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FIRE PROTECTION RESEARCH QUARTERLY PROGRESS REPORT OCTOBER-DECEMBER 1977

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ABSTRACT

This report describes the activities of a Fire Protection Research Project during the period of October-December 1977. It describes a testing program which was undertaken to assess the adequacy of fire retardant coatings as applied on electrical cables. The preliminary results show a remarkable consistency between small scale tests and a full scale single tray testing program.

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FIRE PROTECTION RESEARCH
Quarterly Progress Report
October-December, 1977

Introduction

The long range objective of the Fire Protection Research Program is to confirm the capability of safety features in use or planned for use in nuclear power plants. This objective is to be achieved by full-scale testing and experimental and analytical evaluation of fire phenomenology.

Tests in the first phase of the Fire Protection Research Program evaluated the adequacy of cable tray spacing as designated in Regulatory Guide 1.75, Physical Independence of Electrical Systems, Section 5.14, "General Plant Areas." This section of the guide concerns separation of protective systems in areas of the plant where power cables are included and no source of fuel exists except that provided by the cable materials. Specifically, the first phase tests examined protective systems in large open areas of the plant.

In the second phase tests, the separation distance between cable trays varied. The third phase tests involved stacking trays and conduits where 14 closely stacked trays representing one division of cables and 3 trays representing the second division were displaced by the separation distances of R. G. 1.75. In all those tests the fires were electrically initiated.

The test of phase four employed the same stacked tray arrangement as the third phase tests but was initiated by an "exposure fire." A fully developed fire within a single electrical cable tray was ignited. A series of 12 single-tray tests performed earlier optimized parameters for this type of fire. A barrier was placed over the donor tray until after the propane burners were turned off. Then the barrier was removed to allow the single-tray fire, with only the cable as fuel, to act as a propagation source. The fire spread not only through the closely stacked trays of one division, but also ignited the cables in a redundant safety division.

When the results of the "exposure fire" test were analyzed, it was decided that other fire protection measures should be investigated. Fire retardant coatings is the first of these measures to be investigated experimentally and this quarterly report includes some results. The Water Reactor Safety Research Directorate of the NRC provided a list of fire retardant coatings which consisted of those having an approval from Factory Mutual as of June 1977. These coatings were then "small scale" tested, analyzed, and tested in Sandia's fire test facility. The balance of this report is concerned with these activities.

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Analysis of Coatings

The purpose of analyzing these fire retardant coatings was not to invade upon proprietary interest of composition but to determine the outgassing at relatively low temperature (below 300° C). G . Chromatography and Emission Spectrascopy were used for analysis of the coatings.

Samples of flame retardant coatings were submitted for identification of volatile components. A small quantity (< 1 μg) was placed in a temperature-programmable solid probe and inserted in a UHV mass spectrometer system. The sample was then heated to a minimum temperature of 250° C.

Evolved compounds included beta-chloroethyl phosphate, acetic acid or acetate, dipropyl or dibutyl phthalate, possible diallylp' halate, dibromopropyl or dibromovinyl fragments, ethyl chloride, ethanol, ethylacrylate, ammonia, carbon dioxide, water alcohol, and a chlorine-substituted compound not identified.

Emission Spectroscopy gave the following degradation products: P, Si, B, Mg, Ti, Na, Al, Ca, Fe, Sb. Glass fibers were present together with water or water and alcohol used as coating solvents.

Preparations for Testing

Small Scale

For the small scale tests which were performed at Smithers Scientific Services, Akron, Ohio, quantities of coatings A, C, D, E, and F were applied to two types of electrical cable, supplied by two manufacturers (A and B). The cables used were the same types used in the electrically initiated fire tests and exposure fire tests at Sandia. These were: a three-conductor No. 12 AWG, 30 mil (0.76 mm) crosslinked PE, silicon glass tape, 65 mil (1.65 mm) crosslinked PE jacket, 600 V (Supplier A) and, (2) a single-conductor No. 12 AWG, 30 mil (0.76 mm) crosslinked PE, no jacket, 600 V (Supplier B). The cables were cut into 6-inch pieces and placed in wood forms lined with plastic, a 6 inch (15.2 cm) x 6 inch sample size. The coatings were then troweled to the manufacturer's specified wet thickness and allowed to cure at least lays. Each sample was mounted in the holding fixture fronted by 1-inch (2.54-cm) wire mesh and backed by one layer of aluminum foil and cement board.

Coating A was applied at a wet thickness of 1/8 inch (3.2 mm). The coating was easily applied and dried very hard and flat on both the large and small cables. There was some cracking in the coating after curing.

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Coating C was applied at a wet thickness of 1/8 in. (3.2 mm). The coating adhered to the trowel and made thickness hard to control. When curing, the coated sample warped but remained soft and pliable which allowed the samples to be flattened before testing.

Coating D was applied to a wet thickness of 1/4 in. (6.4 mm). The coating dried very hard and flat. There were some cracks in the surface.

Coating E was easily applied at a nominal wet thickness of 1/4 in. (6.4 mm). The coating dried flat and smooth and remained slightly soft to the touch and pliable after curing.

Coating F was applied to a nominal wet thickness of 3/16 in. (4.8 mm). The coating adhered to the trowel and was difficult to spread evenly. When fully cured, the coating shrank and the samples were warped and curled. The coating dried semirigid and the samples were difficult to flatten.

Full Scale

For the full scale tests performed at Sandia Laboratories, Albuquerque, coatings A, B, C, D, and E were applied to the same cables described previously. The cables were loaded into galvanized-steel, open-ladder trays 18 in. (45.7 cm) wide and 12 ft (3.7 m) long. Although the trays were filled to approximately the tops of the 4-inch siderails of the cable trays, the loading technique allowed maximum air passage through the cables. The loading pattern was a figure 8 in the tray with the crossing point advancing progressively up and down the tray. For the three-conductor cables this resulted in a 25% fill by cross-sectional area and for the single conductor a 15% fill by cross-sectional area (90 three-conductor cables per tray and 450 single-conductor cables per tray). Non-IEEE-383 qualified cable was loaded into additional cable trays to be included in the testing. The type of cable used was three-conductor, 20/10 Poly-PVC, polyethylene insulation, 45 mil (1.14 mm) PVC jacket. The number of cables per tray and percent filled by cross-section were the same as the qualified three-conductor cables previously described.

At the fire site at Sandia, coatings A, B, C, and E were sprayed onto the loaded cable trays by their respective manufacturers. The nominal wet thickness applied to the tops and bottoms of the loaded cable trays was the same as that used in the small scale tests and were applied according to the manufacturers' specifications. Coating B was not included in the small scale tests. Coating F was not included in the full scale tests because of difficulty in obtaining this product from a foreign source. Coating D was applied by Sandia personnel to the manufacturer's specification but was the only trowel-grade coating used and presented a completely different appearance from the sprayed-on coatings.

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The amounts of coating material used to accomplish the necessary wet thickness are as follows:

Coating A	7 gal/tray	Coating D	10 gal/tray
Coating B	7 gal/tray	Coating E	11 gal/tray
Coating C	7 gal/tray		

Small Scale Test Description

The Ohio State University Release Rate Apparatus at Smithers Scientific tested two types of cable and five types of fire-retardant coatings to varying levels of radiant heat flux to determine the ignition time and smoke and heat release rates. The apparatus uses a flow system in which a known, constant flow rate of air enters an environmental chamber. Rate of heat release is monitored by change in temperature of air leaving the chamber. Rate of smoke release is monitored by optical density of gas leaving the chamber. The sample is placed into the environmental chamber, and a small pilot flame is placed to impinge on the center of the lower edge of the vertically placed sample. A radiant planel provides exposure in terms of heat flux to the sample. The test conditions provided air flow of 84 ft^3/min (0.04 m^3/s) with tests at room temperature and at radiant heat flux levels of 1.0 W/cm^2, 2.0 W/cm^2, 3.0 W/cm^2, and 4.0 W/cm^2.

Full Scale Test Description

Single Tray Tests

The test described here was designed to reproduce the conditions of the full scale stacked-tray test of July 6, 1977 as reported in "A Preliminary Report on Fire Protection Research Program," SAND77-1424. An important difference, of course, is that only the ignition tray itself was used in this phase of the fire retardant coatings tests. For each type of coating, two tests were run: One each with the single-conductor cable and the three-conductor cable.

The test procedure and set-up were essentially identical to that used in the July 6 fire tests. An insulated barrier was placed 9.5 in. (24.13 cm) over the ignition tray. The twin-burner assembly was centered beneath the tray so that rungs of the cable tray were not directly over either burner. The distance between the top of each burner and the bottom of the cable tray was 4.75 in. (12.1 cm) (see Figure 1). Thermocouple and calorimeter placement was made as shown in Figure 2. Note that cable thermocouples were in place before spraying or troweling of coatings began.

For each burn cycle, propane and air were turned on for 5-minute periods of time. Previous tests had shown 5-minute periods as optimum for creating the largest donor fire in a cable tray loaded with IEEE-383 qualified cable, provided an open or random cable-fill pattern is maintained. If a fully developed cable-tray fire was not achieved after applying this ignition source for 5 minutes, additional 5-minute ignition cycle were repeated after 5-minute delays. Six ignition cycles were attempted if a fully developed cable tray fire was not achieved.

Figure 1. Typical Full Scale Single Tray Fire Retardant Coating Test Setup

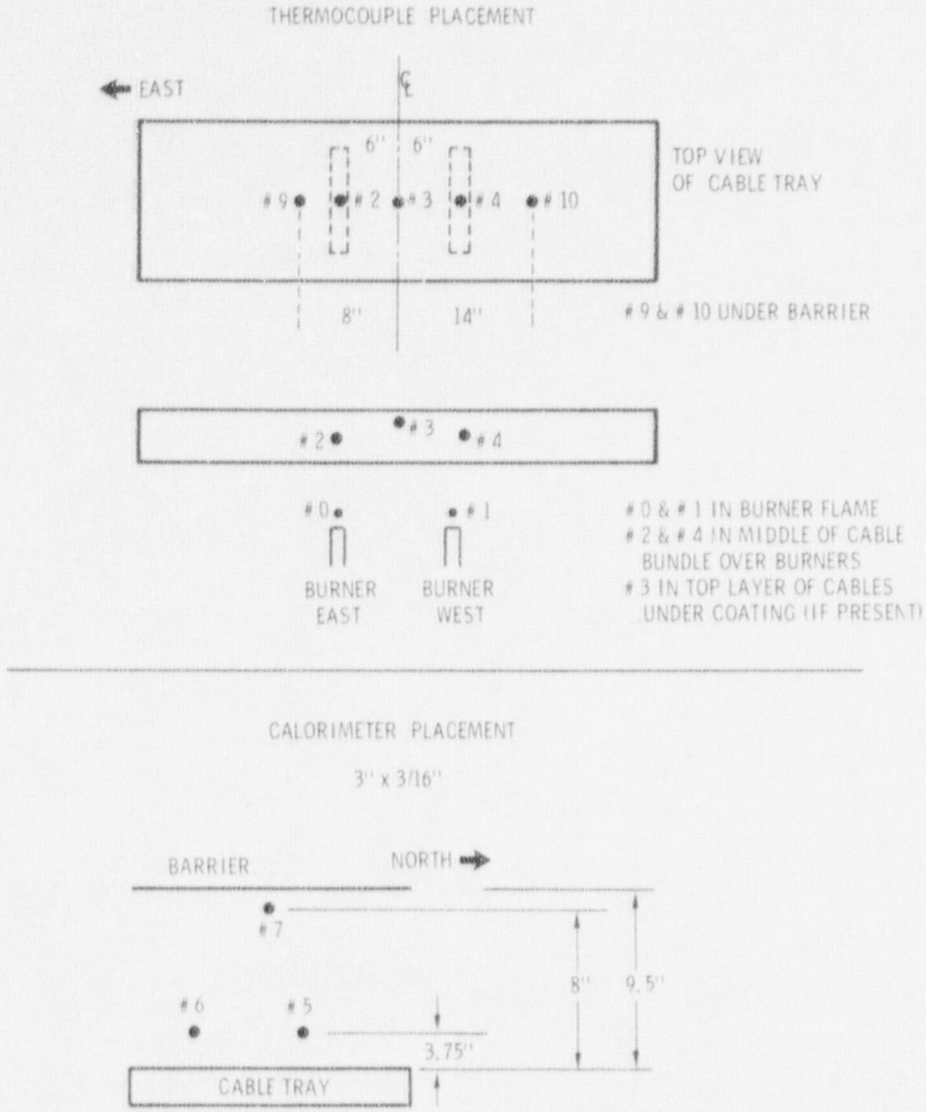

Figure 2. Thermocouple and Calorimeter Placement for Single Tray Test

Thirteen tests were conducted consisting of the following:

2 Uncoated cable trays with IEEE-383 qualified cable (one with single-conductor, one with three-conductor)

1 Uncoated cable tray with non-383 qualified PE/PVC cable, three-conductor

10 Coated cable trays with IEEE-383 qualified cable (5 different coatings each with the two cable constructions)

Electrical resistance measurements of the cable and cable-to-ground were made before and after each test. Current measurements were made before and after each test and recorded throughout each test.

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Figure 3 shows the fire site facility. Each test began with the rear-vent fan off and one front 6-ft x 3-ft (1.8-m x 0.9-m) door open. A 4-ft x 8-ft (1.2-m x 2.4-m) sheet was placed between the door and the test setup to act as an air baffle. The buildings was free of all smoke before each test began. During the test the building exhaust fan was turned on only when and if the smoke accumulation prevented observation of a possible developing fire on the video system employed for that purpose. When turned on, the exhaust system allowed approximately three building-volume changes of air per hour.

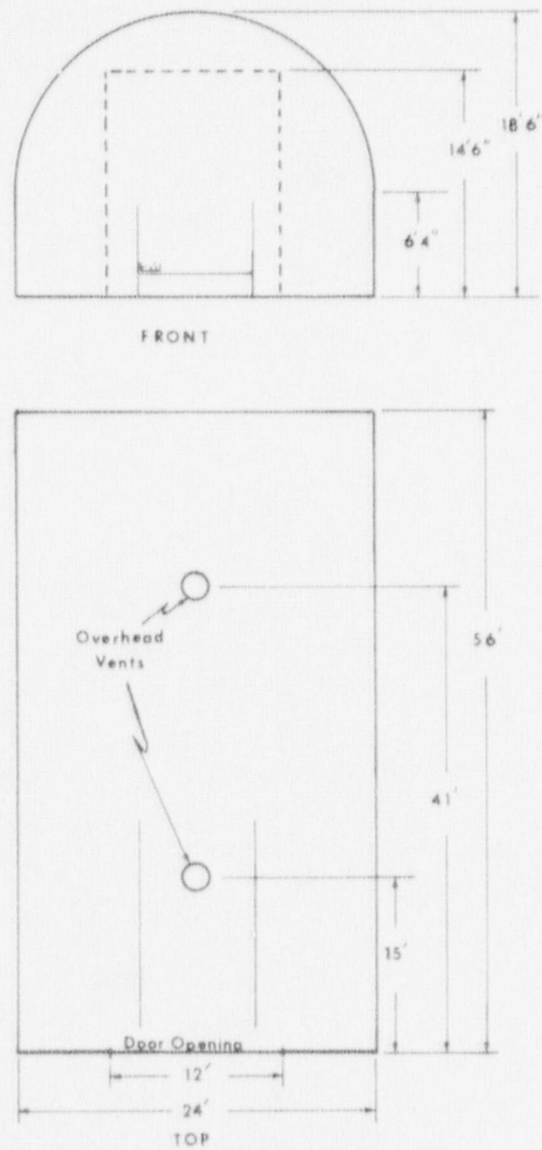

Figure 3. Cable Tray Fire Site

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Table I shows a matrix of all tests completed in this segment of the program.

TABLE I

Test Matrix

Coating	Single Tray Tests: 383 Qualified Cable, Single Conductor	Single Tray Tests: 383 Qualified Cable, Three Conductor	Single Tray Tests: Non-383, Three Conductor	Small Scale Test: 383 Qualified Cable, Single Conductor	Small Scale Test: 383 Qualified Cable, Three Conductor
None	x	x	x	x	x
A	x	x		x	x
B	x	x			
C	x	x		x	x
D	x	x		x	x
E	x	x		x	x
F	x	x		x	x

Small Scale Test Results

Test Narrative

Coating A

Only trace amounts of heat and smoke were released at 1.0 W/cm^2 and room temperature exposure. At radiant heat flux levels of 2.0 W/cm^2, and 3.0 W/cm^2, there was some flashing of the coating in the area impinged by the pilot flame. However, this was sporadic and there was no further burning until ignition of the cables. The burning cables gave off a strong odor.

Coating C

At both room temperature and a heat flux of 1.0 W/cm^2, the coating did not ignite. There were only traces of heat and smoke. The coating ignited at heat flux levels of 2.0 W/cm^2, 3.0 W/cm^2, and 4.0 W/cm^2 and continued to burn until the cables were ignited.

Coating D

At 1.0 W/cm^2, the coating intumesced only slightly, and there was no ignition at room temperature. Upon exposure to higher values of radiant heat, the coating began to intumesce. There was no apparent ignition of the coating, but the intumescing continued for the duration of exposure. The char extended 3 to 4 in. (7.62 to 10.16 cm) from the sample holder. Large pieces of the framed coating fell into the test chamber during the test. Posttest examination showed the cables to be still pliable and the covers intact.

2

Coating E

At room temperature tests and 1.0 W/cm^2 radiant heat flux tests, there was limited ignition of the coating but only at the area of pilot impingement. There was no sustained burning of the coating or the cable. When tested at the radiant heat flux levels of 2.0 W/cm^2, 3.0 W/cm^2, and 4.0 W/cm^2, the coating flashed intermittently for 3 to 6 minutes. After this time, there was no further ignition until the cables began to burn.

Coating F

At 1.0 W/cm^2, the coating showed only a slight flash, and there was no ignition at room temperature. Heat and smoke were minimal. When exposed to radiant heat flux levels of 2.0 W/cm^2 and above, the coating ignited almost immediately. This continued until the cables ignited. While the coating burned, it separated from the cables. During one test, the coating fell out of the sample holder, leaving the cables exposed. Posttest examination showed the coating to come away easily in one piece; there was no adhesion to the cables.

Heat Release Data

Appended Tables A-I through A-XI show the heat release data for the radiant heat flux level of 4.0 W/cm^2. Table II summarizes the results for this same flux level. This heat flux level was chosen as it shows the largest discrimination between results for coatings and provides results consistent with full scale tests. In addition, this heat release is believed to be consistent with the heat flux produced in the full scale test. The full scale heat release of 140,000 Btu/hr (4.1×10^4 W) over a 4.5 ft^2 (0.42 m^2) area corresponds to 9.8 W/cm^2. Since the Btu figure is only an input to the burner (as in IEEE-383) and without stoichiometric reaction data, it is assumed that the actual input to the ignition tray in the full scale test is very near the 4.0 W/cm^2 radiant heat flux level of the small scale tests.

TABLE II

Results of Small Scale Coatings Tests at 4 W/cm^2

Coating	Time to Ignition (minutes)	Time to Maximum Heat Release (minutes)	Cumulative Heat Release at 10 Min. MJ/m^2	Cumulative Heat Release at 15 Min. MJ/m^2
A	8	16	14.6	39.1
C	8	17	28.6	43.7
D	14	28	4.1	8.1
E	24	34	16.2	22.5
F	5	12	23.5	60.4
No Coating 383 Cable	0.8	6	45.7	78.0

Single-Tray Tests

Coating A

Single-Conductor Cable -- After two cycles of ignition source a fire developed in the cable tray and burned for 6 minutes before self-extinguishing. Flame height was 5 to 7 inches (12.7 to 17.8 cm) above cables. With the affected area 35 inches (89 cm) long and 17 inches (43.2 cm) wide. Not all affected areas burned; some of that area was carbon deposited. Little damage was visible on top of the tray, but the coating showed some cracks and splitting beneath cable tray. Cable resistance measurements were: pretest 6.9 ohms, posttest (warm) 7.6 ohms, (cold) 4.38 ohms; cable-to-ground pretest > 20 M ohms, posttest (cold) 9.8 M ohms.

Three-Conductor Cable -- After two cycles of ignition source a fire developed and burned for 15 minutes before self-extinguishing. Flame height was approximately 7 inches (17.8 cm) above cables and the affected area was 30 inches (76.2 cm) long by 15 inches (38.1 cm) wide. Not all of the affected area was burned; carbon deposits blackened the coating which was relatively intact with no major cracks but with some peeling at burn area. Cable resistance measurements were: pretest 5.2 ohms, posttest (cold) 5.06 ohms; cable-to-ground pretest > 20 M ohms, posttest (cold) 9.8 M ohms.

Coating B

Single-Conductor Cable -- After four cycles of the ignition source a fire developed and burned for 7 minutes before self-extinguishing. Flame height was 7 to 9 inches (17.8 to 22.9 cm) above cables and the affected area was 43 inches (109 cm) long and 18 inches (45.7 cm) wide. The burned area was a small portion of the affected area with no damage seen on top of the cables. Burn area on the bottom of cables was 374 $in.^2$ (0.24 m^2). The coating was intact in all other area. Cable resistance measurements were: pretest 5.87 ohms, posttest (warm) 6.5 ohms, (cold) 5.8 ohms; cable-to-ground pretest > 20 M ohms, posttest (warm) 132 ohms, (cold) 4.3 k ohms.

Three-Conductor Cable -- After three cycles of the ignition source a fire developed and burned for 7 minutes before self-extinguishing. Flame height was 5 to 8 inches (12.7 to 20.3 cm) above the cables and the affected area was 40 inches (1.02 m) long by 17 inches (43.2 cm) wide. Not all of affected area was burned; the majority of area only carbon deposited. The coating was intact with no cracks or flakes. Cable resistance measurements were: pretest 5.0 ohms, posttest (warm) 5.6 ohms, (cold) 4.95 ohms; cable-to-ground resistance pretest > 20 M ohms, posttest (warm) 370 k ohms, (cold) 4.9 M ohms.

2

Coating C

Single-Conductor Cable -- After two cycles of ignition source a fire developed in the cable tray and burned for 15 minutes before self-extinguishing. Flame height was greater than 9.5 inches (24.1 cm) and flattened out against, and curled around the edges of the barrier. The affected area was 58 inches (1.5 m) long and 18 inches (45.7 cm) wide. All of the affected area burned and the cable was severely charred. The coating was severely cracked and flaked. Cable resistance measurements were: pretest 5.86 ohms, posttest (warm) 2.83 ohms, (cold) 6.04 ohms; cable-to-ground resistance pretest > 20 M ohms, posttest (warm) 2.2 ohms, (cold) 2.8 ohms.

5

Three-Conductor Cable -- After one cycle of ignition source a fire developed and burned for 40 minutes before self-extinguishing. Flame height was greater than 9.5 inches (24.1 cm), flattening against the barrier and curling around the barrier's sides. Affected area of the tray was 43 inches (1.09 m) long by 18 inches (45.7 cm) wide. All of the affacted area was burned and the cable was charred with the coating cracked and falling off. Cable resistance measurements were: pretest 5.5 ohms, posttest (warm) 5.5 ohms, (cold) 1.82 ohms; cable-to-ground pretest > 20 M ohms, posttest (warm) 71.4 k ohms, (cold) 4.8 M ohms.

Coating D

Single-Conductor Cable -- After six cycles of ignition source no fire developed. No damage or carbon deposits were visible on top of the tray but the burner flame on the bottom caused a 4.5 ft^2 (0.42 m^2) section of coating to intumesce and carbonize. The cables were not damaged. Cable resistance measurements were: pretest 8.4 ohms, posttest (warm) 9.3 ohms; cable-to-ground resistance pretest > 20 M ohms, posttest (warm) > 20 M ohms.

Three-Conductor Cable -- After six cycles of ignition source no fire developed. No damage or carbon deposits were visible on top of the tray. The burner flame on the bottom of the tray caused a 4.5 ft^2 (0.42 m^2) section of coating to intumesce and carbonize. The cables were not damaged. Cable resistance measurements were: pretest 5.4 ohms, posttest (warm) 6.3 ohms; cable-to-ground resistance pretest > 20 M ohms, posttest (warm) > 20 M ohms.

Coating E

Single-Conductor Cable -- After six cycles of ignition source no fire developed. No damage or carbon deposits were visible on top of the tray. The coating was blackened under the tray. Cable resistance measurements were: pretest 9.22 ohms, posttest (warm) 10.35 ohms, (cold) 9.36 ohms; cable-to-ground resistance pretest > 20 M ohms, posttest > 20 M ohms.

Three-Conductor Cable -- After six cycles of ignition source no fire developed. No damage or carbon deposits were visible on top of the tray. Beneath the tray 32 $in.^2$ (206 cm^2) of coating fell off the cables over the burner area (before test completion). Cable resistance measurements were: pretest 4.08 ohms, posttest (warm) 4.8 ohms, (cold) 4.1 ohms; cable-to-ground resistance pretest > 20 M ohms, posttest > 20 M ohms.

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No Coating

IEEE-383 Qualified Single-Conductor Cable -- After one cycle of ignition source a fire developed and burned for 10 minutes before self-extinguishing. Flame height was greater than 9.5 inches (24.1 cm) and curled around barrier edges. The affected area was 34 inches (86 cm) long by 18 inches (45.7 cm) wide. Insulation was consumed and conductors bared. Cable resistance measurements were: pretest 6.3 ohms, posttest (warm) 2.07 ohms, (cold) 1.44 ohms; cable-to-ground resistance pretest > 20 M ohm, posttest > 90 ohms (warm), 24 ohms (cold).

IEEE-838 Qualified Three-Conductor Cable -- After one cycle of ignition source a fire developed and burned for 13 minutes before self-extinguishing. Flame height was greater than 9.5 inches (24.1 cm) and curled around barrier adges. The affected area was 27 inches (68.6 cm) long and 18 inches (45.7 cm) wide. The total area was charred with insulation powdered and flaked off. Cable resistance measurements were: pretest 4.68 ohms, posttest (warm) 3.2 ohms, (cold) 3.6 ohms; cable-to-ground resistance pretest > 20 M ohms, posttest (warm) 25 k, (cold) > 20 M ohms.

Non-qualified (PE/PVC) Three-Conductor Cable -- After one cycle of ignition source a fire developed in the cable tray and burned for 36 minutes before self-extinguishing. Flame height was much greater than 9.5 inches (24.1 cm) and curled around edges of barrier. The affected area was 70 inches (178 cm) long by 18 inches (45.7 cm) wide. The insulation was burned, charred, or melted and molten insulation hung from bottom of tray. Cable resistance measurements were: pretest 5.25 ohms, posttest (warm) 0.4 ohms, (cold) 0.6 ohms; cable-to-ground resistance pretest > 20 M ohms, posttest 0.9 ohms.

Summary of Single-Tray Tests

Appended Figures B-1 through B-12 are temperature and voltage plots for one single-tray test which are included to provide comparative data between these tests and the previously discussed small scale tests and the two-tray tests. Plots such as these are available on all single-tray tests performed but are too bulky for inclusion in this report. Instead, Table III is included as a summary of important parameters obtained during these tests.

TABLE III

Results of Full Scale Single Tray Coatings Tests

Test Number	Coating	Maximum Cable Temperature °F	Maximum Calorimeter Temperature °F	Maximum Barrier Temperature °F	Time to Electrical Short Minutes*	Time to 600°F in Cables Minutes*	Time to Ignition Minutes*	Length of Burn Minutes	Length Affected Area Inches
1*	A	1280	525	Not taken	26	16	10	15	30
2*	C	1600	1380	1500	15	12	5	40	43
3*	B	840	1150	1450	60	60	15	7	40
4	A	1340	740	950	60	5	10	6	35
5	B	1250	480	440	60	5	20	7	43
6	C	1240	1525	1580	24	22	10	15	58
7*	D	200	290	380	60	60	60	0	0
8	D	300	350	420	60	60	60	0	0
9*	No coating 383	1600	1490	1550	9	5	5	13	27
10	No coating 383	1580	1400	1480	5	6	5	10	34
11	E	187	550	750	60	60	60	0	0
12*	E	230	280	325	60	60	60	0	0
13*	No coating Pre-383	1510	1600	1515	6	1	5	36	70

*If full test time of 60 minutes is used, no short nor ignition occurred.

Summary of Results During Reporting Quarter

Preliminary results showed that all coatings offer a measure of additional protection. However, there is a wide range in relative effectiveness of the different coatings tested here. Ranking of coating effectiveness derived from the small scale tests and full scale tests is indicated in Table IV. Ranking of relative fire retardancy between small scale and full scale single-tray tests are consistent. The combined ranking was obtained by assuming that each parameter chosen had equal weight in the ranking. For example, the time to ignition has equal weight with cumulative heat release even though they are reciprocals when used as a measure of combustibility or propagation.

TABLE IV

Ranking of Resistance to Combustion for Small and Full Scale Tests*

Coating	Small Scale	Full Scale Single-Tray Tests
A	4	4
B	Not used	5
C	3	3
D	6	7
E	5	6
F	2	Not used
Uncoated 383	1	2
Uncoated Pre-383	Not used	1

*Ranking in full scale tests is based upon resistance to combustion being proportional to: time to electrical short, time to 900° F in cables, and time to ignition.

Inversely proportional to: maximum cable temperature, maximum calorimeter temperature, and timed length of burn.

Ranking in Small Scale Tests based upon resistance to combustion being proportional to: time to ignition, and time to maximum heat release, and;

Inversely proportional to: cumulative heat release.

All parameters weighted equally.

These tests were aimed at determining some measure of combustibility and propagation but did not include properties which may well be important to the user industry. Some but not all of these properties include ampacity derating, wearability when exposed to moisture, sun, or other hostile environments, asbestos content, or combustion products over 300° C. Additional testing of coded cable trays will be conducted. These tests may include exposure fires other than the IEEE-383 burners discussed in this report.

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Summary of Presentations During Reporting Quarter

On October 7, 1977 L. J. Klamerus presented a paper on the Fire Protection Research Program at a Fire Technology Seminar at Lawrence Livermore Laboratories.

On October 20, 1977 L. J. Klamerus presented a paper on the Fire Protection Research Program at the Conference on Electrical Insulation and Dielectric Phenomena for the National Academy of Sciences Committee on Dielectrics at Albany, NY.

On November 11, 1977 L. J. Klamerus presented a paper on the Fire Protection Research Program and was a panel member at a workshop on Fire Protection Research as part of the Nuclear Regulatory Commission's Fifth Annual Water Reactor Safety Research Meeting in Gaithersburg, MD.

On December 1-2, 1977 L. J. Klamerus participated in a Workshop on Fire Safety Evaluation at New Mexico State University, Las Cruces, NM.

APPENDIX A

Heat Release Data

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TABLE A-I

Heat Release Data Coating A, Single Conductor, Small Scale Test

Cable Size Small

Coating A

Radiant Heat Flux 4.0 W/cm^2

		Test No. 1		Test No. 2	
	Units	Coating	Cable	Coating	Cable
Slope 'E'	$kW/m^2,s$	.22		.63	
Time to Ignition	Seconds	90	597	72	368
Maximum Heat Release Rate	kW/m^2	45.5	102.4	75.9	83.8
Time to Maximum Heat Release	Seconds	124	792	48	750
Cumulative Heat Release	MJ/m^2				
1 minute			.9		3.1
3			5.5		8.6
5			8.6		10.9
7			11.1		13.9
10			16.4		22.5
15			40.7		44.6
20					
25					
30					
35					
40					
45					
50					
55					
60					

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TABLE A-II

Heat Release Data Coating A, Three Conductor, Small Scale Test

Cable Size Large

Coating A

Radiant Heat Flux 4.0 W/cm^2

		Test No. 1		Test No. 2	
	Units	Coating	Cable	Coating	Cable
Slope 'E'	kW/m^2,s	.14		.14	402
Time to Ignition	Seconds	93	450	78	140.4
Maximum Heat Release Rate	kW/m^2	108	147.9	11.4	1134
Time to Maximum Heat Release	Seconds		1125	76	
Cumulative Heat Release	MJ/m^2				
1 minute			.5		.5
3			3.2		1.4
5			4.2		2.3
7			5.4		3.9
10			10.7		8.9
15			38.0		33.0
20			77.2		71.3
25					
30					
35					
40					
45					
50					
55					
60					

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TABLE A-III

Heat Release Data Coating C, Single Conductor, Small Scale Test

Cable Size Small

Coating C

Radiant Heat Flux 4.0 W/cm^2

	Units	Test No. 1 Coating	Test No. 1 Cable	Test No. 2 Coating	Test No. 2 Cable
Slope 'E'	kW/m^2,s	1.01		1.26	
Time to Ignition	Seconds	18	372	24	378
Maximum Heat Release Rate	kW/m^2	85.7	100.2	79.7	96.4
Time to Maximum Heat Release	Seconds	66	612	96	639
Cumulative Heat Release	MJ/m^2				
1 minute			2.5		3.2
3			12.1		12.3
5			19.8		19.6
7			24.4		23.7
10			37.1		35.3
15			54.6		53.2
20					
25					
30					
35					
40					
45					
50					
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TABLE A-IV

Heat Release Data Coating C, Three Conductor, Small Scale Test

Cable Size Large

Coating C

Radiant Heat Flux 4.0 W/cm^2

	Units	Test No. 1 Coating	Test No. 1 Cable	Test No. 2 Coating	Test No. 2 Cable
Slope 'E'	$kW/m^2,s$	1.14		1.58	
Time to Ignition	Seconds	30	522	18	532
Maximum Heat Releast Rate	kW/m^2	75.9	119.1	83.5	136.6
Time to Maximum Heat Release	Seconds	54	1452	72	1338
Cumulative Heat Release	MJ/m^2				
1 minute			3.2		2.5
3			10.7		11.4
5			14.6		16.2
7			16.4		18.7
10			19.1		23.0
15			29.9		37.0
20			49.9		65.8
25			80.8		102.0
30			109.3		
35					
40					
45					
50					
55					
60					

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TABLE A-V

Heat Release Data Coating D, Single Conductor, Small Scale Test

Cable Size Small

Coating D

Radiant Heat Flux 4.0 W/cm^2

		Test No. 1		Test No. 2	
	Units	Coating	Cable	Coating	Cable
Slope 'E'	$kW/m^2,s$	.06		.06	
Time to Ignition	Seconds	210	615	458	960
Maximum Heat Release Rate	kW/m^2	7.6	30.4	11.4	22.8
Time to Maximum Heat Release	Seconds	534	1341	390	1461
Cumulative Heat Release	MJ/m^2				
1 minute			.15		.1
3			.5		.5
5			.9		1.0
7			1.5		2.0
10			2.7		3.6
15			6.4		6.4
20			12.9		9.8
25			20.5		14.6
30					19.6
35					
40					
45					
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55					
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TABLE A-VI

Heat Release Data Coating D, Three Conductor, Small Scale Test

Cable Size Large

Coating D

Radiant Heat Flux 4.0 W/cm^2

		Test No. 1		Test No. 2	
	Units	Coating	Cable	Coating	Cable
Slope 'E'	$kW/m^2,s$	.06		.06	
Time to Ignition	Seconds	408	584	336	1266
Maximum Heat Release Rate	kW/m^2	26.6	30.4	9.9	17.5
Time to Maximum Heat Release	Seconds	858	2022	330	1867
Cumulative Heat Release	MJ/m^2				
1 minute			.1		.1
3			.5		.5
5			1.2		1.1
7			2.5		2.3
10			5.4		5.0
15			11.4		8.2
20			17.7		13.2
25			24.1		19.1
30			30.9		26.4
35			38.2		31.8
40			46.0		37.8
45			52.8		
50			59.7		
55			67.4		
60					

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TABLE A-VII

Heat Release Data Coating E, Single Conductor, Small Scale Test

Cable Size Small

Coating E

Radiant Heat Flux 4.0 W/cm^2

	Units	Test No. 1 Coating	Test No. 1 Cable	Test No. 2 Coating	Test No. 2 Cable
Slope 'E'	$kW/m^2,s$	.44		.44	
Time to Ignition	Seconds	45	900	48	1038
Maximum Heat Release Rate	kW/m^2	40.2	72.1	37.9	87.2
Time to Maximum Heat Release	Seconds	69	1389	42	1470
Cumulative Heat Release	MJ/m^2				
1 minute			1.5		1.6
3			5.0		5.4
5			8.4		8.4
7			12.1		11.6
10			16.4		15.9
15			22.3		21.2
20			29.4		25.7
25			47.4		43.1
30					
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TABLE A-VIII

Heat Release Data Coating E, Three Conductor, Small Scale Test

Cable Size Large

Coating E

Radiant Heat Flux 4.0 W/cm^2

	Units	Test No. 1 Coating	Test No. 1 Cable	Test No. 2 Coating	Test No. 2 Cable
Slope 'E'	kW/m^2,s	.39		.46	
Time to Ignition	Seconds	39	1494	60	2220
Maximum Heat Release Rate	kW/m^2	41.7	118.4	45.5	273.2
Time to Maximum Heat Release	Seconds	90	2400	117	2970
Cumulative Heat Release	MJ/m^2				
1 minute			1.4		1.4
3			5.9		5.7
5			9.8		8.9
7			12.9		11.4
10			18.2		14.3
15			27.6		18.9
20			37.8		23.0
25			46.5		25.3
30			60.5		32.1
35			89.3		47.8
40			128.2		75.4
45			201.2		102.0
50					
55					
60					

TABLE A-IX

Heat Release Data Coating F, Single Conductor, Small Scale Test

Cable Size Small

Coating F

Radiant Heat Flux 4.0 W/cm^2

		Test No. 1		Test No. 2	
	Units	Coating	Cable	Coating	Cable
Slope 'E'	kW/m^2, [illegible]	[illegible]		1.26	
Time to Ignition	Seconds	[illegible]	228	24	252
Maximum Heat Release Rate	kW/m^2	[illegible].9	83.5	69.1	73.6
Time to Maximum Heat Release	Seconds	54	600	32	537
Cumulative Heat Release	MJ/m^2				
1 minute			1.6		2.5
3			5.7		6.6
5			9.3		9.1
7			14.1		14.3
10			26.9		26.2
15					
20					
25					
30					
35					
40					
45					
50					
55					
60					

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TABLE A-X

Heat Release Data Coating F, Three Conductor, Small Scale Test

Cable Size Large

Coating F

Radiant Heat Flux 4.0 W/cm^2

		Test No. 1		Test No. 2	
	Units	Coating	Cable	Coating	Cable
Slope 'E'	$kW/m^2,s$	1.01		1.20	
Time to Ignition	Seconds	18	315	32	378
Maximum Heat Release Rate	kW/m^2	66.4	136.6	70.6	173.0
Time to Maximum Heat Release	Seconds	46	939	42	798
Cumulative Heat Release	MJ/m^2				
1 minute			2.5		2.9
3			7.0		7.0
5			8.2		8.2
7			11.1		10.9
10			19.6		21.4
15			49.4		71.4
20			87.2		
25					
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TABLE A-XI

Heat Release Data Uncoated, Single and Three Conductor, Small Scale Tests

Uncoated Cables	Units	Small Cables		Large Cables	
Radiant Heat Flux	W/cm^2	4 0	4.0	4.0	4.0
Slope 'E'	$kW/m^2,s$	.55	.59	.83	.83
Time to Ignition	Seconds	54	60	42	39
Maximum Heat Release Rate	kW/m^2	89.54	96.75	134.69	125.21
Time to Maximum Heat Release	Seconds	138	126	582	582
Cumulative Heat Release	MJ/m^2				
30 seconds		.59	.73	.99	.94
1 minute		2.05	2.64	2.87	2.86
2		6.51	6.95	6.41	6.18
3		11.61	12.29	10.22	9.22
4		16.12	17.12	13.61	12.17
5		20.27	21.36	17.08	15.30
6		24.14	25.19	20.99	18.93
7		27.42	28.01	26.27	23.49
8		29.42	28.01	32.74	29.57
10				47.91	43.45
12				63.22	56.95
14				77.07	70.16
16				86.25	78.39
18					
20					

Comments: The small cables were totally aflame one minute into the test. They burned very severely at this heat flux.

The large cables began spalling immediately upon entry into the test chamber. The entire surface was flaming after 30 seconds of exposure. Burning lessened at the three minute mark and then became severe again at four minutes. Smoke was very heavy and sooty.

APPENDIX B

Temperature-Time Plots

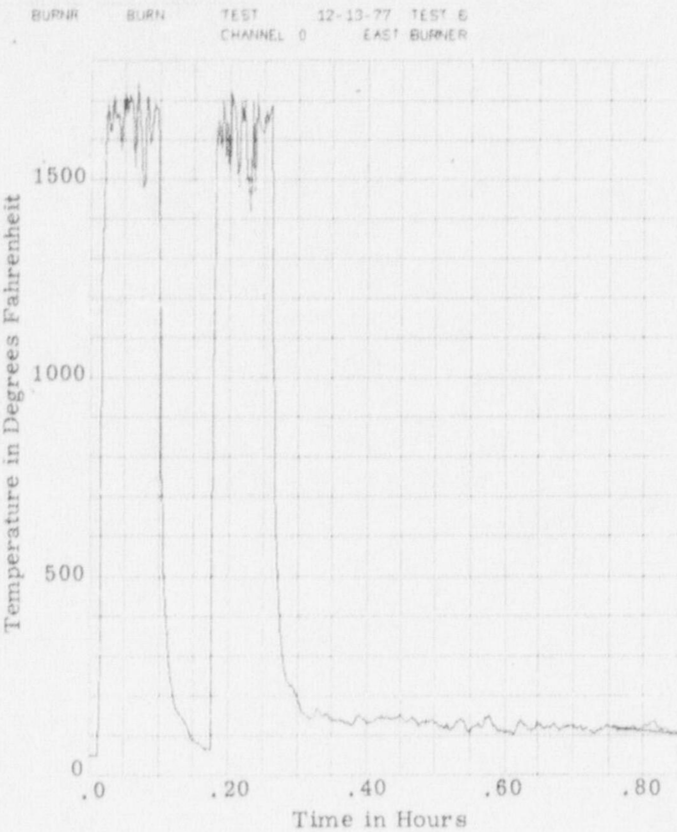

Figure B-1
Temperature-Time Plot of Thermocouple #0 in Burner Flame

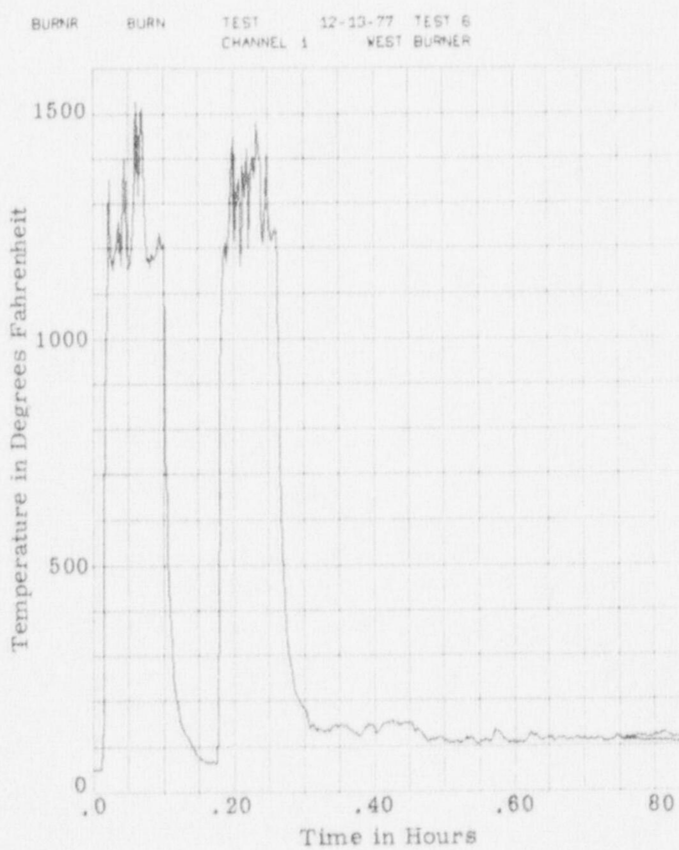

Figure B-2
Temperature-Time Plot of Thermocouple #1 in Burner Flame

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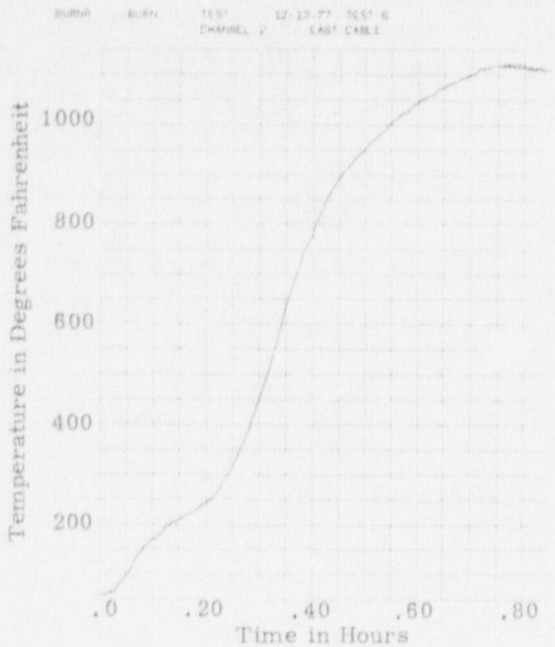

Figure B-3
Temperature-Time Plot of Thermocouple #2 in
Cable Bundle

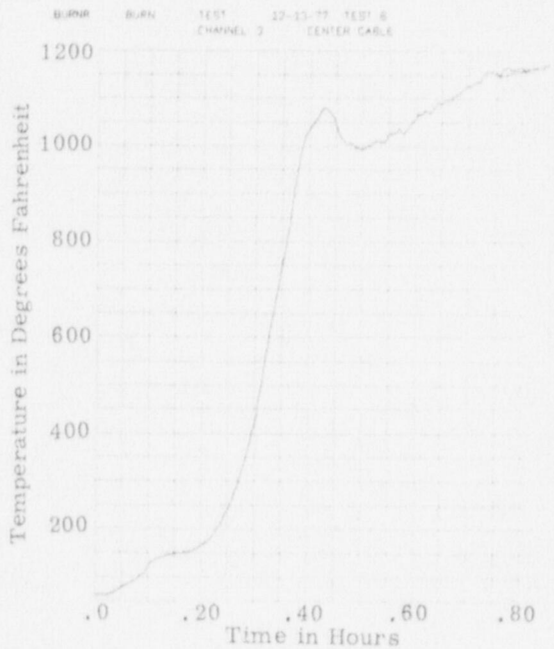

Figure B-4
Temperature-Time Plot of Thermocouple #3 in
Cable Bundle

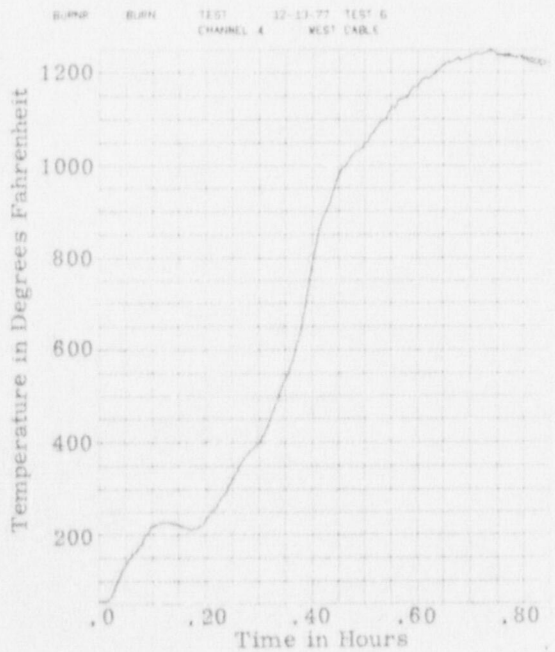

Figure B-5
Temperature-Time Plot of Thermocouple #4 in
Cable Bundle

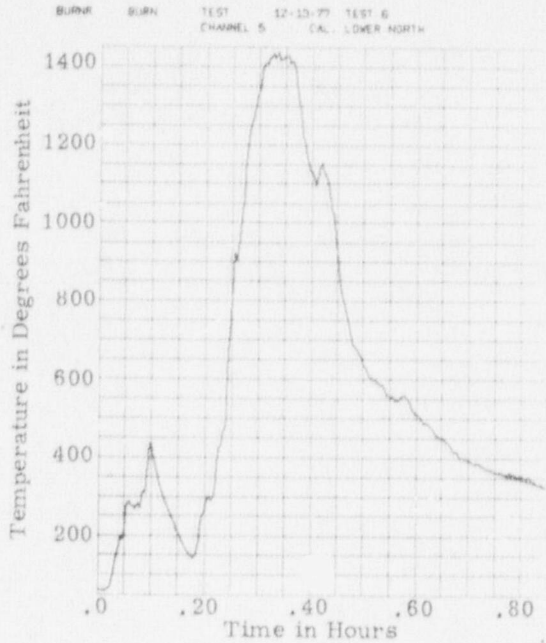

Figure B-6
Temperature-Time Plot of Calorimeter #5
3.75 In. (9.5 cm) Over Cables

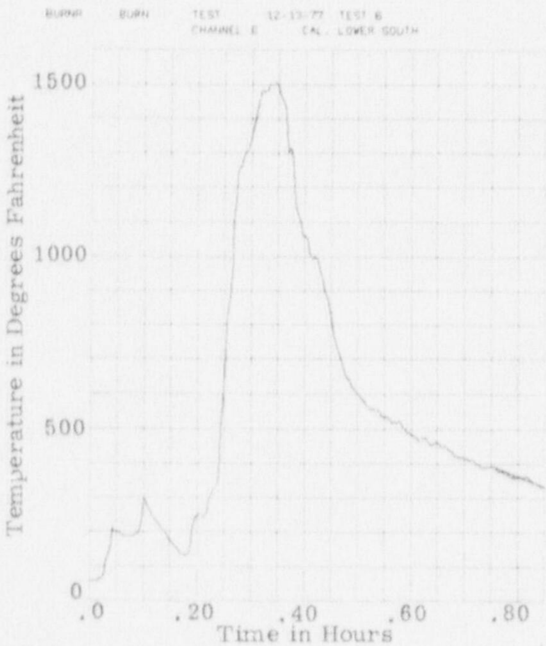

Figure B-7
Temperature-Time Plot of Calorimeter #6
3.75 In. (9.5 cm) Over Cables

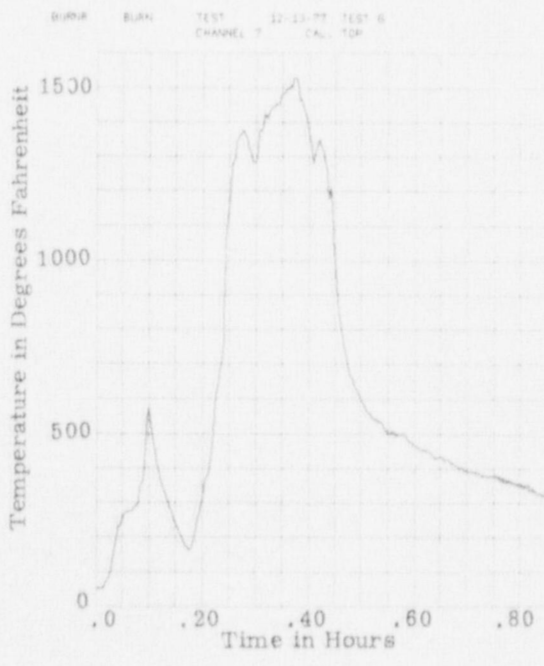

Figure B-8
Temperature-Time Plot of Calorimeter # 7
8.0 In. (20.3 cm) Over Cables

17149

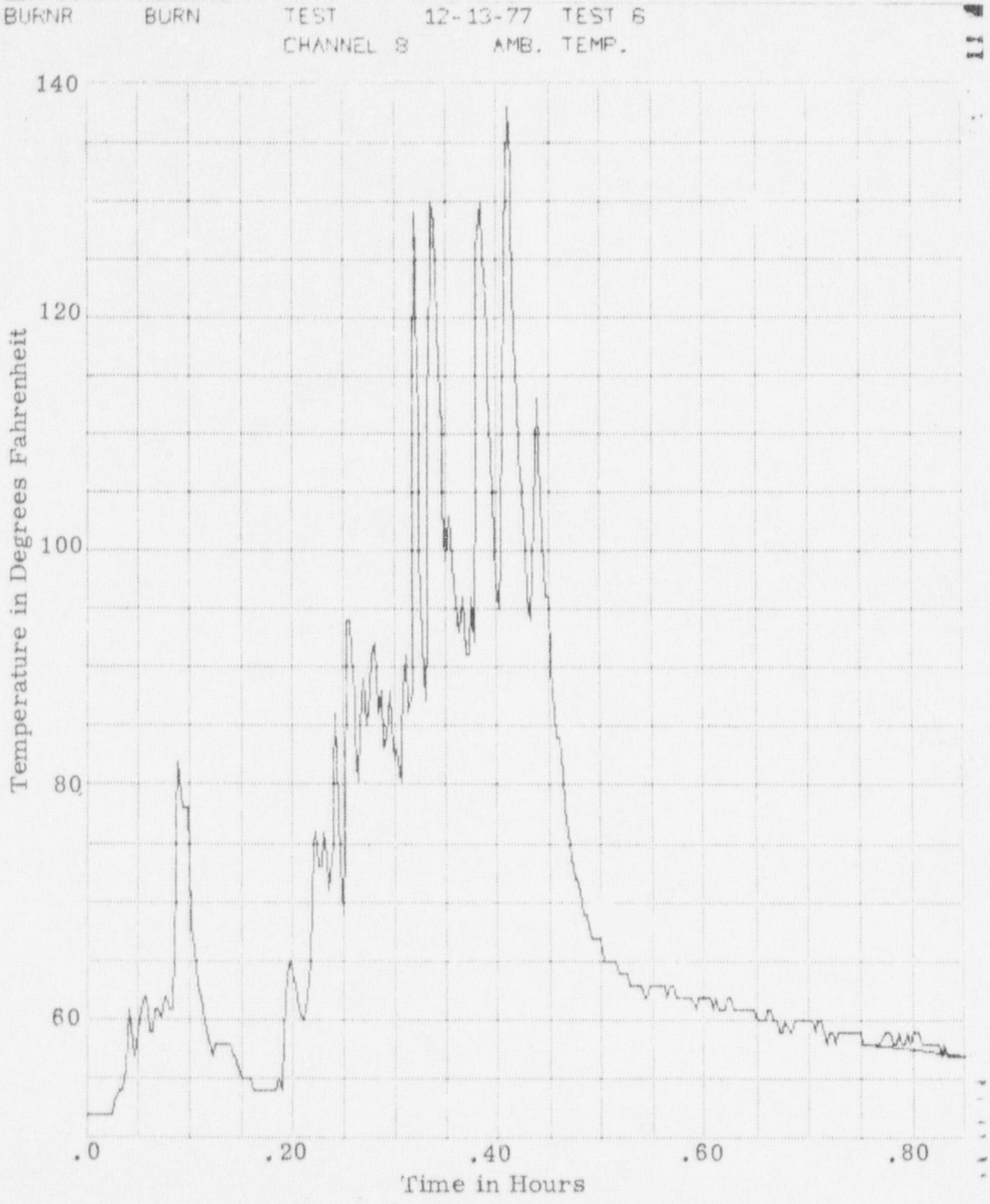

Figure B-9. Temperature-Time Plot of Ambient Temperature in Fire Site Building

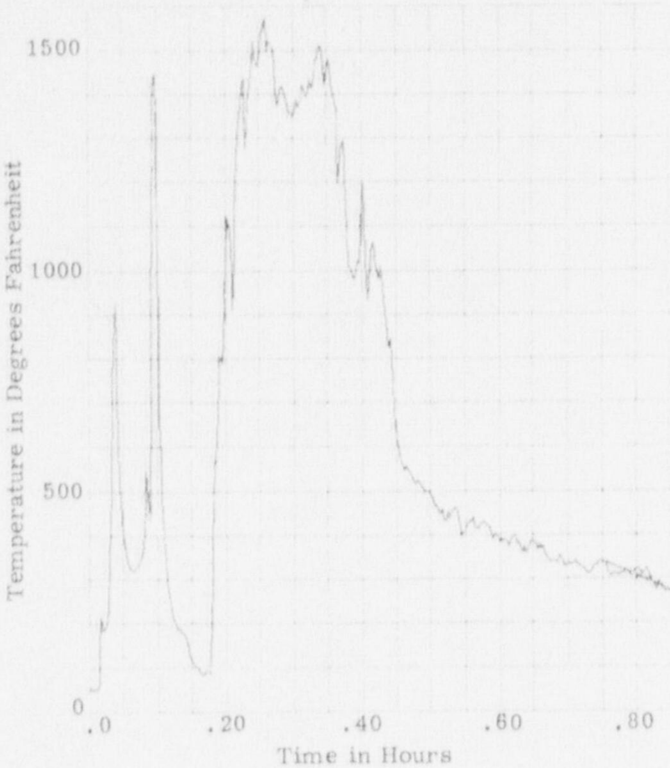

Figure B-10
Temperature-Time Plot of Thermocouple
#9 on Barrier Over Cable Tray

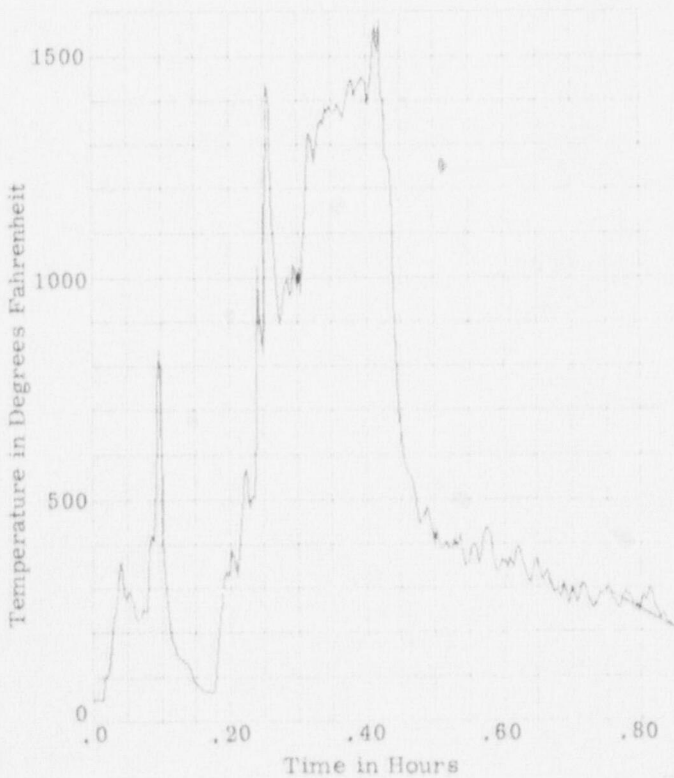

Figure B-11
Temperature-Time Plot of Thermocouple
#10 on Barrier Over Cable Tray

17151

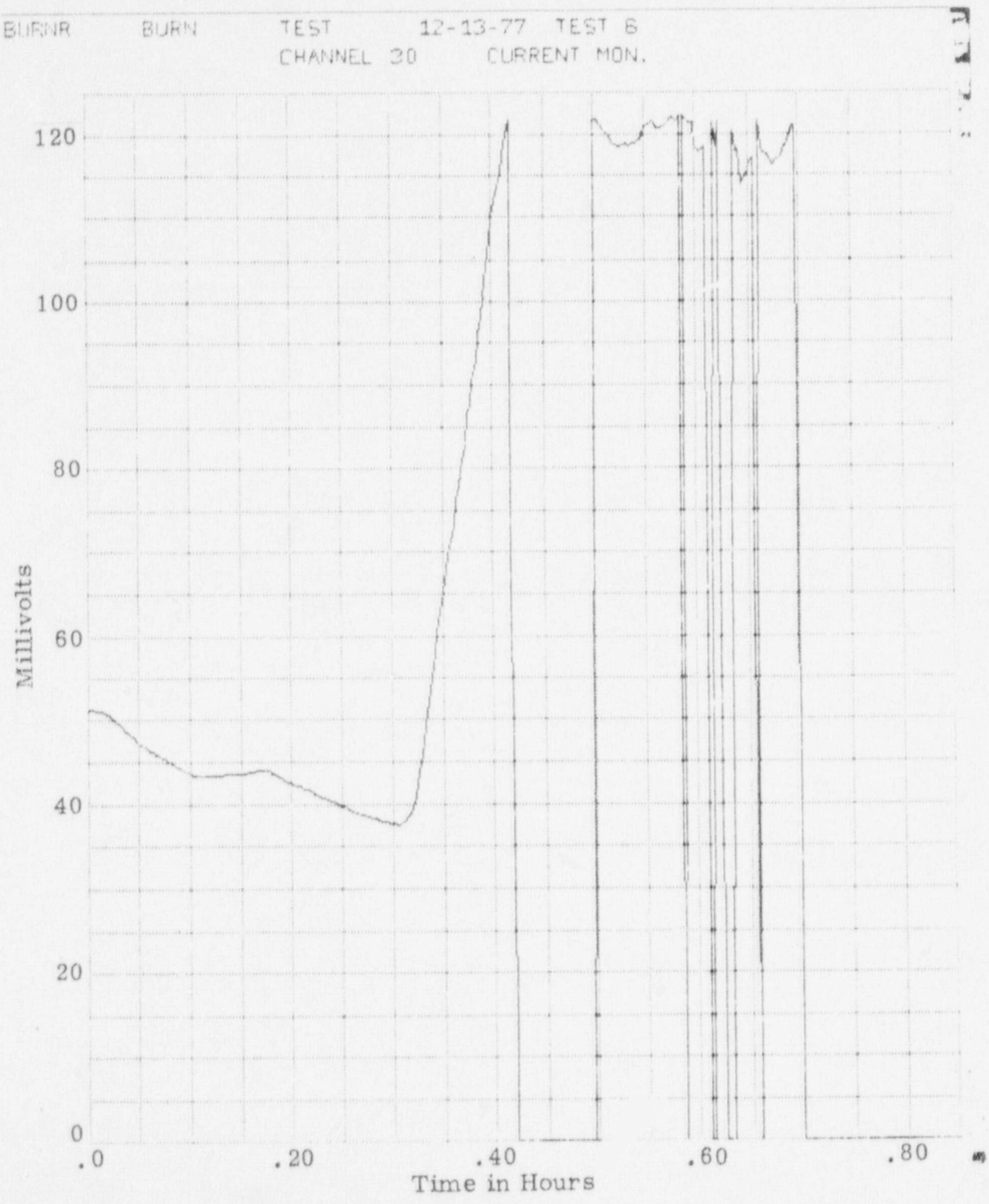

Figure B-12. Voltage-Time Plot During Test

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