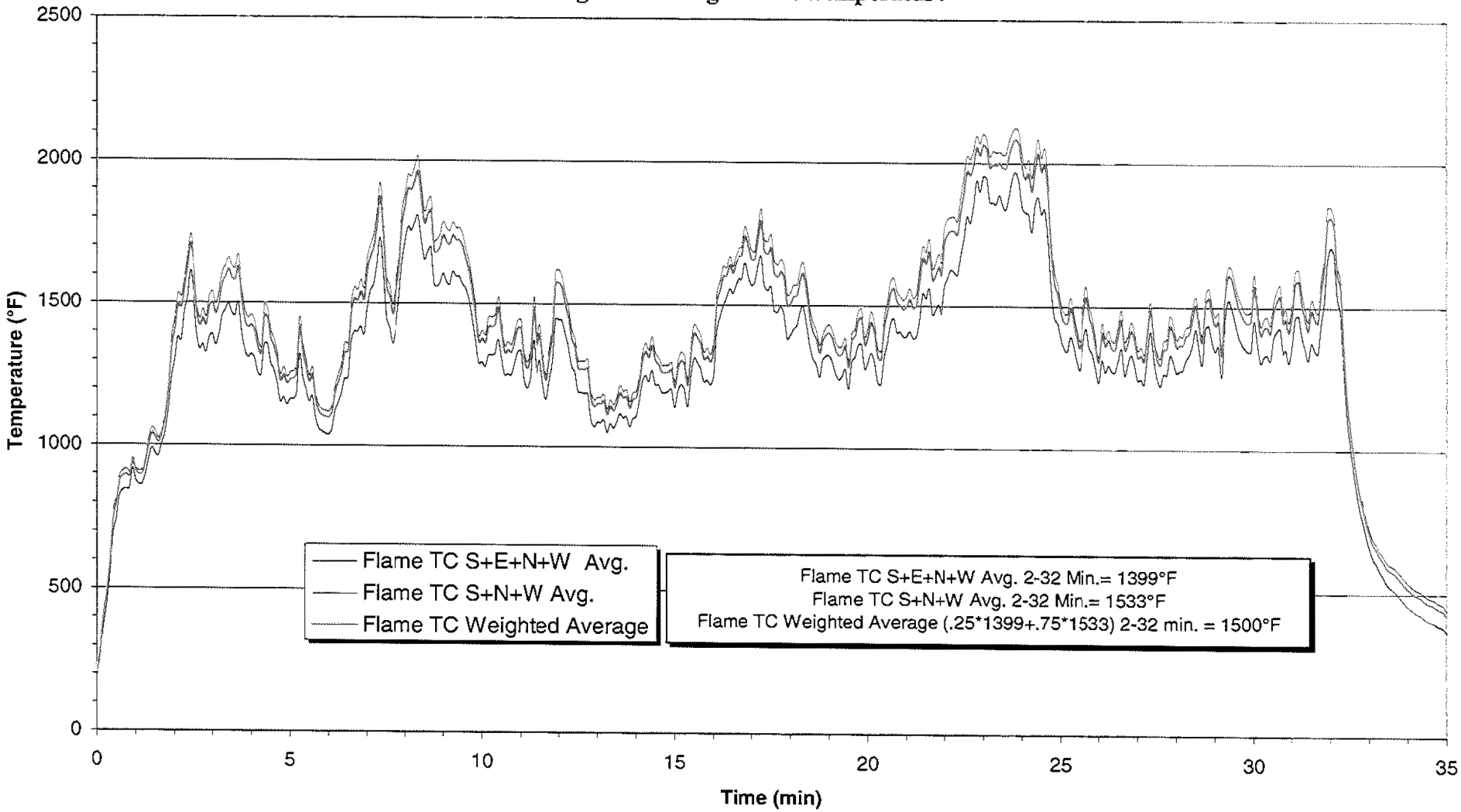
Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT

Figure 1.
Flame Temperatures



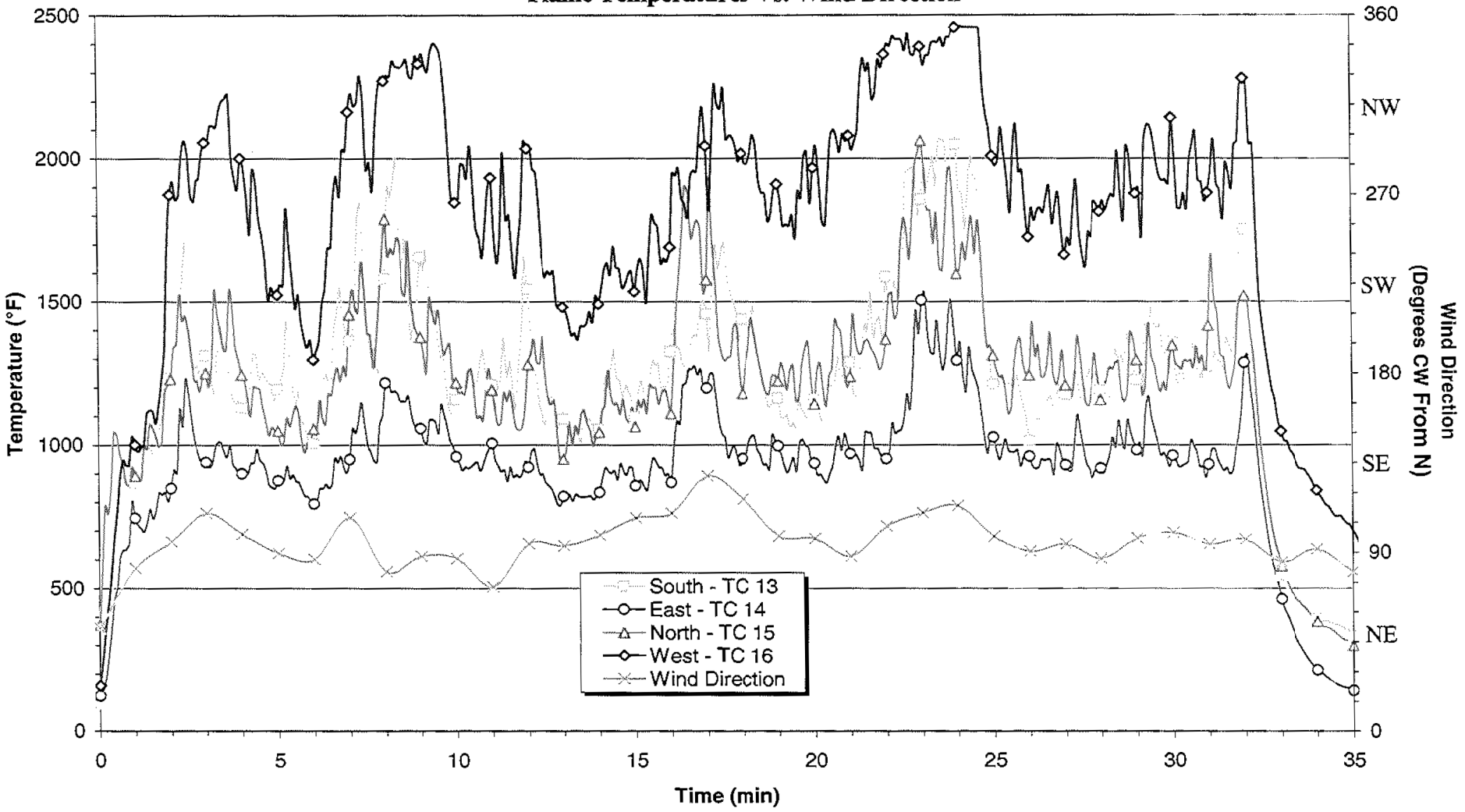
Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT

Figure 2.
Weighted Average Flame Temperature



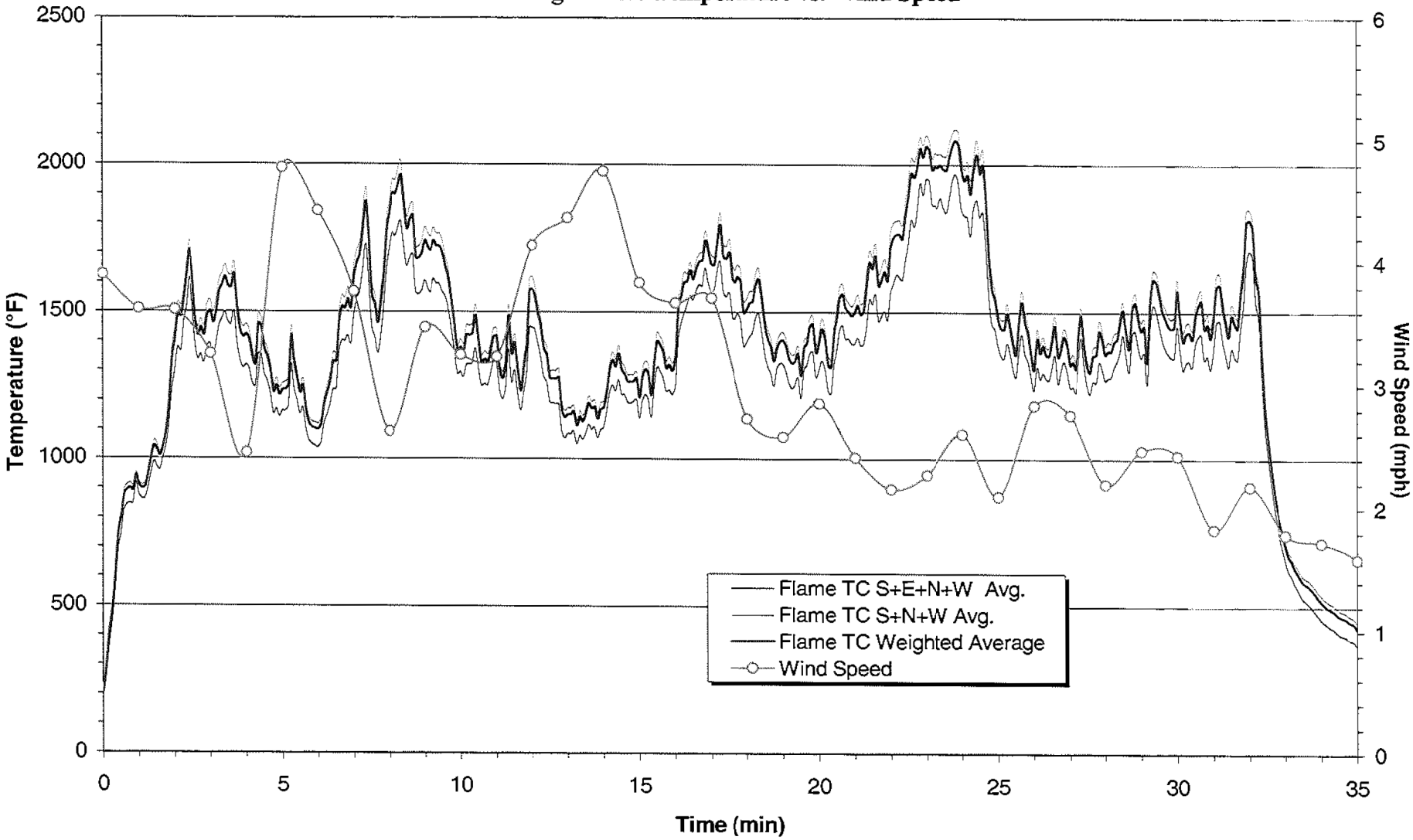
Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT

Figure 3.
Flame Temperatures Vs. Wind Direction



Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT

Figure 4.
Average Flame Temperature vs. Wind Speed



CBC MEMORANDUM

Date: 06/25/01

To: US NRC with respect to Request for Additional Information for the Model No. Eco-Pak Liqui-Rad Transport Unit Pcakage dated May 15, 2001

Cc: File

From: Tom Dougherty, Chairman

RE: Explanatory Representation as to the average flame temperature of the fire test performed at Southwest Research Institute

THERMAL EVALUATION

The LR experienced two separate fire events, as set forth in 10 CFR 71.73, on two separate days, without any repairs or modifications. The first fire event generated an average flame temperature, as measured by all the thermocouples of 1315 degrees F. This condition was caused by intermittent winds as described in the Safety Analysis Report.

The second fire event generated an average flame temperature, as measured by all the thermocouples of 1375 degrees F. This condition was caused by intermittent winds as described in the Safety Analysis report.

In the first fire event TC South, TC West averaged above 1475 degree F. TC East and North averaged below 1475 degrees F, while experiencing periods that exceeded 1475 degrees F.

In the second fire event TC North averaged significant above 1475 degrees F. TC West averaged significantly above 1475 degrees F. TC South averaged below 1475 degrees F while generating significant periods in excess of 1475 degrees F.

It is the opinion of the applicant that all periods of low temperatures were cause by intermittent wind conditions. Further the LR package experienced more than 60 minutes of fire events (2 x the required). The LR package accumulated four thermocouples that accumulated an average temperature of 1532 degrees F over two fire events, therefore meeting the average flame temperature requirements stated in 10CFR 71.73 9c) (4). See Test 1-TC-1 plus Test Two TC-1, TC-3, TC-4.

Thomas F Dougherty

Thomas F. Dougherty, Chairman

THE DEPARTMENT OF FIRE TECHNOLOGY

SOUTHWEST RESEARCH INSTITUTE

Chemistry & Chemical Engineering Division

SAN ANTONIO, TEXAS

Houston, Texas • Detroit, Michigan • Washington, D.C.

SOUTHWEST RESEARCH INSTITUTE

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CHEMISTRY AND CHEMICAL ENGINEERING DIVISION
DEPARTMENT OF FIRE TECHNOLOGY
FAX (210) 522-3377

HYPOTHETICAL ACCIDENT TESTING OF URANYL NITRATE SHIPPING CONTAINERS PER TITLE 10 CFR PART 71.73

FINAL REPORT
Consisting of 110 Pages
SwRI Project No. 01-02759
January 2000

Prepared for:

Columbiana Boiler Company (CBC)
Eco-Pak Specialty Packaging Division
200 West Railroad Street
Columbiana, Ohio 44408

Prepared by:	Reviewed by:	Approved by:
James R. Griffith, Jr., P.E., FPE	Mark R. Ehnstrom	Alex B. Wenzel
Assistant Manager	Sr. Quality Assurance Technologist	Director
Fire Resistance Section	Institute Quality Assurance	Department of Fire Technology

ABSTRACT

This report describes the methods and guidelines Southwest Research Institute (SwRI) followed for the preparation, instrumentation, and conditioning of test specimens; performance of drop tests, leakage tests, and fire endurance tests; reporting of test results; and all applicable documentation of these tasks in accordance with the requirements specified in SwRI Proposal No. 01-23375 and Columbiana Boiler Company (CBC), Eco-Pak Specialty Packaging (ESP) Division, Purchase Order No. 6250. This report includes the program objective, quality assurance requirements, test personnel qualifications, test facilities and instrumentation calibration, test procedure, test item description, test results, and applicable documentation.

The objective of this program was to conduct physical and fire performance evaluation tests of ESP's Uranyl Nitrate Liquids shipping package in accordance with the hypothetical accident conditions specified in Title 10 CFR Part 71.73 to verify the performance under the specified conditions. The test item, identified as the Eco-Pak Liqui-Rad-250®, was subjected first to the physical tests simulating hypothetical accident conditions for free drop and puncture described in Title 10 CFR 71.73 (c), (1) and (3). Following the drop tests, the Eco-Pak Liqui-Rad-250® shipping package was subjected to the thermal effects of the fully engulfing hydrocarbon pool fire exposure described in Title 10 CFR 71.73 (c), (4). Following each test, the physical condition of the Eco-Pak Liqui-Rad-250® shipping package was inspected and the results were recorded. The following table summarizes the results for the pre-drop/post-fire helium leak tests.

Table 1. Helium Leakage Test Results.
Test Item: Eco-Pak Liqui-Rad-250®

TEST	REQUIREMENT (std cc/sec)	MEASUREMENT (std cc/sec)	PASS/FAIL
Pre-Drop			
Primary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	5.9×10^{-9}	Pass
Secondary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	2.5×10^{-8}	Pass
Post-Fire			
Primary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	5.5×10^{-9}	Pass
Secondary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	4.9×10^{-8}	Pass

The following table summarizes the results of the drop testing performed on the Eco-Pak Liqui-Rad-250®. The test item received some damage following the drop test that was considered acceptable by ESP personnel.

Table 2. Eco-Pak Liqui-Rad-250® Drop Testing Performed.

Procedure	Dates	Comments
Test Item in Thermal Chamber	9/15/99	Initial temperature of test item was 90°F.
Conditioning Before Drop	9/16/99	Test item insulation, temperature measurements ranged from -32 to -38.1°F.
30-ft Drop (inverted drop)	9/16/99	Successful drop.
Exterior Physical Measurements	9/16/99	Recorded on data sheets.
30-ft Drop (inverted corner drop)	9/16/99	Successful drop.
Exterior Physical Measurements	9/16/99	Recorded on data sheets.
40-in. Drop (puncture)	9/16/99	Successful drop.
Exterior Physical Measurements	9/16/99	Recorded on data sheets.

The Department of Fire Technology conducted the 30-min pool fire test described in Title 10 CFR 71.73 (c), (4) on September 22, 1999. The average flame temperature during the 30-min plus pool fire exposure was 1375°F. The average initial temperature of the thermocouple fitted to the inside container was 91°F with a maximum temperature of 108°F. The temperature recorded on the outer surface of the inside container after the 30-min pool fire exposure test ranged from 176 to 1145°F. The elevated temperature reading is most likely caused by heat being conducted through the thermocouple (TC) and the TC became separated from the surface of the container.

After a 30-min cool down period, the maximum single point temperature recorded was 610°F, and the average of the sample TC readings was 297°F. Following a 60-min cool down period, the maximum single point temperature recorded was 234°F, and the average sample TC's was 148°F.

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

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1.0 INTRODUCTION

This report describes the methods and guidelines Southwest Research Institute (SwRI) followed for the preparation, instrumentation, and conditioning of test specimens; performance of drop tests, leakage tests, and fire endurance tests; reporting of test results; and all applicable documentation of these tasks in accordance with the requirements specified in SwRI Proposal No. 01-23375 and Columbiana Boiler Company (CBC), Eco-Pak Specialty Packaging (ESP) Division, Purchase Order No. 6250. Testing was conducted by SwRI's Department of Fire Technology located in San Antonio, Texas, on September 14, 16 and 22, 1999. This report includes the program objective, quality assurance requirements, test personnel qualifications, test facilities and instrumentation calibration, test procedure, test item description, test results, and applicable documentation.

2.0 PROGRAM OBJECTIVE

The objective of this program was to conduct physical and fire performance evaluation tests of ESP's Uranyl Nitrate Liquid shipping package in accordance with the hypothetical accident conditions specified in Title 10 CFR Part 71.73, to verify the performance under the specified conditions. The Eco-Pak Liqui-Rad-250® shipping package was subjected first to the physical tests simulating hypothetical accident conditions for free drop and puncture described in Title 10 CFR 71.73 (c), (1) and (3). Following the drop tests, the Eco-Pak Liqui-Rad-250® shipping package was subjected to the thermal effects of the fully engulfing hydrocarbon pool fire exposure described in Title 10 CFR 71.73 (c), (4). Following each test, the physical condition of the Eco-Pak Liqui-Rad-250® shipping package was inspected, and the results were recorded.

3.0 PROGRAM ORGANIZATION

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

The overall program was managed by Mr. James R. Griffith Jr., P.E., FPE, Project Manager in the Department of Fire Technology in the Chemistry and Chemical Engineering Division. The physical

[1] All Figures are located at the end of the report.

(drop) testing was performed by the Structural Dynamics and Environmental Testing Group in the Mechanical and Fluids Engineering Division. The leakage tests were performed by the Test and Fabrication Section of the Materials and Structures Division. SwRI's Quality Assurance Department provided independent surveillance, quality checks, and inspections during the course of this program, as required. The following sections provide further information for each of the supporting technical divisions.

4.0 QUALITY ASSURANCE REQUIREMENTS

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

5.0 TEST ITEM IDENTIFICATION

Eco-Pak Specialty Packaging, Division of Columbiana Boiler Company, was responsible for the design, fabrication, and delivery of the Eco-Pak Liqui-Rad-250® shipping package, which consisted of the inner liquid container and protective overpack. SwRI performed the initial test item preparation including filling the container with a liquid salt solution and clean steel shot and recording preliminary measurements.

The Eco-Pak Liqui-Rad-250® shipping container was constructed in accordance with the detail drawings provided by ESP. Photographic documentation prior to the drop tests and following the drop and fire tests appear in Appendix A, Construction Details and Dimensional Measurements.

6.0 TEST FACILITIES

6.1 Leakage Testing Facilities

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

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

6.2 Drop Testing Facilities

6.2.1 Environmental Conditioning

Low temperature conditioning of the test item before drop testing was done in a chamber built specifically for this project. The schematic diagram of the facility, is shown in Figure 3. The facility was constructed in close proximity to the drop test site to minimize time between removal of the test item from conditioning and drop testing. The test chamber was a plywood box with rigid foam insulation. A removable top was provided for insertion and removal of the test item. A single insulated door was provided for access to the test item. Cooling to the facility was supplied by liquid nitrogen. Thermal monitoring was routed from the chamber to an adjacent building for acquisition and control of the flow of liquid nitrogen. A Watlow controller, referenced to a thermocouple (TC) measuring air temperature in the chamber, controlled the supply of liquid nitrogen. Additional thermocouples were used to monitor the air temperature in the chamber and test item temperatures during conditioning. These data were processed using a Fluke Hydra data logger attached to a computer for data storage. For reporting purposes, data files were reduced following the testing.

6.2.2 Wind Instrumentation

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

6.2.3 Test Pad

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

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

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

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

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

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

6.3 Fire Testing Facilities

The Department of Fire Technology has more than 30,000 sq ft of laboratory space housing advanced fire science analysis equipment and state-of-the-art full-scale furnaces used to evaluate the fire endurance and fire resistance of full-scale construction elements and assemblies. SwRI's large-scale horizontal furnace shown in Figure 4 was available to condition the test item at elevated temperature prior to conducting the pool fire test.

The Department operates a remote test facility located approximately 40 miles from SwRI's San Antonio facility. The remote test facility is isolated on approximately 15,000 acres and has full utility service. The facility is equipped with a mobile technical support trailer housing state-of-the-art rapid data acquisition equipment, environmental condition station, high-speed computer equipment, and photo/video documentation equipment. The test facility and a diagram of the pool fire test setup are shown in Figures 5a and b.

7.0 EQUIPMENT AND INSTRUMENTATION CALIBRATION

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

Table 1. Test Instrumentation.

Item	Model	S/N	Calibration Due Date	Comments
Data Acquisition	Hewlett-Packard	US37003830	17 Aug 2000	Fire Tests
Thermal Controller	Watlow 942	NA	NA	Control only with independent monitoring
Plumb Bob 30 foot Drop Height	NA	NA	16 December 1999	Length based on calibrated tape measure, s/n 30-100T
Plumb Bob 40-in. Drop Height	NA	NA	16 December 1999	Length based on calibrated tape measure, s/n 30-100T
Level	Smartlevel Series 200	PLL-001	NA	Calibration not required.
Data Acquisition	Fluke Helios	4752005	25 June 2000	Fire tests
Weather Station	NA	492	5 January 2000	Fire tests
Inconel Sheathed TC's (Container)	NA	LOT#M482380	14 January 2000	Fire tests
Inconel Sheathed TC's (Flames)	NA	LOT#M055992	30 September 1999	Fire tests
Air Velocity Meter		4000-90-102276	30 July 2000	Drop and Fire Tests
Psychrometer	Benndix 566	J82244-1	29 July 2000	Drop and Fire Tests
Veeco	7MS-40	0972	21 November 1999	Helium Leakage Tests
Multimeter Fluke	8060A	5210280	23 June 2000	Instrument Support

8.0 TEST PROCEDURE

8.1 Initial/Final Inspection and Preparation of Test Item

SwRI performed initial inspection to verify the pretest condition of the Eco-Pak Liqui-Rad-250® shipping package and photographs were taken as necessary. ESP provided the test article and SwRI filled the container with a salt solution and lead shot to simulate a full payload. SwRI conducted an initial leakage test to confirm that the container was airtight. See Appendix A for construction details and drawings of the Eco-Pak Liqui-Rad-250® shipping package.

SwRI installed temperature measuring devices as necessary to monitor the temperature of the test article during the fire test. The temperature measuring devices were selected to ensure that the required information could be obtained without adversely affecting the performance of the system. This includes both the temperature time histories and the peak temperature readings. Slight modification of the container (shown in Figure 6) was required to attach the temperature measuring devices. See Figure 7 for TC and thermal tape locations for the containers.

Helium leakage tests were performed following the initial inspection and test article preparation and at completion of the pool fire test to ensure that the internal container remained air tight.

8.2 Leakage Tests

Leakage tests were performed on the internal container prior to conducting the drop tests and following the pool fire exposure test. The helium leak tests were performed by evacuating the area between the o-ring seals for the blind flanges labeled Detail "A" and Detail "B" of ESP Drawing No. 111898/250. The pressure was reduced to the required level, helium was introduced in the region surrounding the O-ring seals, and the leak rate was measured with a helium leak detector and recorded.

8.3 Drop Testing

The initial physical tests of the Eco-Pak Liqui-Rad-250® shipping package were a series of drop tests as described in Title 10 CFR 71.73 (c), (1) & (3).

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

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

There were three drops of the Eco-Pak Liqui-Rad-250® shipping package in the drop testing phase. The first drop test performed was a 30-ft drop onto the flat surface of the pad with the test item in a vertical, inverted position. The second drop was a 30-ft drop onto a corner of the specimen with the test item inverted. The final drop test was a 40-in. drop onto a puncture bar attached to the center of the steel plate on the drop pad. The puncture bar was constructed of a 6-in. diameter mild steel bar welded into a 2-in. thick steel plate. This plate was, in turn, bolted to the steel plate on top of the drop surface. Following all drops, the damage to the Eco-Pak Liqui-Rad-250® shipping package was observed and recorded.

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

8.4 Fire Performance Evaluation

Following the drop tests, the test items were to be transported to SwRI's Department of Fire Technology for elevated temperature thermal conditioning prior to performing the pool fire test at SwRI's remote test facility. Since the temperature of the test item was approximately 90°F, the elevated temperature thermal soak requirement was waived; and the test article was transported to the remote test site, positioned on the test fixture, and exposed to the specified pool fire conditions for a minimum 30-min period.

Documentation consisted of normal speed video and still photography at a minimum of two locations. The pool fire dimensions were 25 x 25 ft. Fuel was pumped into the pool fire pan during the test at a rate appropriate to maintain a fully engulfed pool fire for 30 min.

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

9.0 TEST RESULTS

9.1 Leakage Test Results

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

The pre-drop helium leakage test was performed on September 14, 1999. A vacuum pump was used to evacuate the containers to the required pressure of less than 1×10^{-3} atm (1×10^{-3} atm = .0147 psi = .761 Torr). The background helium leakage rate was measured, and helium was introduced in the region surrounding the O-ring seals. The leakage rate was measured after 10 min with the helium leak detector, and the results were recorded.

Following completion of the pool fire exposure tests on September 22, 1999, the final post-fire helium leakage tests were performed. A vacuum pump was used to evacuate the containers to the required pressure, and the background helium leakage rate was measured. Helium was introduced in the region surrounding the O-ring seals, and the leakage rate was measured after 10 min with the helium leak detector.

Following completion of the post-fire helium leakage tests, all containers were inspected and found to be undamaged and in good condition with no loss of contents. Table 2 summarizes results for the pre-drop/post-fire helium leak tests. Data log sheets for all leakage tests are found in Appendix C.

9.2 Drop Testing

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

Table 2. Leakage Test Results.
Test Item: Eco-Pak Liqui-Rad-250®

TEST	REQUIREMENT (std cc/sec)	MEASUREMENT (std cc/sec)	PASS/FAIL
Pre-Drop			
Primary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	5.9×10^{-9}	Pass
Secondary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	2.5×10^{-8}	Pass
Post Fire			
Primary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	5.5×10^{-9}	Pass
Secondary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	4.9×10^{-8}	Pass

The drop testing included the following major steps:

1) Conditioning to -20°F of Eco-Pak Liqui-Rad-250®.
2) Initial 30-ft drop test in vertical inverted orientation.
3) Physical inspections of unit.
4) 30-ft drop test on corner, inverted orientation.
5) Physical inspections of unit.
6) 40-in. puncture drop test, side impact.
7) Physical inspections of unit.

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

9.2.1 Assumptions

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

9.2.2 Environmental Conditioning

The low temperature conditioning was done in a chamber to achieve the required test item temperature, -20°F, on the insulation. To measure the surface temperatures, four TC's were placed on the surface of the test item and monitored during the low temperature conditioning. The target air temperature was -40°F, the minimum transportation temperature specified by ESP. In some cases, the air temperature was set lower than this to accelerate the cooling. Because of the thermal mass and insulation of the test item, its response to changes in the air temperature was rapid.

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

Plots of the chamber air temperature and test item temperatures are included in this report as Figure 8. Low-temperature conditioning of the Eco-Pak Liqui-Rad-250® test item started on September 15, 1999, at 4:00 p.m. The chamber air temperature was set to a nominal -40°F.

On September 16, 1999, at 3:21 p.m., Eco-Pak Liqui-Rad-250® was removed from the chamber, and the assigned drop tests were performed. At the time of removal from the conditioning chamber, the insulation had a temperature of less than -33°F.

9.2.3 Drop Testing

Drop testing was performed with the cooled and undamaged Eco-Pak Liqui-Rad-250® test item. After low-temperature conditioning, the test item was removed from the chamber. Immediately before opening the chamber, the test item temperature was less than -33°F (see Figure A-1 in Appendix A). The test item was raised to the required drop height with the crane. The drop height was determined using the calibrated plumb bob attached to the first impact point on the test item. The release of the test item was by a pneumatically actuated quick-release mechanism. No guidance of the test item was provided during the drop. Drop testing was performed under conditions that did not affect the results of the test. The average wind speed was noted, and found to be sufficiently low, so that the packaging did not rotate during testing.

Three tests were performed on Eco-Pak Liqui-Rad-250® shipping package. The first was a 30-ft drop onto the flat surface of the pad with the test item in a vertical inverted orientation. The damage to the test item was measured and recorded following this testing. The second drop was a 30-ft drop onto one corner of the test item in an inverted orientation. The damage to the exterior was again measured and recorded following this testing. The last test was a 40-in. drop onto a puncture bar. Following each of these tests, the damage to the test item was measured and recorded. The construction details and dimensions measurements appear in appendix D.

Table 3 and the explanations that follow summarize the testing performed on this test item. All testing was completed successfully, and all phases of this testing were witnessed by SwRI QA/QC and ESP personnel.

Table 3. Eco-Pak Liqui-Rad-250® Drop Testing Performed.

Procedure	Dates	Comments
Test Item in Thermal Chamber	9/15/99	Initial temperature of test item was 90°F.
Conditioning Before Drop	9/16/99	Test item insulation, temperature measurements ranged from -32 to -38.1°F.
30-ft Drop (inverted drop)	9/16/99	Successful drop.
Exterior Physical Measurements	9/16/99	Recorded on data sheets.
30-ft Drop (inverted corner drop)	9/16/99	Successful drop.
Exterior Physical Measurements	9/16/99	Recorded on data sheets.
40-in. Drop (puncture)	9/16/99	Successful drop.
Exterior Physical Measurements	9/16/99	Recorded on data sheets.

Figure A-2 shows Test 1 (vertical drop, test item inverted). Pre-test conditions were:

- Drop Angle 0 degrees (measured from vertical)
- Drop Height 30 ft to impact face (lowest point while suspended)
- Wind Speed < 1.6 mph

The test item was released cleanly and impacted the drop pad and remained on its top surface following impact (see Figures A-3 and A-4). As a result of the impact, the exterior of the test item, including the angle iron framing, was deformed as shown in Figure A-5. Deformation data of the exterior was measured and recorded by Fire Technology personnel and reported in Appendix C. Video

Figure A-6 shows Test 2 (corner drop, test item inverted). Pre-test conditions were:

- Drop Angle 31.5 degrees (measured from vertical)
- Drop Height 30 ft to impact face
- Wind Speed < 3.7 mph

The test item was released cleanly and the drop was made with the impact in the proper location. The test item fell on its side after impacting the drop pad. As a result of the impact, the exterior of the test item, including the angle iron framing, was deformed further, as shown in Figures A-7 through A-10. Deformation of the unit was measured and recorded by Fire Technology personnel and reported in Appendix C. Video was taken of the drop event and color photographs showing the extent of damage were taken and are included with this report. SwRI QA/QC and ESP personnel witnessed all phases of the drop test.

Figure A-11 shows Test 3 (puncture test, side orientation). Pre-test conditions were:

- Drop Angle 1.5 degrees (longitudinal axis from horizontal)
- Drop Height 40 in. to impact face
- Wind Speed < 1.5 mph

The test item was released cleanly and impacted the drop pad in the proper location and orientation. The test item remained on its side after impacting the cylindrical puncture bar (see Figures A-12 and A-13). Deformation data of the exterior was measured and recorded by Fire Technology personnel and reported in Appendix C. Video was taken of the drop event and color photographs showing the extent of damage were taken and are included with this report. SwRI QA/QC and ESP personnel witnessed all phases of the drop test.

9.3 Fire Performance Evaluation Test

Figure A-14 shows the placement of thermal indicator tapes within the lid opening and Figure A-15 shows the thermocouples penetrating the outer shell. The Eco-Pak Liqui-Rad-250® package was transported to the remote test site in D'Hanis and the pool fire test described in Title 10 CFR 71.73 (c), (4) was performed on September 22, 1999. Messrs. Mike Arnold and Rick McVey representing ESP were present to witness the test. Following initial startup procedures and transfer of 2000 gal of diesel fuel to the burn pan, the data acquisition equipment was verified and the fuel was ignited to begin the 30-min pool fire test. Table 4 lists the significant observations during the pool fire exposure and post-test cool down period.

Following extinguishment, temperature data were recorded during the cool down period. During the cool down, the test article was protected from precipitation and wind effects to eliminate enhanced cooling of the test article.

Time-temperature profiles and test condition graphs taken before and during the pool fire exposure and cool down period are shown in Figures 9 through 12. The average flame temperature recorded by the TC's used to measure the pool fire was 1315°F. This is partly attributed to the wind speed increasing after the test was started. During the test, the average wind speed was 5.9 mph.

Table 4. Pool Fire Test Observations (Test No. 1).

TIME (Min:Sec)	OBSERVATIONS
-0:45	Pool fire ignited to begin pre-burn.
0:00	Pre-burn completed. Flames fully developed across pool surface.
1:00	Test item engulfed by flames. Light north wind blowing flames south. Test item mostly engulfed by flames.
10:00	Continuous light north wind pushing flames south. Intermittent view of test item.
17:45	Small fire plume visible at top of test item.
20:00	Continuous north wind pushing flames south. Intermittent view of test item. Continuous fire plume from test item.
30:00	Continuous north wind pushing flames south. Intermittent view of test item. Continuous fire plume from test item.
33:30	Flames decreasing in pool. Test item mostly visible. Continuous fire plume from test item.
36:00	Small flames remaining on test item. Pool fire nearly extinguished.
39:00	Small flames remaining on test item and in pool.
40:10	No visible flames on test item.
40:15	No visible flames in pool.
45:00	Initial inspection of test item.
50:00	Temperature monitoring of test item continuing (no stop between burn and cool-down period).

Since the wind speed was more than optimal and the flame temperatures were less than required, the pool fire test was repeated without any repairs or modifications to the test item (see Figures A-18 and A-19). Following initial startup procedures and transfer of 2000 gal of diesel fuel to the burn pan, the data acquisition equipment was verified and the fuel was ignited to begin the 30-min pool fire test (see Figures A-20 and A-21). Table 5 lists the significant observations during the pool fire exposure and post-test cool down period (see Figures A-22 and A-23).

Table 5. Pool Fire Test Observations (Test No. 2).

TIME (Min:Sec)	OBSERVATIONS
-0:45	Pool fire ignited to begin pre-burn.
0:00	Pre-burn completed. Flames fully developed across pool surface.
1:00	Light East wind blowing flames west. Test item engulfed in flames.
10:00	Continuous wind blowing flames west. Intermittent view of test item.
17:30	Small fire plume seen emitting from upper side of test item.
20:00	Wind lessens, pool flame nearly vertical. Test item engulfed by flame. Continuous fire plume from test item.
25:00	Slight increase in wind. Intermittent view of test item. Continuous fire plume visible from test item.
30:00	Constant light wind blowing flames west. Intermittent view of test item. Continuous fire plume visible from test item.
32:30	Light wind from southeast blowing flames northwest. Reduced flaming in pool. Test item mostly visible.
35:00	Continuous small fire plume from test item. Pool fire almost extinguished.
36:30	Only very small flames remaining in pool. Fire plume from test item continuous.
39:00	Continuous small fire plume on upper side test item.
45:00	Initial inspection of test item.
50:00	Temperature monitoring of test item continuing (no stop between burn and cool-down period.

Time-temperature profiles and test condition graphs taken before and during the pool fire exposure and cool down period are shown in Figures 13 through 16. The average flame temperature recorded by the TC's used to measure the pool fire was 1375°F and the average wind speed during the test was 3.1 mph.

Tabular data for the test conditions TC measurements appear in Appendix E.

10.0 SUMMARY OF TEST RESULTS

The objective of this program was to conduct physical and fire performance evaluation tests of ESP's Uranyl Nitrate Liquids shipping package in accordance with the hypothetical accident conditions specified in Title 10 CFR Part 71.73 to verify the performance under the specified conditions. The test item, identified as the Eco-Pak Liqui-Rad-250®, was subjected first to the physical tests simulating hypothetical accident conditions for free drop and puncture described in Title 10 CFR 71.73 (c), (1) and (3). Following the drop tests, the Eco-Pak Liqui-Rad-250® shipping package was subjected to the thermal effects of the fully engulfing hydrocarbon pool fire exposure described in Title 10 CFR 71.73 (c), (4). Following each test, the physical condition of the Eco-Pak Liqui-Rad-250® shipping package was inspected and the results were recorded. The following table summarizes the results for the pre-drop/post-fire helium leak tests.

Table 6. Helium Leakage Test Results.

Test Item: Eco-Pak Liqui-Rad-250®

TEST	REQUIREMENT (std cc/sec)	MEASUREMENT (std cc/sec)	PASS/FAIL
Pre-Drop			
Primary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	5.9×10^{-9}	Pass
Secondary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	2.5×10^{-8}	Pass
Post-Fire			
Primary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	5.5×10^{-9}	Pass
Secondary Seal (Detail A on Drawing)	$\leq 1.0 \times 10^{-7}$	4.9×10^{-8}	Pass

The following table summarizes the results of the drop testing performed on the Eco-Pak Liqui-Rad-250®. The test item received some damage following the drop test that was considered acceptable by ESP personnel.

Table 7. Eco-Pak Liqui-Rad-250® Drop Testing Performed.

Procedure	Dates	Comments
Test Item in Thermal Chamber	9/15/99	Initial temperature of test item was 90°F.
Conditioning Before Drop	9/16/99	Test item insulation, temperature measurements ranged from -32 to -38.1°F.
30-ft Drop (inverted drop)	9/16/99	Successful drop.
Exterior Physical Measurements	9/16/99	Recorded on data sheets.
30-ft Drop (inverted corner drop)	9/16/99	Successful drop.
Exterior Physical Measurements	9/16/99	Recorded on data sheets.
40-in. Drop (puncture)	9/16/99	Successful drop.
Exterior Physical Measurements	9/16/99	Recorded on data sheets.

The Department of Fire Technology conducted the 30-min pool fire test described in Title 10 CFR 71.73 (c), (4) on September 22, 1999. The average flame temperature during the 30-min plus pool fire exposure was 1375°F. The average initial temperature of the thermocouple fitted to the inside container was 91°F with a maximum temperature of 108°F. The temperature recorded on the outer surface of the inside container after the 30-min pool fire exposure test ranged from 176 to 1145°F. The elevated temperature reading is most likely caused by heat being conducted through the thermocouple (TC) and the TC became separated from the surface of the container.

After a 30-min cool down period, the maximum single point temperature recorded was 610°F, and the average of the sample TC readings was 297°F. Following a 60-min cool down period, the maximum single point temperature recorded was 234°F, and the average sample TC's was 148°F.

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

SOUTHWEST RESEARCH INSTITUTE
ORGANIZATION CHART

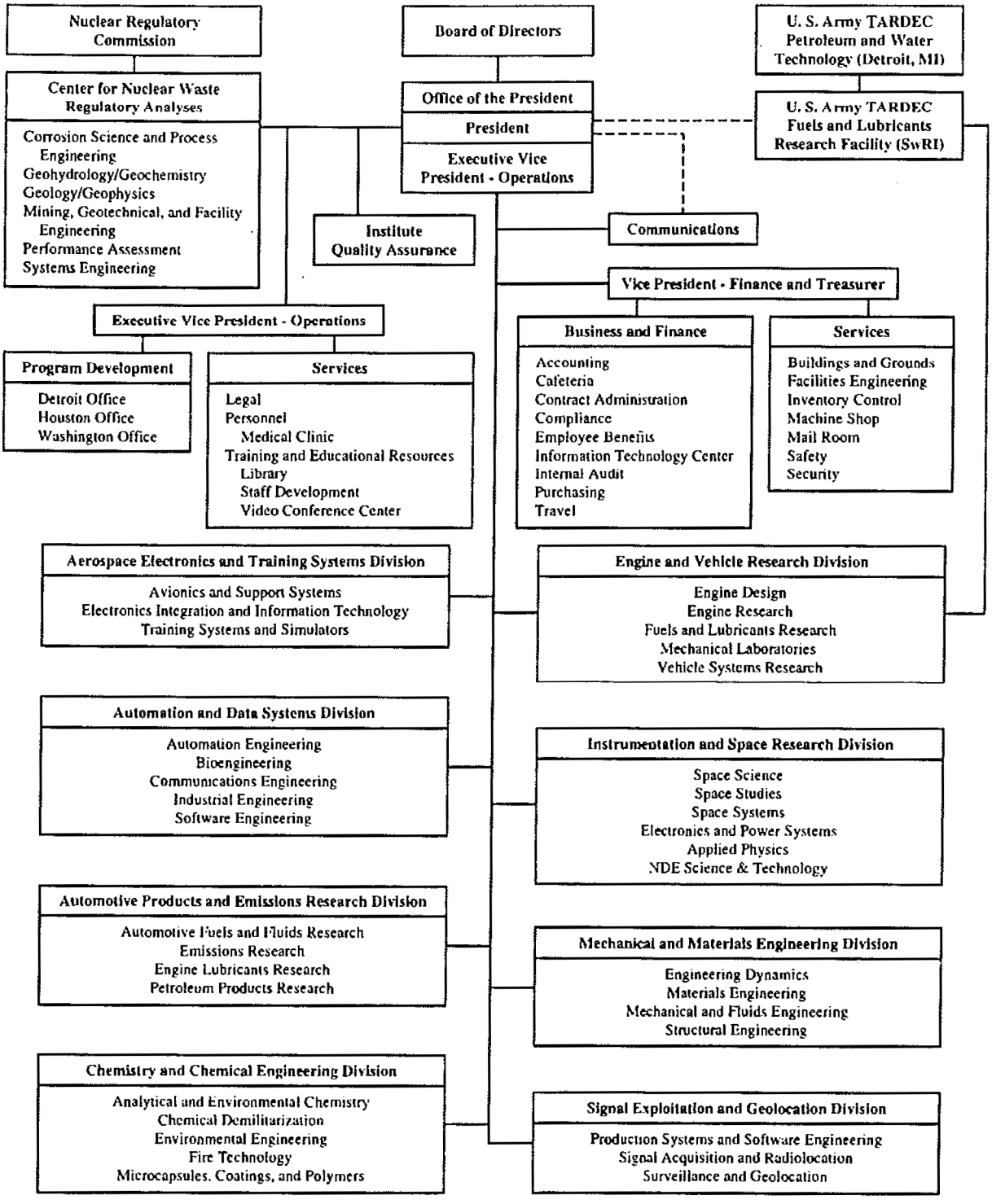


Figure 1. SwRI Organization Chart.

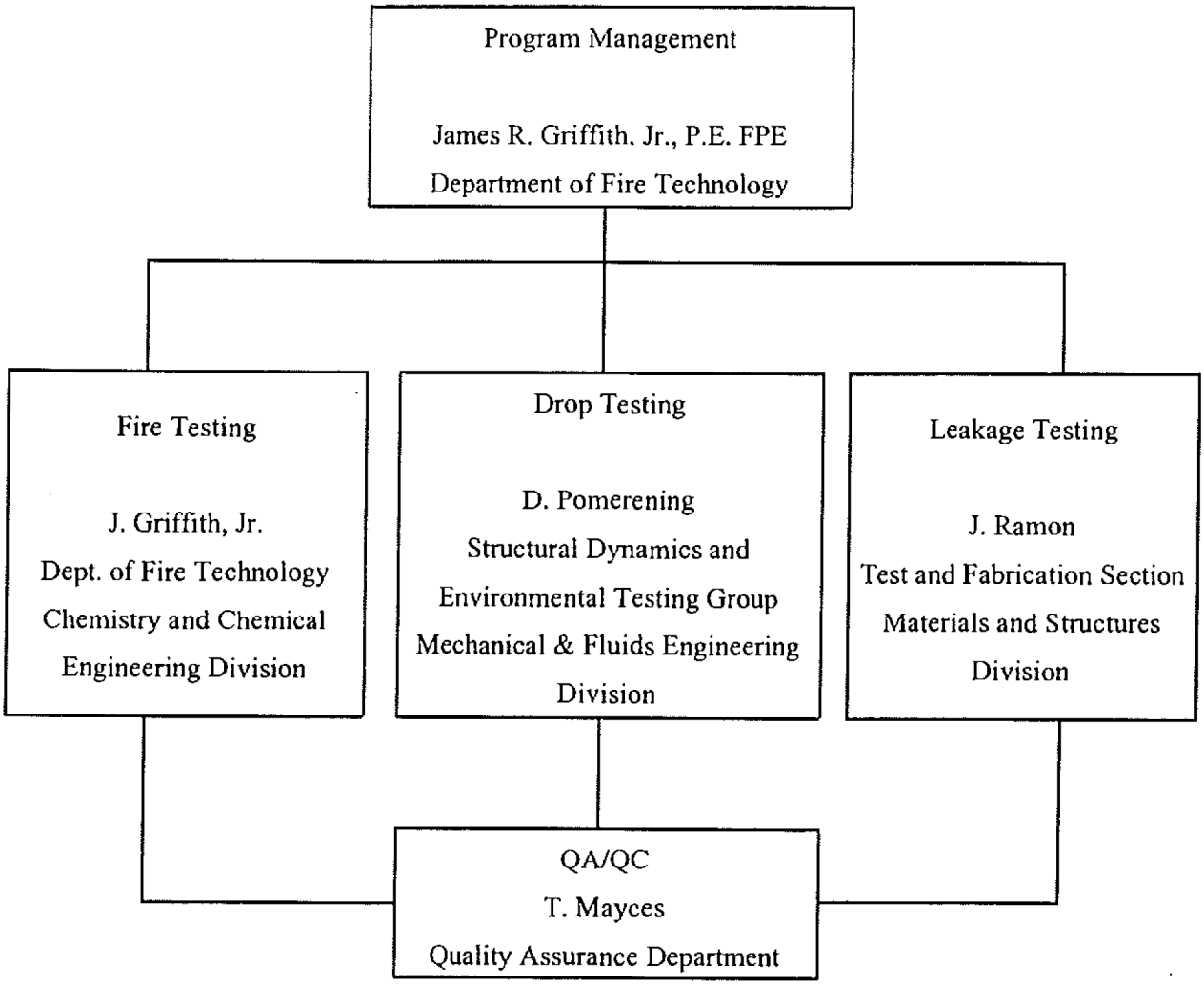


Figure 2. Program Organizational Chart.

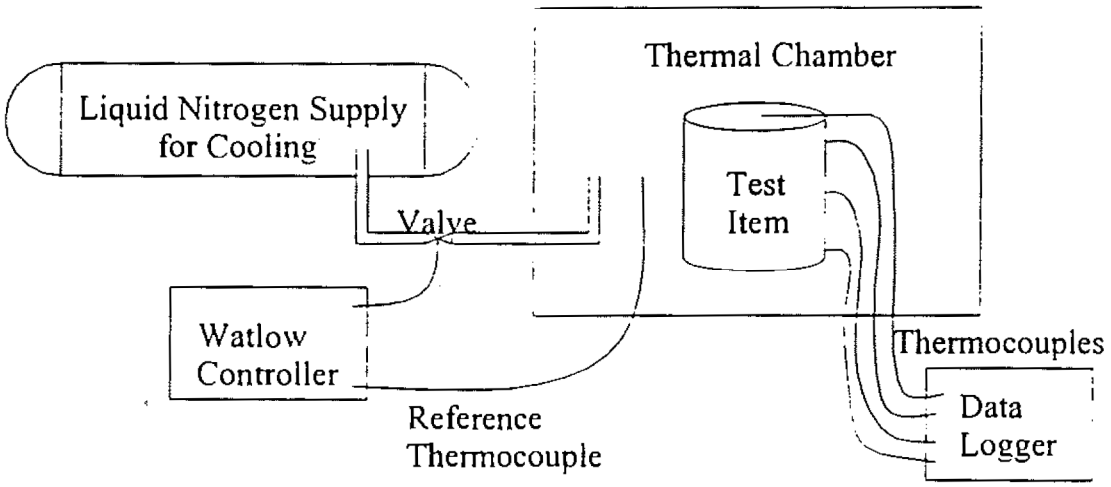


Figure 3. Schematic Diagram of Environmental Conditioning Chamber.

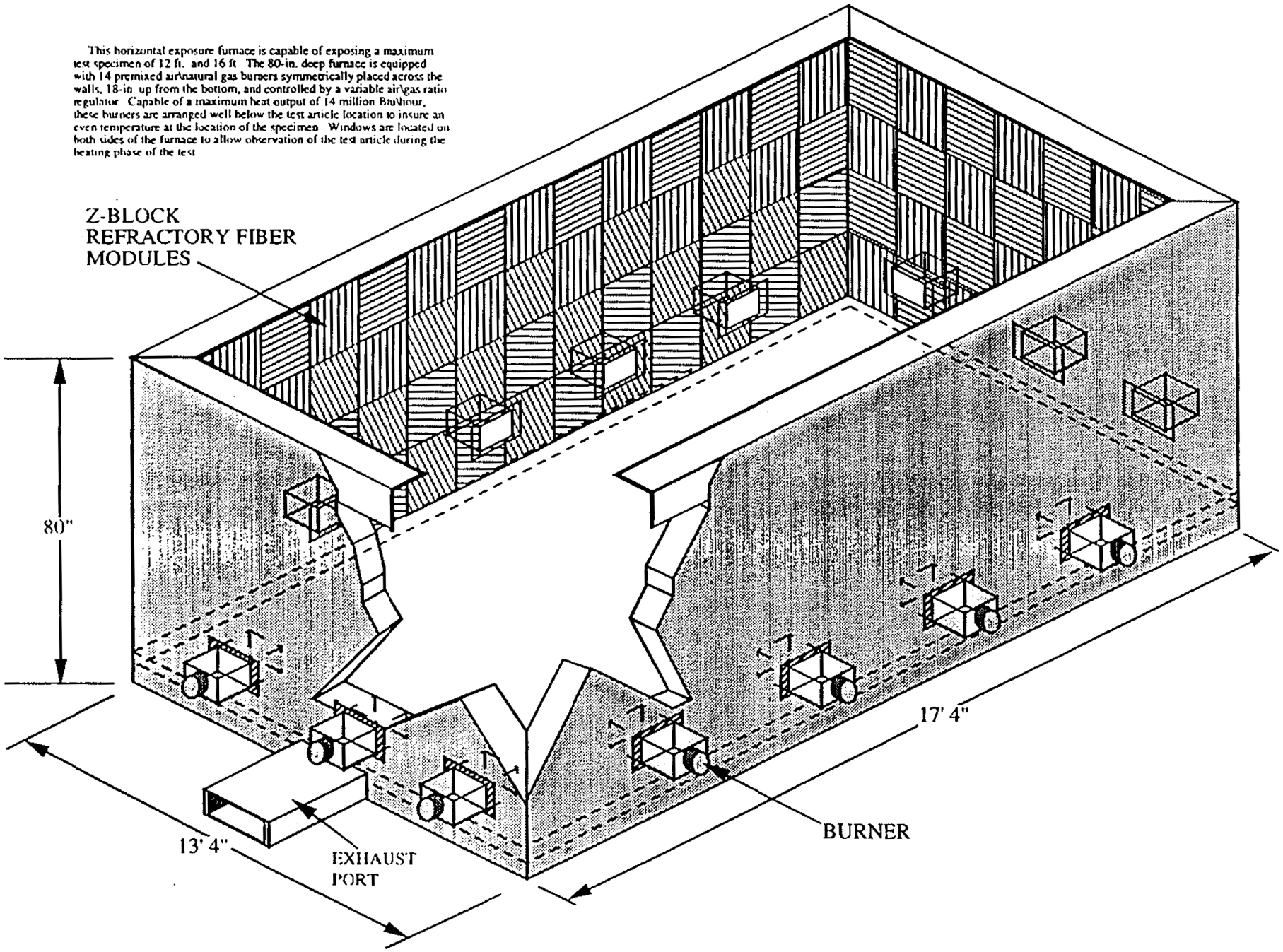


Figure 4. SwRI's Large-Scale Horizontal Furnace.

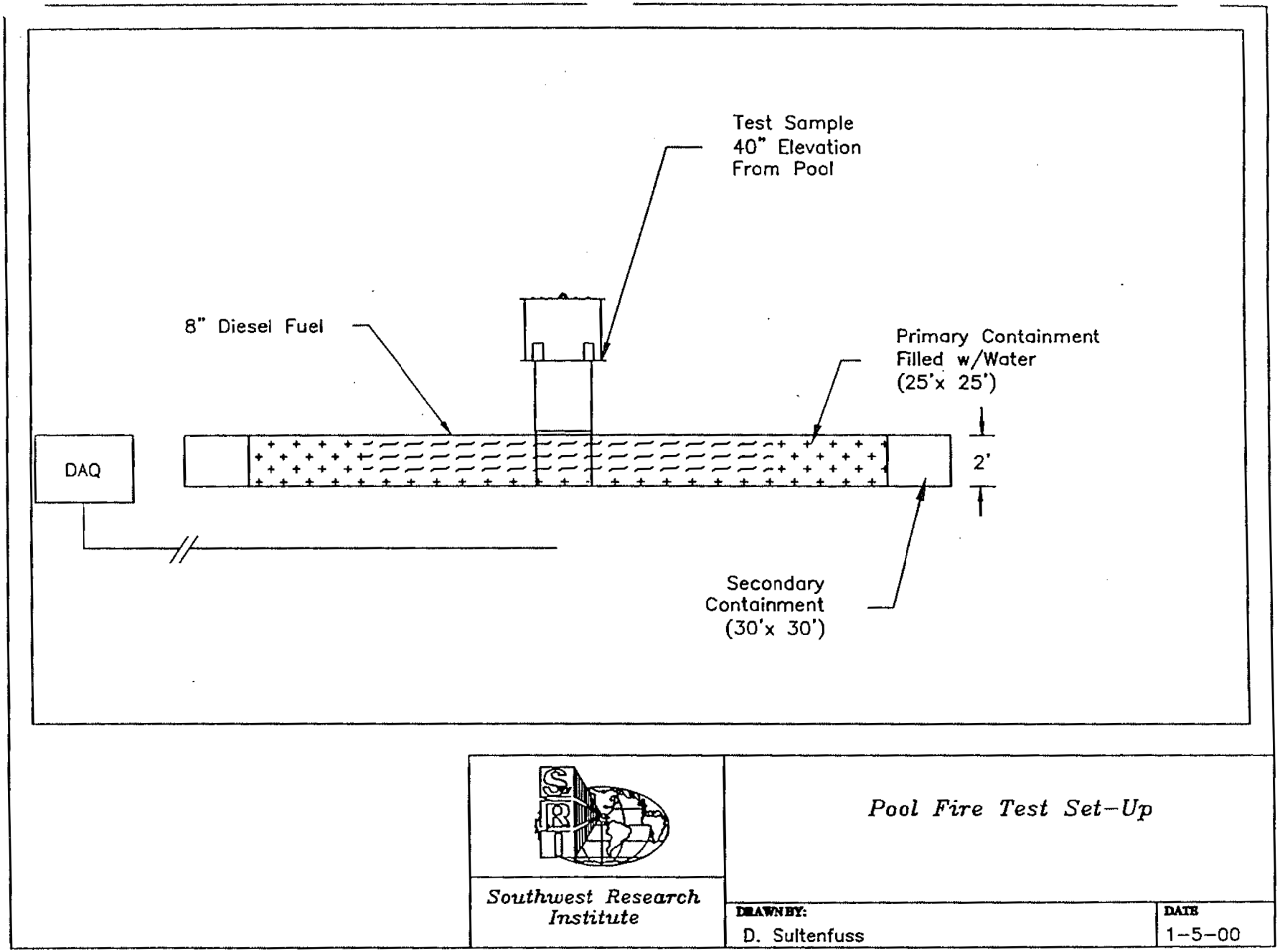


Figure 5a. Pool Fire Test Setup.

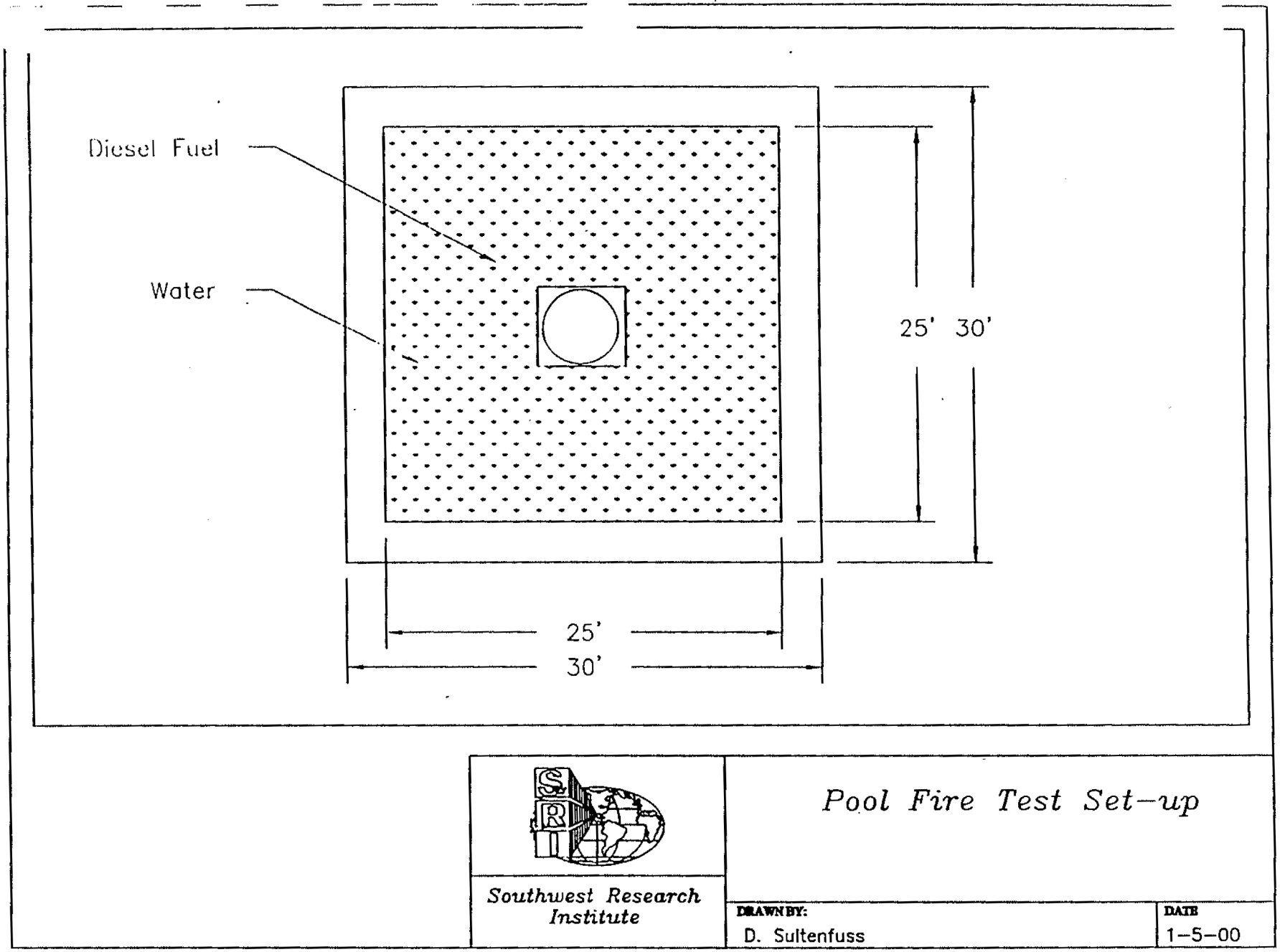
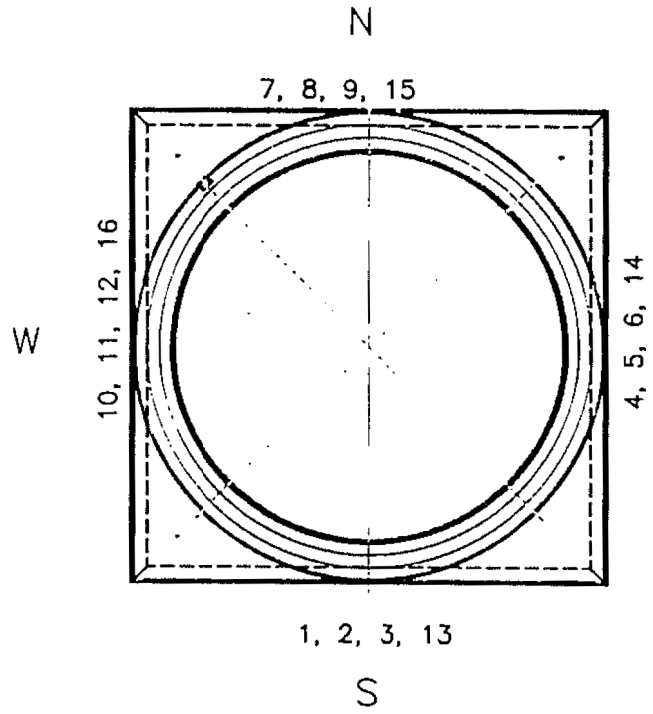
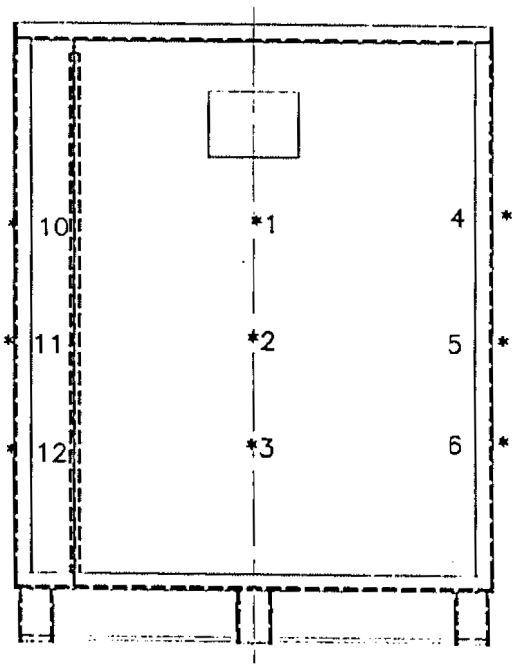


Figure 5b. Pool Fire Test Setup.

Figure 6 – Eco-Pack Liqui-Rad-250® Showing Inner Container has been withheld as Sensitive Unclassified Non-Safeguards Information pursuant to Title 10 of the Code of Federal Regulations 2.390



TC 1–3	South Side
TC 4–6	East Sdie
TC 7–9	North Side
TC 10–12	West Side
TC 13	Flame–South
TC 14	Flame–East
TC 15	Flame–North
TC 16	Flame–West



TC 1–3	South Side
TC 4–6	East Sdie
TC 7–9	North Side
TC 10–12	West Side

Figure 7. Container Thermocouple Locations and Thermal Tape Locations.

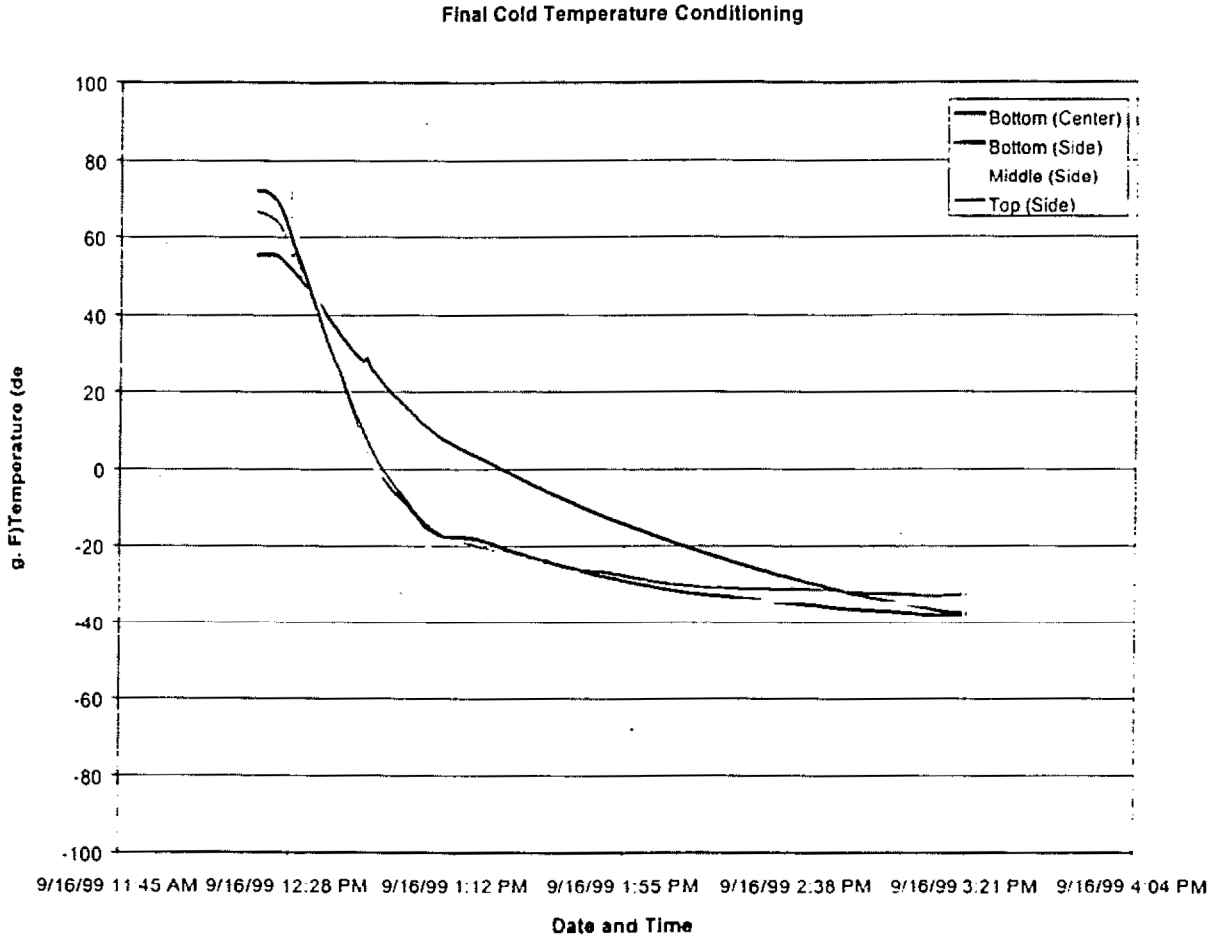


Figure 8. Test Item Temperatures in Conditioning Chamber.

Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 264ECOP1.DAT

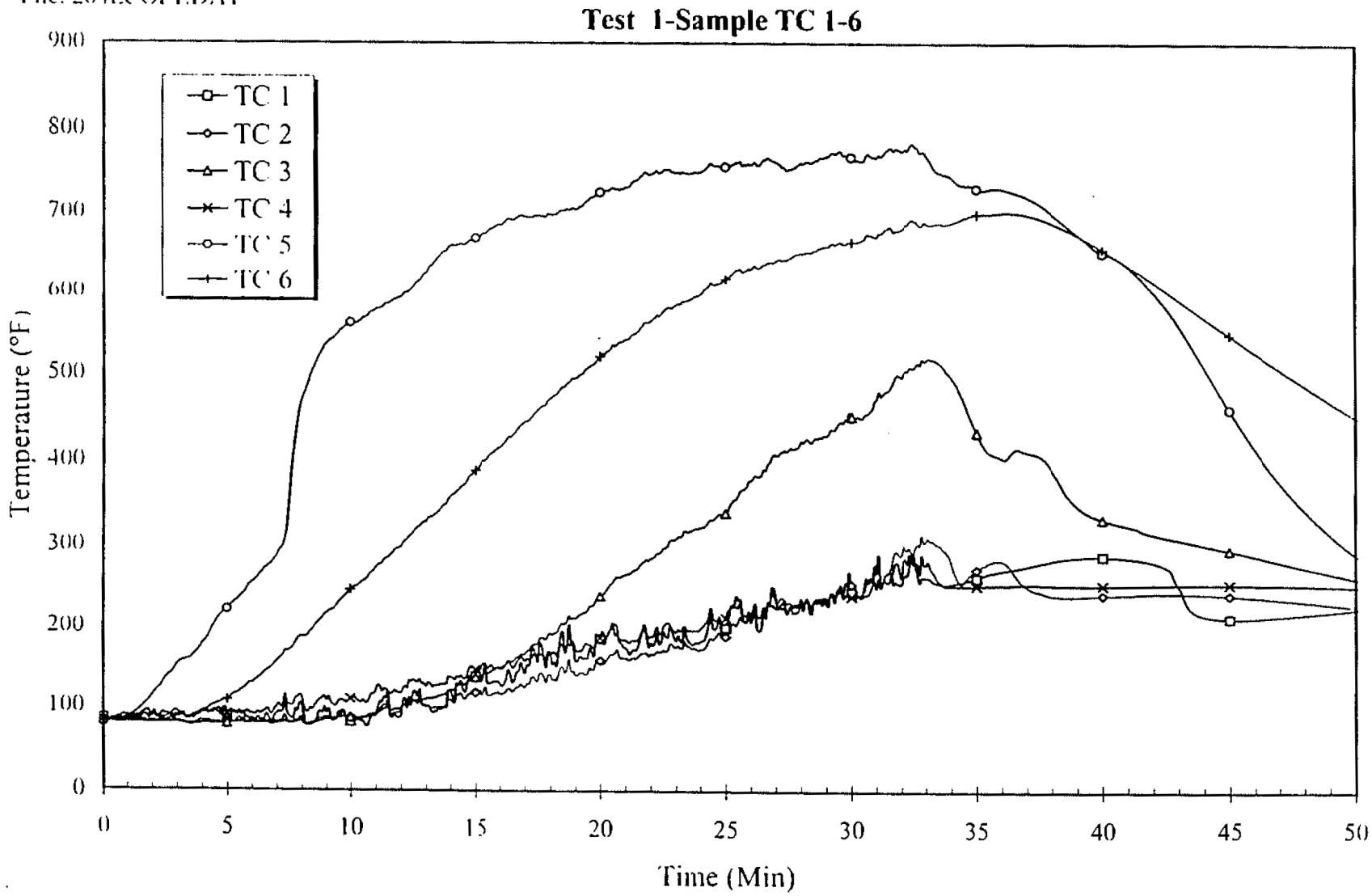


Figure 9. Test 1–Sample Thermocouple Readings.

Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 264ECOP1.DAT

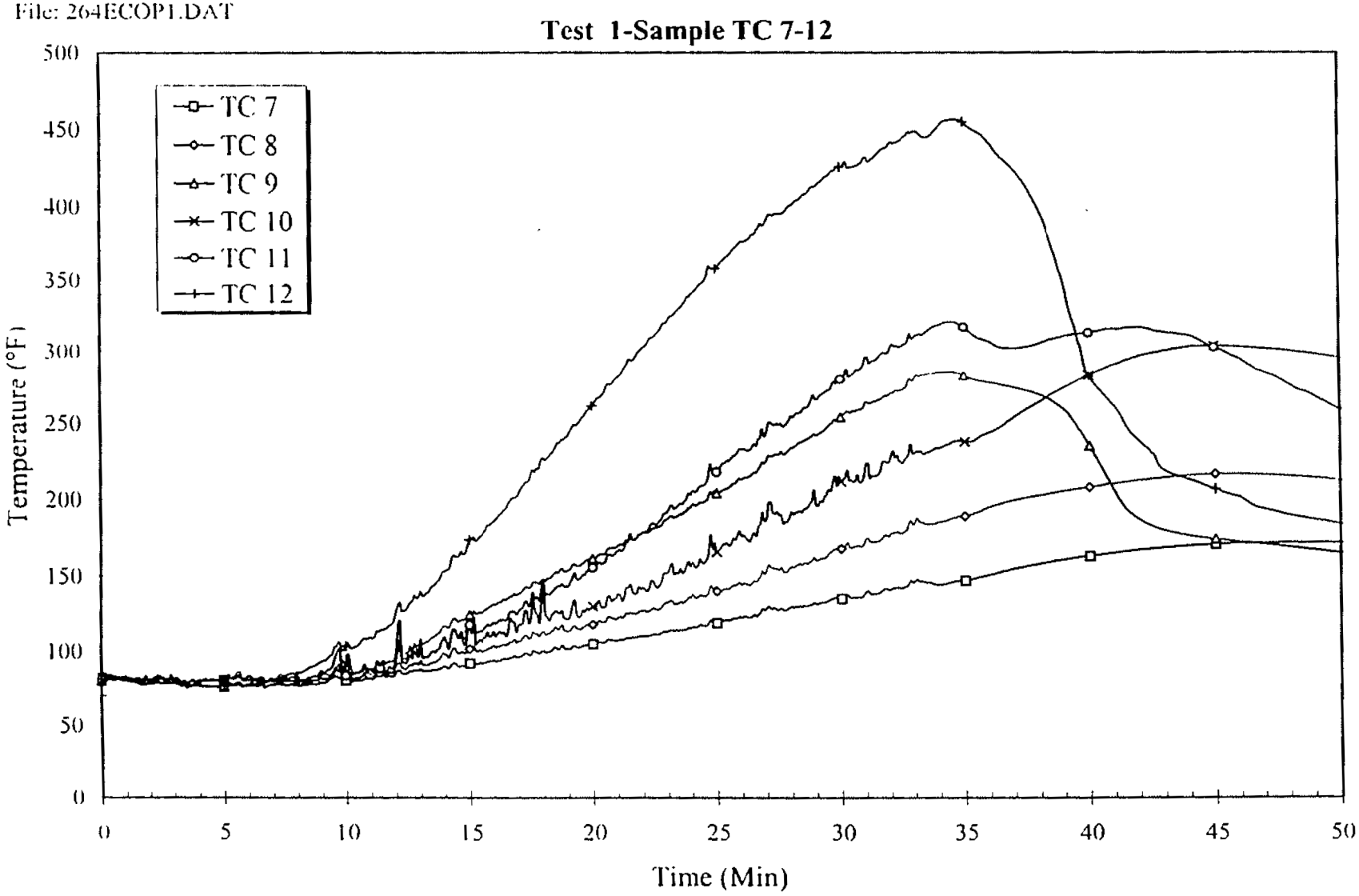


Figure 10. Test 1–Sample Thermocouple Readings.

Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 264ECOP1.DAT

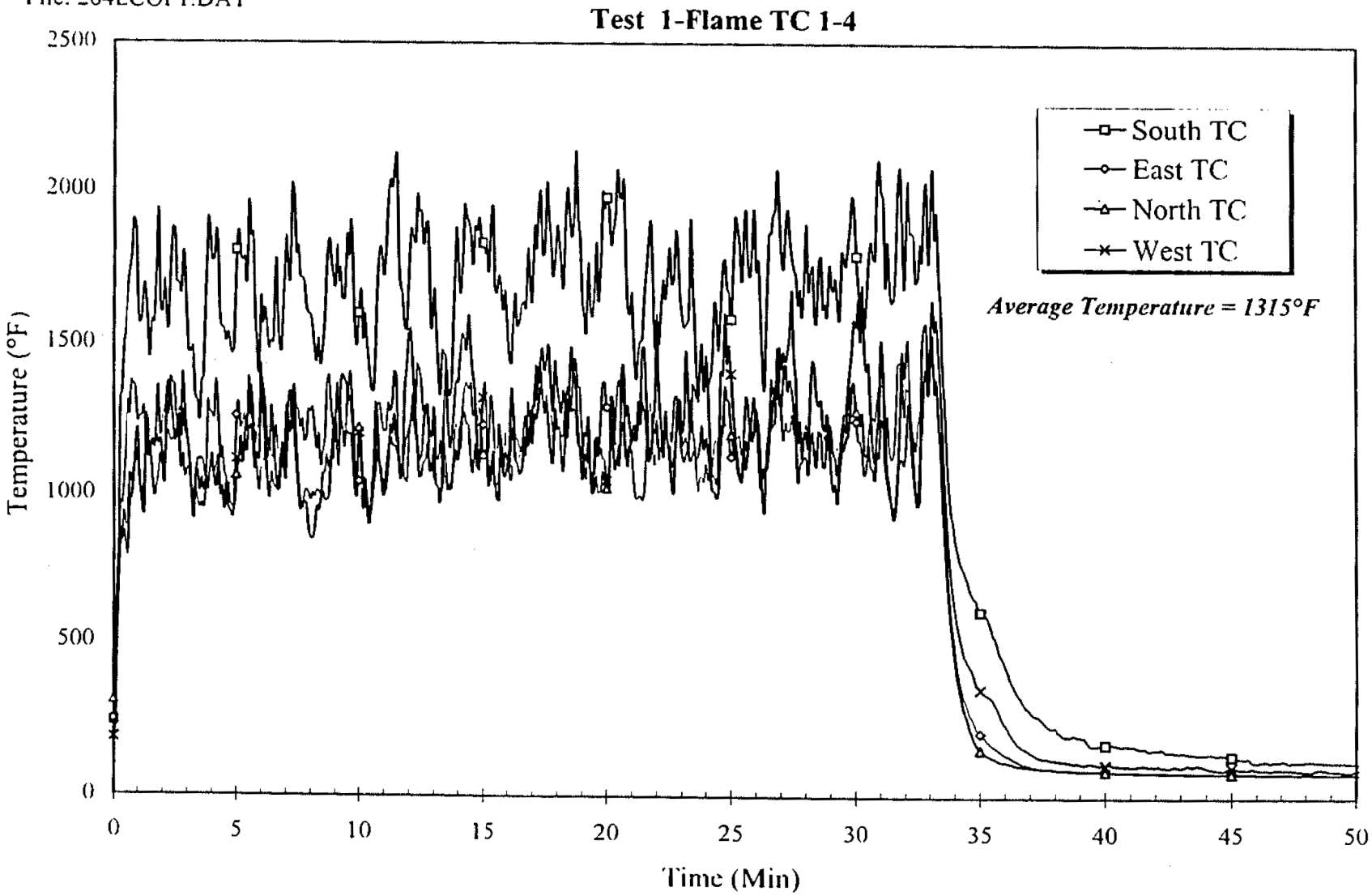


Figure 11. Test 1–Flame Temperature Readings.

Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 264ECOP1.DAT

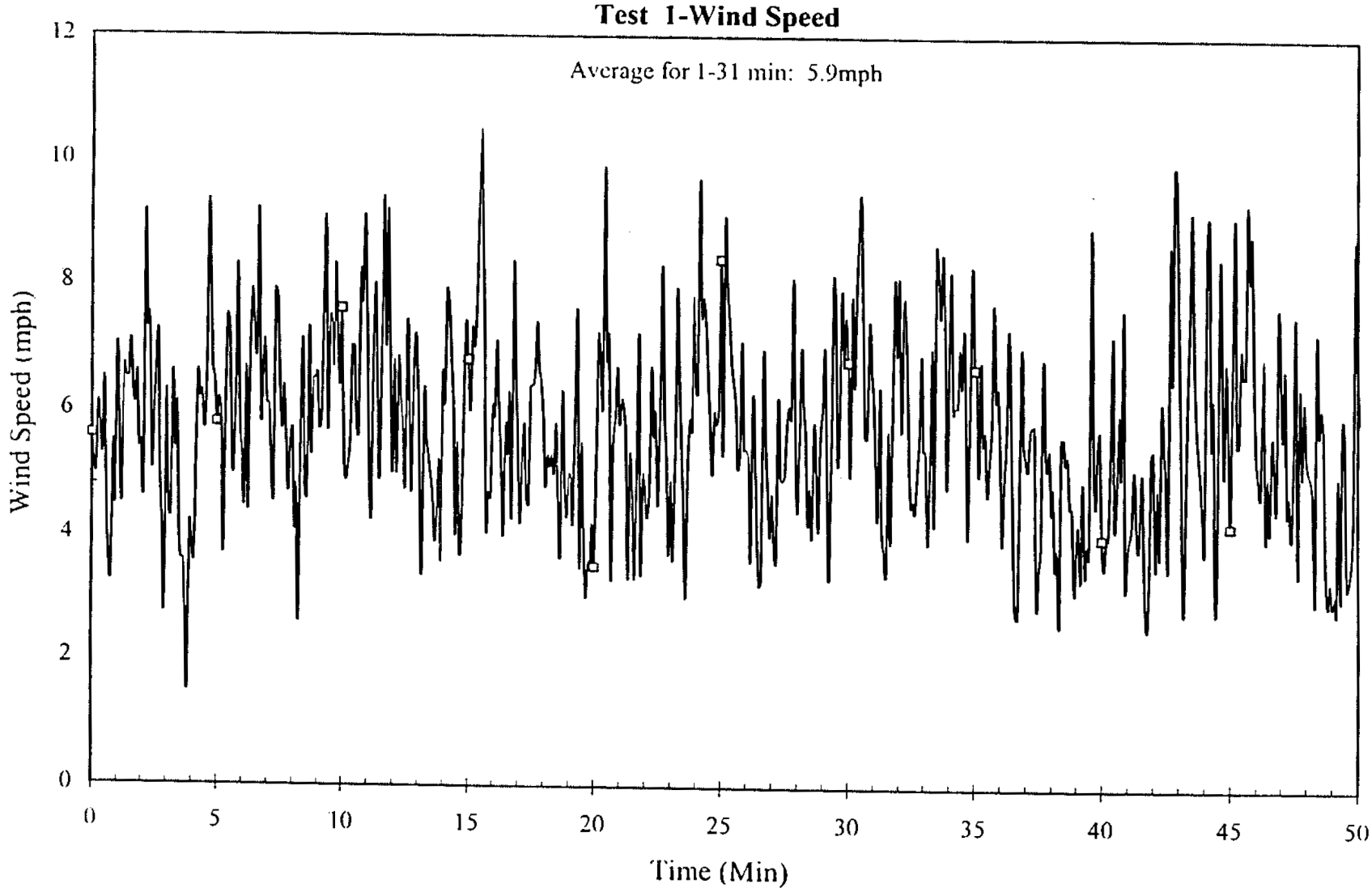


Figure 12. Test 1–Wind Speed.

Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT and ECPOCD.DAT

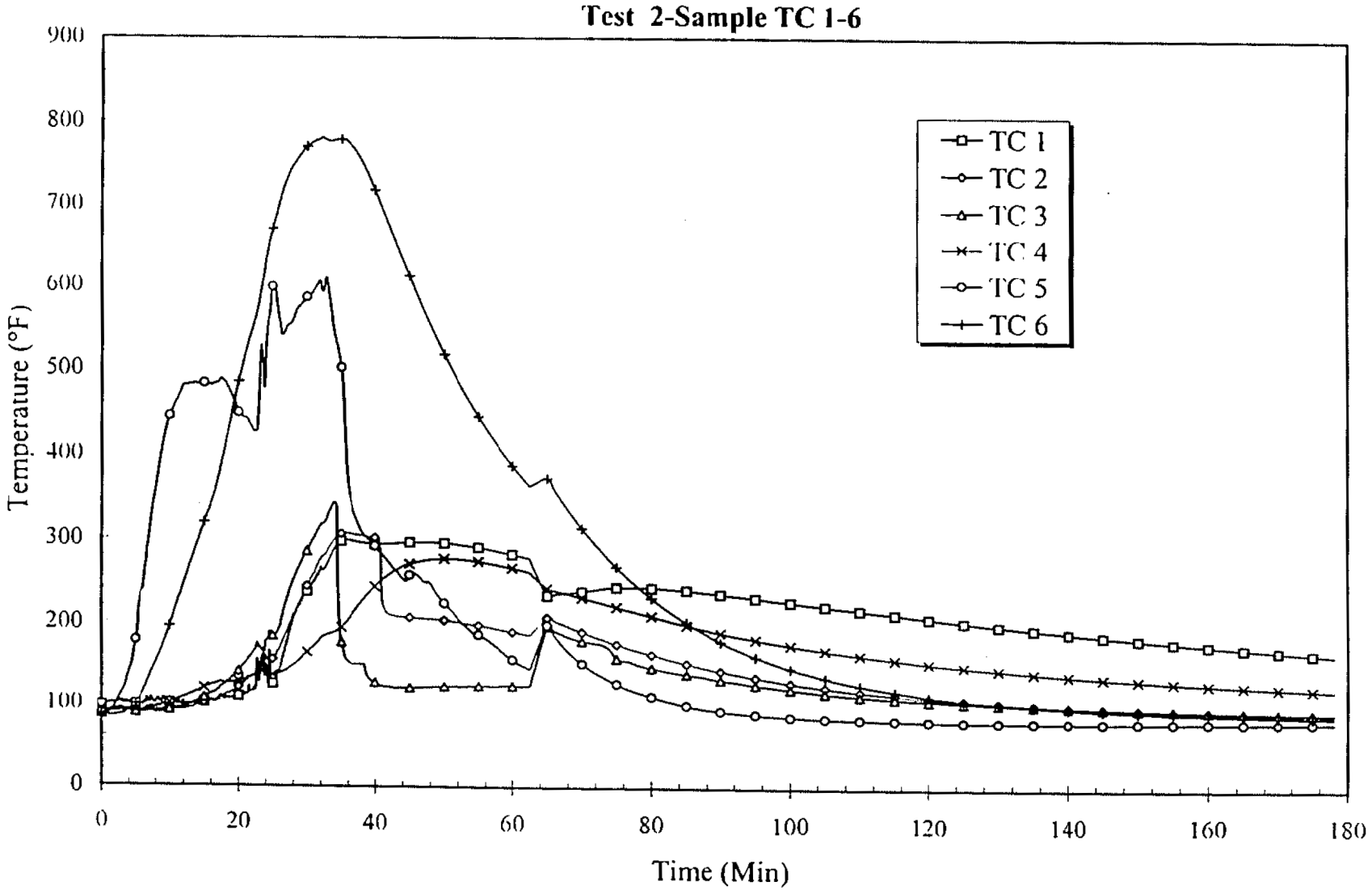


Figure 13. Test 2–Sample Thermocouple Readings.

Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT and ECPOCD.DAT

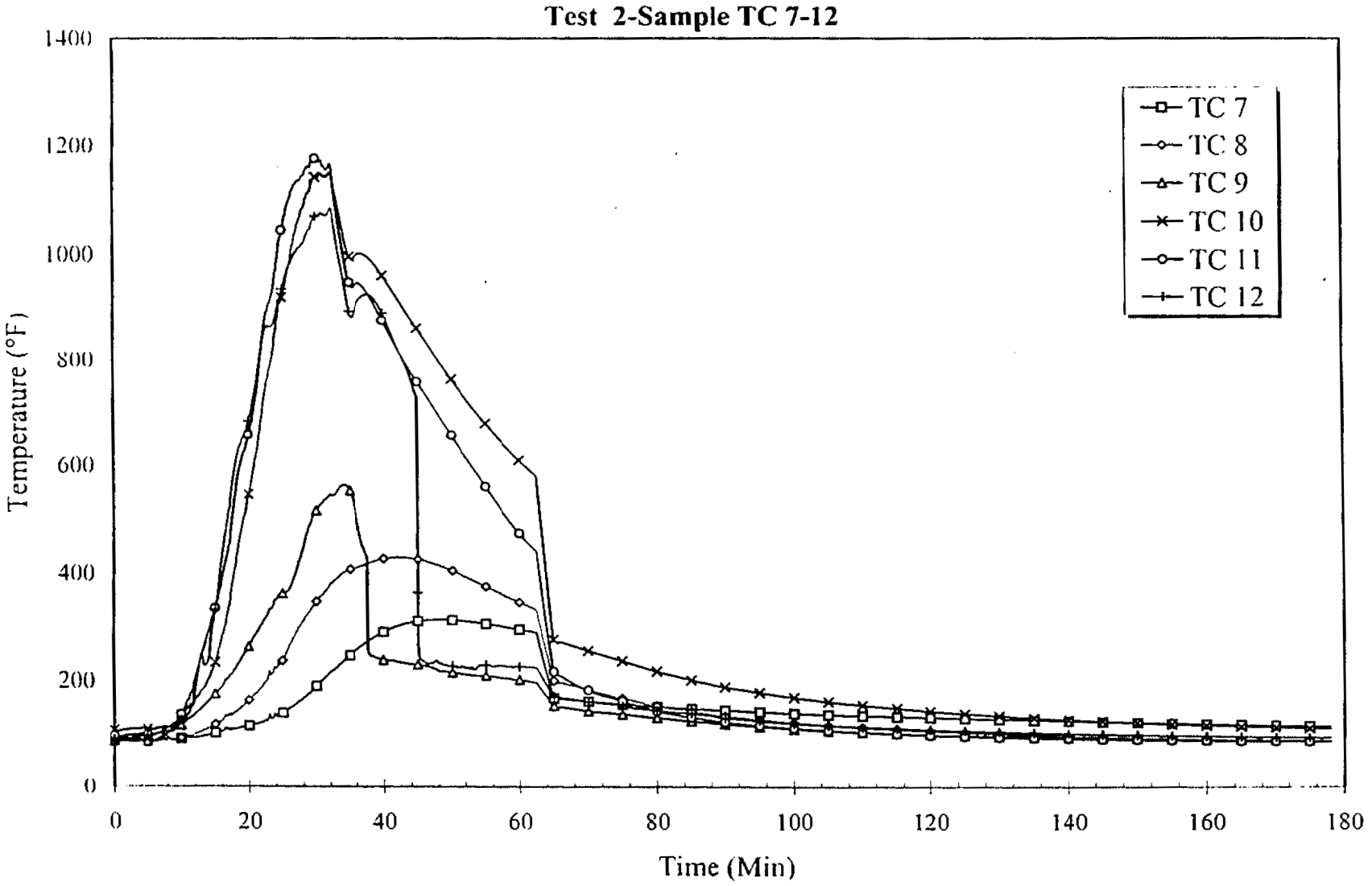


Figure 14. Test 2–Sample Thermocouple Readings.

Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT and ECPOCD.DAT

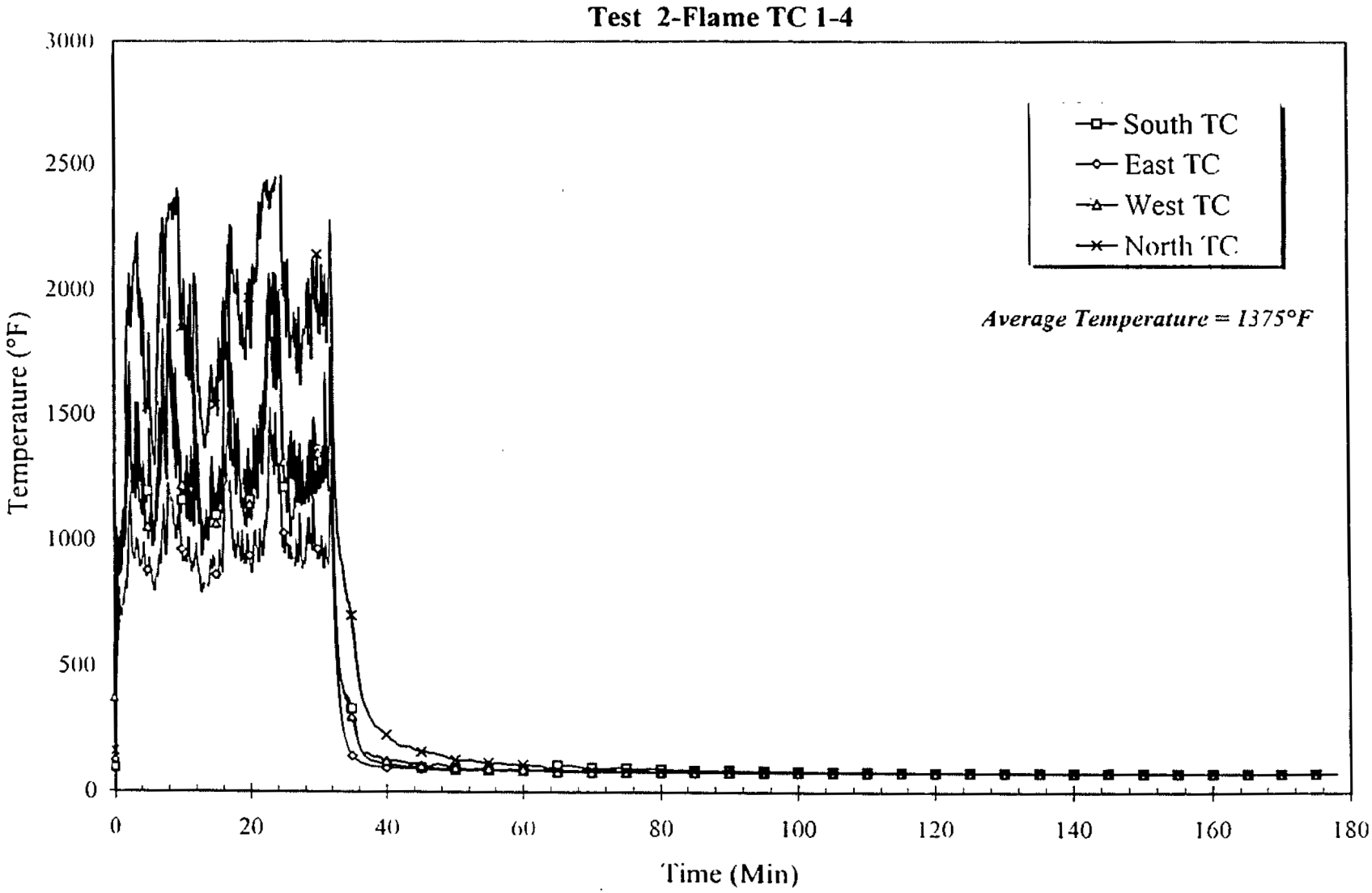


Figure 15. Test 2–Flame Temperature Readings.

Client: ECO-PAK Specialty Packaging
Project No: 01.02759.001
Date: 22 September 1999
File: 265ECOP2.DAT and ECPOCD.DAT

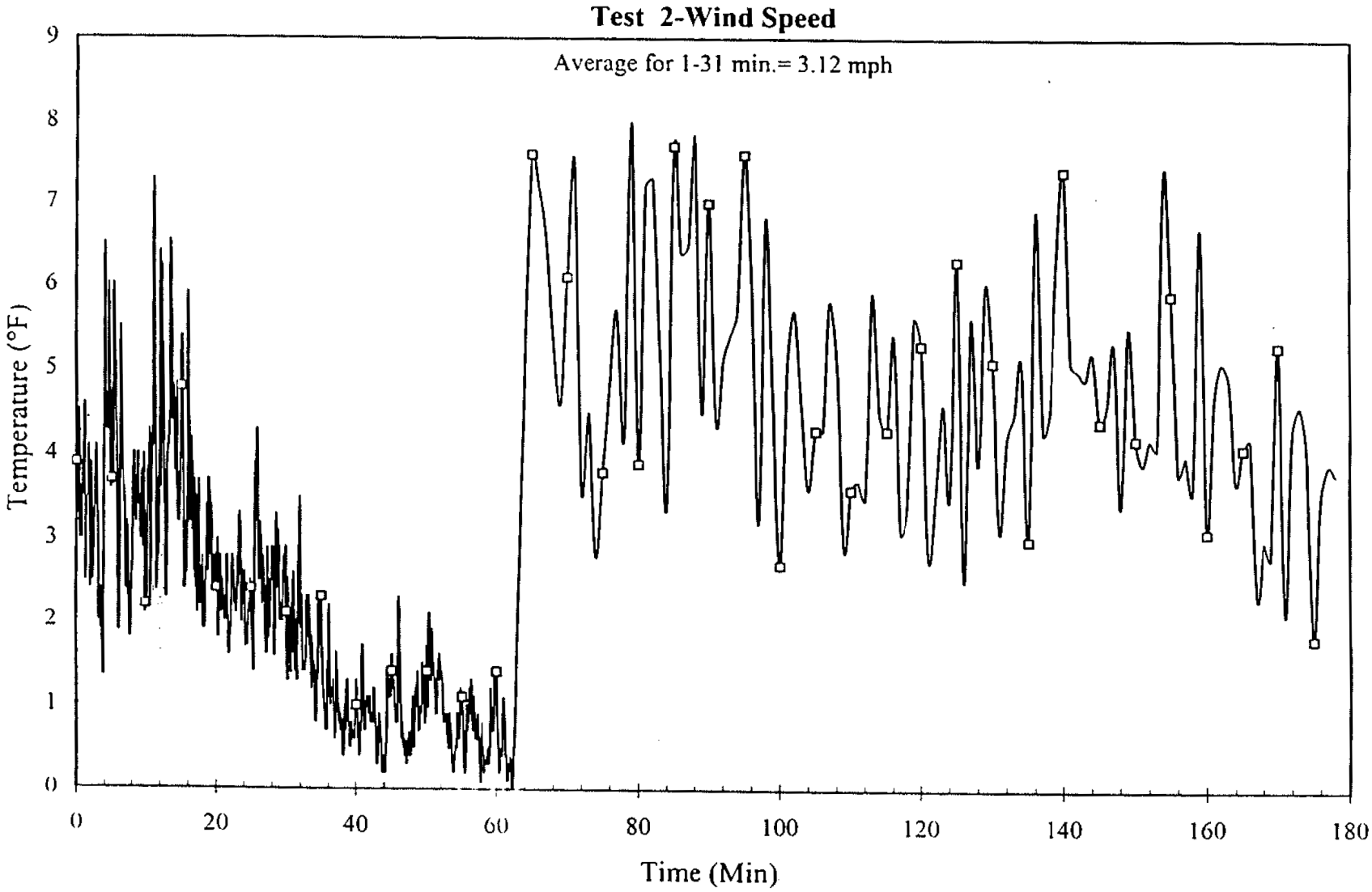


Figure 16. Test 2–Wind Speed.