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

Quarterly Report 4 March 1 - May 31, 1978

L.J. Przybyla and W.J. Christian Underwriters Laboratories, Inc.

U.S. Nuclear Regulatory Commission

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ABSTRACT

Experiments were conducted to establish data on the sensitivity of the results to variations of several parameters of the vertical cable tray fire test described in the IEEE Standard 383. Parameters varied were burner-to-cable distance, air input rate and fuel input rate. As a result of these experiments and previous experience, suggestions for revision of IEEE 383 are made with respect to 1) construction of cable trays, 2) test enclosure, 3) type, size and spacing of cable ties, 4) burner position, 5) mesurement of fuel and air rates, 6) flame temperature, 7) initial room temperature, and 8) reporting of results.

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NUREG/CR-0152 (UL-USNC 75 Q2-3)

Development And Verification Of Fire Tests For Cable Systems and Components

I. Introduction

This is the fourth quarterly report covering the period from March 1 through May 31, 1978. During this period, separate-effects experiments which were conducted as a part of Task A of the contract work scope. Specifically, twenty experiments were conducted to refine parameters of the IEEE 383 cable fire test method.

Several separate-effects experiments were conducted previously and described in Report NUREG/CR-0152 (UL-USNC 75 Q2-3). These experiments were conducted retaining similarity to the IEEE 383 test method, but with full cable trays (nominally 40 percent fill) and two burner ignition sources in order to more closely simulate a severe fire condition. However, experiments with one cable type produced results which were extremely variable because of random movements of the cable during burning and therefore, experiments with full fill cable trays were terminated for the present time.

One criticism about the present test method has been that results obtained are not repeatable between tests or reproducible between testing facilities.

Since a need exists for a reproducible cable fire test method, experiments were conducted to refine the values specified in the present IEEE 383 test method. The object of these experiments was to provide a data basis to establish tolerances for various test parameters and to define a test method with more reproducible results.

The parameters which were varied were 1) burner-to-tray distance, 2) air input rate, and 3) fuel input rate. The plan was to observe the effect of changing the parameters from the values specified in present IEEE 383. Also, since the only measure of cable performance described in the present IEEE 383 test method is the extent of cable damage, the use of cable-jacket temperatures developed during the experiment as a supplemental performance measure was investigated. Cable jacket temperatures might be used to determine actual extent of cable damage, and might also provide a measure of the linear rate of cable deterioration.

II. Experimental Procedure

A. Facility

The cable experiments were conducted inside a heated brick building 37 ft wide, 67 ft long and 21 to 24 ft high as shown in Figure 1. The building was ventilated and free from excessive drafts and spurious air currents, although no specific draft measurements were made.

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 16,000 cfm, which corresponds to one air change every 4 min. There was sufficient air leakage that atmospheric pressure was maintained inside the building while the incinerators were in operation.

B. 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. wide, 11-55 drilling, ribbon burner, 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. The heating value of the commercial grade propane was 2,514 BTU/ft2.*

Cable experiments were conducted using open-ladder type cable 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 nominal 0.125 in. thick (No. 10 MSG) ladder rungs were 1 in. wide with 1/2 in. legs, and were 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 each cable to various rungs of the cable trays as shown in Figure 2.

*Value obtained by test with a recording calorimeter and a sample of propane from the same lot used in testing.

C. Enclosure

An enclosure 8 by 8 by 8 ft high was used to isolate the sample from extraneous environmental effects as shown in Figure 3. It was formed by four steel-framed wall sections, 8 ft square, to which 1/2 in. Marinite boards were fastened. 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

The cables used in these experiments were stranded seven (copper) conductor, No. 12 AWG with three combinations of insulation and jacket materials. Identification of cable materials was on the basis of information provided by the suppliers. The cables are identified in this report only by a code number in the description of the experiments to avoid association of the results with proprietary products at this time. Descriptions of the cables, without identification of the code numbers, are given in Table I.

E. Instrumentation

Type K, Chromel-Alumel thermocouples were used to measure the air and propage temperatures before the mixer and the cable jacket temperatures.

Pressures of the fuel and air within the burner piping before the mixer were measured with differential pressure manometers. Volumetric flow meters were used to monitor propane and combustion-air flow rate.

A thermometer and a barometer were used to measure the ambient air temperature and barometric pressure of the test room prior to each experiment.

F. Method

The experiments were conducted in the sequence shown in Table 2 and in general accordance with the method described in IEEE-383-1974, paragraph 2.5.

Cables were installed in a single layer filling the center 6 in. 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. Each length of cable was fastened to ladder rungs with No. 16 SWG (0.062 in. thick) steel wire at approximately 18 in. O.C. The number of cables per tray and location of fasteners are shown in Figure 2.

The tray was installed vertically in a steel base frame with the rear surface of the cable tray rungs facing the burner. The burner face was positioned 3 in, away from (except in Experiments 5, 6, 11 and 12) and perpendicular to the rear of the cable tray. The center of the burner face was located 24 in. above the base of the tray and midway between ladder rungs.

The temperatures of the cable jacket material were measured in ten experiments. In each of these experiments one cable was instrumented with 12 thermocouples as shown on Figure 4. Each thermocouple was recessed into a notch in the cable jacket, with the notch then filled with a one-part silicone adhesive to fasten the thermocouple to the cable.

The test room was heated to approximately 63 F before the afterburner system was operated in Experiments 1-17. However, no heat was supplied to the test room for Experiments 18-20 since the natural outside air conditions produced the desired room temperature.

To initiate each experiment, a pilot burner flame was ignited. The propane gas and air flows were adjusted to obtain pressures within the specifications outlined in IEEE 383-1974 and/or to obtain the desired volumetric air and fuel inputs under consideration. After the required flows were obtained the experiment was initiated. Specimens were subjected to the burner flame for a 20 min duration after which the burner flame was extinguished.

Throughout each experiment, visual observations were made of the condition of the cable material, flame travel, and other developments pertinent to the fire performance of the cables. Each experiment was concluded when all fire activity had ceased.

III. Results

A. Visual Observations During Experiments

A summary of visual test observations for each cable type are given below. Graphs of maximum flame height versus time are shown in Figures 5-10.

Type I

The cable jacket material melted in advance of the propagating flame. Although the cable jacket material melted, the cable did not fuse together into a single cable mass in the fire region. No fall off of flaming material or other dripping or sparking was observed. As the flames traveled up the tray, the burning cable jacket/insulation material produced white ash. Small pieces of the ash gradually fell to the floor.

Type II

The cable jacket material discolored, blistered and cracked in advance of the flame. No melting of the cable jacket was observed. The outer surface of the cable jacket formed small scales, approximately 1/16 in. in diameter and smaller. A small amount of expansion of the cable insulation and/or jacket materials was observed to occur, although not sufficient to close the space between adjacent cables. While the cable material was flaming crackling noise issued from the burning cable, although no noticable loss of surface particles occurred. As the flames traveled up the tray, the burning cable jacket/insulation material produced white ash. Small pieces of the ash gradually fell to the floor.

Type III

The cable jacket/insulation material swelled in the fire area closing the space between the cables. The ignition flame was then unable to penetrate through the cable mass to the cable front surface. The ignition flame was able to curl about the sides of the cable mass to the front surface of the end cables. In the fire area crackling and popping sounds were audible as some small (approximately 1/16 in. diameter) particles popped away from the cable. The color of the burned cable jacket was a light gray.

Cable Jacket Temperatures - Temperature records for each experiment in which cable jacket thermocouples were installed are shown in Tables 3-12. Isothermal graphs for each instrumented cable experiment are shown in Figures 11-20.

Observations After Test - Maximum cable damage height for each cable was recorded as shown in Table 13. The maximum and average cable damage heights for each experiment is summarized in Table 14.

IV. Discussion

Several effects were observed when the test parameters were varied.

Experiments 1 through 4 were conducted to provide an estimate of the repeatability of the results for fixed test conditions. Heights of damage on individual cables in each experiment are shown in Table 3, and the maximum height of damage for each experiment is shown in Table 14. It is seen that for Experiments 1-3, the variation of the maximum damage height was from 68 to 71 in., whereas the maximum damage neight in Experiment 4 was 87 in. However, Experiment 4 is suspect for the following reason. Room temperature prior to the experiment had inadvertantly been allowed to rise to about 95 F, and then cooled to 64 F by admitting outside air. It is possible that parts of the cable, cable tray, and enclosure were still above room temperature at the start of the experiment, thus increasing the height of damage in that experiment. For this reason, only Experiments 1-3 are being used to estimate the basic repeatibility of the height of damage, which is estimated to be +1-1/2 in.

As shown in results of Experiments 5 and 6, varying the burner distance $\pm 1/2$ in. from the specified 3 in. has a significant effect on cable performance. About a 10 in. difference in height of cable damage was recorded between Experiments 5 and 6. However, little difference in height of cable damage was observed between Experiments 11 and 12 where the burner distance was varied $\pm 1/8$ in.

In Experiments 7 and 8, the air input rate was varied plus 10 percent and minus 6 percent, respectively. The results of these tests show that little difference in cable damage is produced by such a variation in the supply air. This is to be expected, since the air/fuel ratio of the standard ignition flame is approximately 6/1, whereas the stoichiometric air/fuel ratio is about 23/1. With such a fuel-rich mixture, slight variations in the amount of air should not have a significant effect on the nature of the flame heat output.

The fuel input rate was varied in Experiments 9, 10, 13 and 14. A plot of height of cable damage for each of the experiments is shown in Fig. 21. As shown, there is a tendency for increasing cable damage with decreasing fuel input. Approximately a 10 in. difference in cable damage was observed between Experiments 9 and 10 in which the fuel input was varied from 65,000 to 70,000 Btu/hr. However, only a 1 in. difference in cable damage was observed when the fuel input was varied between 71,650 and 67,800 Btu/hr.

As shown in Table 15, initial room temperature for all of the experiments was between 57 and 69 F. Additional room heating was required to obtain the desired room temperatures in Experiments 1-17. Weather conditions produced initial room temperatures in the 60 F range without additional heating in Experiments 18-20.

Visual observations and cable damage in previous cable fire tests suggest that a significant difference in results may be caused by a large variation in initial room temperature. Four cable fire tests according to IEEE 383 were conducted as part of another investigation, and are described in UL Reports, Subject 1277 dated April 18, 1978; and Subject 1277-2, dated June 23, 1978. A summary of the results is shown in Table 16.

The four tests were conducted on one cable type with samples obtained from one cable reel. Besides the variations of initial room temperatures, barometric pressure and humidity, the only difference between Experiments 1-2 and 3-4 was the spacing of cable ties and burner height. However, after allowance for the burner height, Experiments 3 and 4 sustained greater cable damage than did Experiments 1 and 2, which were conducted at lower initial starting temperatures.

In ten of the experiments, cable jacket temperatures were recorded. In Figures 11-20, cable jacket temperatures are plotted on a height versus time graph. These plots may provide information as to the rate of cable burning in each experiment. A comparison of this data with the observed maximum flame height versus time graphs, as shown in Figures 5-10, indicates that there may be a useful correlation between the recorded cable jacket temperature and the observed cable burning. Also, Figures 11-20 suggest that cable damage corresponds with cable jacket temperatures in the 300-400 F range.

Since only a limited number of experiments were conducted, additional experiments would be required to investigate the significance of quantitative measurements of cable jacket temperature. However, the qualitative data on jacket damage is sufficient for establishing test parameter tolerances.

V. Recommendations

It is suggested that the fire test procedure described in NRC Regulatory Guide 1.131 be revised to better define, and elaborate on certain items which presently are only mentioned or excluded entirely. These items are A) construction of cable trays, B) test enclosure, C) type, size and spacing of cable ties, D) tolerance on burner position, E) monitoring of fuel and air input rates, F) flame temperature, G) initial room temperature, and H) reporting of results.

A. Cable Trays

The type of cable tray used has a significant effect on the fire performance of the cables. The cable tray to be used should be completely specified as to its size and construction, including the shape, dimensions and spacing of ladder rungs. Although any standard ladder tray would be adequate, the cable tray described in this Report has been used extensively with good results, and is a reasonable choice for standardization.

B. Enclosure

Since the tests should be free from excessive drafts and spurious air currents, the document should be revised to define the test enclosure. The enclosure used in this investigation seems to provide adequate shelter from superficial air currents within the test room. Also, the rate exhaust from the room should be established. A value to 1800 cfm is suggested as a conservative value, based upon the results of previous experiments in this investigation as reported in NUREG/CR-0152.

C. Cable Ties

The spacing and type of cable ties is very important in obtaining reproducible test results. It is necessary that steel tie wire be specified as the fastening means. When plastic or other low melting temperature material is used as fasteners, the cable usually breaks loose in the fire area. The ensureing random movements of the cables produce significant variability in the results. It is suggested that No. 16 SWG steel wire ties be used to fasten each cable every 18 in. along the cable tray.

D. Burner Position

Presently, the IEEE test method specifies that the burner face shall be 3 in. behind and approximately 2 ft above the bottom of the tray. The sensitivity tests have shown that variations of $\pm 1/8$ in. in the burner-to-tray distance do not produce significant changes in the maximum height of damage. It is therefore suggested that the Standards specify a distance of 3 \pm 1/8 in. between the burner face and the cable tray.

Although the effect of burner height was not investigated, it seems certain that proximity of the burner to a ladder rung would have a significant effect on the results. Additionally, the height above the bottom of the tray to which damage extends will obviously depend on the height of the burner above the bottom of the tray. For both reasons, it is suggested that the height of the burner be specified in the Standard as 24 + 1/8 in.

E. Fuel and Air Input Rates

The present method of monitoring fuel and combustion air input rate is by measuring the pressure of each in the supply lines before the mixer and measuring the flame temperature. Previous experience has shown that monitoring pressure is a coarse means of regulating the ignition flame since any restrictions in the line, changes in density of the fuel and air, and the heat produced by the burning cable have significant effects on the recorded pressures. Use of rotameters in lieu of the manometers, with compensation for the gas densities provides an accurate means of monitoring fuel and air flow rates.

The Standard should specify that the tests are to be conducted with a fuel input rate of $70,000\ (\pm1,600)$ Btu/hr and an air input rate of $163\ (\pm10)$ SCFH.

F. Flame Temperature

The flame temperature requirement should be deleted since it is a very difficult quantity to measure.

G. Initial Room Temperature

Although we presently do not have a great quantity of data, it is suspected that initial room temperature has a significant effect on results.

The present tests, conducted with initial room temperatures between about 58 and 69 F, suggest that variations over this range do not significantly affect the results. Until further information becomes available, it is suggested that the Standard specify a tolerance of +5 F for initial room temperature, which should correspond with initial cable temperature. The center value of the initial room temperature should probably be specifed as 75 F for maximum convenience.

H. Reporting of Results

A definition of cable damage should be included in the Standard. Although more or less sophisticated determinations of jacket and insulation properties might be conceived for assessing damage, these do not appear to be necessary. A definition of damage as melting, blistering, or charring appears to be sufficient for this test.

These suggestions are based on results of a limited number of experiments. If greater detailed quantitative results are desired concerning the repeatability and reproducibility of the test, further experimentation would be required. It is recommended, therefore, that round-robbin testing be undertaken to obtain this additional data.

Although reporting of cable jacket temperatures appears to be beneficial, more experimentation would have to be conducted before any specific proposal could be made. However, the techniques and time required for proper placement of the cable jacket temperatures may be too demanding for inclusion of this measurement in a standard test of this nature at this time.

Table 1 Cable Description

Approximate Cable Jacket Thickness, In.	0.134	0.050	0.068
Cable Jacket Material	Cnlorosulphonated polyethylene	Polyvinyl chloride	Polychloroprene rubber
Approximate Conductor Insulation/ Jacket Thickness, In.	0.028/0.017	0.022/0.006	0.044/-
Insulation/Jacket Material	Ethylene propylene rubber/caloro-sulphonated poly-ethylene	Polyvinyl chloride/ nylon	Crosslinked poly- ethylene
Cable Cross Section Diameter, In.	0.785	0.515	0.618
Designation	EPN :ypalon/Hypalon	PVC-Nylon/PVC	XLPE/Neoprene

Table 2 IEEE 383 Cable Experiments

Experiment	Caole Type	Fuel Input	Air Input	Air/Fuel Ratio	Burner Distance (In.)	Cable Jacket Temperature Measurement
1	I	70,000	163	5.9/1	3	Yes
2	I	70,000	163	5.9/1	3	Yes
3	I	70,000	163	5.9/1	3	Yes
4	I	70,000	163	5.9/1	3	Yes
5	I	70,000	163	5.9/1	3-1/2	No
6	1	70,000	163	5.9/1	2-1/2	No
7	I	70,000	180	6.5/1	3	No
8	I	70,000	153	5.5/1	3	No
9	I	65,000	163	6.3/1	3	No
10	I	75,000	163	5.5/1	3	No
11	I	70,000	163	5.9/1	3-1/8	No
1.2	I	70,000	163	5.9/1	2-7/8	No
13	I	71,650	163	5.7/1	3	No
14	I	67,800	163	6.0/1	3	No
15	II	70,000	153	5.9/1	3	Yes
16	11	70,000	163	5.9/1	3	Yes
1.7	11	70,000	163	5.9/1	3	Yes
18	111	70,000	163	5.9/1	3	Yes
19	111	70,000	163	5.9/1	3	Yes
20	111	70,000	163	5.9/1	3	Yes

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	Time (Min)	Pre-		2	3	77		2	00	502	8-10-2	00100	10	2 6 7 8 7 9 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	5 9 9 8 7 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	111098765	113 111 10 9 8 7 6 5	5 4 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	11098765	11098765	2 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4	20 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Tab's 4 Cable Jacket Temperatures Experiment 2 (Degrees F)

96	99	98	66	armed	100		Low		00	-	-	10	10	0	0	10	5	10		10	152
90	64	06	0	143	1-	00	(4)	00	20	1-	N	The	0		10	10	10	in	W	S	S
84	51	0	CAU	152	0	3	M	S	(17)	N	ind	0	0	0	0	00	00	00	00	00	00
78	111	(100)	10	212		print	0	The	M	1747)	m		-			On	2	C31	0	179	750
(In.)	5.7	66	(77)	165	(m)	conf	0	Pro-	3	0		-	-	150	5	S	(4)	m	3	(30)	CU
Height 66	1		Lon	204	00	0	-	00	5	27	mil	0	0	gran.	0	0	10	(2)	3	m	225
09	09	-		319	50	0	40	Un.	-	#	0	0	00	-17	3	3	and	9	0	0	292
5.4	29	0		305	W	M	med	03	0	9	-	1	0	N	-		0	prof	-	0	327
48	57	and.	0	948		D															
42	99	Ē	0	981	97	15	30		0	(7)	(4)	-7	00	27	27	CVI	00	9			0
36	09	54		1571			09		54	0	53	27	5	5.2		19	50	20	2 3	9 5	
30	09	20	57	1530	96	52	09	0	00	5	20	0.5	52	2	200		33	50	137	50	23
Time (Min)	1			m	17	5	9	7	00											19	

Table 5 Cable Jacket Temperatures Experiment 3 (Degrees F)

Time						Не	ight (In.)				
(Min)	30	36	42	48	54	60	66	72	78	84	90	96
Pre- test	60	60	-	60	64	55	51	55	60	57	60	77
test 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17	1593 1505 1416 1521 1438 1329 1570 1222 1351 1394 1705 1526 1265 1287 1570 1438 1222	598 795 1412 1505 1482 1373 1200 1061 926 905 947 880 816 816 774 778 761	453 598 778 841 867 850 816 714 667 649 628 615 606 589 606 589	300 108 104 112 598 812 705 576 506 475 449 440 431 431 435 413	190 247 390 585 624 675 675 537 431 386 345 336 323 318 314	173 217 305 426 519 593 546 395 336 287 296 283 274 265 260 256 252	143 169 225 296 359 379 372 309 274 256 252 238 234 230 225 221 217	121 143 169 212 247 269 274 260 252 237 234 230 221 212 208 208 208	112 134 156 186 217 234 234 212 195 190 186 182 173 173 169 169	100 121 138 160 186 195 190 182 169 165 160 160 156 152 152 147	95 108 121 143 160 169 165 160 156 157 147 147 143 143	90 100 117 125 143 152 147 143 143 143 143 138 138 138
18 19 20	1570 1450 1482	756 735 714	546 541 537	417 413 408	300 296 296	252 252 247	212 212 208	204 204 199	165 165 165	147 147 143	143 143 143	134 134 134

Table 6 Cable Jacket Temperatures Experiment 4 (Degrees F)

1638 386 42 48 1638 386 520 278 1330 515 547 346 1268 939 926 832 1268 939 926 832 1393 956 948 816 1415 1045 964 637 1437 986 645 714 1437 985 624 554 1188 896 589 515 1393 842 589 515 1437 799 585 489 948 744 563 444 1265 772 563 444 1265 772 563 444 1265 774 550 418 884 706 547 427 1286 795 520 395 1286 795 520 395								
638 386 520 27 330 515 547 34 348 515 547 34 348 515 547 34 268 939 926 83 268 939 926 83 393 956 948 81 415 1045 964 63 415 1045 964 63 417 986 645 71 437 985 624 55 437 985 624 55 437 985 624 55 437 985 624 55 948 842 585 48 265 744 563 44 265 744 563 44 265 714 563 44 265 714 563 44 265 714 563 45	54	Hei 60	ght (1 66	n.)	78	8.4	06	96
638 386 520 27 948 778 865 58 268 939 926 83 268 939 926 83 415 1045 964 63 415 1045 964 63 415 1045 964 63 437 985 624 55 437 985 624 55 437 789 585 44 265 714 563 44 265 714 563 44 308 752 520 41 884 766 547 42 265 714 563 43 265 714 563 43 265 774 520 41 308 795 520 39	55	09	55	7.7	55	76	55	55
330 515 547 34 268 939 926 83 926 83 939 926 83 939 926 83 939 926 83 939 926 83 939 926 83 939 926 981 607 52 948 948 744 563 445 714 563 445 726 520 39 520 39 520 39 520 39	LC.	10		0	0	CV	pene	
948 778 865 58 268 939 926 83 393 956 948 81 415 1045 964 63 417 986 645 71 437 985 624 55 487 981 607 52 488 896 589 51 488 896 589 51 488 744 563 44 265 744 563 44 265 744 563 44 265 744 563 44 265 744 563 44 265 744 563 44 265 714 563 44 286 736 520 39 286 736 520 39 286 735 520 39 287 736 520 39	0	0	100	0	N	cr	10	
268 939 926 83 393 956 948 81 415 1045 964 63 437 986 645 71 188 896 624 55 188 896 624 55 188 896 589 51 188 896 589 51 437 799 585 48 265 744 585 48 265 74 563 44 265 714 563 44 884 706 547 42 884 706 547 42 286 736 520 39 286 795 520 39	0	0	0	cr	=	10	27	N
393 956 948 81 415 1045 964 63 415 1045 964 63 437 986 645 71 986 645 71 188 896 624 55 188 896 589 51 393 842 589 51 437 799 585 48 265 744 563 44 265 744 563 44 884 706 547 42 884 706 547 42 286 795 520 39 286 795 520 39	00	3	0	100	00	00	10	二寸
415 1045 964 63 437 985 624 55 086 981 607 52 188 896 589 51 393 842 589 51 437 799 585 48 265 724 563 44 265 772 563 44 265 772 563 44 308 795 520 41 308 795 520 41 308 795 520 39	628	533	391	261	234	230	199	165
757 986 645 71 437 985 624 55 086 981 607 52 188 896 589 51 393 842 585 51 437 799 585 48 265 744 563 44 265 744 563 44 265 714 563 44 884 706 547 42 286 736 520 41 286 795 520 39 201 795 520 39	0	3	5	mid	0	in	N	00
437 985 624 55 086 981 607 52 188 896 589 51 393 842 585 51 437 799 585 48 265 744 563 44 265 744 563 44 265 774 520 41 884 706 547 42 884 736 520 39 286 795 520 39	-	6	3	0	N	00	===	0
086 981 607 52 188 896 589 51 393 842 585 58 437 799 585 48 948 744 563 44 265 74 563 44 265 714 520 41 884 706 547 42 884 736 520 39 286 795 520 39	0	-	50	N	-	5	00	m
188 896 589 51 393 842 585 51 437 799 585 48 948 744 563 44 265 752 563 44 265 714 520 41 884 706 547 42 308 736 520 39 286 795 520 39 201 795 520 39	100	ZŽ.	00	N	O	0	0	5
393 842 585 51 437 799 585 48 948 744 563 44 265 752 563 44 265 772 520 41 884 706 547 42 308 736 520 39 286 795 520 39 201 795 520 39	00	-	0	0	二十	-7	OV	50
437 799 585 48 948 744 563 44 265 752 563 45 265 714 520 41 884 706 547 42 308 736 520 39 286 795 511 39 201 795 520 39	0	二	27	00	27	5	N	In
948 744 563 44 265 752 563 44 265 714 520 41 884 706 547 42 308 736 520 39 286 795 511 39 201 795 520 39	5	10		N	O	1	0	5
265 752 563 45 265 714 520 41 884 706 547 42 308 736 520 39 286 795 511 39 201 795 520 39	0	(4)	0	0	5	==	-	-
265 714 520 41 884 706 547 42 308 736 520 39 286 795 511 39 201 795 520 39	CN	0	二十	m	-	CU	0	3
308 706 547 42 308 736 520 39 286 795 511 39 201 795 520 39	10	-	pared	0	00	0	===	N
338 736 520 39 286 795 511 39 201 795 520 39	5	15	0	0	5	0	m	prod
286 795 511 39 201 795 520 39	-13	N	Low	3	m	00	[4]	0
201 795 520 39	-	0	M	0		mad	ON	9
	mind	-	5	0	0	0	N	0
265 778 497 38	med	00	5	1	-	5	proof	00

Table 7 Cable Jacket Temperatures Experiment 15 (Degrees F)

Time						Не	ight (In.)				
(Min)	30	_36	42	48	54	60	66	72	78	84	90	96
Pre- test	57	60	66	55	57	54	48	55	57	55	55	52
1	1011	454	243	37	143	143	121	95	108	95	95	51
2	1180	515	291	234	160	164	134	104	112	108	99	81
3	1062	555	305	252	177	173	138	113	121	121	104	95
11	965	714	318	270	190	164	147	121	134	126	108	100
5	965	859	336	296	212	204	160	135	117	135	121	104
6	990	1032	368	319	230	221	169	135	147	135	126	113
7	1015	1019	466	382	265	247	190	152	156	152	138	121
8	1138	905	628	449	296	265	204	165	164	165	143	126
9	1145	948	837	498	323	283	221	178	177	165	152	135
10	1158	1007	901	537	345	296	225	182	182	174	152	139
11	1231	1074	930	546	359	327	234	181	187	178	138	143
12	1300	1104	930	542	363	314	234	195	187	195	152	143
13	1338	1104	943	520	359	309	234	195	187	174	152	143
14	1333	1159	1011	515	359	309	230	195	187	178	152	148
15	1330	1163	1040	515	350	305	230	195	187	178	152	143
16	1321	1176	1074	515	341	300	230	195	187	178	152	143
17	133	1189	1091	515	341	296	230	195	187	178	152	143
18	1343	1202	1108	511	332	291	225	195	187	178	152	143
19	1343	1270	1176	515	327	291	230	195	187	178	152	143
20	1352	1287	1201	511	323	283	225	195	187	178	152	143

Table 8 Cable Jacket Temperatures Experiment 16

		Table	0	0000	(Degree	es F)	2					
(Min)	30	36	7 7	48	54	90	ight (In.)	7.8	84	06	96
0	09	56	1	56	54	73	55	55	55	55	53	56
test												
-	0	500	3	0	con	63	3	0	pred	96	1.1	95
2	76	prod	1	rend	-	00	m	c	N	66	06	
c	0		00	3	40	10	=	med	CV	0	96	0
) 7	00	-	00	27	1	67	寸	S	3	0	66	-4
2	00	0	0	0	0	-	5	(4)	3	CU	0	and
9	10	17	CV	00	0	=	10	===	:27	CV	ent	CV
7	0	0.5	40	-	N	0	1	5	=	(4)	med	m,
- 00	at	1 1	-3	0	=		204	169	169	143	125	138
0	8	76	0	-	1	二寸	0	-	0	-	m	-
		10	-	3	0	-	+	∞	-	5	===	22
	=	0	1	27	prod	3	med	00	-	0		10
	m	10	10	0	OJ	0	0	0	00	0	#	15
	m	9	-	00	m	my	(7)	0	0	0		5
	12	0	15	5	3	5	N	0	00	0	5	0
	00	020	二寸	S	N	00	N	0	00	0	5	0
	0	0.4	10	M	N	0	CV	0	00	0	5	0
	00	10	0	=#	prod	∞	red	0	00	0	5	0
	0	0.5	00	5	rod	9	0	0	00	0	5	0
	96	05	0		0	1-	-	0	00	0	5	0
20	968	1070	939	1111	300	196		0	00	0	27	0

Table 9 Cable Jacket Temperatures Experiment 17 (Degrees F)

Time						Не	ight (In.)				
(Min)	30	36	42	48	54	60	66	72	78	84	90	96
Pre-	64	66	55	66	64	64	64	_	62	66	62	66
test												
1	1615	413	248	190	147	138	125	147	125	104	99	99
2	1544	511	301	238	182	164	143	164	138	121	108	108
3	1710	576	323	260	199	182	160	182	143	138	117	121
24	1638	602	332	269	208	186	169	190	147	143	125	125
5	1615	863	255	287	230	199	177	195	151	143	130	130
6	1710	880	400	318	247	212	186	208	164	151	138	138
7	1683	981	511	386	278	243	208	225	177	164	147	147
8	1660	867	620	475	323	274	234	243	190	182	156	160
9	1593	927	897	563	363	309	252	256	208	186	164	164
10	1575	1011	935	624	408	332	269	274	225	195	177	173
11	1580	1079	1019	671	422	345	274	274	225	199	177	177
12	1478	1185	994	752	408	341	274	279	551	208	182	177
13	1535	1159	1007	701	399	332	274	279	212	508	182	182
14	1482	1163	1019	688	386	327	269	279	208	204	182	182
15	1513	1137	1024	671	372	318	265	279	208	204	182	182
16	1465	1159	998	680	363	314	260	279	204	199	186	182
17	1434	1159	1011	662	359	300	252	279	199	195	186	182
18	1307	1146	914	671	354	300	252	274	204	195	186	182
19	1382	1219	918	671	345	296	252	274	199	190	182	182
20	1352	1184	948	649	341	291	247	274	199	190	182	182

Table 10 Cable Jacket Temperatures Experiment 18 (Degrees F)

Time						Не	ight (In.)				
(Min)	30	_36_	42	48	54	60	66	72	78	84	90	96
Pre-	-	-	-	69	69	69	68	68	61	61	61	69
test												
1	1456	407	235	170	118	129	114	98	81	79	75	89
2	1508	403	275	200	137	140	127	107	88	86	81	97
3	1559	339	240	206	151	149	142	118	96	94	87	106
14	1549	324	242	225	171	160	154	128	103	100	93	93
5	1557	322	254	236	190	171	166	139	110	107	98	119
6	1460	327	271	247	208	181	174	148	116	112	103	125
7	1576	339	287	261	223	192	183	158	123	119	108	131
8	1513	350	303	272	236	203	192	166	128	125	113	137
9	1497	361	321	283	247	211	200	174	133	126	117	142
10	1266	373	332	294	259	220	208	181	167	162	122	147
11	1062	380	340	299	269	227	216	189	174	167	152	152
12	1148	389	347	306	279	237	555	195	179	170	157	156
13	1050	399	359	315	287	243	227	201	184	169	161	160
14	681	410	372	325	296	248	232	207	189	176	166	164
15	418	418	381	329	302	253	238	213	195	183	170	168
16	473	429	387	335	307	258	240	216	199	185	173	170
17	598	447	397	343	314	266	247	220	503	188	176	173
18	674	456	403	345	319	270	250	223	207	193	178	175
19	944	456	403	346	323	271	251	225	209	201	181	177
20	617	456	403	348	327	272	253	227	210	194	182	178

Table 11 Cable Jacket Temperatures Experiment 19 (Degrees F)

30	36	42	48	54	60	_66_	72	78	84	90	96
-	-	-	69	69	69	70	70	65	65	69	70
1562 1639 1609 1467 1592 1581 1577 1554 1489 1619 1644 1629 1612 1627 1662 1650 1639 1637	293 372 347 336 337 349 358 379 395 405 429 436 447 453 462	188 226 235 240 257 272 286 295 307 319 331 343 350 358 361 370 380 381	153 182 197 210 229 245 260 269 278 286 293 302 307 314 316 324 329 332	128 150 169 186 204 219 233 244 255 261 270 280 284 290 294 297 300 302	127 143 154 164 176 187 198 205 214 219 227 236 245 245 255 256	121 139 152 164 172 182 191 198 205 208 216 224 227 232 234 237 238 239	103 115 127 137 147 156 166 173 179 184 191 198 201 207 211 212 215 215	101 112 122 129 137 145 153 159 165 169 175 181 184 189 192 194 197 198	96 107 116 124 130 138 145 151 155 159 165 170 172 177 180 181 184	90 99 106 113 119 126 132 138 147 152 157 160 164 167 169 171	86 95 103 110 117 123 129 135 139 144 148 153 165 167 168 169
1534	463	379	331	300	254	238	214	197	185	174	169
	1562 1639 1609 1467 1592 1581 1577 1554 1489 1619 1644 1629 1612 1662 1650 1639 1637 1645	1562 293 1639 372 1609 347 1467 336 1592 337 1581 341 1577 349 1554 357 1489 368 1619 379 1644 392 1629 405 1612 415 1627 429 1662 436 1650 447 1639 453 1637 462	1562 293 188 1639 372 226 1609 347 235 1467 336 240 1592 337 257 1581 341 272 1577 349 286 1554 357 295 1489 368 307 1619 379 319 1644 392 331 1629 405 343 1612 415 350 1627 429 358 1662 436 361 1650 447 370 1639 453 380 1637 462 381 1645 462 380	69 1562 293 188 153 1639 372 226 182 1609 347 235 197 1467 336 240 210 1592 337 257 229 1581 341 272 245 1577 349 286 260 1554 357 295 269 1489 368 307 278 1619 379 319 286 1644 392 331 293 1629 405 343 302 1612 415 350 307 1627 429 358 314 1662 436 361 316 1650 447 370 324 1639 453 380 329 1637 462 381 332 1645 462 380 330	69 69 1562 293 188 153 128 1639 372 226 182 150 1609 347 235 197 169 1467 336 240 210 186 1592 337 257 229 204 1581 341 272 245 219 1577 349 286 260 233 1554 357 295 269 244 1489 368 307 278 255 1619 379 319 286 261 1644 392 331 293 270 1629 405 343 302 280 1612 415 350 307 284 1627 429 358 314 290 1662 436 361 316 294 1650 447 370 324 297 1639 453 380 329 300 1637 462 381 332 302	30 36 42 48 54 60 - - 69 69 69 1562 293 188 153 128 127 1639 372 226 182 150 143 1609 347 235 197 169 154 1467 336 240 210 186 164 1592 337 257 229 204 176 1581 341 272 245 219 187 1577 349 286 260 233 198 1554 357 295 269 244 205 1489 368 307 278 255 214 1619 379 319 286 261 219 1644 392 331 293 270 227 1629 405 343 302 280 236 1612	30 36 42 48 54 60 66 - - 69 69 69 70 1562 293 188 153 128 127 121 1639 372 226 182 150 143 139 1609 347 235 197 169 154 152 1467 336 240 210 186 164 164 1592 337 257 229 204 176 172 1581 341 272 245 219 187 182 1577 349 286 260 233 198 191 1554 357 295 269 244 205 198 1489 368 307 278 255 214 205 1619 379 319 286 261 219 208 1644 392 331	69 69 69 70 70 1562 293 188 153 128 127 121 103 1639 372 226 182 150 143 139 115 1609 347 235 197 169 154 152 127 1467 336 240 210 186 164 164 137 1592 337 257 229 204 176 172 147 1581 341 272 245 219 187 182 156 1577 349 286 260 233 198 191 166 1554 357 295 269 244 205 198 173 1489 368 307 278 255 214 205 179 1619 379 319 286 261 219 208 184 1644 392 331 293 270 227 216 191 1629 405 343 302 280 236 224 198 1612 415 350 307 284 240 227 201 1627 429 358 314 290 245 232 207 1662 436 361 316 294 249 234 211 1650 447 370 324 297 254 237 212 1639 453 380 329 300 255 238 215 1637 462 381 332 302 256 239 215 1645 462 380 330 302 255 238 215	30 36 42 48 54 60 66 72 78 - - - 69 69 69 70 70 65 1562 293 188 153 128 127 121 103 101 1639 372 226 182 150 143 139 115 112 1609 347 235 197 169 154 152 127 122 1467 336 240 210 186 164 164 137 129 1592 337 257 229 204 176 172 147 137 1581 341 272 245 219 187 182 156 145 1577 349 286 260 233 198 191 166 153 1554 357 295 269 244 205 198 173	30 36 42 48 54 60 66 72 78 84 - - - 69 69 69 70 70 65 65 1562 293 188 153 128 127 121 103 101 96 1639 372 226 182 150 143 139 115 112 107 1609 347 235 197 169 154 152 127 122 116 1467 336 240 210 186 164 164 137 129 124 1592 337 257 229 204 176 172 147 137 130 1581 341 272 245 219 187 182 156 145 138 1577 349 286 260 233 198 191 166 153 145	30 36 42 48 54 60 66 72 78 84 90 - - - 69 69 69 70 70 65 69 1562 293 188 153 128 127 121 103 101 96 90 1639 372 226 182 150 143 139 115 112 107 99 1609 347 235 197 169 154 152 127 122 116 106 1467 336 240 210 186 164 164 137 129 124 113 1592 337 257 229 204 176 172 147 137 130 119 1581 341 272 245 219 187 182 156 145 138 126 1577 349 286 2

Table 12 Cable Jacket Temperatures Experiment 20 (Degrees F)

Time (Min)	30	36	42	48	54	H31	ight (I	(n.)	7.8	9.4	9.0	96
0	68	68	68	68	68	99	89	19	19	19	19	19
test												
-	45	54	OU	5	m	and	and	0	0	ON	85	83
10	45	36	in	0	10	no	con	-	and	0		On
i cr	古代	19	-	0	VO		-	CV	CV	provide	100	0
17	07	12	10	prod	co	10	10	m	CV	CV	0	pered
r.	36	16	10	cr	0	40	10	3	m	N	1	gered
0	36	1.1	co	1	garad	00	trans	7	27	CY	1	CU
7	34	74	0	5	CV	13	CT	5	27	CY	í	CV
- 00	17	99	-	40	m	0	00	0	10	27		3
0	-	76	N	0	in	mod	0	-	0	二十	3	3
10	5	74	===	0	10		0	1-	10	15	-7	二寸
11	000	73	un	0	Pm	CU	med	00	Free	15	27	27
12	10	75	100	0	· Prom	or		0	Low	S	二寸	===
13	0	09	1	-	00	27	CV	194	178	165	151	151
77	0.4	76	00	CV	00		OU	0	00	5	5	5
15	0	52	00	N	0	-	CVI	0	00	French	In	5
16	88	75	0	3	0	10	m	0	00	Prince	0	5
17	-	76	0	3	0	15	m	proof	∞	Com	0	0
18	77	70	0	-	0	5	m	inne	0		0	0
10	17	76	0	-	0	10	m	-	0	Proper	0	0
20	718	1205	398	341	307	261	235		03	I.m	0	0

Cable										Exp	perime	ent No).							
No.	1	2	3	4	5	6	7	- 8	ō	10	11	12	13	14	15	16	17	18	19	20
								Fı	cont S	Surfac	<u>e</u>									
1	65.0	66.0	62.5	78.0	70.5	60.0	63.0	65.0	72.0	64.0	74.0	70.0	66.0	72.0	46.5	47.5	48.0	41.0	47.0	38.0
2										64.0										
3										66.0										
4										66.0										2
5										67.0										
6										68.0								45.0	47.0	48.0
7										68.0					50.0	48.0	52.5			
8	67.0	69.0	63.5	81.0	71.0	60.0	65.0	65.0	74.0	66.0	70.0	76.0	69.0	69.0						
								Re	ear S	urface	2									
1	55.0	57.0	-	79.0	67.0	51.0	55.0	57.0	71.0	61.0	73.0	72.0	64.0	72.0	46.5	46.0	46.0	45.0	49.0	44.5
2	55.0	62.0	-							63.0										
3	60.0	63.0	-							64.0										
4	61.0	63.0	-							64.0										
5	62.0	63.0	-							64.0										
6	60.0	63.0	-							64.0								46.0	45.5	49.0
7	56.5	63.0	-	81.0	67.5	53.0	58.0	60.0	72.0	60.0	73.0	74.0	67.5	68.0	48.5	47.5	50.0			
8	55.5	63.0	-	81.0	62.0	50.0	60.0	58.0	70.5	60.0	73.0	72.0	67.0	65.0						

Table 14 Cable Damage Summary

Experiment No.	Maximum Cable Damage Height (In.)	Average Cable Damage Height (In.)
1	69.0*	67.7*
2	71.0*	69.3*
3	68.0*	65.2*
4	87.0*	83.6*
5	72.5*	71.6*
6	63.0*	62.0*
7	69.0*	65.9*
8	68.0*	67.2*
9	78.0*	75.8*
10	68.0*	66.1*
11	74.0*	73.2*
12	76.0*	75.0*
13	71.0*	69.7*
14	72.0*	71.4*
15	50.0*	48.0*
16	48.0*	47.7*
17	53.0*	50.6*
18	46.0**	45.3**
19	49.0**	46.6**
20	49.0**	46.4**

^{*}Front surface **Rear Surface

Table 15 Initial Temperatures

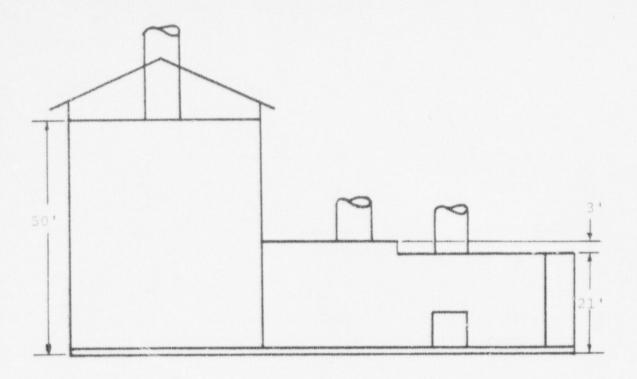
Experiment No.	Average Initial Cable Jacket Temperature	Initial Room Air Temperature
1	60	64
2	62	58
	60	59
3 4	63	64
5	_	64
6	_	63
7		64
8	**	65
9	_	51
10		65
11		65
12		64
13		64
14	-	62
15	56	63
16	57	64
17	63	64
18	66	67
	68	69
19 20	68	67
20	00	01

Table 16 Summary of Supplemental Cable Experiments

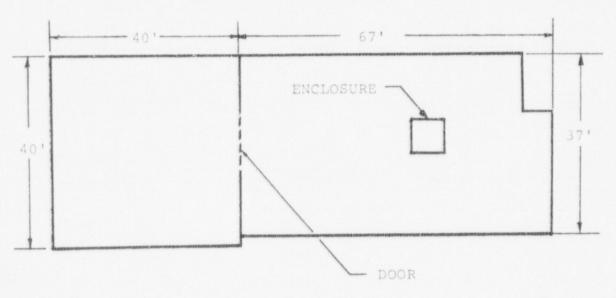
	Exp. 1*	Exp. 2*	Exp. 3*	Exp. 4*
Cable tie spacing (in.) Initial room temperature (F) Barometric pressure (In./Hg) Relative humidity Maximum height of cable	27 42 29.58 38	27 43 29.60 38	18 70 29.34 48	18 72 29.35 46
damage (in.)**	72	78	82	83

^{*}Experiment numbering from Reports Subjects 1277 and 1277-2.

^{**}Adjusted to allow for differences in burner height.



ELEVATION VIEW



PLAN VIEW

Figure 1 - Facility

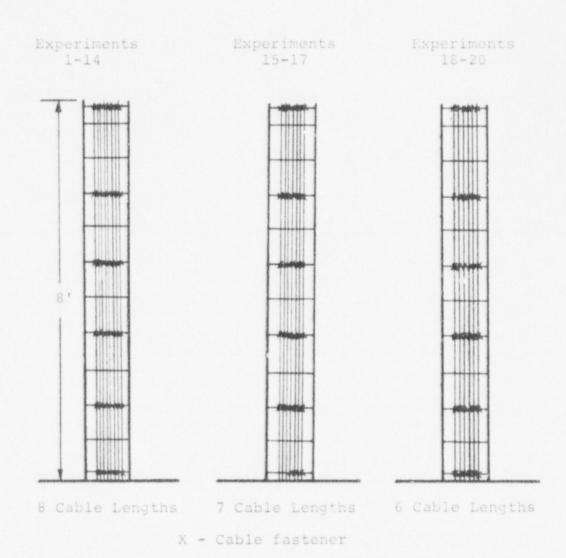
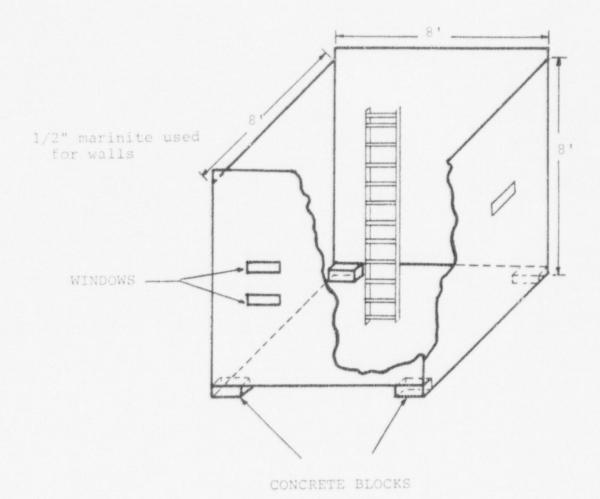


Figure 2 - Cable Tray and Cable Installation



Each Wall May Be Raised Or Lowered Independently

Figure 3 - Enclosure

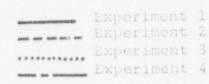
Front Surface

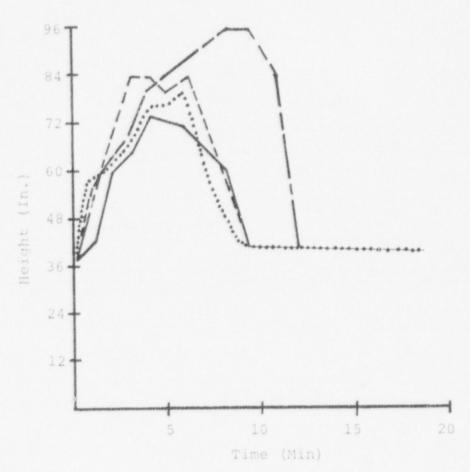


* Thermocouple Location

Instrumented cable installed along the center line of the cable tray in Experiments 15-17, or 1/4 the cable diameter from cable tray center line in Experiments 1-4 and 18-20.

Figure 4 - Cable Jacket Thermocouples





Pigure 5 - Maximum Flame Height vs Time Experiments 1-4

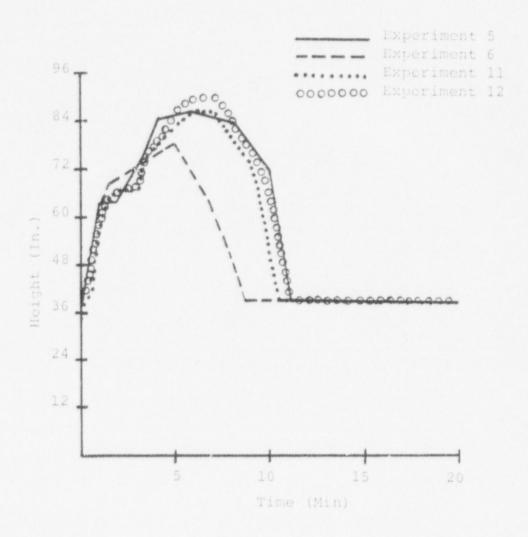


Figure 6 - Maximum Flame Height vs Time Experiments 5, 6, 11 and 12

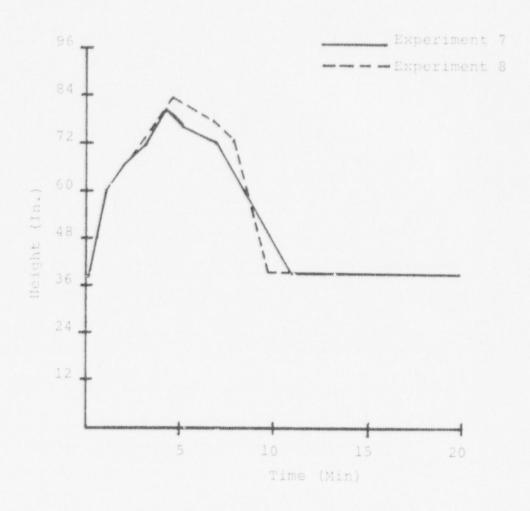


Figure 7 - Maximum Flame Height vs Time Experiments 7 and 8

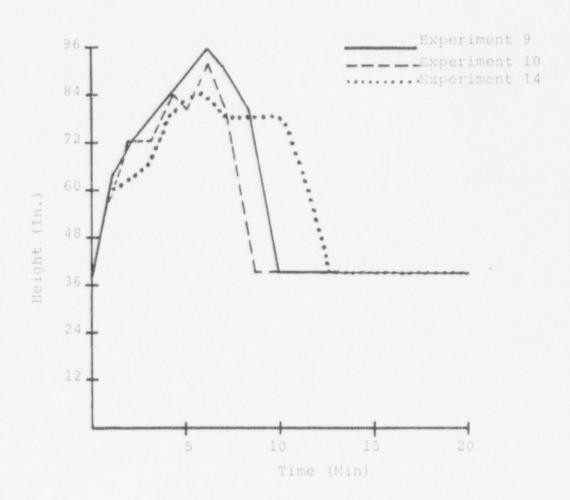


Figure 8 - Maximum Flame Height vs Time Experiments 9, 10 and 14

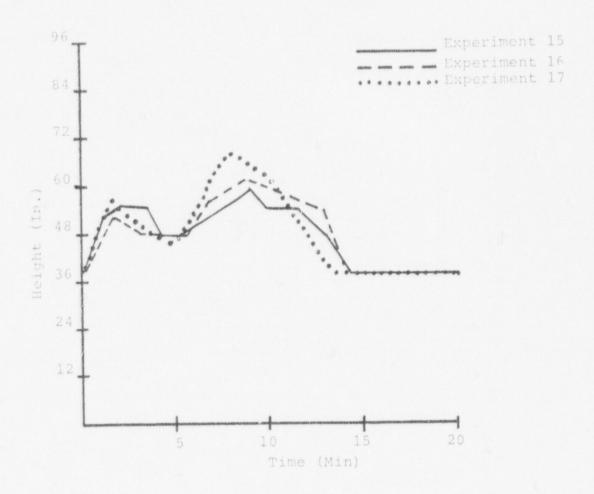


Figure 9 - Maximum Flame Height vs Time Experiments 15, 16 and 17

Ű

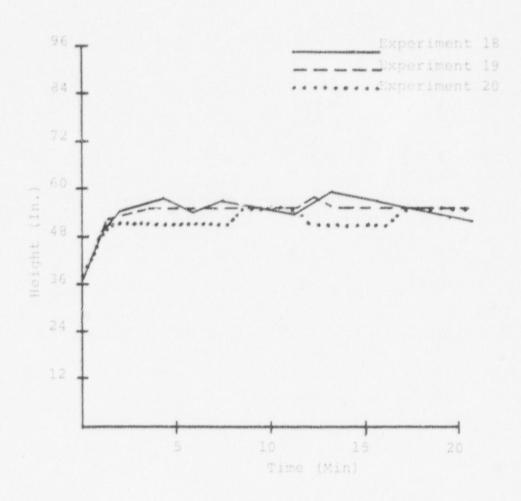
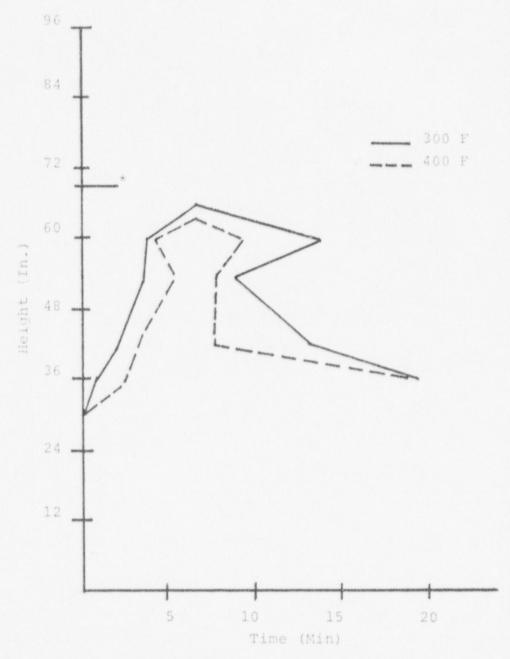
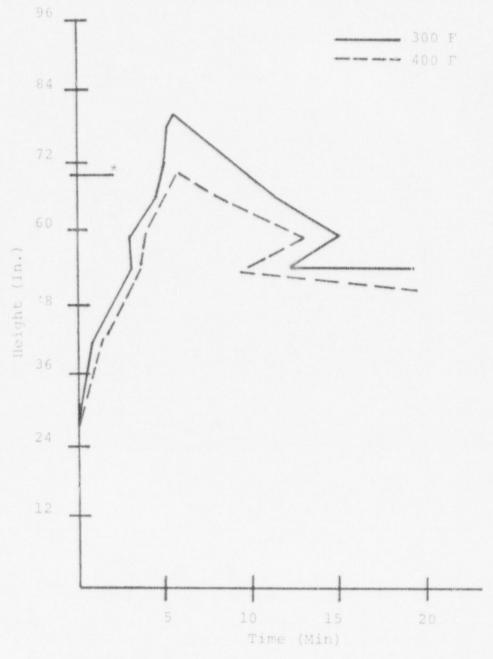


Figure 10 - Maximum Flame Height vs Time



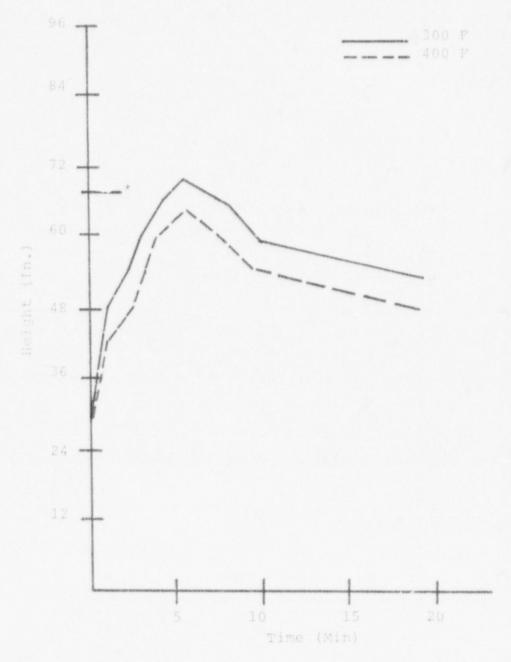
* - Maximum cable damage height.

Figure 11 - Cable Jacket Temperature
Experiment 1



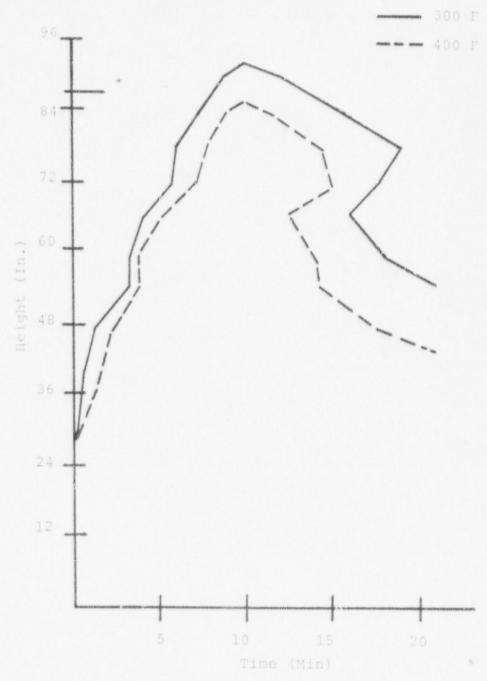
* - Maximum cable damage height.

Figure 12 - Cable Jacket Temperature Experiment 2



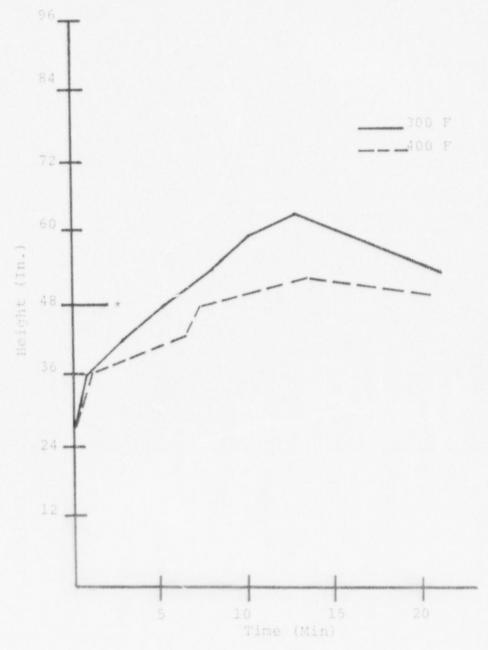
* - Maximum cable damage height.

Figure 13 - Cable Jacket Temperature Experiment 3



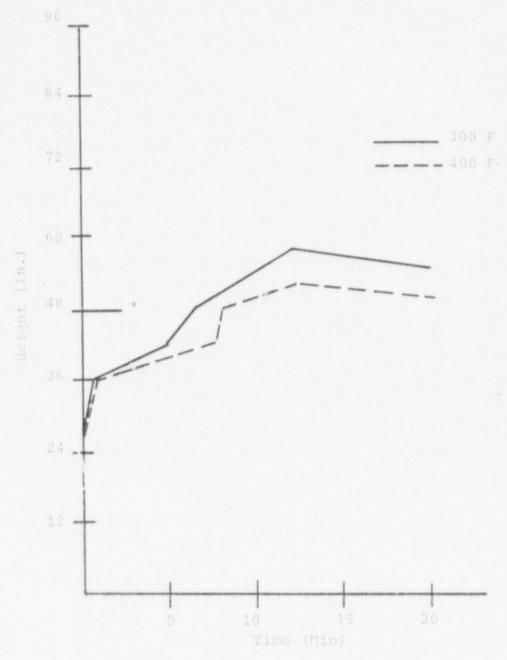
* - Maximum cable damage height.

Figure 14 - Cable Jacket Temperature Experiment 4



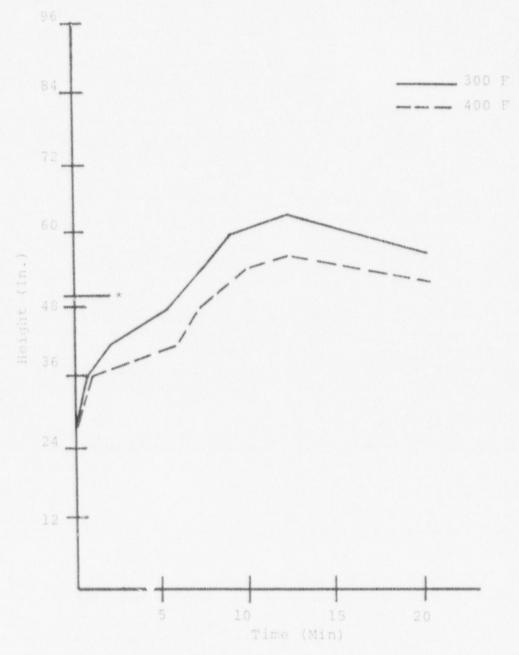
* - Maximum cable damage height.

Figure 15 - Cable Jacket Temperature Experiment 15



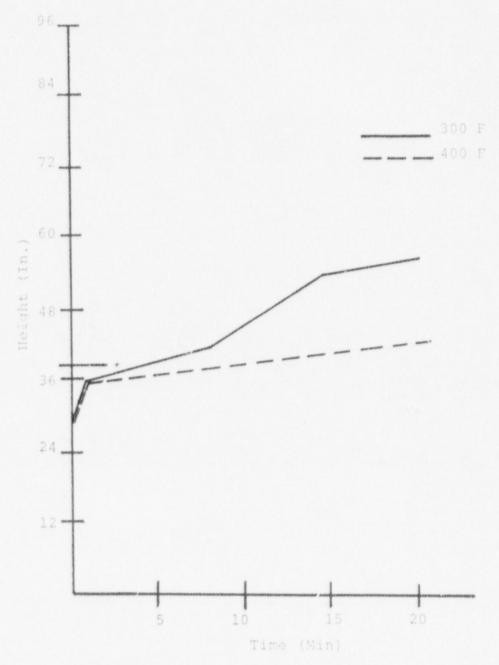
* - Maximum cable damage height.

Figure 16 - Cable Jacket Temperature Experiment 16



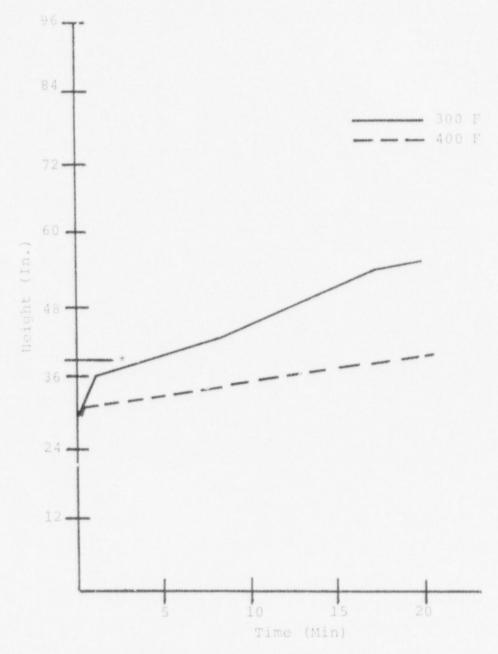
* - Maximum cable damage height.

Figure 17 - Cable Jacket Temperature Experiment 17



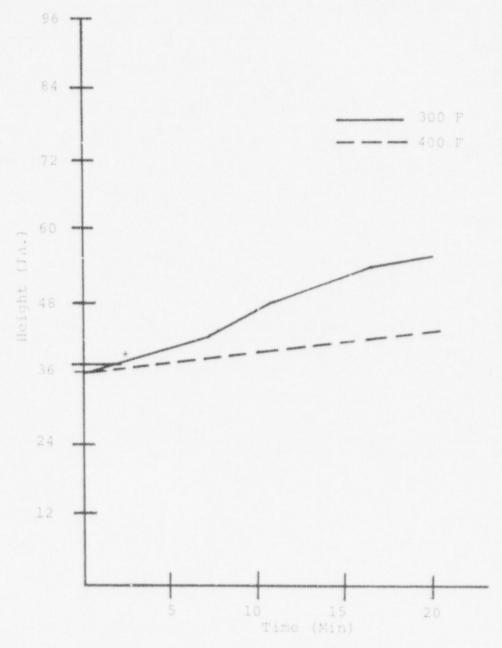
* - Maximum cable damage height.

Figure 18 - Cable Jacket Temperature Experiment 18



* - Maximum cable damage height.

Figure 19 - Cable Jacket Temperature Experiment 19



* - Maximum cable damage height.

Figure 20 - Cable Jacket Temperature Experiment 20

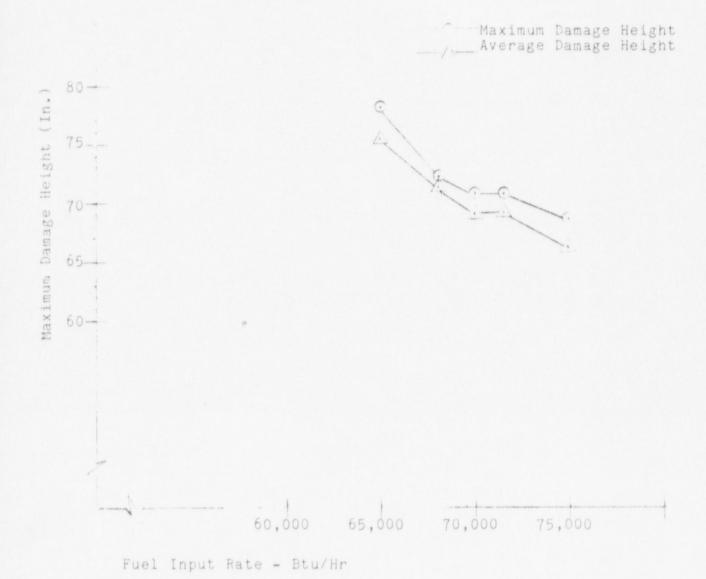


Figure 21 - Maximum Height of Cable Damage Versus Fuel Input

NRC FORM 335 U.S. NUCLEAR REGULATORY COMMISSION BIBLIOGRAPHIC DATA SHEET		1 REPORT NUMBER (Assigned by DDC)	
		NUREG/CR-0346	
4 TITLE AND SUBTITLE (Add Volume No., if appropriate) Development And Verification Of Fire Tests For Cable Systems and System Components		2. (Leave blank)	
		3. RECIPIENT'S ACCESSION NO.	
/ AUTHORISI		5 DATE REPORT C	OMPLETED
L. J. Przybyla and W. J. Christian		July	1978
Underwriters Laboratories Inc. 333 Pfingsten Road Northbrook, Illinois 60062		DATE REPORT IS	
		HTACM	YEAR
		August	1978
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8. ABSTRACT (200 words or less)			
Experiments were conducted to estable of the results to variations of several peable tray fire test described in the IEE	arameters of Standard	of the vert	ical
cable tray fire test described in the IEE varied were burner-to-cable distance, air rate. As a result of these experiments a suggestions for revision of IEEE 383 are 10 construction of cable trays, 2) test espacing of cable ties, 4) burner position and air rates, 6) flame temperature, 7) in	arameters of Standard input rate of previous made with inclosure,	of the vert. 383. Parameter and fuel of the sexperience respect to the sexperience of fuel of the sexperience of fuel to the sexperience of the s	ical meters input e, ze and
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