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DEVELOPMENT AND VERIFICATION OF FIRE TESTS FOR CABLE SYSTEMS AND SYSTEM COMPONENTS

Quarterly Reports 2 and 3
September 1, 1977 - February 28, 1978

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Abstract

Experiments were performed to define the effects of a number of test parameters on the results of vertical flame tests of tray-mounted cables in a configuration similar to that specified by IEEE Standard 383. Parameters considered were fuel input rate, fuel-air ratio, burner location, and test cell configuration. In order to reduce time and material costs for the experiments, the parameters were first investigated with an inert instrumented board to simulate a full cable tray. Measurements of temperatures and heat flux along the board were used to define the range of parameters to be used in experiments with actual cables. Full cable trays, 8 ft long, were used in these experiments; and observations were made of the flame travel distances and air temperatures on both faces of the tray, as well as temperature distribution along the jacket of one cable in each tray. Two burners of the type specified in IEEE 383, one at each tray face, provided the ignition source. Experiments with one cable type produced results which were extremely variable because of random movements of the cable bundle during burning. Since measures to remove this variability by permanently fixing cable positions would remove realism from the test, experimentation with full cable trays was discontinued. Measurements of jacket temperature distribution obtained in these experiments indicated that it may be possible to determine the upward progression of cable damage in that way. Future experiments to study the effects of test parameters on the IEEE 383 standard test are outlined.

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Development And Verification Of Fire Tests For Cable Systems And Components

I. Introduction

This is a combined second and third quarterly report covering the period September, 1977 through February, 1978. During the report period, the activities were concerned with separate effects tests being conducted as a part Task A of the contract work scope.

Activities reported in the previous quarterly report led to a test plan for better defining test parameters of an IEEE-383 type fire test. The planned experiments which were carried out during the report period being addressed here involved consideration of the following parameters:

1. Burner variables
    a. Fuel input rate
    b. Fuel-air ratio
    c. Burner location

2. Test cell size and configuration

3. Cable material
    a. PVC/Nylon
    b. EP/Hypalon
    c. XLPE/Neoprene

It was intended to maintain as much similarity to the IEEE-383 test as possible, but to conduct the tests with full cable trays (nominally 40 percent fill) in order to more closely simulate worst case conditions. The use of full cable trays dictated that a two-burner arrangement be used, one at each face of the tray with half of the fuel flow supplied to each burner.

In order to conserve time and reduce the material costs for these tests, a series of measurements was performed using an instrumented inert surface to simulate a full cable tray and to determine the effects of burner variables on the characteristics of the flame. This series is referred to as burner sensitivity experiments. Measurements of temperatures and heat fluxes, as well as visual observations of flame size and stability, were used as an initial screening of the sensitivity of the test to burner and enclosure variables.

Information obtained from the burner sensitivity experiments led to the definition of 11 experiments using full cable trays to obtain information not available from the burner sensitivity experiments. This included data on the reproducibility of the test; the effects of ambient temperature, fuel input, fuel-air ratio, enclosure size, and cable type; and estimates of ventilation required for removal of combustion products. As described later, the full series was not carried out because of problems with reproducibility. The procedures followed and results are briefly described in the following sections.

II. Experimental Procedure

A. Facility

The burner sensitivity and cable experiments were conducted inside various heated buildings. The buildings were ventilated and free from excessive drafts and spurious air currents.

During the cable experiments all exterior doors were closed and all roof vents in the building were opened. The roof vents were ducted to an exhaust and smoke incineration system. The nominal volumetric flow rate through the afterburner system was 16000 cfm, which corresponds to one air change every 9 min. The building had sufficient air leakage that atmospheric pressure was maintained while the incinerators were in operation.

B. Apparatus

The burner apparatus consisted of two burner heads and a Venturi air-fuel mixer as described in IEEE 383-1974. The burner heads were 10 in. wide, 11-55 drilling, ribbon burners, and the mixer was a No. 14-18. Both were manufactured by the American Gas Furnace Co. Bottled commercial grade propane and laboratory compressed air were used in the experiments. A sketch of the burner apparatus is shown in ILL. 1.

C. Enclosure

An enclosure 8 by 8 by 8 ft high was used to isolate the sample from extraneous environmental effects as shown in ILL. 2. It was formed by four steel-framed wall sections, 8 ft square, to which 1/2 in. Marinite boards were fastened. Marinite boards were manufactured predominantly from inorganic materials and are Classified as to fire hazard as 0 flame spread, fuel contributed, and smoke developed. The sections were clamped together at the four corners so that each could easily be raised or lowered independently. The interior surfaces of the enclosure were painted flat black. Several observation windows and an access door were provided.

D. Samples

Burner sensitivity experiments were conducted with an instrumented board in lieu of cable samples as shown in ILL. 3. The board was 8 ft high and 12 in. wide and consisted of a steel frame to which a 1/2 in. Marinite board was fastened. The exposed surface of the board was painted flat black.

Cable experiments were conducted using open-ladder trays, 8 ft long and 12 in. wide. The side channels were 3-3/8 in. deep with 1 in. flanges and fabricated from No. 16 MSG (0.060 in. thick) cold-rolled steel. The No. 10 MSG (0.125 in. thick) ladder rungs were 1 in. wide with 1/2 in. legs tack-welded to the side rails at 9 in. intervals. Steel wire ties formed from No. 16 SWG (0.062 in. thick) were used to fasten the cables to the top and bottom rungs of the cable trays. Nylon ties were used at various other locations to maintain positioning of cables prior to test (except in experiment 6).

The cables used in these experiments were stranded seven (copper) conductor, No. 12 AWG with PVC conductor insulation, nylon conductor jacket, and PVC cable jacket. The cable jacket thickness was 0.050 in. The conductor jacket was 0.006 in. thick and the insulation thickness was 0.022 in. The overall cable diameter was 0.515 in.

The tray loading in all the experiments was 40 percent. Cables were arranged in a pattern as shown in ILL. 4. This pattern was developed to attain an interweave of cables which would be reproducible from experiment to experiment. Each pair of cables was secured to the trays with steel wires placed at the bottom and top rungs. Nylon ties were then used at every third ladder rung along the remaining cable tray length, except in experiment 6. In this experiment, the cables were fastened as described above but with all steel ties.

E. Instruments

Instruments used to measure the properties of the environment in the burner sensitivity and cable sample experiments were as follows:

1. Heat Flux - Seven Gardon type calorimeters manufactured by HyCAL were used to measure the heat flux incident on the instrumented board in the burner sensitivity experiments.

2. Temperature - In the burner sensitivity experiments, Type K Chromel-Alumel thermocouples were used to measure the air, board surface, propane and combustion air temperatures. In the cable experiments, similar thermocouples measured air, cable jacket, propane, and combustion air temperatures. The unshielded board-surface and cable-jacket thermocouples formed from 0.005 in. and 0.010 in. diameter wire, respectively. The remaining thermocouples were shielded and formed from 22 ga wire.

3. Flow Rate and Pressure - Pressures of the fuel and air within the burner apparatus piping were measured with differential pressure manometers. Rotameters were used to measure propane and combustion-air flow rates. An orifice meter was used ahead of each burner to monitor equivalent flow to each burner in the cable experiments.

4. Oxygen Concentration - The concentration of oxygen in the air entering the test enclosure during the cable experiments was measured with an oxygen cell manufactured by the Bacharack Instrument Co.

5. Air Velocity - The velocity of the air entering the bottom openings of the enclosure was measured with a hot-wire anemometer.

6. Recorders - Electrical signals from the various thermocouples, oxygen cell, and calorimeters were recorded by various line and multiple point recorders.

F. Method

Burner Sensitivity Experiments - Forty-two burner-sensitivity experiments were conducted as shown in Tables 1-3. The object of these experiments was to investigate the effects of burner-to-board spacing, air/fuel ratio , fuel-supply rate, and the size and configuration of the inlet openings at the bottom of the enclosure. Visual observations of the flame as well as temperature and heat-flux measurements were used to judge these effects.

The burner sensitivity experiments were conducted with the instrumented board located at the center of the enclosure. Initially, the enclosure was placed on the floor with no bottom inlet openings. However, during experimentation, various sections of the enclosure were raised and lowered to observe the effect of the opening geometry on the visual appearance of the flame. Raised sections were supported at the corners on concrete blocks.

The burner apparatus consisted of one burner head and mixer as described in IEEE 383-1974. Two sheets of Marinite board were placed along-side of the board sample to divide the enclosure in half. The purpose of dividing the room in half was to simulate the two-burner condition used in the cable experiments. A sketch of the enclosure and apparatus is shown in ILL. 2.

Flow meters were used to measure the air and propane flow rates for each experiment. A continuous record of propane weight was used as a check in determining the flow rate for each experiment. Nominal heat-release rate of the burners was calculated from the flow rate and the heating value of propane. However, the actual heat output of the flame for each experiment may have been slightly less than the calculated value as a result of incomplete combustion and impurities in the commercial grade propane used. Exact heat release rates of 35,000; 70,000; and 105,000 BTU/Hr were not obtained since only qualitative performance data was desired.

Temperatures of the air approximately one inch from the board surface were measured with fifteen Type K thermocouples. Temperatures of the board surface were measured with fifteen Type K thermocouples. These thermocouples were recessed into a small grooved impressed in the board surface. Thermocouple locations are shown in ILL. 3.

The heat flux incident on the board sample was measured with seven calorimeters (ILL.), and the temperatures of the propane gas and air in the burner apparatus were measured just prior to the mixer.

The general pattern for the experiments was to vary the air flow rate for each burner distance and fuel input under consideration. The burner height was adjusted in each experiment so as to provide maximum flame impingement at 12 in. above the base of the board sample. Each experiment was continued until steady state conditions were reached, as indicated by the calorimeters. Throughout each experiment, visual observations were made of the character of the burner flame. The experimental sequence is shown in Tables 1-3.

Cable Sample Experiments - Originally, eleven cable experiments were planned. The object of the experiments was to determine effects of fuel input, air/fuel ratio, cable type, enclosure geometry, and cable material on the outcome of cable fire tests.

However, only six cable sample experiments were conducted. The cable sample experiments were conducted within the enclosure with the front and rear wall sections raised above the floor to provide 12 in. high air inlets at floor level. The cable tray specimen was placed at the center of the enclosure.

Two burner heads were used to provide an ignition source on each side of the cable tray sample. Previous testing had shown that when 40 percent filled trays are fire tested, a burner on each side of the tray was required to provide a uniform ignition source for the sample. The flow rates of fuel-air mixture to each burner head were controlled by globe valves placed between the mixer and the burners.

Initially, pressure was measured at the inlet to each burner head in order to balance the flow rates in the burners. However, it was later decided that this might not be sufficient. Therefore, orifice meters were installed ahead of each burner to balance the flow rates in the remaining experiments. Pressure differentials across the orifices were balanced prior to and monitored during each experiment, but the orifices were not calibrated to provide an absolute measurement of flow rate. Rotameters were used to measure the air and propane flow rates, and the indicated rates were corrected for the actual temperatures and pressures of the air and propane. The air/fuel ratio for the experiments was 8 to 1, and the nominal heat release rate was 70,000 BTU/Hr.

Temperatures of the air approximately 3/8 in. away from the front and rear plane of the cable tray were measured with shielded Type K thermocouples located as shown in ILL. 5.

Temperatures of the cable jacket of one cable located in the approximate center of the top layer were measured with 8 thermocouples in experiment 1, and 14 thermocouples in the remaining experiments, as shown in ILL. 4. Each thermocouple was recessed into a notch in the cable jacket, and the groove was filled with a one-part silicone adhesive to fasten the thermocouple to the cable.

Temperatures within the center of the cable bundle along the centerline of the cable tray were measured with four thermocouples, as shown in ILL. 5. Additional thermocouples were used to measure the temperatures of the air entering the front and rear inlets to the enclosure, and the temperatures of the propane gas and supply air before the mixer.

Also, the oxygen deletion and velocity of the air entering the enclosure through the front and rear inlets were measured.

Each cable sample was subjected to the ignition flame for the entire duration of the test, and total test time varied from experiment to experiment. A test was generally terminated when the fire activity had diminished to only the ignition-flame region or when the entire sample was involved in flame, and additional temperature measurements would not be useful.

Throughout each test, visual observations were made of the character of the ignition flame, the condition of the cable material, and flame travel.

III. Results And Discussion

A. Burner Sensitivity Experiments

One parameter under consideration in these experiments was the air/fuel ratio. The air/fuel ratio was varied from 2.5/1 to 11/1. Presently, the NRC regulatory guide 1.131 specifies a 5/1 ratio for the cable qualification tests. Under the previous NEL-PIA investigation the air/fuel ratio was 3/1 for the conducted cable fire tests.

At the minimum air-fuel ratio for any specific burner distance the flame appeared very long and luminous. The flame was sporadically blown away from the board sample with the flame ends curled back toward the center of the flame as shown in ILL. 6.

At the maximum air-fuel ratio for any specific burner distance the flame appeared mostly blue in color. The flame produced a very local high temperature region at the point of contact with the board sample.

The effect of increasing the fuel input was that the flames became longer and impinged for a greater length along the surface of the board sample. For example for the nominal 105,000 BTU/Hr flame reached an approximate maximum height of 3 ft, 6 in. as shown in ILL. 7, while the nominal 35,000 BTU/Hr flame reached an approximate maximum height of 2 ft.

At each fuel input and air/fuel ratio, there existed a maximum burner spacing. If exceeded, the flame tended to detach from the board surface and the flame ends would curl toward the center of the flame. Also, there existed a minimum burner spacing below which the flame appeared to deflect off the board sample and issue back under the burner head as shown in ILL. 8.

A range of usable burner spacings was visually observed for each fuel rate and air/fuel ratio. The usable spacings increased with increasing input and air/fuel ratio.

The combustion air and board temperatures recorded were found to vary greatly during an experiment. Even when a flame appeared visually to be uniform and steady, the temperatures fluctuated producing a large temperature range for each experiment. Therefore, heat flux measurements were used as a qualitative comparison of flame performance.

ILL. 9 shows a graph of incident heat flux versus distance from the burner for various air/fuel ratios for the nominal 105,000 BTU fuel input. The amount of heat flux on the sample was approximately twice as great near the burner as compared to a 35,000 BTU/Hr fuel input shown in ILL. 10. Also, the same amount of heat flux was obtained at a location approximately twice the distance from the burner for the 105,000 BTU/Hr fuel input as compared to the 35,000 BTU/Hr fuel input. This together with the visual observation of a large flame with respect to an 8 ft sample, was the basis for not considering a 105,000 fuel input (210,000 two burner system) for the cable experiments.

The 35,000 BTU/Hr fuel input graph shown in ILL. 10 plots the heat flux for air/fuel ratios from 3/1 to 10/1. It was noted that the heat flux curves for ratios of 6.5/1, 8/1, and 10/1 were early identical. Thus, a slight change in air/fuel ratio within this range should have little effect on flame behavior. It was noted also that the 8/1 air/fuel ratio produced a very uniform and steady flame (exp. 18), as shown in ILLS. 11 and 12. Therefore, it was judged that the burner parameter for the cable sample experiments be established as 35,000 BTU/Hr fuel input with a 8/1 air/fuel ratio at a burner spacing of 2-3/4 from the tray sample.

B. <u>Cable Sample Experiments</u>

Originally eleven cable experiments were planned as shown in Table 4. The first three experiments were to be conducted to determine reproducibility of the test method.

Also, the object of two experiments was to demonstrate how the air/fuel ratio may affect cable burning, even though the incident heat flux to the board sample was insensitive to the air/fuel ratio in the range considered.

Additionally, it was intended that an experiment be conducted with an increased fuel input of 70,000 BTU/Hr per burner (140,000 BTU/Hr total). Other considerations were ambient temperature, enclosure size, and cable type.

Although the performance of the cable under the exposure condition was of main interest, supplemental information on inlet opening air velocity and oxygen depletion were recorded for each experiment.

A summary of the results of the six experiments conducted are shown in Table 5. The visual observations for the experiments were as follows:

> The general fire performance of the cables observed in each experiment was for the cable material to melt in advance of the flame. The melted cable material filled the voids between cables, then coagulated forming one cable mass. Flaming generally occurred on the surface of the coagulated mass. Fire activity was dependent upon the manner in which the coagulated mass formed.
>
> In experiment 1, flaming gradually traveled along the front surface up to approximately 6 ft at 13 min. Then, the flaming appeared to diminish over the front surface but the flaming then progressed along the surface of the cable mass at the western side rail of the cable tray. Flaming on rear surface was less than on front surface reaching a maximum of 4.25 ft at 6 min. The experiment was terminated at 36 min.
>
> In experiment 2, flaming gradually traveled along the front surface reaching 5.1 ft at 13 min. The flaming was not uniform across the surface but traveled up the western side of the front surface at a greater rate. Flaming of the rear surface was less than on the front surface. Between approximately 20 min and 38 min flaming receded and fire activity was mainly restricted to the ignition flame region. However, after 39 min flames issuing from the center of the cable mass ignited the front surface and flames propagated very rapidly to the end of the tray by 41 min, 30 sec. The entire front surface was involved in flames at this time. The experiment was terminated at 47 min.

Flaming in experiment 3 was uniform across the front and rear surfaces and propagated steadily along the tray as shown in ILL. 13. Flaming reached 8 ft at 13 min on the front surface and at 19 min on the rear surface. The experiment was terminated at 23 min.

In experiment 4, flaming gradually traveled along the front surface reaching 5 ft, 6 in. at 9 min. Then, the flaming diminished over the front surface but the flaming then intensified and progressed along the cable mass near the western side rail to a maximum of 7.5 ft at 17 min. Flaming on rear surface propagated steadily to a maximum of 8 ft at 20 min. The experiment was terminated at 40 min.

In experiment 5, flaming gradually traveled along the front surface reaching 6 ft, 1 in. at 13 min. The flaming then diminished on the front surface while flaming along the surface of the cable mass at the western side rail propagated to a maximum of 6 ft, 8 in. at 16 min, as shown in ILL. 14. Flaming on rear surface propagated steadily to a maximum of 9 ft at 30 min. The experiment was terminated at 35 min.

Flaming in experiment 6 was the least as compared to the other experiments. Flaming was uniform across the front and rear surfaces. Flaming reached a maximum of 5 ft at 11 min on the front surface and a maximum of 6.5 ft at 42 min on the rear surface.

The damage to the front and rear cable surfaces is shown in ILLS. 15 and 16. The extent of damage varied significantly for each experiment.

The remaining planned experiments were not conducted since reproducibility of the test method was not established.

Initially, it was thought that the variation in fire activity and damage was a result of cold and possibly varying ambient temperatures. However, experiments 3 and 5 were conducted at approximately the same room temperature but produced significantly different results as shown in ILLS. 17 and 18.

Visual observations during the experiments noted that the amount and location of flaming and sustained damage was dependent upon the formation of the coagulated mass. The formation of the mass varied among experiments since it was dependent upon the location and amount of cable movement.

Experiment 6 was conducted with all steel ties so as to provide more restraint to the cable movement during fire exposure. However, due to the relatively small amount of cable movement during fire exposure a larger coagulated cable mass formed and decreased the fire activity as compared to other experiments.

Therefore, based upon the observations and measurements obtained, the following was concluded:

1. Random, unpredictable cable movement during fire exposure has a significant effect on fire propagation along the cables.

2. The random cable movement can be reduced by use of steel tie wires, but this greatly reduces the flame propagated for this cable type at least.

3. The use of steel ties may make the test method reproducible, but because of the restraint against random cable movement the method would not be at all indicative of behavior in actual fire conditions.

4. A standard test method using 40 percent tray fill as a means to predict actual fire condition performance is not feasible at least for this one cable type.

5. There seems to be no apparent advantage in conducting tests with 40 percent filled trays. Therefore, current effort will revert to refining the parameters of the present IEEE-383 document. It is acknowledged that this method is just a screening test which may not be directly related to actual field fire performance. However, cable jacket temperature measurements may be useful as an added performance measurement other than a pass-fail criteria presently used. Cable jacket measurements can be used to establish a cable performance criteria based upon time (rate of propagation).

6. The minimum oxygen concentration was 18 percent for the experiments conducted. The maximum air velocity into the enclosure at floor level was 1800 cfm. This information will be used as a guideline in establishing ventilation requirements.

IV. Future Activity

During the next report period, sixteen experiments are planned to refine the parameters of the IEEE383 document. The object of the experiments is to establish sensitivity of the test to burner distance, air/fuel ratio, fuel input, and ambient temperature. In addition, the feasibility of including measurements of cable jacket temperature will be investigated. The planned sequence is shown in Table 6.

If these efforts are successful, an IEEE 383 type test will have been defined with respect to the important operating parameters, with appropriate tolerances.

BURNER SENSITIVITY EXPERIMENTS

Exp No.	Nominal Burner Intensity (BTU/HR)	Burner Height (In.)	Burner Distance (In.)	Inlet* Height (In.)	Nominal Air/Fuel Ratio
1	35,000	10.75	1.75	0	3/1
2	35,000	10.75	1.375	0	3/1
3	35,000	10.75	1.375	0	6.5/1
4	35,000	10.75	1.375	0	11/1
5	105,000	10.75	3.25	0	2.5/1
6	105,000	9.875	6	11.5	5/1
7	105,000	9.25	6	11.5	5/1
8	105,000	9.25	6	11.5	3.5/1
9	105,000	8	6	11.5	3.5/1
10	105,000	8	4	11.5	3.5/1
11	105,000	8	2	11.5	3.5/1
12	35,000	11.25	0.5	12	3/1
13	35,000	11.25	0.5	12	6.5/1
14	35,000	11.25	0.5	12	5/1
15	35,000	6.875	2.75	12	3/1
16	35,000	6.875	2.75	12	5/1

* Only front panel raised. All experiments conducted in 8 x 8 ft enclosure divided in half to simulate a two burner condition.

Table 1

BURNER SENSITIVITY EXPERIMENTS

Exp No.	Nominal Burner Intensity (BTU/HR)	Burner Height (In.)	Burner Distance (In.)	Inlet Height (In.)	Nominal Air/Fuel Ratio
17	35,000	7.625	2.75	12	6.5/1
18	35,000	8.5	2.75	12	8/1
19	35,000	9	2.75	12	10/1
20	35,000	7.25	1.5	12	3/1
21	35,000	7.875	1.5	12	5/1
22	35,000	8.625	1.5	12	6.5/1
23	35,000	9.5	1.5	12	8/1
24	35,000	10.625	1.5	12	10/1
25	105,000	9.5	1.5	12	2.5/1
26	105,000	11.25	1.5	12	3.5/1
27	105,000	11.25	1.5	12	5/1
28	105,000	8	5	12	2.5/1
29	105,000	8.5	5	12	3.5/1
30	105,000	9.5	5	12	5/1
31	105,000	10.625	5	12	6/1
32	105,000	9.875	3	12	2.5/1
33	105,000	10	3	12	3.5/1

Table 2

BURNER SENSITIVITY EXPERIMENTS

Exp No.	Nominal Burner Intensity (BTU/HR)	Burner Height (In.)	Burner Distance (In.)	Inlet Height (In.)	Nominal Air/Fuel Ratio
34	105,000	10.625	3	12	5/1
35	70,000	11.5	1	12	4/1
36	70,000	12	1	12	5/1
37	70,000	8	1	12	5.5/1
38	70,000	10.125	3	12	4/1
39	70,000	10.375	3	12	5/1
40	70,000	10.5	3	12	5.5/1
41	70,000	11.125	2	12	4/1
42	70,000	11.25	2	12	5/1

Table 3

PROPOSED CABLE EXPERIMENTS

Input BTU/Hr	Percent Fill	Cable	Room Size	Air/Fuel Ratio	Spacing Of Burner	Starting Room Temp. Deg. F	Comment
70,000	40	PVC/NYL	8x8	8:1	2-3/4"	70 - 75	Reproducibility
70,000	40	PVC/NYL	8x8	8:1	2-3/4"	70 - 75	Reproducibility
70,000	40	PVC/NYL	8x8	8:1	2-3/4"	70 - 75	Reproducibility
70,000	40	PVC/NYL	8x8	8:1	2-3/4"	Existing	Ambient Temperature
140,000	40	PVC/NYL	8x8	8:1	By Trial	70 - 75	Burner Input
70,000	40	PVC/NYL	12x12	8:1	2-3/4"	70 - 75	Room Size
70,000	40	PVC/NYL	8x8	6:1	2-3/4"	70 - 75	Air Rate
70,000	40	PVC/NYL	8x8	10:1	2-3/4"	70 - 75	Air Rate
70,000	40	XLPE/NEO	8x8	8:1	2-3/4"	70 - 75	Cable Type
70,000	40	EP/HYO	8x8	8:1	2-3/4"	70 - 75	Cable Type
70,000	40	XLPE/XLPE	8x8	8:1	2-3/4"	70 - 75	Cable Type

Table 4

CABLE SAMPLE EXPERIMENTS

ALL EXPERIMENTS CONDUCTED WITH A 70,000 BUT/HR NOMINAL FUEL INPUT

AT A 8/1 AIR TO FUEL RATIO

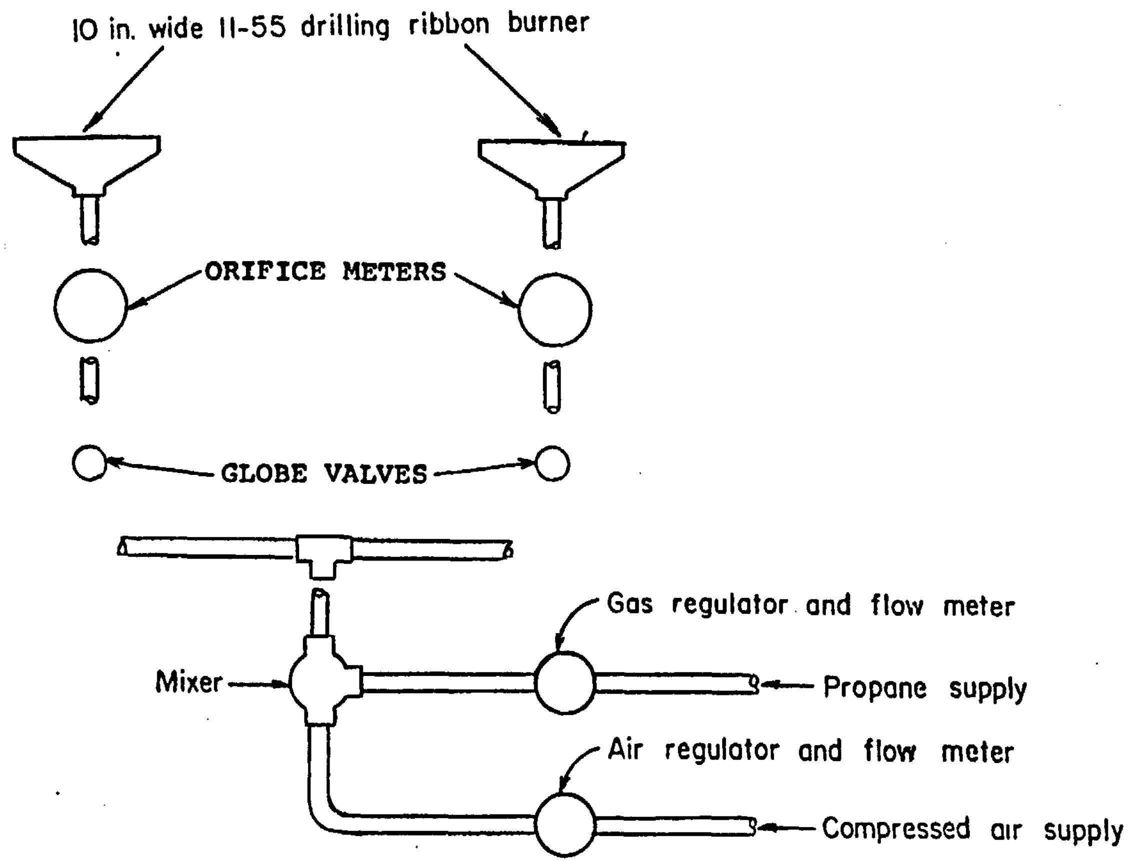
Experiment No.	1	2	3	4	5	6
Starting Air Temperature (°F)	15	31	64	30	63	67
Initial Cable Jacket Temperature (°F)	-	30	68	39	66	70
Max. Flame Height (Ft)						
Front Surface	7 @ 16 min	8 @ 41 min	10 @ 21 min	7.5 @ 17 min	6.6 @ 15 min	5 @ 11 min
Rear Surface	4.25 @ 6 min	4.5 @ 46 min	9 @ 21 min	8 @ 20 min	8.3 @ 19 min	6.5 @ 42 min
Max. Damage (Ft)						
Front Surface	8	8	8	8	5.25	4
Rear Surface	6	4.75	8	7.25	8	6.3
Max. Inlet Air Flow (Ft/Min)	100	120	155	160	150	150
Min. O_2 Concentration (Percent)	18 @ 24 min	19 @ 20 min	20 @ 16 min	20 @ 32 min	-	20 @ 44 min
Test Duration (Min)	36	47	23	40	35	45

Table 5

PROPOSED IEEE 383 EXPERIMENTS

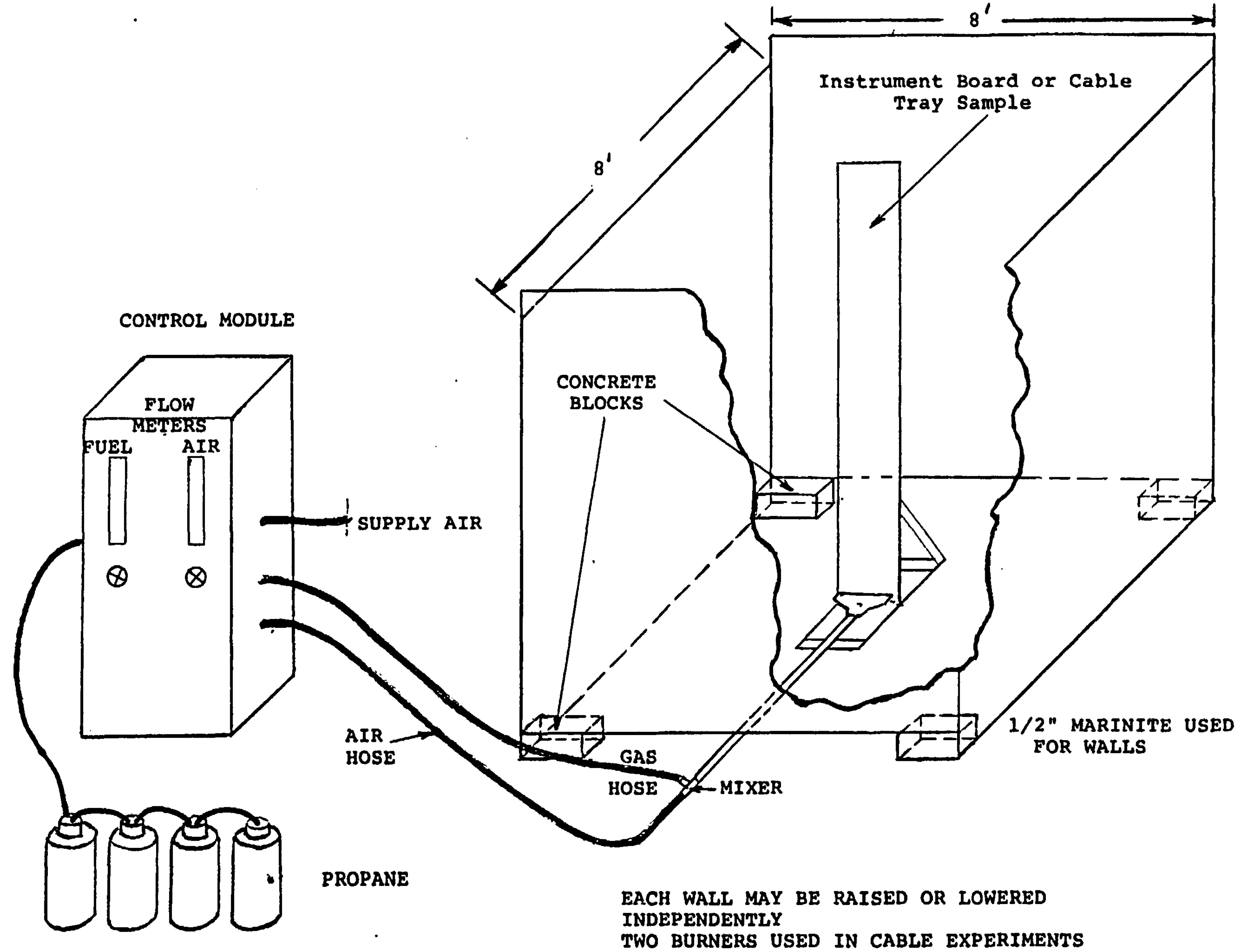
Test	Burner Distance, (In.)	Air/Fuel Ratio	BTU/HR Input	Ambient Temperature (F)	Material	Jacket Temperature Measured	Comment
1	3	6/1	70,000	60 - 65	PVC/Nylon	Yes	Reproducibility
2	3	6/1	70,000	60 - 65	PVC/Nylon	Yes	Reproducibility
3	3	6/1	70,000	60 - 65	PVC/Nylon	Yes	Reproducibility
4	3	6/1	70,000	Cold (20)	PVC/Nylon	Yes	Temperature
5	±1/2	6/1	70,000	60 - 65	PVC/Nylon	No	Spacing
6	±1/2	6/1	70,000	60 - 65	PVC/Nylon	No	Spacing
7	3	By Trial	70,000	60 - 65	PVC/Nylon	No	Air
8	3	By Trial	70,000	60 - 65	PVC/Nylon	No	Air
9	3	6/1	By Trial	60 - 65	PVC/Nylon	No	Gas
10	3	6/1	By Trial	60 - 65	PVC/Nylon	No	Gas
11	3	6/1	70,000	60 - 65	XLPE/NEO	Yes	Material
12	3	6/1	70,000	60 - 65	XLPE/NEO	Yes	Reproducibility
13	3	6/1	70,000	60 - 65	XLPE/NEO	Yes	Reproducibility
14	3	6/1	70,000	60 - 65	EP/HYP	Yes	Material
15	3	6/1	70,000	60 - 65	EP/HYP	Yes	Reproducibility
16	3	6/1	70,000	60 - 65	EP/HYP	Yes	Reproducibility

Table 6



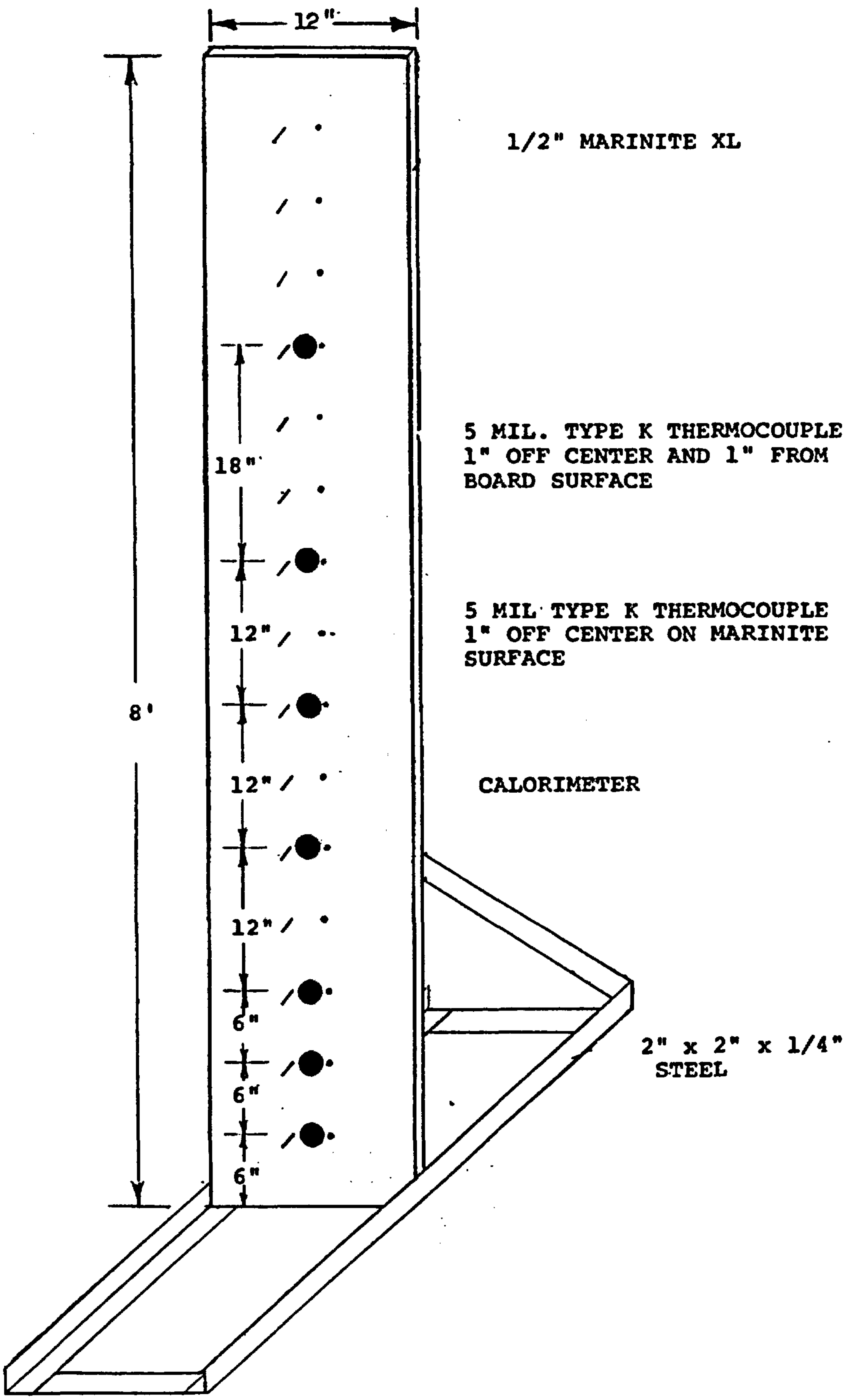
CABLE EXPERIMENTS - TWO BURNERS USED.
BURNER-SENSITIVITY EXPERIMENTS - ONE BURNER USED WITHOUT GLOBE VALVE AND ORIFICE METER

ILL. 1 BURNER APPARATUS

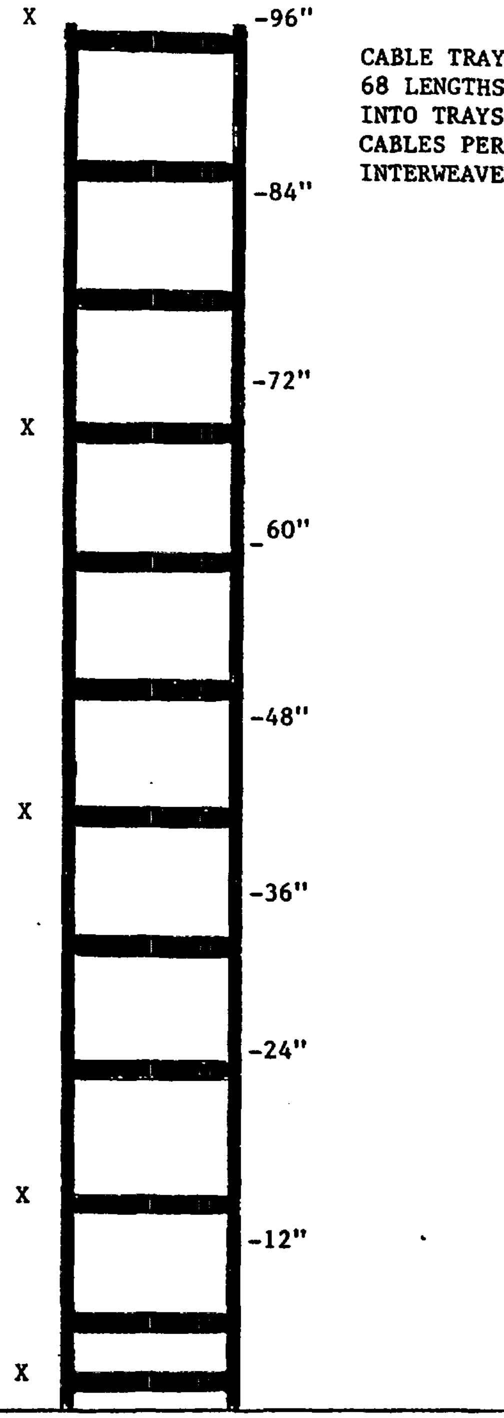


ILL. 2 SCHEMATIC DRAWING OF ENCLOSURE AND TEST SETTING

USNC75



ILL. 3 BOARD USED IN ALL BURNER SENSITIVITY EXPERIMENTS USNC75



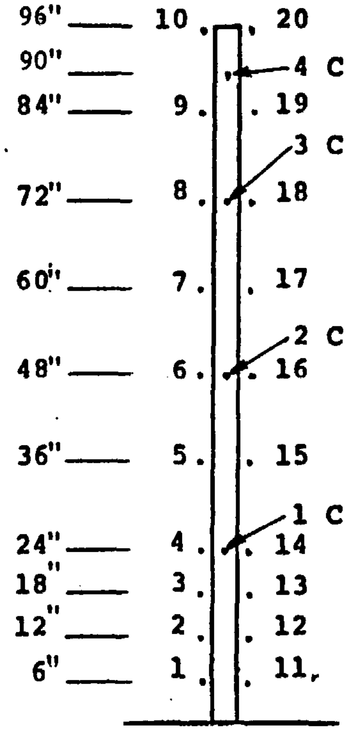
CABLE TRAYS LOADED TO 40% FILL. 68 LENGTHS OF CABLES INSTALLED INTO TRAYS IN 4 LAYERS OF 17 CABLES PER LAYER. CABLES INTERWEAVED IN EACH LAYER.

X - CABLES FASTENED TO RUNG

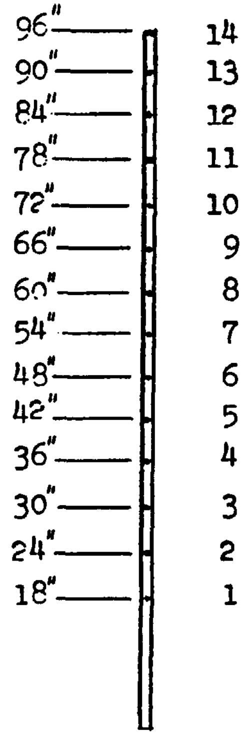
USNC75

ILL. 4 CABLE TRAY LOADING

AIR & CORE THERMOCOUPLE NO.



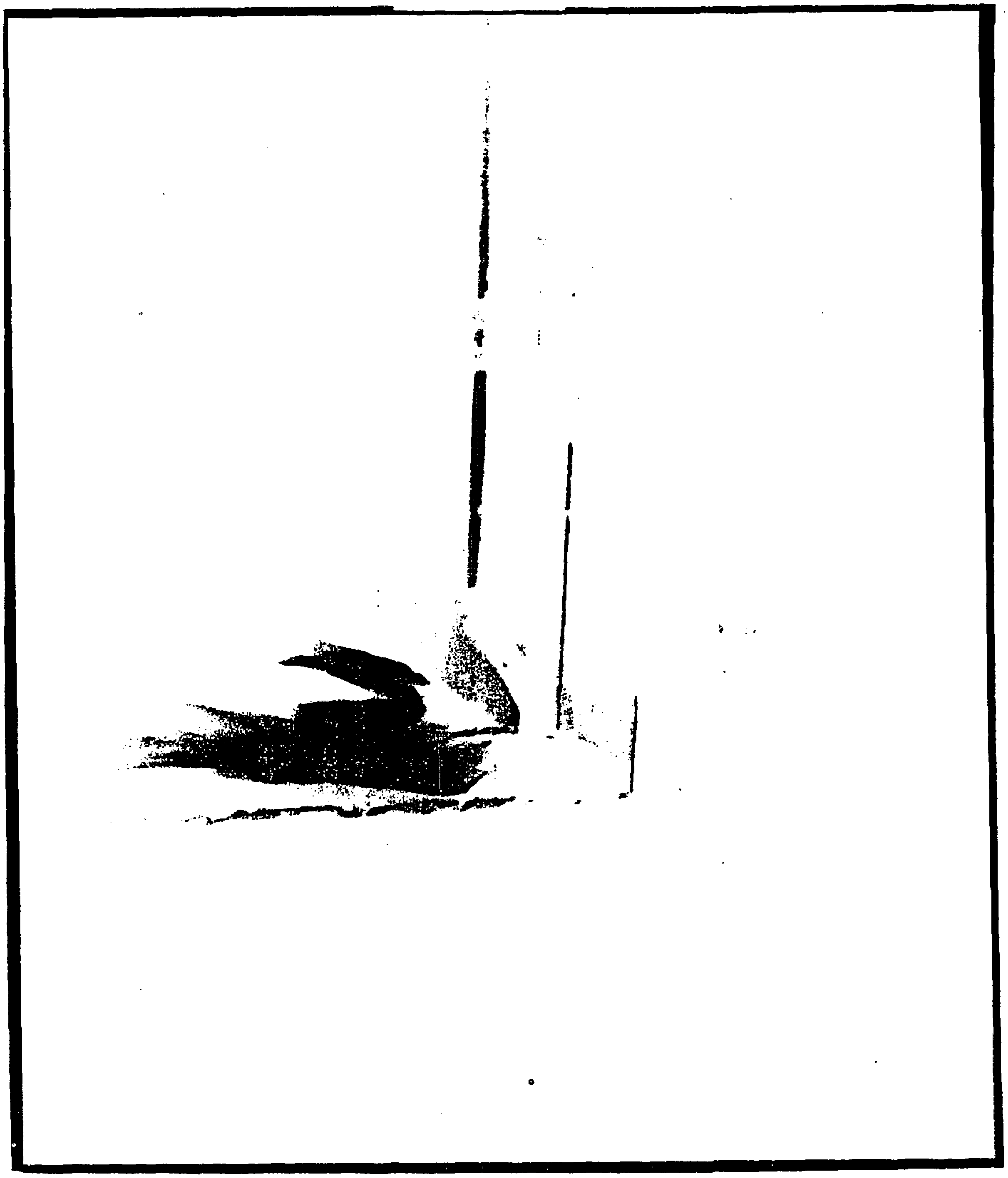
CABLE JACKET THERMOCOUPLE NO.



ALL AIR THERMOCOUPLES LOCATED 3/8 IN. FROM SURFACE OF CABLE TRAY
CORE THERMOCOUPLES LOCATED IN THE CENTER OF THE CABLE BUNDLE ALONG THE CENTERLINE OF THE TRAY

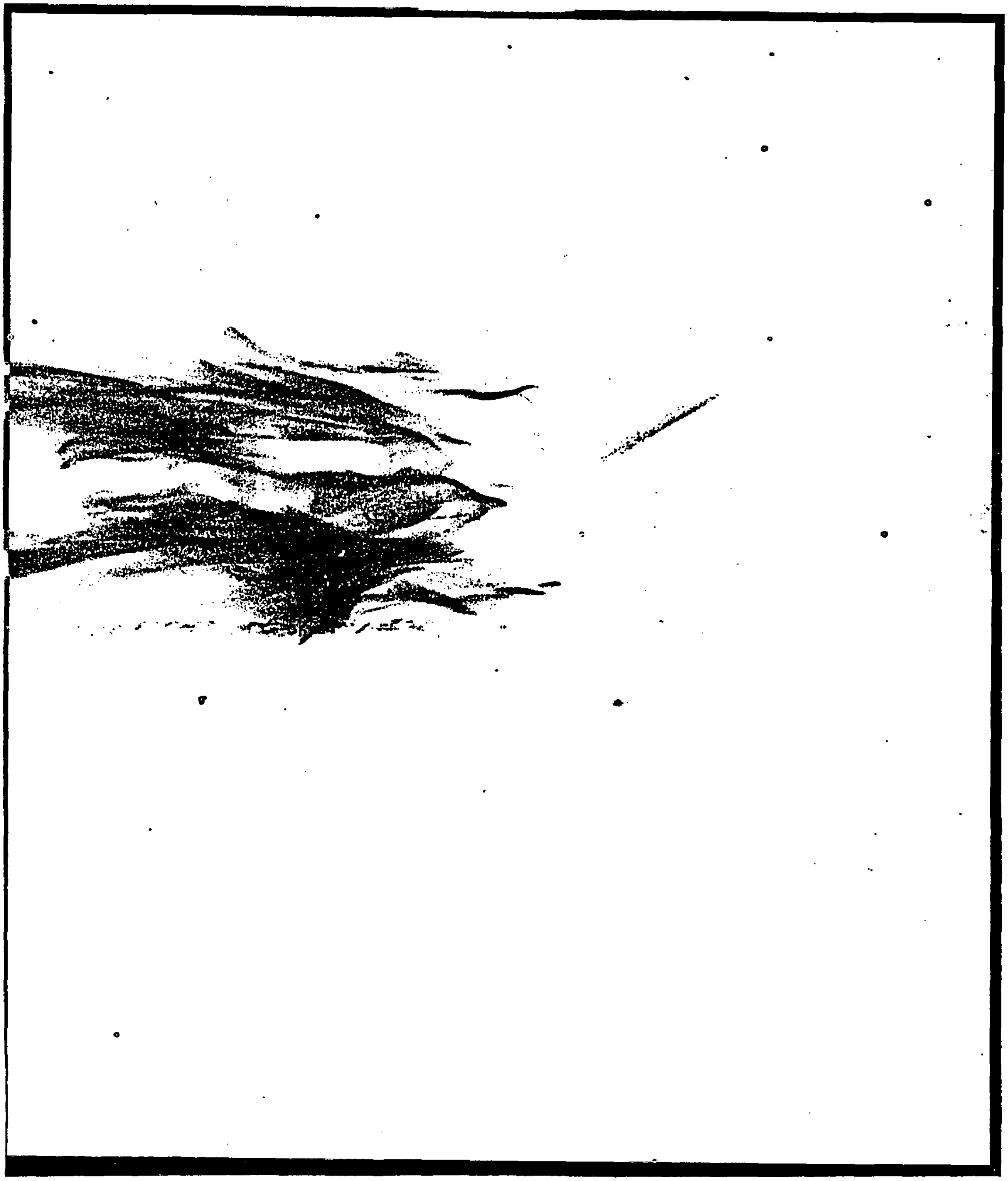
THERMOCOUPLE INSTALLED INTO CABLE JACKET AND COVERED WITH ADHESIVE. NOTE THERMOCOUPLES NO. 2, 4, 7, 10, 13 AND 14 NOT USED IN CABLE EXPERIMENT No. 1

ILL. 5 THERMOCOUPLE LOCATIONS



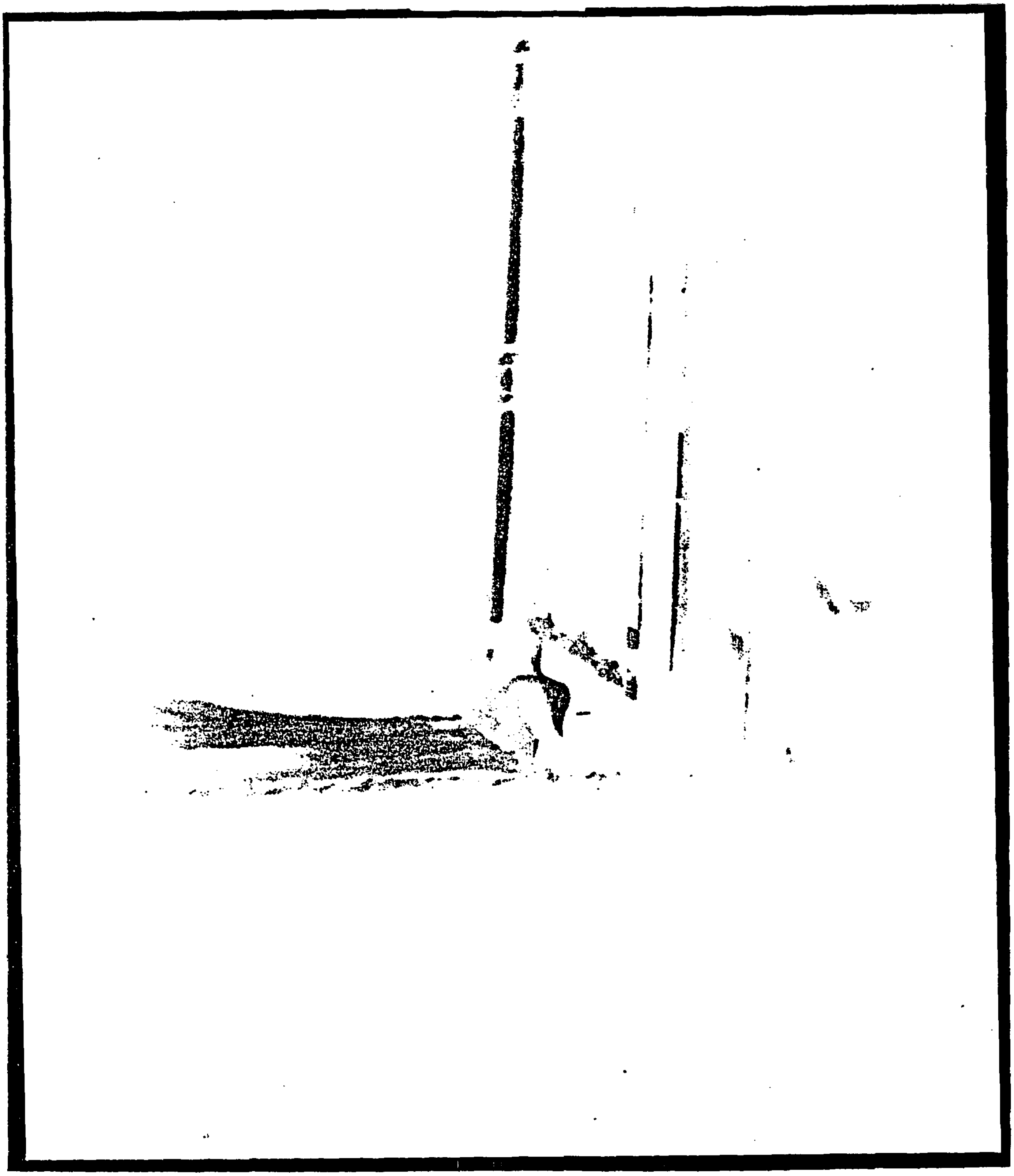
BURNER SENSITIVITY EXPERIMENT 13

USNC75
ILL. 6



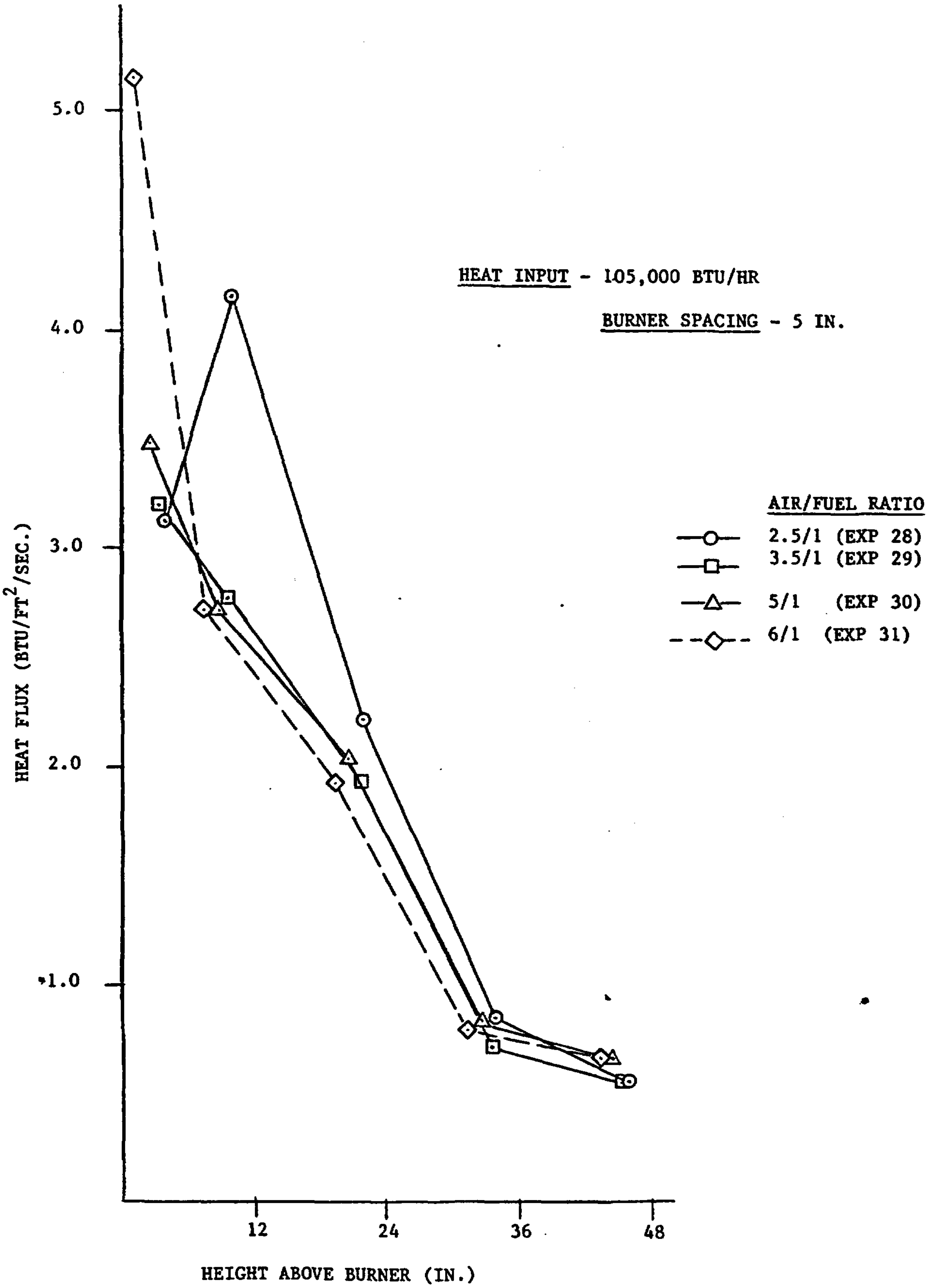
BURNER SENSITIVITY EXPERIMENT 30

USNC75
ILL. 7



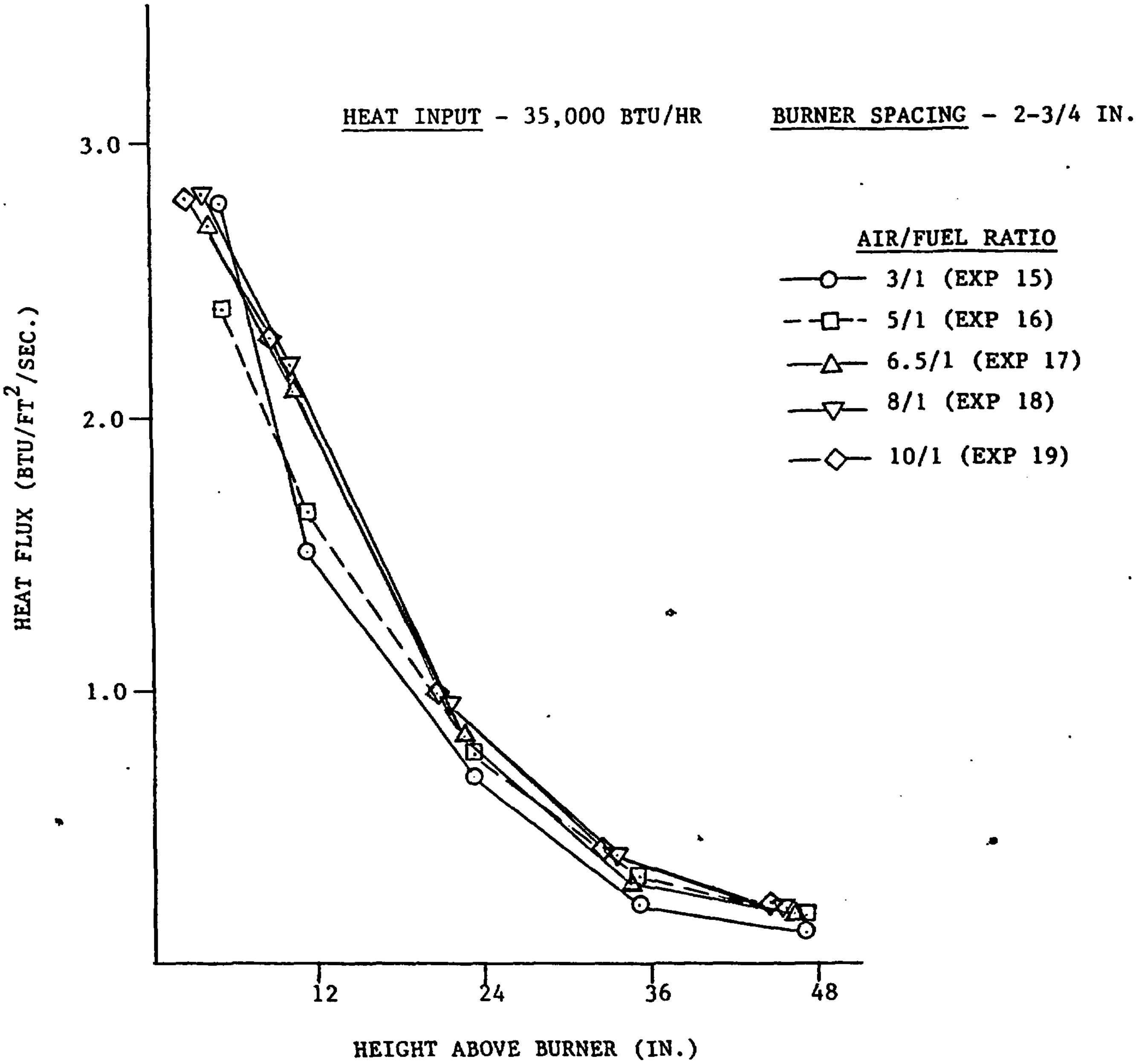
BURNER SENSITIVITY EXPERIMENT 16

USNC75
ILL. 8



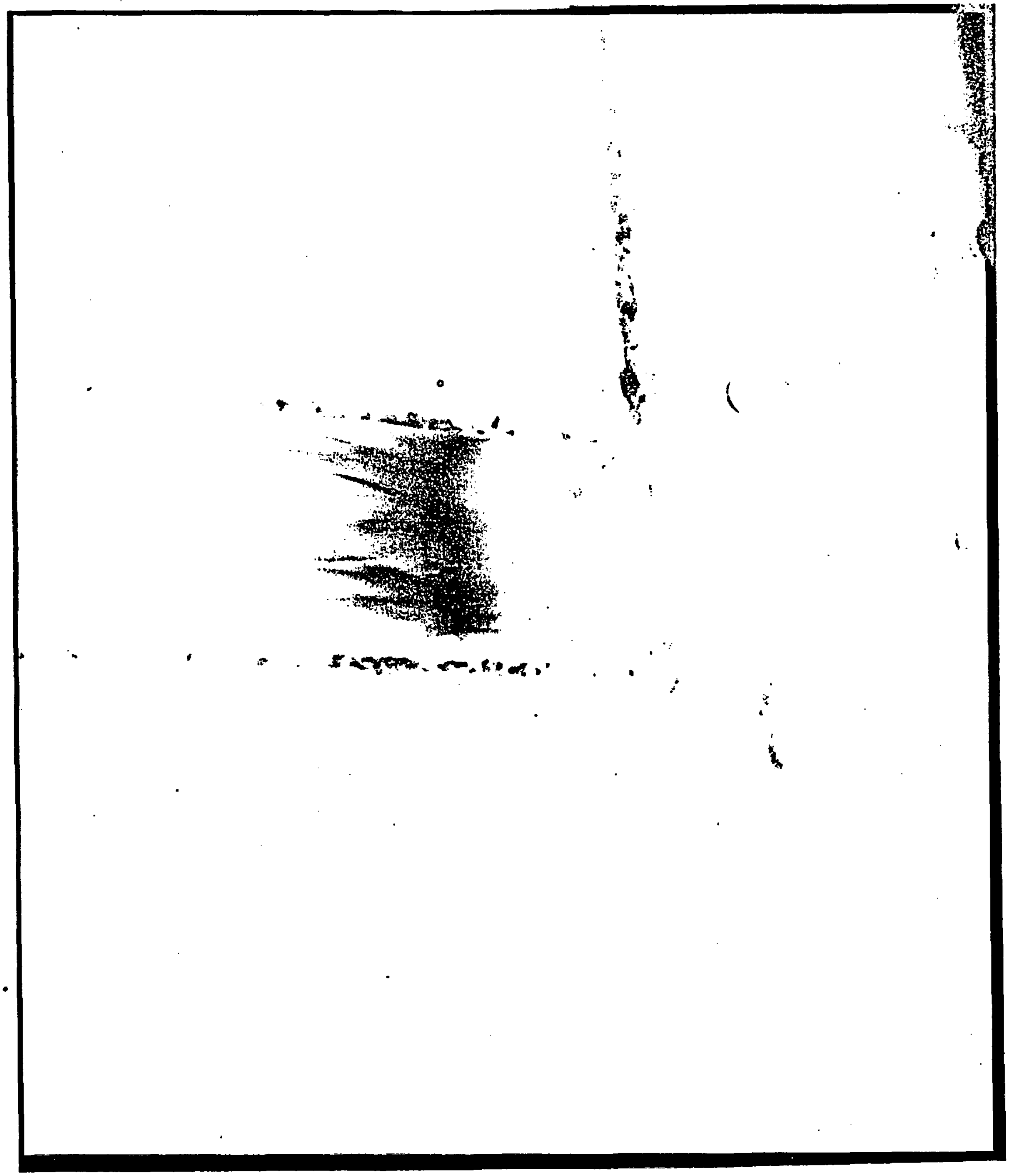
USNC75

ILL. 9 HEAT-FLUX PROFILES FOR VARIOUS FUEL-AIR RATIOS: 105,000 Btu/hr



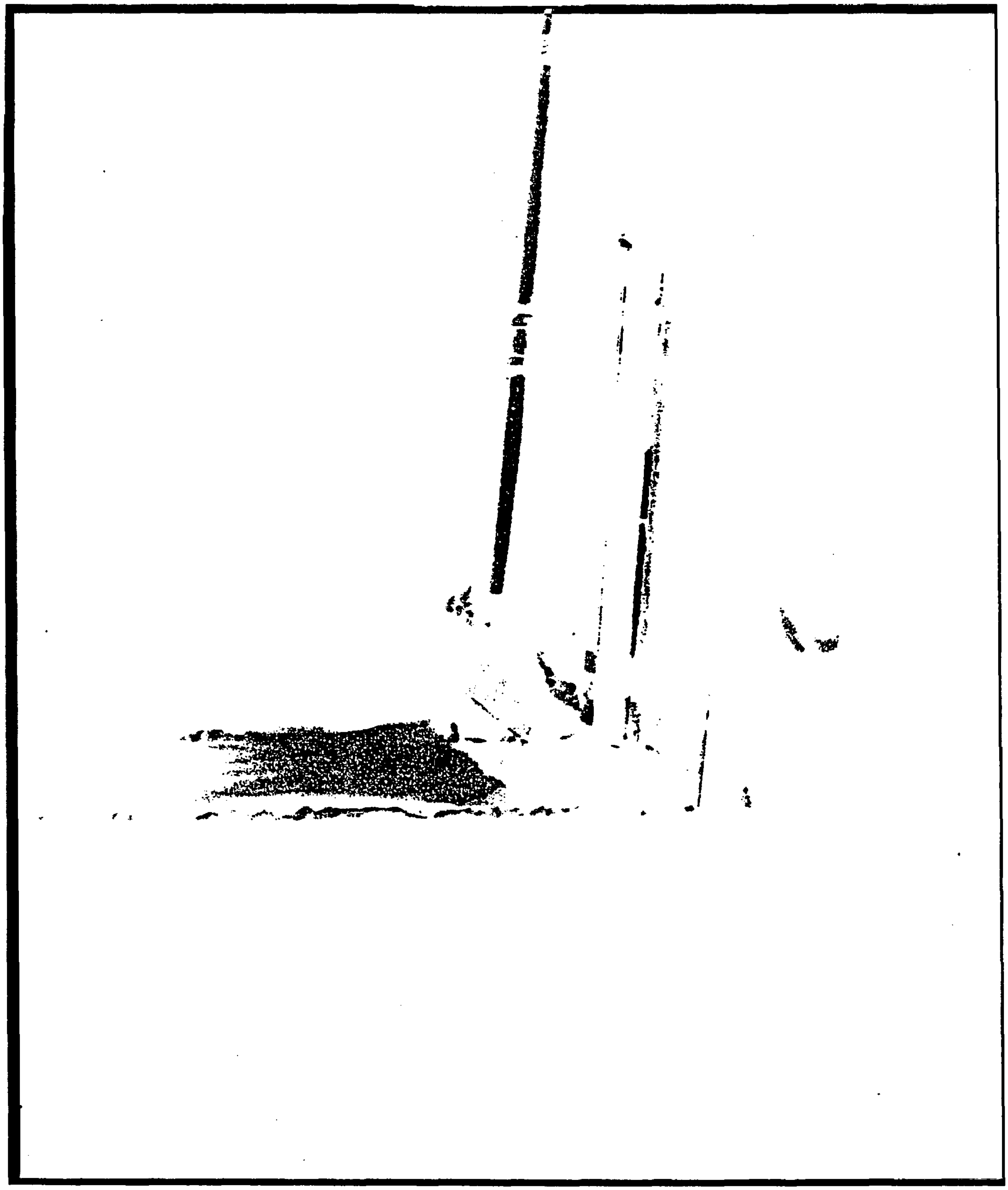
USNC75

ILL. 10 HEAT-FLUX PROFILES FOR VARIOUS FUEL-AIR RATIOS: 35,000 Btu/hr



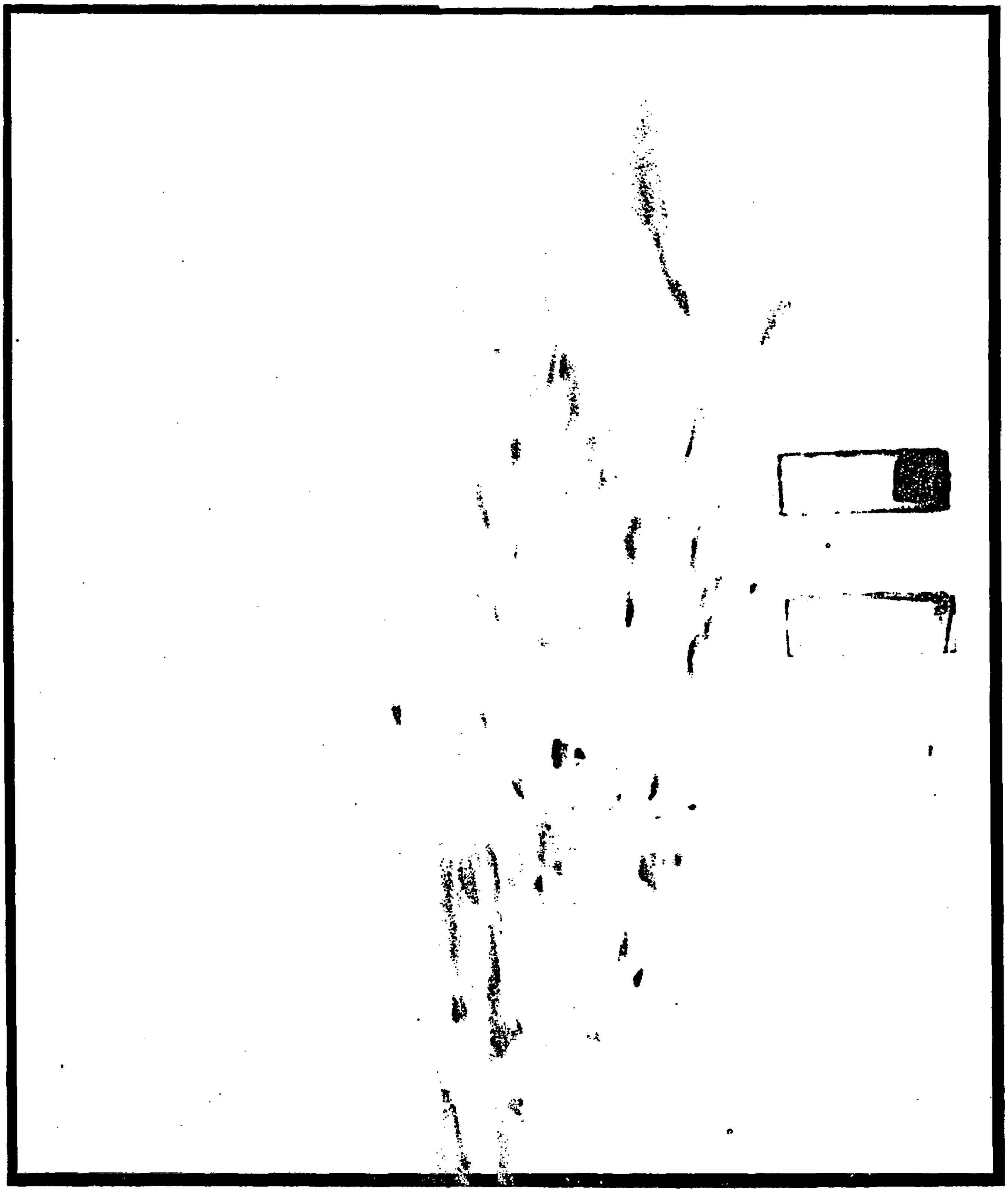
BURNER SENSITIVITY EXPERIMENT 18

USNC75
ILL. 11



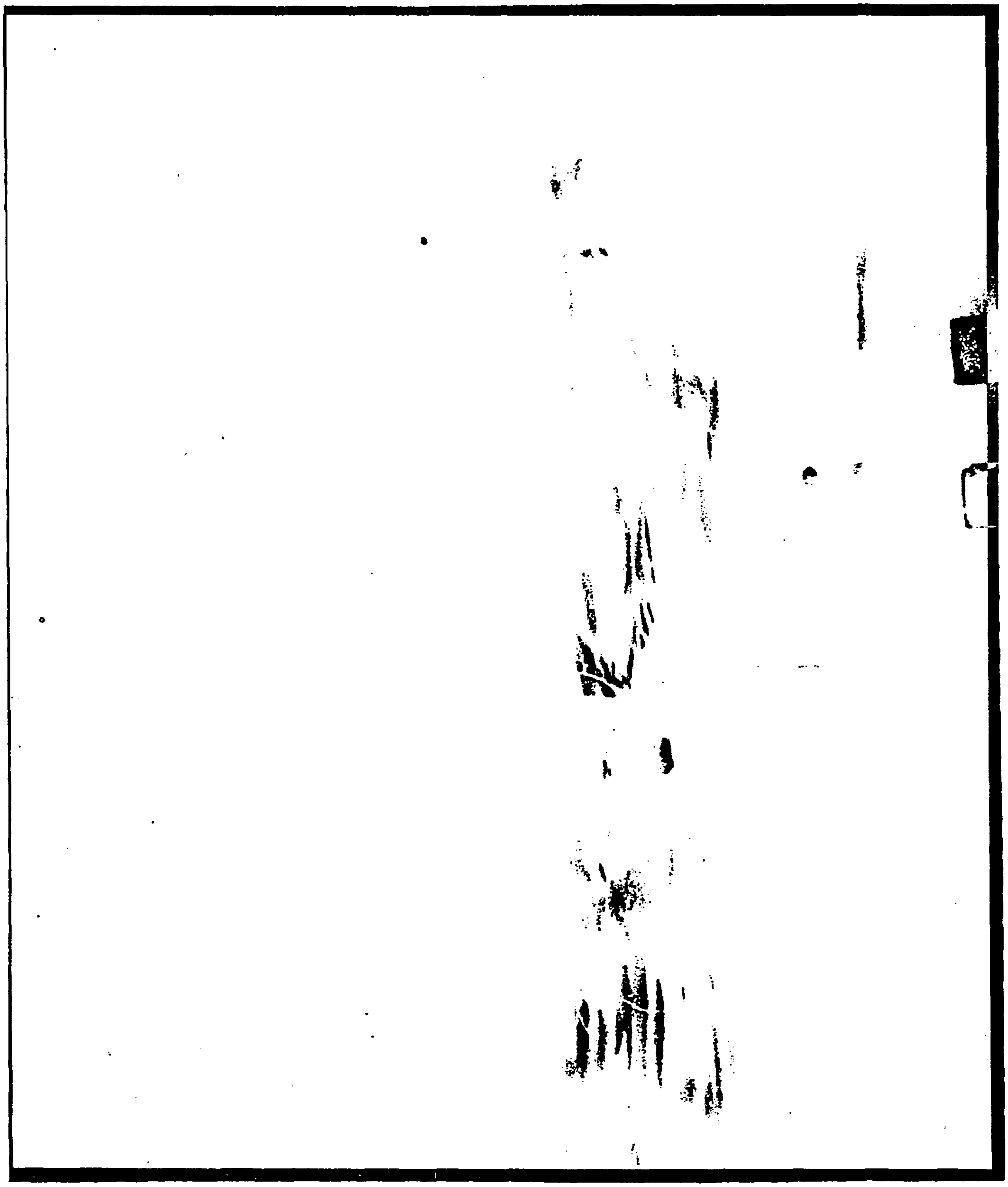
BURNER SENSITIVITY EXPERIMENT 18

USNC75
ILL. 12



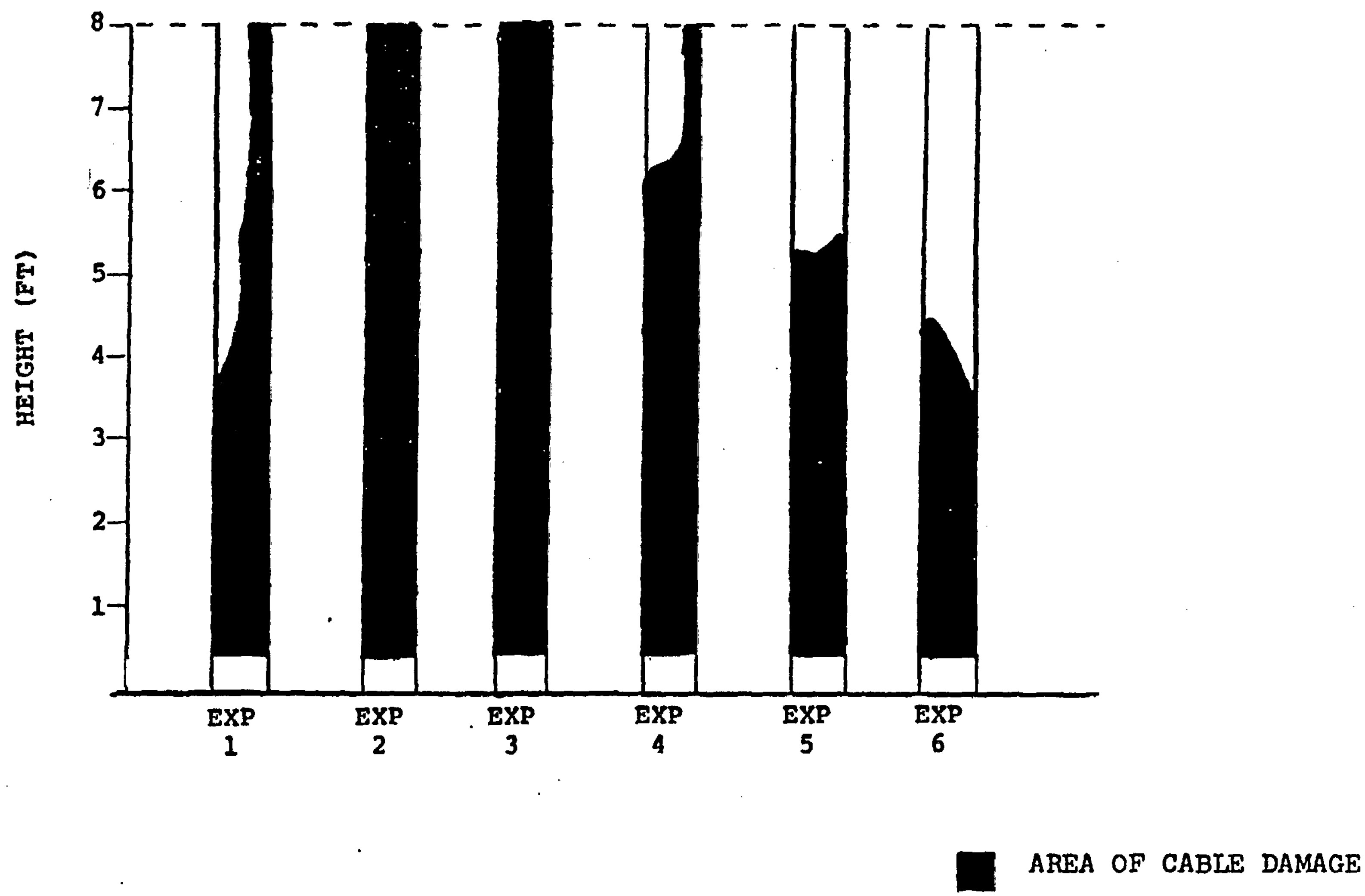
REAR CABLE TRAY FLAMING
CABLE EXPERIMENT 3

USNC75
ILL. 13

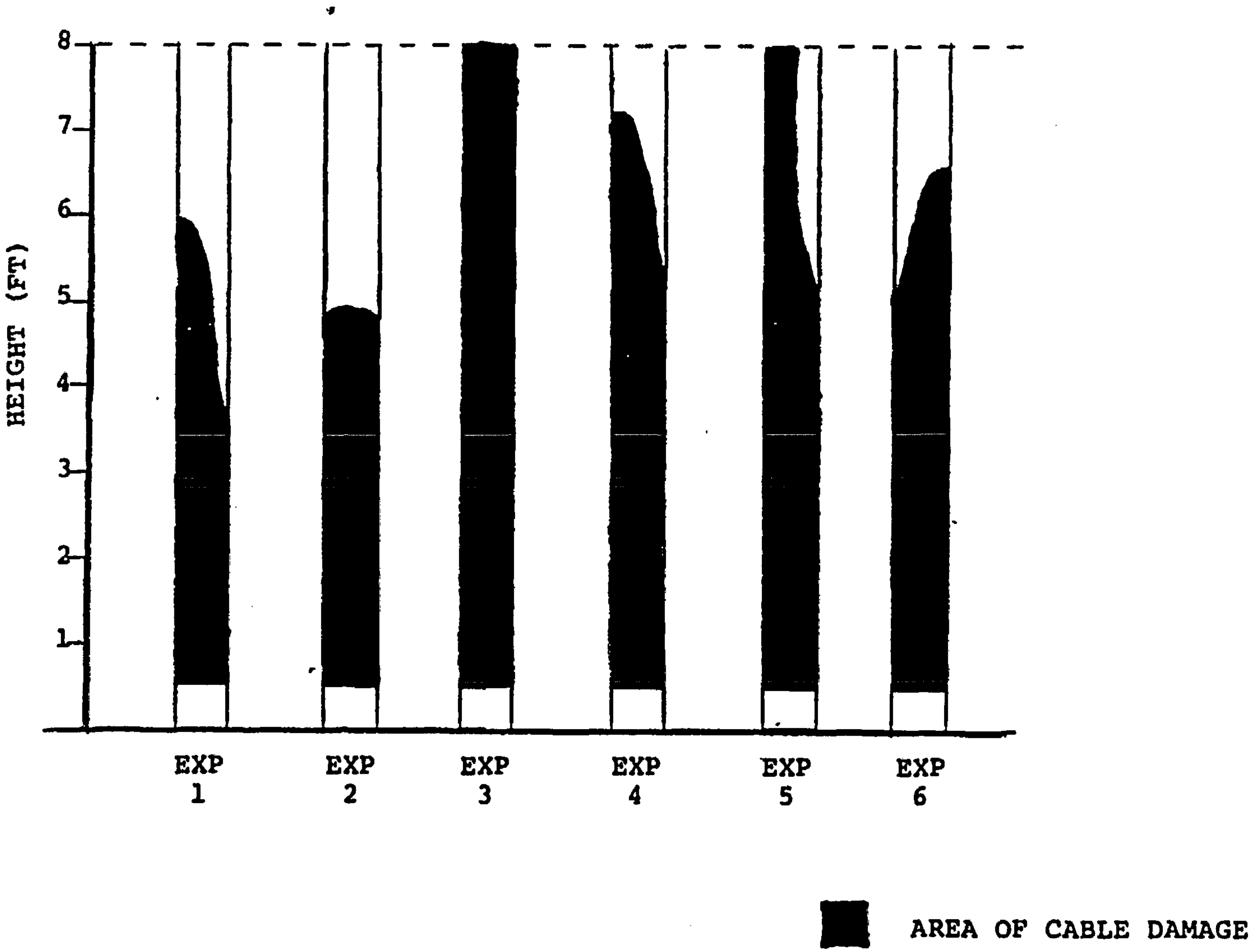


REAR CABLE TRAY FLAMING
CABLE EXPERIMENT 5

USNC75
ILL. 14



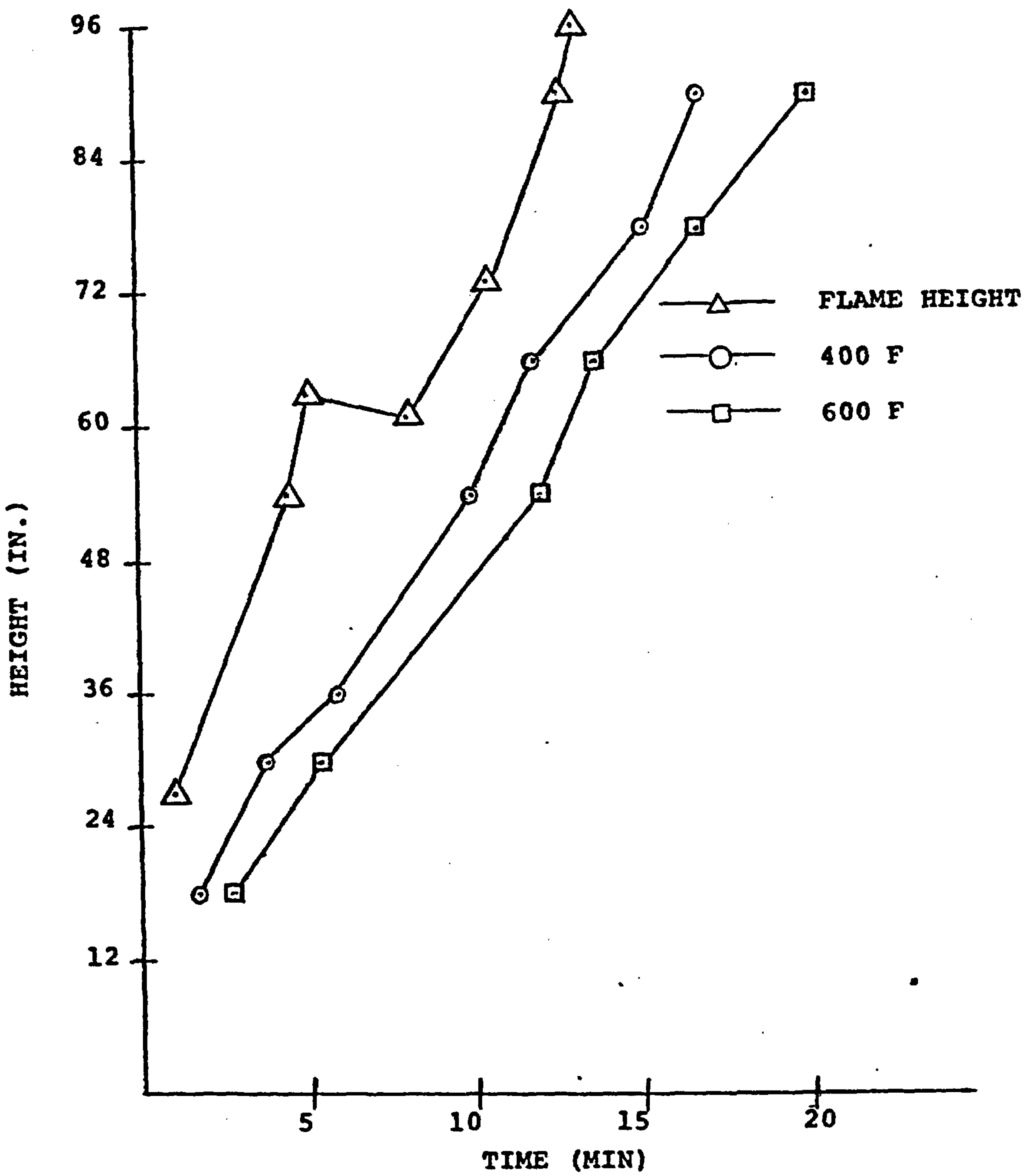
ILL. 15 CABLE DAMAGE ON FRONT FACE OF TRAY



ILL. 16 CABLE DAMAGE ON REAR FACE OF TRAY

USNC75

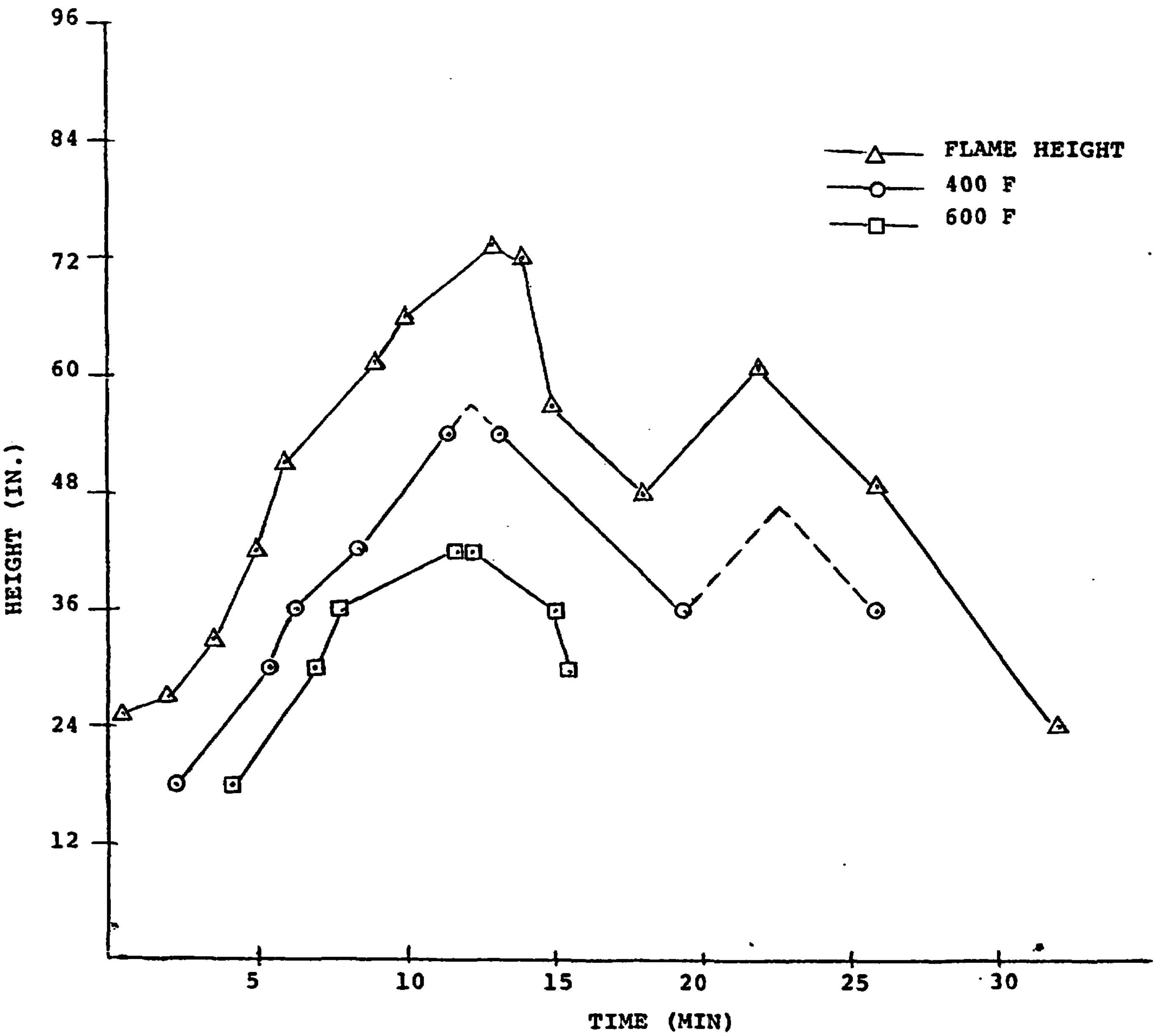
EXPERIMENT NO. 3



USNC75

ILL. 17 FLAME HEIGHT VERSUS TIME COMPARED WITH CABLE JACKET TEMPERATU

EXPERIMENT NO. 5



USNC75

ILL. 18 FLAME HEIGHT VERSUS TIME COMPARED WITH CABLE JACKET TEMPERATURES - EXPERIMENT 5