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Development and Verification of Fire Tests for Cable Systems and System Components

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ABSTRACT

Experiments were conducted to study the effects of a forced ventilation on the results of the IEEE 383 flame test for tray cables. Three sets of experiments were conducted on three types of cables. The first set was a control in which cable samples were tested in a free-convection environment within an 8 x 8 x 8 ft (2.44 x 2.44 x 2.44 m) enclosure. In the second set, the cable samples were tested within an enclosure with a 1500 CFM (708 l/s) forced ventilation. In the third set, the cable samples were tested within an enclosure with the ventilation rate of either 1200 CFM (566 l/s) or 1800 CFM (849 l/s). The results showed that the rate of flame propagation and the maximum cable damage were not affected when the enclosure and forced ventilation were used. It is recommended that the test method be revised to specify the use of an enclosure and forced ventilation.

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<u>Development And Verification Of</u>
<u>Fire Tests For Cable Systems And Components</u>

1. INTRODUCTION

The goal of the fire protection research program sponsored by the U.S. Nuclear Regulatory Commission is to provide data relative to the operation of Class I systems when subjected to a design-basis fire condition. This program has been broken into eleven elements. These elements and their status are described in NUREG-0581. Of concern in this Report is Program Element No. 5. The object of this element is 1) to assess the repeatability and reproducibility of the vertical flame tests for tray cables outlined in IEEE 383, and 2) to develop small-scale cable system qualification tests.

Separate-effects experiments relevant to Phase 1 of Program Element 5 have been conducted by Underwriters Laboratories. These experiments were conducted to 1) investigate the sensitivity of results to changes in the test method, and 2) better define the test method. Test conditions such as enclosure configuration, air input, fuel input, and burner position were studied. The results and recommendations from these experiments are reported in NUREG/CR-0152, and NUREG/CR-0346.

The results of these experiments are applicable to tests conducted within rooms large enough that the room ventilation does not influence the air flow through the enclosure. In order to obtain reproducible test results in tests conducted in small rooms, it is necessary to provide for controlled ventilation of the enclosure itself, independent of the room ventilation. Program activities during the period of March 1 through May 31, 1980 consisted of modifying the test enclosure to provide for forced ventilation, and investigation of the effects of ventilation on the test results.

2. EXPERIMENTAL PLAN

The plan was to conduct three sets of experiments. A summary of this plan is shown in Table 1.

The first set was a control to provide a measure of cable performance without forced ventilation. Three tests were conducted on each of three cable types. The ventilation through the enclosure was natural convention caused by the fire itself.

The second set was conducted with a fixed ventilation rate established through the enclosure. Again, three experiments were conducted on each of three cable types. The cable types tested represented the expected range of flame propagation rate along most cables. The object of this set was to determine if performance is significantly affected by a specific ventilation rate over the range of cable burning behaviors.

The third set was conducted with two different ventilation rates Two tests were conducted on each of two cable types. The object this set was to determine the sensitivity of test results to var ations of the ventilation rates.

3. EXPERIMENTAL PROCEDURE

3.1 Facility

The cable experiments were conducted in a heated building 37 ft (11.28 m) wide, 67 ft (20.42 m) long and 21 to 24 ft (6.40 to 7.32 m) high.

During the cable experiments all exterior doors were closed or doorways sealed and all roof vents in the building were opened. The roof vents were ducted to an exhaust and smoke incineration system. There was sufficient air leakage in the building that atmospheric pressure was maintained inside the building while the exhaust system was in operation.

3.2 Test Apparatus

3.2.1. Enclosure

The experiments were conducted with the sample located within an enclosure. The enclosure isolated the sample from extraneous air current in the building. The control experiments were conducted within the enclosure as shown in Fig. 1. The four sided enclosure allowed air to be drawn into the enclosure through two 1 ft (305 mm) high by 8 ft (2.44 m) wide openings along the base. The products of combustion flowed through the open top by free convection.

The remaining experiments were conducted with the same enclosure but with a hood and forced ventilation added as shown in Fig. 1. The hood and duct system provided a means of providing ventilation through the enclosure. A baffle was suspended beneath the duct outlet and above the cable sample to divert the forced air movement away from the sample.

The interior surfaces of the enclosure were gypsum board painted flat black. Several windows were provided to permit visual observations during the experiments.

3.2.2. Burner Apparatus

The burner apparatus consisted of one burner head and a Venturi air-fuel mixer as described in IEEE 383-1974. The burner head was a 10 in. (254 mm) wide, 11-55 drilling, ribbon burner, and the mixer was a No. 14-18. Both were manufactured by the American Gas Furnace Co.

3.2.3. Sample Support

The cable sample was supported in an open-ladder type cable tray. The tray was 8 ft (2.44 m) high and 12 in. (305 mm) wide. The side channels were 3-3/8 in. (86 mm) deep with 1 in. (25 mm) flanges and fabricated from No. 16 MSG [0.060 in. (1.5 mm) thick] cold-rolled steel. The nominal 0.125 in. (3.2 mm) thick (No. 10 MSG) ladder rungs were 1 in. (25 mm) wide with 1/2 in. (13 mm) legs, and were tack-welded to the side rails at 9 in. (229 mm) intervals.

3.2.4. Samples

The cables used in these experiments were stranded seven (copper) conductor, No. 12 AWG. Three different combinations of insulation and jacket materials were used. Identification of cable materials was on the basis of information provided by the suppliers. The cables are identified in the description of the experiments by a Code letter to avoid association of the results with proprietary products. Descriptions of the cables, without reference to the code are given in Table 2.

3.2.5. Instrumentation

Air velocity, temperature and oxygen concentration were measured near the cable sample and either at the enclosure inlet or in the enclosure exhaust duct. The location of the instrumentation is shown in Fig. 2.

Chromel-Alumel thermocouples were used to measure air temperature, and oxygen concentrations were measured with Bacharach electrochemical sensor cells. Bidirectional probes and an electronic barometer were used to measure air velocities.

3.2.6. Operation

The experiments were conducted in general accordance with the method described in IEEE-383-1974, Par. 2.5

Cables were installed in the tray in a single layer filling the center 6 in. (152 mm) portion of the tray, and spaced approximately 1/2 cable diameter apart. Since the cable diameter was different for each cable type, the number of lengths of cables installed into the tray was different for each cable type. Either 6 lengths (Type X), 7 lengths (Type Z) or 8 lengths (Type Y) were used. Each length of cable was fastened to ladder rungs with No. 16 SWG (0.062 in. (1.6 mm) thick) steel wire at every other rung (approximately 18 in. (457 mm) OC).

The tray was supported vertically in a steel base frame with the rear surface of the cable tray rungs facing the burner head. The burner face was positioned 3 in. (76 mm) away from and perpendicular to the cable tray. The center of the burner face was located 24 in. (610 mm) above the base of the tray and midway between ladder rungs.

The test room was heated, if needed, prior to the start of each experiment. The mean starting temperature for this series of experiments was 72 F (22.2 C). The starting temperature for each group of experiments is given in Table 3.

To initiate each experiment, a pilot burner flame was ignited. The propane fuel gas and air flows were then adjusted and the experiment initiated. The fuel flow was established at 70,000 (± 250) BTU/Hr (20,517 ± 73 W) considering the heat value of the propane used to be about 2,500 BTU/ft^3 (93,150 J/l). The air flow to the burner was established at 163 (± 5) SCFH (1.28 ± 0.04 l/s).

For experiments with forced ventilation, the desired ventilation rate was established prior to the test. The ventilation was continued but not controlled to maintain the pretest value during the test, but varied from the initial value depending on the convectional air flow conditions.

The cable sample was exposed to the ignition flame for 20 min, except in several experiments in which the ignition flame was extinguished earlier. These experiments were terminated prior to 20 min since continuation of the experiment would not provide any additional data.

Throughout each experiment, visual observations were made of the condition of the cable material and flame travel. The velocity, temperature, and the oxygen concentration at two locations were recorded about every three seconds.

4. RESULTS

4.1 Cable Material Response To Fire

Type X

The cable jacket/insulation material appeared to soften in advance of the propagating flame. In the fire region, the cable jacket/ insulation material swelled and eventually closed the spaces between the cables. Flaming on the rear surface (burner side) was then unable to penetrate through to the front surface. The ignition flame was mainly deflected upward along the rear surface with sporadic flame fragments curling around the sides to the front surface. Crackling and popping sounds were audible as some (approximately 1/16 in. [1.6 mm] diameter) particles popped away from the cable in the fire region. The burned cable jacket material was light gray and remained attached to the conductors.

Type Y

The cable jacket/insulation material discolored, blistered, and cracked in advance of the propagating flame. In the fire region, the cable jacket/insulation material cracked although there was no apparent melting or swelling of the jacket material. Popping sounds were audible with small pieces of material about 1/16 in. (1.6 mm) diameter, observed popping away from the cable. The burned cable material charred and some random loss of the charred material occurred.

TYPE Z

The cable jacket/insulation material tended to melt in advance of the propagating flame, and the melted material appeared to run down into the fire region. In the fire region, the cable jacket/ insulation material was uniformly involved in flame.

Crackling sounds were audible but no material was seen popping from the cable. The burned cable material formed a dark ash which gradually fell from the cable.

4.2 Flame Propagation

The maximum flame height was recorded several times during each experiment. The average maximum flame height for each group of experiments using the same cable type was plotted versus time and is shown in Figure 3.

The flame height for the Type Z cable after it had reached the top of the tray is not reported.

4.3 Cable Damage

The maximum height of cable damage was recorded for each experiment. The average of the maximum height of cable damage for groups of experiments with cable Types X and Y is shown in Figure 4.

The maximum height of cable damage for all experiments with Type Z cable was 8 ft (2.44 m), the full tray height.

5. DISCUSSION

5.1 Effect On Results

The enclosure and forced ventilation did not significantly affect the cable performance in these tests.

The rate of flame propagation was not significantly affected. As shown in Figure 3, the average rate of flame propagation was about the same for the control experiments and for the forced ventilation experiments.

The only anomaly was the group of experiments with the Type Y cable with 1500 CFM (708 l/s) forced ventilation. Although the rate of flame propagation was about the same as compared to the control experiments, the flame activity occurred about two minutes later. This delay did not change the maximum flame height or the maximum cable damage height.

The maximum height of cable damage was not affected significantly by forced ventilation, as shown in Figure 4. For Types Y and X cable, the average of the maximum damage heights within any group of experiments with forced ventilation differed from the average for the control experiments by 1-1/2 in. (38.1 mm) or less. This may be compared to the variation in maximum damage height within a single group of experiments of 3 in. (76 mm).

The full cable height was damaged for all experiments with Type Z cable. Accordingly, a comparison to determine the effect of forced ventilation could not be obtained for this cable.

5.2 Other Ventilation Effects

5.2.1. Increased Flame Propagation

It is possible that forced ventilation would increase the air velocity near the sample and tend to increase flame propagation rate.

Average air velocities near the sample for all three cable types are shown in Figures 5, 6, and 7. The air velocity plotted is the average for the group of experiments. As shown, the air velocity was very low. When forced ventilation was used the air velocity did tend to increase as compared to the control experiments. However, it should be noted that the air velocity near the sample was always very low as compared to the flame velocity itself. Thus, the observed increases in air velocity near the sample [about 25 ft/min (0.13 m/s) to 100 ft/min (0.50 m/s)], would not be expected to significantly influence the flame velocity.

5.2.2. Decreased Oxygen Concentration

Experiments were conducted to determine if the build up of products of combustion would significantly decrease the available oxygen near the sample because of the slow air flow through the enclosure.

The Type Z cable produced the largest quantity of combustion products and at the fastest rate. The minimum oxygen concentration near the sample is given in Table 4. For both the control experiments and the experiments with forced ventilation, there was no more than about a 0.3 percent decrease in the oxygen concentration. This small decrease would not be expected to significantly affect the cable performance.

6. FINDINGS

Based upon these results, it appears that cable performance would not be significantly affected when a forced ventilation through the enclosure of 1500 ± 300 CFM (708 ± 14.2 l/s) is used.

7. RECOMMENDATIONS

In NUREG/CR-0346 recommendations for revising the fire test procedure in NRC Regulatory Guide 1.131 were given. As a result of the work reported herein, it is further recommended that an enclosure similar to that described herein be used. The enclosure should be constructed of inorganic materials and provided with several sealed windows for observation. The fire test procedure should specify a forced ventilation rate of 1500 ± 300 CFM (708 ± 14.2 l/s) through the enclosure.

The ventilation rate should be measured by air flow measurements in the exhaust duct. During a test, the velocity may vary because of convective forces developed by the fire. It is not considered to be necessary to control the ventilation to account for this transient change.

These recommendations are based on results of a limited number of experiments conducted at only one facility. It is recommended that round-robbin testing be undertaken to determine the repeatability and reproducibility of the test results.

Table 1 Experimental Plan

Set One (Control)

No. of Experiments	Cable Type	Ventilation
3	X	Free convection
3	Y	Free convection
3	Z	Free convection

Set Two

No. of Experiments	Cable Type	Ventilation
3	X	1500 CFM (708 l/s)
3	Y	1500 CFM (708 l/s)
3	Z	1500 CFM (708 l/s)

Set Three

No. of Experiments	Cable Type	Ventilation
2	Z	1200 CFM (566 l/s)
2	Y	1800 CFM (849 l/s)

Table 2 Cable Description

Designation	Cable Cross Section Diameter, In. (mm)	Insulation/Jacket Material	Approximate Conductor Insulation/ Jacket Thickness, In. (mm)	Cable Jacket Material	Approximate Cable Jacket Thickness, In. (mm)
X EPR-Hypalon/Hypalon	0.785 (19.9)	Ethylene propylene rubber/chloro-sulphonated poly-ethylene	0.028/0.017 (0.7/0.4)	Chlorosulphonated polyethylene	0.134 (3.4)
Y XLPO/XLPO	0.493 (12.5)	Crosslinked polyolefin	0.030/- (0.8/-)	Crosslinked polyolefin	0.054 (1.4)
Z PE-PVC/PVC	0.602 (15.3)	Polyethylene/ Polyvinyl chloride	0.029/0.012 (0.7/0.3)	Polyvinyl chloride	0.062 (1.6)

Table 3 Starting Temperature

Set One

Cable Type	Average Temperature Deg F (C)
X	70.0 (21.1)
Y	71.1 (21.7)
Z	69.1 (20.6)

Set Two

Cable Type	Average Temperature Deg F (C)
X	70.5 (21.4)
Y	72.8 (22.6)
Z	73.9 (23.3)

Set Three

Cable Type	Average Temperature Deg F (C)
Y	74.9 (23.8)
Z	77.3 (24.9)

Ind. Maximum - 77.9 F (25.5)
Ind. Minimum - 68.0 F (20.0)
Mean - 72.0 F (22.2)

Table 4 Oxygen Concentration**

Type Z Cable - Near Sample

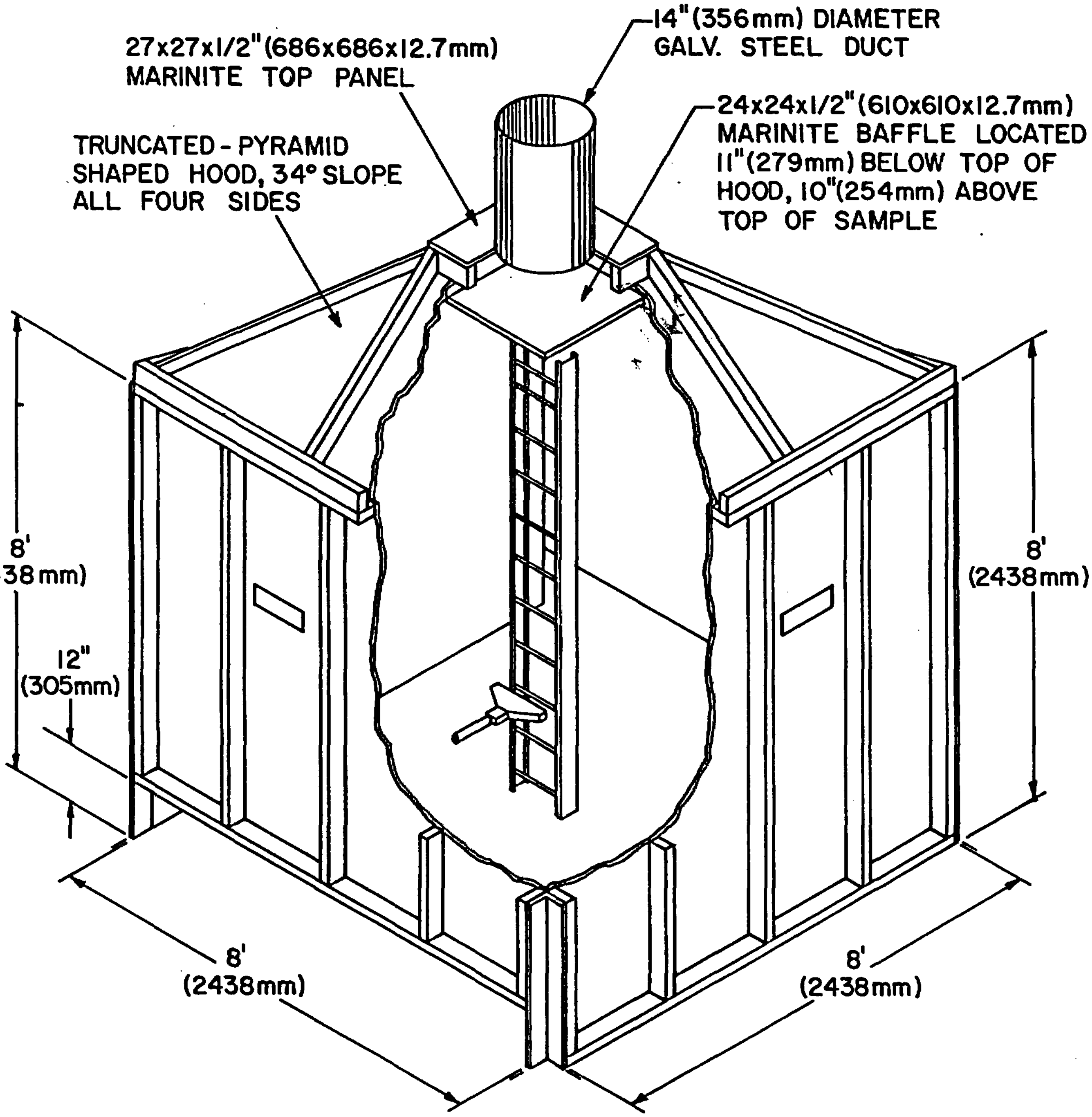
Experiment Group	Percent O_2 *	
Control	20.95 20.97 20.90	Average 20.94
1500 CFM (708 l/s)	20.88 20.72 20.48	Average 20.69
1200 CFM (566 l/s)	20.73 20.75	Average 20.74

* - Sensor calibrated assuming 21 percent O_2 in room air.

** - Minimum concentration during the period of increasing flame propagation.

CABLE TEST ENCLOSURE

NOTE: EXPERIMENT NOS. 1-9 CONDUCTED IN ENCLOSURE WITHOUT DUCTED HOOD.



ENCLOSURE AND HOOD CONSTRUCTED OF 1/2"(12.7mm) THICK GYPSUM WALLBOARD ON NOM. 2x4"(51x102mm) LUMBER FRAMEWORK. UPPER 24"(610mm) OF HOOD PROTECTED WITH 1/4"(6.4mm) THICK CERAMIC BOARD. INTERIOR PAINTED FLAT BLACK.

FIG. 1

INSTRUMENTATION

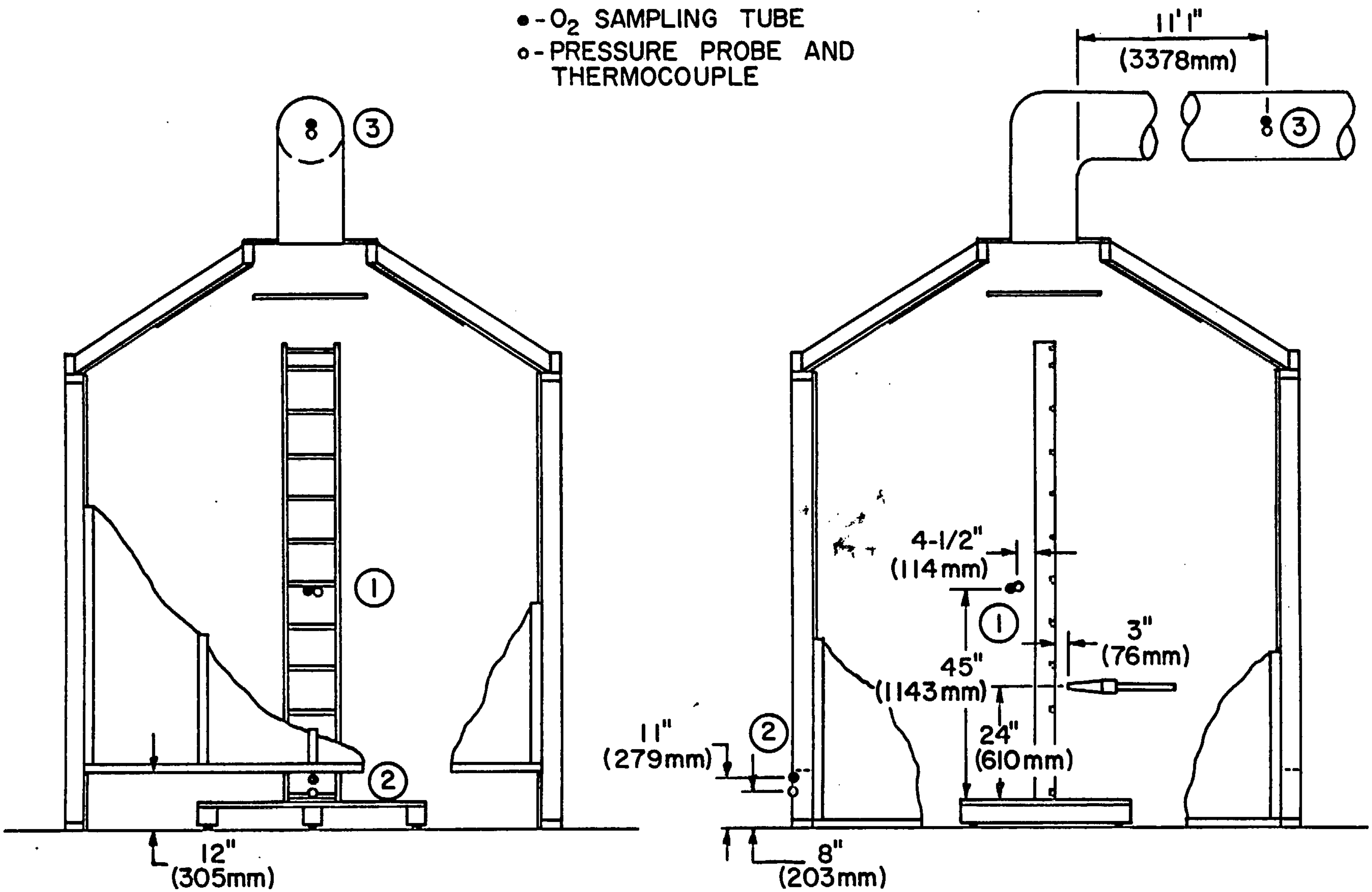


FIG. 2

FLAME HEIGHT

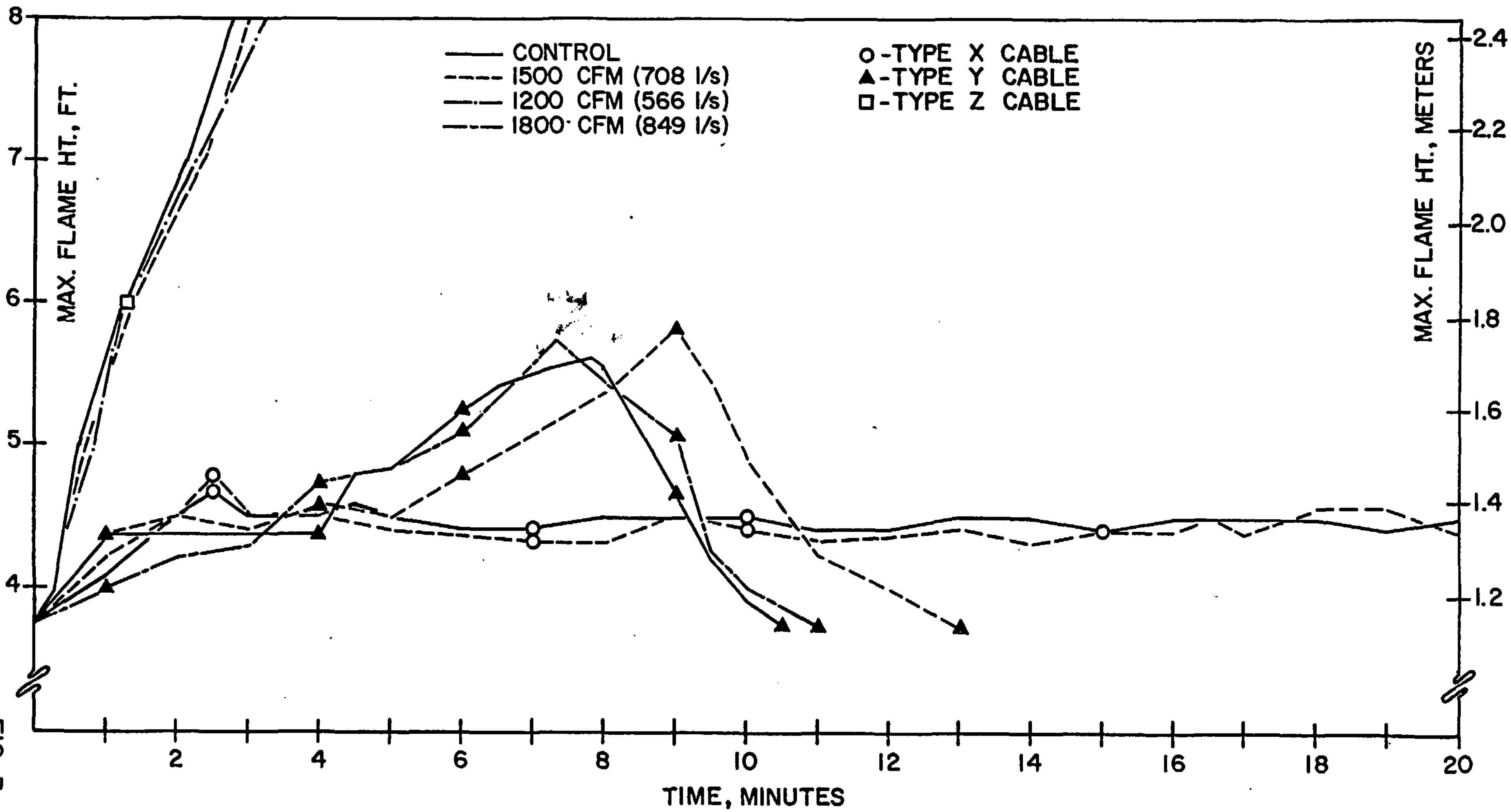


FIG. 3

CABLE DAMAGE HEIGHT

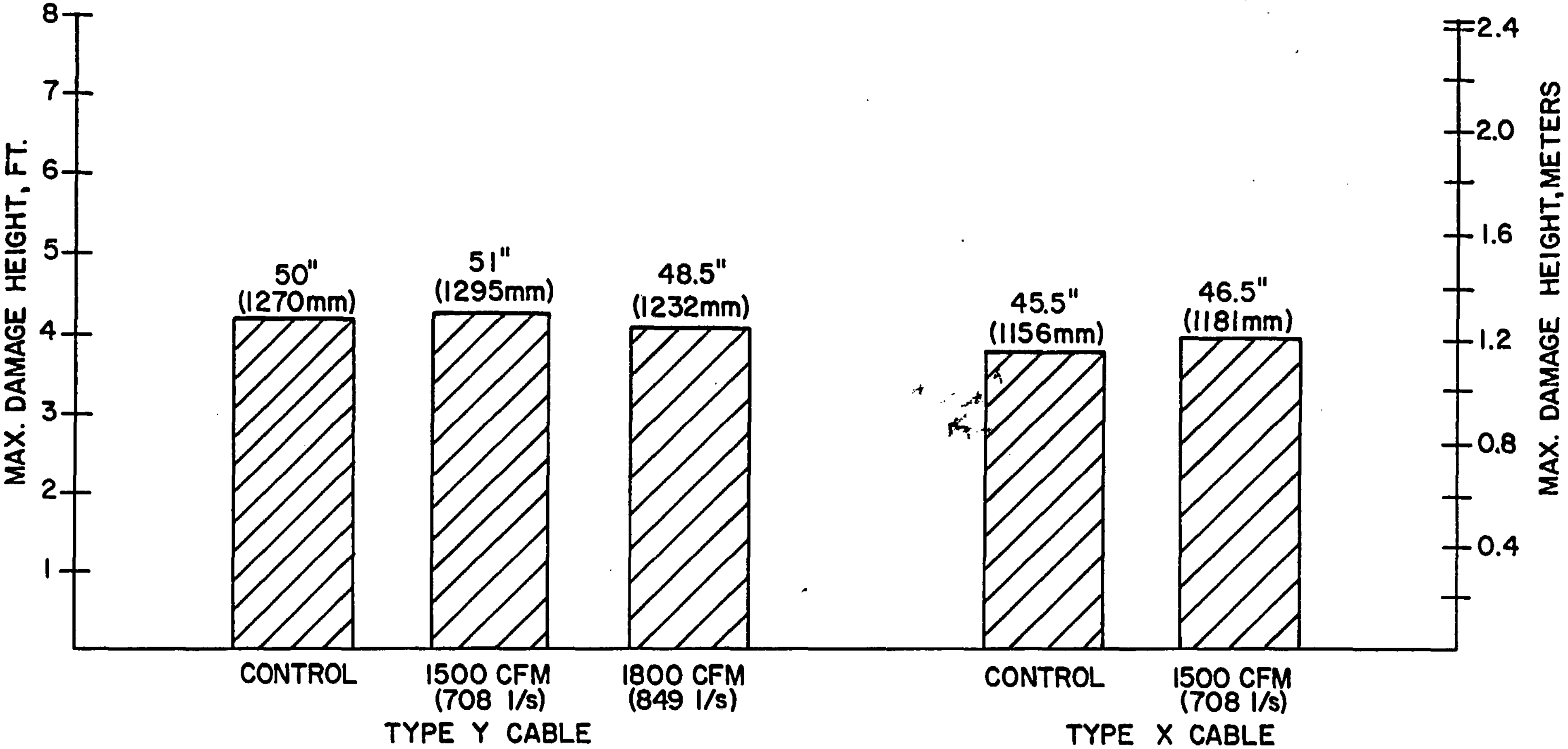


FIG. 4

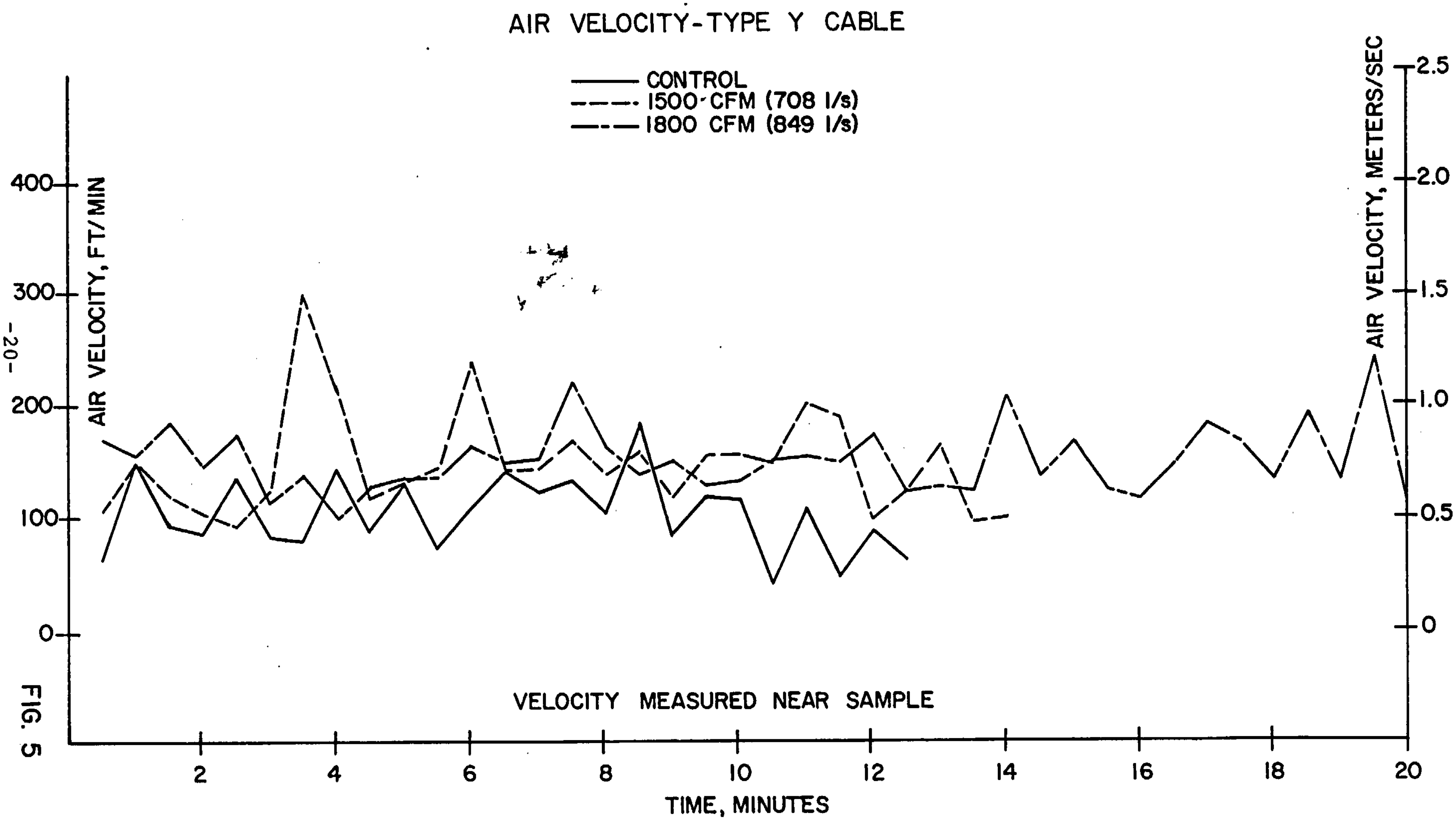

AIR VELOCITY-TYPE Y CABLE
CONTROL
1500 CFM (708 l/s)
1800 CFM (849 l/s)
AIR VELOCITY, FT/MIN
AIR VELOCITY, METERS/SEC
VELOCITY MEASURED NEAR SAMPLE
TIME, MINUTES
0
100
200
300
400
0.5
1.0
1.5
2.0
2.5
2
4
6
8
10
12
14
16
18
20

FIG. 5

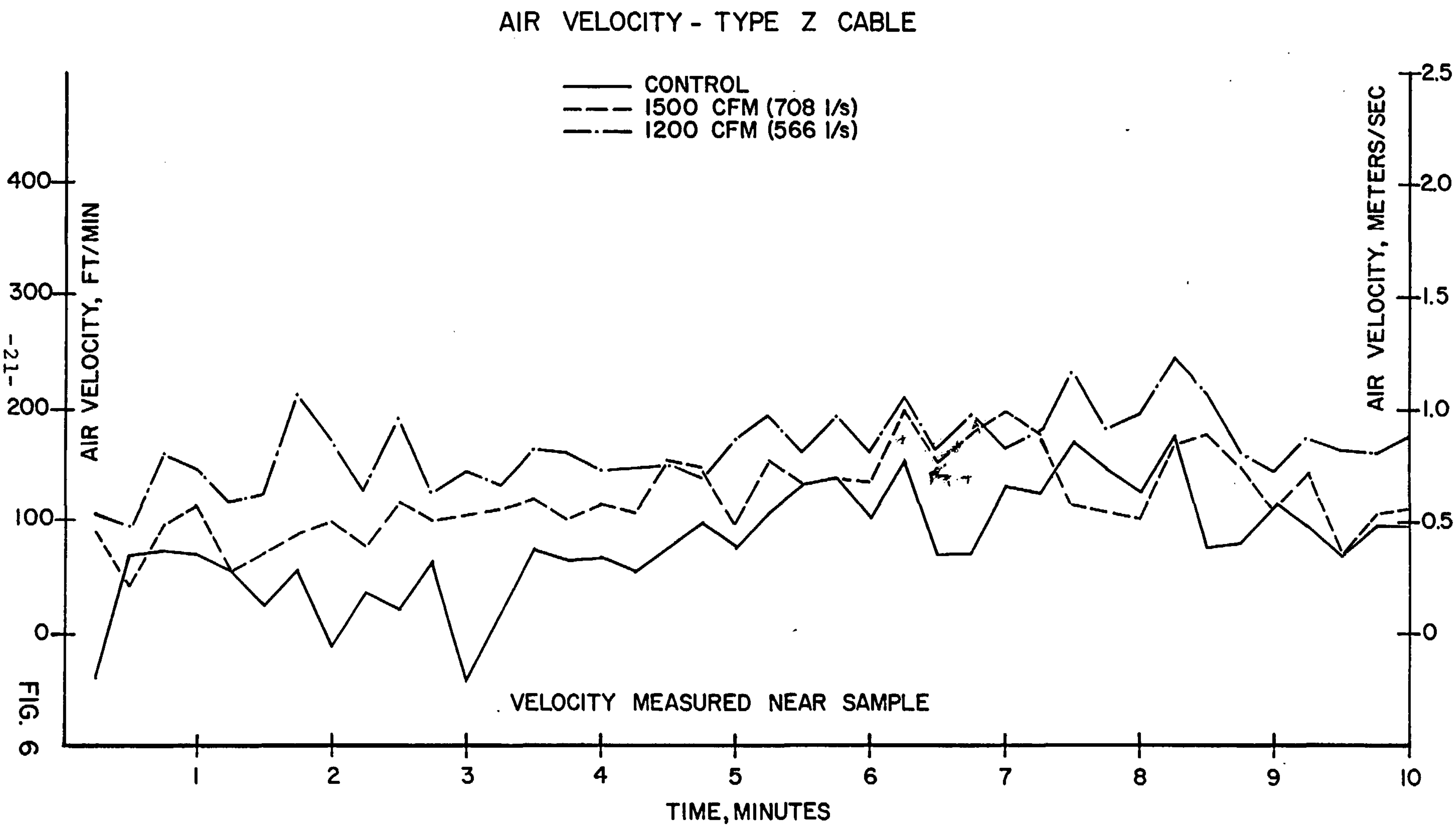

AIR VELOCITY - TYPE Z CABLE
CONTROL
1500 CFM (708 l/s)
1200 CFM (566 l/s)
AIR VELOCITY, FT/MIN
400
300
200
100
0
AIR VELOCITY, METERS/SEC
2.5
2.0
1.5
1.0
0.5
0
VELOCITY MEASURED NEAR SAMPLE
1
2
3
4
5
6
7
8
9
10
TIME, MINUTES

FIG. 6

AIR VELOCITY - TYPE X CABLE

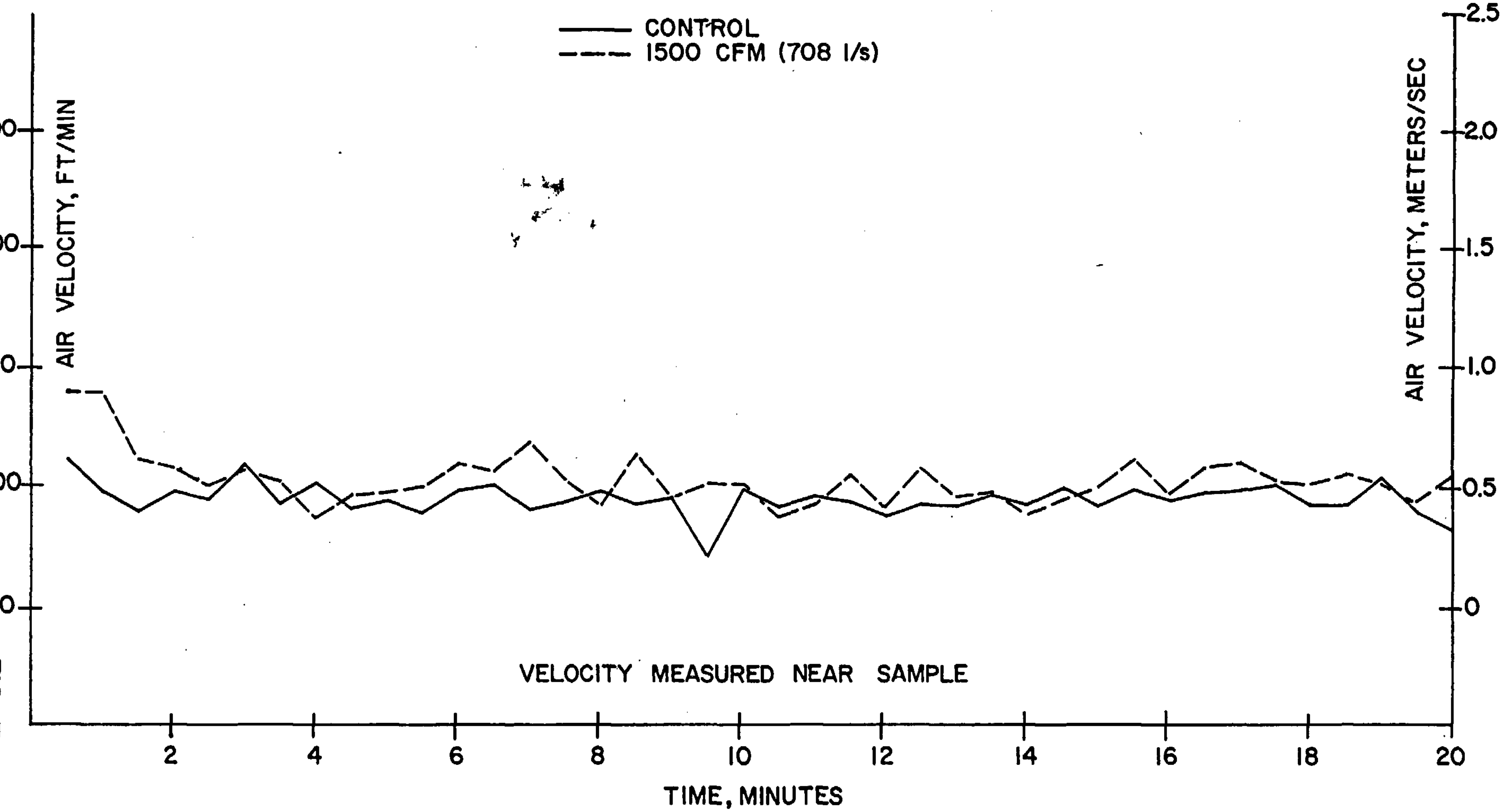


FIG. 7

NRC FORM 335 (7-77) U.S. NUCLEAR REGULATORY COMMISSION **BIBLIOGRAPHIC DATA SHEET**	1. REPORT NUMBER (Assigned by DDC) NUREG/CR-1552 UL-USNC 75 Q
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16. ABSTRACT (200 words or less)

Experiments were conducted to sutdy the effects of a forced ventilation on the results of the IEEE 383 flame test for tray cables. Three sets of experiments were conducted on three types of cables. The first set was a control in which cable samples were tested in a free-convection environment within an 8 x 8 x 8 ft (2.44 x 2.44 x 2.44 m) enclosure. In the second set, the cable samples were tested within an enclosure with a 1500 CFM (708 l/s) forced ventilation. In the third set, the cable samples were tested within an enclosure with the ventilation rate of either 1200 CFM (566 l/s) or 1800 CFM (849 l/s). The results showed that the rate of flame propagation and the maximum cable damage were not affected when the enclosure and forced ventilation were used. It is recommended that the test method be revised to specify the use of an enclosure and forced ventilation.

17. KEY WORDS AND DOCUMENT ANALYSIS — 17a. DESCRIPTORS

IEEE 383, Flame Test,
Enclosure, Forced Ventilation,
Cable Damage, Oxygen Depletion,
Air Velocity

17b. IDENTIFIERS/OPEN-ENDED TERMS

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