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RP

A Preliminary Report on Fire Protection Research Program Fire Barriers and Fire Retardant Coatings Tests

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To Recipients of Report: "A Preliminary Report on Fire Protection Research Program Fire Barriers and Fire Retardant Coatings Tests," NUREG/CR-0381 (SAND 78-1456)

The enclosed report describes the results of a series of tests on fire retardant coatings. These tests provide a basis for measuring the effectiveness of coatings in preventing initiation or propagation of fires and show good reproducibility over a range of scales.

In practice, however, the prospective user of fire retardant coatings will also need to consider other factors, such as thickness, ampacity, durability (including aging) asbestos content, ease of application and cost. Thus, the enclosed report represents only one of the inputs needed in those selecting fire retardant coatings for use in nuclear power plants.

Finally, the Nuclear Regulatory Commission believes that it would be inappropriate to use the data herein to competitive advantage.

Saul Levine

Saul Levine, Director
Office of Nuclear Regulatory Research

Enclosure:
As stated above

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A PRELIMINARY REPORT ON FIRE PROTECTION RESEARCH PROGRAM* FIRE BARRIERS AND FIRE RETARDANT COATINGS TESTS

Leo J. Klamerus

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*Further evaluation of these tests is continuing. Additional tests which may affect the conclusions contained herein are underway.

ABSTRACT

An exposure fire test at Sandia Laboratories showed that the Regulatory Guide 1.75 separation guidelines and IEEE-383 fire retardancy standards for safety cables are not sufficient, in themselves, to protect against such fires. Additional measures have been required by NRC to protect essential safety systems against the effects of fires. Two of these measures are fire barriers or fire-retardant coatings on cabling. This report describes the second phase of a small scale and full scale testing program which has been undertaken to assess the adequacy of coatings. In addition, full scale tests are described using exposure fires to appraise the adequacy of some fire barriers placed between horizontal cable trays. The preliminary results show that all coatings and barriers offer some measure of additional protection. Their relative effectiveness is demonstrated by quantitative information obtained in the donor and donee cable trays. An evaluation of other protective measures will be undertaken in future studies.

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SUMMARY

Previous electrically initiated fire tests of IEEE-383[1] qualified cable loaded into trays revealed a margin of safety in the spatial separation distances of Regulatory Guide 1.75[2] for such fires.[3] An exposure fire on July 6, 1977 at Sandia indicated that the Regulatory Guide 1.75 separation guidelines and IEEE-383 fire-retardant standards for safety cables are not sufficient in themselves to protect against such an exposure fire.[4] Thus additional measures have been required by NRC to protect essential safety systems against the effects of fires. Two of these additional measures are fire barriers and fire retardant coatings applied on the cabling. Previous small scale and full scale tests were performed to assess the adequacy of coatings.[5] The tests showed that all coatings offer some measure of additional protection; however, there was a wide range of relative effectiveness of the different coatings.

This report describes additional small scale and full scale test results which were obtained for one fire-retardant coating not included in the series of tests previously reported. It also describes additional tests performed on fire-retardant coatings and fire barriers using two types of exposure fires. One exposure fire, using propane, was used in the previous coatings tests and described in SAND78-0518 and SAND77-1424. Well known IEEE-383 ribbon burners were used for this fire source. The second type of exposure fire used diesel fuel and was included for comparison with propane fire.

The preliminary results show that all coatings and barriers offer some measure of additional protection. The wide range in relative effectiveness of the different coatings is once again demonstrated. As in the previous work, small scale correlated well with full scale tests in the determination of relative effectiveness of the fire retardant coatings.

A PRELIMINARY REPORT ON FIRE PROTECTION RESEARCH PROGRAM FIRE BARRIERS AND FIRE RETARDANT COATINGS TESTS

Introduction

Tests in the first phase of the Fire Protection Research Project 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 as 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 was varied. The third phase tests involved stacked trays and conduits. Fourteen closely stacked trays, representing one division of cables, and three trays, representing the second division, were displaced by separation distances specified RG 1.75. Fires were electrically initiated in all of these tests.

The phase four test employed the same stacked tray arrangement as the third but was initiated by an exposure fire, a fully developed fire in a single electrical cable tray. A series of 12 single-tray tests ignited by exposure to propane burner flames was performed earlier to optimize cable fill and ignition time for this type of fire. A barrier was placed over the donor tray to shield the upper trays 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.

After the results of the exposure fire tests were analyzed, other fire-protection measures which might prevent propagation were investigated. Fire-retardant coatings were the first of these measures to be investigated experimentally and was the subject of SAND78-0518. The Water Reactor Safety Research Directorate of the NRC had provided the list of fire-retardant coatings being approved by Factory Mutual as of June 1977. One additional coating, which gained approval in July 1977, was "small cable" tested and full scale tested in Sandia's fire test facility. The results of these tests are reported here. Additionally, information was sought on the adequacy of fire-retardant coatings as applied to non-IEEE-383 qualified cables. Certain fire barriers used to prevent fire propagation between horizontal cable trays were included in the full scale testing. Finally, in answer to questions concerning the comparison of the propane-fueled exposure fires to a realistic fire which could possibly occur in a nuclear power plant, each fire-retardant coating was tested in a two tray stacked configuration over a hydrocarbon fuel fire.

These and previous tests were aimed at determining some measure of combustibility and propagation but did not include characteristics which may be of equal or greater importance to the user industry in choosing a method of assuring fire safety. Some of these considerations include the impact of ampacity derating, durability when exposed to hostile environments, and asbestos content.

Preparations for Testing

Small Scale

In the small scale tests performed at Smithers Scientific Services, Akron, Ohio, Coating G was applied to two types of electrical cable, supplied by two manufacturers (I and II). The cables were the same types used in the electrically initiated fire tests and exposure fire tests at Sandia. These were: (1) 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 I) and, (2) a single-conductor No. 12 AWG, 30 mil (0.76 mm) crosslinked PE, no jacket, 600 V (Supplier II). 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 30 days. 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 G 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 no cracking in the coating after curing.

Full Scale

In the full scale tests performed at Sandia Laboratories, Albuquerque, coatings A, B, C, E, and G were applied to the cables previously described. The cables were loaded into galvanized steel, open-ladder trays, 18 inches (45.7 cm) wide and 12 feet (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 cables formed a figure 8 with the crossing point advancing progressively up and down the tray. This resulted in a 25% fill by cross-sectional area for three-conductor cables and a 15% fill by cross-sectional area for the single-conductor. (Ninety three-conductor cables per tray and 450 single-conductor cables per tray). Non-IEEE-383 qualified cable to be included in the testing was loaded into additional cable trays. 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 Sandia fire site, coatings A, B, C, E, and G 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 to the manufacturers' specifications. At least six top and six bottom measurements of each cable tray were made by Sandia personnel in the area of the fire zone to determine this wet thickness. Wet thicknesses applied were: Coatings A, B, C, and G -- 1/8 inch (3.22 mm); Coating E -- 5/32 inch (4.0 mm).

Small Scale Test Description

The Ohio State University Release Rate Apparatus at Smithers Scientific tested the two types of IEEE-383 qualified cables, previously described. These were covered with fire-retardant coating G and tested 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 and constant rate of air enters an environment chamber. Rate of heat release is monitored by changes 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 panel provides a heat flux exposure 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 ignition tray 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.

The test procedure and set-up were essentially identical to those used in the July 6 fire test. An insulated barrier was placed 9.5 inches (24.1 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 was 4.75 inches (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 of coatings began.

For each burn cycle, propane and air were turned on for five minutes. Previous tests had shown five 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 was maintained. If a fully developed cable tray fire was not achieved after applying this ignition source for five minutes, additional five-minute ignition cycles were repeated, at five-minute intervals, to a maximum of six cycles.

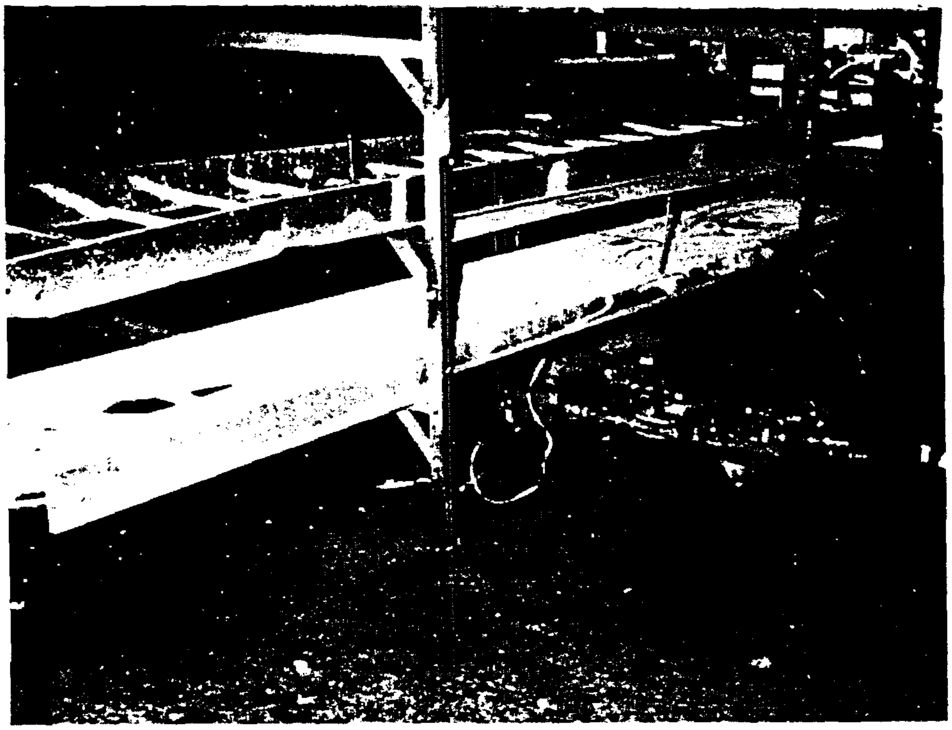

Figure 1. Typical Full Scale Single-Tray Fire Retardant Coating Test Setup

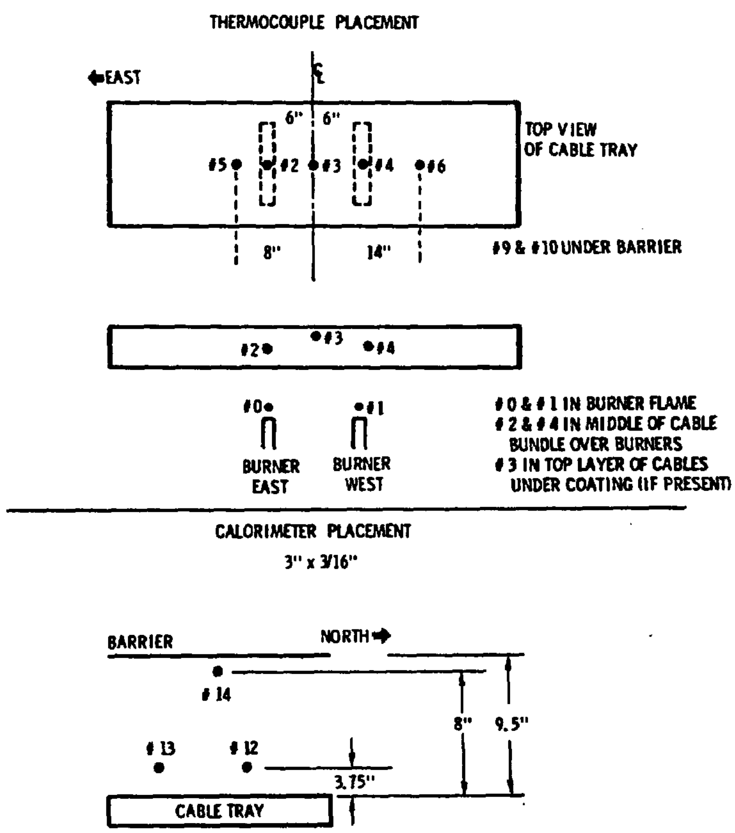

Figure 2. Thermocouple and Calorimeter Placement for Single-Tray Tests

Ten single tray tests were conducted consisting of the following:

Two ladder cable trays with IEEE-383 qualified cable (one with single-conductor, one with the three-conductor), each with Coating G applied

Three solid bottom cable trays with no cover (one with single-conductor IEEE-383 qualified, one with three-conductor IEEE-383 qualified, one with three-conductor non-qualified PE/PVC), no coatings

Three solid bottom cable trays with vented cover (one with single-conductor IEEE-383 qualified, one with three-conductor IEEE-383 qualified, one with three-conductor non-qualified PE/PVC), no coatings

One ladder cable tray with ceramic wool 1-inch blanket over three-conductor non-qualified PE/PVC, no coating

One ladder tray with an unvented solid tray cover over three-conductor non-qualified PE/PVC, no coating.

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.

Figure 3 shows the fire site facility. Each test began with the rear-vent fan off and one front door 6-ft x 3-ft (1.8-m x 0.9-m) 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 building 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.

Two-Tray Tests

To test for fire propagation between two trays a second series of tests was conducted. In these tests, the physical arrangement of the lowest two trays in the July 6 fire test was used. The trays were placed horizontally with one tray 10.5 inches (26.7 cm) above the other (see Figure 4). In tests where IEEE-383 qualified cable was used, the bottom tray was loaded with three-conductor cable and the top tray with single-conductor cable. In tests which used non-qualified PE/PVC the same three-conductor cable was used in both trays. An insulated barrier was placed 9.5 inches (24.1 cm) over each tray. The barrier over the bottom tray was movable and could be quickly slid from between the cable trays when it was determined that a fire had developed in the bottom tray. Thermocouples and calorimeters were placed as shown in Figure 2 for each tray. Thermocouples in the cable bundle were in place before application of fire-retardant coatings or cable tray covers.

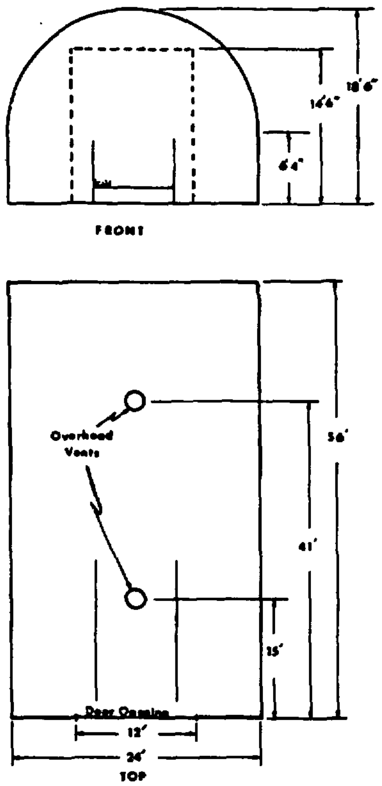

Figure 3. Cable Tray Fire Site

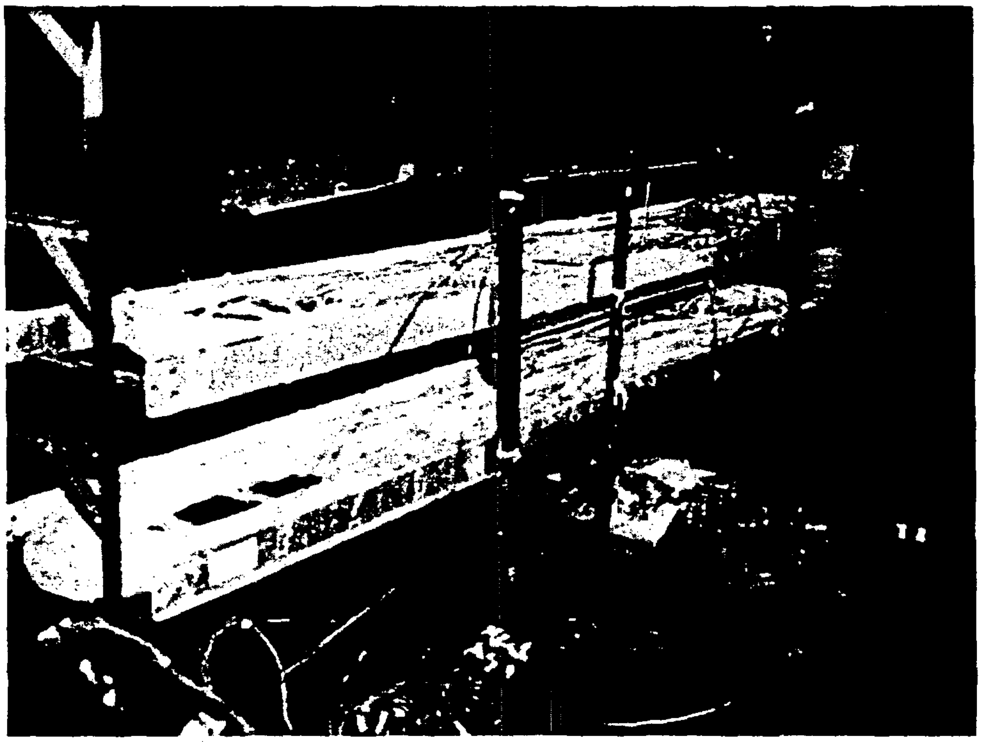

Figure 4. Typical Full Scale Two-Tray Test Setup

The test procedure and set-up were essentially identical to those used in the July 6 test. The same five-minute burn cycles used in the single-tray tests were repeated in these two-tray tests up to a maximum of six ignition cycles. Electrical resistance and current measurements of the cable were made as in the single-tray tests. Building air movement was also handled as in the single-tray tests.

Eleven two-tray tests were conducted consisting of the following:

Four tests with two coated (Coatings A, B, C, and G) cable trays with non-383 qualified PE/PVC cable, three-conductor

Two tests with two coated (Coatings C and G) cable trays with IEEE-383 qualified cable (bottom tray with three-conductor; top tray with single-conductor)

Five tests with two uncoated cable trays with non-383 qualified PE/PVC, three-conductor (one with ceramic wool blanket over open ladder trays, one with solid bottom trays and no cover, one with solid tray covers and no venting, one with solid bottom trays and vented cover, one with a one inch solid fire barrier placed between open ladder trays).

Spilled Fuel Fire Tests

A third series of tests was conducted to test for the effect upon two coated cable trays exposed to a spilled hydrocarbon fuel fire. In these tests the same arrangement of cable trays was used as in the previous two-tray tests. A major difference was that no barrier was placed between the two trays so that both trays might be exposed to the fuel fire. Instead of the two propane-fueled IEEE-383 ribbon burners, a pan 3 feet (91.4 cm) x 1.5 feet (45.7 cm) was placed at the same height (4.75 inches - 12.1 cm) below the bottom cable tray. Before each test, two gallons (7.6×10^{-3} m^3) of Diesel fuel #2 was put into the pan and ignited with the aid of approximately 5 ounces (1.5×10^{-4} m^3) of mineral spirits.

Five two-tray diesel fuel fire tests were conducted with two coated (coatings A, B, C, E, and G) cable trays with non-383 qualified three-conductor PE/PVC cable.

Table I shows a matrix of all tests previously completed and reported in SAND78-0518. This is repeated here for reference.

Table II shows a matrix of coatings tests and Table III shows a matrix of barrier tests completed in this segment of the program and reported here.

TABLE I

Test Matrix of Coatings Tests

12/77 - 1/78

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

TABLE II

Test Matrix of Coatings Tests

4/78 - 5/78 - 6/78

	Single Tray Tests			Two Tray Tests		Oil-Pan	Small Scale Test	
	383 Qualified Cable		Non-383			Fire	383 Qualified Cable	
Coating	Single Conductor	Three Conductor	Three Conductor	383 Qualified Cable	Non-383	Non-383	Single Conductor	Three Conductor
A					X	X		
B					X	X		
C				X	X	X		
E						X		
G	X	X		X	X	X	X	X

TABLE III

Test Matrix of Barrier Tests

4/78 - 5/78 - 6/78

Barrier Type	Single Tray Tests: 383 Qualified Cable: Single Conductor	Single Tray Tests: 383 Qualified Cable: Three Conductor	Single Tray Tests: Non-383: Three Conductor	Two Tray Tests: 383 Qualified Cable	Two Tray Tests: Non-383
Ceramic wool blanket over ladder tray			X		X
Solid bottom tray no cover	X	X	X		X
Solid cover no vents ladder tray			X		X
Vented cover solid bottom	X	X	X		X
One inch fire barrier between trays					X

Small Scale Test Results

Test Narrative

Coating G -- 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 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. There was no further ignition until the cables began to burn.

Heat Release Data

Appended Tables A-I and A-II show the heat release data for the radiant heat flux level of 4.0 W/cm^2. Table IV summarizes the results of these tests together with the results of the small scale tests reported in SAND78-0518. As previously described, the 4.0 W/cm^2 radiant heat flux level shows the largest discrimination between results.

TABLE IV

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 Minutes MJ/m^2	Cumulative Heat Release at 15 Minutes 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
G	12.5	22	21.5	37.5
No Coating 383 Cable	0.8	6	45.7	78.0

Full Scale Test Results

Single-Tray Tests

Nonqualified (PE/PVC) three-conductor cable, ladder tray ceramic wool cover

After one ignition cycle a fire developed on the bottom of the tray and flames approximately 6 to 8 inches (15 to 20 cm) high were observed around both edges of the tray.

After six ignition cycles the fire had not penetrated the ceramic wool cover.

The affected area on the bottom of the tray was approximately 120 inches (3.05 m) long and 18 inches (45.72 cm) wide.

Weight loss was 23.5 lb (10.7 kg).

	Cable Resistance	Circuit-to-Ground Resistance
Pretest	5.26 ohms	>20 m ohms
Posttest (warm)	.25 ohms	>20 m ohms
Posttest (cold)	.36 ohms	>20 m ohms

Nonqualified (PE/PVC) three-conductor cable, solid bottom tray

During the second ignition cycle, a fire started at one edge of the tray, apparently as a result of the ignition of flammable gases being given off by the heated cable.

The fire continued to burn for approximately 40 minutes before self-extinguishing. The affected area was approximately 72 inches (182.88 cm) long and 18 inches (45.72 cm) wide. Weight loss was 16 lbs (7.3 kg). See Figure 5.

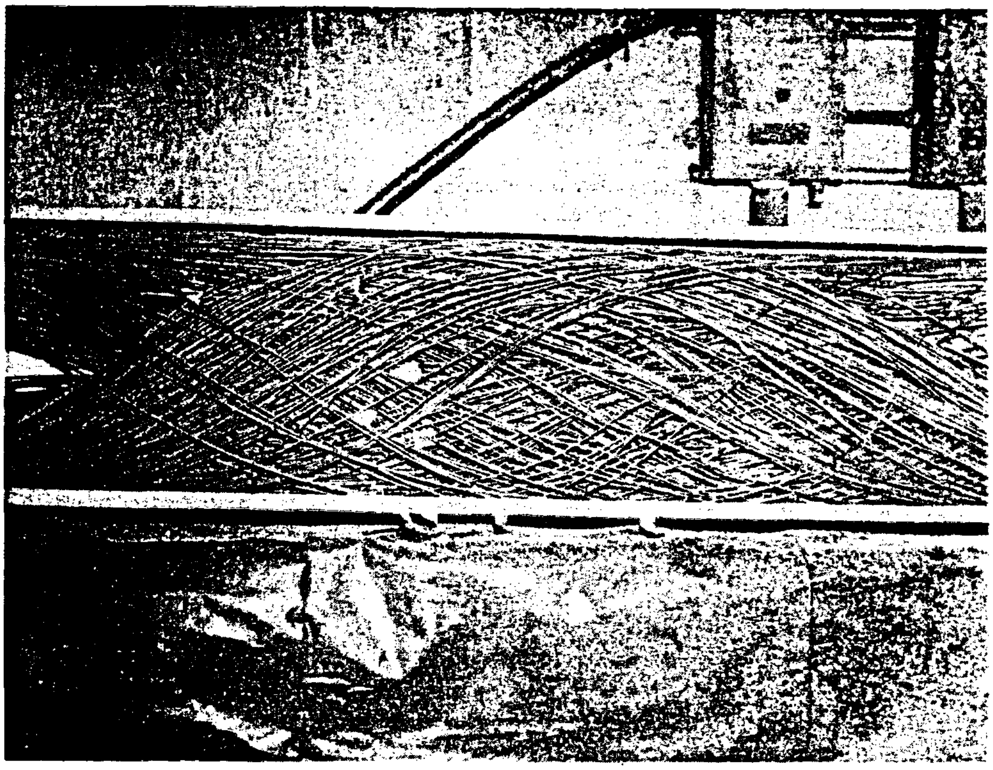

Figure 5. Nonqualified (PE/PVC) three conductor cable solid bottom tray after test 23

	Cable Resistance	Circuit-to-Ground Resistance
Pretest	5.04 ohms	>20 m ohms
Posttest (warm)	.34 ohms	2 ohms
Posttest (cold)	.15 ohms	260 ohms

IEEE-383 qualified three-conductor cable, solid bottom tray

No fire developed after six cycles of ignition source.

There was no apparent damage to cables and no measurable weight loss.

	Cable Resistance	Circuit-to-Ground Resistance
Pretest	5.24 ohms	>20 m ohms
Posttest (warm)	6 ohms	>20 m ohms
Posttest (cold)	5.18 ohms	>20 m ohms

IEEE-383 qualified single-conductor cable, solid bottom tray

No fire developed after six cycles of ignition source.

There was no apparent damage to cables.

Weight loss was measured as 1/4 pound (0.1 kg).

See Figure 6. Note cable placement for maximum air passage.

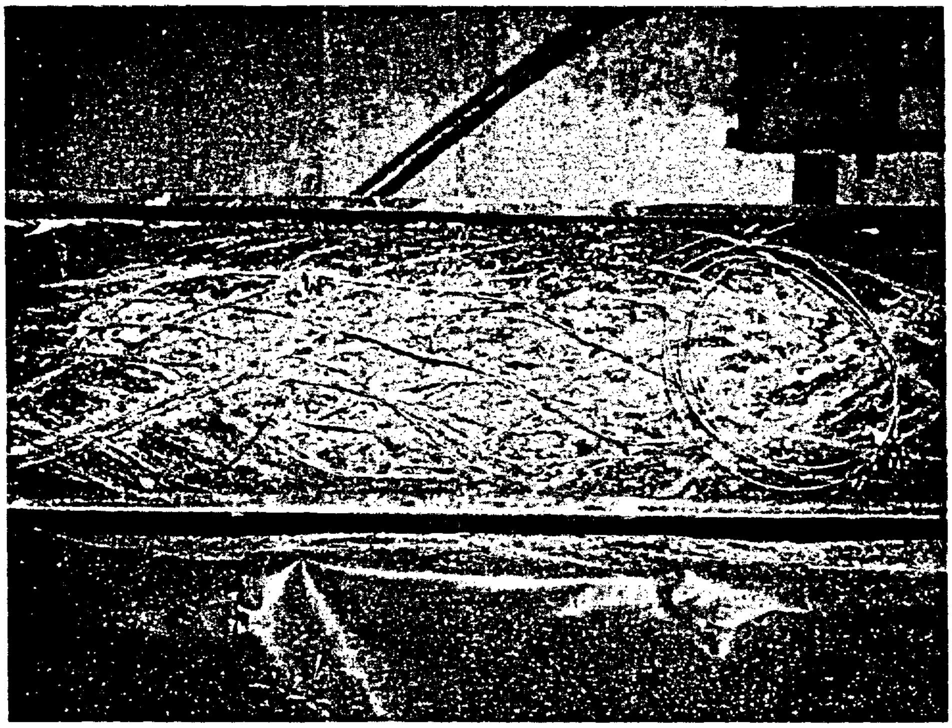

Figure 6. IEEE-383 qualified single-conductor cable solid bottom tray after test 25

	Cable Resistance	Circuit-to-Ground Resistance
Pretest	9.75 ohms	>20 m ohms
Posttest (warm)	11.26 ohms	>20 m ohms
Posttest (cold)	9.65 ohms	>20 m ohms

Coating G

IEEE-383 qualified single-conductor cable, ladder tray

After two ignition cycles a small fire developed in the tray. The fire self-extinguished after approximately two minutes.

A seemingly large fire was observed after the fourth cycle, but it too lasted approximately two minutes.

After the sixth cycle a small fire appeared intermittently for approximately ten minutes.

The affected area was approximately 44 inches (111.76 cm) long and 18 inches (45.72 cm) wide on the bottom of the tray, and 30 inches (76.2 cm) long and 18 inches (45.72 cm) wide on the top side of the tray.

Weight loss was 5.5 lbs (2.5 kg).

	Cable Resistance	Circuit-to-Ground Resistance
Pretest	8.02 ohms	>20 m ohms
Posttest (cold)	7.65 ohms	>20 m ohms

Coating G

IEEE qualified three-conductor cable ladder tray

After two ignition cycles a small fire, which flickered for approximately one minute, was observed on the bottom of the tray.

A small fire was also observed after the fourth, fifth, and sixth cycles.

The fire self-extinguished approximately four minutes after completion of the sixth cycle.

The affected area was approximately 36 inches (91.44 cm) long and 18 inches (45.72 cm) wide on the bottom, and 30 inches (76.2 cm) long and 18 inches (45.72 cm) wide on the top of the tray.

Weight loss was 4.75 lbs (2.2 kg).

	Cable Resistance	Circuit-to-Ground Resistance
Pretest	5.3 ohms	>20 m ohms
Posttest (warm)	5.85 ohms	>20 m ohms
Posttest (cold)	5.3 ohms	>20 m ohms

Nonvented Solid Top on Ladder Tray

Nonqualified (PE/PVC) three-conductor cable

After the first ignition cycle a fire was observed which continued to burn for approximately 71 minutes.

There was a large amount of heavy smoke from the start of the test.

Flammable gases were given off which burned between the cover and the top of the tray.

The affected area was approximately 89 inches (226.06 cm) long and 18 inches (45.72 cm) wide.

Weight loss was 28.25 lbs (12.8 kg).

	Cable Resistance	Circuit-to-Ground Resistance
Pretest	5.7 ohms	>20 m ohms
Posttest (warm)	N/A	N/A
Posttest (cold)	.33 ohms	.4 ohms

Vented Top Covers on Solid Bottom Tray

IEEE-383 qualified three-conductor cable

After six ignition cycles no fire was observed.

Upon removel of the covers an oily black coating was noted on the underside of the covers and some of the insulation on the cables had melted slightly.

Affected area of insulation damage was approximately 24 inches (60.96 cm) long and 18 inches (45.72 cm) wide. The bottom of the tray had a blackened area approximately 72 inches (182.88 cm) long and 18 inches (45.72 cm) wide.

Weight loss was 1 lb (0.5 kg). See Figure 7.

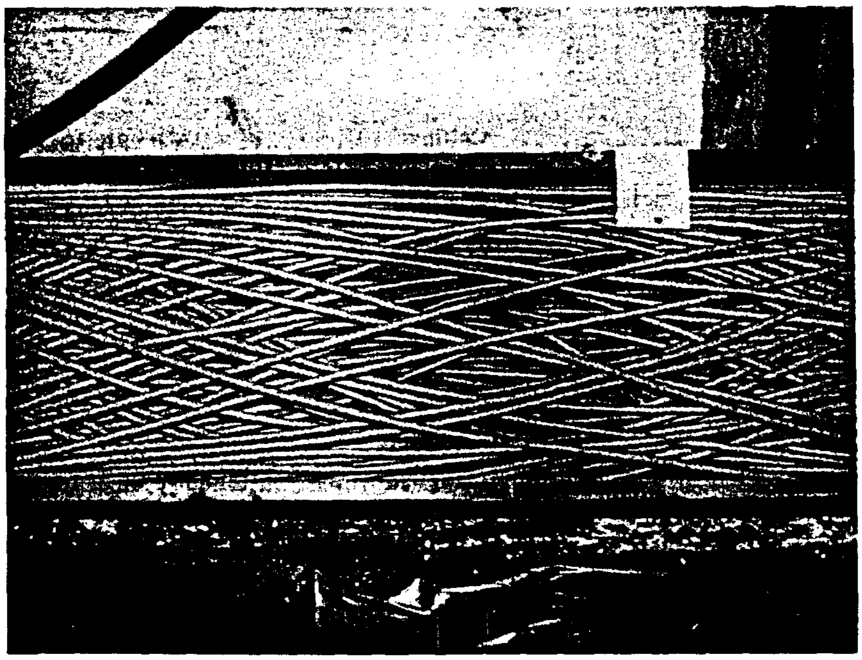

Figure 7. IEEE-383 qualified three-conductor cable with a vented top cover removed from a solid bottom tray after test 37

	Cable Resistance	Circuit-to-Ground Resistance
Pretest	5.25 ohms	>20 m ohms
Posttest (warm)	N/A	N/A
Posttest (cold)	7.77 ohms	>20 m ohms

Vented top covers solid bottom tray

IEEE-383 qualified single-conductor cable

After six ignition cycles no fire was observed.

Upon removal of the covers it was noted that the cables in the center of the tray were stuck together due to insulation damage.

The bottom of the tray was blackened over an area approximately 72 inches (182.88 cm) long and 18 inches (45.72 cm) wide.

Weight loss was 0.3 lb (0.1 kg).

	Cable Resistance	Circuit-to-Ground Resistance
Pretest	6.43 ohms	>20 m ohms
Posttest (warm)	7.6 ohms	182 k ohms
Posttest (cold)	6.35 ohms	4 m ohms

Vented top covers on solid bottom tray

Nonqualified (PE/PVC) three-conductor cable

A fire was observed after the second ignition cycle which continued to burn for approximately 61 minutes before self-extinguishing.

After the test it was noted that the covers were warped due to the heat.

The affected area was approximately 108 inches (274.32 cm) long and 18 inches (45.72 cm) wide.

Weight loss was 19.75 lbs (9.0 kg).

See Figure 8.

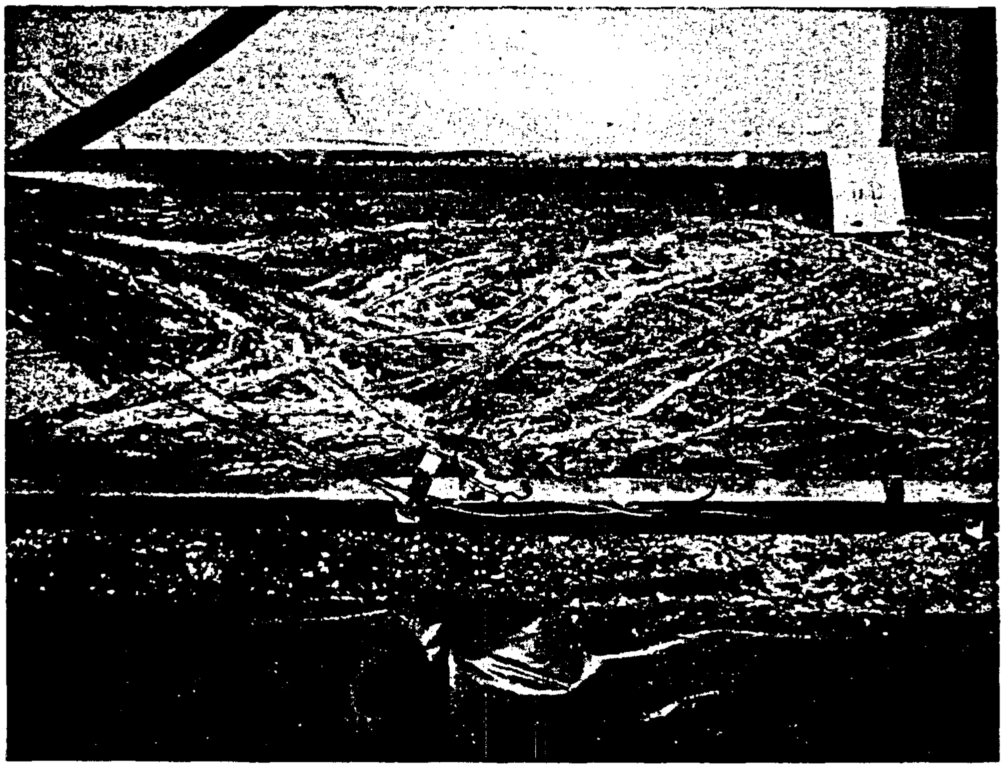

Figure 8. Nonqualified (PE/PVC) three conductor cable with a vented top cover removed from a solid bottom tray after test 39

	Cable Resistance	Circuit-to-Ground Resistance
Pretest	5.07 ohms	>20 m ohms
Posttest (cold)	.48 ohms	2.05 ohms

Summary of Single-Tray Tests

Appended Figures B-1 through B-11 are temperature and voltage plots for one single-tray test. They are included to provide comparative data among these tests, the two-tray tests, and as the small scale tests. Plots such as these were obtained on all single-tray tests performed but are too bulky for inclusion in this report. Table V is included as a summary of important parameters obtained during these tests.

TABLE V

Results of Full Scale Single-Tray Tests

Test	Coating, Barrier, Cable, etc.	Max. Cable Temp. (°F)	Max. Calorimeter Temp. (°F)	Max. Barrier Temp. (°F)	Time To Electrical Short (min)	Time to 900°F In Cables (min)	Time To Ignition (min)	Length of Burn (min)	Length Affected Area (in.)	Wt. Loss (lbs)
22	Ladder ceramic wool PVC no coating	1200	500	800	2	11	5	72	120	23.90
23	Solid bottom PVC no top no coating	1400	1600	1400	4	18	10	40	72	16
24	Solid bottom no top 383 3-cond no coating	400	295	340	60	60	60	0	0	0
25	Solid bottom no top 383 1-cond no coating	350	320	350	60	60	60	0	0	0
26	Ladder 383 1-cond coating G	1330	900	600	40	30	60	0	30	5.5
27	Ladder 383 3-cond coating G	525	460	600	60	60	30	4	30	4.75
36	Solid cover ladder no coating PVC	1050	390	550	3	27	5	71	89	28.25
37	Solid bottom vented top 383 qual. 3-cond no coating	440	385	340	60	60	60	0	24	1
38	Solid bottom vented top 383 qual. single-cond no coating	590	410	360	60	60	60	0	24	0
39	Solid bottom vented top PVC no coating	1000	975	925	5	27	10	60.2	108	19.75

Two-Tray Tests with Propane Exposure Fire

Nonqualified (PE/PVC) three-conductor cable, ladder tray, ceramic wool cover on top of both trays

During the second ignition cycle, a fire of sufficient size to warrant removal of the barrier between the upper and lower trays was observed and the barrier pulled.

The fire burned for approximately 45 minutes but did not propagate to the upper tray.

The affected area of the lower tray was approximately 108 inches (2.74 m) long and 18 inches (45.72) wide.

Weight loss of the lower tray was 12.5 lbs (5.7 kg).

See Figure 9.

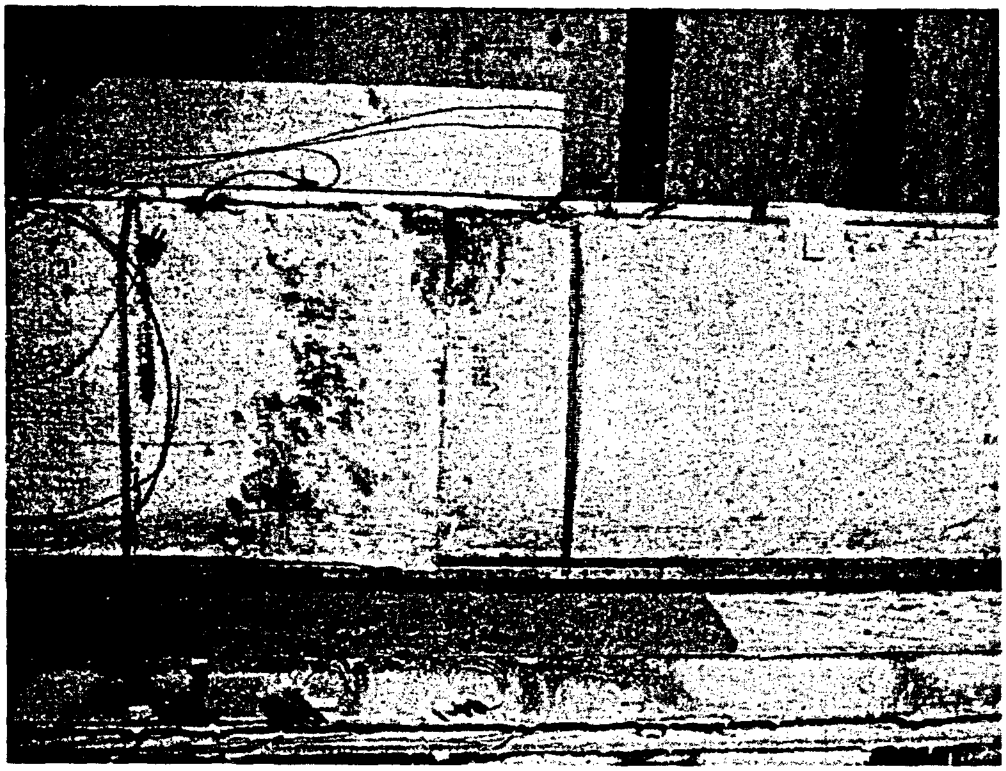

Figure 9. Nonqualified (PE/PVC) three conductor cable in a laddar tray (lower tray) showing ceramic wool cover after test 28.

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	4.43 ohms	>20 m ohms
Posttest (warm)	.27 ohms	.9 ohms
Posttest (cold)	.35 ohms	.26 ohms
Top tray:		
Pretest	4.72 ohms	>20 m ohms
Posttest (warm)	4.96 ohms	>20 m ohms
Posttest (cold)	4.72 ohms	>20 m ohms

Coating G

IEEE-383 qualified single-conductor cable in top tray; IEEE-383 qualified three-conductor cable in bottom tray

After the third ignition cycle a fire was observed and the barrier separating the upper and lower trays was removed. The fire continued to burn for approximately 14 minutes before self-extinguishing.

The fire did not propagate to the top tray.

The affected area of the bottom tray was approximately 36 inches (91.44 cm) long and 18 inches (45.72 cm) wide on the bottom of the tray, and 24 inches (60.96 cm) long and 18 inches (45.72 cm) wide on the top of the tray.

Weight loss of the bottom tray was 4 lbs (1.8 kg).

See Figures 10, 11, 12, and 13.

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	4.94 ohms	>20 m ohms
Posttest	5.11 ohms	>20 m ohms
Top tray:		
Pretest	9.45 ohms	>20 m ohms
Posttest (cold)	9.7 ohms	>20 m ohms

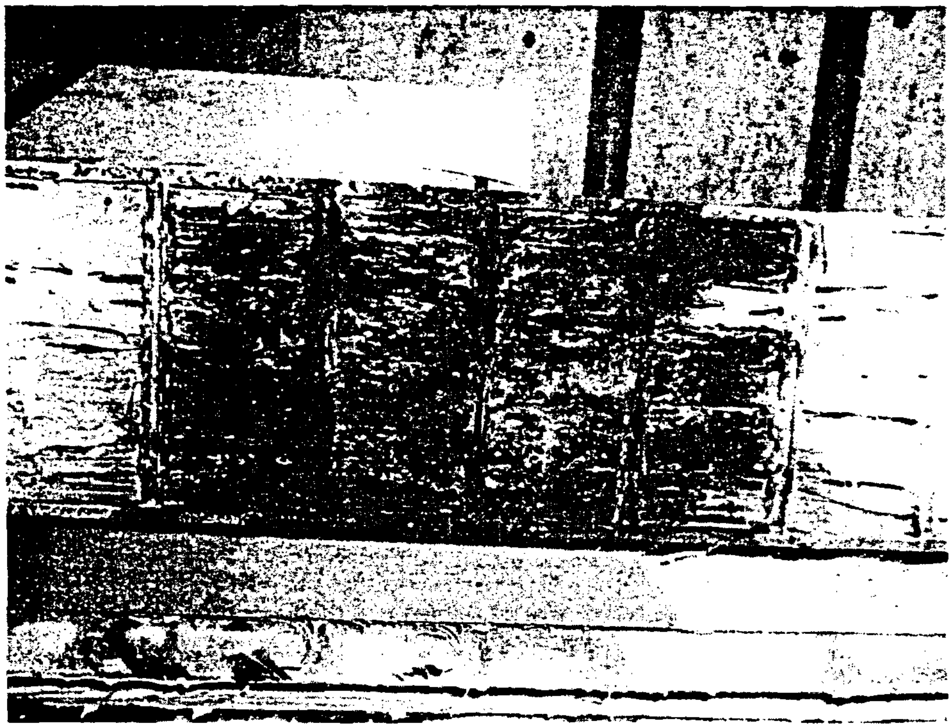

Figure 10. IEEE-383 qualified three-conductor cable with coating G. Bottom view of tray after test 29

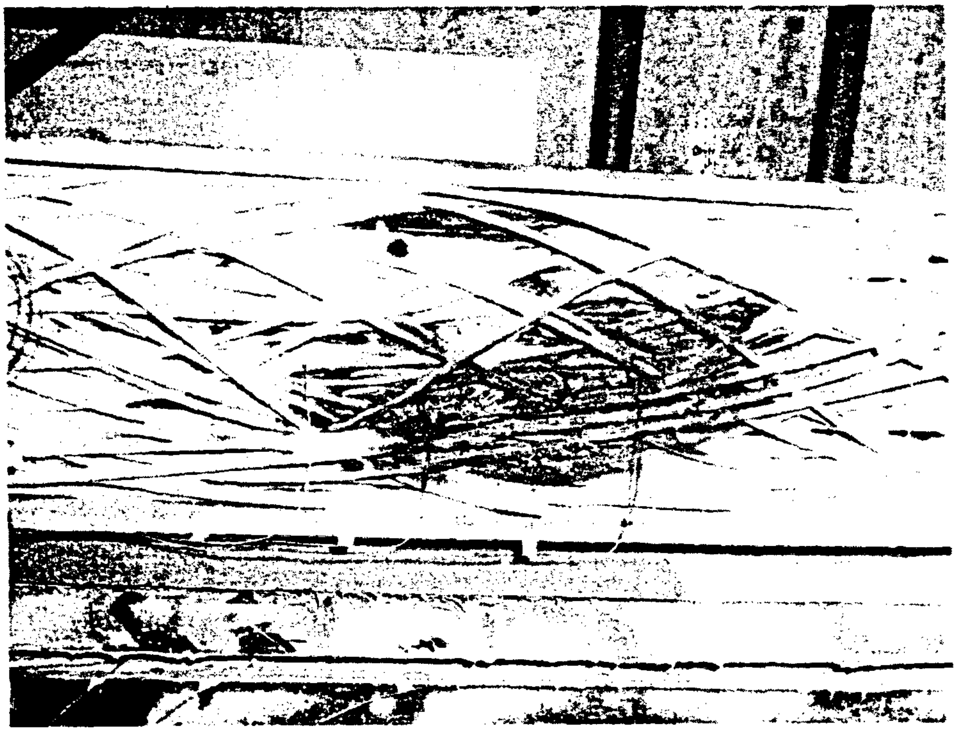

Figure 11. IEEE-383 qualified three-conductor cable with coating G. Top view of bottom tray after test 29

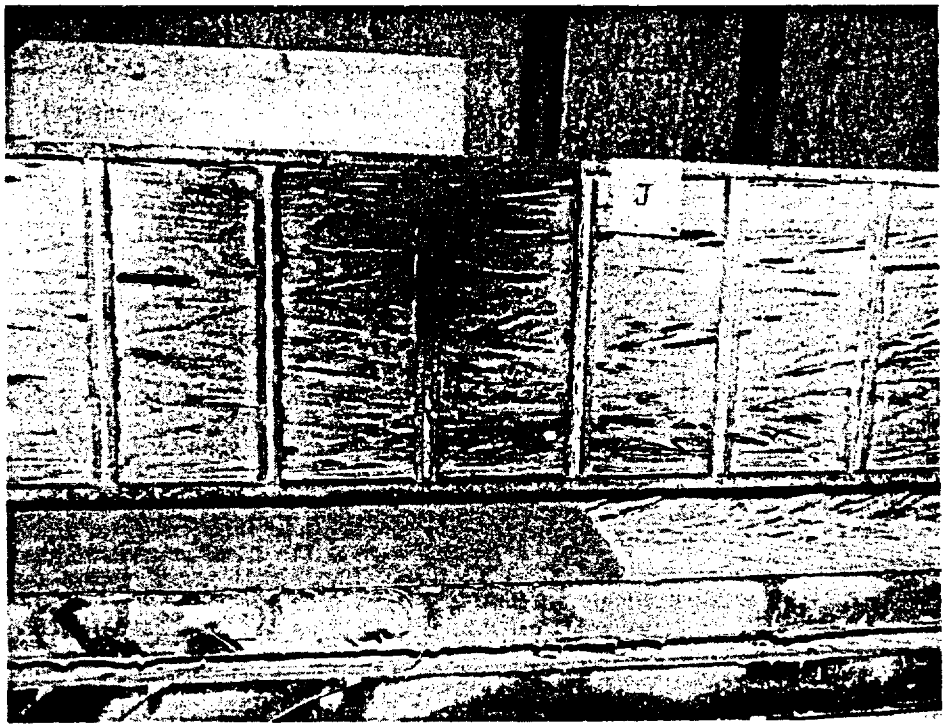

Figure 12. IEEE-383 qualified single-conductor cable with coating G. Bottom view of top tray after test 29

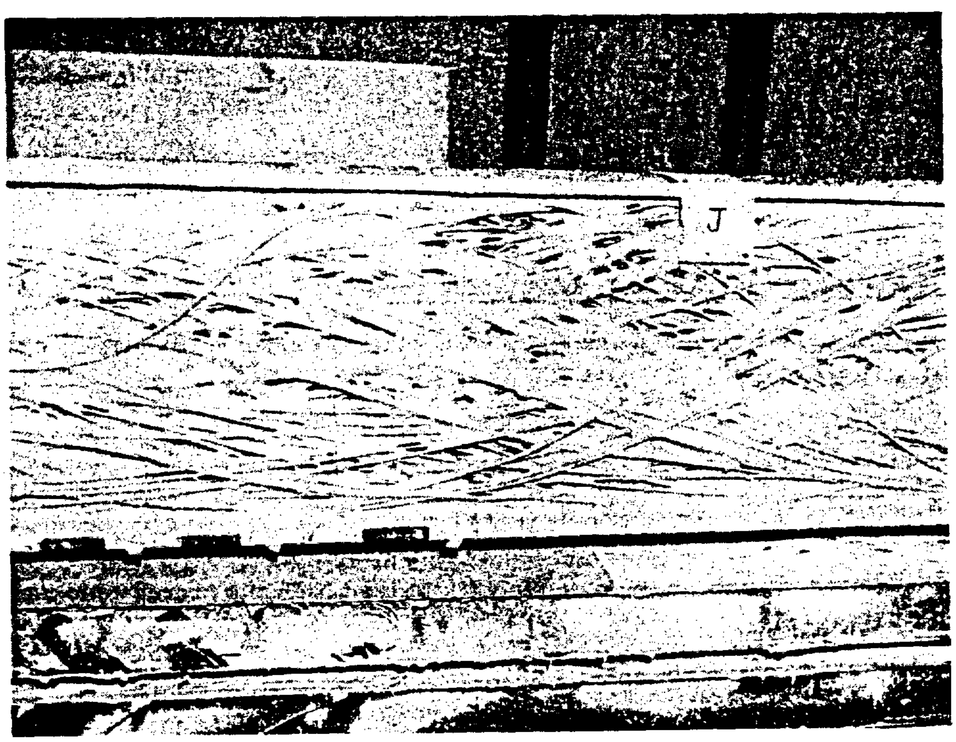

Figure 13. IEEE-383 qualified single-conductor cable with coating G. Top view of top tray after test 29

Coating G

Nonqualified (PE/PVC) three-conductor cable, ladder tray

After the second ignition cycle a fire was observed and the barrier separating the top and bottom trays was removed.

The fire continued to burn for approximately 15 minutes before self-extinguishing.

The fire did not propagate to the top tray.

The affected area of the lower tray was approximately 36 inches (91.44 cm) long and 18 inches (45.72 cm) wide on the bottom, and 24 inches (60.96 cm) long and 18 inches (45.72 cm) wide on the top. The upper tray had a blackened area approximately 30 inches (76.2 cm) long and 18 inches (45.72 cm) wide.

Weight loss of the bottom tray was 3.25 lbs (1.5 kg).

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	4.53 ohms	>20 m ohms
Posttest (warm)	.70 ohms	.74 ohms
Posttest (cold)	.69 ohms	.54 ohms
Top tray:		
Pretest	5.11 ohms	>20 m ohms
Posttest (warm)	5.45 ohms	>20 m ohms
Posttest (cold)	5.25 ohms	>20 m ohms

Coating B

Nonqualified (PE/PVC) three-conductor cable, ladder tray

After the second ignition cycle a small fire was observed which self-extinguished approximately 2 minutes later.

After the third cycle a fire was observed and the barrier separating the top and bottom trays was removed.

The fire continued to burn for approximately 8 minutes but did not propagate to the top tray.

The affected area of the bottom tray was approximately 36 inches (91.33 cm) long and 18 inches (45.72 cm) wide on the lower side and 24 inches (60.96) long and 18 inches (45.72 cm) wide on the upper side. The top tray was blackened in an area approximately 24 inches (60.96 cm) long and 18 inches (45.72 cm) wide.

Weight loss of the lower tray was 5 lbs (2.3 kg).

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	5.24 ohms	>20 m ohms
Posttest (cold)	1 ohm	135 ohms
Top tray:		
Pretest	4.75 ohms	>20 m ohms
Posttest (cold)	4.78 ohms	>20 m ohms

Coating A

Nonqualified (PE/PVC) three-conductor cable ladder tray

After the second ignition cycle a small fire was observed which flickered until the second cycle. After the second cycle the barrier separating the top and bottom trays was removed and the fire continued to burn for approximately 26 minutes before self-extinguishing.

The fire did not propagate to the top tray.

The affected area of the bottom tray was approximately 36 inches (91.44 cm) long and 18 inches (45.72 cm) wide on the lower side, and 30 inches (76.2 cm) long and 18 inches (45.72 cm) wide on the upper side. The top tray was blackened in an area approximately 72 inches (182.88 cm) long and 18 inches (45.72 cm) wide.

Weight loss of bottom tray was 7.5 lbs.

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	4.87 ohms	>20 m ohms
Posttest (warm)	.88 ohms	167 ohms
Posttest (cold)	1.08 ohms	165 ohms
Top tray:		
Pretest	5.93 ohms	>20 m ohms
Posttest (warm)	6.36 ohms	>20 m ohms
Posttest (cold)	6.15 ohms	>20 m ohms

Coating C

Nonqualified (PE/PVC) three-conductor cable, ladder tray

Early into the first ignition cycle the cable and coating began to produce heavy smoke. After the third cycle a fire was observed and the barrier separating the top and bottom trays was removed.

The fire continued to burn for approximately 30 minutes, during which the fire propagated to the top tray. The top tray burned for approximately 67 minutes.

The affected area of the bottom tray was approximately 60 inches (152.4 cm) long and 18 inches (45.72 cm) wide. The affected area of the top tray was approximately 84 inches (213.36 cm) long and 18 inches (45.72 cm) wide.

Weight loss of the bottom tray was 38.75 lbs (17.6 kg).

Weight loss of the top tray was 57 lbs (25.9 kg).

See Figures 14, 15, 16, 17, and 18.

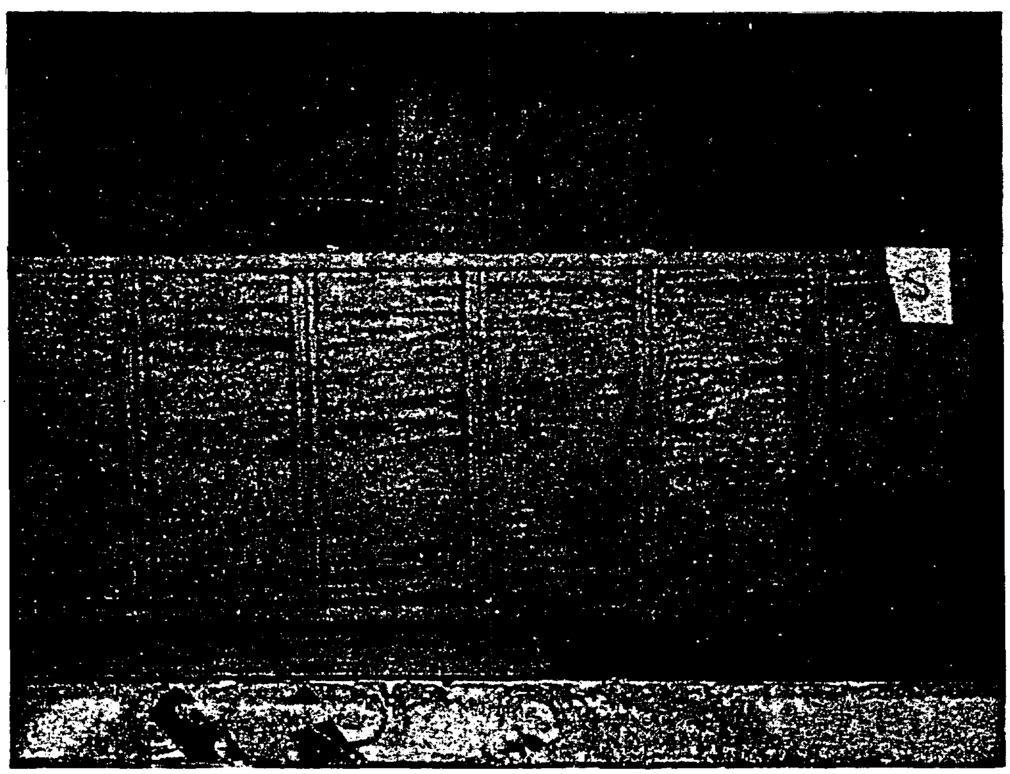

Figure 14. Nonqualified (PE/PVC) three-conductor cable with coating C. Bottom view of tray before test 33.

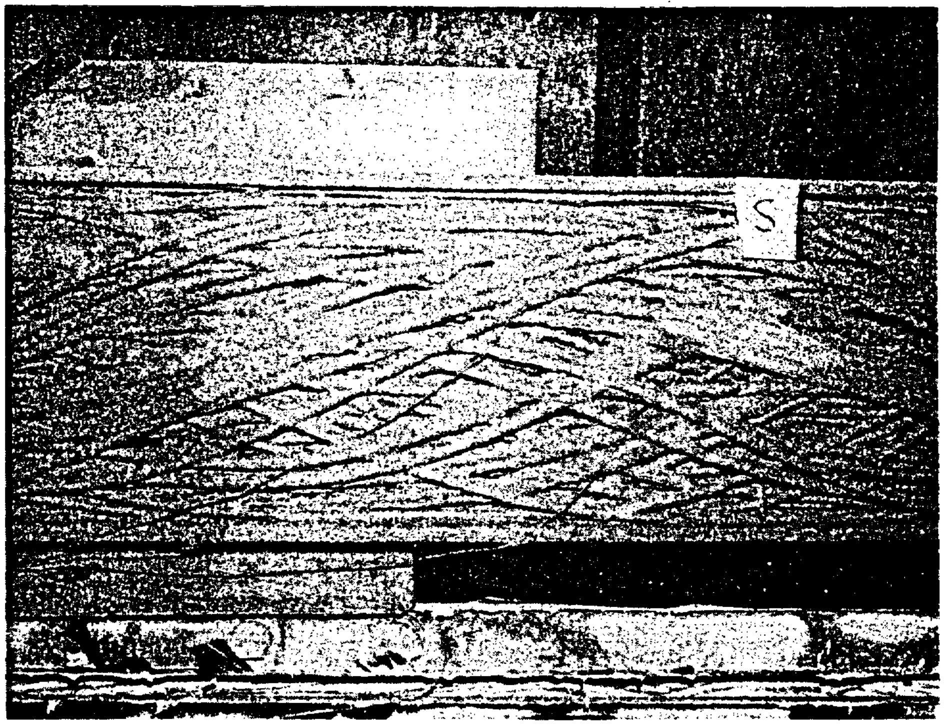

Figure 15. Nonqualified (PE/PVC) three-conductor cable with coating C. Top view of tray before test 33

Figure 16. During Test 33 with propane burner off and barrier removed.

Figure 17. During Test 33 after second tray ignites and is fully developed

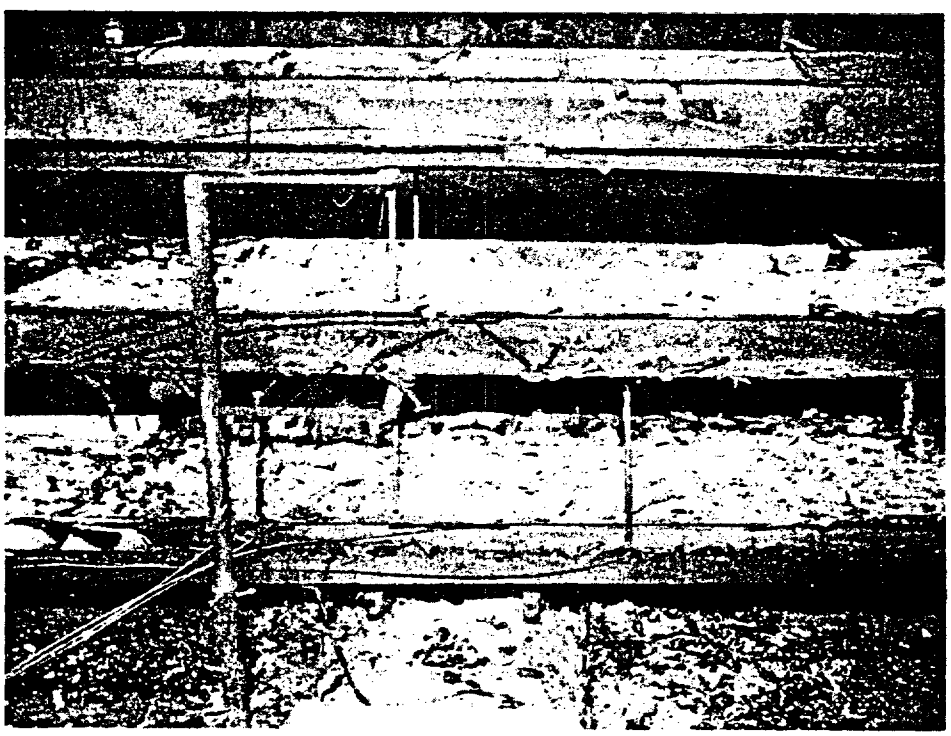

Figure 18. After Test 33

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	5.54 ohms	>20 m ohms
Posttest (warm)	.75 ohms	.2 ohms
Posttest (cold)	N/A	N/A
Top tray:		
Pretest	5.42 ohms	>20 m ohms
Posttest (warm)	.38 ohms	.65 ohms
Posttest (cold)	N/A	N/A

Solid Bottom Trays

Nonqualified (PE/PVC) three-conductor cable

During the third ignition cycle, a small fire was observed which burned approximately four minutes before self-extinguishing.

Subsequent ignition cycles failed to produce a fire and the test was terminated at the end of six cycles with no fire.

The affected area of the bottom tray was approximately 43 inches (109.22 cm) long and 18 inches (45.72 cm) wide.

Weight loss of the bottom tray was 1.5 lbs (0.7 kg).

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	4.82 ohms	>20 m ohms
Posttest (warm)	.71 ohms	8.00 m ohms
Posttest (cold)	.71 ohms	6.20 m ohms
Top tray:		
Pretest	4.96 ohms	>20 m ohms
Posttest (warm)	5.18 ohms	>20 m ohms
Posttest (cold)	4.94 ohms	>20 m ohms

Coating C

IEEE-383 qualified three-conductor cable in bottom tray

IEEE-383 qualified single-conductor cable in top tray (ladder trays)

After the first ignition cycle a small fire was observed on the bottom tray. The fire self-extinguished after approximately three minutes.

After the second cycle the fire was larger and the barrier separating the upper and lower trays was removed.

The fire continued to burn for approximately 47 minutes before self-extinguishing, but did not propagate to the second tray.

The affected area of the bottom tray was approximately 48 inches (121.92 cm) long and 18 inches (45.72 cm) wide on the lower side, and 53 inches (134.62 cm) long and 18 inches (45.72 cm) wide on the upper side.

The upper tray had an affected area approximately 54 inches (137.16 cm) long and 18 inches (45.72 cm) wide on the lower side, and 48 inches (121.92 cm) long and 18 inches (45.72 cm) wide on the upper side.

Analysis of infrared thermovision data showed a maximum flame temperature of 825°C was reached just as the barrier was pulled.

Weight loss of the bottom tray was 28.5 lbs (12.9 kg).

Weight loss of the top tray was 23.5 lbs (10.6 kg).

See Figure 19.

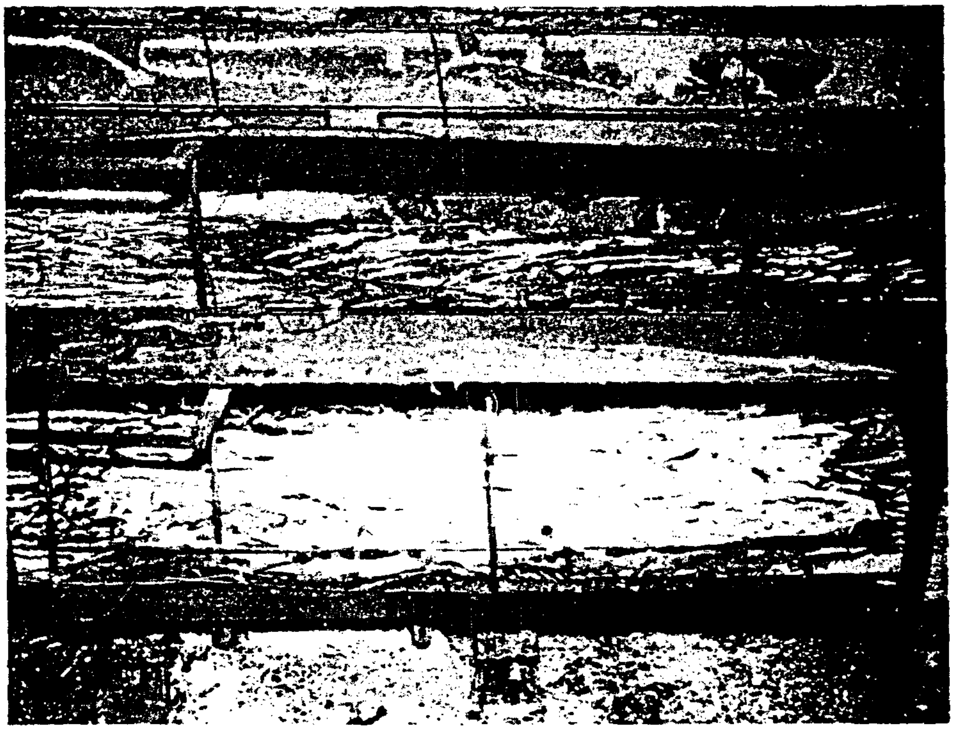

Figure 19. After Test 35

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	5.17 ohms	>20 m ohms
Posttest (cold)	1.98 ohms	6.2 k ohms
Top tray:		
Pretest	9.74 ohms	>20 m ohms
Posttest (cold)	8.81 ohms	1.50 ohms

Vented Top Covers Solid Bottom Trays

Nonqualified (PE/PVC) three-conductor cable

After the second ignition cycle a fire was observed in the lower tray and the barrier separating the upper and lower trays was removed.

The fire continued to burn for approximately 55 minutes, but did not propagate to the top tray.

Upon removal of the covers it was noted that the cables in the upper tray were stuck to the tray bottom due to insulation melting.

The affected area of the bottom tray was approximately 66 inches (167.64 cm) long and 18 inches (45.72 cm) wide. The top tray was blackened on the lower side over its entire surface.

Weight loss of the lower tray was 12.5 lbs (5.7 kg).

See Figure 20.

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	5.3 ohms	14 m ohms
Posttest (cold)	.4 ohms	1.7 ohms
Top tray:		
Pretest	5.36 ohms	5.7 m ohms
Posttest (cold)	2.00 ohms	.89 ohms

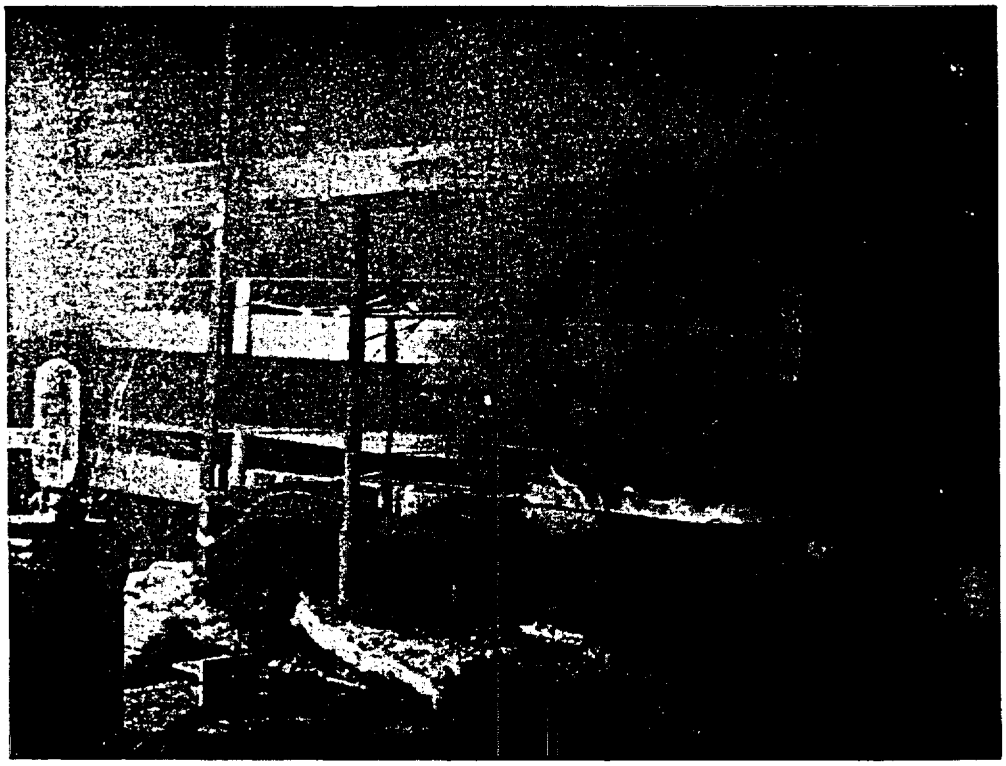

Figure 20. During Test 40

Nonvented Top Covers, Ladder Trays

Nonqualified (PE/PVC) three-conductor cable

After the second ignition cycle a fire was observed and the barrier separating the top and bottom trays was removed.

The fire continued to burn for approximately 68 minutes before self-extinguishing, but did not propagate to the top tray.

There was a great deal of heavy smoke early in the test.

The affected area of the lower tray was approximately 120 inches (304.8 cm) long and 18 inches (45.72 cm) wide.

Weight loss was 17.75 lbs (8.1 kg).

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	4.63 ohms	>20 m ohms
Posttest (cold)	.35 ohms	.35 ohms
Top tray:		
Pretest	5.06 ohms	>20 m ohms
Posttest (cold)	5.05 ohms	>20 m ohms

Ceramic Board Barrier Between Ladder Trays

Nonqualified (PE/PVC) three-conductor cable

After the first ignition cycle a fire was observed in the bottom tray which continued to burn for approximately 42 minutes before self-extinguishing.

The fire did not propagate to the top tray.

The affected area of the bottom tray was approximately 120 inches (304.8 cm) long and 18 inches (45.72 cm) wide. The cables in the top tray appeared to have been damaged by the fire on one end where the ceramic board barrier did not extend far enough to protect the complete 12 foot (3.6 m) length of tray. The 1-inch (2.54 cm) thick ceramic board was 8 feet (2.4 m) long and extended 6 inches (15.2 cm) beyond the tray on each side.

Weight loss of the bottom tray was 37.5 lbs (17.0 kg).

See Figures 21 and 22.

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	5.23 ohms	>20 m ohms
Posttest (warm)	.27 ohms	.03 ohms
Posttest (cold)	.28 ohms	.28 ohms
Top tray:		
Pretest	4.72 ohms	>20 m ohms
Posttest (warm)	1.53 ohms	>20 m ohms
Posttest (cold)	1.69 ohms	8 k ohms

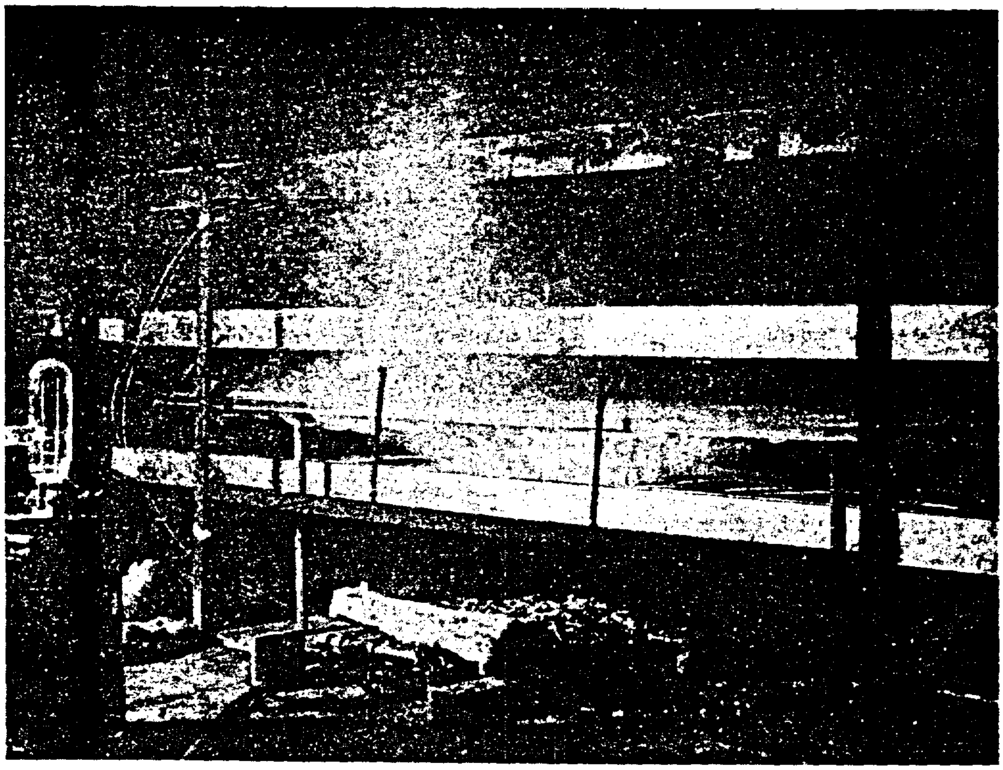

Figure 21. During Test 42

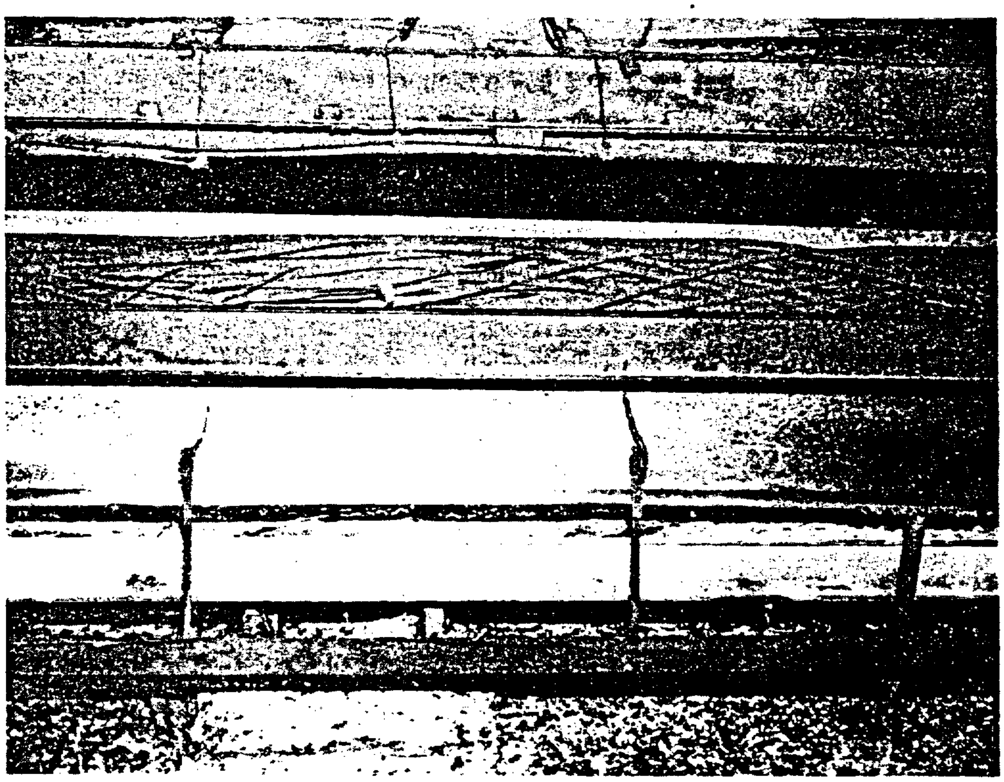

Figure 22. After Test 42

Summary of Two-Tray Tests with Propane Ignition

Temperature and voltage plots of each tray were obtained during the two-tray tests in the same manner as described for the single-tray tests. Data extracted from such plots for each test provided comparisons between the previous single-tray tests and other two-tray tests. Rather than include all plots for each test, Table VI summarizes important parameters obtained during these tests.

Two-Tray Tests with Diesel Fuel Exposure Fire

Coating E

Nonqualified (PE/PVC) three-conductor cable, ladder tray

The ignition source for this test was a diesel fuel fire which burned for approximately 13 minutes before self-extinguishing.

During the ignition cycle a small fire was observed in the top tray, but extinguished at approximately the same time as the oil pan fire.

The affected area of the bottom tray was approximately 84 inches (213.36 cm) long and 18 inches (45.72 cm) wide on the lower side, and 36 inches (91.44 cm) long and 18 inches (45.72 cm) wide on the upper side. The top tray had an affected area approximately 84 inches (213.36 cm) long and 18 inches (45.72 cm) wide. The bottom tray showed no apparent cable damage, but the top tray had a damaged spot near the center apparently caused by faulty coverage of the coating in that area.

Weight loss of the bottom tray was 6.25 lbs (2.8 kg).

Weight loss of the top tray was 4.25 lbs (1.9 kg).

See Figures 23 and 24.

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	4.72 ohms	1.61 m ohms
Posttest (warm)	1.04 ohms	1.04 m ohms
Posttest (cold)	.96 ohms	.5 m ohms
Top tray:		
Pretest	5.45 ohms	.35 m ohms
Posttest (warm)	1.67 ohms	28.76 ohms
Posttest (cold)	1.61 ohms	.25 k ohms

TABLE VI

Results of Full Scale Two-Tray Tests

Test	Coatings, Barriers Cable, etc.	Max. Cable Temp. (°F)	Max. Calorimeter Temp. (°F)	Max. Barrier Temp. (°F)	Time to Electrical Short (min)	Time to 900°F In Cables (min)	Time to Ignition (min)	Length of Burn (min)	Length Affected Area (in.)	Wt. Loss (lbs)	Propagation
					Top						
28	Ladder ceramic wool PVC no coating	100	98	116	60	60	60	0	0	0	No
29	Ladder 383 cable single-cond coating G	160	133	170	60	60	60	0	0	0	No
30	Ladder PVC coating G	255	243	270	60	60	60	0	0	0	No
31	Ladder PVC coating B	156	93	135	60	60	60	0	0	0	No
32	Ladder PVC coating A	167	174	208	60	60	60	0	0	0	No
33	Ladder PVC coating C	1580	1460	1475	28	37	12**	67	84	57	Yes
34	Solid bottom tray no coating PVC cable	91	127	128	60	60	60	0	0	0	No
35	Coating C 383 cable single-cond ladder tray	1050	320	430	25	51	60	0	0	23.5	No
40	Solid bottom vented top PVC no coating	265	170	190	45	60	60	0	0	0	No
41	Solid top open ladder PVC no coating	250	87	94	60	60	60	0	0	0	No
42	1-inch solid barrier between open ladder trays PVC no coating	265	-	560	14*	60	60	0	0	0	No
					Bottom						
28	Same as top	900	330	500	2	13	15	45	108	12.5	
29	Three-cond 383 rest same as top	545	1100	1320	30	60	15	14	24	4	
30	Same as top	640	1050	750	6.6	60	10	15	24	3.25	
31	Same as top	870	925	1275	14	60	15	8	24	5.0	
32	Same as top	1260	1200	1440	6	13	10	26	30	7.5	
33	Same as top	1580	1400	1500	6	21	15	30	60	38.8	
34	Same as top	650	480	430	8	60	20	4	43	1.5	
35	3-cond 383 qual. same as top for rest	1600	1525	1500	15	3	10	47	53	28.5	
40	Same as top	1300	780	430	5	16	10	55	66	12.5	
41	Same as top	1500	305	340	5	4	10	67.5	120	17.75	
42	Same as top	1350	-	400	2	1	5	42	120	37.5	

*Short occurred beyond end of 8 ft. barrier as fire progressed beyond that point in bottom tray.
**After removal of barrier.

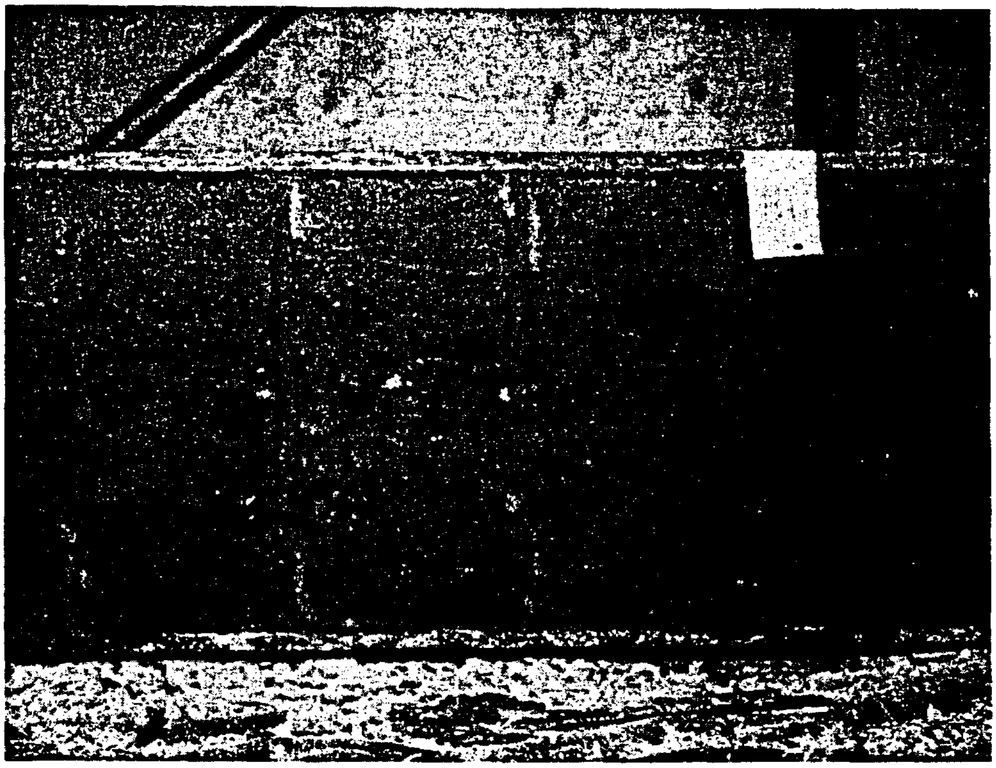

Figure 23. Bottom of Lower Tray After Test 43

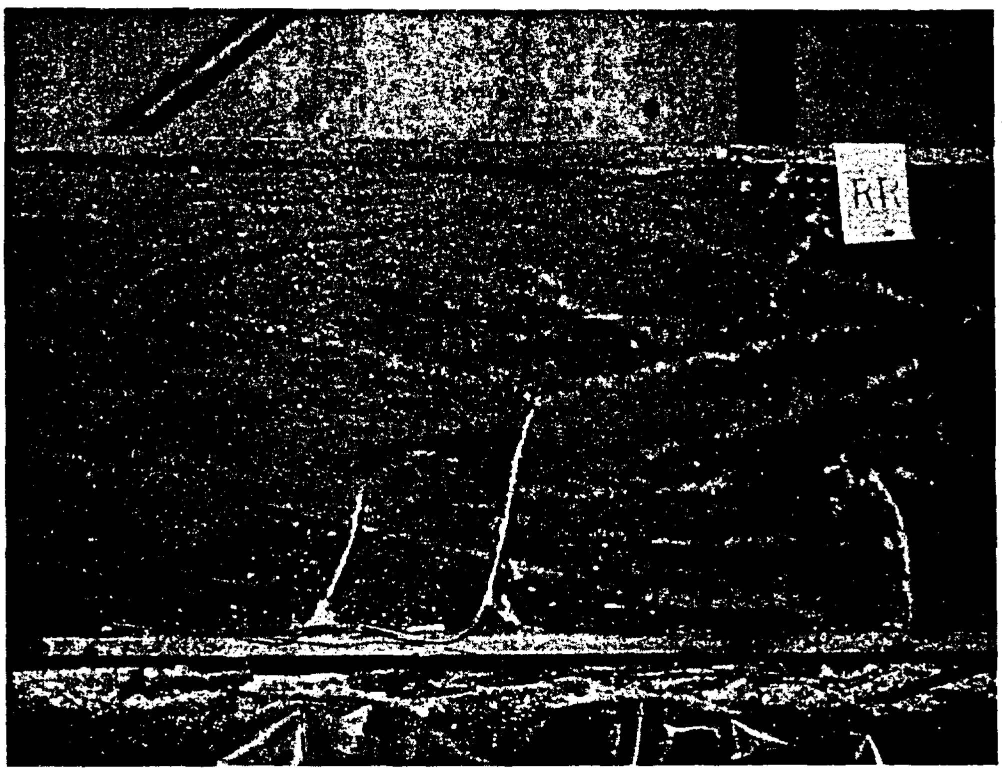

Figure 24. Top of Lower Tray After Test 43

Coating B

Nonqualified (PE/PVC) three-conductor cable, ladder tray

The ignition source for this test was a diesel fuel fire which burned for approximately 12 minutes before self-extinguishing.

At the end of the ignition cycle the bottom tray was burning. The fire continued to burn for approximately 30 minutes before self-extinguishing, but did not propagate to the top tray.

After the test it was noted that the upper side of the top tray had molten PVC bubbling from cracks in the coating.

The affected area of the bottom tray was approximately 80 inches (203.2 cm) long and 18 inches (45.72 cm) wide on the lower side, and 66 inches (167.64 cm) long and 18 inches (45.72 cm) wide on the upper side. The top tray had approximately the same affected area.

Weight loss of the bottom tray was 20.25 lbs (9.2 kg).

Weight loss of the top tray was 10.50 lbs (4.8 kg).

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	4.92 ohms	250 k ohms
Posttest (warm)	.96 ohms	22.3 ohms
Posttest (cold)	.77 ohms	3.3 k ohms
Top tray:		
Pretest	5.31 ohms	966 k ohms
Posttest (warm)	1.97 ohms	.31 ohms
Posttest (cold)	1.59 ohms	9.9 ohms

Coating G

Nonqualified (PE/PVC) three-conductor cable, ladder tray

The ignition source for this test was a diesel fuel fire which burned for approximately 12 minutes before self-extinguishing.

Both trays were on fire after the ignition cycle. The fire in the bottom tray burned approximately 42 minutes before self-extinguishing; the top tray burned approximately 45 minutes before self-extinguishing.

The affected area of the bottom tray was approximately 72 inches (182.88 cm) long and 18 inches (45.72 cm) wide on the lower side, and 66 inches (167.64 cm) long and 18 inches

(45.72 cm) wide on the upper side. The top tray had an affected area approximately 84 inches (213.36 cm) long and 18 inches (45.72 cm) wide. Before the test it was noted that the bottom tray presented somewhat unusual cable placement in that there were large spaces where air could pass freely through the cables. This condition undoubtedly contributed to the unusual case of both trays being on fire at the end of the ignition source fire.

Weight loss was 39 lbs (17.7 kg) in the top tray and 24.75 lbs (11.2 kg) in the bottom tray.

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	4.43 ohms	3 m ohms
Posttest (warm)	.57 ohms	200 ohms
Posttest (cold)	.58 ohms	350 k ohms
Top tray:		
Pretest	4.93 ohms	1.5 m ohms
Posttest (warm)	.38 ohms	.88 ohms
Posttest (cold)	.47 ohms	.56 ohms

Coating A

Nonqualified (PE/PVC) three-conductor cable, ladder tray

The ignition source for this test was a diesel fuel fire which burned for approximately 13 minutes before self-extinguishing.

After the ignition cycle a fire was observed in the bottom tray which burned for approximately 42 minutes before self-extinguishing. The fire did not propagate to the top tray.

After the test it was noted that molten PVC had bubbled from cracks in the coating of the top tray.

The affected area of the bottom tray was approximately 72 inches (182.88 cm) long and 18 inches (45.72 cm) wide. The top tray had a similar affected area.

Weight loss was 22.25 lbs (10.1 kg) in the bottom tray and 15.75 lbs (7.1 kg) in the top tray.

	Cable Resistance	Circuit-to Ground Resistance
Bottom tray:		
Pretest	4.69 ohms	4.8 m ohms
Posttest (warm)	N/A	N/A
Posttest (cold)	1.06 ohms	60 k ohms
Top tray:		
Pretest	4.93 ohms	2.4 m ohms
Posttest (warm)	N/A	N/A
Posttest (cold)	1.13 ohms	191.2 ohms

Coating C

Nonqualified (PE/PVC) three-conductor cable, ladder tray

The ignition source for this test was a diesel fuel fire which burned for approximately 11 minutes before self-extinguishing.

After the ignition cycle a fire was observed in the bottom tray which burned for approximately 37 minutes during which it propagated to the top tray. The top tray burned for approximately 43 minutes before self-extinguishing.

The affected area of the bottom tray was 84 inches (213.36 cm) long and 18 inches (45.72 cm) wide. The top tray had an affected area approximately 96 inches (243.84 cm) long and 18 inches (45.72 cm) wide.

Weight loss was 45.25 lbs (20.5 kg) for the bottom tray and 57.75 lbs (26.2 kg) for the top tray.

See Figures 25, 26, 27, and 28.

	Cable Resistance	Circuit-to-Ground Resistance
Bottom tray:		
Pretest	4.89 ohms	1 m ohm
Posttest (warm)	N/A	N/A
Posttest (cold)	0.65 ohms	0.44 ohms
Top tray:		
Pretest	4.71 ohms	500 k ohms
Posttest (warm)	N/A	N/A
Posttest (cold)	0.47 ohms	0.45 ohms

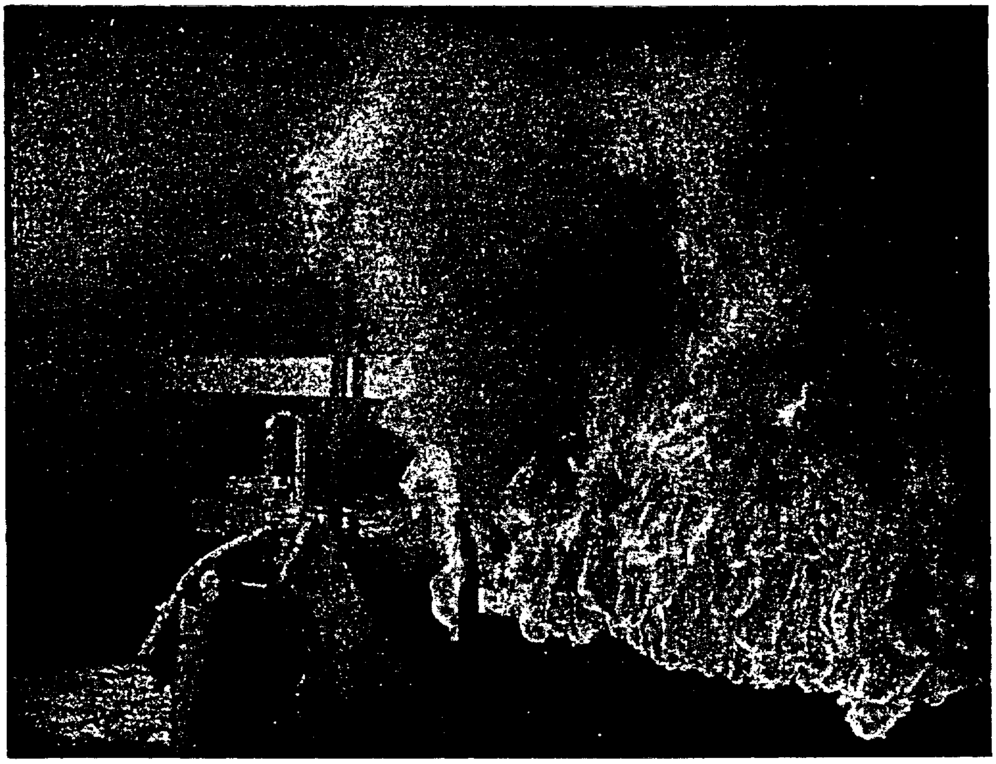

Figure 25. Diesel Fuel Burning During Test 47

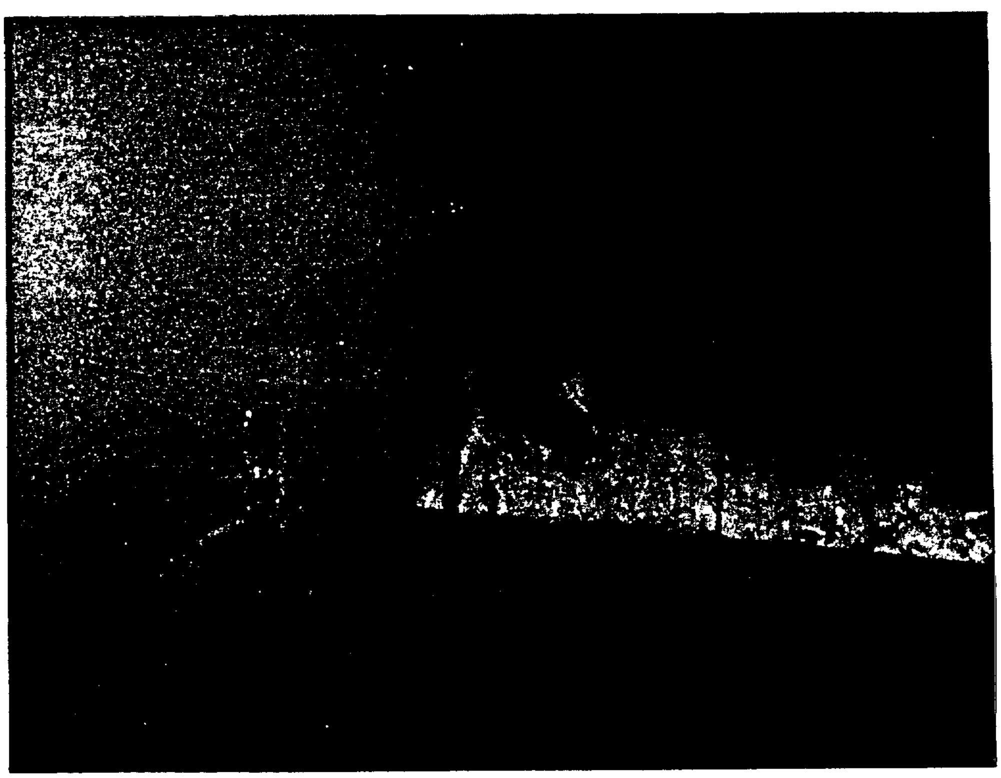

Figure 26. After Diesel Fuel Fire has Extinguished and Bottom Tray has Ignited in Test 47

Figure 27. After Diesel Fuel Fire has Extinguished and Both Cable Trays have Ignited in Test 47

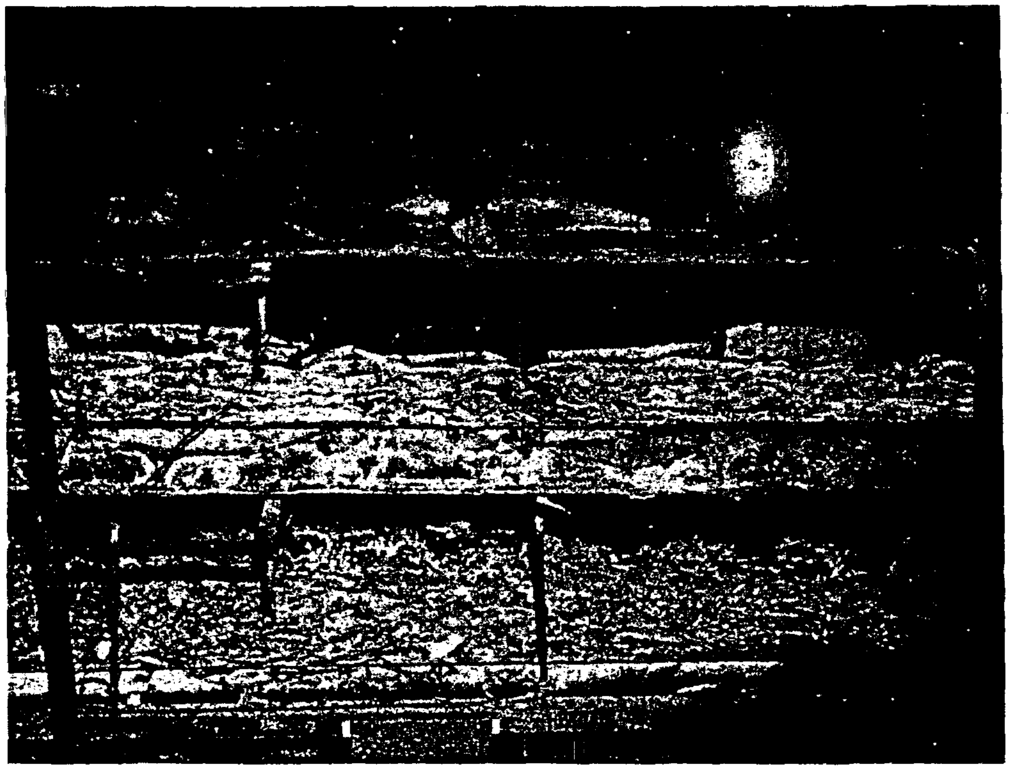

Figure 28. After Test 47

Summary of Diesel Fuel Exposure Fires

Temperature and voltage plots were obtained for each test as in the previous propane fueled exposure fires. Data extracted from these plots for each test provided comparisons between that test and all other tests. Rather than include all plots for each test, Table VII summarizes important parameters obtained during these tests. Appended Figures C-1 through C-20 are some of the temperature and voltage plots for one diesel fuel fire. The temperatures of C-1 and C-2 were measured one inch (2.54 cm) over the fuel and may be compared to the temperatures taken one inch over the propane fueled ribbon burner by channels #0 and #1. These plots are shown in Figures B-1 and B-2 in this report as well as in SAND78-0518. Other plots may be compared directly to the propane fueled fires, as measurement locations are the same.

Conclusions

Preliminary results show that all coatings and barriers offer a measure of additional protection. No propagation to the second tray was observed in any of the two tray tests where IEEE-383 qualified cable was used. In the three tests where propagation to the second tray was observed, non-qualified cable was used. Two of these tests were with the same fire retardant coating (coating C) and were initiated by two different exposure fires (propane fueled IEEE-393 ribbon burners, and diesel fuel #2 in a pan). The other test was with a different fire retardant coating (coating G) and was initiated by a diesel fuel fire. It must be pointed out that in the diesel fueled fires no barriers were used between the cable trays so that the fuel from the cable in the bottom tray was not the only heat source to the upper tray to produce propagation.

There is a wide range in relative effectiveness of the different fire retardant coatings tested here. Table VIII summarizes a ranking of coating effectiveness derived from the small scale and full scale tests reported here and in SAND78-0518 (March 1978). These rankings are based on both combustion and propagation properties. There is no attempt to rank the fire barriers. There was no attempt to protect the ignition tray; only to prevent propagation to other trays. Ease of combustion in the ignition tray, therefore, has no meaning with regard to the relative effectiveness of the barrier. Indeed, there is some justification in the argument that this is also the main function of the fire retardant coatings.

During the execution of the 26 tests reported here, a considerable amount of chlorine was released from the combustion of the electrical cables. This chlorine combined in the test site with available hydrogen to form hydrochloric acid. This appeared as corrosive oily substance that discolored unprotected metal in the building and occasionally dripped from the ceiling.

TABLE VII

Results of Full Scale Two-Tray Tests Exposed to Diesel Fuel Fires
(No Barriers Between Trays)

Test	Coatings, Cable	Max. Cable Temp. (°F)	Max. Calorimeter Temp. (°F)	Max. Barrier Temp. (°F)	Time to Electrical Short (min)	Time to 900°F In Cables (min)	Time to Ignition (min)	Length of Burn (min)	Length Affected Area (in.)	Wt. Loss (lbs)	Propagation
					Top						
43	Open ladder PVC Coating E	255	1100	1180	19	60	None	0	0	4.25	No
44	Open ladder PVC Coating B	670	725	780	11	60	None	0	72	10.5	No
45	Open ladder PVC Coating G	1560	1530	1580	11	12	12	45.5	84	39	Yes
46	Open ladder PVC Coating A	675	830	1140	11	60	None	0	72	15.75	No
47	Open ladder PVC Coating C	1700	1330	1400	7	5	11.5	43	96	57.75	Yes
					Bottom						
43	Same as top	485	1400	1430	10	60	None	0	36	6.25	
44	Same as top	1450	1580	1480	6	15	12.5	30.5	66	20.25	
45	Same as top	1400	1530	1550	11	20	12	42	66	24.75	
46	Same as top	1560	1470	1400	10	13	13	42	72	22.25	
47	Same as top	1610	1570	1550	3	10	11.5	37	84	45.25	

A test of coating C on IEEE-383 qualified cable in a full scale two-tray configuration appeared marginally below propagation, as reported in SAND78-0518. This test was repeated as test number 35 in this report and duplicated its performance. A 23.5 pound (10.7 kg) weight loss in the top tray indicates that although no flame resulted (therefore no propagation) there were products of pyrolysis driven off. This series of tests correlates with the previous series of tests, and both seem to be in agreement with the small scale tests performed on the coating materials. In addition, the fuel fires were reproducible among themselves and gave the same relative ranking of the cable coating materials as obtained with the propane fueled exposure fire. If one 5-minute cycle of the propane burners is thought of as a unit standard, then 2 gallons ($7.6 \times 10^{-3} m^3$) of diesel fuel in a 3 ft x 1.5 ft (0.91 m x 0.5 m) pan appears to be approximately equivalent to three such units in its effect on a cable tray.

TABLE VIII

Fire Retardant Coating Tests
Ranking of Resistance to Combustion (Relative)
(Lowest Numerical Value Provides Most Resistance)

Coating	Small Scale	Single-Tray Tests	Full-Scale Two-Tray Tests Propane Fueled	Full-Scale Two-Tray Tests Diesel Fuel Fire
A	4	5	4	3
B	-	4	3	2
C	5	6	6	5
D	1	1	1	-
E	2	2	2	1
F	6	-	-	-
G	3	3	5	4
Uncoated 383 cable	7	7	7	-
Uncoated per 383 cable	-	8	8	-

References

1. IEEE Standard for Type Test of Class IE Electric Cables, Field Splices, and Connections for Nuclear Power Generating Stations, Std. 383-1974.

2. US Atomic Commission Regulatory Guide 1.75, Physical Independence of Electric Systems, February 1974.

3. L. J. Klamerus and R. H. Nilson, "Cable Tray Fire Tests," SAND77-1125 C, July 1977.

4. L. J. Klamerus, "A Preliminary Report on Fire Protection Research Program (July 6, 1977 Test)," SAND77-1424, October 1977.

5. L. J. Klamerus, "A Preliminary Report on Fire Protection Research Program Fire Retardant Coatings Tests (December 7, 1977 - January 31, 1978)," SAND78-0518, March 1978.

APPENDIX A

TABLE A-I

Heat Release Data--Coating G, Single-Conductor, Small Scale Test

Cable Size: Small

Coating: G

Radiant Heat Flux: 4.0 W/cm^2

	Units	
Time to Ignition	Sec	450
Maximum Heat Release Rate	kW/m^2	90
Time to Maximum Heat Release	Sec	844
Cumulative Heat Release	MJ/m^2	
5 minutes		9.0
10 minutes		22.2
15 minutes		44.9
20 minutes		55.7
25 minutes		64.4
30 minutes		72.0

TABLE A-II

Heat Release Data--Coating G, Three-Conductor, Small Scale Test

Cable Size: Large

Coating: G

Radiant Heat Flux: 4.0 W/cm^2

	Units	
Time to Ignition	Sec	1050
Maximum Heat Release Rate	kW/m^2	166
Time to Maximum Heat Release	Sec	1785
Cumulative Heat Release	MJ/m^2	
5 minutes		9.4
10 minutes		20.8
15 minutes		30.0
20 minutes		40.1
25 minutes		60.9
30 minutes		99.4

APPENDIX B

Temperature and Voltage Versus Time Plots for Test 22 (3-Conductor PE/PVC Non-qualified Cable, Single-Tray Test, Open Ladder Tray, Ceramic Wool Blanket on Top of Tray)

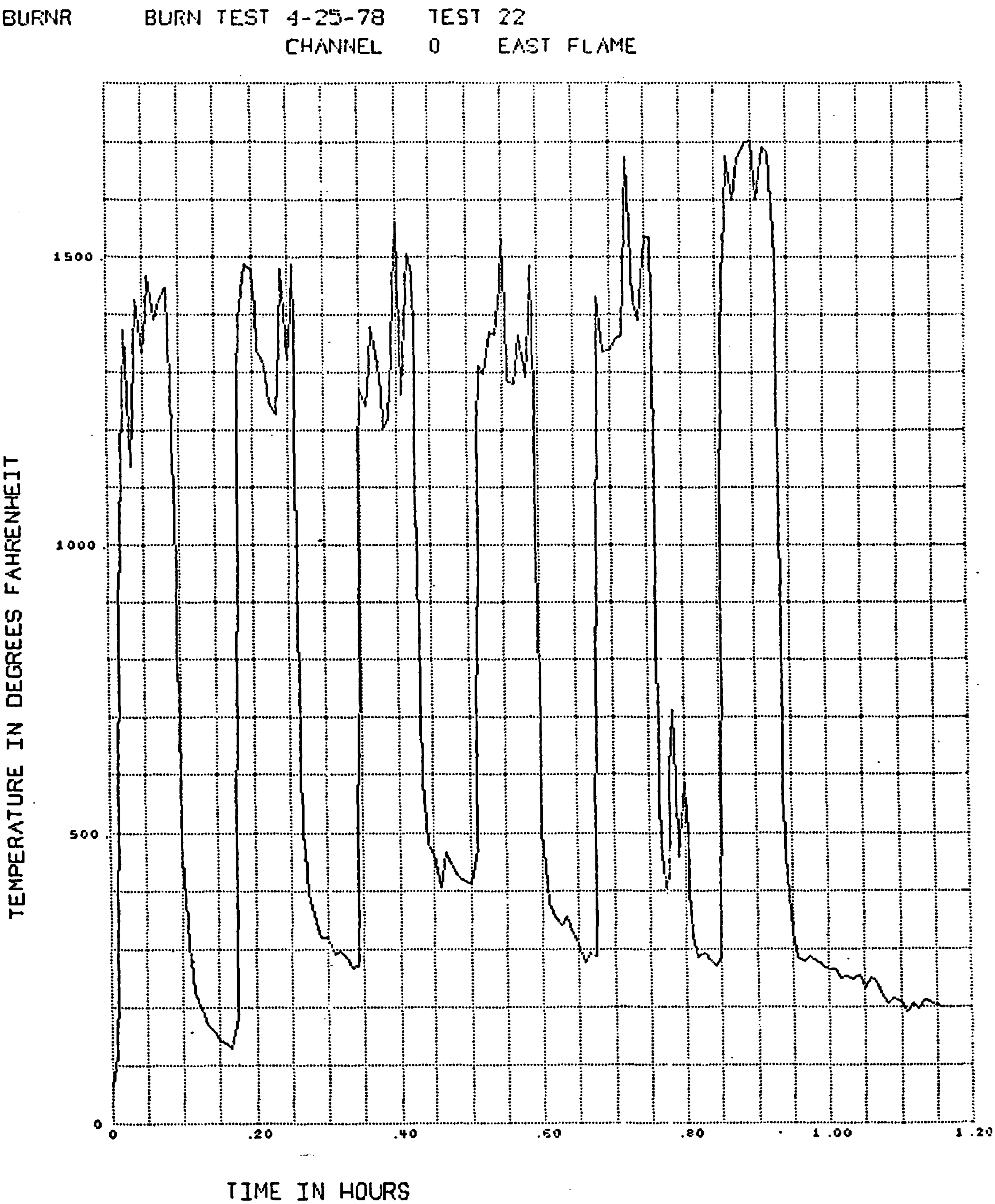

Figure B-1. Thermocouple No. 0 in Burner Flame

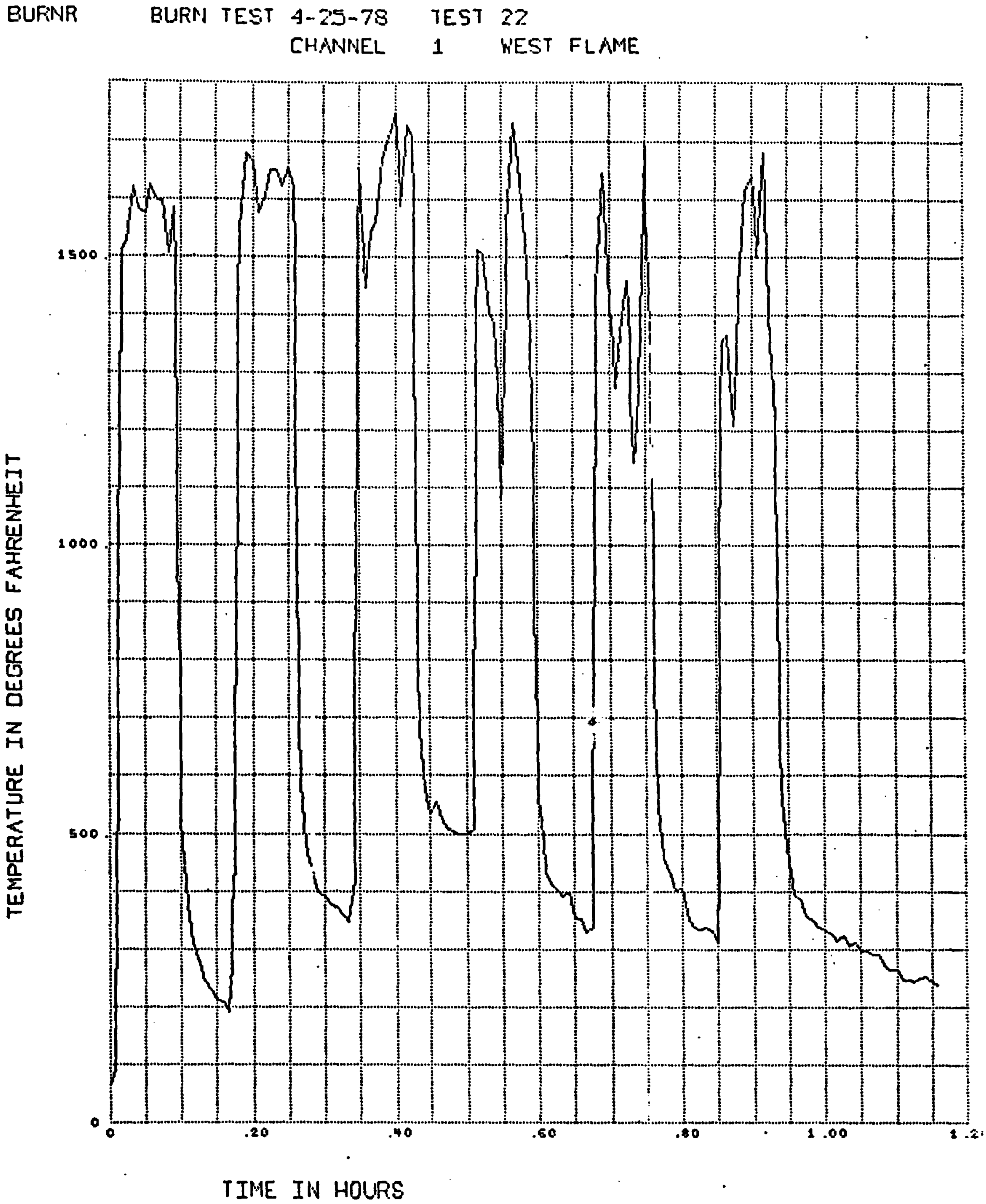

Figure B-2. Thermocouple No. 1 in Burner Flame

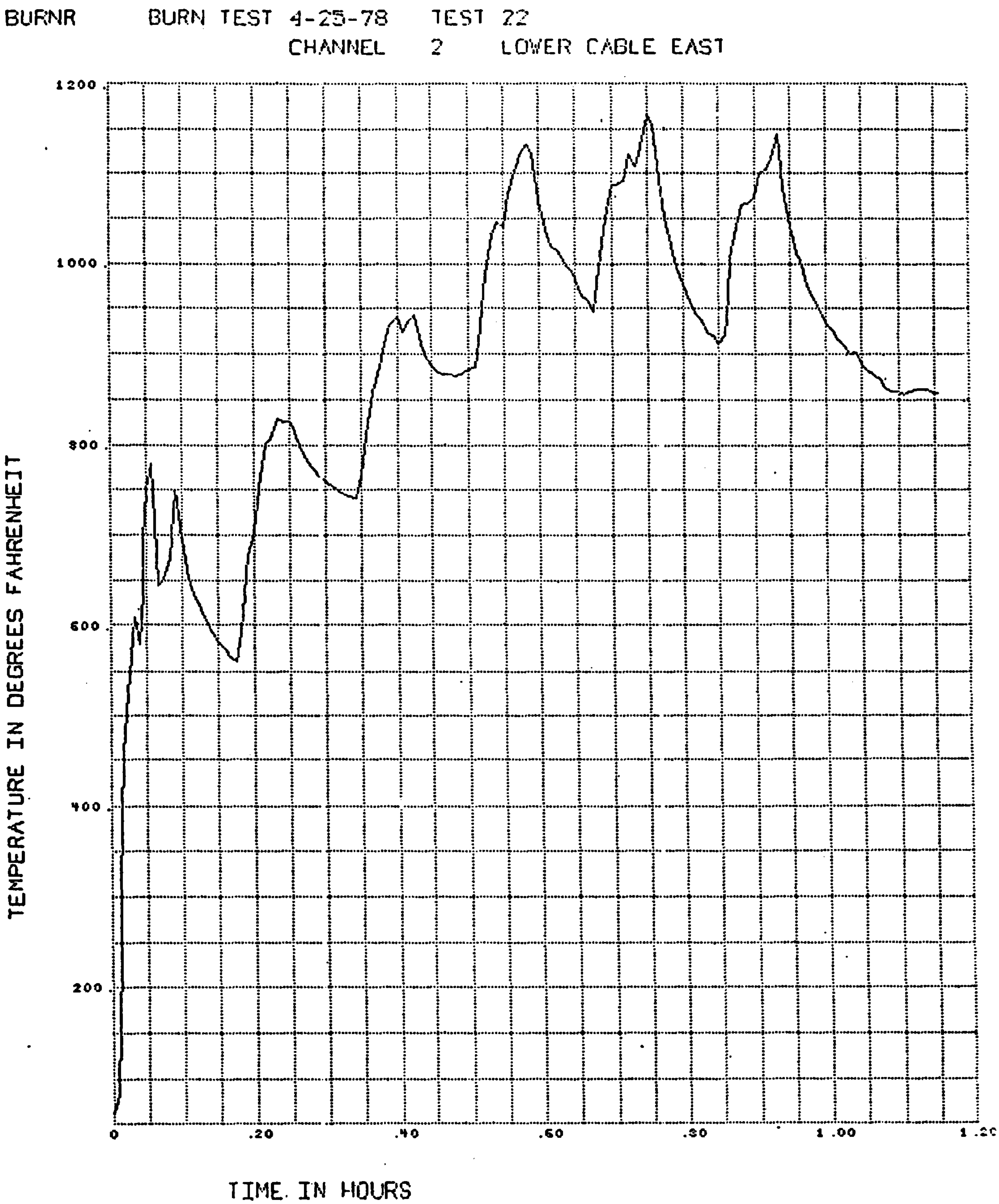

Figure B-3. Thermocouple No. 2 in Cable Bundle

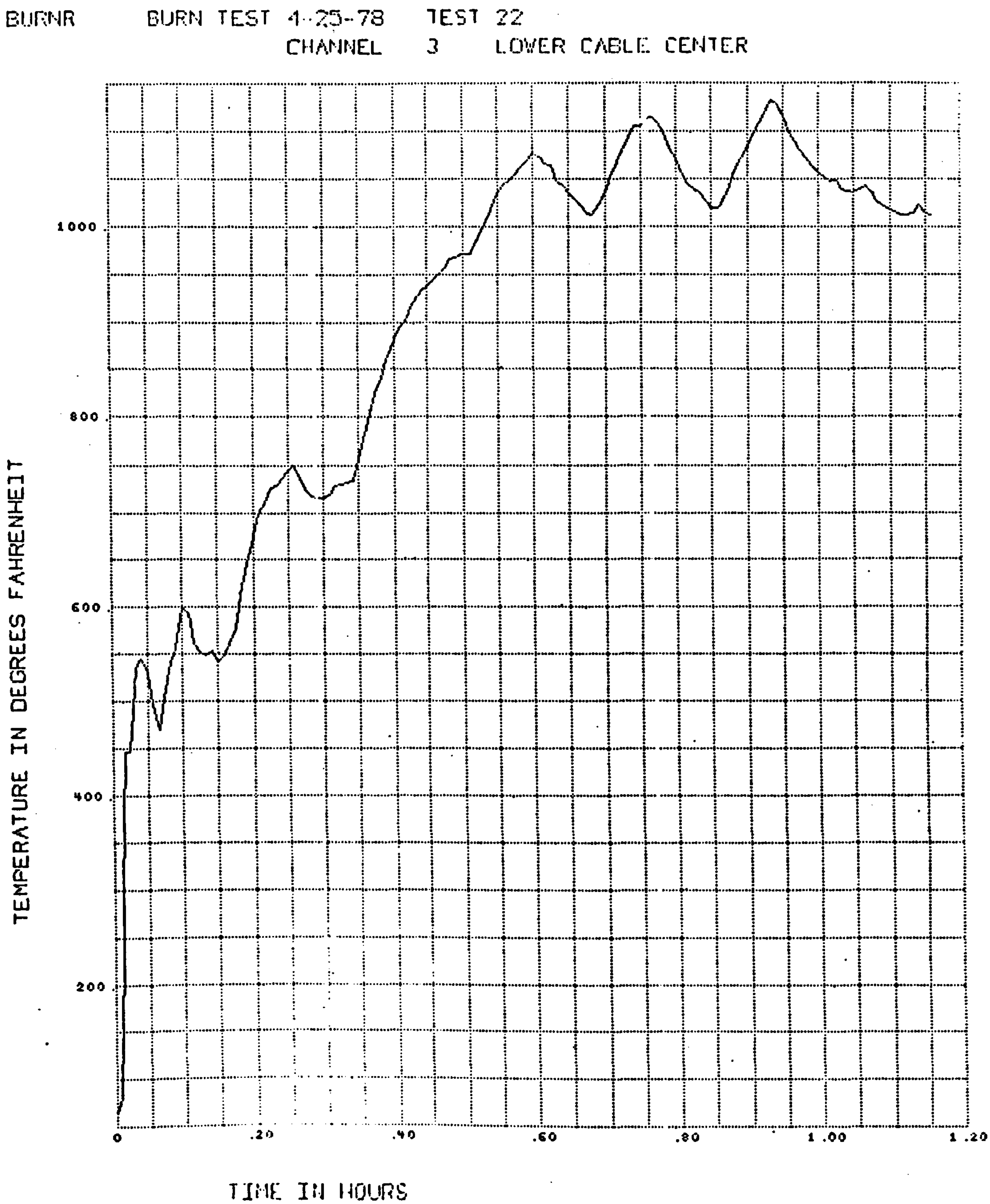

Figure B-4. Thermocouple No. 3 in Cable Bundle

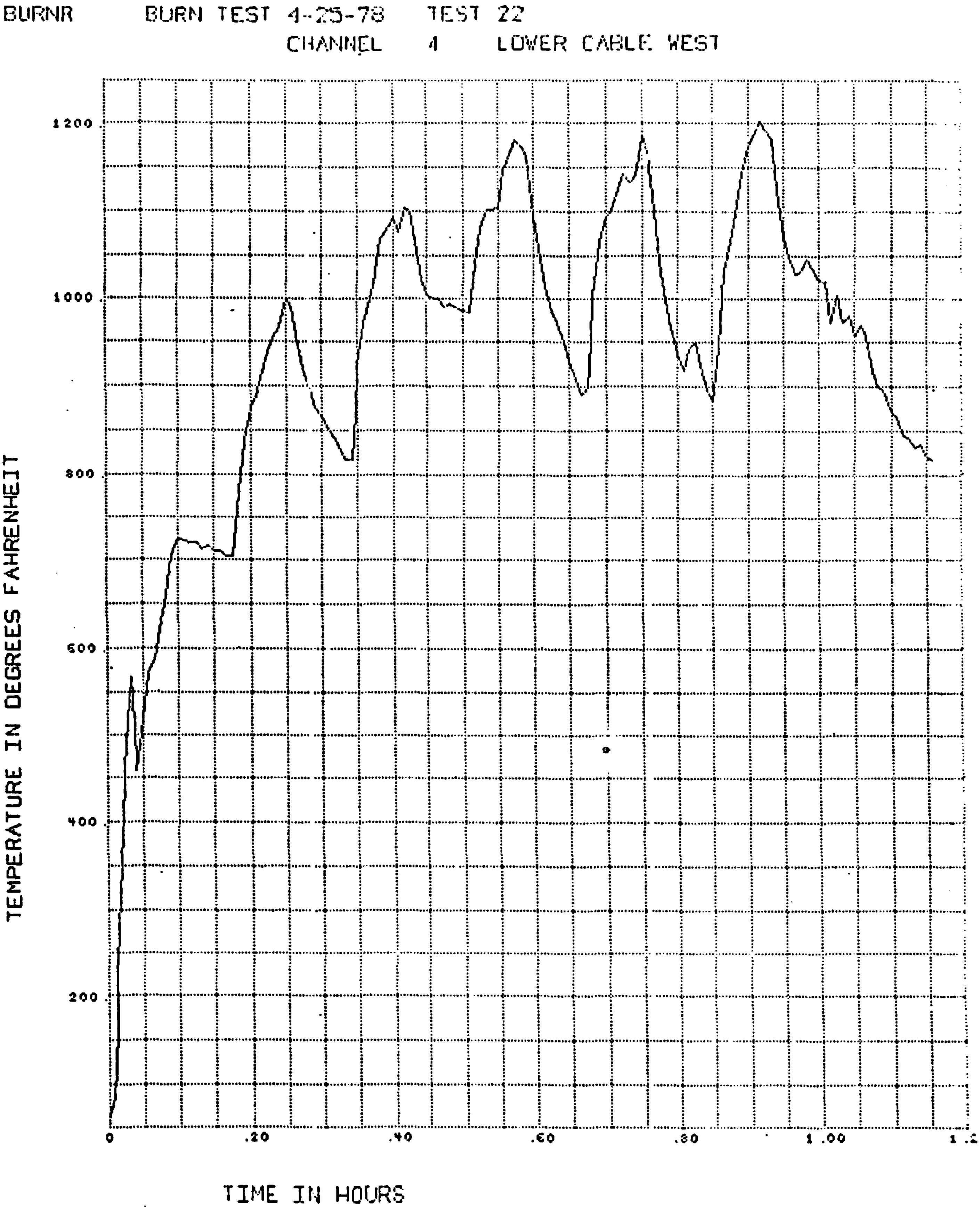

Figure B-5. Thermocouple No. 4 in Cable Bundle

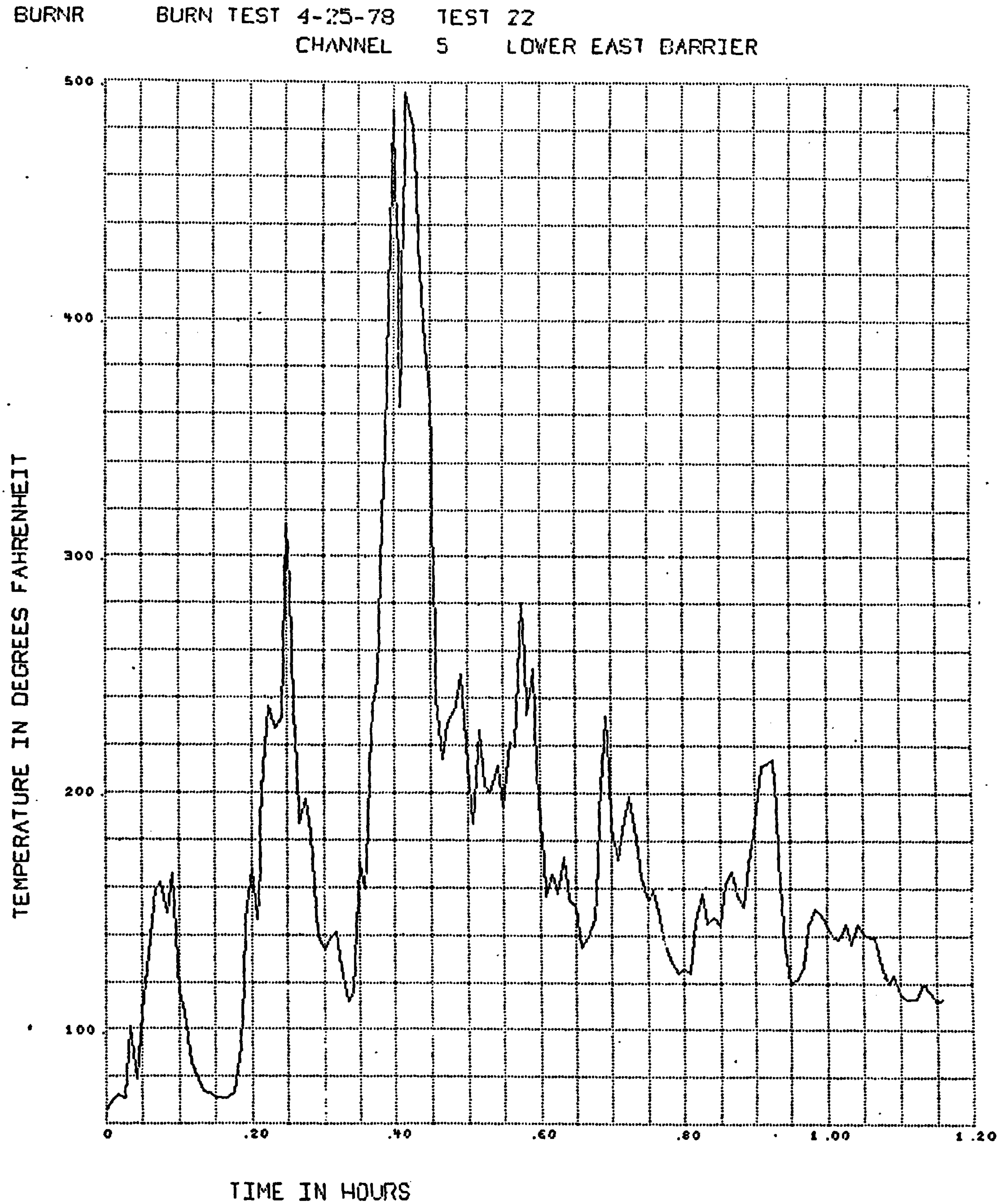

Figure B-6. Thermocouple No. 5 at Barrier Over Cable Tray

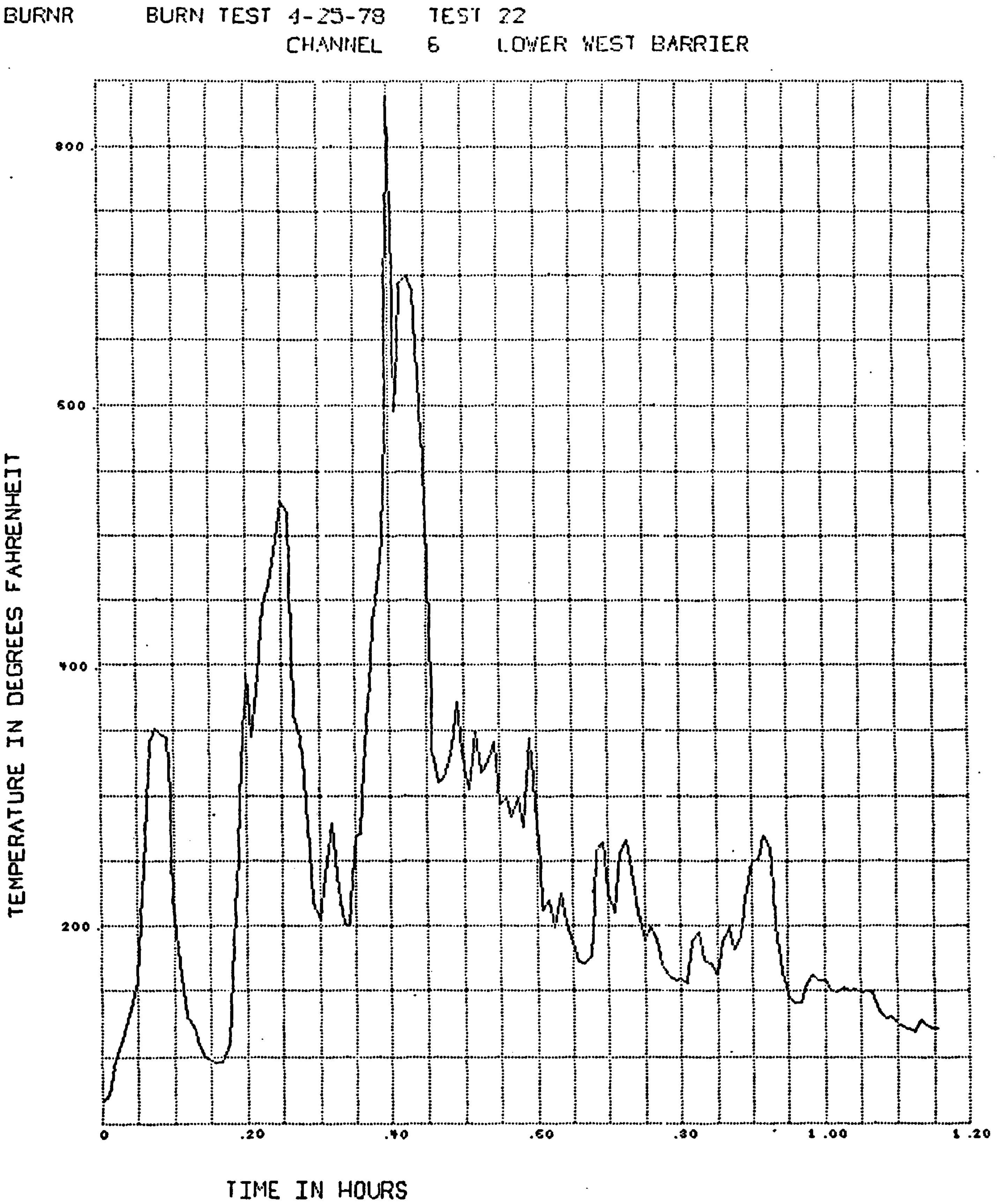

Figure B-7. Thermocouple No. 6 at Barrier Over Cable Tray

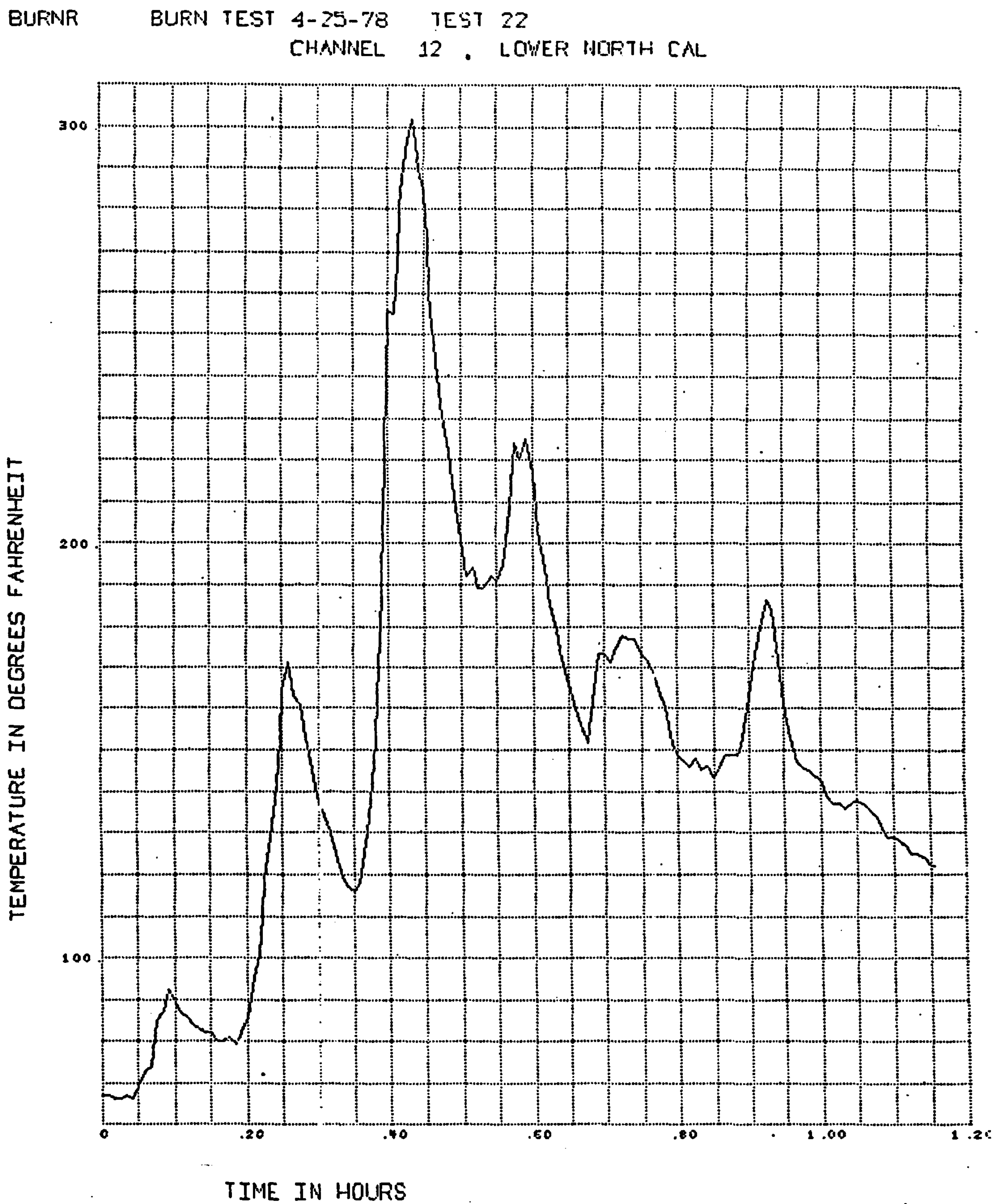

Figure B-8. Calorimeter No. 12, 3.75 inches (9.5 cm) Over Cables

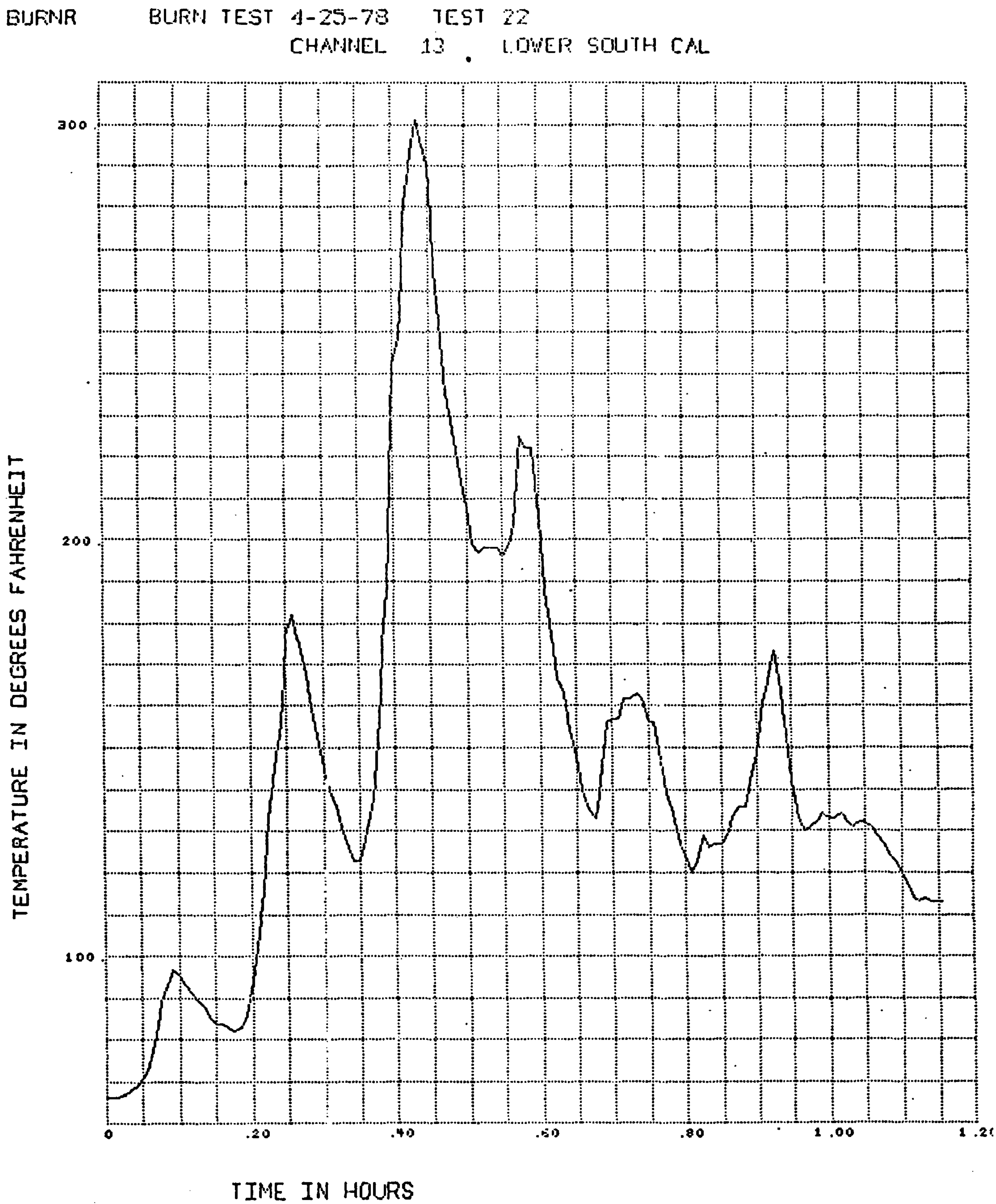

Figure B-9. Calorimeter No. 13, 3.75 inches (9.5 cm) Over Cables

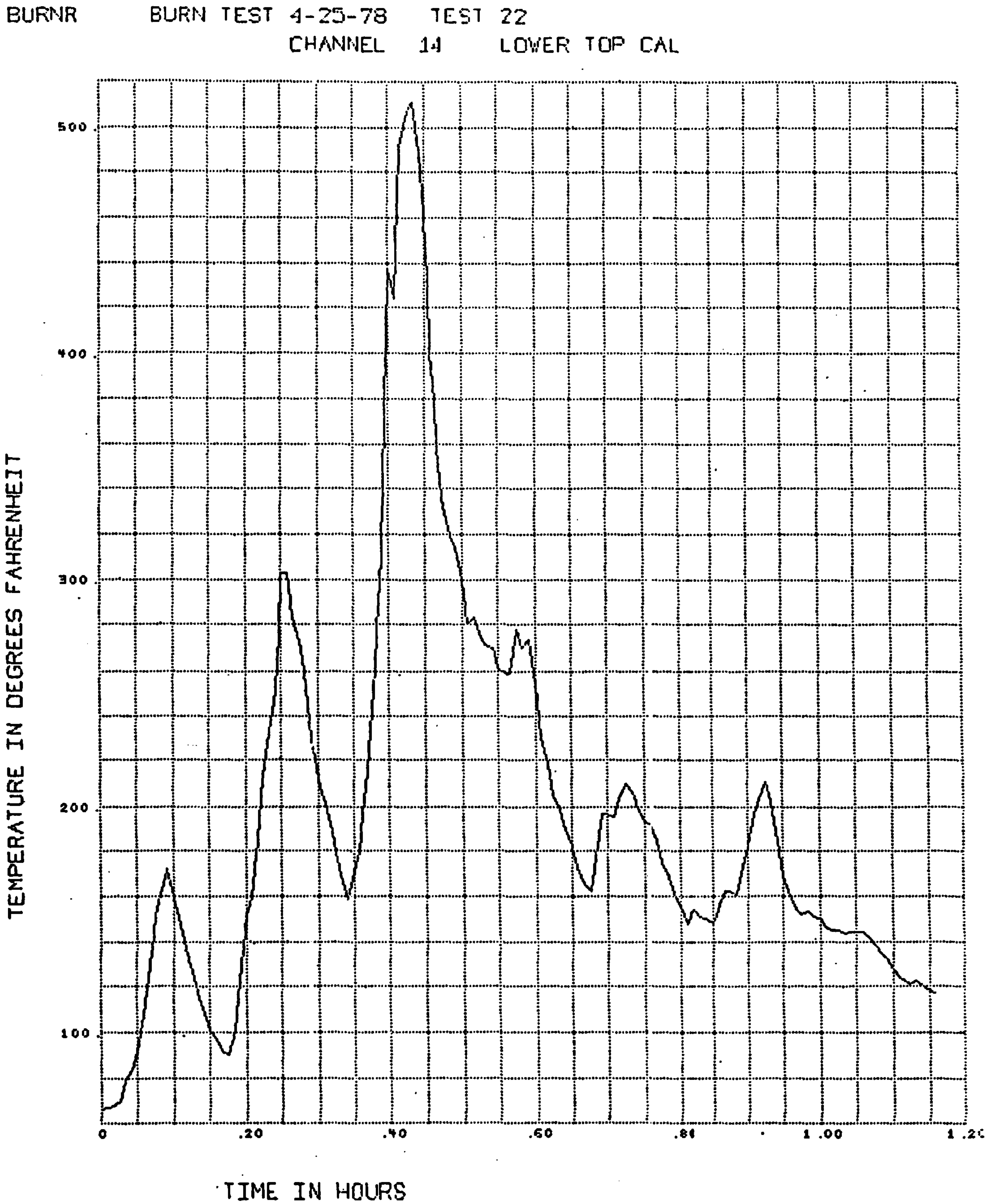

Figure B-10. Calorimeter No. 14, 8.0 inches (20.3 cm) Over Cables

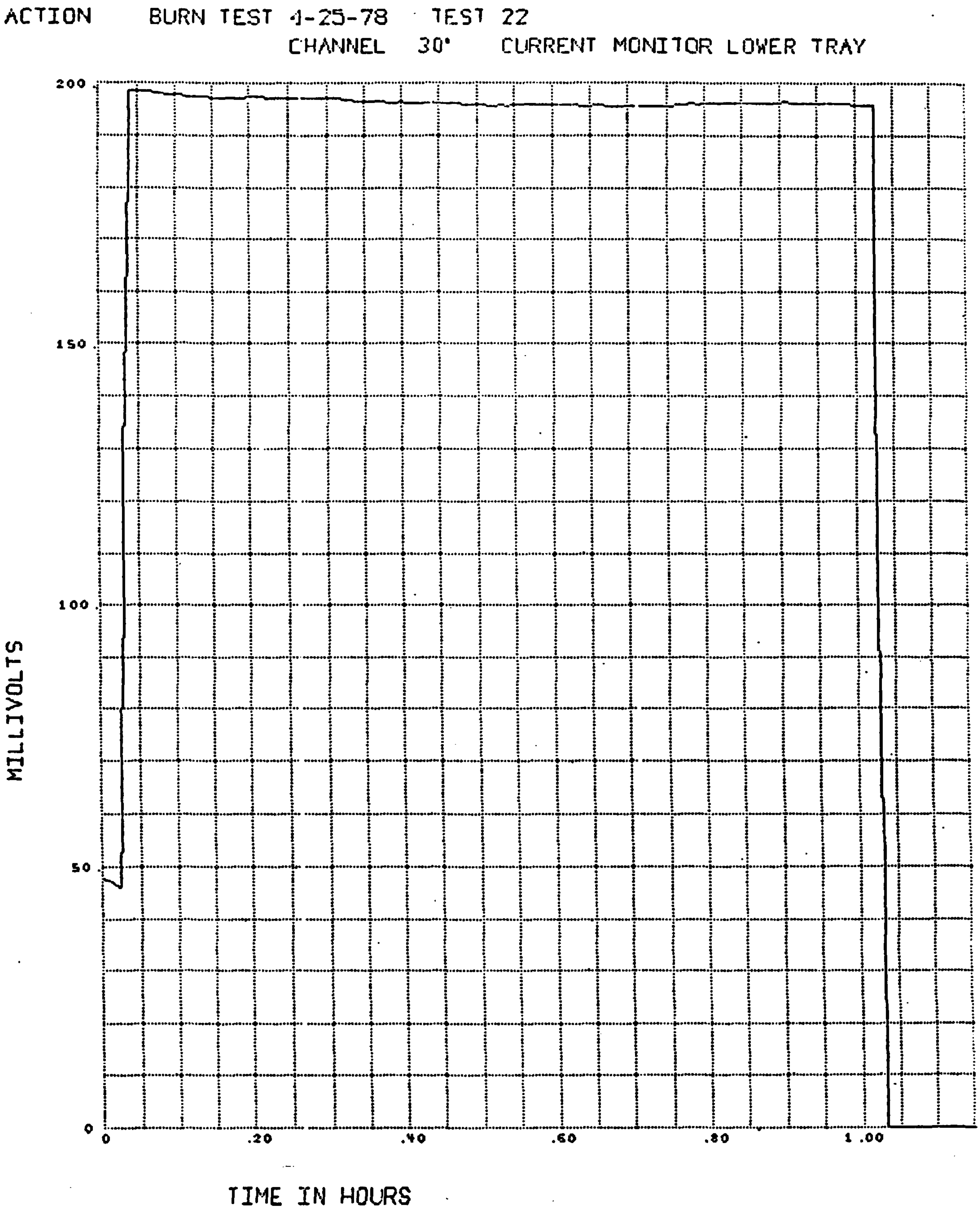

Figure B-11. Current Monitor During Test

APPENDIX C

Temperature and Voltage Versus Time Plots for Test 44 (Diesel Fuel Exposure Fire, 3-Conductor PE/PVC Non-qualified Cable, Two-Tray Test, Open Ladder Tray, Coating B)

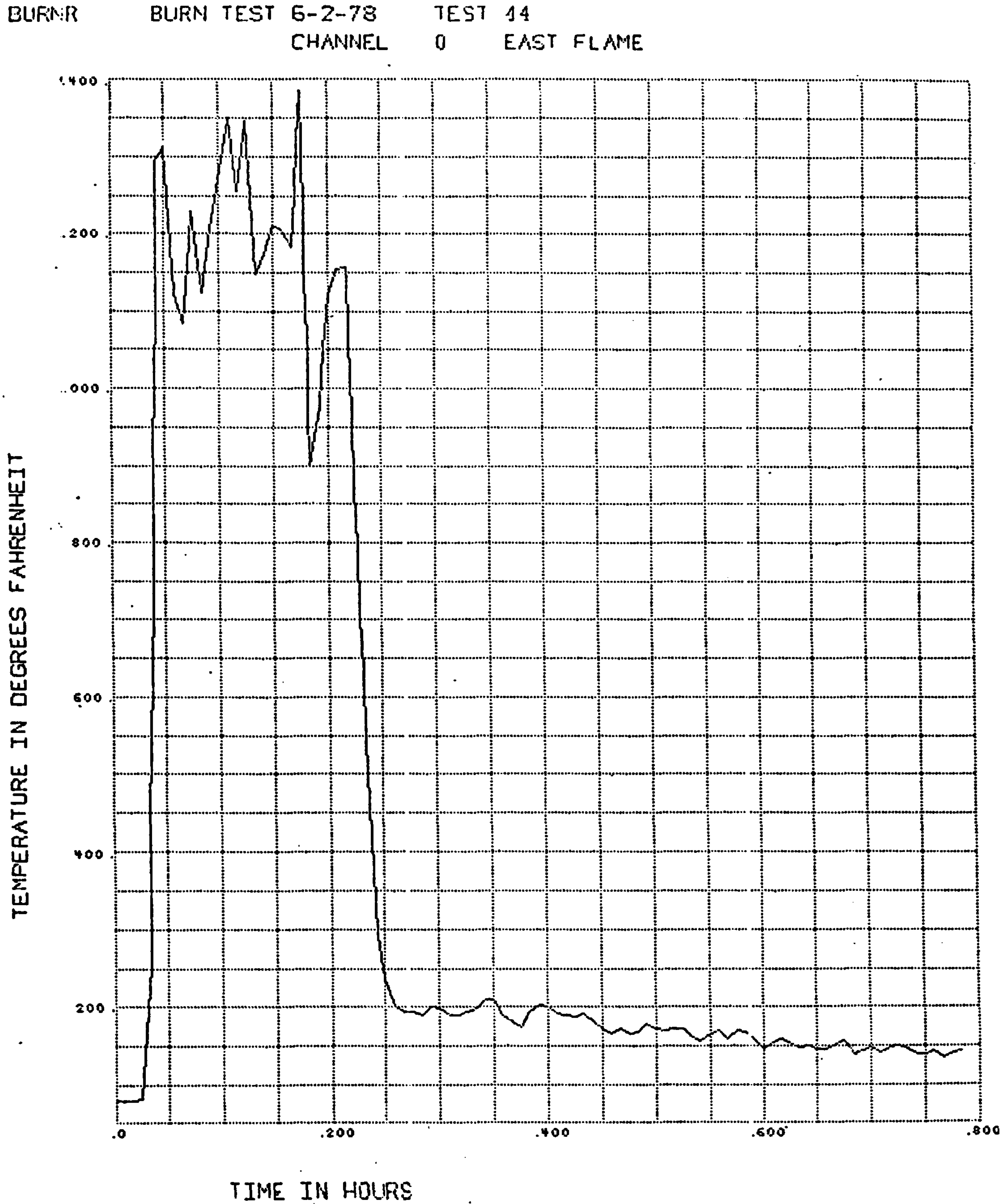

Figure C-1. Thermocouple No. 0, One inch (2.54 cm) Above Fuel, Lower Tray

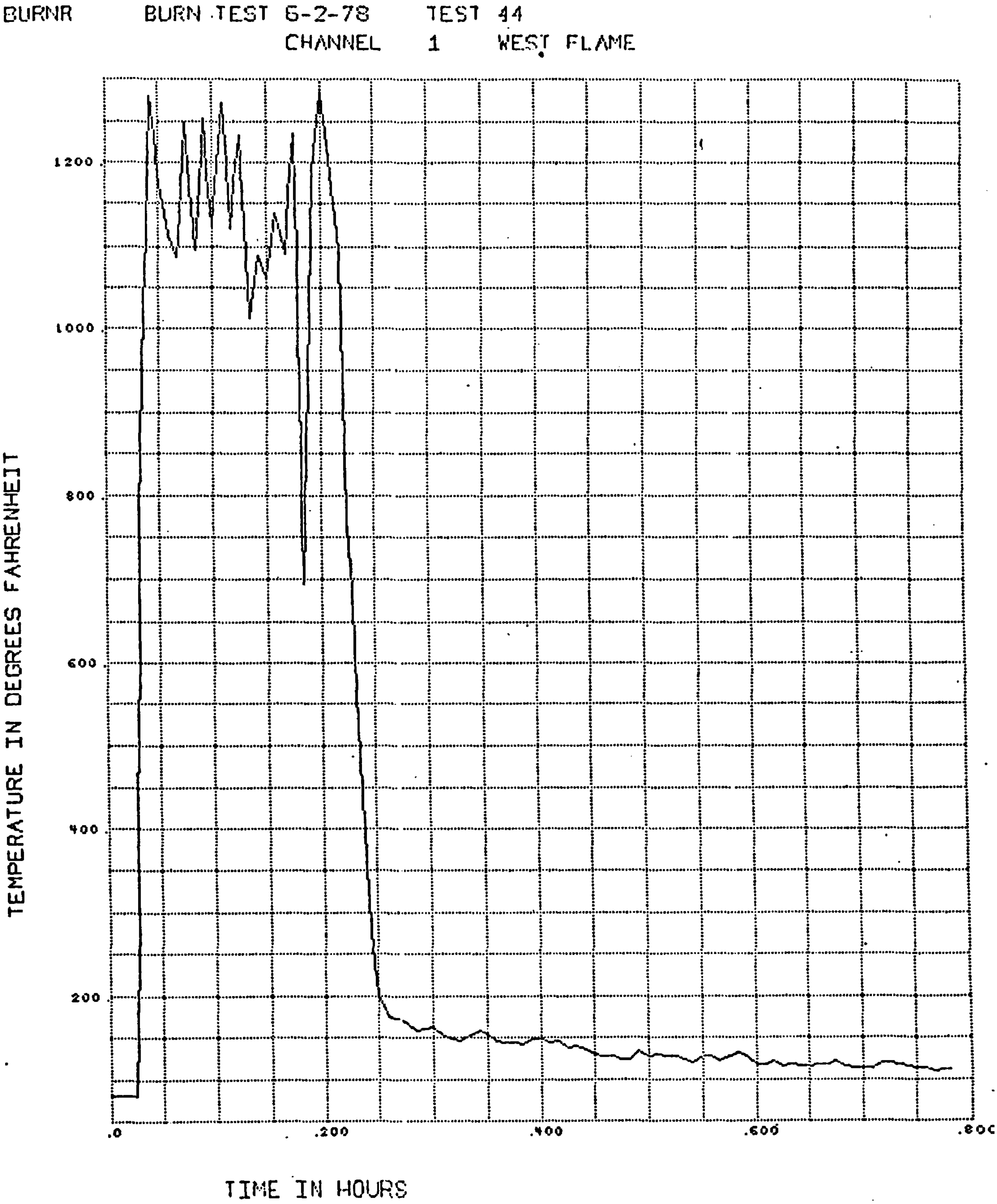

Figure C-2. Thermocouple No. 1, One inch (2.54 cm) Above Fuel, Lower Tray

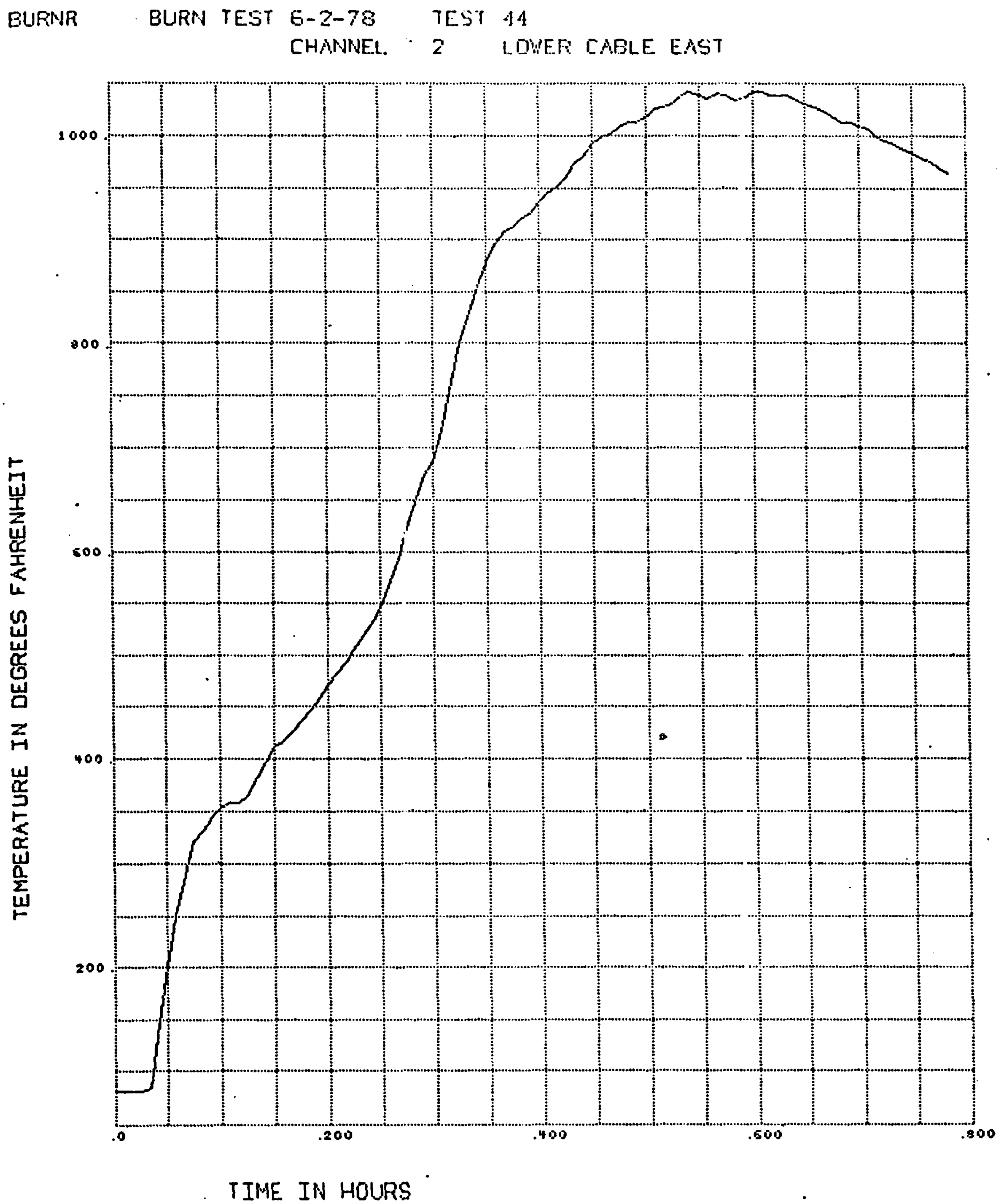

Figure C-3. Thermocouple No. 2 in Cable Bundle, Lower Tray

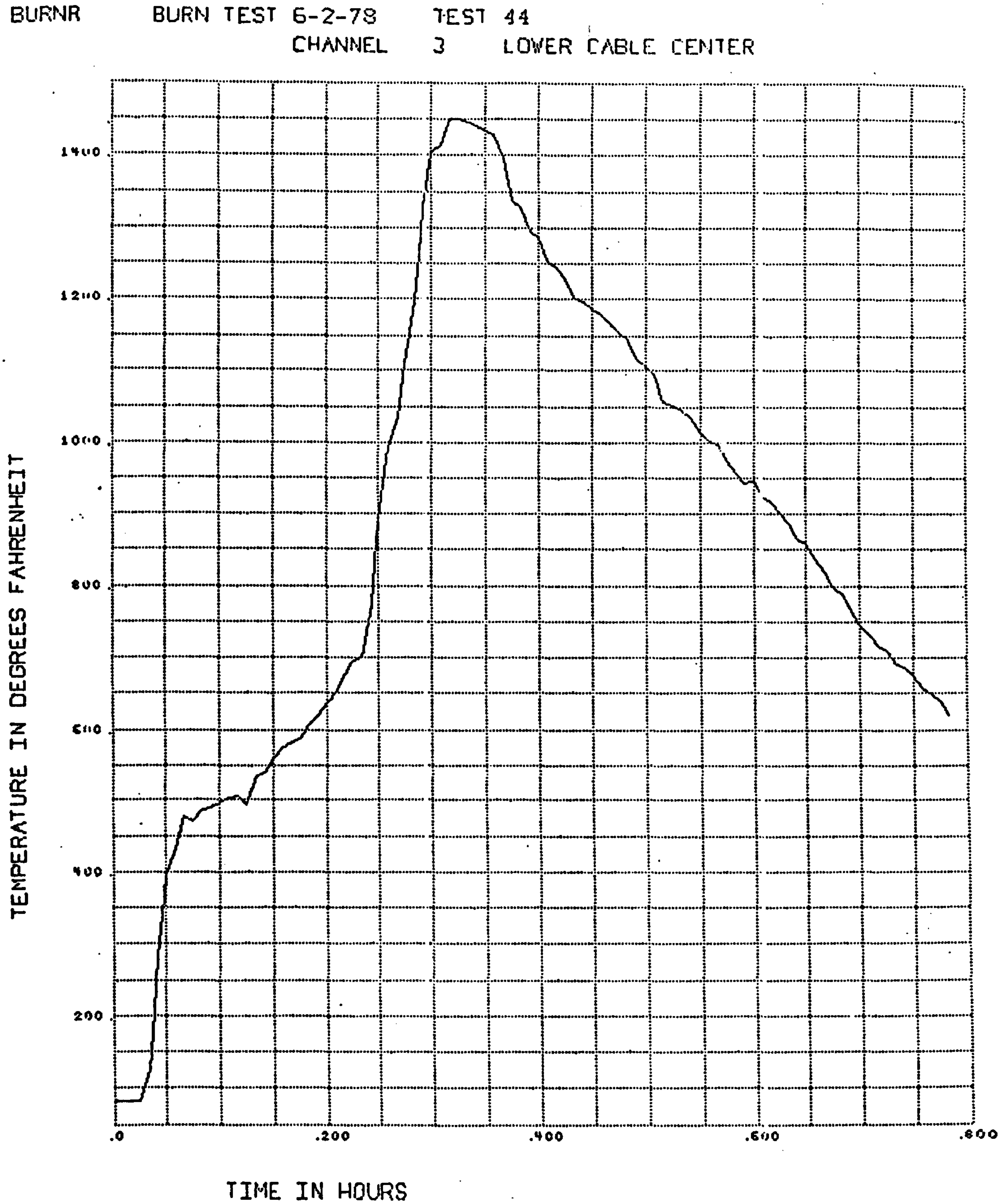

Figure C-4. Thermocouple No. 3 in Cable Bundle, Lower Tray

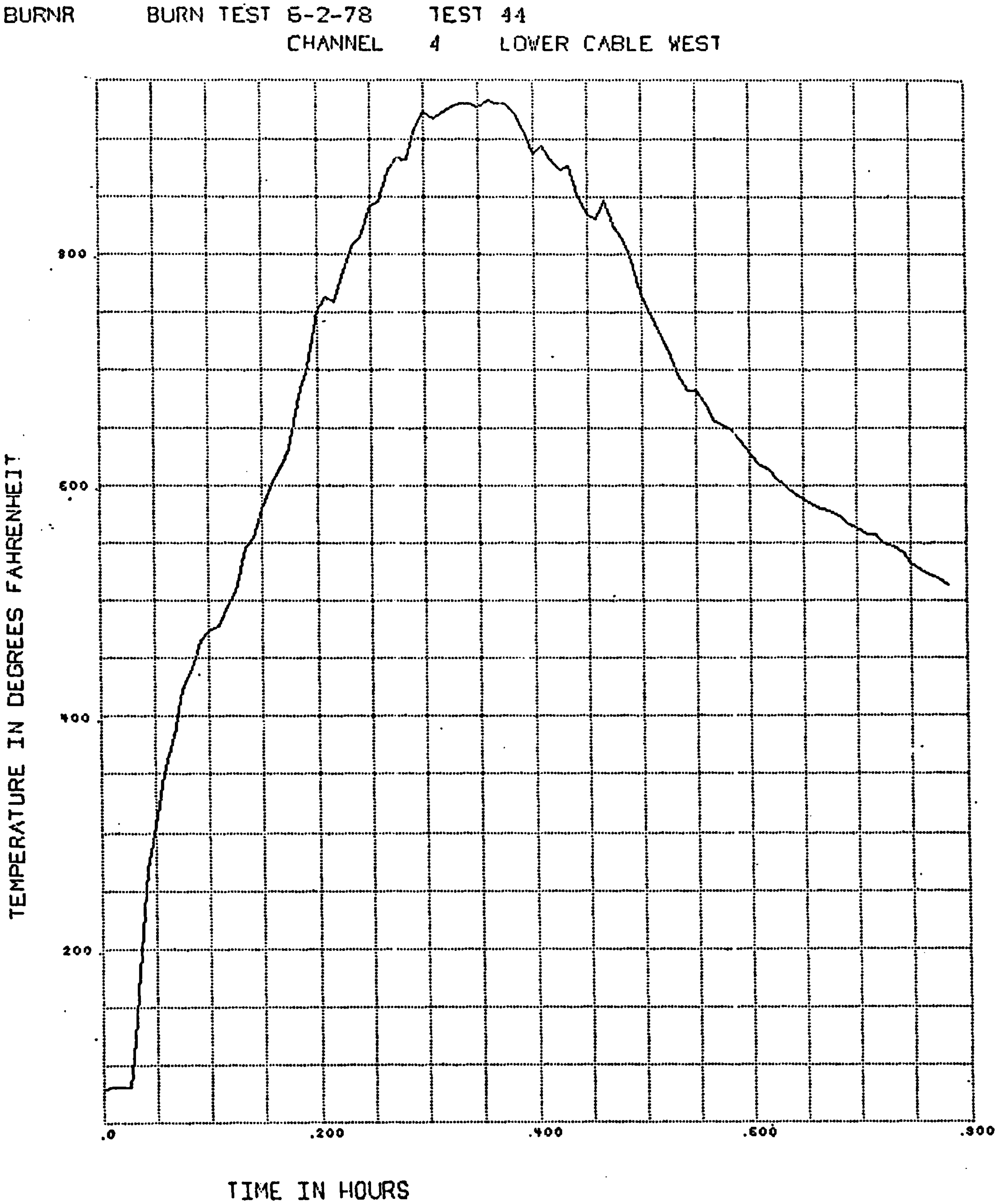

Figure C-5. Thermocouple No. 4 in Cable Bundle, Lower Tray

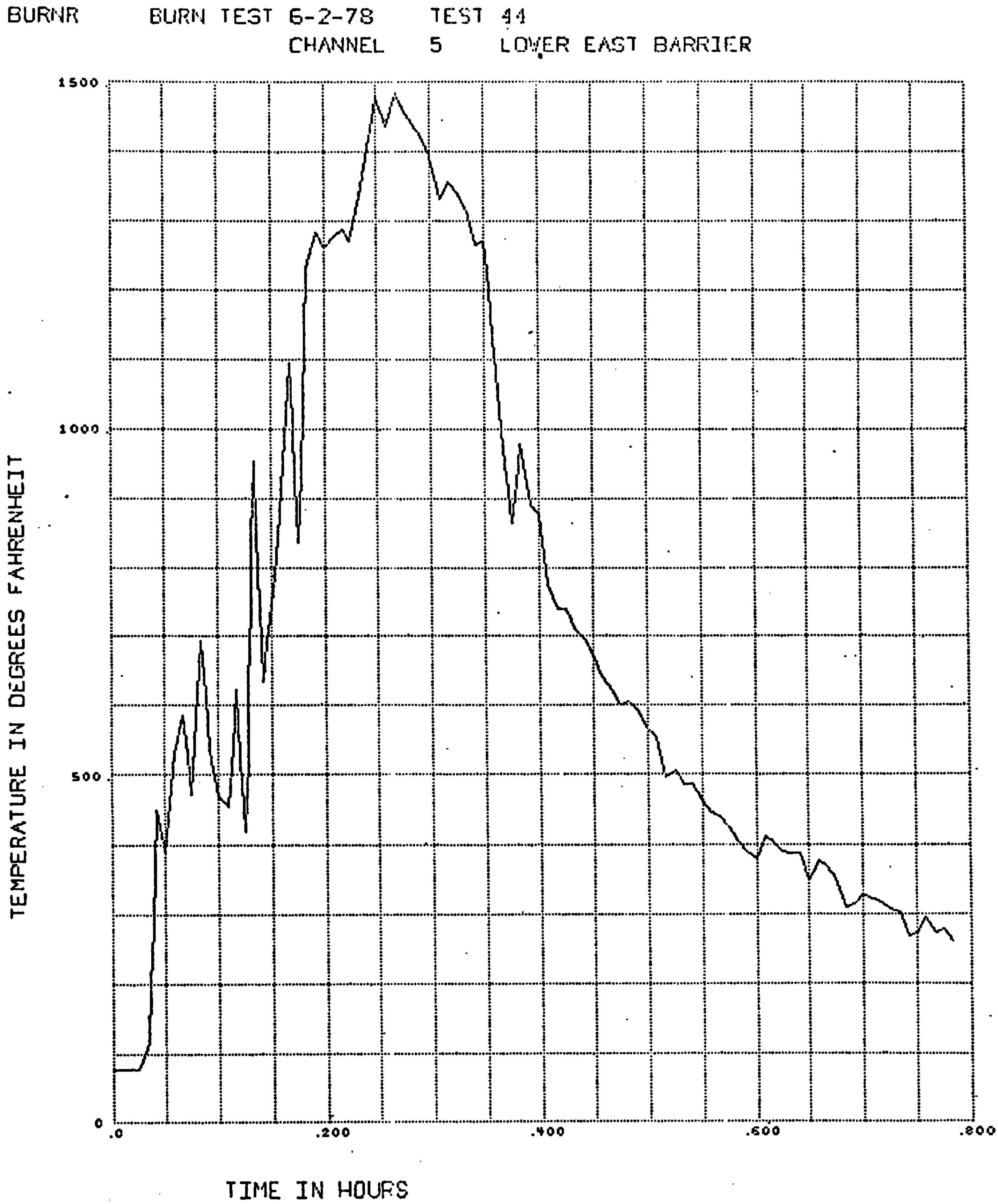

Figure C-6. Thermocouple No. 5 at Barrier Over Lower Tray

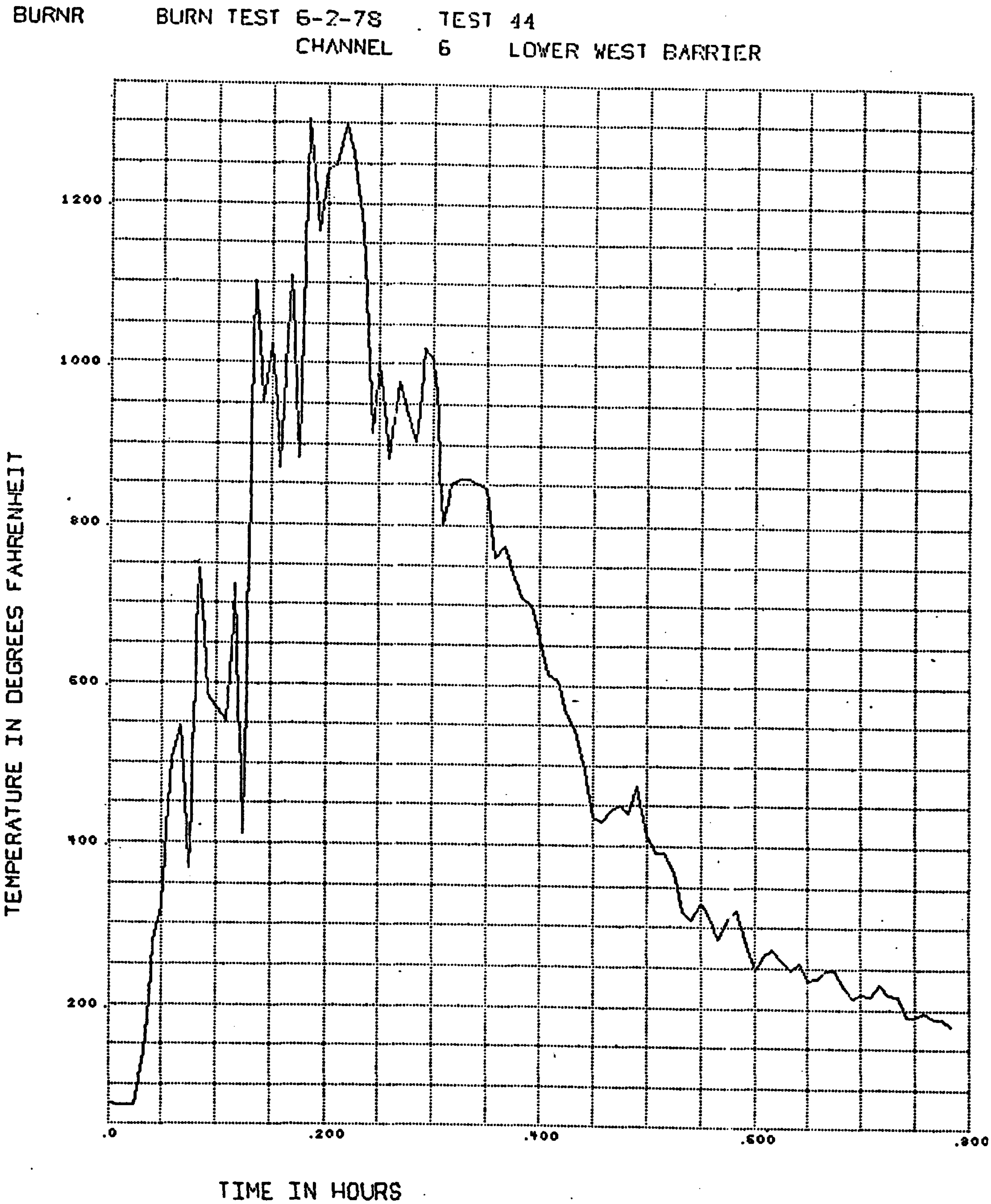

Figure C-7. Thermocouple No. 6 at Barrier Over Lower Tray

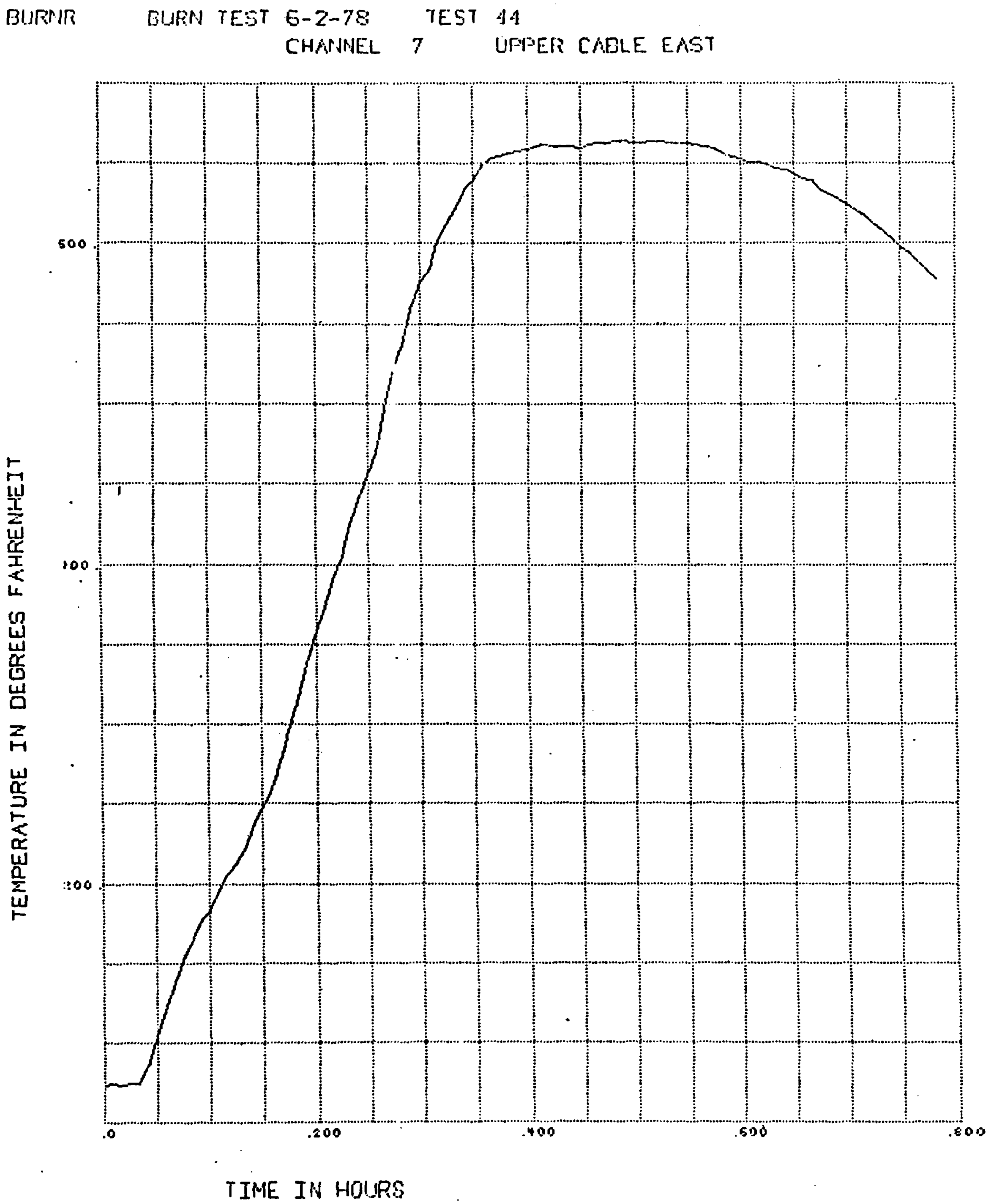

Figure C-8. Thermocouple No. 7 in Cable Bundle, Upper Tray

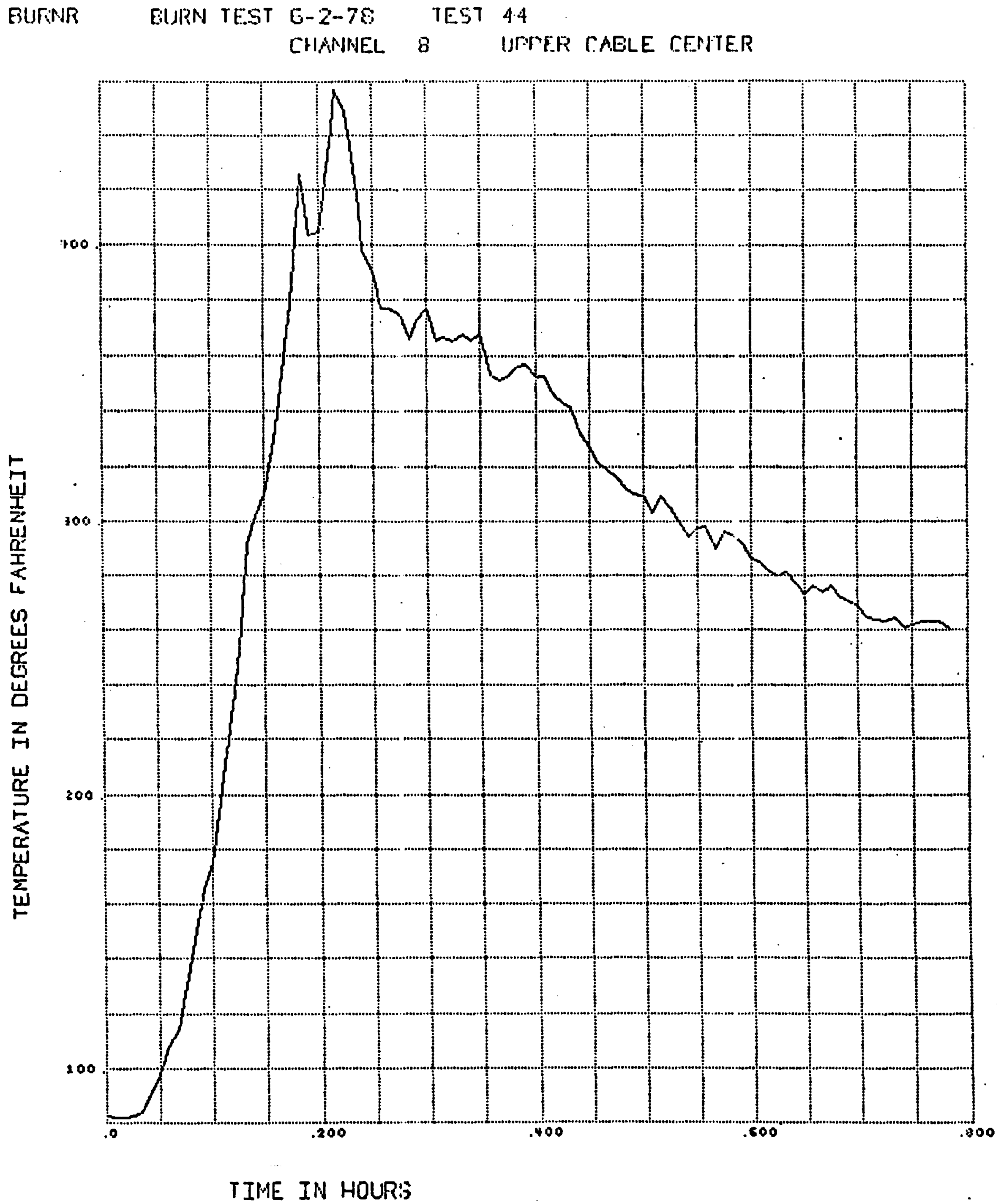

Figure C-9. Thermocouple No. 8 in Cable Bundle, Upper Tray

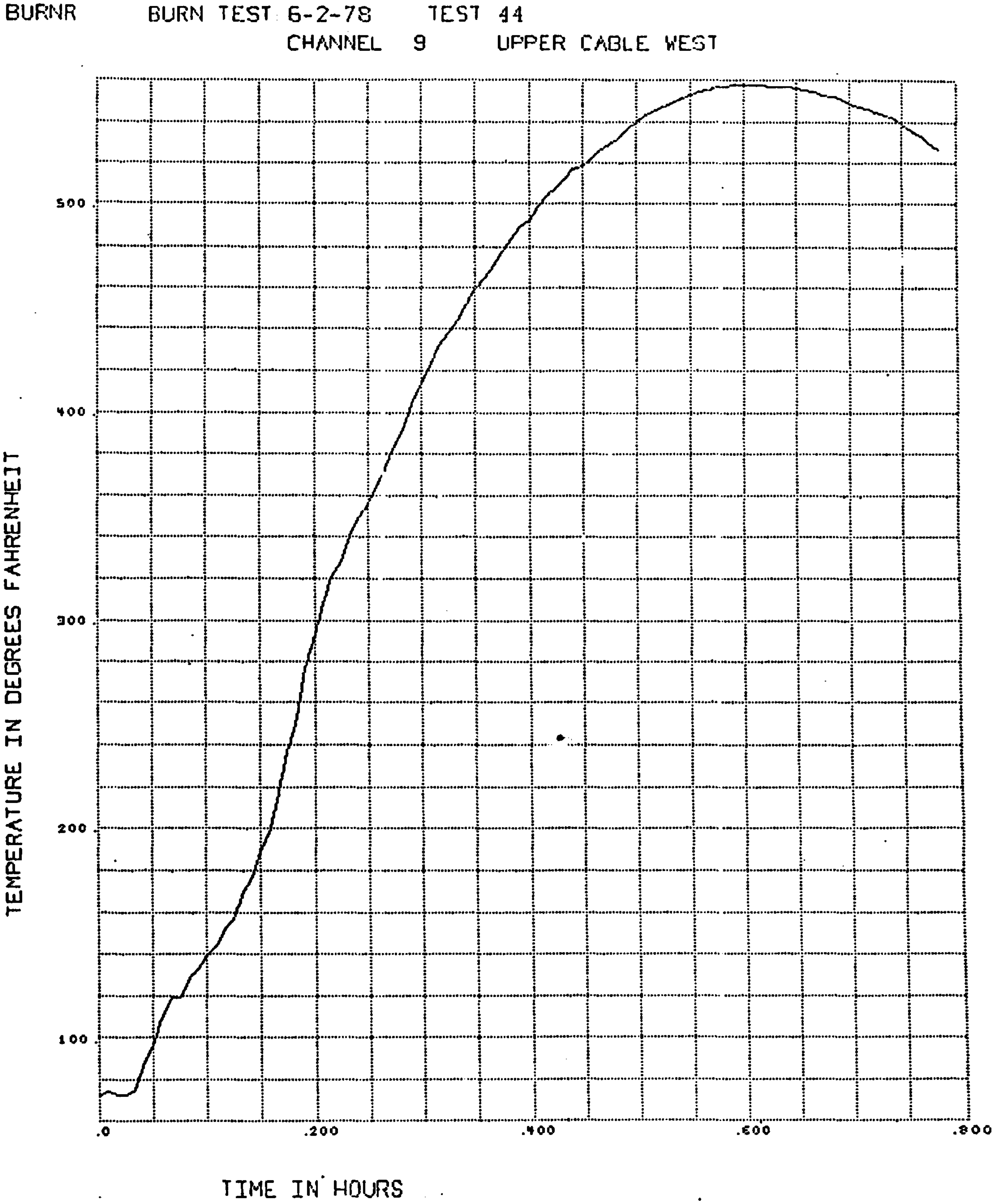

Figure C-10. Thermocouple No. 9 in Cable Bundle, Upper Tray

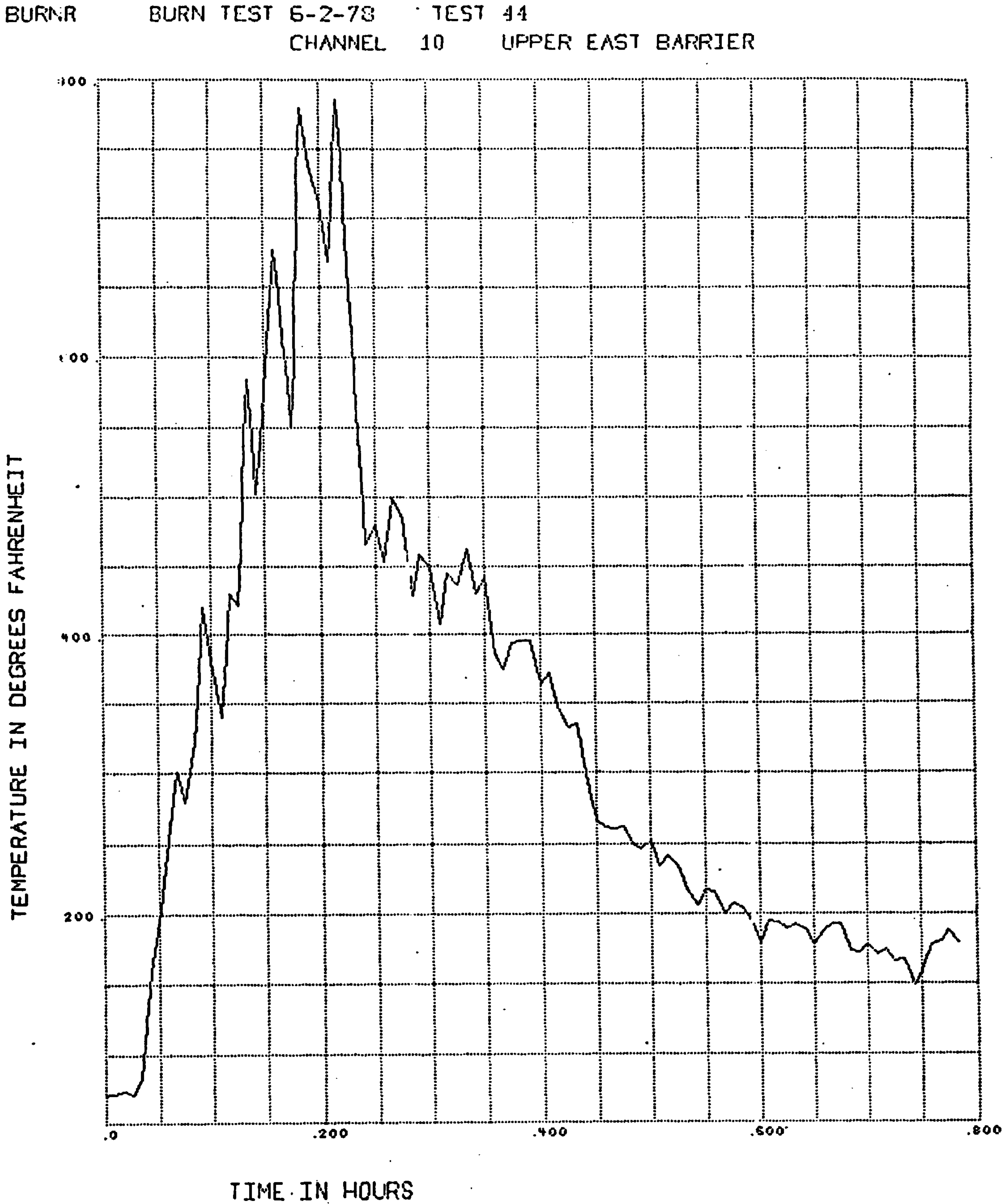

Figure C-11. Thermocouple No. 10 at Barrier Over Upper Tray

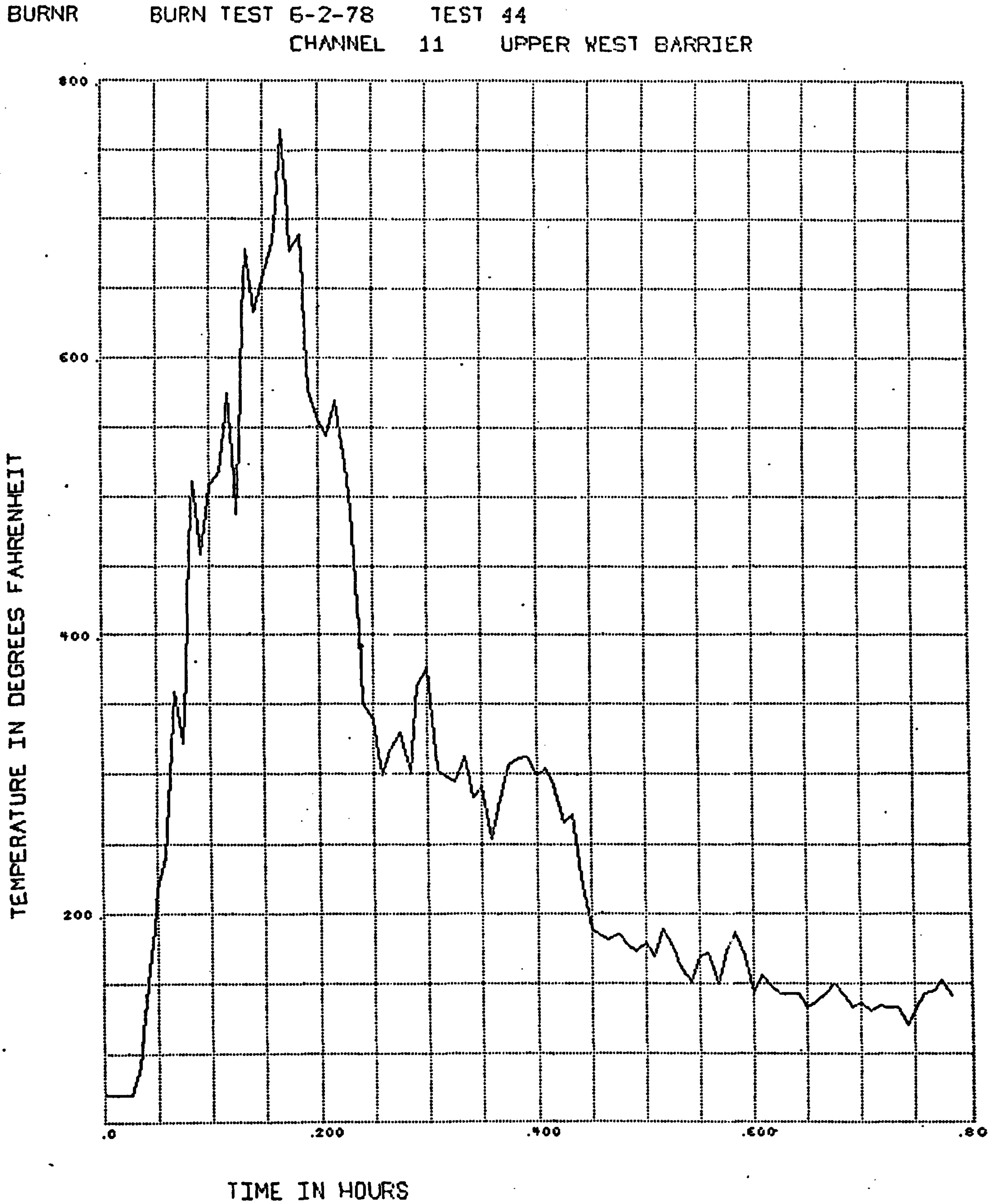

Figure C-12. Thermocouple No. 11 at Barrier Over Upper Tray

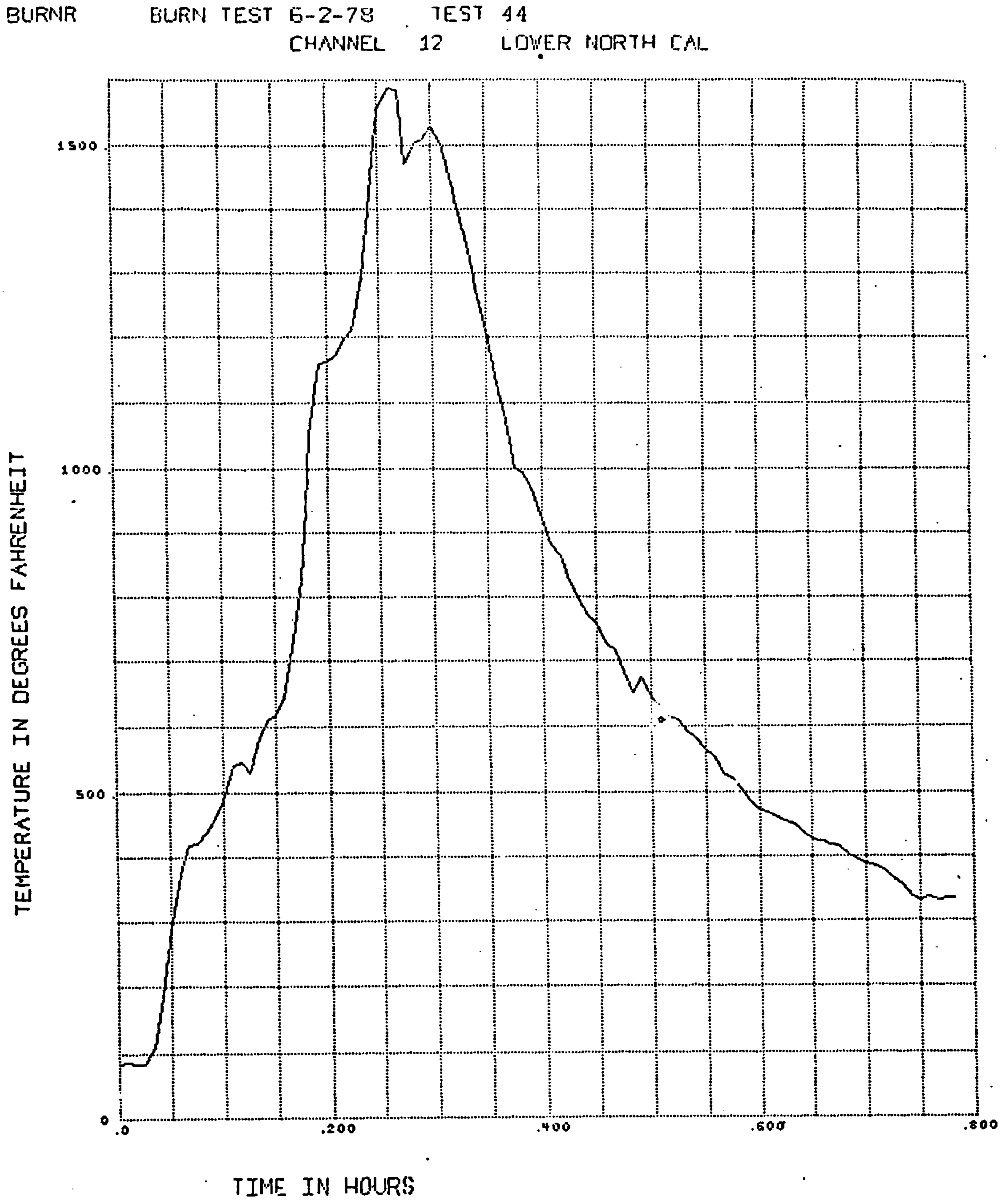

Figure C-13. Calorimeter No. 12, 3.75 inches (9.5 cm) Over Cables Lower Tray

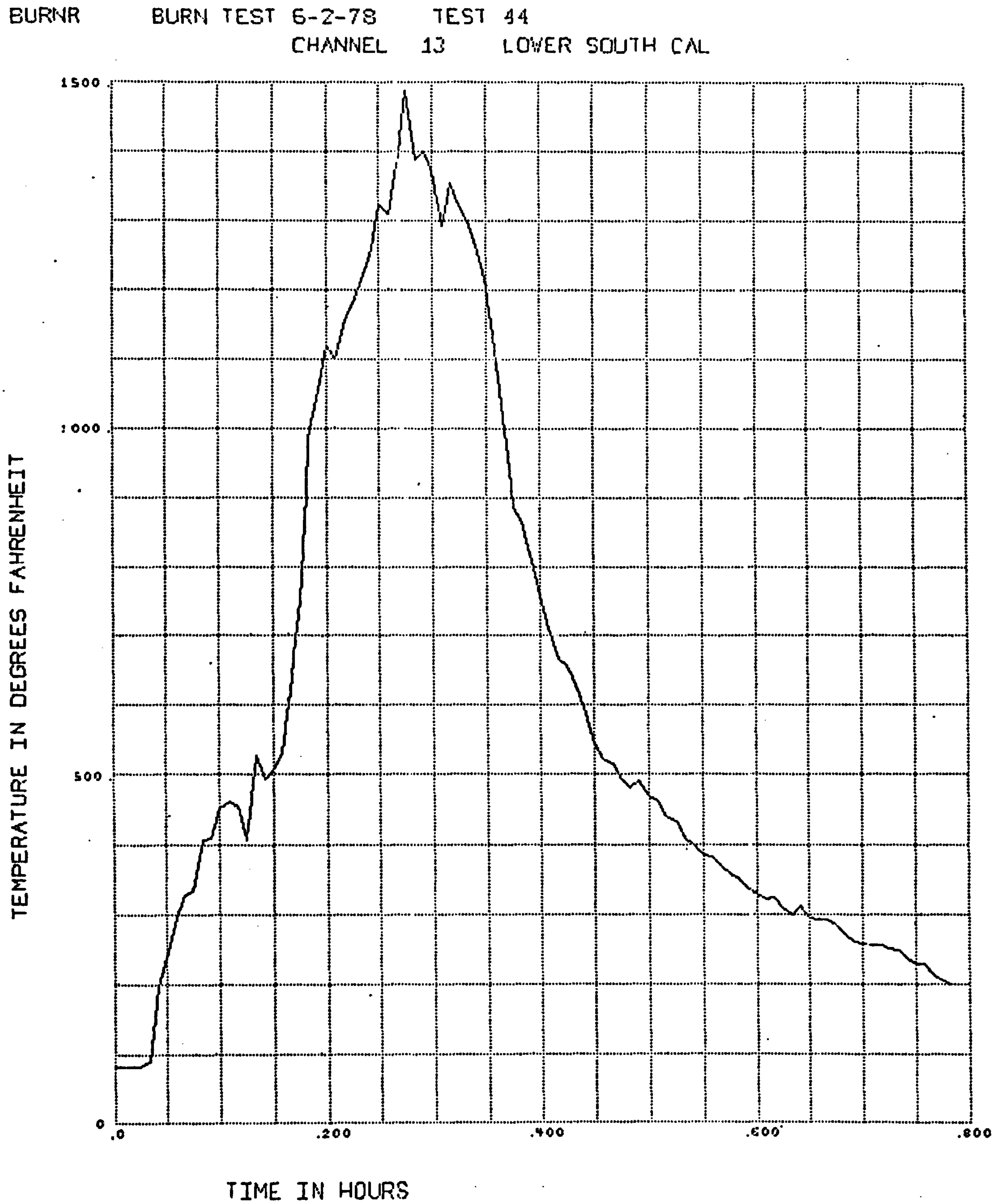

Figure C-14. Calorimeter No. 13, 3.75 inches (9.5 cm) Over Cables Lower Tray

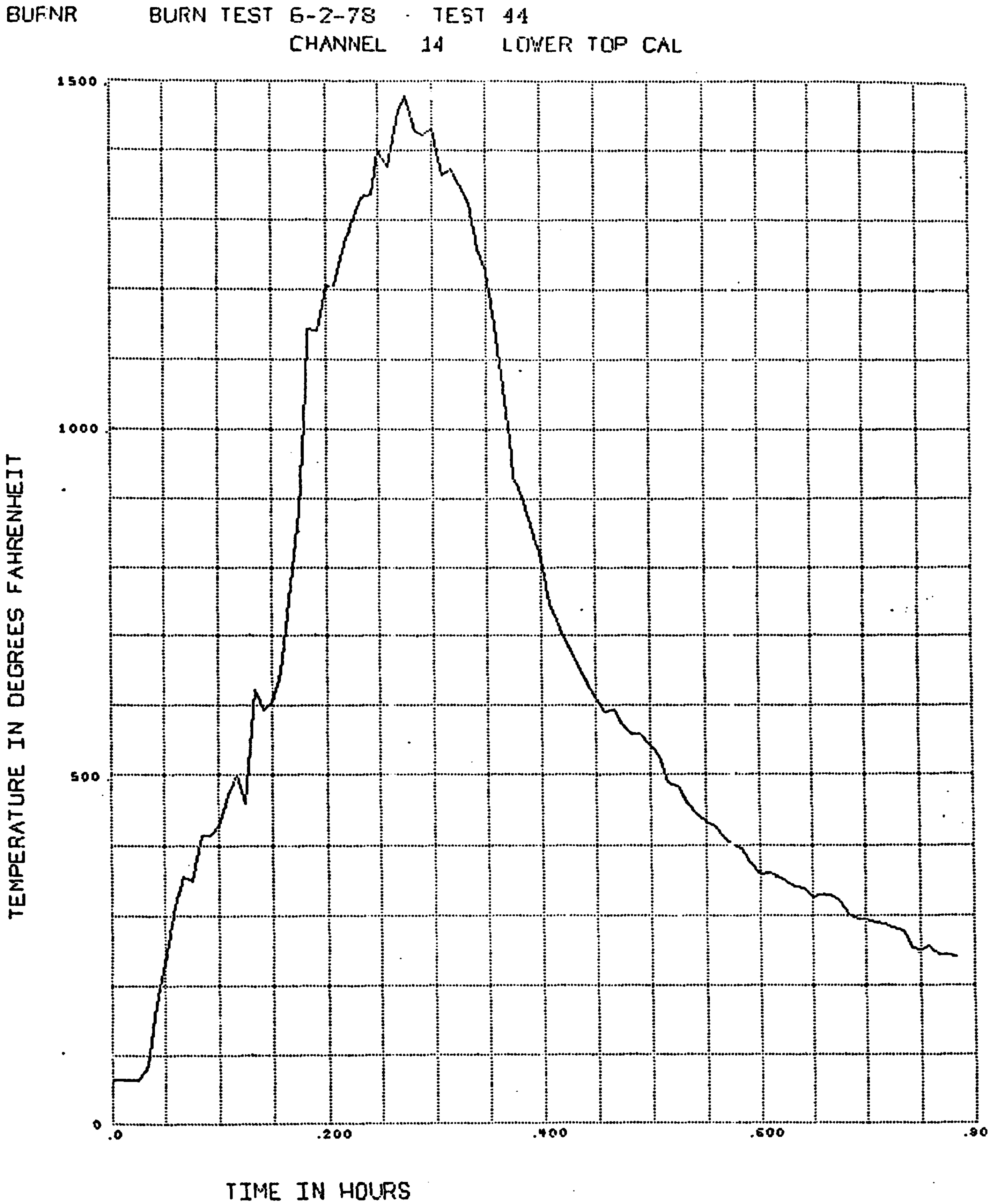

Figure C-15. Calorimeter No. 14, 8.0 inches (20.3 cm) Over Cables Lower Tray

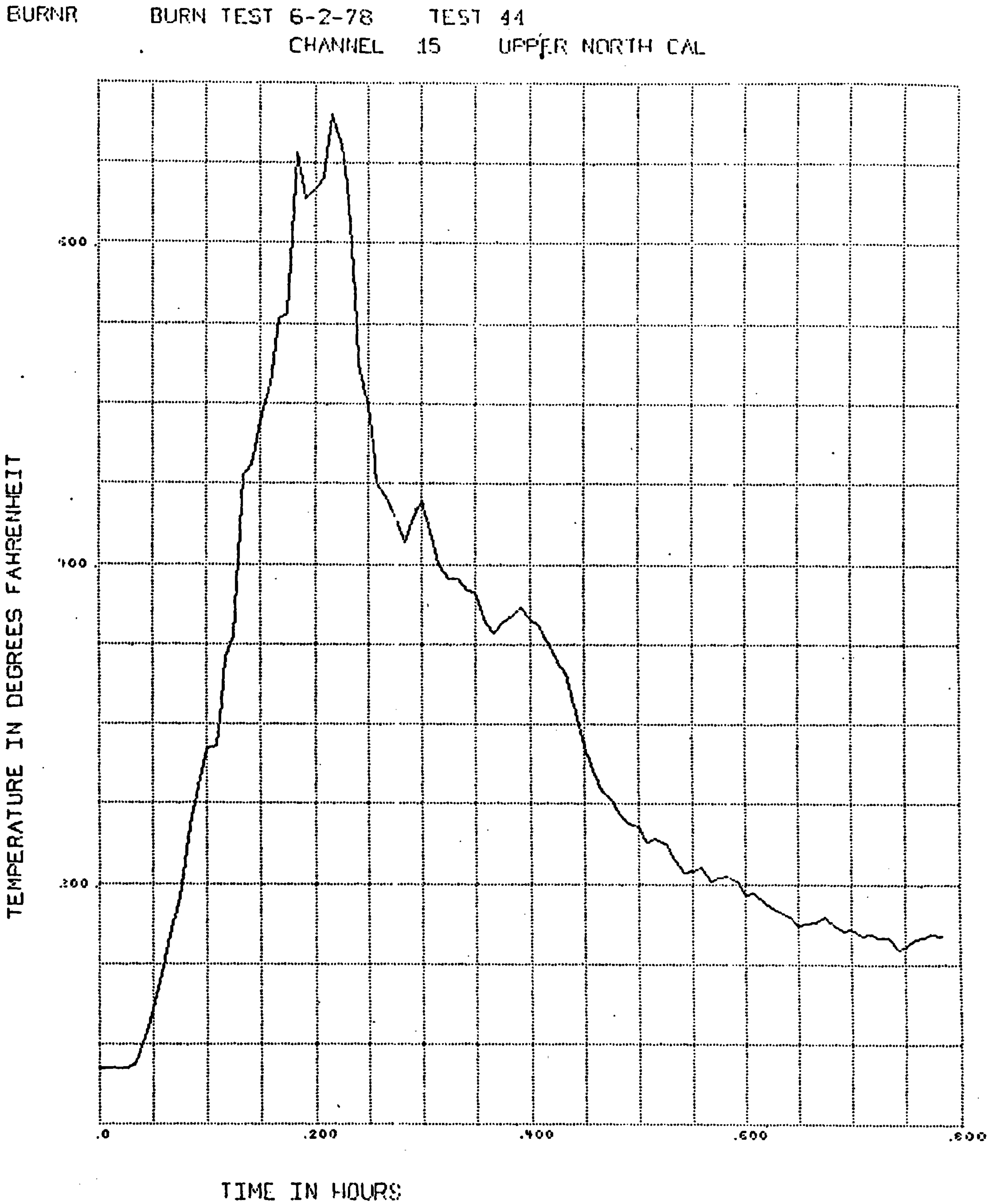

Figure C-16. Calorimeter No. 15, 3.75 inches (9.5 cm) Over Cables Upper Tray

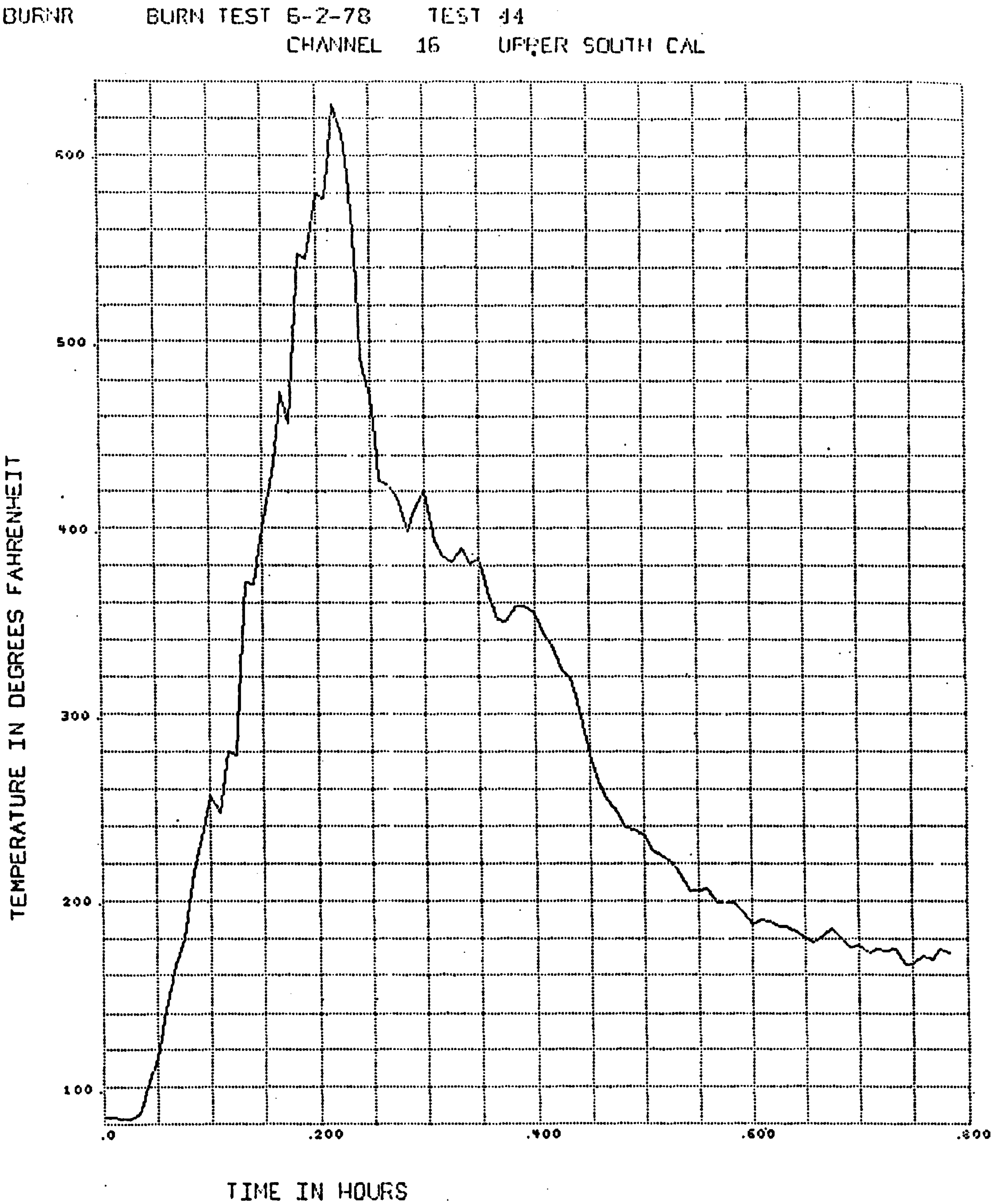

Figure C-17. Calorimeter No. 16, 3.75 inches (9.5 cm) Over Cables Upper Tray

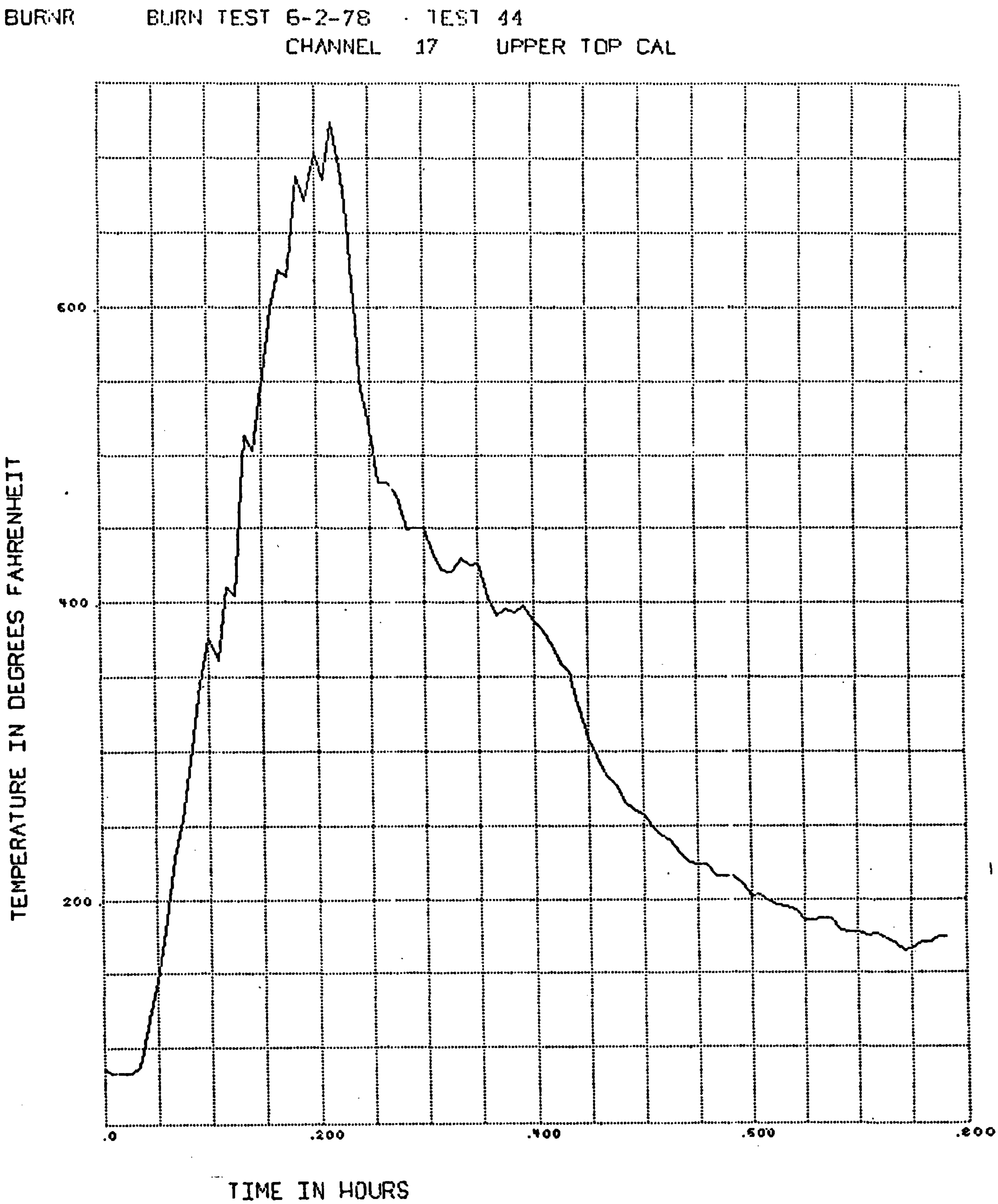

Figure C-18. Calorimeter No. 17, 8.0 inches (20.3 cm) Over Cables Upper Tray

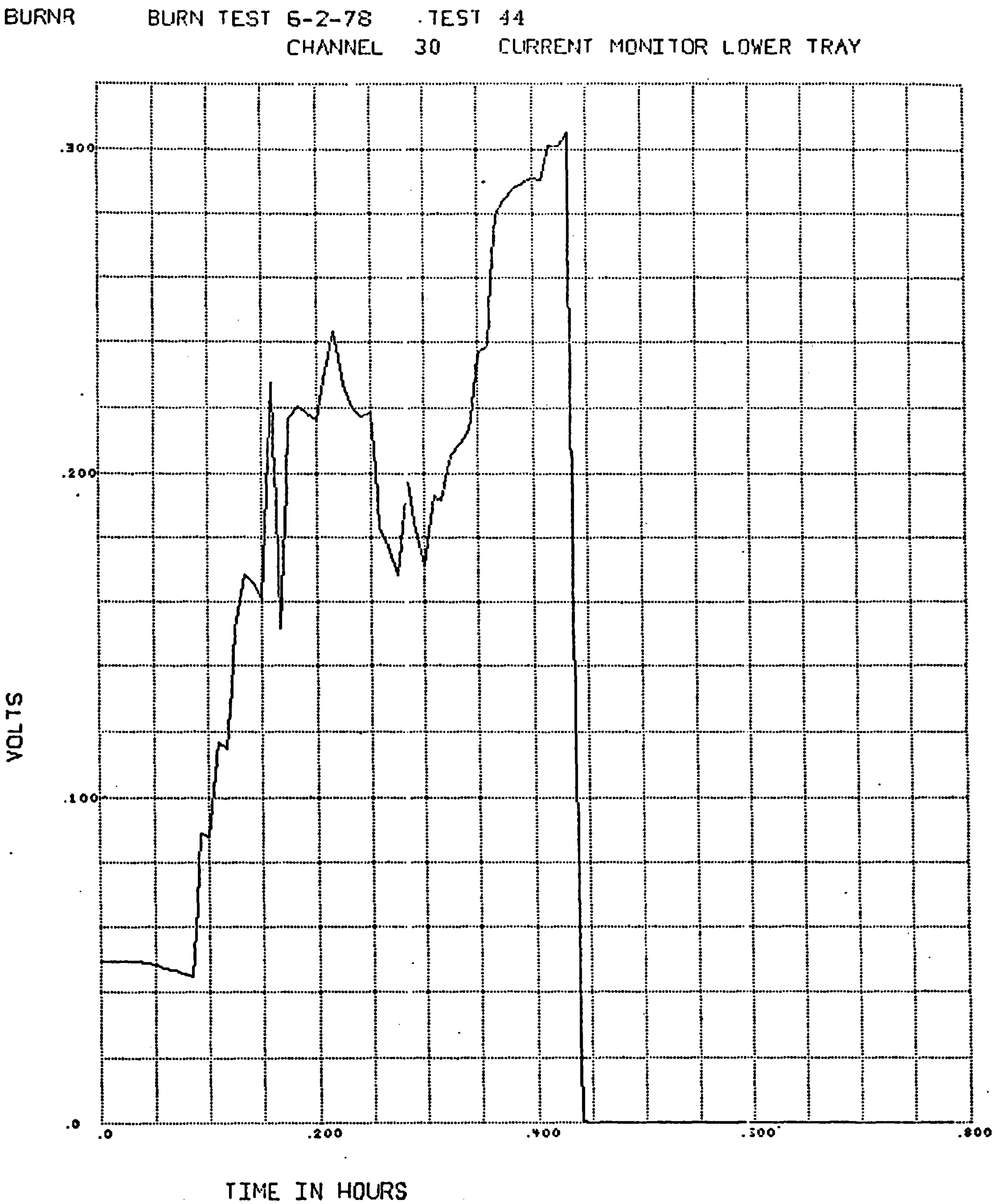

Figure C-19. Current Monitor Lower Tray

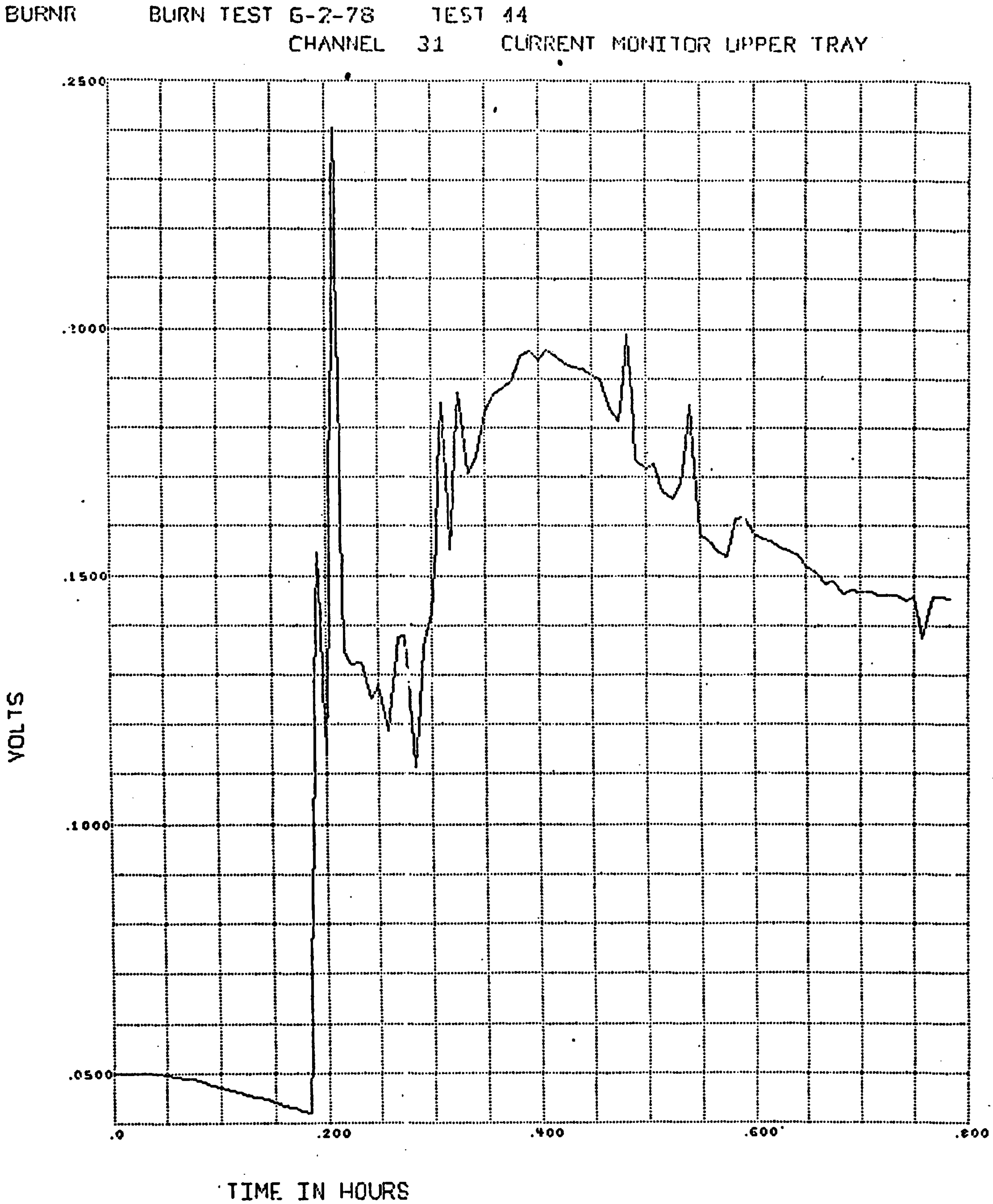

Figure C-20. Current Monitor Upper Tray

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