cc: Chris Harkey, Konto orig: Tom 19.6

U.S. Department of Transportation
Federal Railroad Administration

Evaluation of the Thermal Effectiveness of Urethane Foam and Fiberglass as Insulation Systems for Tank Cars

→ Tom Dalrymple E&P 6/9/93

William P. Wright
Wayne A. Slack
Willis F. Jackson

U.S. Army Laboratory Command
Ballistic Research Laboratory
Aberdeen Proving Ground, MD 21005-5066

FRA/ORD-87/11

July 1987

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Technical Report Documentation Page

1. Report No.	FRA/ORD-87/11
2. Government Accession No.	
3. Recipient's Catalog No.	
4. Title and Subtitle	EVALUATION OF THE THERMAL EFFECTIVENESS OF URETHANE FOAM AND FIBERGLASS AS INSULATION SYSTEMS FOR TANK CARS
5. Report Date	DECEMBER 1985
6. Performing Organization Code	
7. Author(s)	William P. Wright, Wayne A. Slack, Willis F. Jackson
8. Performing Organization Report No.	
9. Performing Organization Name and Address	U. S. Army Laboratory Command Ballistic Research Laboratory ATTN: SLCBR-TB-S Aberdeen Proving Ground, MD 2]005-5066
10. Work Unit No. (TRAIS)	
11. Contract or Grant No.	DTFR53-84-X-00008
12. Sponsoring Agency Name and Address	Department of Transportation Federal Railroad Administration 400 Seventh Street, S.W. Washington, D.C. 20590
13. Type of Report and Period Covered	Final May 1985 - September 1985
14. Sponsoring Agency Code	

15. Supplementary Notes

This work was monitored by the Equipment & Operating Practices Safety Research Division of the Federal Railroad Administration

16. Abstract

A total of 39 thermal fire tests were conducted using the torch fire facility for the Federal Railroad Administration. These tests were performed in accordance with the procedures presented in Title 49, Code of Federal Regulations, Part 179. 105-4. The insulations tested were urethane foam and fiberglass. Urethane foam is installed on a number of railroad tank cars which are used to transport chlorine. Fiberglass constitutes the insulation system on a number of tank cars which are used to transport other materials. In this test series, it was found that urethane foam can hold the tank car shell below 493 °F in the environments which may exist in railroad accidents. This test criteria is a more stringent requirement than previously imposed for the insulation system of the chlorine tank car. The fiberglass performed much better than anticipated when a means was provided to hold it in place in the test fixture during the tests. It was recommended that the test specimen holder be redesigned and tests performed on fiberglass to determine if the modification is satisfactory and to verify that fiberglass has the ability to hold the back plate temperature below 800 °F.

17. Key Words	18. Distribution Statement
Thermal Systems, Railroad Tank Cars, Urethane Foam, Fire Tests, Fiberglass, Safety, Chlorine	This document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	22	

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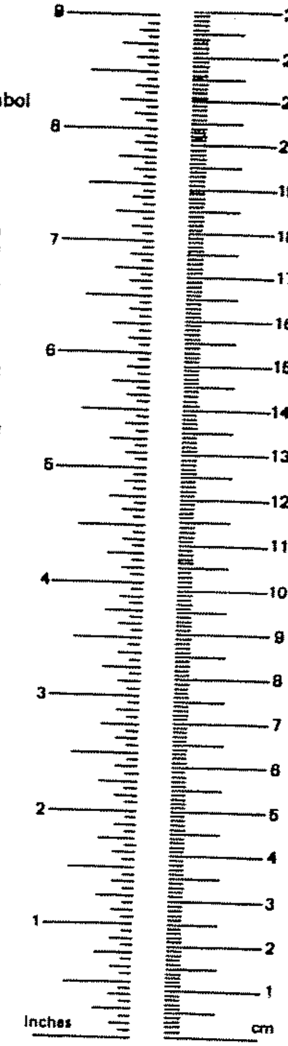
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

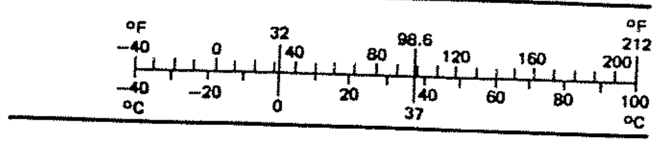
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in. = 2.54 cm (exactly). For other exact conversions and more detail tables see NBS Misc. Publ. 286. Units of Weight and Measures. Price $2.25 SD Catalog No. C13 10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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I. INTRODUCTION

The Ballistic Research Laboratory (BRL) has been under contract to the Federal Railroad Administration (FRA) to operate and maintain a torch fire facility used to test insulation systems for railroad tank cars. Under a final contract of this nature, the BRL provided training for personnel from the FRA Transportation Test Center (TTC) and proceeded to transfer control of the facility to TTC. An important aspect of the training was the performance of a number of actual thermal fire tests on insulation systems which were of interest to the FRA. This report constitutes the documentation of those tests and a number of torch calibration tests which were also performed.

The insulations in question were urethane foam and fiberglass. The main impetus for testing these insulations were results obtained in a recent series of tests performed on candidate insulation systems for the chlorine tank car (Ref. 1). In those tests, the temperatures measured which represented the insulating qualities of the systems were much lower than expected based on previous experience. This was attributed to several important modifications in the design of the insulation test assembly. These modifications did not constitute a change in the test procedures or standards, but did provide solutions to several problem areas and in fact enabled tests to more fully satisfy the test procedures defined in the federal regulations (Ref. 2). The design characteristics of the test equipment are presented below.

A total of 39 tests were conducted. These consisted of 19 calibration tests, 7 tests on urethane foam, and 13 tests on fiberglass. Two of the fiberglass tests were performed in the previous test series under a different contract. An informal report on each test which contained all of the data generated was delivered to the FRA, but only the most pertinate data are used in this document. The purpose of the calibration tests was to verify the operational efficiency of the torch facility and to determine the correct equipment settings. The latter was especially important since a wind shield had been installed and was being used for the first time.

II. TEST PERFORMANCE STANDARDS

The Test Performance Standards are based on data generated in an extensive research program concerning the thermal protection of the propane tank car. The regulations cite not only the level of protection an insulation system must provide, but also the procedures which must be used in the performance of a test. The insulation must provide a certain level of protection in a pool fire environment and a torch fire environment, both of which are defined. In order to ensure that a specific environment can be generated, the regulations describe a specific test to calibrate the equipment or facility being used. Four types of tests were performed as described in Reference 2. These are the pool fire calibration test, the torch fire calibration test, the pool fire insulation test, and the torch fire insulation test.

Prior to actually testing an insulation system, a pool fire calibration is required to verify that the torch fire facility is operating with sufficient efficiency that a proper pool fire environment can be created. A pool fire environment is a representative environment that a surface area of a tank car is exposed to while the tank car is engulfed in the flames of a pool fire. Such a pool fire would be a typical one which might occur at the site of a wrecked railroad train.

The requirements for the performance of a pool fire calibration test are as follows: "A pool fire environment shall be simulated in the following manner; (i) The source of the simulated pool fire shall be a hydrocarbon fuel. The flame temperature from the simulated pool fire shall be at 1,600 ^{o}F, plus or minus 100 ^{o}F, throughout the duration of the test. (ii) An uninsulated square steel plate (bare plate) with thermal properties equivalent to tank car steel shall be used. The plate dimensions shall be not less than one foot by one foot by nominal 5/8-inch thick. The plate shall be instrumented with not less than nine thermocouples to record the thermal response of the plate. The thermocouples shall be attached to the surface not exposed to the simulated pool fire, and shall be divided into nine equal squares with a thermocouple placed in the center of each square. (iii) The pool fire simulator shall be constructed in a manner that results in total flame engulfment of the front surface of the bare plate. The apex of the flame shall be directed at the center of the plate. (iv) The steel plate holder shall be constructed in such a manner that the only heat transfer to the back side of the plate is by heat conduction through the plate and not by other heat paths. (v) Before the plate is exposed to the simulated pool fire, none of the temperatures shall be in excess of 100 ^{o}F, nor less that 32 ^{o}F. (vi) A minimum of two thermocouple devices shall indicate 800 ^{o}F after not less than 12 minutes nor, more than 14 minutes of simulated pool fire exposure."

A torch fire calibration test is required for the same reason as the pool fire calibration test except that the verification is to ascertain that an acceptable torch fire environment can be created. A torch fire environment is a simulation of the environment a tank car is exposed to when it has impinging on its outer surface a propane torch caused by a punctured propane tank car located nearby.

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1. W. Wright, W. Slack, and W. Jackson, THERMAL INSULATION SYSTEMS STUDY FOR THE CHLORINE TANK CAR, FRA-ORD-85-10, April 1985, Federal Railroad Administration, 400 Seventh Street, S. W., Washington, D.C. 20590

2. Title 49, Code of Federal Regulations, Part 179.105-4

The required procedure for performing a torch fire calibration test is as follows: "A torch fire environment shall be simulated in the following manner: (i) The source of the simulated torch shall be a hydrocarbon fuel. The flame temperature from the simulated torch shall be 2,200 °F, plus or minus 100 °F, throughout the duration of the test. Torch velocities shall be 40 miles per hour plus or minus 10 miles per hour throughout the duration of the test. (ii) An uninsulated square steel plate with thermal properties equivalent to tank car steel shall be used. The plate dimensions shall be not less than four feet by four feet by nominal 5/8-inch thick. The plate shall be instrumented with not less than nine thermocouples to record the thermal response of the plate. The thermocouples shall be attached to the surface not exposed to the simulated torch and shall be divided into nine equal squares with a thermocouple placed in the center of each square. (iii) The steel-plate holder shall be constructed in such a manner that the only heat transfer to the back side of the plate is by heat conduction through the plate and not by other heat paths. The apex of the flame shall be directed at the center of the plate. (iv) Before exposure to the simulated torch, none of the temperature recording devices shall indicate a plate temperature in excess of 100 °F or less than 32 °F. (v) A minimum of two thermocouples shall indicate 800 °F in a time of 4.0 minutes, plus or minus 0.5 minutes of torch simulation exposure."

Whenever a successful calibration test is run, the same distance between the torch nozzle and the front surface of the bare plate must be used in the following test of an insulation system. The importance of that distance is easy to understand, since normally, the greater its value, the cooler is the flame at the front surface of the bare plate. For convenience, this distance is referred to as the TN/SS Distance, where TN and SS implies torch nozzle and specimen surface, respectively.

The procedure for submitting an insulation system to the pool fire environment according to Reference 2 is as follows: " (i) The thermal insulation system shall cover one side of a steel plate identical to that used to simulate a pool fire. (ii) The uninsulated side of the steel plate shall be instrumented with not less than nine thermocouples placed as described above to record the thermal response of the steel plate. (iii) Before exposure to the pool fire simulation, none of the thermocouples on the thermal insulation system's steel plate configuration shall indicate a plate temperature in excess of 100 °F nor less than 32 °F. (iv) The entire insulated surface of the thermal insulation system shall be exposed to the simulated pool fire. (v) The pool fire simulation test shall run for a minimum of 100 minutes. (vi) A minimum of three successful simulation pool fire tests shall be performed for each thermal insulation system in question." During the 100 minutes, none of the thermocouples shall exceed 800 °F in order for a test to be judged a successful test.

The procedure for submitting an insulation system to the torch fire environment according to Reference 2 is as follows: "(i) The thermal insulation system shall cover one side of a steel plate identical to that used to simulate a torch fire as described above. (ii) The back of the steel plate shall be instrumented with not less than nine thermocouples placed as described above to record the thermal response of the steel plate. (iii) Before exposure to the simulated torch, none of the thermocouples on the thermal insulation system steel plate configuration shall indicate a plate temperature in excess of 100 °F nor less than 32 °F. (iv) The entire outside surface of the thermal insulation system shall be exposed to the simulated torch fire environment. (v) A torch simulation test shall be run for a minimum of 30 minutes. (vi) A minimum of two successful torch simulation tests shall be performed for each thermal insulation system." During the 30 minutes, none of the thermocouples shall exceed 800 °F in order for a test to be judged a successful test.

The work "successful" was used in the regulations to indicate that an insulation system was performed within the test criteria; and that a minimum of three successful pool fire tests and two successful torch fire tests are required in order for an insulation system to be judged an approved system. An assumption was that those tests to be used would be legitimate in that, from a physical standpoint, the regulations were met and nothing occurred which could be judged as a reason for concluding that the tests were unfair.

One of the procedural variations from the regulations was that the thickness of the steel back plate used in the insulation tests of urethane foam was 0.779 inches rather than the 5/8 inches as specified in Reference 2. That modification was made because many chlorine tank cars have a shell thickness of at least 0.779 inches. In addition, the steel plate was made of TC-128B steel to correspond to the typical chlorine tank car shell. Two of the fiberglass tests reported here were conducted in a previous test series where the TC-128B back plate was used. These two tests were performed in between the primary tests of candidate insulation systems for the chlorine tank car and were exploratory in nature. Consequently, the back plate was not changed to the conventional one used to test fiberglass.

Another variation concerned the torch insulation tests. According to Reference 2, a separate successful calibration test must be performed prior to testing each type of insulation system. In this program, the urethane foam was done in that manner, but the fiberglass testing was essentially in the area of research. The problem was that fiberglass performed extremely well, but then in other tests the insulation failed. Consequently, a substantial effort was made to determine the cause of this inconsistency. As will be indicated in the following sections, it was found that whenever the fiberglass was held in place in the test fixture the test was successful. The failures were due to the fiberglass specimens falling down and exposing the backplate thermocouples. At any rate, many of the fiberglass tests were performed without the prior performance of calibration tests.

III. THE TORCH FIRE FACILITY & TEST SETUP

The torch fire facility was designed to produce a large hydrocarbon fuel flame for impingment on the front surface of a test specimen so that its insulating qualities could be evaluated. The characteristics of the flame corresponded to the requirements cited in Reference 2. Therefore, the facility was qualified as one approved for testing insulation systems.

The propane flame was generated by the torch device displayed in Figure 1. The basic structure of the torch was two four-inch diameter pipes leading vertically from a propane supply tank and then horizontally to the torch nozzle. One of the pipes was used to transport propane vapor while the other was used to transport liquid propane. Each pipe had a compressed air actuated valve which was used to regulate the propane flow rate. Prior to reaching the nozzle, the two pipes joined so that a mixture of liquid and vapor propane flowed through the nozzle. These valves were regulated by a torch operator remotely from inside an instrumentation and control trailer. The propane valve was opened about 28 percent and the liquid valve was closed. That combination of valve openings produced a flame with the desired thermal characteristics.

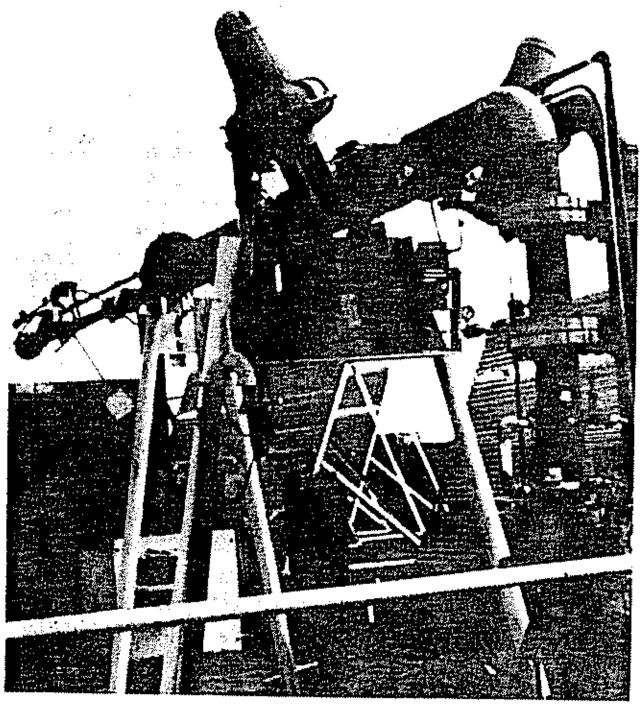

Figure 1: The Propane Flame Generator

The configuration of the insulation test assembly holder and the supporting cart were as shown in Figure 2. The cart was setting on a track so that the TN/SS Distance could be changed to fit the need of a specific test. The holder, which actually supported the test specimen assembly, was mounted vertically on top of the cart. The holder consisted of a holder box, a rear flame shield, and a rear enclosure. Thermocouples were mounted on the test assembly and other locations on the holder. The leads to these thermocouples were passed through the six-inch pipe indicated in Figure 2. The purpose of the rear flame shield was to prevent flames from wrapping around the holder box and heating up the outside surface of the rear enclosure. The inside surfaces of the holder box and the rear enclosure were lined with insulation, two inches thick, to minimize the loss of heat. A thermal blanket was placed over the rear enclosure and the six-inch pipe to further protect against significant heat transport out of or into the rear enclosure.

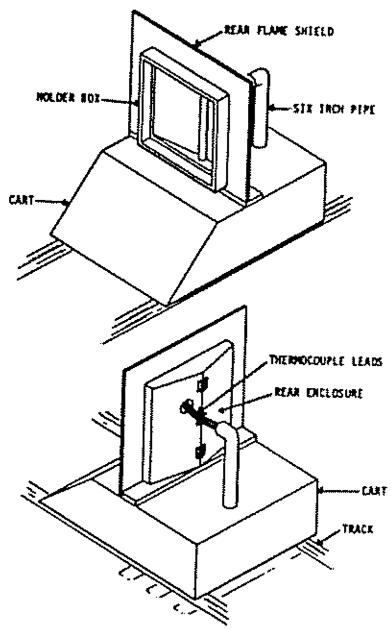

Figure 2: The Insulation Test Assembly Holder and Cart

The test specimen assembly consisted of a sandwich of thermal insulation, backed by a steel plate, referred to as the back plate, and covered on the front (toward the torch nozzle) by a eleven gauge steel plate, referred to as the jacket. This combination corresponded to a section of a jacketed type insulated tank car. The physical characteristics of the sandwich structure were as shown in Figure 3.

The back plate was the first component of the test assembly installed on the holder box. It was four feet square and 0.799 inches thick in the tests of urethane foam, but was only 0.625 inches thick otherwise. The former thickness was to simulate the shell thickness of the chlorine tank car and the latter was to simulate the shell thickness of the propane tank car. The design was such that the thickness of the plate extended completely beyond the front edge of the holder box. In the center of the front surface of the back plate was a square bracket. The bracket was similar to stand-off brackets used in the construction of some chlorine tank cars. The bracket was 4.0 inches high, 3.0 inches wide, and 6.0 inches long.

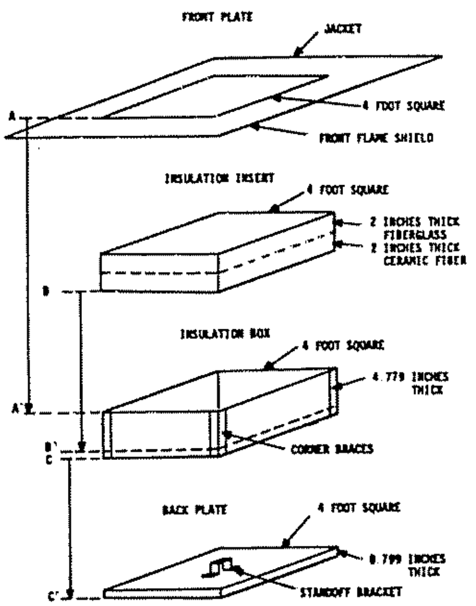

Figure 3: The Insulation Test Assembly

The insulation specimens were four-foot square that fitted snugly inside the insulation box. A three sided rectangular shaped incision was made in the insulation to accommodate the stand-off bracket. The flap of insulation was pushed under the top of the bracket such that the steel bracket completed a thermal short circuit. That is, no thermal insulation barrier was placed between the top of the bracket and the inner surface of the jacket. Such a barrier was not included because none exists in at least some of the chlorine tank cars. All other metal to metal surfaces were separated by a thermal barrier to preclude unauthorized heat conduction.

The jacket was the last component to be installed. An extension of jacket metal beyond the insulation box was for the purpose of diverting the torch flames to prevent them from heating the sides of the box. This extension was referred to as the front flame shield. About four inches of insulation was placed over the sides of the insulation box and between the front and rear flame shields to reduce further the possibility of heat conduction through the sides. Insulation was stuffed under the insulation box and a row of fire bricks placed on top of the cart against the front of the jacket.

In the performance of previous tests, it was found that variations in the wind constituted the dominate factor which caused inconsistencies in data between one test and another. For that reason a wind shield was constructed. The wind shield consisted of a solid vertical wall which surrounded the holder, the cart, and the entire track on which the cart was moved to vary the TN/SS Distance. It was 16 ft high, 20 ft wide, and 47 ft long. There was no top cover on the final design, although it was found that a partial cover was probably desirable. The torch nozzle extended inside the south end of the wind shield. The solid wall on the south end extended from the top edge down to several inches above the torch nozzle. On either side of the torch nozzle, a canvas was stretched from the lower edge of the solid portion to the ground. In the center of the south wall the canvas was opened for the purpose of allowing air to enter the enclosure and supply oxygen to the torch flame. This opening also allowed personnel to enter the wind shield for the purpose of changing the test specimen. Changes in the wind shield which led to the final version are explained below.

IV. DATA ACQUISITION

The Data Acquisition System consisted of several devices which recorded with redundancy in order to minimize the chance of losing data. The key device in the system was the Fluke Data Logger which accepted 28 channels of measurements. The device transformed the signals into units consistent with the parameters measured and passed the data to other devices. Besides obtaining a permanent record, data concerning the operation of the facility was displayed for monitoring purposes. That was important because adjustments during testing were required to maintain an appropriate flame environment. More important, such monitoring would have provided information which could have warned of developing circumstances that would have warranted aborting the test for safety reasons.

Definitions of the 28 channels are listed in Table 1. In those cases where locations of measuring devices were defined by indicating right or left, the observer was assumed to be facing the rear of the holder. The temperature signals were immediately converted from millivolts to degrees Fahrenheit, tabulated, and stored. The other parameters listed were stored in millivolts (or volts) and converted later by the formulas given in Table 1.

TABLE 1: FLUKE DATA LOGGER CHANNELS

Channel Number	Parameter & Location	
1	Temp. - Back Plate,	Top Left Square
2	Temp. - Back Plate,	Top Center Square
3	Temp. - Back Plate,	Top Right Square
4	Temp. - Back Plate,	Center Left Square
5	Temp. - Back Plate,	Center Center Square
6	Temp. - Back Plate,	Center Right Square
7	Temp. - Back Plate,	Bottom Left Square
8	Temp. - Back Plate,	Bottom Center Square
9	Temp. - Back Plate,	Bottom Right Square
10	Temp. - Rear Enclosure,	Free Air, Back
11	Temp. - Back Plate,	Center Left Edge
12	Temp. - Back Plate,	Center Top Edge
13	Temp. - Back Plate,	Center Right Edge
14	Temp. - Rear Encl.,	Center Left Side
15	Temp. - Rear Encl.,	Center Left Door
16	Temp. - Rear Encl.,	Center Right Door
17	Temp. - Rear Encl.,	Center Right Side
18	Temp. - Jacket,	Center Left Square
19	Temp. - Jacket,	Top Center Square
20	Temp. - Jacket,	Center Right Square
21	Temp. - Water Bath	
22	Temp. - Torch Orifice	
23	Speed (mph) = # mv/10,	Wind
24	Direction (Deg) = # mv,	Wind
25	Pressure (psi) = # mv x 10,	Supply Tank
26	Percent Open = # v x 100,	Liquid Valve
27	Percent Open = # v x 100,	Vapor Valve
28	Pressure (psi) = # mv x 10,	Torch Orifice

The first nine channels provided the temperatures on the back plate. These were the most important set of data since they served as the basis for evaluating the insulation systems in question. The same nine channels were used to acquire temperatures on the back of the bare plate in calibration tests. The positions of the nine thermocouples were in accordance with the regulations presented in Reference 2. That is, in the center of each of nine equal size squares was attached a thermocouple. Viewing the back plate from the rear of holder, the signals for Channel Number 1 and Channel Number 9 were measured by thermocouples located in the centers of the top-left and the bottom-right squares, respectively. The others were located in numerical order; proceeding left to right and top to bottom. The nine thermocouples in question were referred to as the back plate thermocouples.

Figure 4 presents a sample of a bargraph of the temperature measurements made by the nine back plate thermocouples during a test. The bargraph generation began at time zero and the first set of bars presented the initial temperatures measured by each thermocouple. For every tenth data readout cycle from the data logger, the bargraph was extended to reflect the new temperatures and the temperature values at that particular cycle were printed out below the appropriate bar. The elapsed time and the actual time were printed out near the top of the graph. The top of the bars at each cycle recorded were retained and a series of horizontal lines were generated on each bar. The separation of these provided a qualitative view as to how rapid the temperature had risen while the test was in progress and the relative height of the bars gave a good measure as to how the test had proceeded. The bargraph was shown on the screen of the Hewlett Packard 9845 Computer as it was generated so the torch facility operator could use the information to make corrections or terminate the test if the temperatures exceeded some critical temperature level. A hard copy of the bargraph was printed out each time new information was added and these became a permanent part of the test record.

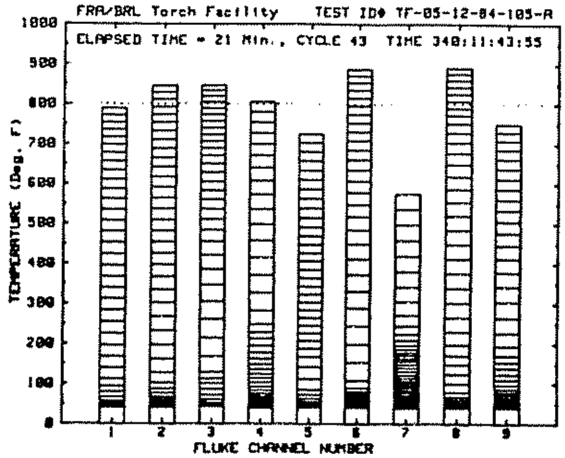

Figure 4: A Dynamic Bargraph of the Back Plate Temperatures

There was interest in determining the conduction of heat to the back plate through the sides of the insulation box. Therefore, three thermocouples were installed near the edges of the back plate. As noted in Table 1, the numerical designation for these thermocouples were 11, 12, and 13. These measurements were only taken during the testing of insulation systems.

Channel Numbers 14 through 17 corresponded to thermocouples which were positioned outside the rear enclosure and mounted directly on the steel surface. The purpose of these measurements was to determine if a substantial amount of heat was lost through these surfaces. The term "center" refers to the middle of the surface and half way up the holder. The side of the rear enclosure was taken to be the surface behind the rear flame shield. Thermocouples were mounted on the back of the jacket to measure the level of the temperature on the front surface of the insulation. These proved to be quite useful for monitoring the location of the torch flame relative to the center of the jacket. The channels used for this purpose were Numbers 18 through 20, which were in line with the back plate thermocouples 4, 2, and 6, respectively. The wind speed and direction were recorded on Channels 23 and 24, respectively. The remaining channels were used to record values which indicated important information concerning the operation of the facility. All of these were displayed on the console.

V. SUMMARY OF TESTS

The tests described in this report are listed in Table 2. Many of the tests are calibration tests which were needed to determine the TN/SS Distance inside the new wind shield. Several modifications in the wind shield were required before a satisfactory performance was achieved. In addition to urethane foam and fiberglass, a pool fire test and a torch fire test were conducted with no insulation between the jacket and the back plate. These were to research the basic characteristics of the test setup. A total of 37 tests were conducted in this test series with the first two of those listed having been done in the previous test series.

TABLE 2: SUMMARY OF TESTS PERFORMED

Test No.	ID Number	Test Specimen	Test Type
1	TF-21-06-84-CHL-B	(G-1)	Torch
2	TF-23-06-84-CHL-A	(G-2)	Pool
3	TF-03-11-84-CHL-A	(Bare)	Pool
4	TF-03-11-84-CHL-B	(Bare)	Pool
5	TF-06-11-84-CHL-A	(Bare)	Pool
6	TF-06-11-84-CHL-B	(Bare)	Pool
7	TF-06-11-84-CHL-C	(Bare)	Pool
8	TF-06-11-84-CHL-D	(Bare)	Pool
9	TF-07-11-84-CHL-A	(Bare)	Pool
10	TF-07-11-84-CHL-B	(Bare)	Pool
11	TF-07-11-84-CHL-C	(F-1)	Pool
12	TF-08-11-84-CHL-A	(F-2)	Pool
13	TF-09-11-84-CHL-A	(F-3)	Torch
14	TF-10-11-84-CHL-A	(Bare)	Torch
15	TF-10-11-84-CHL-B	(Bare)	Torch
16	TF-11-11-84-CHL-A	(Bare)	Torch
17	TF-11-11-84-CHL-B	(Bare)	Torch
18	TF-12-11-84-CHL-A	(Bare)	Torch
19	TF-12-11-84-CHL-B	(F-4)	Pool
20	TF-13-11-84-CHL-A	(F-5)	Pool
21	TF-13-11-84-CHL-B	(F-6)	Torch
22	TF-14-11-84-CHL-A	(F-7)	Torch
23	TF-04-12-84-RES-A	Air	Torch
24	TF-04-12-84-105-B	(Bare)	Torch
25	TF-04-12-84-RES-C	Air	Pool
24	TF-05-12-84-105-A	(A-1)	Torch
25	TF-05-12-84-105-B	(A-2)	Torch
26	TF-05-12-84-105-C	(Bare)	Torch
27	TF-06-12-84-105-A	(B-2)	Torch
28	TF-06-12-84-105-B	(B-3)	Torch
29	TF-06-12-84-RES-C	(G-3)	Torch
30	TF-07-12-84-RES-A	(G-4)	Torch
31	TF-07-12-84-RES-B	(G-5)	Torch
32	TF-10-12-84-RES-A	(A-3)	Torch
33	TF-10-12-84-RES-B	(C-1)	Torch
34	TF-11-12-84-RES-A	(Bare)	Pool
35	TF-11-12-84-RES-B	(Bare)	Pool
36	TF-11-12-84-RES-C	(Bare)	Pool
37	TF-12-12-84-RES-A	(Bare)	Pool
38	TF-12-12-84-RES-B	(G-6)	Torch
39	TF-12-12-84-RES-C	(G-7)	Torch

The tests are listed in the order of performance, but are grouped in categories for discussion purposes. These categories are Pool Fire Tests, Torch Fire Tests, Urethane Foam Tests, and Fiberglass Tests. In addition, a short discussion of the two tests performed with no insulation in the insulation box is presented. In the list the calibration tests are identified by the term "Bare". The insulation tests can be identified by the specimen symbol which is explained below.

The Identification Number attached to each of the tests was generated on the following basis. The first two letters signifies that the test was performed using the torch facility. The six following numbers indicates the day, the month, and the year in which the test was performed. The following three letters are to provide some indication as to the purpose of the test. In this case, CHL, 105, and RES signify Chlorine Tank Car, 105 Tank Car, and Research, respectively. The last letter indicates the order in which the test was done in a particular day. A number of the ID Numbers have a "C" as the last letter which indicates that three tests were done in a single day. That was made possible by the wind shield.

A list of the densities of the test specimens are presented in Table 3. The urethane foam specimens were identified by the letter "F" with densities near 2.81 lbs/cu ft. Four groups of fiberglass specimens were available. The "A", "G" and "C" groups were manufactured by the Owens Corning Company and the "B" group was manufactured by the CertainTeed Company. The "A" and "G" groups had densities around 0.75 lbs/cu ft and the "C" and "B" groups had densities near 1.0 lb/cu ft. The "G" group had a light plastic mesh attached; the significance of which is discussed in the text below.

TABLE 3: DENSITIES OF THE INSULATION SPECIMENS

Test Specimen	Densities (kg/cu m)	(lbs/cu ft)
	Urethane Foam	
F-1	42.9	2.68
F-2	44.2	2.76
F-3	45.0	2.81
F-4	43.9	2.74
F-5	46.0	2.87
F-6	46.9	2.93
F-7	43.9	2.74
	Owens-Corning Fiberglass	
A-1	11.7	0.73
A-2	11.9	0.74
A-3	11.6	0.73
G-1	12.0	0.75
G-2	12.0	0.75
G-3	12.0	0.75
G-4	11.8	0.74
G-5	12.3	0.76
G-6	12.3	0.76
G-7	11.6	0.73
C-1	16.0	1.00
	CertainTeed Fiberglass	
B-2	15.8	0.99
B-3	14.9	0.93

VI. POOL FIRE CALIBRATION TESTS

A number of pool fire calibration tests were required before the best TN/SS Distance had been achieved, because the wind shield had been modified. Initially the entire south end of the wind shield was open and immediately it was decided that some wind control would be necessary from that direction. The first attempt to do that was the placement of a heavy canvas which could not be moved or adjusted easily. Once that proved to be unsatisfactory, the end was covered by metal from the top down to six inches above the torch nozzle. The remaining area was covered with a light canvas, with an opening in the middle to accommodate the torch nozzle and to allow air to enter the wind shield. That design was the final arrangement used throughout the remainder of the test period. The data for these tests are presented in Figures 5 through 16.

The results from the first pool fire calibration test using the wind shield are presented in Figure 5. The TN/SS Distance used was 21.5 feet which was the distance used without the wind shield. Since the wind shield was intended to neutralize wind effects, the test was conducted even though the wind speed exceeded three miles per hour. That value was the maximum which was previously accepted as the upper limit when starting a test without the wind shield. As Figure 5 shows, the wind speed was above that criteria during most of the test. From the video monitor, it was concluded that the flame tended toward the right edge of the test plate. The bare plate temperatures also indicated such a trend because Thermocouples 1, 4, and 7 measured the highest values. The trend was attributed to two factors. One was the large opening in the heavy canvas on the right side of the south end, with the left side secured tight against the west wall of the shield. The other factor was the existence of two port holes in the right side of the wind shield. These port holes were two feet square in size. The port holes were made to allow side-video coverage of the torch flame. The port holes and the large opening in the canvas caused the draft in the wind shield to be off center and hence caused the torch impingement to be off center. It was concluded that the wind shield helped a great deal even though this particular test was not successful.

The same day the test was repeated with no modification of the wind shield except that the port holes were covered with one-half inch thick plexiglass. As shown in Figure 6, the wind speed was below three miles per hour during the entire test. That in combination with the fact that the plexiglass remained intact caused the bare plate temperatures to rise smoothly. That was an indication that the torch flame had remained on the center of the test plate. All thermocouples measured 800 °F before 14 minutes, with only one reaching that value before 12 minutes. Consequently, it was concluded that the test was a success. However, an improvement in the wind shield was required so that successful tests could be conducted during periods when the wind speeds exceeded three miles per hour.

The wind shield was modified prior to conducting the third pool fire calibration test. The heavy canvas was removed and metal was placed over the south end from the top of the wind shield down to about six inches from the top of the torch nozzle. On either side of the torch nozzle, the remaining opening was covered with a light canvas except for an opening in the middle which was about four feet wide. That opening was to permit a draft into the wind shield and to allow space for the torch structure. That space also provided a convenient way for personnel to enter the wind shield to change the insulation specimens. The plexiglass partially melted in the previous test due to the high temperatures. That caused it to lose its transparency which precluded its usefulness. The plexiglass was replaced with heavy plate glass.

Temperatures and wind speed for the third pool fire calibration test are presented in Figure 7. The wind speed was generally low through most of the test. The test appeared to proceed well to about six minutes even though the plate glass had shattered almost immediately due to vibrations in the wind shield. It was felt that unwanted draft effects occurred due to the open port holes and that was the reason the test was marginal. Two of the thermocouples measured 800 °F before 12 minutes. It was decided to place steel over the port holes prior to repeating the test. As will be seen in the following discussion, this made a significant difference in the torch flame.

The data from the following three tests are presented in Figures 8 through 10. These tests were conducted with TN/SS Distances of 21.5 feet, 22.0 feet, and 22.5 feet, respectively. The wind speed during each test was calm. The shapes and spread in each set of curves are similar with little indication of wind effects. In each case, the flame temperature at the surface of the bare plate was too hot, but as the TN/SS Distance was increased, the flame temperature became cooler. These sets of curves show that the wind shield helped a great deal to make the torch flame consistent from test to test. However, more tests were needed to determine the best TN/SS Distance.

Two more pool fire calibration tests were conducted prior to pool fire testing of urethane foam. The temperatures and wind speed for the first of these tests are given in Figure 11. The TN/SS Distance used was 23.5 feet which was one foot longer than in the previous test and the wind was calm. As the data indicates, the flame temperature at the front surface of the bare plate was too low. The second test was conducted with a TN/SS Distance of 23 feet, but again the flame temperature was too low. In this case, the wind was high with peaks reaching seven miles per hour. With the need to begin testing the urethane foam, it was decided to begin these tests with a TN/SS Distance of 22.5 feet.

The remaining pool fire calibration tests were conducted following the fire testing of urethane foam and following a two week period of inactivity. These were in preparation for test-

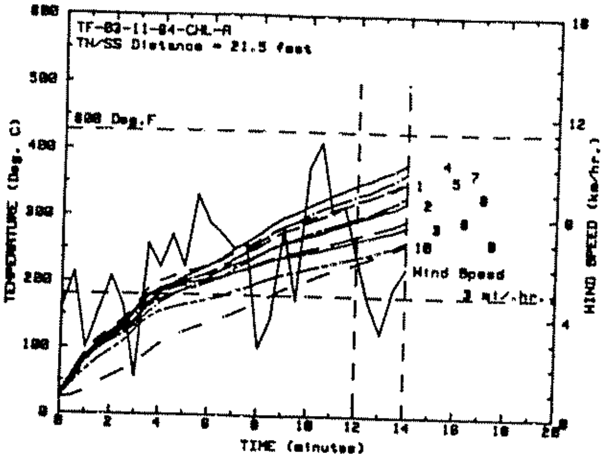

Figure 5: Temperatures and Wind Speed for the First Pool Fire Calibration Test

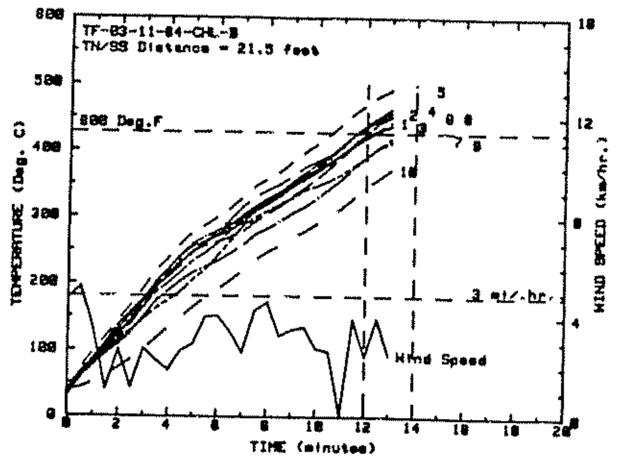

Figure 6: Temperatures and Wind Speed for the Second Pool Fire Calibration Test

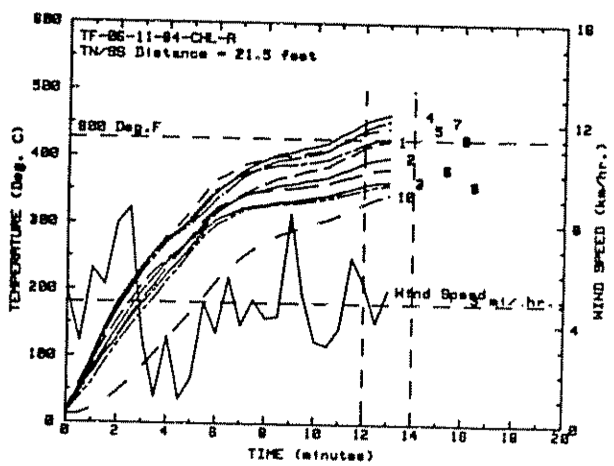

Figure 7: Temperatures and Wind Speed for the Third Pool Fire Calibration Test

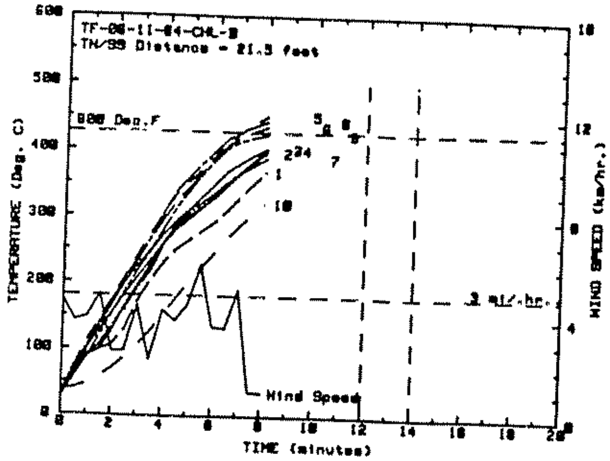

Figure 8: Temperatures and Wind Speed for the Fourth Pool Fire Calibration Test

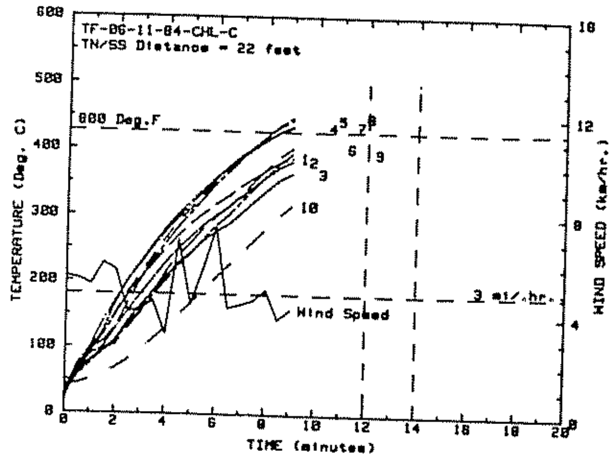

Figure 9: Temperatures and Wind Speed for the Fifth Pool Fire Calibration Test

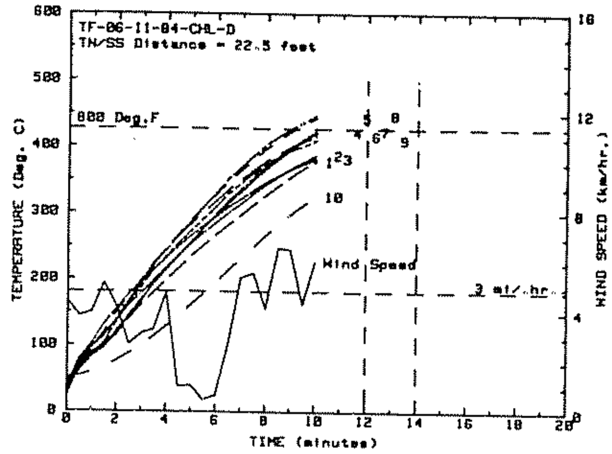

Figure 10: Temperatures and Wind Speed for the Sixth Pool Calibration Test

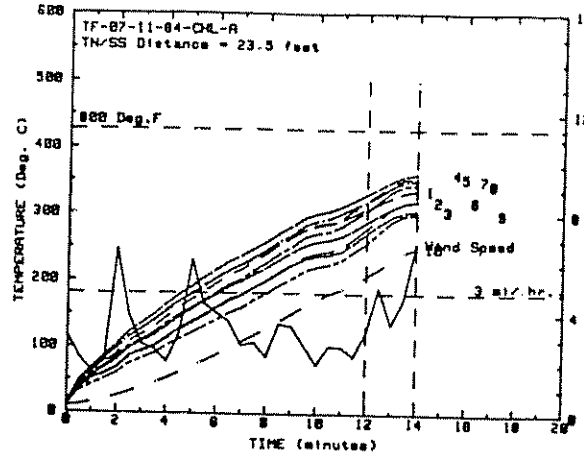

Figure 11: Temperatures and Wind Speed for the Seventh Pool Fire Calibration Test

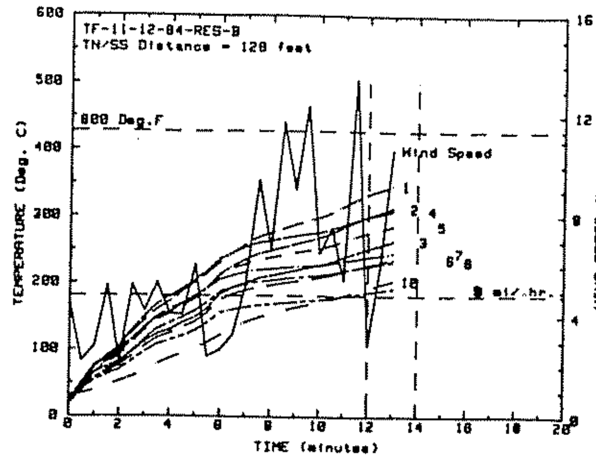

Figure 14: Temperatures and Wind Speed for the Tenth Pool Fire Calibration Test

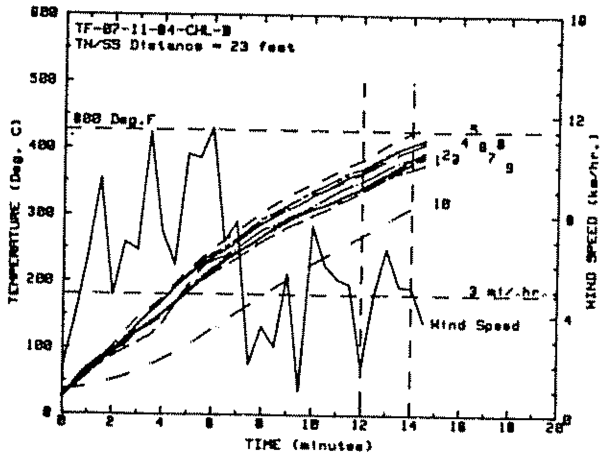

Figure 12: Temperatures and Wind Speed for the Eighth Pool Fire Calibration Test

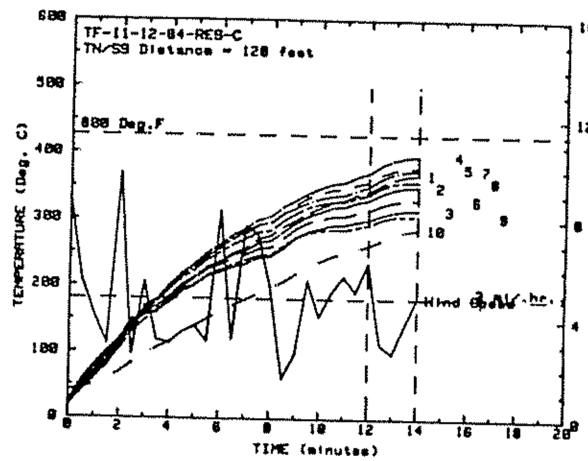

Figure 15: Temperatures and Wind Speed for the Eleventh Pool Fire Calibration Test

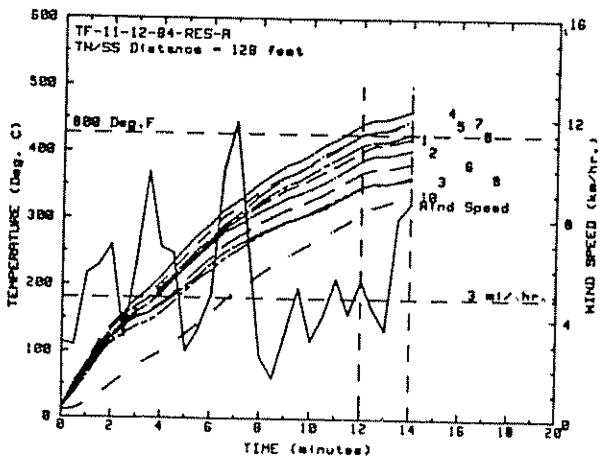

Figure 13: Temperatures and Wind Speed for the Ninth Pool Fire Calibration Test

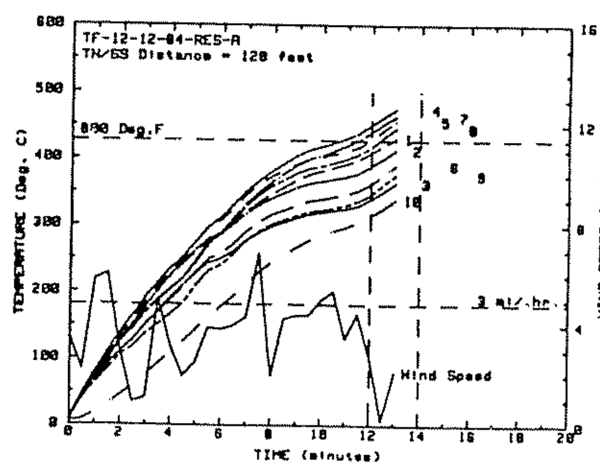

Figure 16: Temperatures and Wind Speed for the Twelfth Pool Calibration Test

ing fiberglass, but no pool fire tests were conducted due to intense interest in the torch fire testing of that insulation. The data from the four tests, which constituted the ninth, tenth, eleventh, and twelfth in the series, are presented in Figures 13 through 16. The ninth and twelfth were successful, but the tenth and eleventh were not. The data indicates that the wind had an affect even in the presence of the wind shield, but the rates of temperature increase were consistent from test to test. Only when wind gusts reached high levels were there significant correlations between temperature variations and variations in the wind speed. Based on these pool fire calibration tests and experience gained in previous test programs, it was concluded that a chance for achieving a successful pool fire calibration test on each single attempt was much greater with the wind shield in place.

VII. TORCH FIRE CALIBRATION TESTS

Wind effects on torch fire tests were small compared to effects on pool fire tests. That was because the TN/SS Distance was not as long and therefore the torch flame was much stronger at the surface of the test specimen. As a consequence of utilizing the wind shield, the wind speed had no detectable influence even when it reached 10 miles per hour. This was quite evident from the data generated in the seven torch calibration tests conducted. The data from these tests are presented in Figures 17 through 23.

The results for the first torch calibration test are presented in Figure 17. The TN/SS Distance used was 12 feet, which was the correct value without the wind shield. The temperatures measured indicated a successful test since only one thermocouple exceeded 800 °F prior to 3.5 minutes and a minimum of two reached 800 °F in the interval between 3.5 minutes and 4.5 minutes. In this test, the wind speed exceeded 10 miles per hour at various times.

For verification purposes, the test was repeated with the same TN/SS Distance. The data, presented in Figure 18, indicated that the heating effect of the flame was greater than in the previous test and again the wind speed exceeded 10 miles per hour.

The test was repeated with the TN/SS Distance increased to 12.5 feet so that the heating effect of the flame would be less. However, as shown in Figure 19, the heating effect of the flame increased. One explanation for this could be that as the distance was increased, the flame had more opportunity to entrain oxygen, thus aiding in the combustion processes. With the flame enclosed inside the wind shield, it may be that oxygen entrainment became more difficult. However, since the calibration test procedure was based on the study of results from previous tests which determined that when a successful calibration test is performed using this facility the flame temperature at the bare plate is approximately 2200 °F, it was assumed that the same was true even inside the flame shield. That is, whenever a successful calibration test was run inside the wind shield, the temperature of the flame was assumed to have been 2200 °F at the front surface of the bare plate.

The final determination of the best TN/SS Distance was accomplished after performing four more calibration tests. The TN/SS Distance was increased to 13 feet. The data, presented in Figure 20, indicated that the heating effect of the flame increased again over the previous test. The next three tests were performed with the TN/SS Distance increased to 14 feet. The first test of these three resulted in temperatures which showed that the heating effect of the flame was greater than in the previous test. The data from this test are presented in Figure 21. The data from the next two tests are presented in Figures 22 and 23, respectively. The data in Figure 22 indicated that the heating effect of the flame was greater than previously, but the data in Figure 23 showed that the heating effect of the flame had decreased. As a consequence of these final tests, it was decided that the best value for the TN/SS Distance was 14 feet and that value was used in all of the torch fire tests on the insulation specimens. As indicated above, the purpose of these tests was to determine the best value for the TN/SS Distance because in fact all of the calibration tests were successful in terms of the regulations. That is, in every test a minimum of two thermocouples indicated 800 °F in the time of four minutes, plus or minus 0.5 minutes.

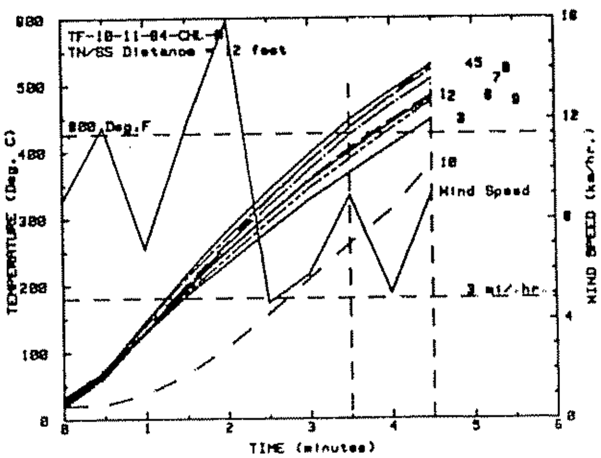

Figure 17: Temperature and Wind Speed for the First Torch Fire Calibration Test

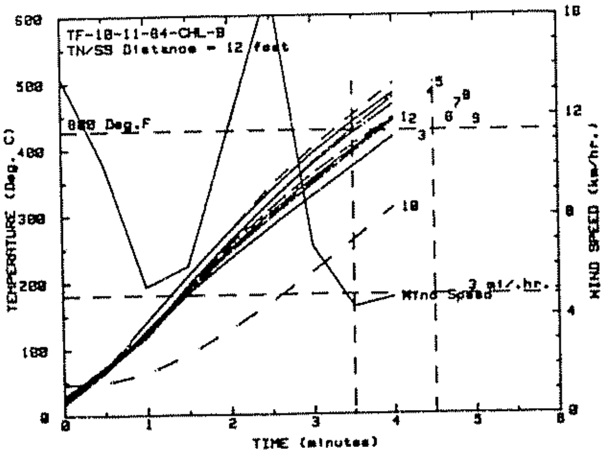

Figure 18: Temperatures and Wind Speed for the Second Torch Fire Calibration Test

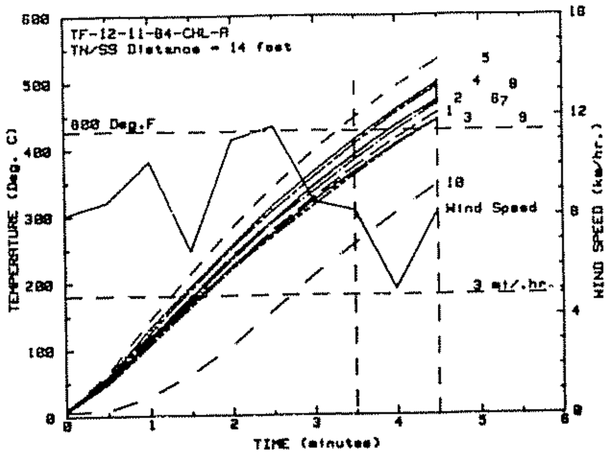

Figure 21: Temperatures and Wind Speed for the Fifth Torch Fire Calibration Test

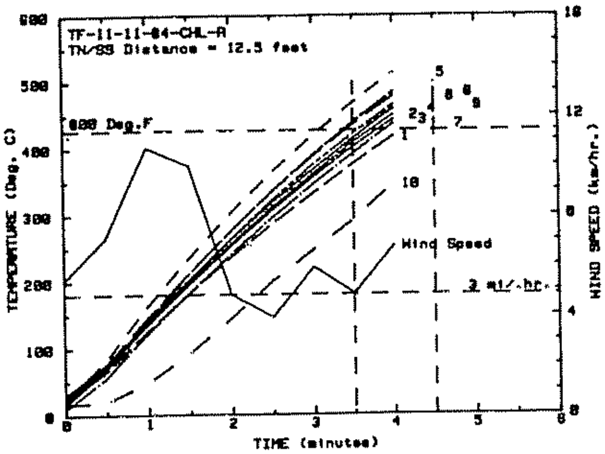

Figure 19: Temperatures and Wind Speed for the Third Torch Fire Calibration Test

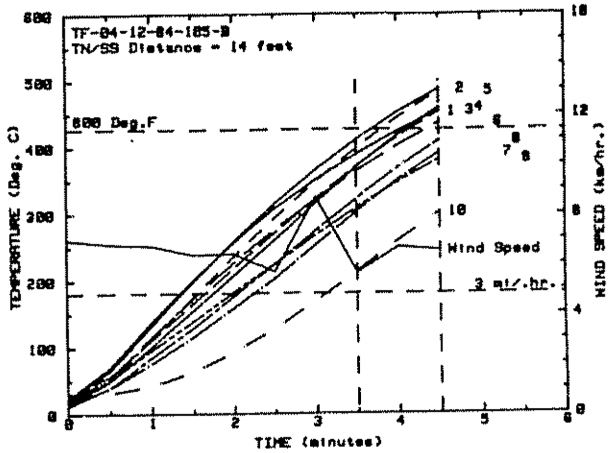

Figure 22: Temperatures and Wind Speed for the Sixth Torch Fire Calibration Test

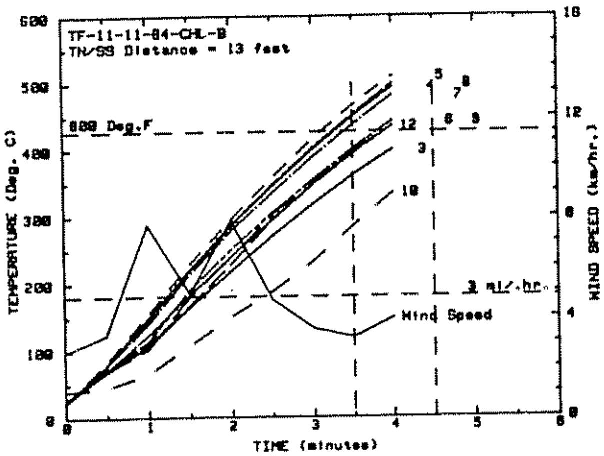

Figure 20: Temperatures and Wind Speed for the Fourth Torch Fire Calibration Test

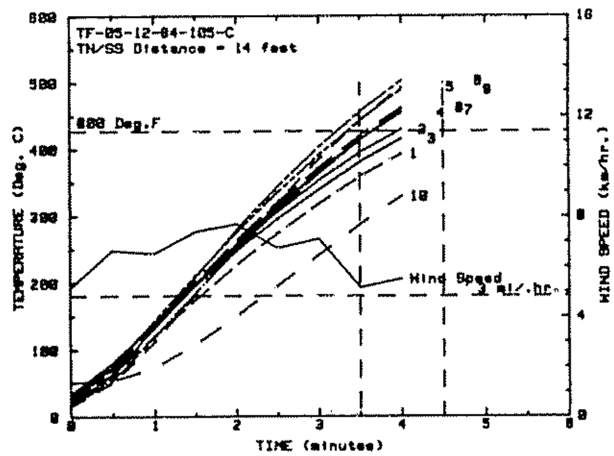

Figure 23: Temperatures and Wind Speed for the Seventh Torch Calibration Test

VIII. THERMAL TESTS OF URETHANE FOAM

Urethane foam has been a standard insulation system used in the construction of chlorine tank cars. With the discovery that chlorine vapor can cause serious corrosion in tank car steel in the neighborhood of 493 °F, it was believed that a better insulation system would be needed. Therefore, insulation systems, which included a type of ceramic fiber, were chosen and tested. The results of those tests, which were done with an improved testing facility, exceeded expectations. That prompted an interest in the testing of urethane foam with the modified equipment. The use of the modified equipment did not cause a fundamental change in the test, but constituted a more precise application of the performance standards. A total of seven fire tests were done with urethane foam as the insulation system. The data for these tests are presented in Figures 24 through 37.

The wind speed and jacket temperature data from the first torch fire test are presented in Figure 24. The closeness of the jacket temperature curves indicates that the flame remained centered on the test specimen, even though the wind speed exceeded 10 miles per hour several times. In addition, the flame evidently remained steady since the jacket temperatures varied little from approximately 1400 °F. It was believed that the wind shield had been especially effective in this case.

The jacket temperature and wind speed data for the second torch fire test are presented in Figure 26. In this case, the wind speed was fairly low but appeared to have affected the torch flame much more than in the previous test. The same was true for the third torch fire test according to the data presented in Figure 28. In both of these tests, the wind was from the south. The jacket temperatures for both tests remained in the vicinity of 1400 °F.

The following is a simple explanation as to why the wind shield appeared to be more effective against north winds than to south winds. The torch facility was located on a flat surface carved out of a hillside. Therefore, the terrain on all sides of the facility was above the highest point on the wind shield except for the side facing north. As a result, any wind which came from the south, southwest, or southeast, moved off of the high terrain and could affect the air flow through the open top of the wind shield. On the other hand, a north wind came off of a terrain level below the ground level of the torch site. Therefore, the wind had difficulty entering the top of the wind shield. For that reason, it is believed that the wind shield could be more effective if perhaps two-thirds of the top were covered, starting from the south end. The remaining one-third would be required to provide passage for the combustion products from the torch

The back plate and rear enclosure air temperatures for these three torch fire tests are presented in Figures 25, 27, and 29. The results are very similar between each test and no temperature exceeded 493 °F except for the values measured by Thermocouple Number 2 in the first test mentioned. It required five to seven minutes for the back plate temperatures to begin to rise above ambient and then the rate of increase was slow enough for the rear enclosure air temperature rise to maintain pace with the back plate temperatures. Between five and seven minutes, the data indicates several humps in the temperture levels. The added heat input was probably from the burning urethane foam. The urethane foam was a blacken ash-like substance at the end of the test with the quantity of ash decreasing from the top of the insulation box toward the bottom. Consequently, the upper thermocouples (Numbers 1, 2, and 3) were not as protected as the others and therefore measured the highest temperatures.

The data for the four pool fire tests are presented in Figures 30 through 37. As the data shows, the wind oscillated rapidly over the 100 minute period with values exceeding 10 miles per hour. The highest peaks were experienced in the first of this group of tests. Even though gusts of wind entered the wind shield, the shield essentially smoothed out or averaged out the effects on the torch flame. That can be seen most clearly in the first test whose data are presented in Figure 30. The jacket temperatures reach about 1100 °F and due to an increase in the wind speed, declined to approximately 1000 °F. Then, as the wind gradually increased on the average, the jacket temperatures remained at about the same level. However, separation between curves shows that the wind was able to blow the flame off center to some degree. From direct observation, it could be seen that after being pushed away from the center of the test specimen, the flame had a tendency to recover its central position. The data from the remaining tests indicates also the stabilizing effect of the wind shield. In the four tests, the jacket temperatures were in the range between 1000 °F and 1200 °F, with a tendency toward the latter when the wind had its minimum effect.

The back plate temperatures for all four pool fire tests of urethane foam indicates that this material is an effective insulation and suitable for use in the construction of chlorine tank cars. Only in two of the pool fire tests did the Number 1 Thermocouple measure temperatures above 493 °F with no other temperatures measurement above that level. Normally the Number 5 Thermocouple would have measured the highest values due to the stand-off bracket. However, the urethane foam was a hard solid substance and for that reason could not be installed with the stand-off bracket in place. Therefore, the bracket was removed for the urethane foam tests.

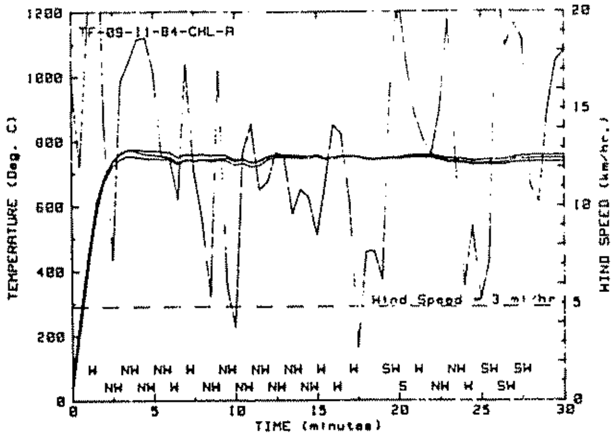

Figure 24: Jacket Temperatures and Wind Speed for the First Torch Fire Test of Urethane Foam (F-3)

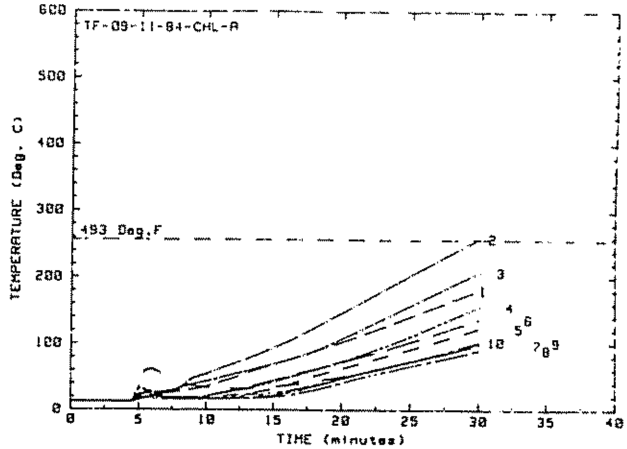

Figure 25: Back Plate and Rear Enclosure Air Temperatures for the First Torch Fire Test of Urethane Foam (F-3)

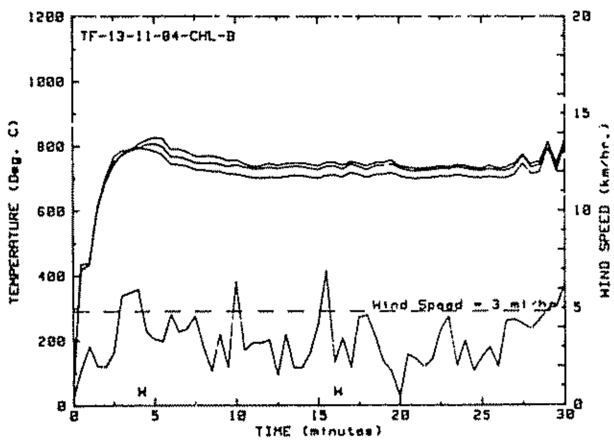

Figure 26: Jacket Temperatures and Wind Speed for the Second Torch Fire Test of Urethane Foam (F-6)

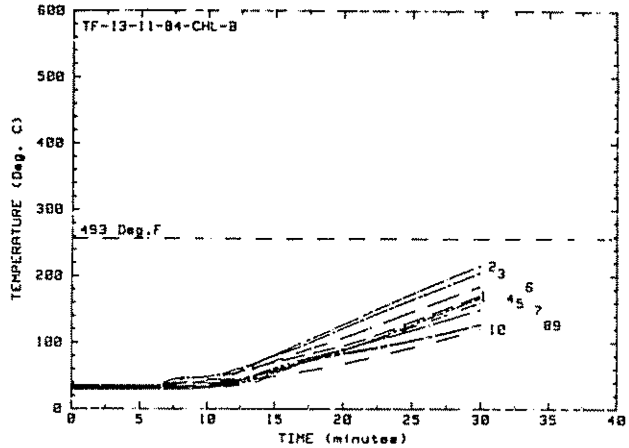

Figure 27: Back Plate and Rear Enclosure Air Temperatures for the Second Torch Fire Test of Urethane Foam (F-6)

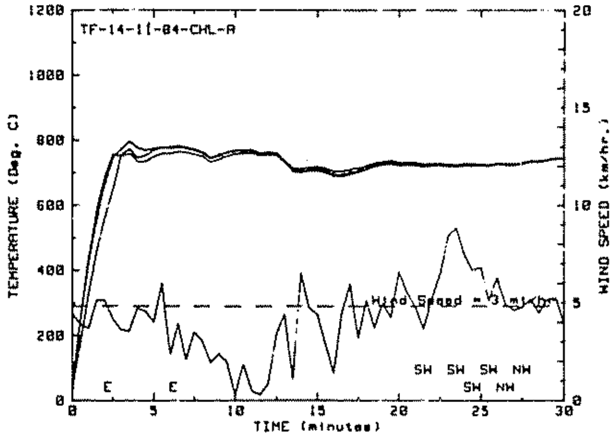

Figure 28: Jacket Temperatures and Wind Speed for the Third Torch Fire Test of Urethane Foam (F-7)

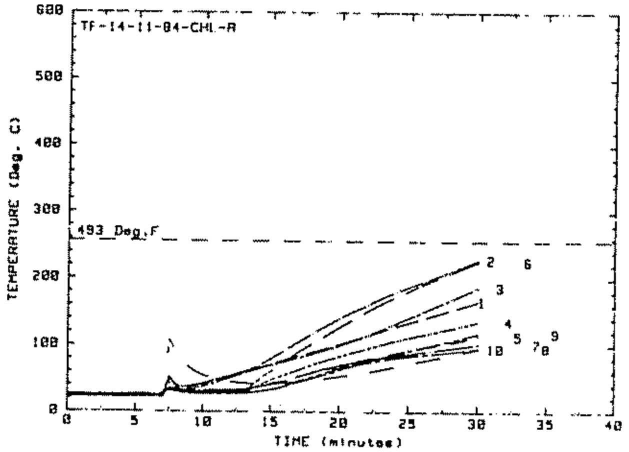

Figure 29: Back Plate and Rear Enclosure Air Temperatures for the Third Torch Fire Test of Urethane Foam (F-7)

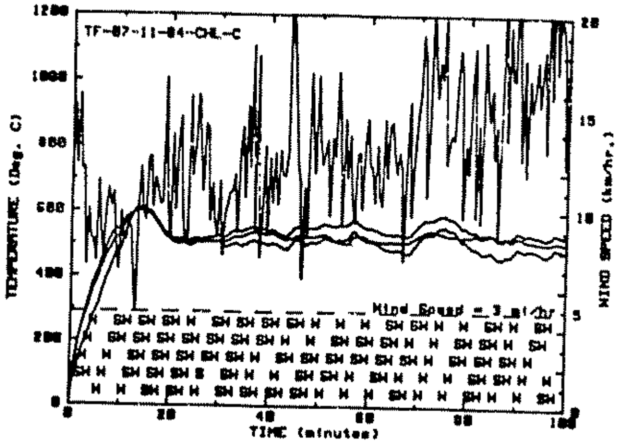

Figure 30: Jacket Temperatures and Wind Speed for the First Pool Fire Test of Urethane Foam (F-1)

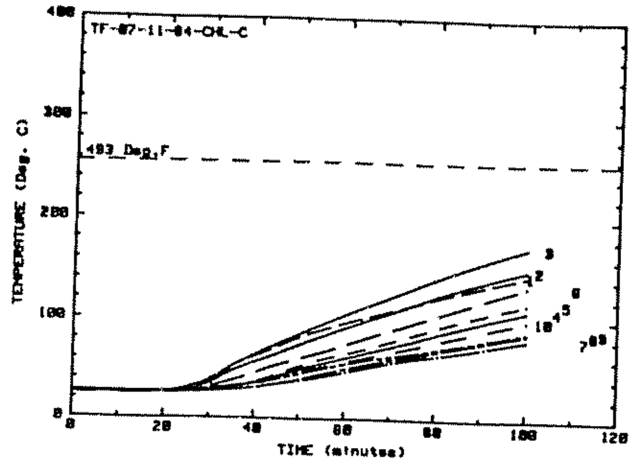

Figure 31: Back Plate and Rear Enclosure Air Temperatures for the First Pool Fire Test of Urethane Foam (F-1)

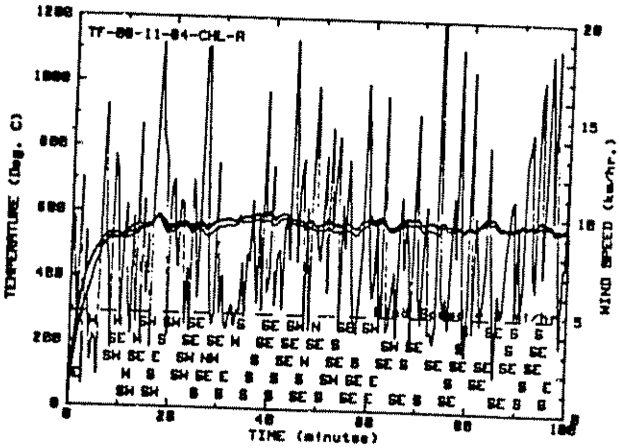

Figure 32: Jacket Temperatures and Wind Speed for the Second Pool Fire Test of Urethane Foam (F-2)

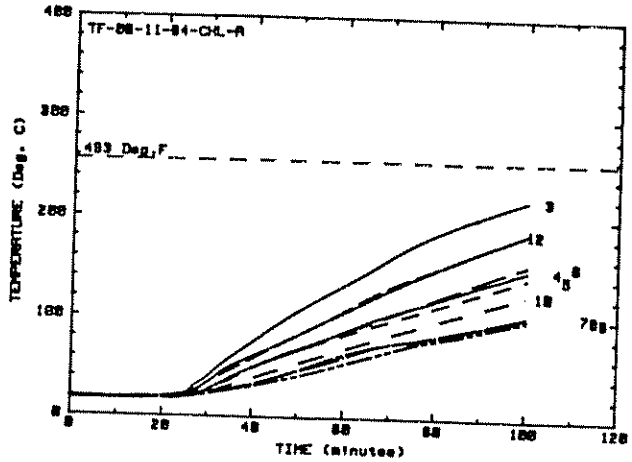

Figure 33: Back Plate and Rear Enclosure Air Temperatures for the Second Pool Fire Test of Urethane Foam (F-2)

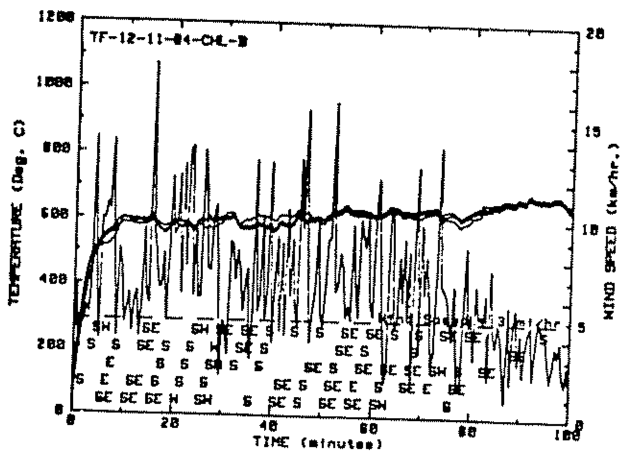

Figure 34: Jacket Temperatures and Wind Speed for the Third Pool Fire Test of Urethane Foam (F-4)

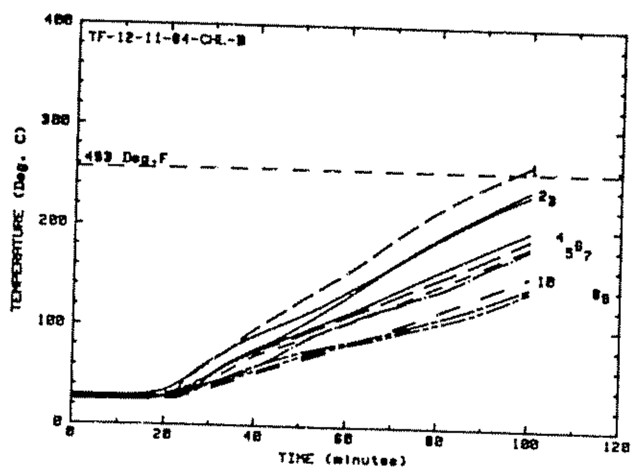

Figure 35: Back Plate and Rear Enclosure Air Temperatures for the Third Pool Fire Test of Urethane Foam (F-4)

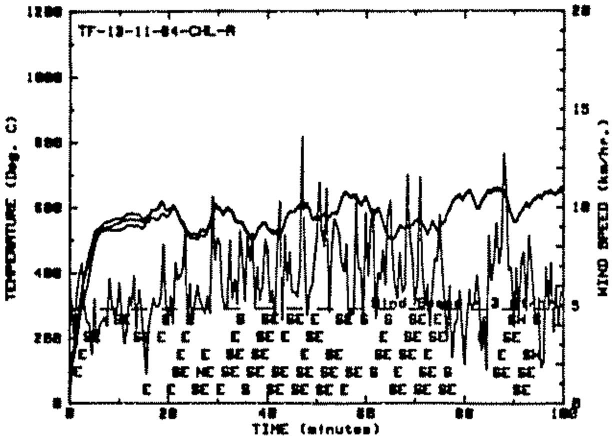

Figure 36: Jacket Temperatures and Wind Speed for the Fourth Pool Fire Test of Urethane Foam (F-5)

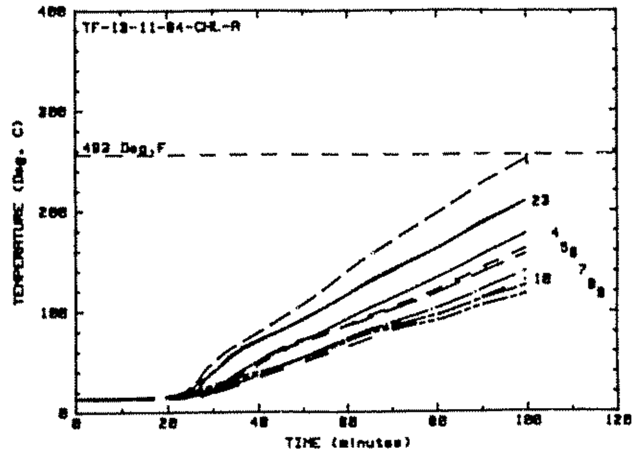

Figure 37: Back Plate and Rear Enclosure Air Temperatures for the Fourth Pool Fire Test of Urethane Foam (F-5)

IX. TORCH FIRE TESTS OF FIBERGLASS

Similarly, as with urethane foam, interest in testing fiberglass developed due to the data generated in the testing of ceramic fiber insulation systems. Therefore, in the previous tests conducted in June 1984, two tests were conducted on fiberglass. Prior to the tests, there was little hope that the fiberglass would hold the back plate temperature below 800 °F. It was expected that the insulation would break down in a short time in the intense heat, especially in the torch fire simulation environment. The unexpected low values obtained created a whole new interest in testing fiberglass. The data from the fiberglass tests are presented in Figures 38 through 63.

The results from the pool fire test and the torch fire test performed on fiberglass in June 1984 in the previous test series are presented in Figures 38 through 41. The wind speed and the jacket temperatures for the pool fire test indicates that perhaps a slightly cool flame environment existed. The temperature averaged around 1100 °F. No wind shield was present, but the wind speed was fairly calm. The back plate temperatures never exceeded 200 °F with the exception of the temperatures measured by the Number 5 thermocouple. That thermocouple measurements were influenced by the metal stand-off bracket which acted as a heat conductor through the fiberglass.

In the torch fire test, the jacket temperatures reached approximately 1600 °F within five minutes and remained there for the full 30 minute interval. One of the three thermocouple lead connections was faulty so the values measured by that one should be disregarded. The back plate temperatures, shown in Figure 41 remained below 500 °F which indicated that the fiberglass did not entirely break down. Post-test inspection revealed that the fiberglass, while having its structure affected greatly by the extreme heat, still held its position in front of the back plate. While not considered important at the time, a thin plastic mesh, which had been placed against the back plate had melted and an outline of the mesh was imprinted on the surface of the back plate. The insulating performance had far exceeded expectations. The back plate used was made of TC-128B steel and was 0.779 inches thick which was similar to the steel used in the manufacture of some types of chlorine tank cars. A standard back plate required in the regulations was used in the fiberglass tests in this series, but this difference was not considered to be significant. The very low back plate values obtained in these tests formed the basis for continuing the tests. The remaining tests utilized the 0.625 inch thick back plate made of steel similar to the steel used to construct the propane tank car. Also, the remaining tests were performed using the wind shield.

The second torch fire test results are presented in Figures 42 and 43. On removing the jacket following the test, it was observed that the fiberglass had melted, with the remains located near or on the bottom of the insulation box. The insulation held up well for approximately five minutes and then the back plate temperatures began to rise and the jacket temperatures began to decline at about the same time. In 21 minutes, the test was stopped because four thermocouple measurements had exceeded 800 °F. These results were in sharp contrast to the test performed in June 1984. It was decided to repeat the test with a sample from the same group of fiberglass specimens.

The results from the third torch fire test of fiberglass are presented in Figures 44 and 45. The test proceeded normally. The post-test examination revealed that the fiberglass had melted with the remains having fallen to the bottom of the insulation box. As in the previous test on this weight of fiberglass, failure started at five minutes. However, the shapes of the back plate temperature curves, having lower slopes, indicated a slower heating trend. The plastic

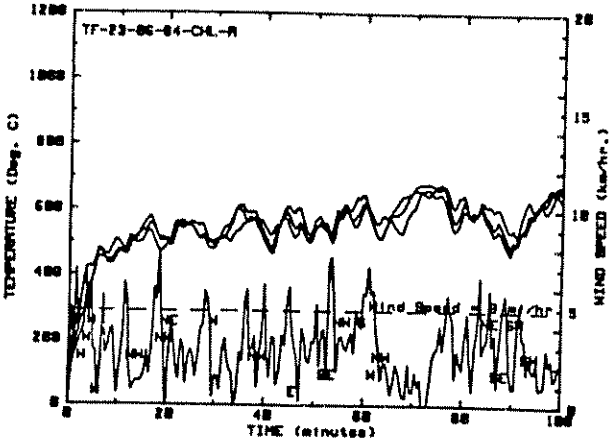

Figure 38: Jacket Temperatures and Wind Speed for the Pool Fire Test of Fiberglass (G-2)

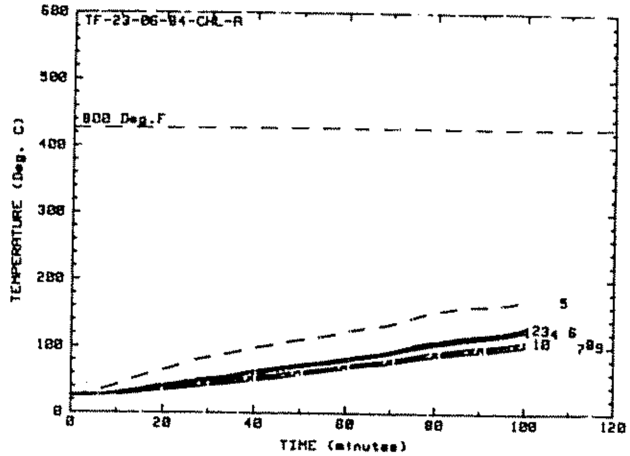

Figure 39: Back Plate and Rear Enclosure Air Temperatures for the Pool Fire Test of Fiberglass (G-2)

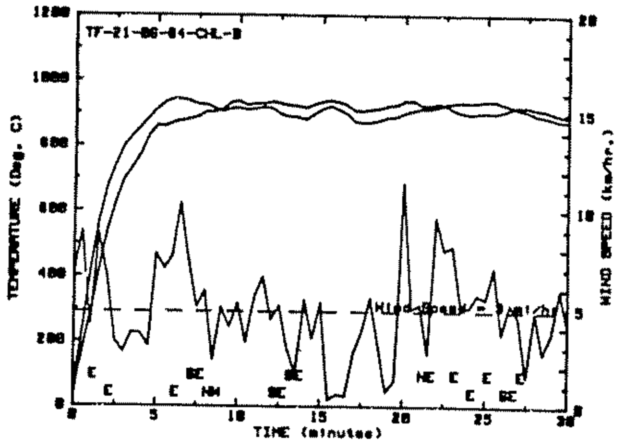

Figure 40: Jacket Temperatures and Wind Speed for the First Torch Fire Test of Fiberglass (G-1)

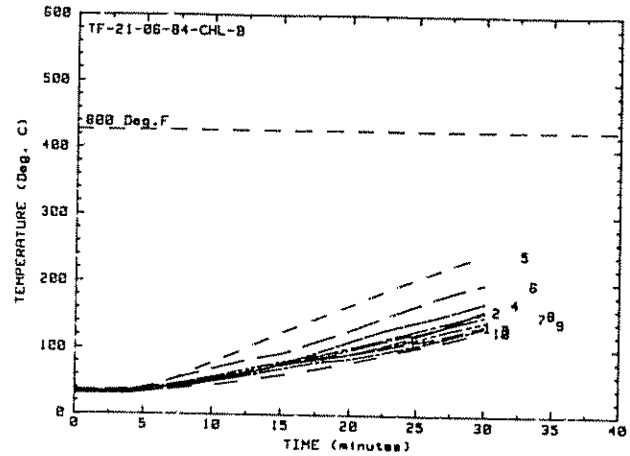

Figure 41: Back Plate and Rear Enclosure Air Temperatures for the First Torch Fire Test of Fiberglass (G-1)

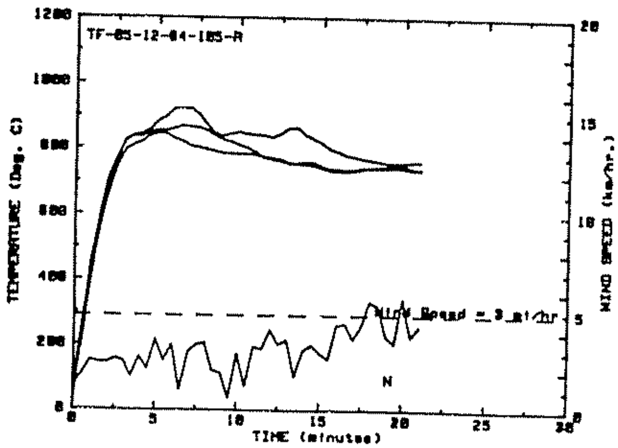

Figure 42: Jacket Temperatures and Wind Speed for the Second Torch Fire Test of Fiberglass (A-1)

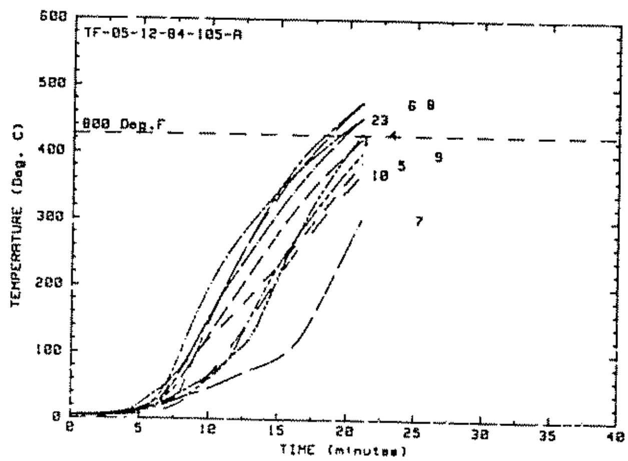

Figure 43: Back Plate and Rear Enclosure Air Temperatures for the Second Torch Fire Test of Fiberglass (A-1)

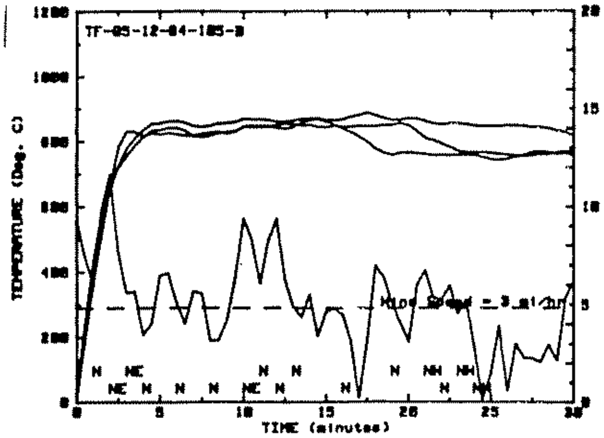

Figure 44: Jacket Temperatures and Wind Speed for the Third Torch Fire Test of Fiberglass (A-2)

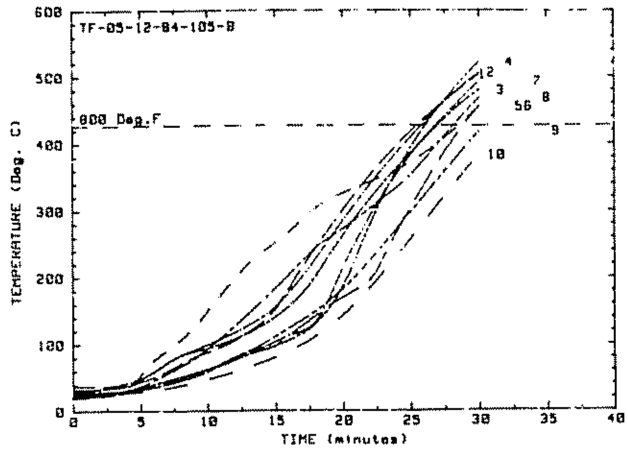

Figure 45: Back Plate and Rear Enclosure Air Temperatures for the Third Torch Fire Test of Fiberglass (A-2)

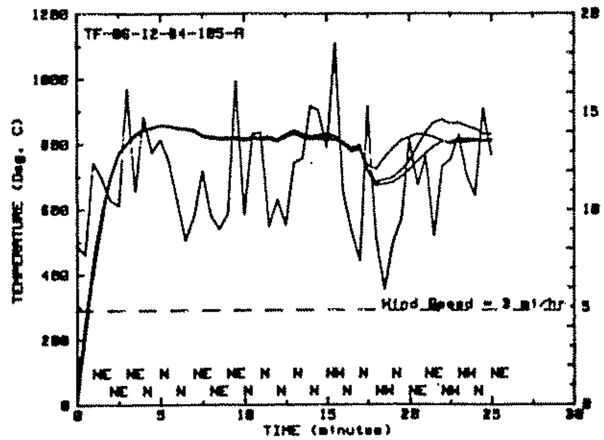

Figure 46: Jacket Temperatures and Wind Speed for the Fourth Torch Fire Test of Fiberglass (B-2)

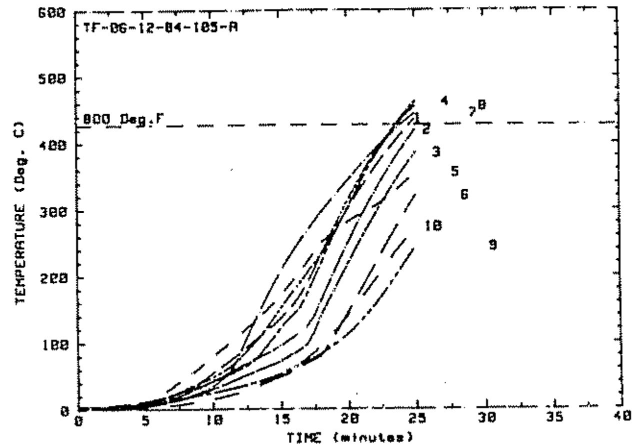

Figure 47: Back Plate and Rear Enclosure Air Temperatures for the Fourth Torch Fire Test of Fiberglass (B-2)

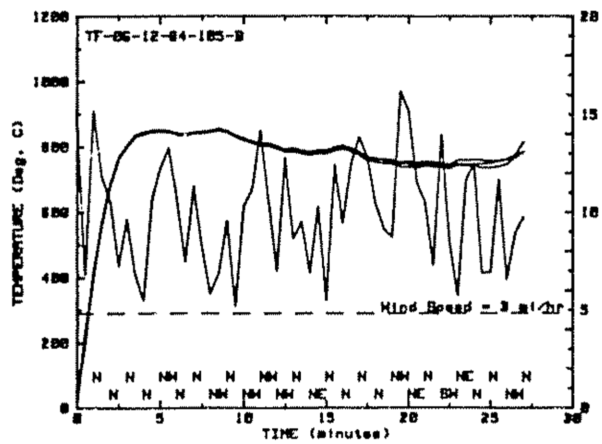

Figure 48: Jacket Temperatures and Wind Speed for the Fifth Torch Fire Test of Fiberglass (B-3)

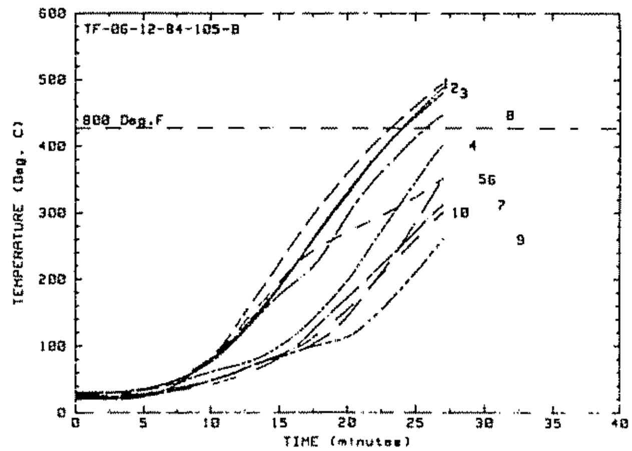

Figure 49: Back Plate and Rear Enclosure Air Temperatures for the Fifth Torch Fire Test of Fiberglass (B-3)

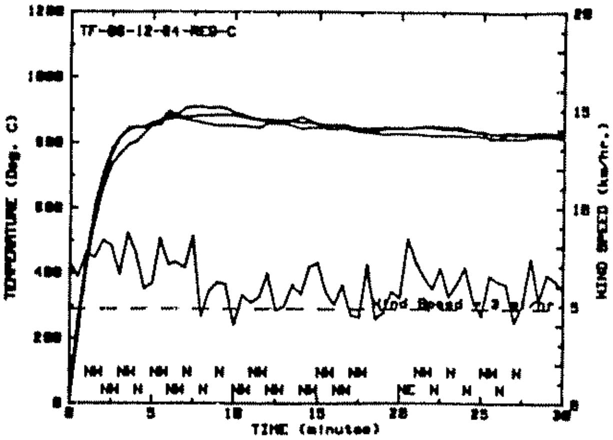

Figure 50: Jacket Temperatures and Wind Speed for the Sixth Torch Fire Test of Fiberglass (G-3)

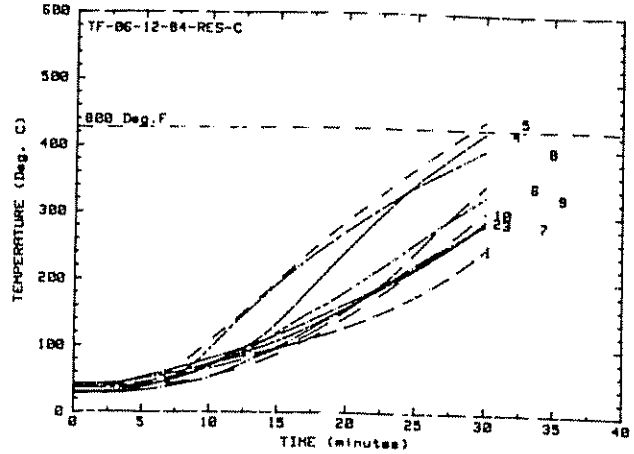

Figure 51: Back Plate and Rear Enclosure Air Temperatures for the Sixth Torch Fire Test of Fiberglass (G-3)

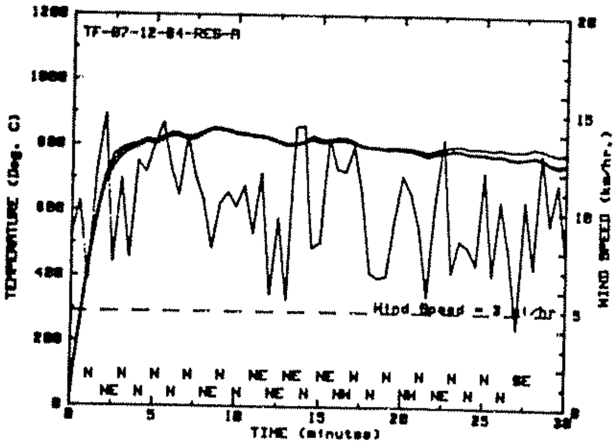

Figure 52: Jacket Temperatures and Wind Speed for the Seventh Torch Fire Test of Fiberglass (G-4)

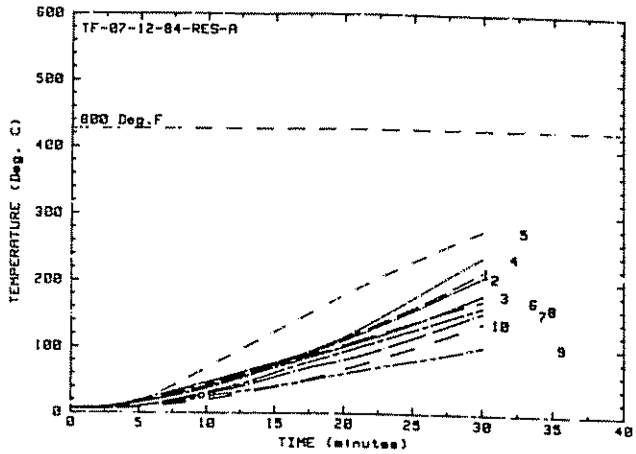

Figure 53: Back Plate and Rear Enclosure Air Temperatures for the Seventh Torch Fire Test of Fiberglass (G-4)

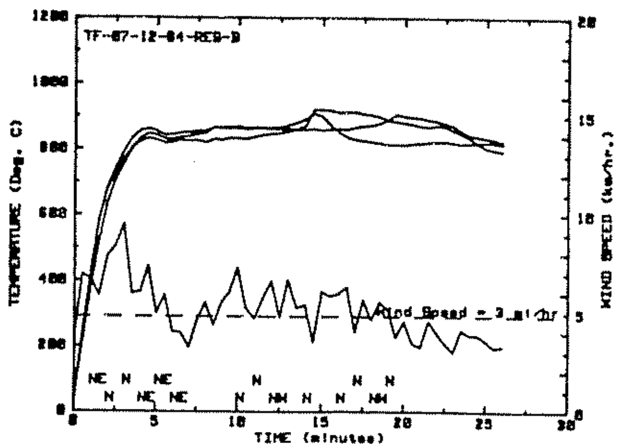

Figure 54: Jacket Temperatures and Wind Speed for the Eighth Torch Fire Test of Fiberglass (G-5)

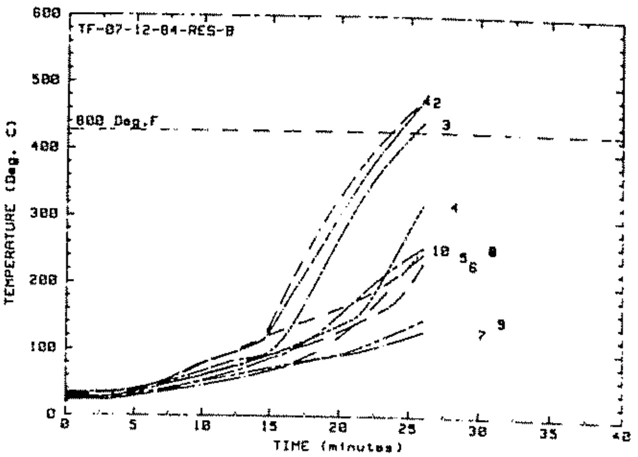

Figure 55: Back Plate and Rear Enclosure Air Temperatures for the Eighth Torch Fire Test of Fiberglass (G-5)

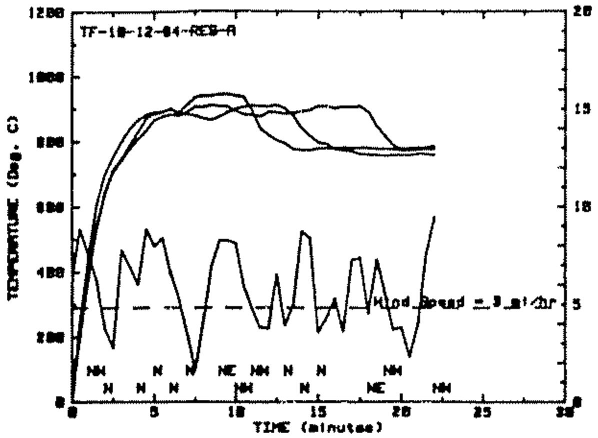

Figure 56: Jacket Temperatures and Wind Speed for the Ninth Torch Fire Test of Fiberglass (A-3)

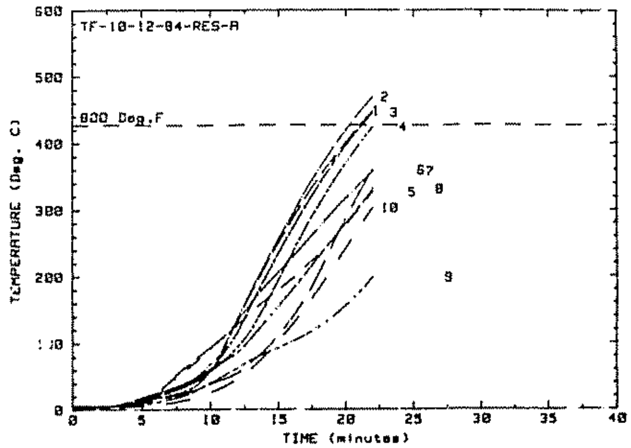

Figure 57: Back Plate and Rear Enclosure Air Temperatures for the Ninth Torch Fire Test of Fiberglass (A-3)

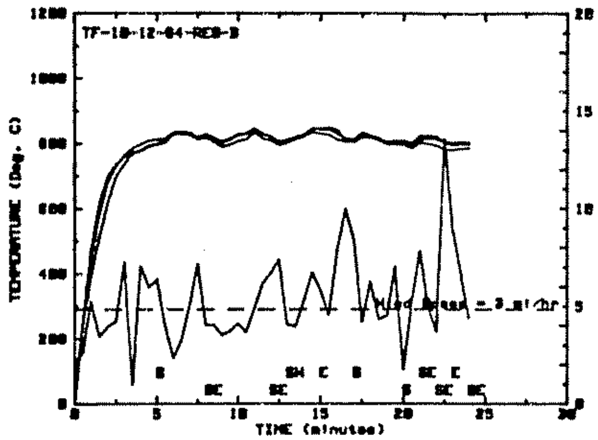

Figure 58: Jacket Temperatures and Wind Speed for the Tenth Torch Fire Test of Fiberglass (C-1)

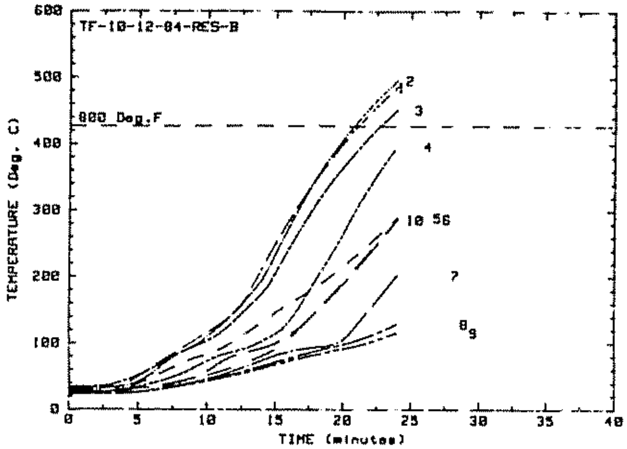

Figure 59: Back Plate and Rear Enclosure Air Temperatures for the Tenth Torch Fire Test of Fiberglass (C-1)

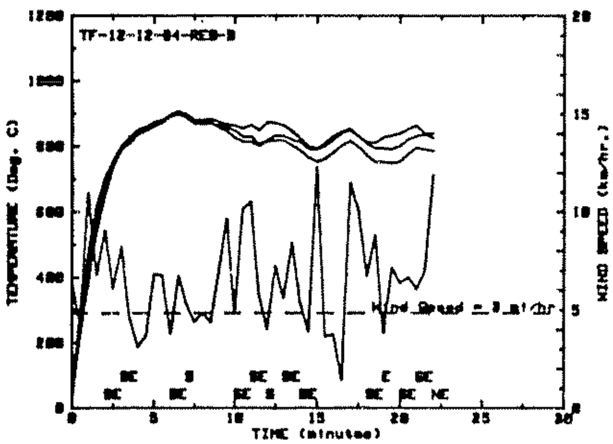

Figure 60: Jacket Temperatures and Wind Speed for the Eleventh Torch Fire Test of Fiberglass (G-6)

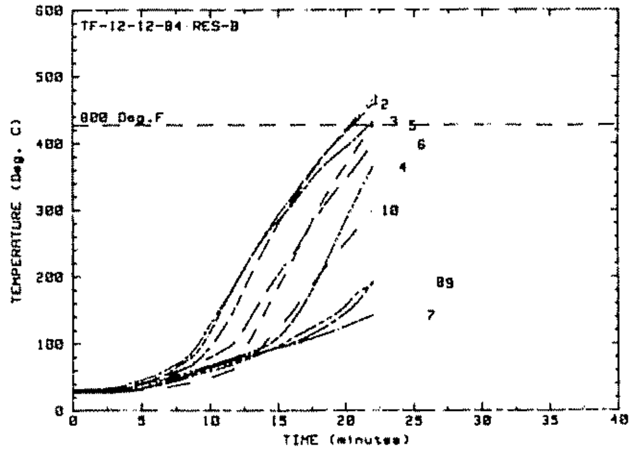

Figure 61: Back Plate and Rear Enclosure Air Temperatures for the Eleventh Torch Test of Fiberglass (G-6)

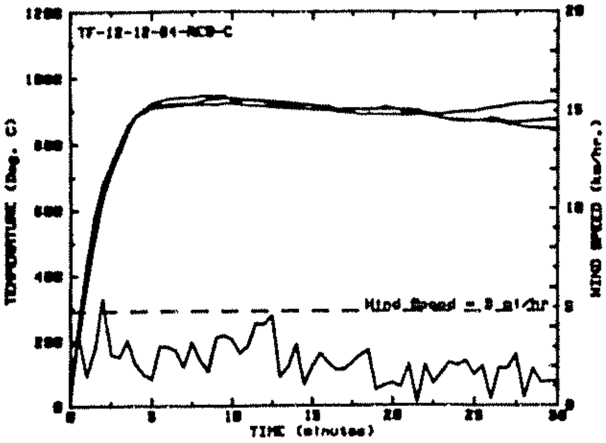

Figure 62: Jacket Temperatures and Wind Speed for the Twelfth Torch Fire Test of Fiberglass (G-7)

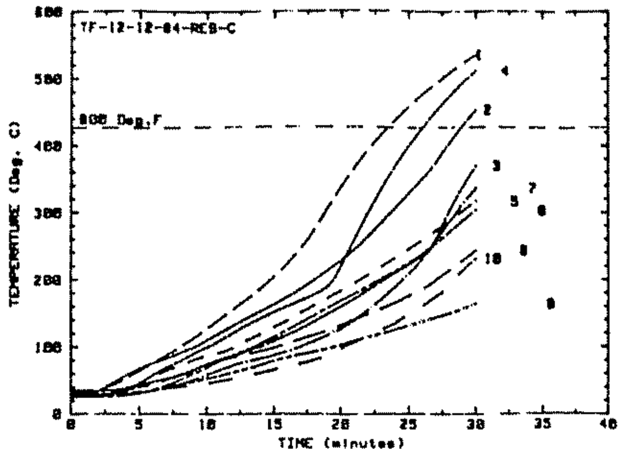

Figure 63: Back Plate and Rear Enclosure Air Temperatures for the Twelfth Torch Fire Test of Fiberglass (G-7)

mesh in the June 1984 tests was the only difference between those and the tests conducted in this series. It appeared very likely that the plastic mesh had provided an adhesive effect between the fiberglass and the back plate and thus held the fiberglass in place.

The fourth and fifth torch fire tests on fiberglass were conducted with heavier weight speciments (B-2 and B-3). This was to ascertain if the added mass would improve the results. The data from these two tests are presented in Figures 46 through 49. There was no plastic mesh installed with these specimens. In the fourth test, the heavier fiberglass performed better than the lighter specimens in whose tests the plastic mesh was not used. Not before ten minutes did the rate of temperature increase begin to rise, with measurements from the upper thermocouples starting first. The number 5 thermocouple measurement's rate of increase began to decline at 15 minutes. This was attributed to an accumulation of falling fiberglass on the standoff bracket. The temperature curves separated into two groups with the higher positioned ones providing the hotter temperature measurements. That trend implied that the insulation fell toward the bottom of the insulation box.

The sixth, seventh, and eighth tests were conducted with specimens from the same group as the one tested in June 1984 (G-3, G-4, and G-5). The data from these tests are presented in Figures 50 through 55. As aluded to previously, the plastic mesh was included in this group of specimens. In the sixth test the insulation held the back plate temperatures below 800 ^{o}F with the only exception being the temperatures measured by thermocouple number 5. All of the curves shown in Figure 51 are clustered together except for curves representing data measured by thermocouples numbers 5, 4, and 8. These curves are also grouped together, but are higher. This was a strange trend since the thermocouples positioned in the highest locations measured the lower values. The problem could have been due to inexperience of personnel who installed the specimen and for that reason may have not placed the mesh snug against the back plate. The initial back plate temperatures were very close to 100 ^{o}F with the range of values being from 81 ^{o}F to 102 ^{o}F. That accounts for the initial spread in the temperature curves.

The seventh test was a repeat of the sixth and was conducted the following morning. Therefore, the initial back plate temperatures were all near 44 ^{o}F. The insulation was carefully installed with the plastic mesh pressed against the surface of the back plate. The results from this test are shown in Figures 52 and 53 and are essentially a duplication of the results from the test conducted in June 1984. On inspection behind the jacket, it was clearly indicated that the fiberglass had remained in position in the test fixture and that the plastic mesh was responsible.

An investigation was conducted as to the purpose of the plastic mesh which accompanied the G group of test specimens. It was found that in the construction of tank cars, the mesh was put on the outside of the insulation away from the tank car shell. Its purpose was to prevent short insulation fibers from pregnating the air and irritating the workers during installation. In the eighth test, the plastic mesh was placed between the fiberglass and the jacket in order to simulate the situation just described. The results from the eighth test are presented in Figures 54 and 55. In this case, the plastic mesh helped for 15 minutes, but the insulation fell after that. At the time the fiberglass fell, the thermocouples numbered 1, 2, and 3 became exposed. The data from the other thermocouples showed that the fiberglass was effective over those areas where it remained in place; a factor which supported previous observations.

The ninth torch fire test was with a specimen from a light-weight group without a plastic mesh (A-3). The results are presented in Figures 56 and 57. A 3M-77 Sparay Adhesive was used to see if such a technique would be effective in holding the fiberglass in place. According to the temperature data, the technique was not effective.

The tenth torch fire test was with a specimen from a medium-weight group (C-1). No plastic mesh or any technique to hold the fiberglass in place was used in the test. The results are presented in Figures 58 and 59. The trend in the temperature data was as expected since there was no reason to believe any improvement would be shown. However, the test was performed since the insulation was available and it was desirable to test a sample specimen from that group.

The eleventh torch fire test was a return to the light-weight fiberglass which included the plastic mesh (G-6). The plastic mesh was placed against the back plate but the stand-off bracket was removed. The data are presented in Figures 60 and 61. The results indicate that the insulation failed to remain in position. It was speculated that in addition to the plastic mesh, the stand-off bracket was needed to support the insulation.

The final (twelfth) torch fire test was on the light-weight fiberglass specimens which included the plastic mesh (G-7). The results are presented in Figures 62 and 63. In this test, the fiberglass was placed over the stand-off bracket. This was not a successful test because by placing the insulation over the bracket, the specimen did not cover completely the four-foot square front surface of the back plate. Therefore, one side of the back plate was not protected during the test. This type of test should be repeated with an over-sized test specimen to ensure that the back plate surface is covered. The reason for this test was to simulate the construction of tank cars where the fiberglass is placed over the stand-off bracket.

X. THERMAL TESTS WITH AIR

To understand the thermal transport processes of the torch facility, two tests were conducted with no insulation in the insulation box. One was a pool fire test, while the other was a torch fire test. The data from these tests are presented in Figures 62 through 65. The torch fire test results were as anticipated. That is, even though the wind speed was very high, the jacket temperatures remained steady near 1400 ^{o}F. The back plate began immediately to heat up so that at 12.5 minutes, two of the thermocouples had measured values above 800 ^{o}F. At that point, the test was terminated. As pointed out above, the flame temperature for the torch fire environment was assumed to have been 2200 ^{o}F.

The pool fire test had a very different result. The jacket temperature never exceeded 750 ^{o}F and remained steady around 700 ^{o}F. The flame temperature of the pool fire environment was assumed to have been 1600 ^{o}F. These jacket temperatures constitutes values 400 to 500 ^{o}F below those obtained when an insulation was placed in the insulation box. The back plate temperatures rose slowly and did not exceed 550 ^{o}F in the 100 minute period. The final slope of the curves indicate that an equalibrium condition was being approached where an equal amount of heat would be lost and gained. The low jacket temperatures were consistent with observations in previous tests where it was noticed that the jacket temperature increased with the ability of the insulation to act as a thermal barrier.

XI. CONCLUSIONS AND RECOMMENDATIONS

A great improvement in the testing efficiency of the facility was experienced using the wind shield. The data generated in pool fire tests were of higher quality than obtained previously and tests could be started when the wind speed was substantially higher than three miles per hour. Consequently, as many as three tests were performed in a single day. However, the tests showed that the wind shield could be improved by providing a cover for the top. Such a cover should extend from the torch nozzle end of the wind shield to perhaps two-thirds of the distance to the other end. Some opening is required to provide passage for the combustion gases to flow out.

The tests performed on urethane foam provided results which indicate that this insulation meets the proposed performance standard for the chlorine tank car. That is, the insulation was capable of holding the back plate temperature below 493 ^{o}F. These tests were performed without the stand-off bracket which would have caused the number 5 thermocouple to measure higher temperatures. However, such a "hot spot" would not probably be significant in a final analysis.

Fiberglass performed very well when a means was provided to hold it in place. That support was provided only when the plastic mesh was installed between the fiberglass and the front of the back plate. The characteristics of the plastic mesh should be studied to determine the mechanism which enabled it to provide adhesive for holding the fiberglass against the back plate surface.

It is further recommended that the holder be redesigned so that insulations, such as fiberglass, can be correctly tested. The reason is that the burden for holding the insulation in place lies with the test procedure and not with the producer of the product. A possible approach is to install a wider and taller insulation box. The extra insulation beyond the four-foot square area, which is required by the regulations, may retain its integrity and thereby support the portion being subjected to the intense heat. One concept is to move the rear flame shield to the front edge of the rear enclosure and increase its width by sixth inches. The insulation box could then be constructed one foot wider on all sides. While such an insulation box could accommodate a larger test specimen, the changes

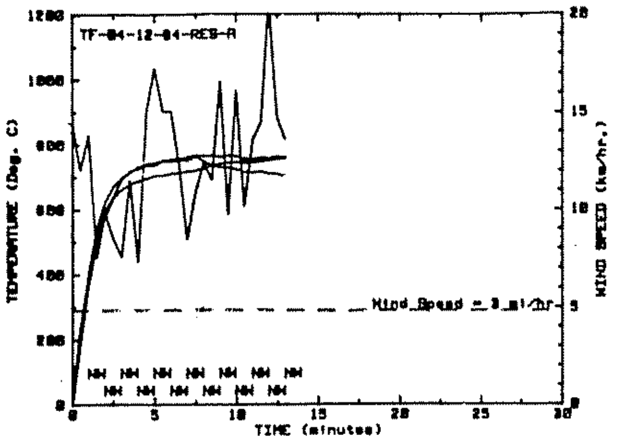

Figure 64: Jacket Temperatures and Wind Speed for the Torch Fire Test of Air

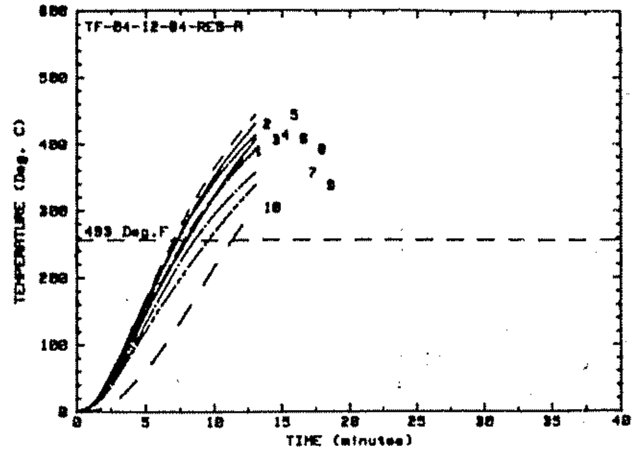

Figure 65: Back Plate and Rear Enclosure Air Temperatures for the Torch Fire Test of Air

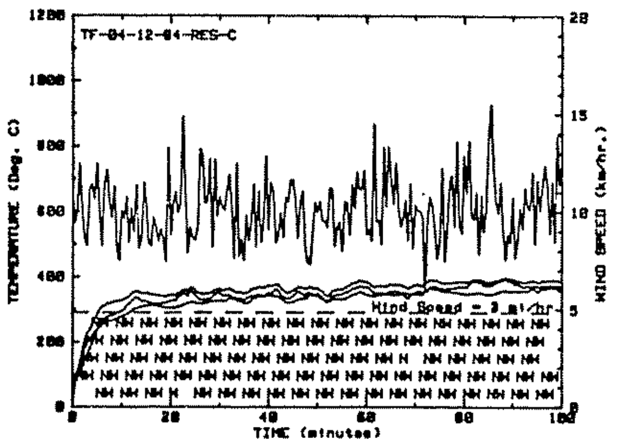

Figure 66: Jacket Temperature and Wind Speed for the Pool Fire Test of Air

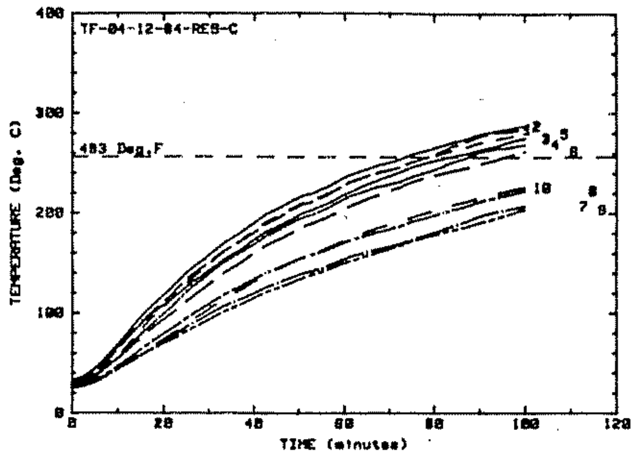

Figure 67: Back Plate and Rear Enclosure Air Temperatures for the Pool Fire Test of Air

would require devising a new method for attaching the insulation box to the rear enclosure. Such a design change would not be costly and may solve the problem being addressed. Once such a holder becomes available, fiberglass should be retested.