NUREG/CR-0833
SAND79-0966

RP

Fire Protection Research Program Corner Effects Tests

Leo J. Klamerus

Printed December 1979

Sandia Laboratories

SF 2900 Q(7-73)

Prepared for

U. S. NUCLEAR REGULATORY COMMISSION

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FIRE PROTECTION RESEARCH PROGRAM CORNER EFFECTS TESTS

Leo J. Klamerus

Date Published: December 1979

Sandia Laboratories
Albuquerque, New Mexico 87185
operated by
Sandia Corporation
for the
U. S. Department of Energy

Prepared for
Division of Reactor Safety Research
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555
Under Memorandum of Understanding DOE 40-550-75
NRC FIN No. A1010

ABSTRACT

Under the direction of the Nuclear Regulatory Commission, Sandia Laboratories has been conducting confirmatory research in fire protection for nuclear power plants. During all previous full scale fire tests at Sandia Laboratories involving fires, both electrically and exposure initiated, an open area in a nuclear power plant was simulated. The question was often asked, "How much contribution to fire severity does a reradiating ceiling and wall make?" This report presents the results of several tests which address this question. By quantifying the effects of corner reradiation (i.e., a ceiling joining a wall) at different distances from a horizontal array of cable trays ignited by an exposure fire, it was found for the cables tested that fire damage, as measured by the extent of cable insulation degradation, varied approximately as the inverse of the square of the distance separating the cables from the corner. As experienced in previous Sandia fire tests, the difference in fire resistance between IEEE-383 qualified cable and unqualified cable was apparent in these corner-configuration tests.

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Executive Summary

Previous electrically initiated fire tests of IEEE-383 qualified cable loaded into trays revealed a margin of safety in the spatial distances of Regulatory Guide 1.75 for such fires. An exposure fire on July 6, 1977, at Sandia Laboratories 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. Thus additional measures have been required by the Nuclear Regulatory Commission (NRC) to protect essential safety systems against the effects of fires. Two of these 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, while only full scale tests were performed to judge the adequacy of barriers. The tests showed that all coatings and barriers offer some measure of additional protection; however, there was a wide range of relative effectiveness of the different coatings.

This report describes full-scale fire tests on horizontally oriented cable trays to determine the effects of a ceiling and wall corner configuration for various distances from cable trays. The same experimental procedures used in the previous exposure fire initiation tests were used in the tests described here. IEEE-383 ribbon burners were used for the fire source. The effect of reradiation from corners was quantified for both IEEE 383 qualified and unqualified cable in terms of equations relating insulation weight loss and heat flux to the separation

distance between a cable tray and corner. As expected and confirmed by testing, the inverse of the square of the separation distance between the corner and tray dominates the severity of cable damage. Beyond a diagonal distance of 6 feet (1.8m) the corner effects are negligible.

FIRE PROTECTION RESEARCH PROGRAM
CORNER EFFECTS TESTS

I. Introduction

The Office of Nuclear Regulatory Research of the United States Nuclear Regulatory Commission is conducting confirmatory research in areas considered important to protecting the health and safety of the public. Fire protection, established by NUREG-0050, "Recommendations Related to Browns Ferry Fire," is one area of such research.[1]

The objectives of the Fire Protection Research Project at Sandia Laboratories are to

(1) provide data either to confirm the suitability of current design standards and regulatory guides for fire protection and control in light water reactor power plants, or to indicate areas where they should be updated;

(2) obtain data to facilitate either modification or generation of standards and guides (changes are to be made where appropriate to decrease the vulnerability of the plant to fire, provide for better control of fires, mitigate the effects of fires on plant safety systems, and remove unnecessary design restrictions);

(3) obtain fire effects data and assess improved equipment, design concepts, and fire prevention methods that can be used to reduce vulnerability to fire.

II. Background

When the project was initiated in July 1974, the only task was to provide the experimental and analytical information to evaluate the adequacy of cable tray spacing designated in Regulatory Guide 1.75, Section 5.14, which covers separation of protective systems in areas of the plant where power cables are included and the only source of fuel is that provided by the cable materials.[2] All evaluations were to involve the testing of equipment and configurations representative of those in new nuclear power plant designs.

It was decided that a survey of industry should be made to determine current design practices. The cooperation by members of the nuclear power industry was outstanding. Personal visits and correspondence elicited responses from 13 architect-engineering firms, 13 utility companies, and 13 cable manufacturers. Three nuclear power plants were visited, although design practices of existing nuclear power plants were not evaluated. Information obtained during this survey has proven valuable in determining cable and cable tray configurations, cable loading, and types of cable assignments in cable trays. The survey also solicited information about previous incidents and experiences, including the cable tray fire at San Onofre 1 in 1968 and the subsequent investigation to determine the cause.[3]

Since initiating a fire in power cable electrically may be difficult, it was decided early in the project to conduct the test with 12 AWG, the smallest power cable normally used in nuclear power plants, to minimize the amperage demands in the test setup. A preliminary heat transfer analysis was also performed at that time. Only a rough analysis was considered necessary to determine the approximate current required to raise the cable insulation to a combustion temperature and to determine if the conductor temperature is at its melting point (1083°C) when the outside of the cable insulation is at its combustion temperature. The analysis showed that currents in the range of 100 to 120 amperes would raise the cable insulation to its combustion temperature. This agreed with subsequent testing.

With the results of the survey and the preliminary analysis as guidelines, a test facility was developed to perform full scale testing of electrically initiated fires. Although it was originally intended to test all known types of cable currently specified and accepted, the large number of cable types, coupled with budget limitations, precluded such broad testing. Screening indicated that tests of two cable types most likely to propagate a fire would comprise a conservative approach.

The relative ranking of cable types was based on three different evaluations and were chosen to complement, not duplicate, other evaluations. The evaluations used were: a small scale electrically initiated cable insulation fire test, Underwater Laboratories (UL) FR-1 flame test,[4] and a pyrolyzer and thermal chromatograph test (measure of insulation outgassing as a function of temperature).

Although the small scale electrically initiated cable insulation fire test and the UL FR-1 test indicated that none of the cables under evaluation would be capable of propagating a fire (in support of IEEE-383 qualification),[5] two cable types were designated for use in the full scale tests by a relative figure of merit. Work performed in Europe in 1975 on radiation and fire resistance of insulating materials was brought to our attention and is in good agreement with our ratings.[6] These designated cable types were (1) a three-conductor No. 12 AWG, 30 mil (0.76 mm) crosslinked polyethylene (PE), silicon glass tape, 65 mil (1.65 mm) crosslinked PE jacket, 600 V, and (2) a single-conductor No. 12 AWG, 30 mil (0.76 mm) crosslinked PE, no jacket, 600 V. These were used on all subsequent electrically initiated and exposure fire tests whenever IEEE-383 qualified cable was to be used.

II.1 Electrically Initiated Fire Tests

Three phases of full scale electrically initiated fire tests in horizontal cable trays were performed. The first phase was intended to evaluate the adequacy of cable tray spacing as designated in Regulatory Guide 1.75, Section 5.14. Vertical separation of independent divisions is designated as 5 feet (1.52 m) and the horizontal separation as 3 feet (0.91 m).

The second phase was concerned with varying the separation distance between cable trays. Phase three required a stacking or matrix of 14 cable trays as one division with cable trays representing the second division separated by distances as specified in Regulatory Guide 1.75. The vertical and horizontal separations in the first division were 10.5 and 8 inches (0.27 m and 0.20 m), respectively, while the separation between divisions was again 5 and 3 feet. All testing involved equipment and cables representative of those in new nuclear power plant designs.

Coupons of aluminum, galvanized iron, and mild steel were hung in the building and periodically removed for corrosion analysis. A profilometer used for this purpose did not show significant corrosion during the electrically initiated tests.

An oxygen analyzer and gas sample manifold were installed and gas samples were taken before and during the fires. No depletion of oxygen was found in the fire area. Flame retardant antimony bromide, an organophosphate, and a high molecular wax material were found in the gas samples.

Remote controlled cameras were installed for closed circuit television, color movies, photographic thermometry, and infrared thermometry. Television was used to monitor the testing and for determining when to attempt gas ignition (explosive bridgewires and electric matches were spaced over the ignition point and simulated arcing), when to take gas samples, and when to start movie cameras. The movies not only provided a record of the event but gave information on the ignition mechanism and flame velocity. Despite lack of success in igniting the gases with simulated arcing, the movies show that in real situations combustible gases can and do ignite as the flame producing mechanism. Flame velocity was measured so that the convective heat transfer coefficient could be calculated. The photographic thermometry and infrared thermography were to supplement the discrete spatial measurements taken with thermocouples and slug calorimeters. On each test a minimum of 31 thermocouples and slug calorimeters were placed in these test setups and connected to recorders.

Air velocity was varied somewhat during the tests because of conflicting opinions on worst-case conditions. Opinions varied from zero flow, which might be encountered in a cable spreading room, to high air velocity providing abundant oxygen, which might be encountered near an exhaust fan in the open plant area. As a compromise, air velocities for the different tests ranged between 2 and 30 ft/min (0.01 and 0.15 m/s) These measurements were made with a hot wire anemometer before each test; only fan exhaust velocities were monitored during the test.

Seven full scale tests were run in the three phases previously described. Spacing was reduced in phase two to 10.5 inches (0.27 m) vertically and 8 inches (0.20 m) horizontally. In all seven tests all circuits other than the ignition tray circuits remained functional. This was determined by operation of these circuits for some period of time after the test. In addition, samples of the cable insulation at the bottom of the tray over the fire zone were measured for any mechanical change. They showed less than 10% increase in elongation due to the fire. Quite often this small increase is attributed to a small change in crosslinking due to heat.

Results of these electrically initiated fire tests were reported in seven "quick look" reports to the NRC[7-13] and a summary paper.[14]

2

II.2 Exposure Fire Test (July 6, 1977)

A full-scale fire exposure test was performed at Sandia Laboratories on July 6, 1977.[15] The test was conducted with a single safety division being represented by 14 filled cable trays. Again the 14 trays were spaced 10.5 inches vertically and 8 inches horizontally. Three additional filled trays representing the second or redundant safety division were placed vertically and horizontally adjacent to the top of that 7 x 2 matrix of trays. The separation distances between redundant divisions were those minimum distances allowed by Regulatory Guide 1.75.

A 5-minute exposure to standardized (IEEE-383 ribbon type) propane burners produced a fully developed fire within a single cable tray. Optimized parameters for this type of fire were obtained in a series of 12 single-tray tests performed earlier. A barrier was placed over the donor tray until after the propane burners were turned off and was then removed to allow the single-tray fire, with only the cable as fuel, to act as a propagation source. The fire not only propagated through the closely stacked trays of one division but also ignited the cables in the redundant safety division.

The results of this test show that fire propagation with flame retardant (IEEE-383 qualified) cable in an open-space horizontal configuration between redundant safety divisions, separated by the minimum distances specified by Regulatory Guide 1.75, is possible if a fully developed cable fire is assumed. Comparison of data from this test with the previous electrically initiated fire tests show that size (area of fire) and time (length of time flames reached a given area in upper trays) were the principal parameters which allowed propagation of this fire. The typical electrically initiated fire had an axisymmetric luminous zone about 6 inches (15.2 cm) in diameter while the luminous zone in the exposure fire test was approximately 2 feet (61 cm) long and 1.5 feet (45.7 cm) wide. This increase in characteristic dimensions increased the emissivity and view factor which in turn increased the radiation heat transfer to the higher trays. The longest period of time an electrically initiated fire remained on the thermocouple or calorimeter area was 240 seconds while this same area was in the flames for 400 seconds in this exposure fire test.

Comparison of thermocouple records for previous tests and the test described here shows a 1400°F (760°C) temperature above the cables at 3/8 inch (0.95 cm) in the electrically initiated fires and at 2.5 inches (6.35 cm) in this fire. A temperature of 1000°F (583°C) was seen at 3 inches (7.62 cm) above the cables in the electrical fires but 8 inches (20.32 cm) above the cables in this fire. These temperatures suggest that the fire resulting from the exposure fire was slightly more severe, but this could have been merely because of a larger fire zone which caused the thermocouples to read closer to true local gas temperature.

Heat flux is comparable in both types of tests, varying within 20% at corresponding heights on all tests. This fact, plus the lack of large changes in other measurable characteristics, might suggest that the electrically initiated fires were marginally below the capability of propagation across the minimum (10.5 in. or 27.7 cm) vertical distance between trays used to represent one of the redundant divisions. By the same token, this exposure fire test was marginally above ignition as seen from the fact that the donor fire tray stopped flaming within one minute after the tray vertically above this one ignited.

Schedule 40, 3-inch (76.2 mm) pipe was used as conduit containing additional cable and was included in this test. Continuity and insulation resistance measurements of the cables in the conduit were taken before and after the test. Although continuity measurements were normal, insulation resistance showed short circuits to the conduit on all conduits above the third tray. The insulation appeared to have turned to ash without flaming, leaving the conductors touching each other and the pipe.

II.3 Fire Retardant Coatings and Fire Shield Tests

The test of July 6, 1977, showed that additional measures were required to protect essential safety systems against the effects of fire and confirmed the Nuclear Regulatory Commission's position in requiring that protection. Two of these additional measures may be fire retardant coatings applied on the cable trays and fire shields between cable trays. Small-scale and full-scale testing was performed on the fire retardant coatings. Full-scale testing of the coatings consisted of both propane- and diesel-fueled exposure fires. Propane-fueled exposure fires were used to test the ability of various fire shields to prevent fire propagation between horizontal cable trays. These tests are reported in References 16 and 17.

II.4 Small Scale Testing of Coatings

For small scale testing, coatings were applied to both types of electrical cable used in the electrically initiated and exposure fire tests at Sandia. The cables were cut into 6-inch (15.2-cm) pieces and placed in wood forms lined with plastic, a 6 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.

The Ohio State University release rate apparatus tested two types of cables and six 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 used a flow system in which a known, constant flow rate of air enters an environment chamber. Rate of heat release is monitored by changes in temperature of air leaving the chamber and rate of smoke release by optical density of gas leaving the chamber. The sample is put into the environmental chamber and a small pilot flame is placed to impinge on the center of the lower edge of the vertical sample. A radiant panel provides exposure in terms of heat flux to the sample. The test conditions provide 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, 2, 3 and 4 W/cm^2.

II.5 Single-Tray Full Scale Tests

For the full-scale tests performed at Sandia Laboratories, coatings were applied to the same 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 side-rails of the cable trays, the loading technique allowed maximum air passage through the cables. The loading pattern is 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 sectional area and for the single-conductor, a 15% fill (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. This cable 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.

Coatings 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 was applied according to the manufacturer's specifications.

The test described here was designed to reproduce the ignition tray conditions of the full scale stacked-tray test of July 6, 1977.[15] An important difference of course, is that only the ignition tray itself was used in this first phase of the fire-retardant coatings tests. For each type of coating, three tests were run: one each with the single-conductor cable, the three-conductor qualified cable, and the unqualified cable.

The test procedure and setup were essentially identical to the July fire test. An insulated barrier was placed 9.5 inches (24.1 cm) over the ignition tray. The twin burner assembly was so placed beneath the tray 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). Cable thermocouples were in place before spraying of coatings began.

Propane and air were turned on for 5-minute periods for each burn cycle. 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 was maintained. If a fully developed cable tray fire was not achieved after applying this ignition source for 5 minutes, additional 5-minute ignition cycles (up to a total of six) were repeated after 5-minute delays.

Fifteen tests were conducted on coatings, as follows: 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; 12 coated cable trays witn IEEE-383 qualified cable (six different coatings each with two cable constructions).

Eight single-tray tests were conducted with various fire shields to determine combustibility requirements before two-tray testing for fire propagation.

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

II.6 Two-Tray Full Scale Tests

Another series of two-tray tests was conducted to test for fire propagation between trays. In these tests, the physical arrangement of the lowest two trays in the July 6, 1977 fire test was used. The trays were placed horizontally, with one tray 10.5 inches (26.7 cm) above the other. When IEEE-383-qualified cable was used, the bottom tray was loaded with three-conductor and the top with single-conductor cable. 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 swiftly removed from between the cable trays when a fire developed in the bottom tray. As in the single-tray tests, thermocouples and calorimeters were placed in each tray.

The same 5-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. Twenty-four two-tray tests were conducted.

Temperature and voltage of each tray were obtained during the double-tray tests. Data extracted for each test provided for comparisons with the previous single-tray tests and other two-tray tests.

II.7 Diesel-Fueled Exposure Fires

Another series of tests used the two-tray configuration previously described. However, the ignition source was a diesel-fueled fire which burned for about 13 minutes before self-extinguishing. Another important difference is that no barrier was placed between the trays so that both trays might be exposed to the diesel fire.

II.8 Characterization of Cable Tray Fires

As described in the referenced reports, characterization of these fires revealed a margin of safety in the separation criteria of the regulatory guide for electrically initiated fires in IEEE-383-qualified cable. However, exposure fire tests have shown it is possible for a fire to propagate across the vertical separation distance between safety divisions if a fully developed cable fire is the initiating event.

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, nonqualified cable had been used. Two of these tests were with the same fire-retardant coating and were initiated by two different exposure fires (propane-fueled IEEE-383 ribbon burners, and diesel fuel in a pan). The other test was with a different fire retardant coating and was initiated by a diesel-fueled fire. It must be pointed out that, in the diesel fuel 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.

III. Corner Effects Testing

Throughout the previous testing, cable tray arrays were arranged to simulate the open plant area with no ceiling or wall in proximity. The question of what effect is contributed by such proximity was not forgotten. This report describes a modest series of full scale tests to determine a quantitative measure of this effect. The same cable types, ladder trays, fire facility and fire testing procedures were used in these tests as in the previous tests.

Originally, it was planned to have concrete walls and ceilings provide a corner to simulate the usual conditions found in a nuclear power plant. A review of fire literature and a brief investigation led to the conclusion that a corner made of ceramic fiber boards would be little different from a concrete corner for the duration of the test fire.[18,19,20] This construction was used for ease of assembly and economy. Six 4 x 8 foot (1.2 x 2.4 m) ceramic fiber boards 1 inch (2.54 cm) thick were arranged as shown in Figure 1 to form a corner above and beside two horizontally oriented cable trays.

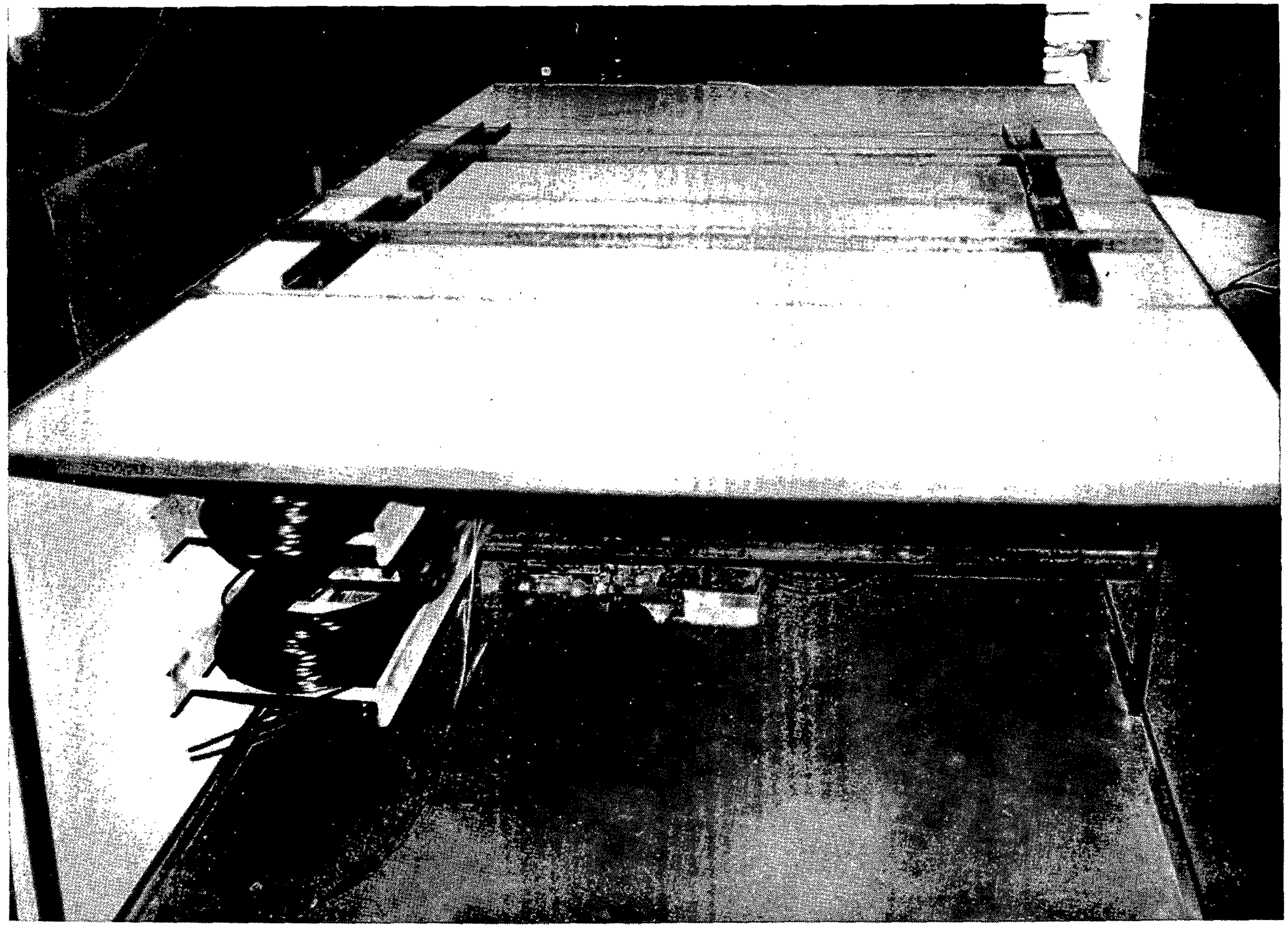

Figure 1
View of Corner Effects Test Setup

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 (90 cables per tray).

Two types of cable were used in these tests. One type was IEEE-383-qualified 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. The other type was non-IEEE-383-qualified cable, three-conductor, 20/10 Poly-PVC, polyethylene insulation, 45 mil (1.14 mm) PVC jacket.

This test was designed to reproduce the ignition tray conditions of the full scale exposure fire cable tray tests previously performed at Sandia.[15,16,17] The trays were placed horizontally with one tray 10.5 inches (26.7 cm) above the other (Figure 2). An insulated barrier was placed 9.5 inches (24.1 cm) over the bottom tray. The barrier was movable and could be quickly removed from between the cable trays when it was determined that a fire had developed in the bottom tray. In these tests one 5-minute burn cycle from the two 10-inch (25.4 cm) ribbon burners was used to provide ignition. As used in other full-scale testing, input to the burners was 140,000 Btu/hour (41 kW) for the 5-minute exposure fire. Thermocouples and calorimeters were placed as shown in Figure 3. Electrical

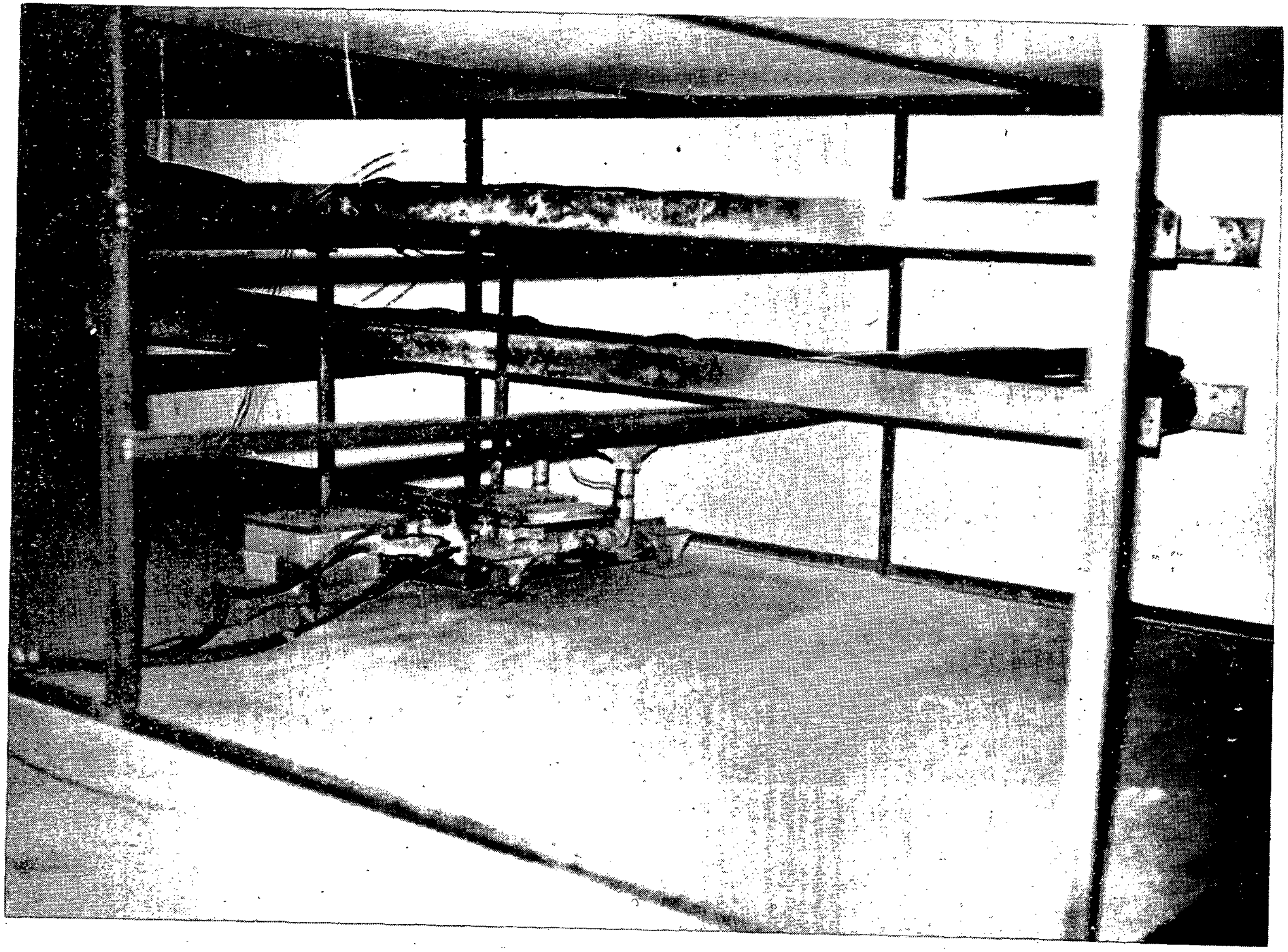

Figure 2
Cable Tray and Burner Arrangement

measurements for short circuits and open circuits were made before, during, and after each test. A more complete description of the instrumentation for these tests is contained in Appendix A.

Six tests were run in this series, three each with the IEEE-383 qualified and unqualified cable. The three distances from the ceiling to the top tray were 10.5, 18, and 120 inches (0.27, 0.46, and 3.05 m). The wall distances to the edge of the tray were 5, 10.5, and 60 inches (0.13, 0.27, and 1.52 m).

IV. Test Results

The results of all six tests are given in Tables 1 through 5. The corner effects are observable in the top tray data as these are from the tray actually in the corner. Effective measures of corner effects are weight loss and maximum heat flux (Table 2) for IEEE-383 qualified cable. Although these same parameters are consistent for nonqualified cable (Table 4), the differences are less because this cable burns well without corner effects. Note the time of burn for qualified and unqualified cable (Tables 2 and 4). The average length of burn time for qualified cable was 23 minutes and for unqualified cable it was 48 minutes. Table 5 summarizes the temperatures measured at a point 3 feet (0.91 m) horizontally from the top tray in each test. This is the dimension given in Regulatory Guide 1.75 as the minimum horizontal separation distance between redundant safety divisions in the open plant area.

Figures 4 and 5 show IEEE-383-qualified cable in the upper trays after the minimum and maximum corner effects tests (minimum

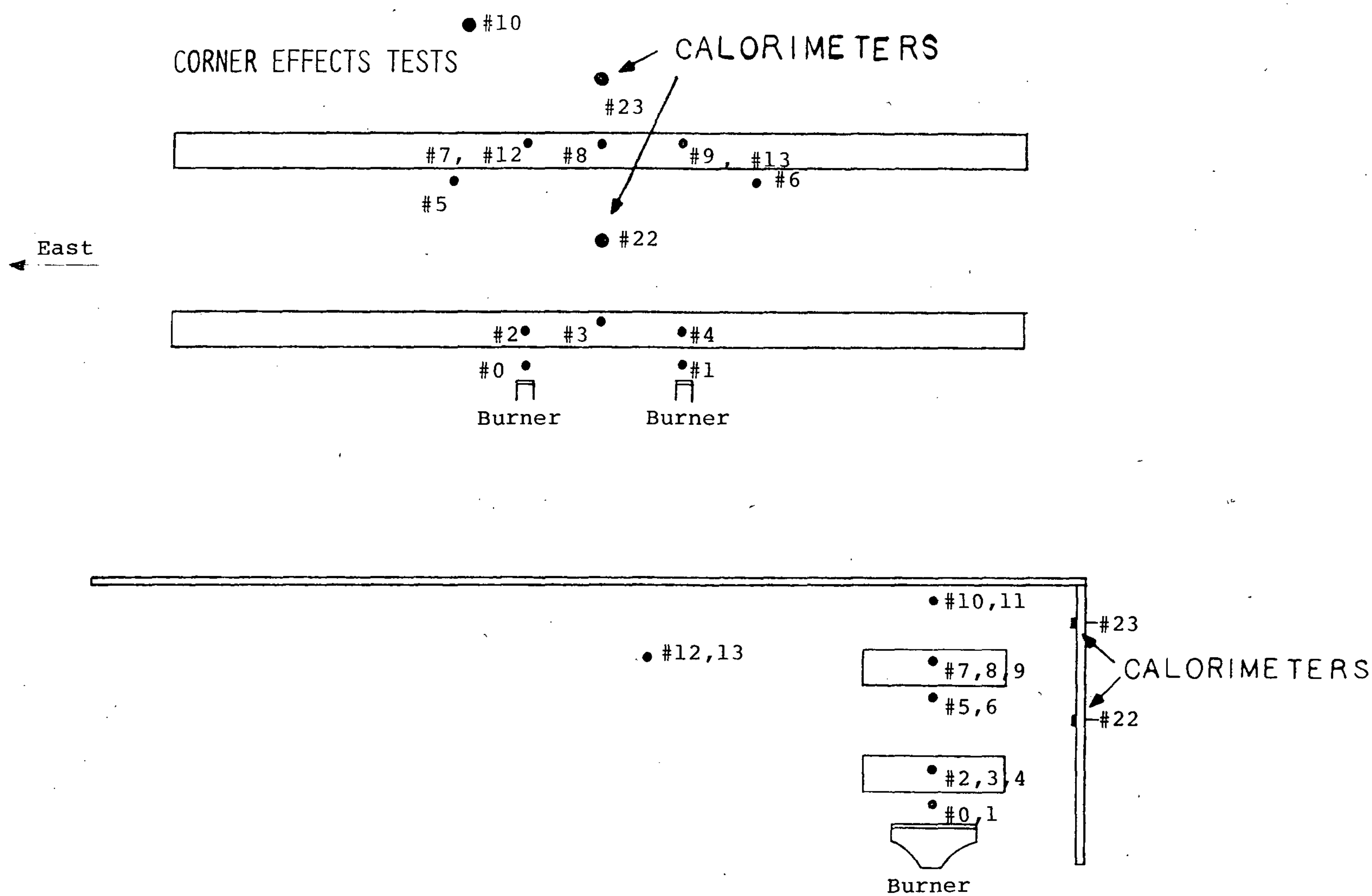

Figure 3. Thermocouple and Calorimeter Placement
(Data channel numbers shown, see Appendix B)

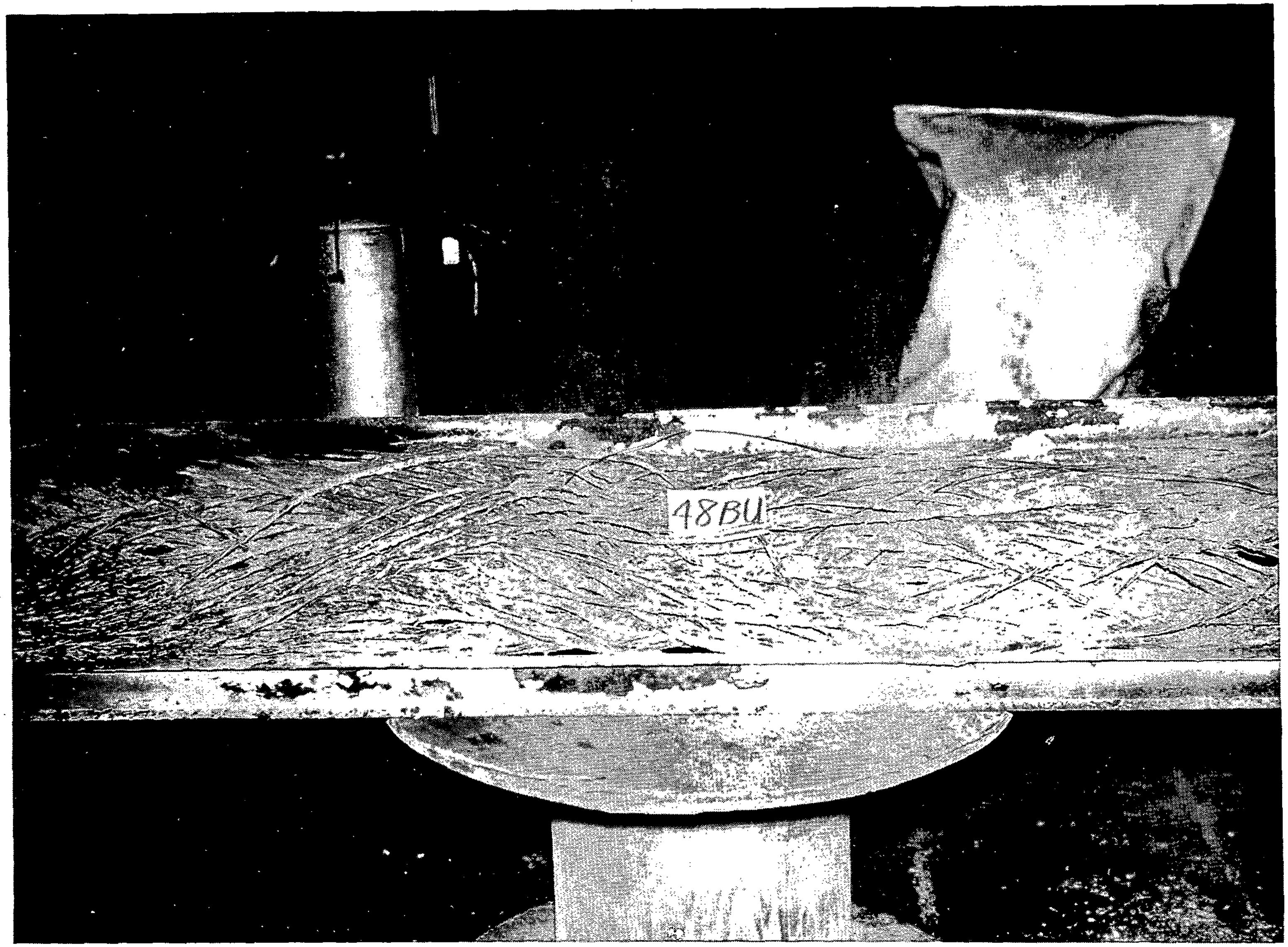

Figure 4. IEEE-383 Qualified Cable in Upper Tray After Corner Effects Test with Smallest Distance to Corner

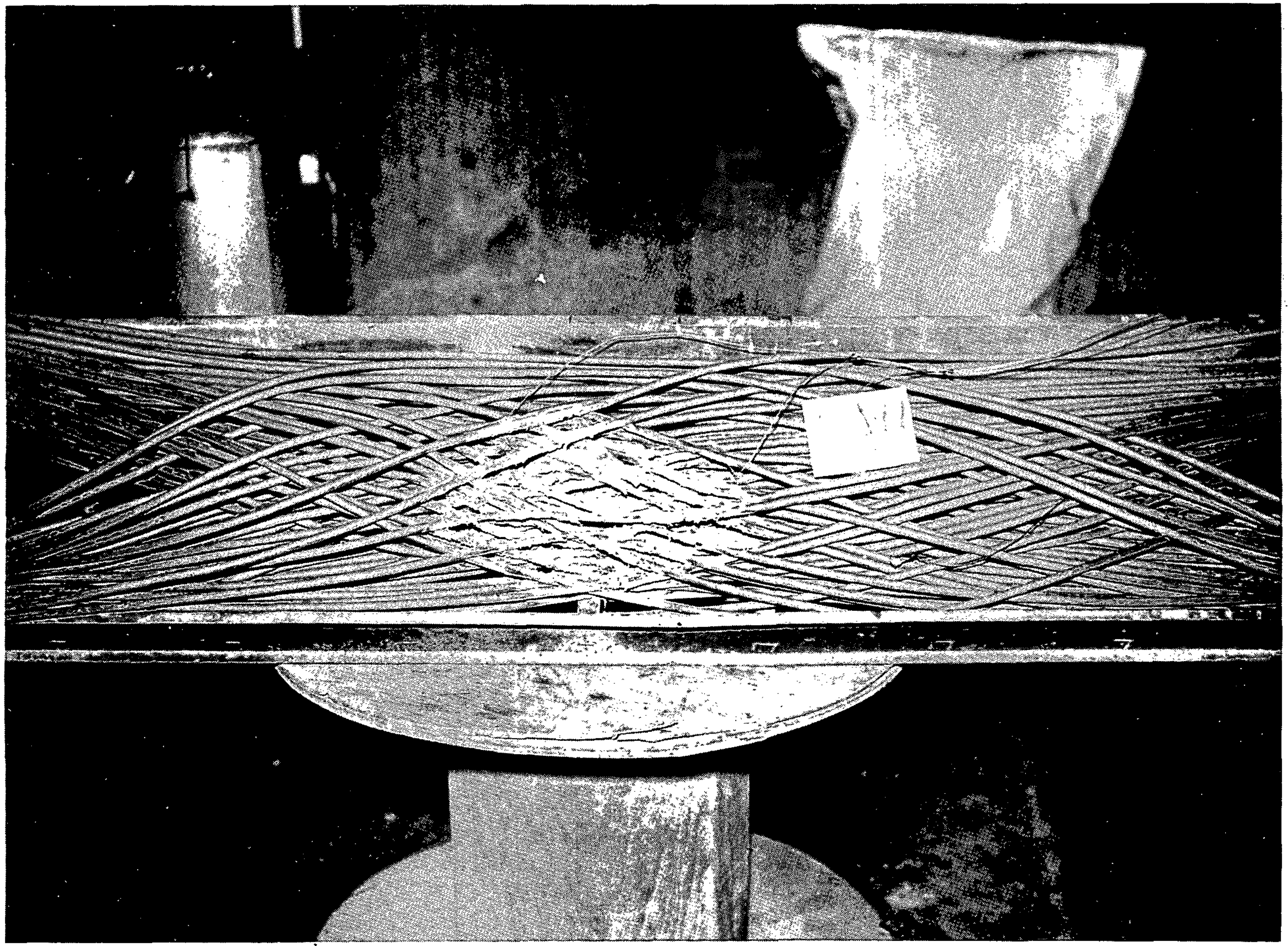

Figure 5. IEEE-383 Qualified Cable in Upper Tray After Corner Effects Test with Largest Distance to Corner

and maximum distances to the corner, diagonal distance of 11.6 and 134.2 inches, 29.5 and 341 cm).

Figures 6 and 7 are plots of approximating functions for weight loss and heat flux in terms of the diagonal distance from the top of the top tray to a corner. It was expected that an inverse square relationship would be in evidence and indeed that is the dominant term in the approximating functions for $11<x<140$ in inches ($28<x<356$ cm).

For unqualified cable:

$$W = 27 + 511X^{-1} - 2876X^{-2}$$

$$H = 1.09 \times 10^{4} + 2.1 \times 10^{5}X^{-1} - 8.47 \times 10^{5}X^{-2}$$

For IEEE-383-qualified cable:

$$W = -3 + 892X^{-1} - 4645X^{-2}$$

$$H = 152 + 3.06 \times 10^{5}X^{-1} - 1.09 \times 10^{6}X^{-2}$$

where

W = weight loss in pounds

H = heat flux in Btu/ft^2 hour

X = diagonal distance from top tray to the corner in inches.

Some comments on these approximating functions are as follows:

1) Although the relationship between corner proximity and certain fire severity parameters is demonstrated, these functions are derived for two types of cable. It is expected that all cables would demonstrate similar effects but differ in magnitude of fire severity.

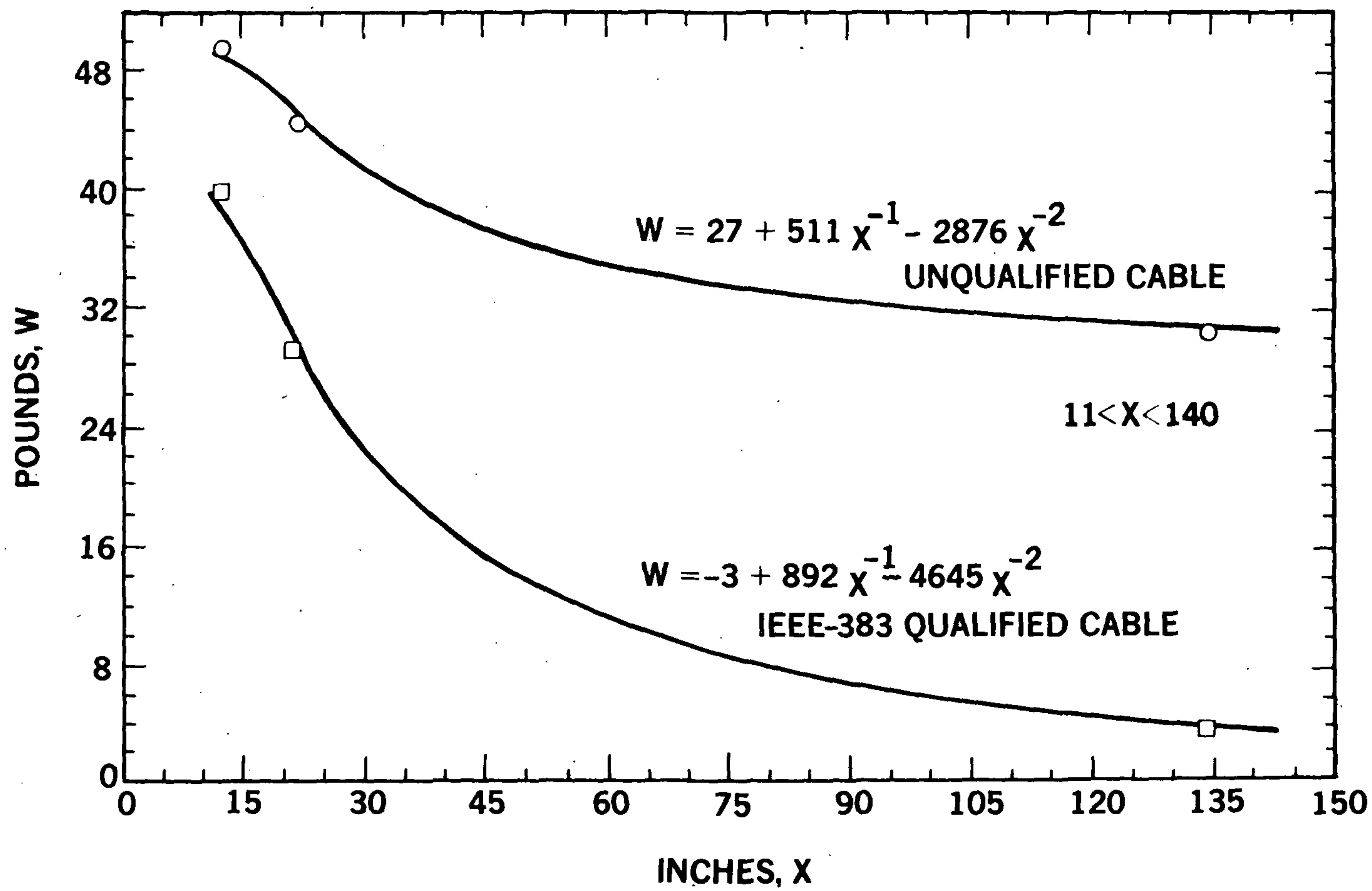

Figure 6. Corner Effects Tests Weight Loss, Top Tray

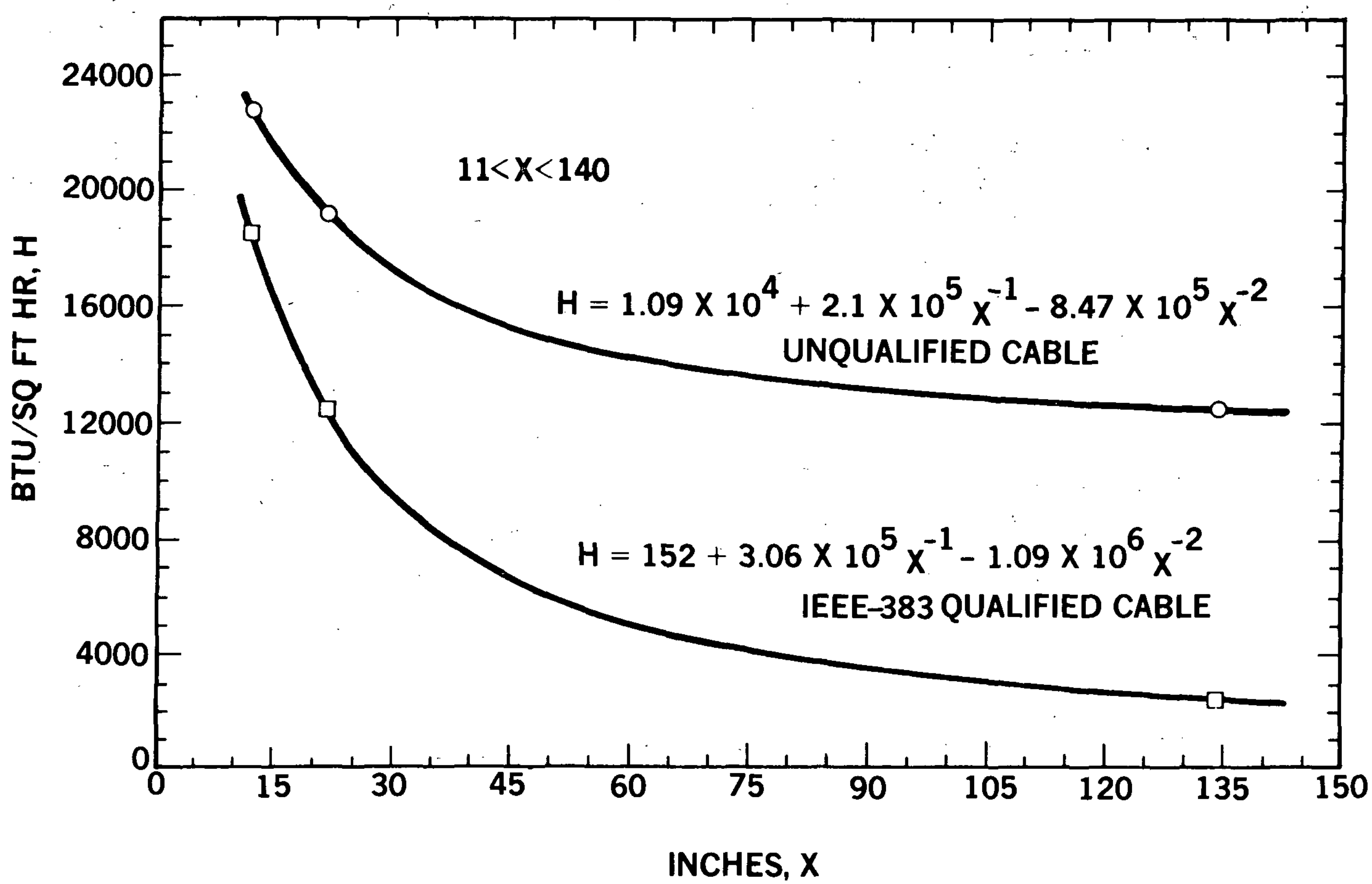

Figure 7. Corner Effects Tests Heat Flux, Top Tray

2) The functional relationship should be asymptotic to some value of fire severity. We have seen evidence that at large distances from a ceiling, small changes in spacing make no difference in fire severity. In the limit the approximating function does approach a fixed value.

3) The minimum corner distance used in these tests is a reasonable minimum in order to allow access to the trays in a real power plant situation. This distance should also be a lower bound for using these approximating functions as it is unreasonable to expect a very large rise in fire severity as the distance is decreased toward zero. The proximity of ceiling and wall would probably introduce a secondary effect of oxygen depletion in this unrealistic situation, but was not a factor in the tests described in this report.

4) The weight loss term as a measure of corner effects is intentionally not normalized by burn time. A severe fire can result from a slow long-burn or a fast short-burn. We have combined these effects here.

5) Beyond a diagonal distance of 6 feet (1.8m) the corner effects are negligible.

Table I

383-Qualified Cable, Bottom Tray

Distance From Corner Fixture	Max Cable Temp (°C)	Max Heat Flux (Btu/ft^2 hr)	Max Barrier Temp (°C)	Time to Elect. Short Cable to Cable (Min)	Time to Elect. Short Cable to Tray (Min)
Side = 5 in. Top = 10.5 in.	920	8,640	750	10	4
Side = 10.5 in. Top = 18 in.	790	6,300	880	12	4
Side = 60 in. Top = 120 in.	208	1,610	550	*	5

Distance From Corner Fixture	Time to 500°C*** in Cables (Min)	Time to Ignition (Min)	Length of Burn (Min)	Length Affected Area (In)	Weight Loss (Lbs)	Rate of Burn (Lbs/Min)
Side = 5 in. Top = 10.5 in.	1	5	35	54	17.5	.50
Side = 10.5 in. Top = 18 in.	11	15	22	54	17.25	.78
Side = 60 in. Top = 120 in.	**	5	7	22	1.75	.25

*Cable to cable short did not occur.
**Temperature did not reach 500°C.
***Autoignition temperature of some cables.

Table II

383-Qualified Cable, Top Tray

Distance From Corner Fixture	Max Cable Temp (°C)	Max Heat Flux (Btu/ft^2 hr)	Max Barrier Temp (°C)	Time to Elect. Short Cable to Cable (Min)	Time to Elect. Short Cable to Tray (Min)
Side = 5 in. Top = 10.5 in.	980	18,430	900	14	9
Side = 10.5 in. Top = 18 in.	840	12,330	830	18	17
Side = 60 in. Top = 120 in.	790	2,370	160	17	10

Distance From Corner Fixture	Time to 500°C In Cables (Min)	Time to Ignition (Min)	Length of Burn (Min)	Length Affected Area (In)	Weight Loss (Lbs)	Rate of Burn (Lbs/Min)
Side = 5 in. Top = 10.5 in.	10	10	20	120	39.75	1.99
Side = 10.5 in. Top = 18 in.	18	19	24	72	29.5	1.23
Side = 60 in. Top = 120 in.	21	7.5	25	16	3.75	.15

Table III

Non-383 - Qualified Cable, Bottom Tray

Distance From Corner Fixture	Max Cable Temp (°C)	Max Heat Flux (Btu/ft^2 hr)	Max Barrier Temp (°C)	Time to Elect. Short Cable to Cable (Min)	Time to Elect. Short Cable to Tray (Min)
Side = 5 in. Top = 10.5 in.	810	20,900	880	2	1
Side = 10.5 in. Top = 18 in.	770	12,140	850	2	1
Side = 60 in. Top = 120 in.	830	11,700	870	2	2

Distance From Corner Fixture	Time to 500°C In Cables (Min)	Time to Ignition (Min)	Length of Burn (Min)	Length Affected Area (In)	Weight Loss (Lbs)	Rate of Burn (Lbs/Min)
Side = 5 in. Top = 10.5 in.	4	5	45	144	33.25	.74
Side = 10.5 in. Top = 18 in.	5	5	45	132	32	.71
Side = 60 in. Top = 120 in.	5	5	50	102	29	.58

Table IV

Non-383 - Qualified Cable, Top Tray

Distance From Corner Fixture	Max Cable Temp (°C)	Max Heat Flux (Btu/ft^2 hr)	Max Barrier Temp (°C)	Time to Elect. Short Cable to Cable (Min)	Time to Elect. Short Cable to Tray (Min)
Side = 5 in. Top = 10.5 in.	880	22,800	860	6	6
Side = 10.5 in. Top = 18 in.	720	19,080	880	7	6
Side = 60 in. Top = 120 in.	820	12,420	790	7	6

Distance From Corner Fixture	Time to 500°C In Cables (Min)	Time to Ignition (Min)	Length of Burn (Min)	Length Affected Area (In)	Weight Loss (Lbs)	Rate of Burn (Lbs/Min)
Side = 5 in. Top = 10.5 in.	6	8	54	144	49.5	.92
Side = 10.5 in. Top = 18 in.	11	6	50	144	44.75	.89
Side = 60 in. Top = 120 in.	10	6	39	96	30.5	.78

Table V

Temperature Measurements at Three Feet Horizontally from Top Tray

Distance From Corner Fixture	383-Qualified Cable Max Temp (°C)	Non-383 Qualified Cable Max Temp (°C)
Side = 5 in. Top = 10.5 in.	268	345
Side = 10.5 in. Top = 18 in.	136	315
Side = 60 in. Top = 120 in.	13	83

5

V. References

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APPENDIX A

Cable Tray Instrumentation for Corner Effects Tests

P. D. Walkington

Cable Tray Instrumentation for Corner Effects Tests

To evaluate the corner effects upon a cable tray fire, the test setup was instrumented with temperature and heat flux sensors. The temperature sensors were positioned to measure the cable temperature at three different locations in each tray and the air temperature above, below, and adjacent to the receptor tray as shown in Figure 3. For these measurements, a chromel/alumel ("K") thermocouple with an ungrounded junction encased in a stainless steel sheath was used throughout the test series.

To characterize the fire in the donor and receptor trays, two water cooled calorimeters were used to measure the total radiant and convective heat transfer taking place at the instrumented locations. The calorimeters were mounted in the sidewall with their sensing surface facing towards the center area above each tray as shown in Figure 3. The temperature and heat flux data from an IEEE-383 qualified cable test with a ceiling separation of 10.5 inches and a sidewall separation of 5 inches is shown in Appendix B.

Along with the thermal instrumentation, several cable parameters were recorded throughout the test series--resistance, weight, and affected area of cable. Before and after each test, the cable resistance and cable to tray resistance was measured. During the test, each cable was monitored for shorts or opens in the cable bundle and for shorting to the tray (ground). This information is shown in Tables 1, 2, 3, and 4. Each cable tray was also weighed before and after testing to determine weight loss, which is also shown, as are the fire duration and affected area (length of burned area) for each tray. The receptor cable tray fire start time and flameout time were recorded on a video recorder using a TV camera placed in the test chamber.

All the instrumentation from the test setup was hard-wired into the control building and recorded by a data logger on magnetic tape. A TV camera and video recorder were used to monitor each test while still photographs were used for documentation.

Prior to the test series, the instrumentation system was calibrated. The data logger, interface wiring, and thermocouples were checked with a fluidized bath at 65° and 260°C. These thermocouples were compared against a certified chromel/alumel thermocouple and against two different glass stem thermometers having ranges of 50° to 80°C and 195° to 305°C obtained from the Sandia Standards Laboratory. The calorimeters were calibrated by the manufacturer but, since the calorimeter output signal was in millivolts, the voltage range on the data logger was checked against another calibrated voltage source. Then, after each test, the millivolt output signal was converted to Btu/ft^2-hr. by using the calorimeter's calibration curves, an example of which is included in this appendix.

CERTIFICATE OF CALIBRATION

DATE 6-20-78

CUSTOMER Sandia Labs

P.O. NO. 59-2301

INST. TYPE Calorimeter

MODEL C-1301-A-30-072

ABSORPTIVITY .89

CERTIFIED RECORD OF CALIBRATION DATA ON THE INSTRUMENT DESCRIBED ABOVE. THE DATA WAS OBTAINED IN HY-CAL ENGINEERING'S THERMAL FLUX FACILITY

REFERENCE STANDARD 9791

TESTED BY

Q.C. APPROVAL

OFFICIAL SEAL
JULIE A. HANGO
NOTARY PUBLIC-CALIFORNIA
LOS ANGELES COUNTY
My Commission Expires June 28, 1978

SUBSCRIBED AND SWORN TO BEFORE ME THIS ____ DAY OF ____ 19__

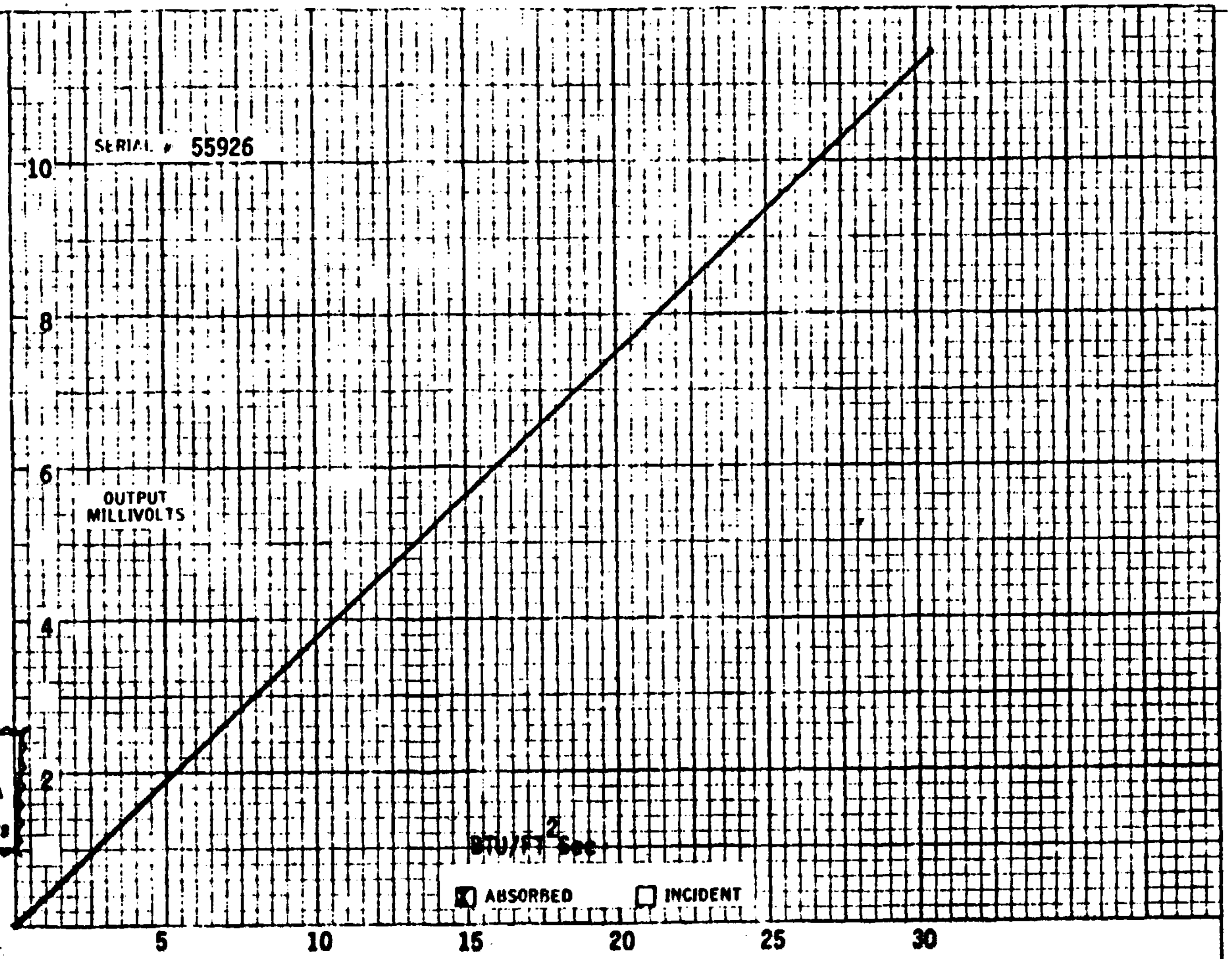

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Figure A-1. Calorimeter Calibration Curve

APPENDIX B

Temperature, Heat Flux, and Voltage vs Time Plots for a Corner Effects Test Using IEEE-383 Qualified Cable at Minimum Distance Between The Top Tray and Corner

Comments: Although the symmetry of the experiment is evident in all top tray and barrier measurements the bottom tray and burner measurements show the effects of an open door to the west of the test setup.

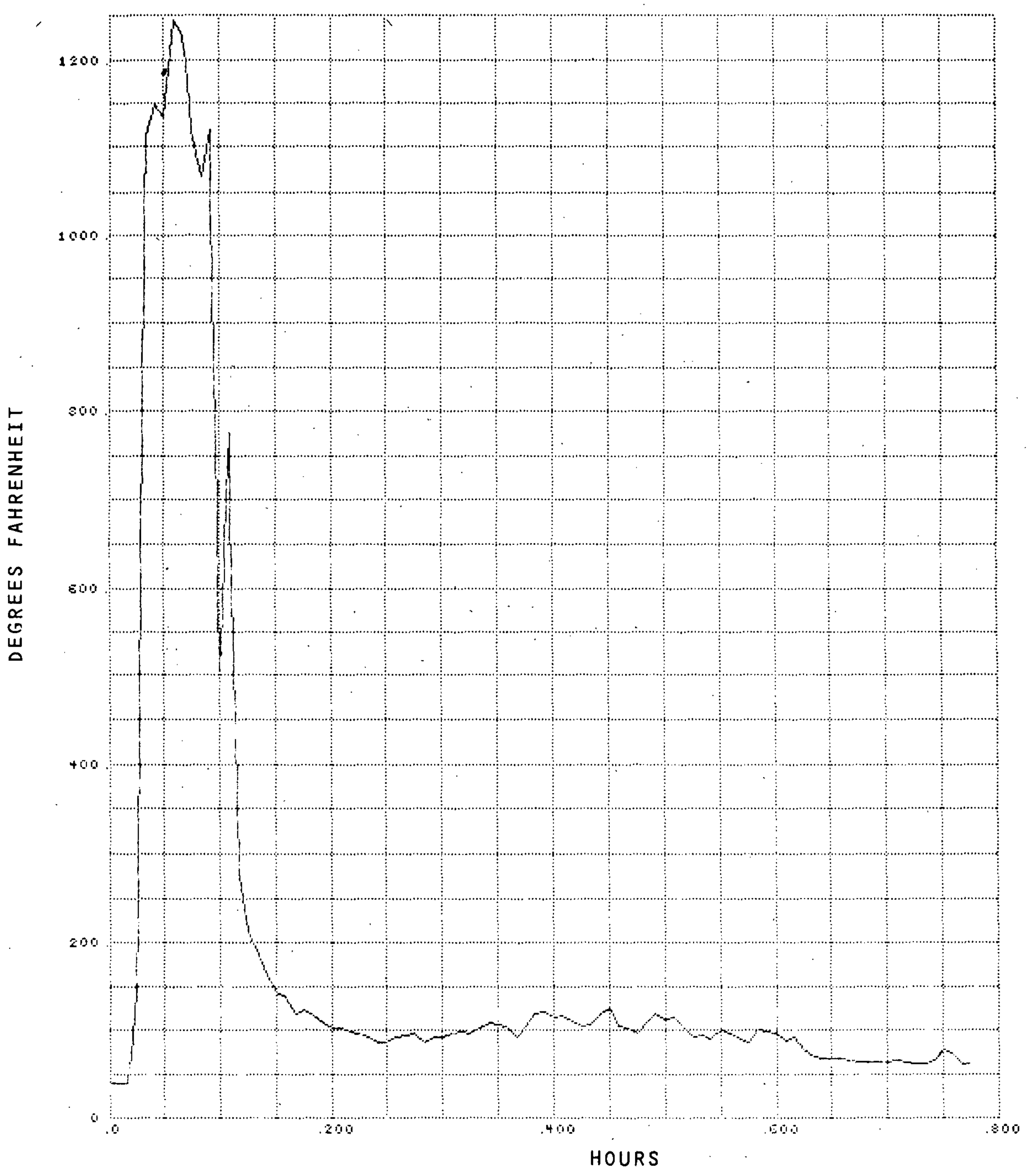

Figure B-1. Burn Test Number 48B, Channel 0, East Burner

6

1, West Burner

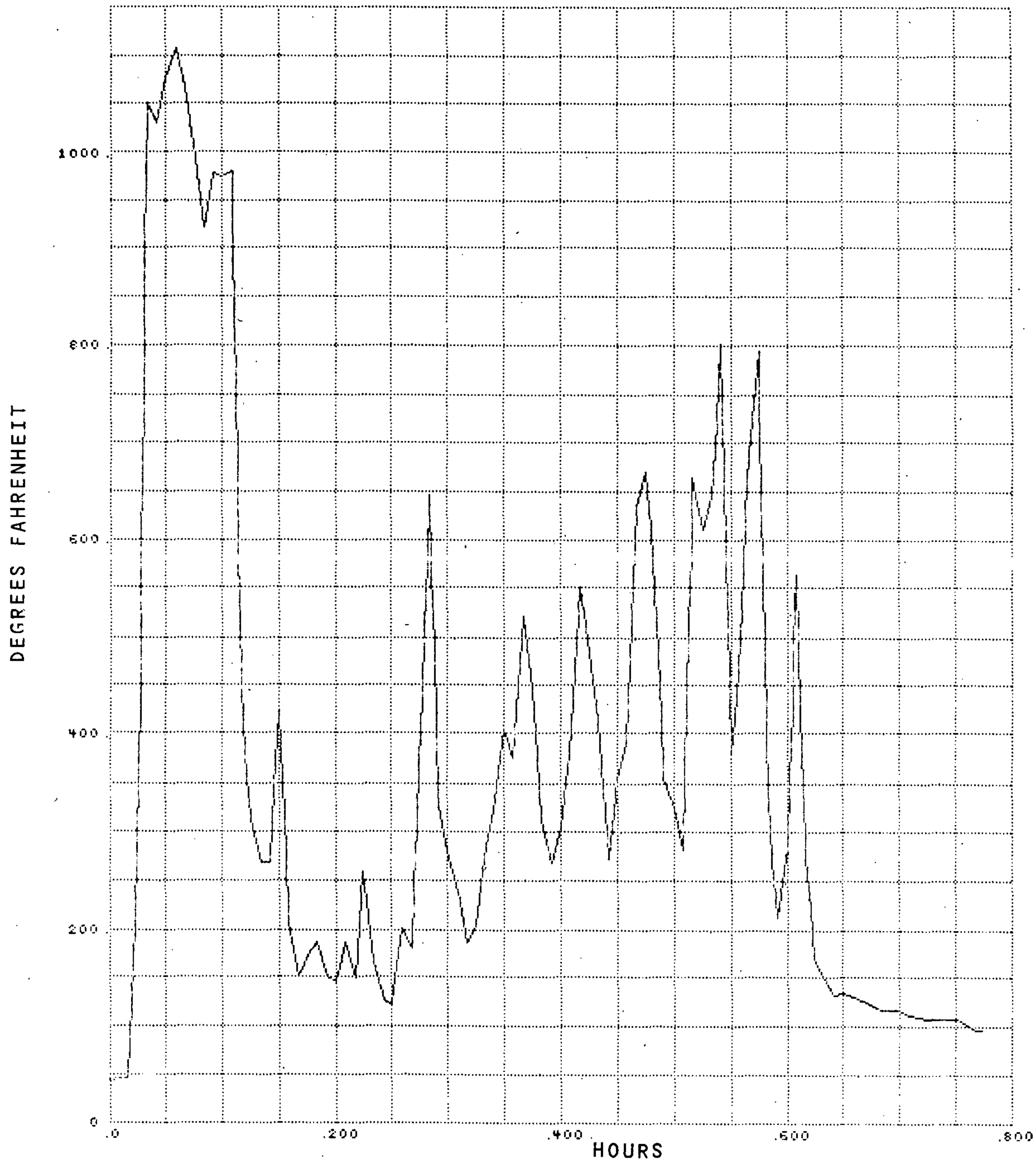

Figure B-2. Burn Test Number 48B, Channel 1, West Burner

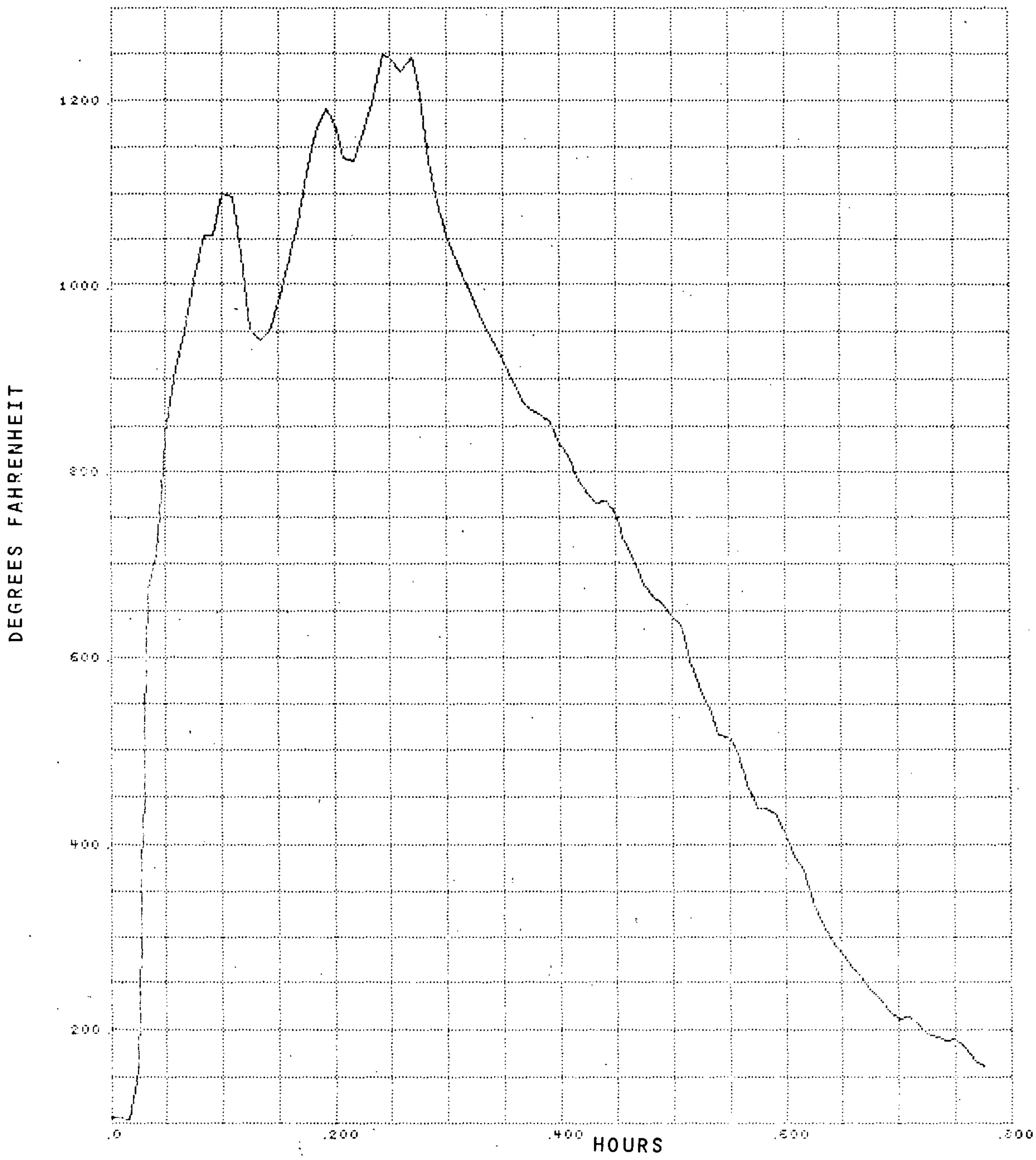

Figure B-3. Burn Test Number 48B,
Channel 2, East Lower Tray

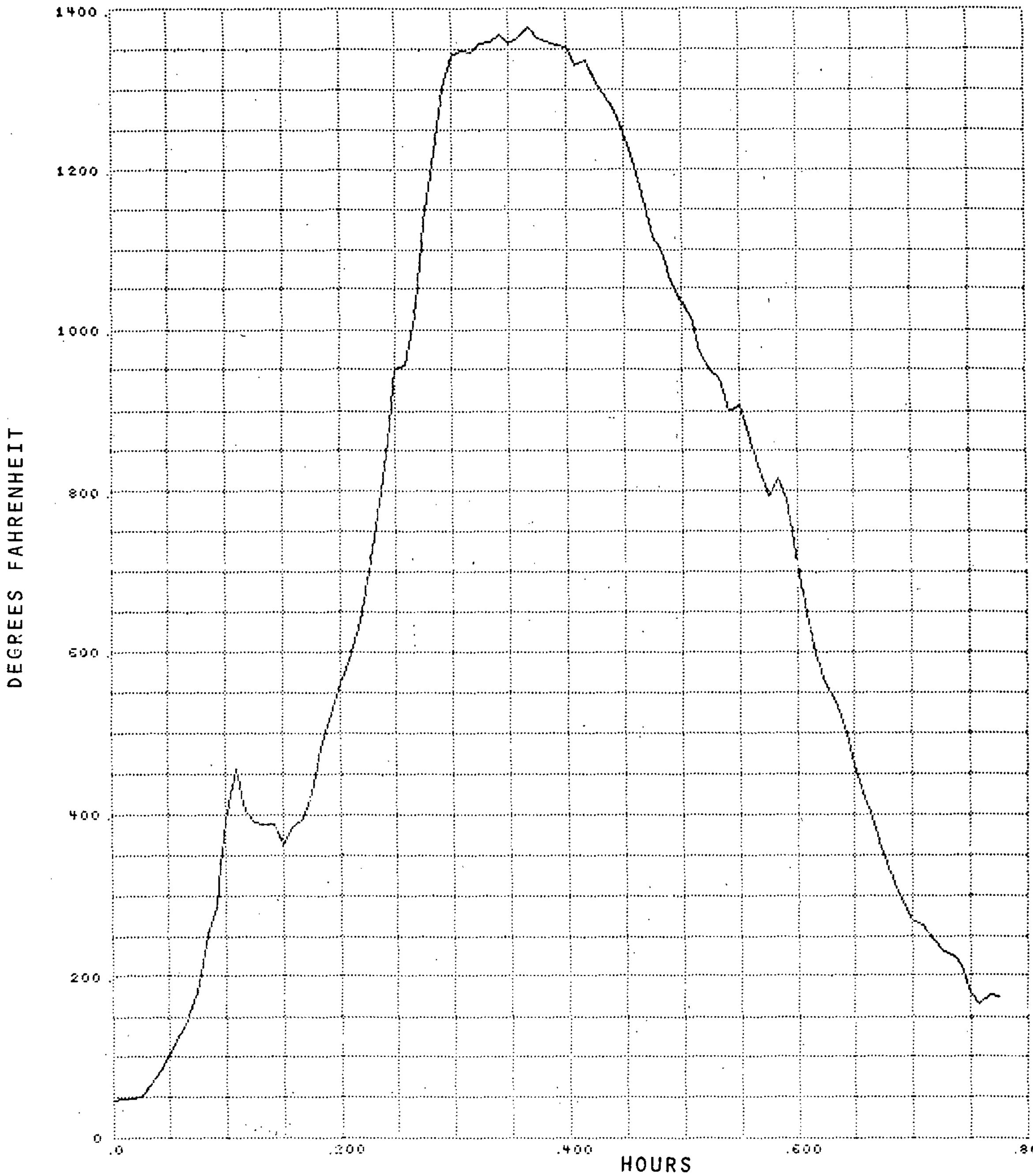

Figure B-4. Burn Test Number 48B, Channel 3, Center Lower Tray

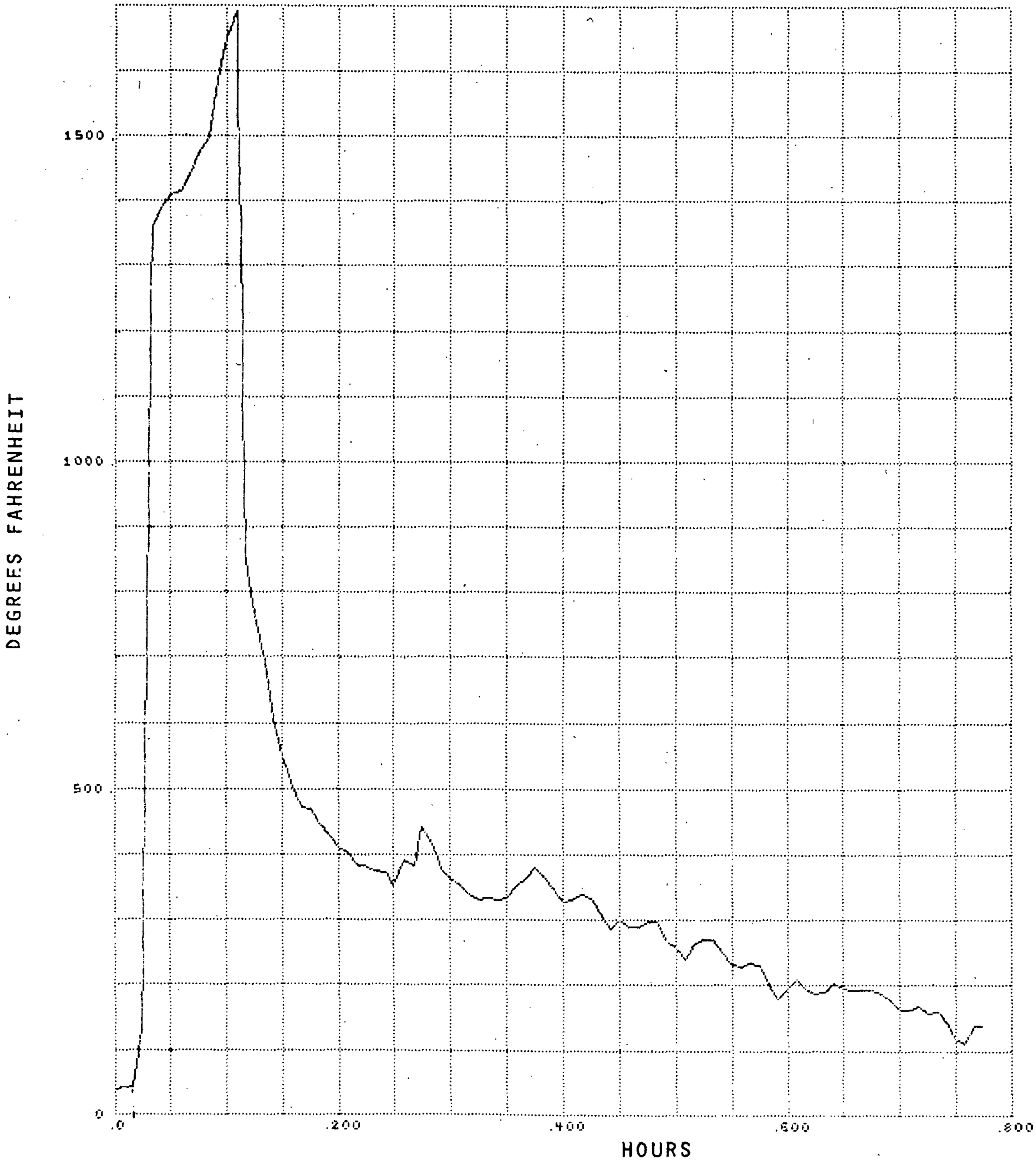

Figure B-5. Burn Test Number 48B,
Channel 4, West Lower Tray

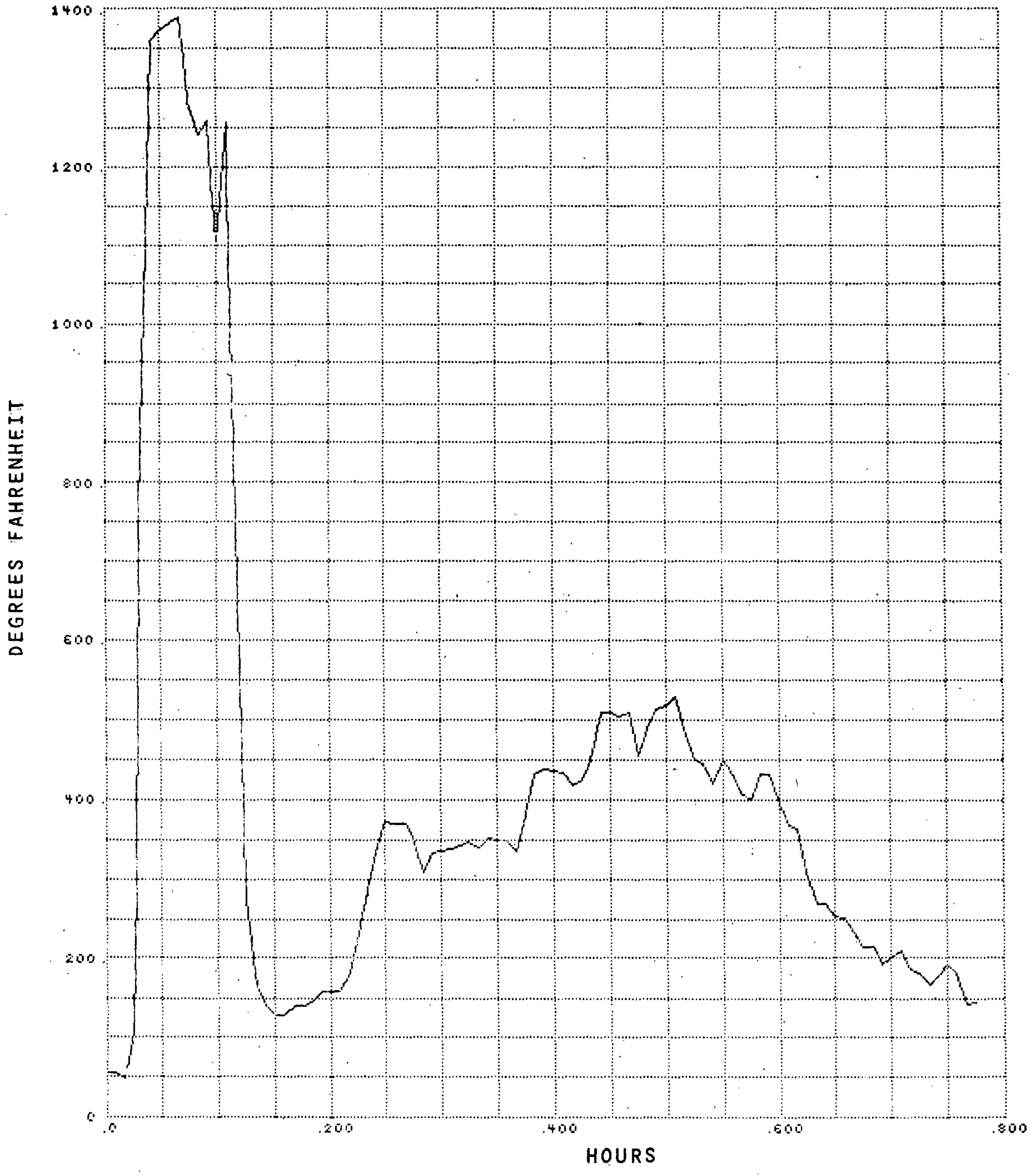

Figure B-6. Burn Test Number 48B,
Channel 5, East Lower Barrier

6

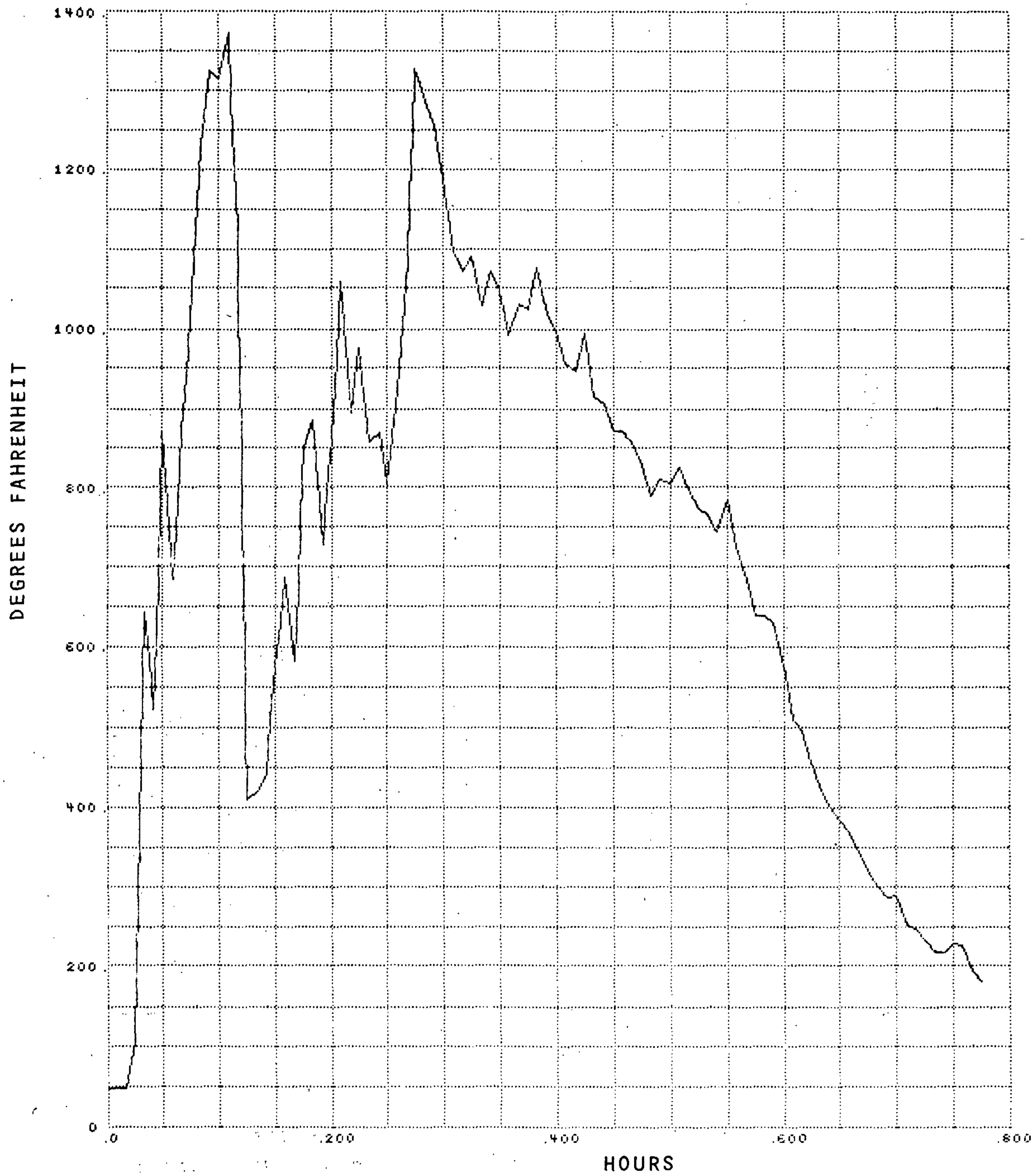

Figure B-7. Burn Test Number 48B,
Channel 6, West Lower Barrier

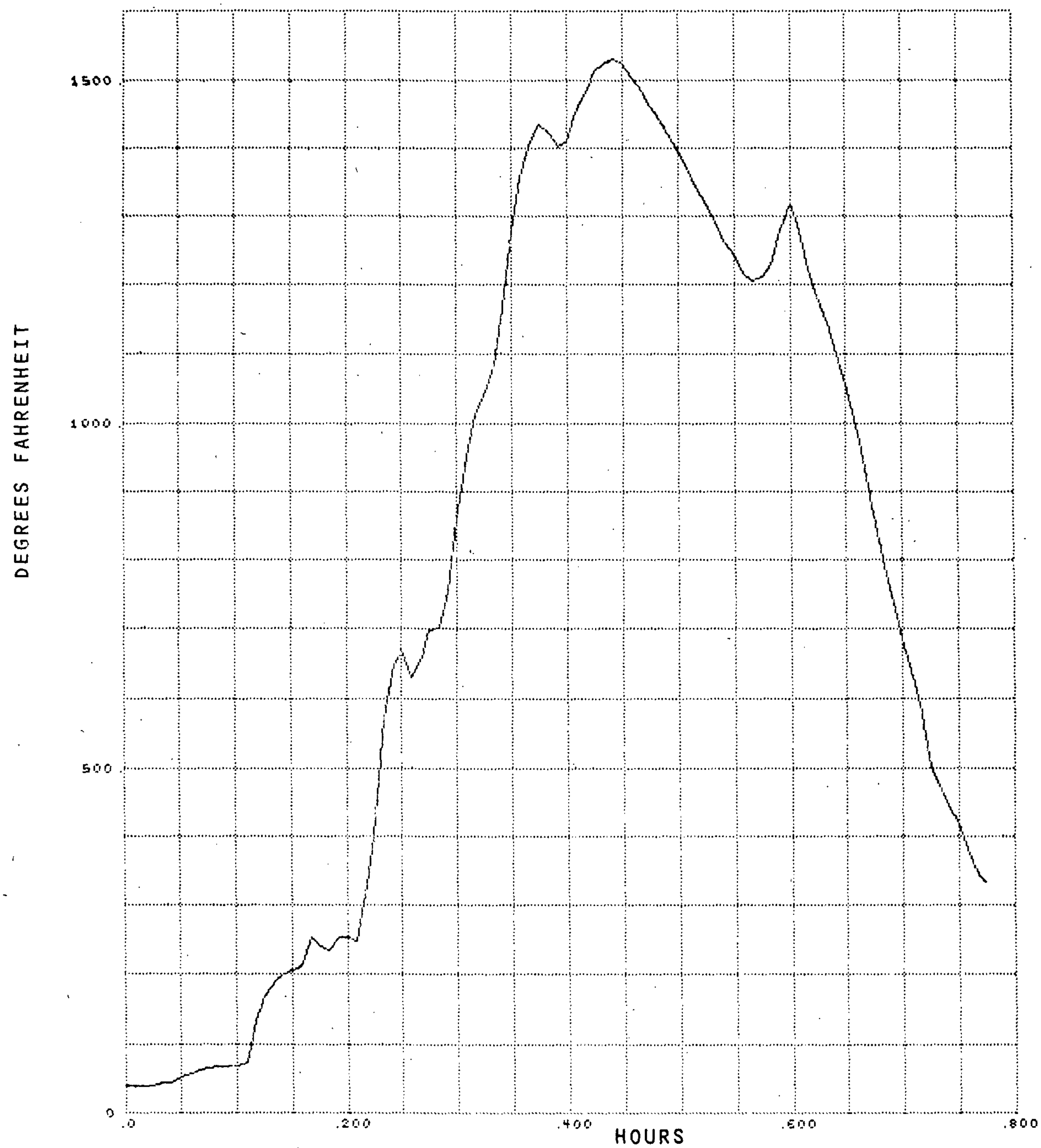

Figure B-8. Burn Test Number 48B,
Channel 7, East Upper Tray

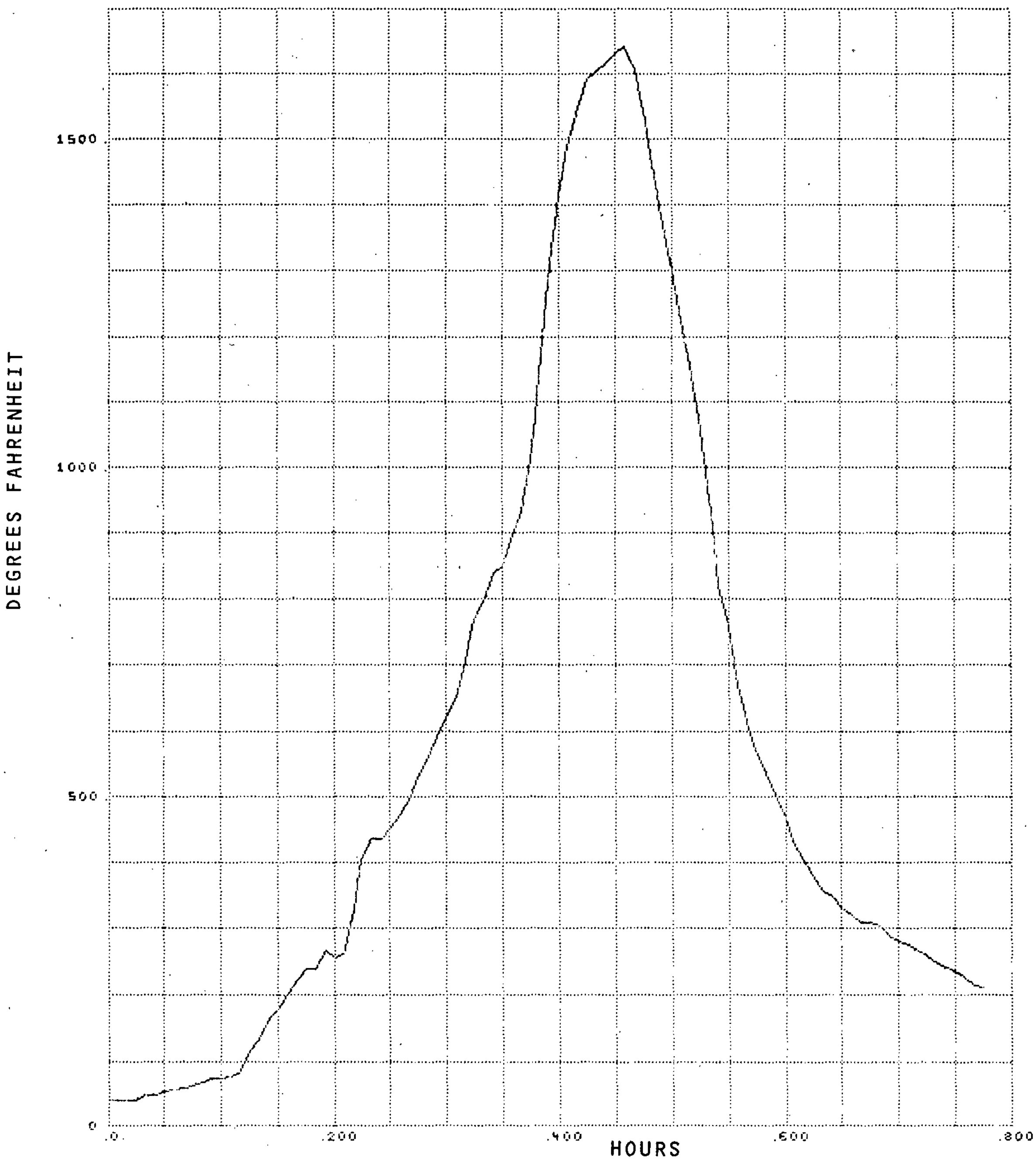

Figure B-9. Burn Test Number 48B,
Channel 8, Center Upper Tray

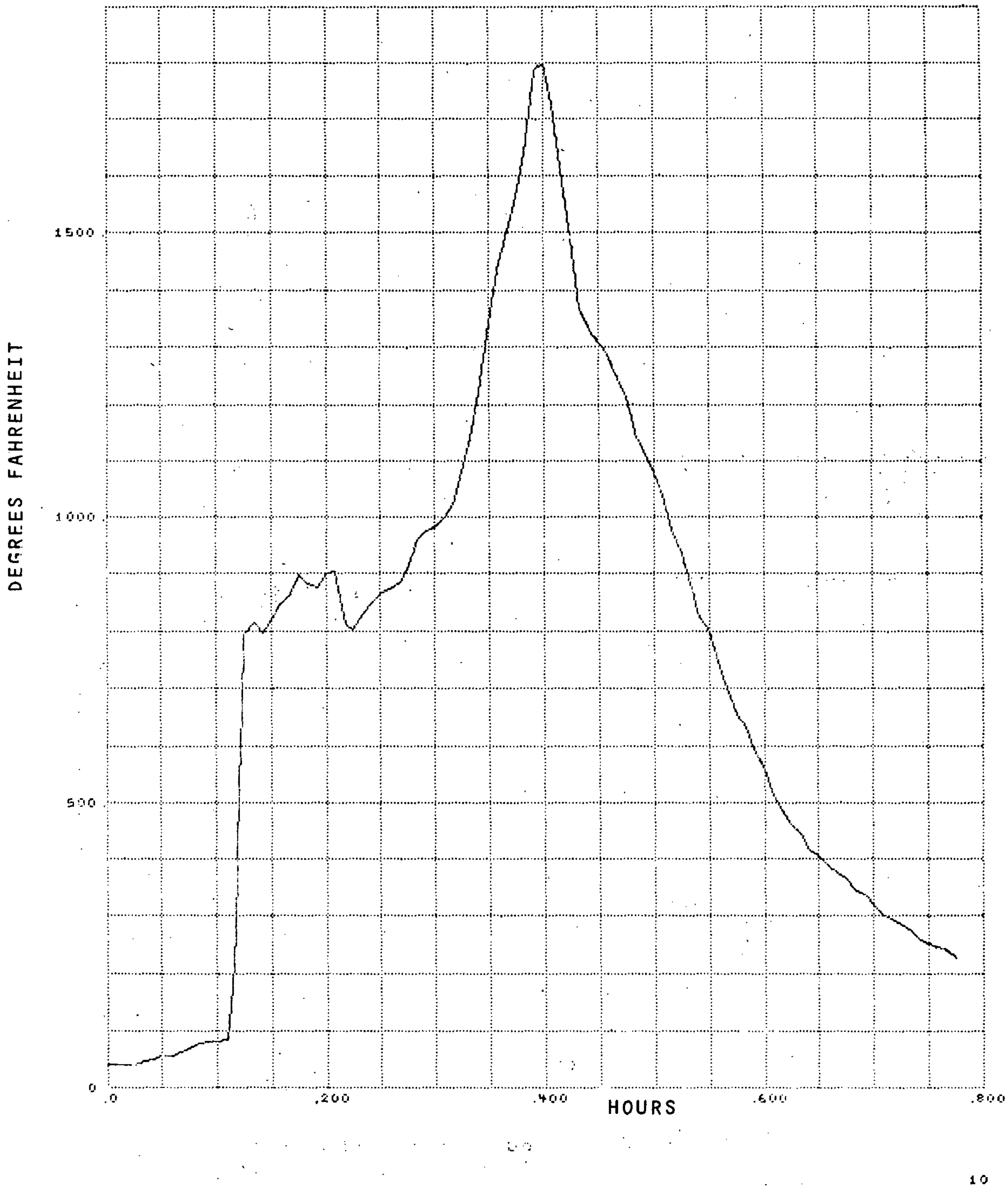

Figure B-10. Burn Test Number 48B,
Channel 9, West Upper Tray

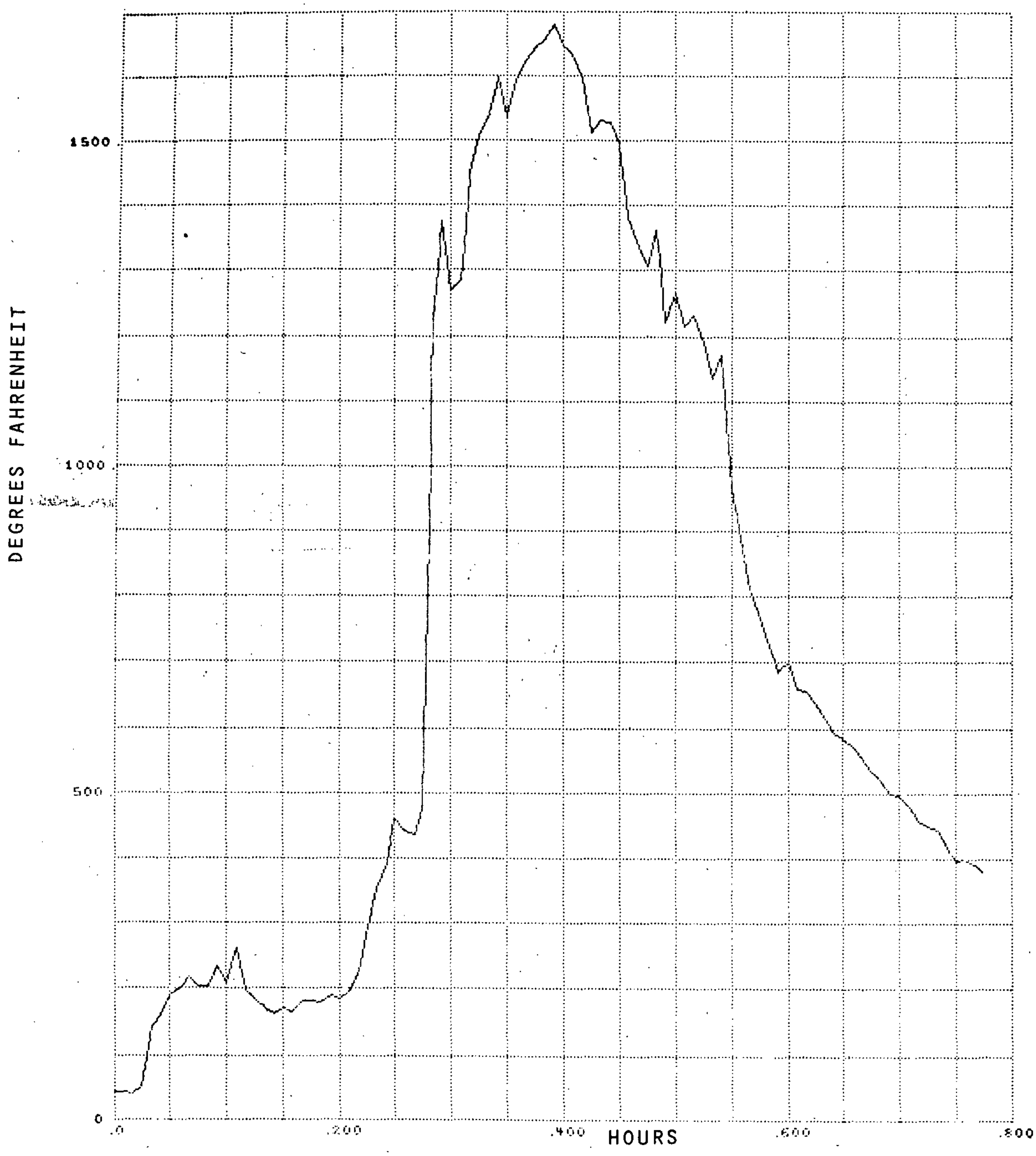

Figure B-11. Burn Test Number 48B, Channel 10, East Ceiling

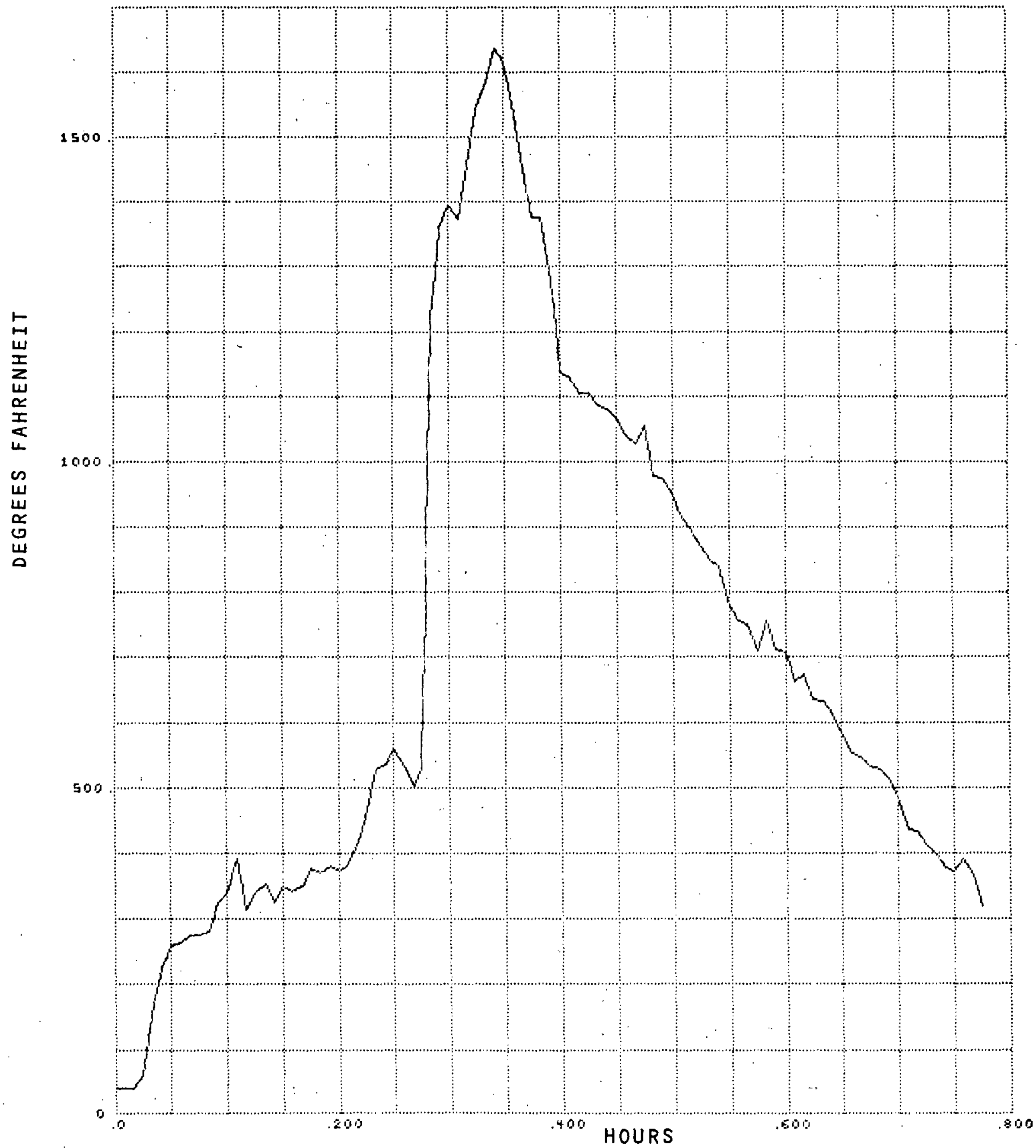

Figure B-12. Burn Test Number 48B,
Channel 11, West Ceiling

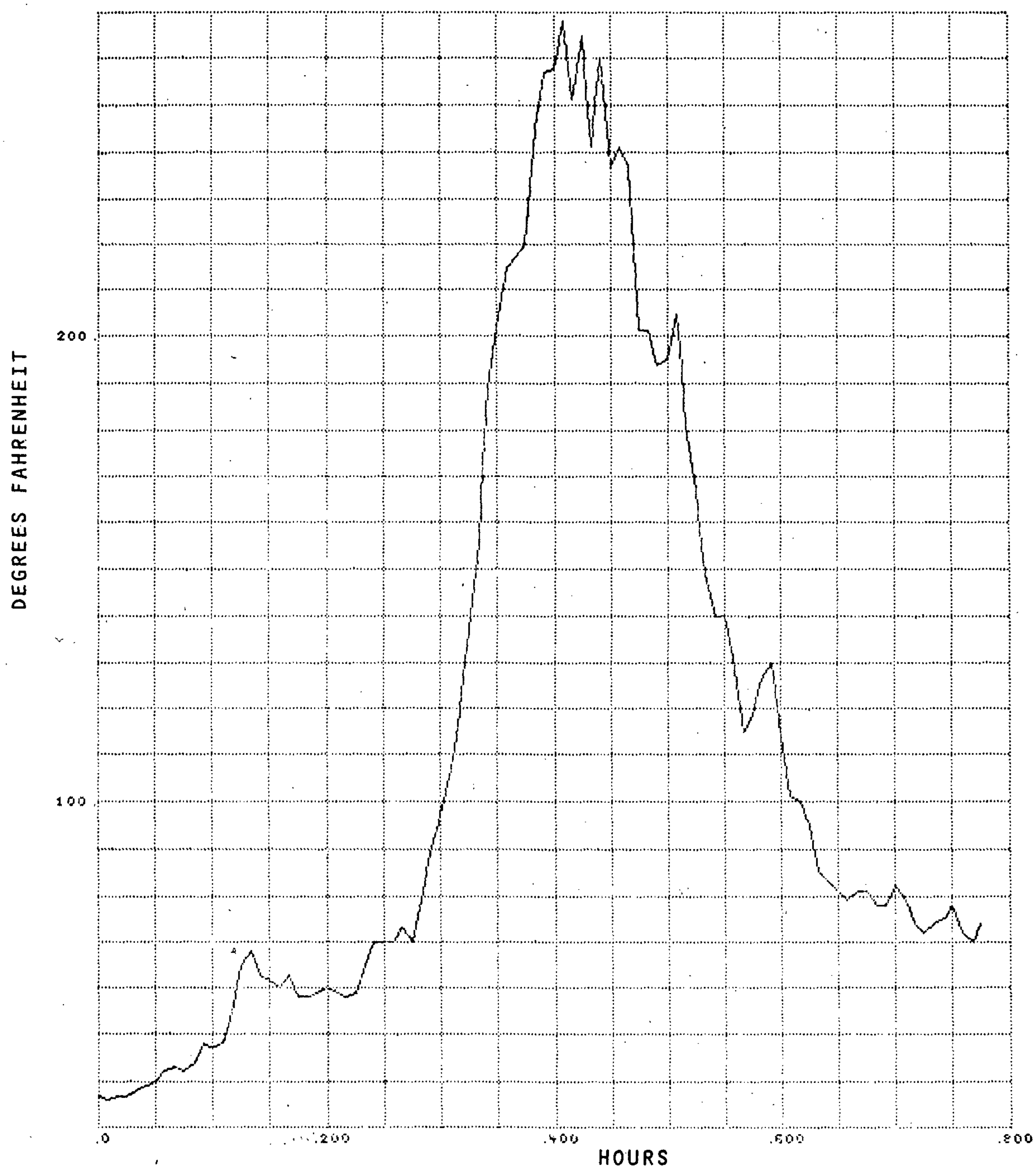

Figure B-13. Burn Test Number 48B,
Channel 12, North Tray East

8

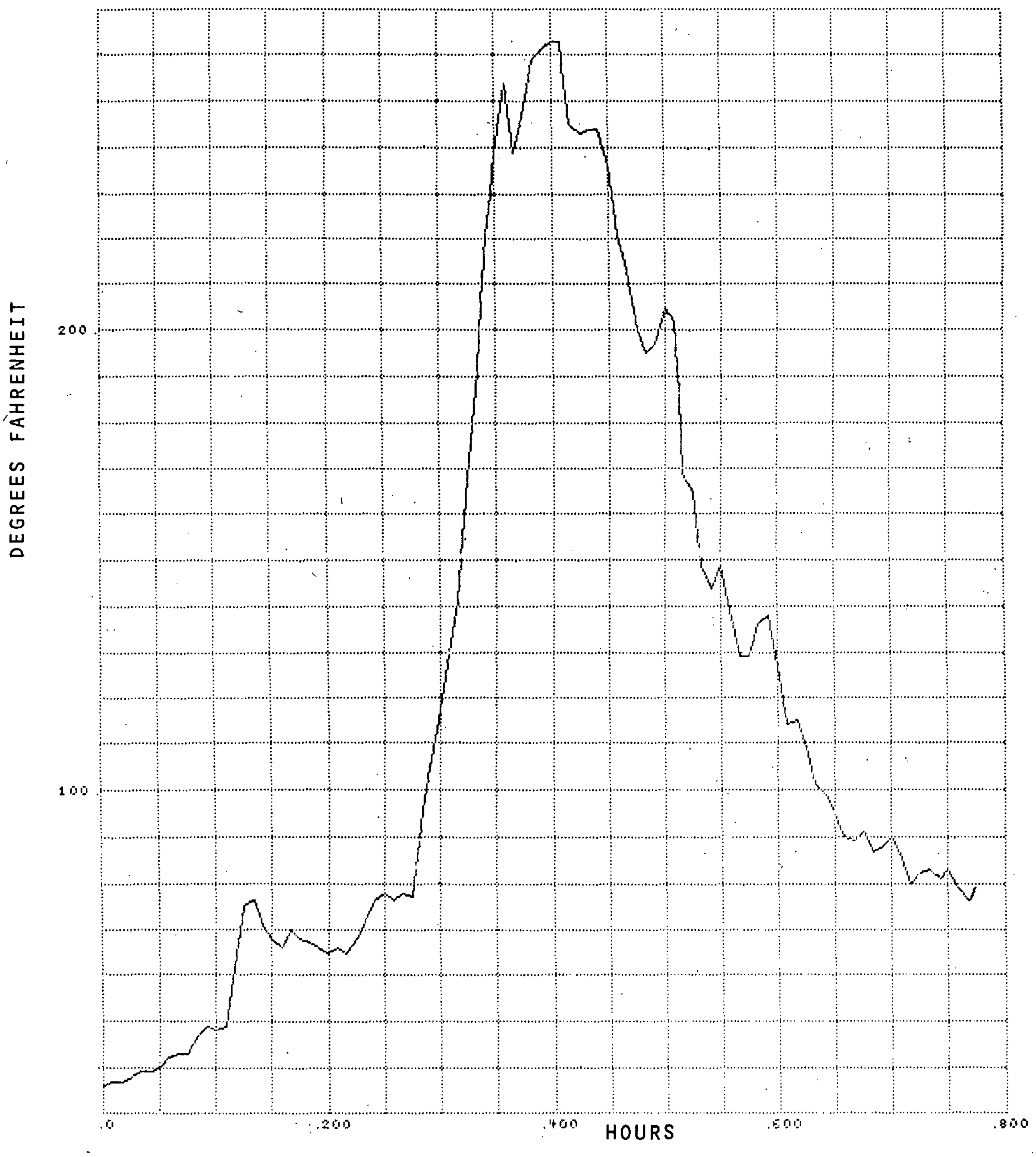

Figure B-14. Burn Test Number 48B,
Channel 13, North Tray West

14

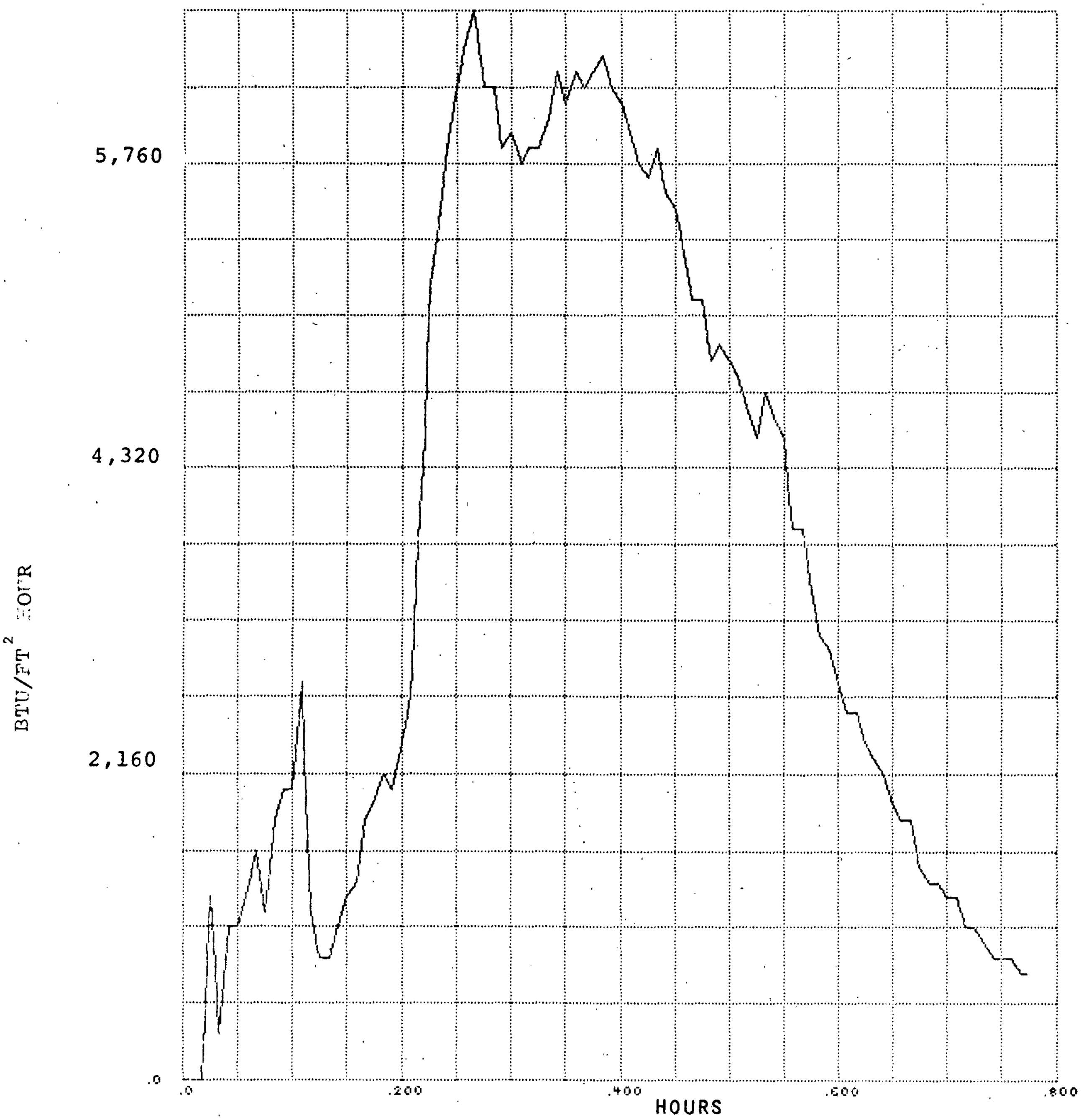

Figure B-15. Burn Test Number 48B,
Channel 22, Lower Heat Flux

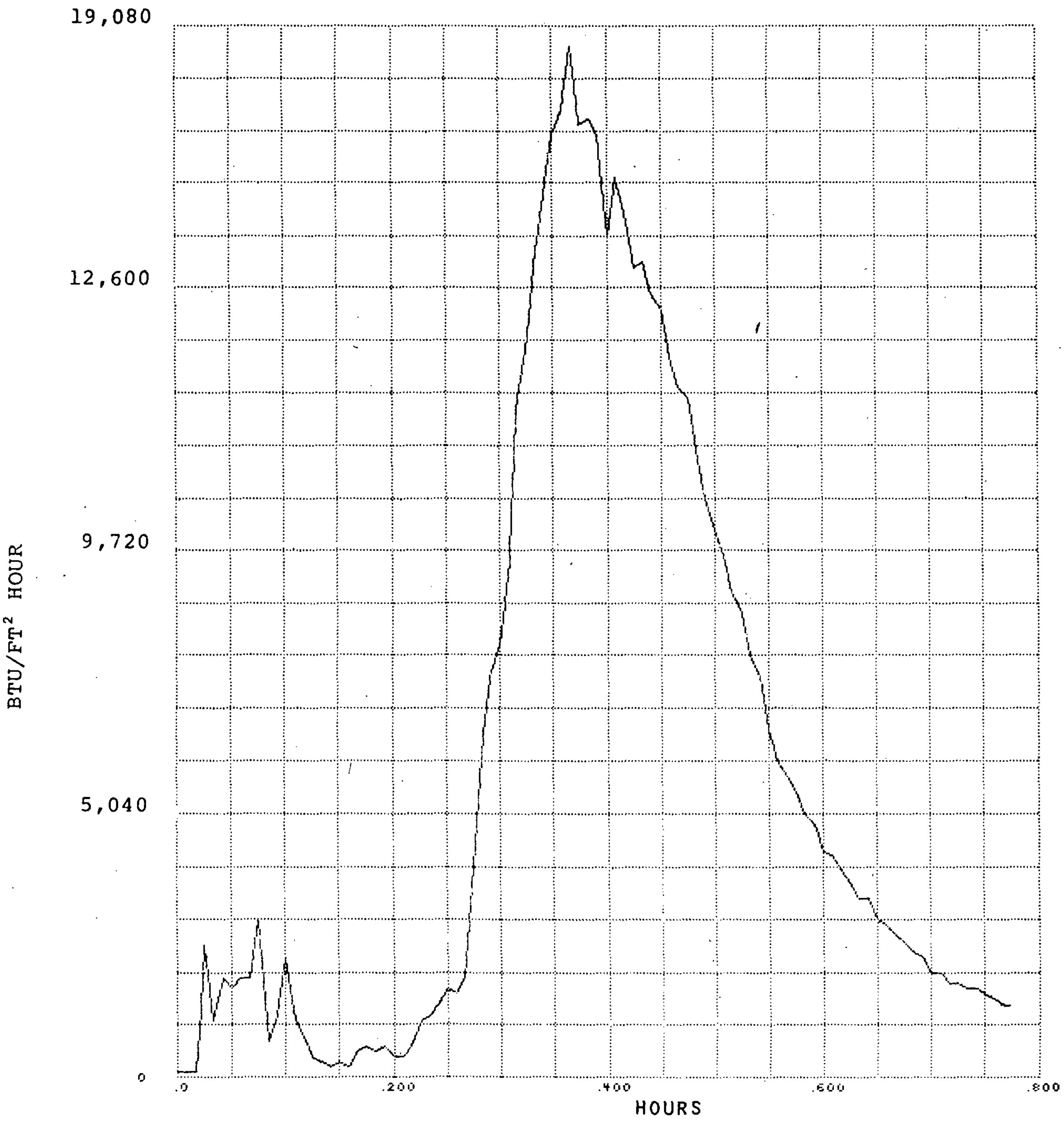

Figure B-16. Burn Test Number 48B,
Channel 23, Upper Heat Flux

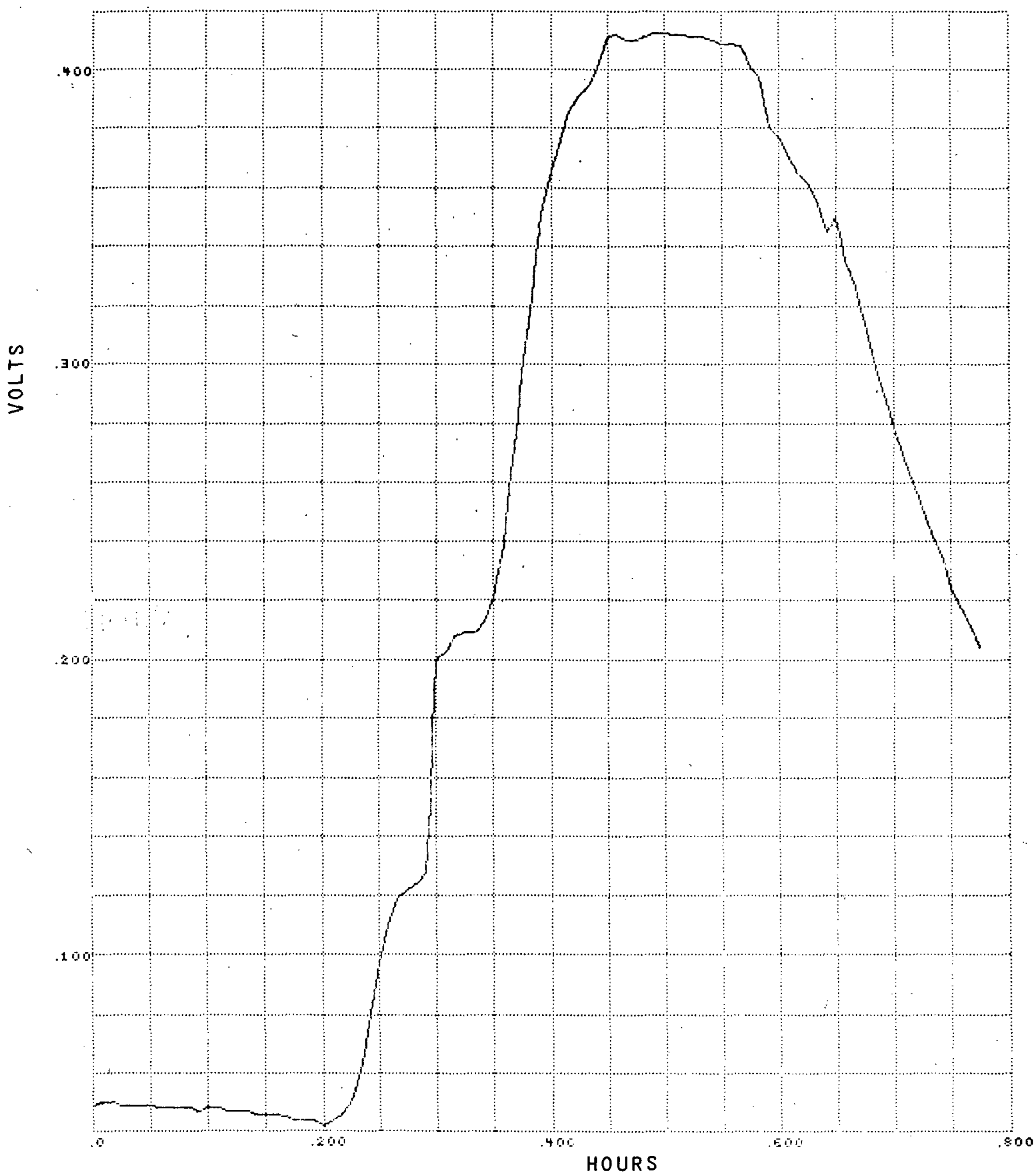

Figure B-17. Burn Test Number 48B,
Channel 24, Upper Tray Current

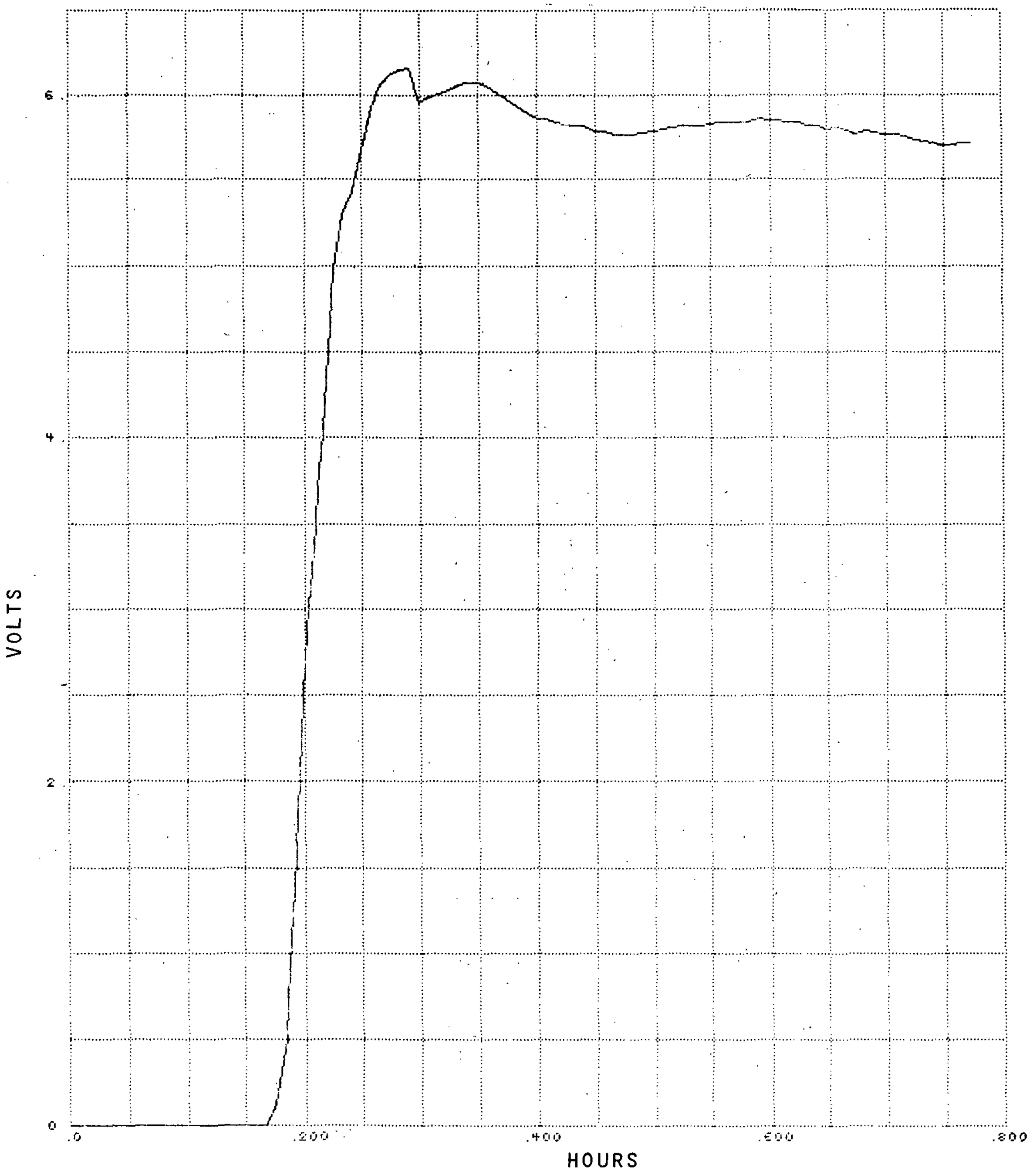

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Figure B-18. Burn Test Number 48B,
Channel 25, Upper Tray to Ground

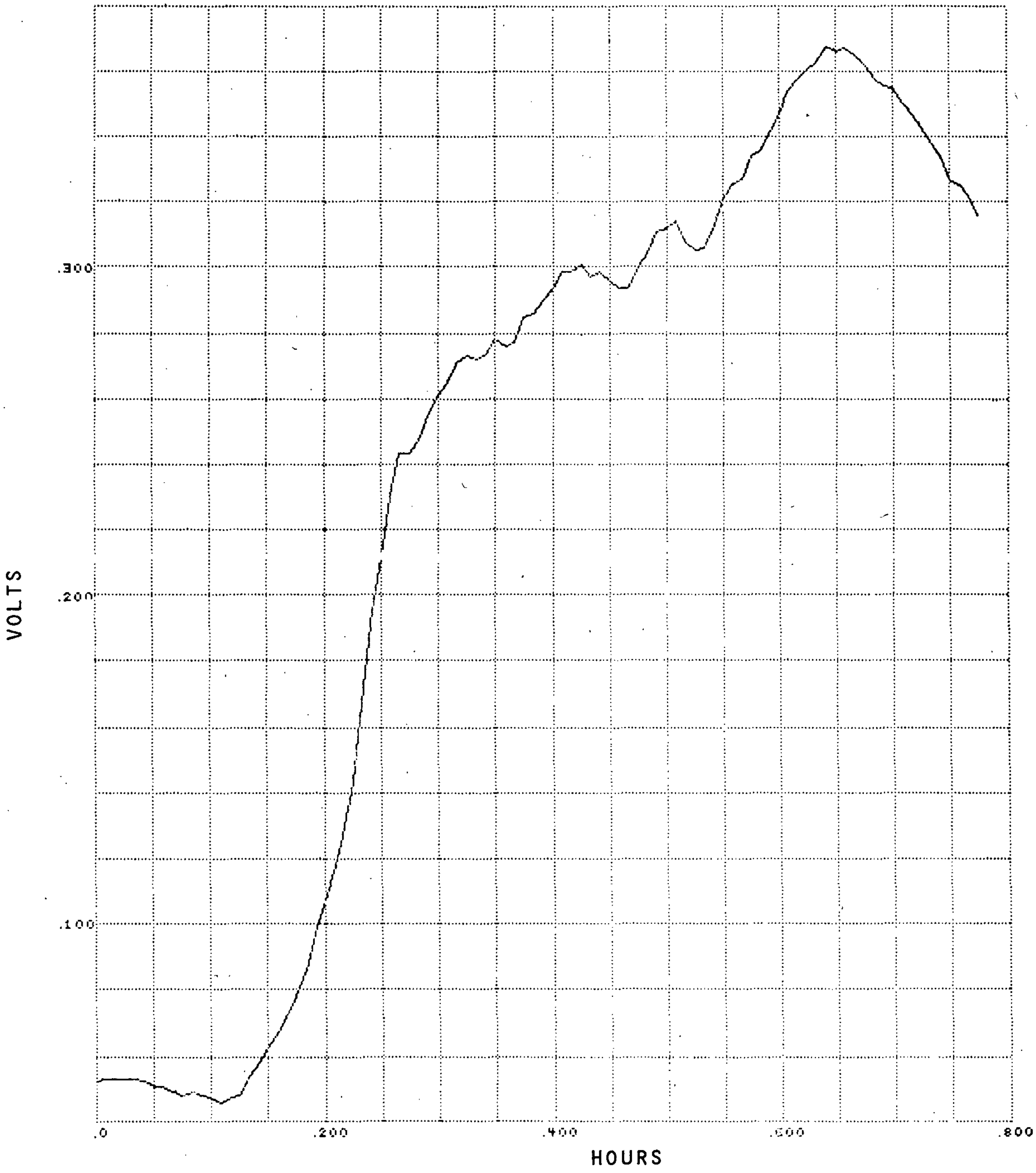

Figure B-19. Burn Test Number 48B, Channel 26, Lower Tray Current

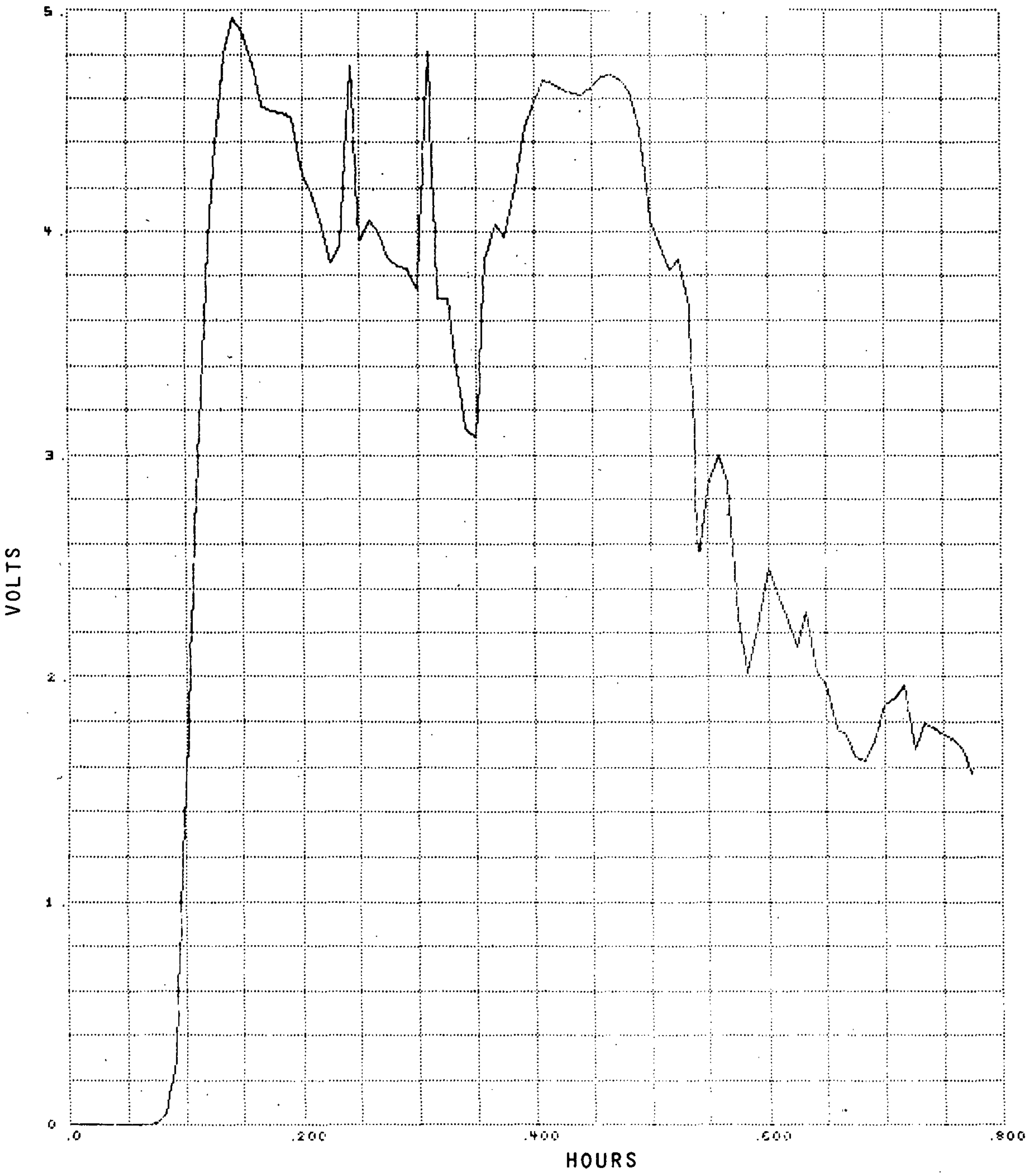

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Figure B-20. Burn Test Number 48B,
Channel 27, Lower Tray to Ground

Acknowledgements

The tests described in this report were ably performed by L. D. Lambert and P. D. Walkington. In addition, Appendix A on instrumentation was written by P. D. Walkington.

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