INTERNATIONAL LIMITED COMBUSTIBLE PLENUM CABLE FIRE TEST PROJECT

Technical Report

THE
FIRE PROTECTION
RESEARCH FOUNDATION

FIRE RESEARCH

THE FIRE PROTECTION
RESEARCH FOUNDATION

ONE BATTERYMARCH PARK
QUINCY, MASSACHUSETTS, U.S.A. 02269
E-MAIL: Foundation@NFPA.org

INTERNATIONAL LIMITED COMBUSTIBLE PLENUM CABLE FIRE TEST PROJECT

Technical Report

Prepared by

Frederic B. Clarke III
Benjamin/Clarke Associates, Inc.

and

Richard G. Gewain
Hughes Associates, Inc.

THE
FIRE PROTECTION
RESEARCH FOUNDATION

FIRE RESEARCH

1 Batterymarch Park
Quincy, Massachusetts USA 02269

FOREWORD

The International Limited Combustible Plenum Cable Fire Test Project (originally the International Permanent Plenum Cable Fire Test Project) was initiated by the Research Foundation in response to a need expressed by NFPA 90A *Installation of Air Conditioning and Ventilation Systems* standard-writers for additional documentation regarding the fire performance of products that go into air handling plenum spaces.

This report provides the documentation of the project's work at Intertek Testing Services NA Inc./ ETL and at Underwriters Laboratories Inc.

The Foundation expresses gratitude to project Co-technical Directors and report authors Frederic B. Clarke III and Richard G. Gewain. The Foundation and authors thank the project's two laboratories, technical advisory committee and thirteen sponsors listed on the following page, for their contributions of expertise, product, and the financial resources required to complete this project. In addition, the laboratories are to be commended for their openness and cooperation.

A technical advisory committee, such as the one for this project, is generally made up of individuals and groups who have expertise or an interest related to the subject of a Research Foundation project, some of whom are also Principal Sponsors who provide financial support for the project. A technical advisory committee provides review and advice regarding a project. The content and conclusions contained in Research Foundation reports, however, are solely those of the authors of the report, and participation on a technical advisory committee does not necessarily imply agreement with those contents and conclusions.

INTERNATIONAL LIMITED COMBUSTIBLE PLENUM CABLE FIRE TEST PROJECT

Technical Advisory Committee

ATOFINA Chemicals, Inc.

AlphaGary Corp.

Ausimont USA, Inc.

Berk-Tek Inc.

Cable Design Technologies

Frederic B. Clarke III

Daikin America, Inc.

Dyneon

E.I duPont de Nemours & Co.

Richard G. Gewain

Lucent Technologies

Precision Cable Company

Prestolite Wire Corporation

Solvay Advanced Polymers, Inc.

Teknor Apex Company

William A. Webb, P.E.

FIRE PROTECTION RESEARCH FOUNDATION

INTERNATIONAL LIMITED COMBUSTIBLE PLENUM CABLE FIRE TEST PROJECT: FINAL REPORT, MARCH, 2001

1. BACKGROUND 2
2. SCOPE 3
   2.1 Objective 3
   2.2 Strategy 3
      2.2.1 Research Plan 3
      2.2.2 Test Plan 4
3. RESULTS 6
   3.1 NFPA 262 and NFPA 255 Tests on Cables 6
      3.1.1 Phase 1 results 6
      3.1.2 Phase 2 results 7
   3.2 Phase 2, Aging Studies 12
   3.3 Phase 2, Slitting of Cable 12
   3.4 NFPA 259 to Measure Potential Heat 12
4. DISCUSSION OF RESULTS 14
   4.1 NFPA 262 and NFPA 255 14
      4.1.1 Background 14
      4.1.2 Repeatability and Reproducibility 14
   4.2 NFPA 259 16
      4.2.1 Background 16
      4.2.2 Repeatability and Reproducibility 17
      4.2.3 The Prodedure Used for Determining the PotentialHeat of Wire and Cable (based on 4-pair UTP plenum cable) 19
5. CONCLUSIONS 20
6. REFERENCES 20
7. APPENDIX – DEFINITIONS – NFPA 90A 21
8. APPENDIX – DERIVATION OF THE RELATIONSHIP BETWEEN THE SMOKE PARAMETERS MEASURED IN NFPA 255 AND NFPA 262 21
9. APPENDIX – LABORATORY DATA 23

FIRE PROTECTION RESEARCH FOUNDATION

INTERNATIONAL LIMITED COMBUSTIBLE PLENUM CABLE FIRE TEST PROJECT: FINAL REPORT

1. BACKGROUND

NFPA Standard 90A-1999[1] requires materials used in plenums to meet the following:

"2-3.10.2 **Ceiling Cavity Plenum**. The space between the top of the finished ceiling and the underside of the floor or roof above shall be permitted to be used to supply air to the occupied area, or return or exhaust air from or return and exhaust air from the occupied area, provided that the following conditions are met:

(a) All materials exposed to the airflow shall be noncombustible or limited combustible and have a maximum smoke developed index of 50.

Exception No. 1: The following materials shall be permitted in the ceiling cavity plenum where listed as having a maximum peak optical density of 0.5 or less, an average optical density of 0.15 or less, and a maximum flame spread distance of 5 ft (1.5 m) or less when tested in accordance with the specified test method:

(a) Electrical wires and cables and optical fiber cables – NFPA 262, Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces.

2-3.10.6 **Raised Floor Plenum**. The space between the top of the finished floor and the underside of a raised floor shall be permitted to be used to supply air to the occupied area, or return or exhaust air from or return and exhaust air from the occupied area, provided that the following conditions are met:

(a) All materials exposed to the airflow shall be noncombustible or limited combustible and shall have a maximum smoke developed index of 50.

Exception No. 1: The following materials shall be permitted in the raised floor plenum where listed as having a maximum peak optical density of 0.5 or less, an average optical density of 0.15 or less, and a maximum flame spread distance of 5 ft (1.5 m) or less when tested in accordance with the specified test method:

(a) Electrical wires and cables and optical fiber cables – NFPA 262, Standard Method of Test for Flame Travel and Smoke of Wires and Cables for Use in Air-Handling Spaces"

Note: Definition of terms is included in Appendix.

At present all plenum-rated wire and cable used outside of metal conduit qualifies under Exception No. 1. As a result of concerns about fire load buildup and smoke production resulting from the concentration of cables in plenums, these issues are presently under review.

2. PROJECT SCOPE

2.1 Objective

The goal of the Fire Protection Research Foundation Program is to determine how to use NFPA 255 and NFPA 259 to test and evaluate wire and cable. Specifically, the objectives are:

- Develop harmonized Steiner Tunnel listing protocols for permanent[1] plenum cables related to NFPA 262/UL910 and NFPA 255.
- Document calorimeter design and test criteria based on NFPA 259 to accommodate samples.
- Conduct literature search and full-scale plenum reference tests for permanent plenum cable.
- Analyze data for utility for fire performance criteria and standards.
- Coordination and liaison with contemporaneous research projects (i.e., ASHRAE, NRC and BRE/FRS).

2.2 Strategy

2.2.1 Research Plan

The proposed research plan using two testing laboratories consists of the following tasks:

Phase I:

1. Agree on a set of initial wire and cable test samples.

2. Develop a mounting method for wire and cable tests using NFPA 255.

3. Conduct NFPA 255 fire tests on selected cables using the agreed upon mounting method and compare the results obtained by the two test laboratories.

4. Conduct fire tests using NFPA 262.

5. Conduct literature search on potential heat calorimetry and effect of aging on fire properties.

6. Develop a procedure for the preparation of test samples tested in accordance with NFPA 259.

---

[1] "Permanent" cable is referred to as "limited combustible" cable throughout this report

7. Develop test data on each component in the wire and cable test samples tested using NFPA 259.

8. Analyze the test data and prepare a report providing a description of test samples, test procedures and test data.

Phase II:

1. Devise and carry out a plan to eliminate possible causes for observed differences in smoke measurement results in the two laboratories.

2. Develop a procedure for slitting the wire and cable test samples for NFPA 255 tests as required by the definition of limited combustible material.

3. Develop a procedure to determine the effects of aging on flame spread and smoke index. It was agreed to condition the samples at 100°C and 121°C and compare NFPA 255 test results with those obtained using the ASTM E1354 Cone Colorimeter [2].

4. Preparation of reports.

2.2.2 Test Plan

A total of five plenum-type cables were selected for the initial phase of the project. They were:

Designation	Construction	Primary Insulation Material	Jacket material
A	4-pr., UTP	3 prs FEP; 1 pr PE	LSFR PVC
B	4-pr., UTP	FEP	LSFR PVC
C	4-pr., UTP	FEP	PVDF
D	4-pr., UTP	MFA	ECTFE
E	4-pr., UTP	FEP	FEP

Abbreviations: UTP = unshielded twisted pair
PE = polyethylene
FEP = perfluorinated ethylene/propylene copolymer
LSFR PVC = low-smoke flame-retarded poly(vinyl chloride)
PVDF = poly(vinylidene fluoride)
MFA = perfluorinated ethylene/methyl vinyl ether copolymer
ECTFE = ethylene/chlorotrifluoroethylene copolymer

In Phase II, three of the 5 cable samples, A, C and E, were tested further. The samples tested in Phase II were, however, from different production lots than those in Phase I. The experimental plan was as follows:

Phase I

NFPA 255

- Cable supported as provided in NFPA 255 Appendix B-7, Plastics
- All tests carried out at both laboratories
- 5 replicates on intact cable

NFPA 262

- Both laboratories
- Single test on each cable

NFPA 259

- Both laboratories
- Duplicate tests on all complete cable constructions, components separately ground
- Duplicate tests on complete constructions except copper, components separately ground.
- Duplicate tests on all insulations
- Duplicate tests on all jackets
- Duplicate tests on all copper conductors
- Duplicate tests on all rip cord
- Duplicate tests on Sample E, complete construction, prepared by cutting up bulk cable

Phase II

Calibration Studies:

NFPA 255

- Both laboratories
- Duplicate tests on series of low-smoke samples
    - IRCB
    - Red oak
    - Acoustical insulation board
    - Glass fiber batt and blanket
    - Pan of heptane (burner off)

Aging studies

ASTM E1354

- Single laboratory
- Duplicate tests on all samples plus a third test if first two do not agree within standard error.
- Test samples at 3 fluxes, 35, 50 and 75 kW/m^2:
- 3 sample sets: tested as received; tested after 100C for one week; tested after 121C for one week.

NFPA 255

- Duplicate tests on samples aged under conditions to be determined consistent with NFPA 90A

Slitting

NFPA 255

- Single laboratory
- Multiple tests on slit samples

3. RESULTS

Unless otherwise noted, all the experimental data presented in the Tables in the body of this report (i.e., not including the Appendix) are the average of multiple runs. The tabulated value is followed by the calculated standard deviation

3.1 NFPA 262 and NFPA 255 Tests on Cables

3.1.1 Phase 1 Results

Cables were tested in the Steiner Tunnel under two regimes: NFPA 255 and NFPA 262. The key results are shown in Table 3.1 (complete results can be found in Appendix 9). The maximum extent of flame travel in feet in both tests is listed as FT. The measured smoke developed indexes (SDI) from NFPA 255 are presented as well as the peak optical density (pkOD) and average optical densities (avOD) from NFPA 262.

In general, the flame travel distances exhibited by all five cables in both tests were well within the limits for plenum use. As for detailed repeatability and reproducibility information, however, only NFPA 255 can be evaluated here, since multiple runs of NFPA 262 were not carried out. The NFPA 255 flame travel distances appeared to be highly repeatable in each laboratory, as evidenced by the small variance of the measurements, but not particularly reproducible, as can be seen by comparing this variance with the interlaboratory results.

Depending on the sample, the difference between laboratories was from 1.5 to ten times the root-mean variance for repeatability.

With respect to the smoke measurements, multiple determinations of the SDI by a given laboratory on a given cable agreed with one another quite closely but the SDI's reported by the two labs for the same cables were widely separated: the results reported by Laboratory 2 are, with one exception, systematically higher than those of Laboratory 1.

3.1.2 Phase 2 Results

The work on Tunnel smoke measurements in Phase 2 concentrated on exploring means whereby the differences between laboratories could be reduced. Following a series of discussions, the two laboratories agreed to support the cables at 1-foot intervals. Prior to retesting cables, however, a series of calibrations was undertaken.

3.1.2.1 Calibrations

The SDI of a material is the area under the sample's smoke absorption curve, but it is expressed as a percent of the area under the same curve when the sample is red oak. Red oak can vary, so two laboratories using different sources of red oak may get different SDI's for the same material even if the smoke measured is identical. Hence, the first step was to ensure that the two laboratories used red oak from the same source and, that being accomplished, to compare the results of burning that material. Samples of inorganic reinforced cement board (IRCB) and mineral-board acoustical tile – both from a common source – were were also evaluated. Finally, to isolate the smoke measurement function of the tunnels, pans of heptane were burned as well.

The results of these calibration studies appear in Table 3.2. As can be seen, settling on a single red oak source resulted in very close agreement. In addition, the laboratories agreed to use a running average of red oak smoke values to calculate SDI values. For the cable studies in Phase 2, the two laboratories employed almost identical normalization values: 71.0 %-min and 71.4%-min respectively.

3.1.2.2 Cables

Three cables were evaluated in the Phase 2 Tunnel tests: samples A, C and E. The SDI results on cable samples as-received appear in Table 3.3 and show interlab agreement within about 20% in two cases (Cable A and E). The third sample, Cable C, shows a very low SDI in tests at both labs, although in percentage terms the disparity is considerable. The significance of this observation will be discussed in Sec. 4.

TABLE 3.1
PHASE 1: COMPARISON OF TUNNEL TEST RESULTS

	NFPA 255				**NFPA 262**					
	Laboratory 1 Data		**Laboratory 2 Data**		**Laboratory 1 Data**[2]			**Laboratory 2 Data**[2]		
Cable	Flame travel	SDI	Flame travel	SDI	Flame travel	Peak OD	Avg. OD	Flame travel	Peak OD	Avg. OD
A	2.9 ± 0.2	467 ± 30	2.0 ± 0.0	895 ± 49	0.6	0.49	0.16	0.5	0.5	0.21
B	1.6 ± 0.7	468 ± 78	0.9 ± 0.3	857 ± 33	0.5	0.40	0.09	0.5	0.28	0.08
C	0.7 ± 0.5	75 ± 27	0.1 ± 0.2	272 ± 41	0.7	0.22	0.04	1.0	0.05	0.02
D	2.4 ± 0.3	298 ± 44	0.4 ± 0.2	822 ± 53	1.0	0.23	0.06	0.5	0.16	0.05
E	0.7 ± 0.3	66 ± 11	0.0 ± 0.0	42 ± 5	0.0	0.04	0.01	0.0	0.01	0.01

[2] Single value; no standard deviation calculated.

TABLE 3.2
PHASE 2: MEASUREMENTS ON CALIBRATION MATERIALS, NFPA 255

	Laboratory 1		Laboratory 2	
Sample	Flame travel dist., ft.	Area under smoke curve[3]	Flame travel dist., ft.	Area under smoke curve[3]
IRCB	0	2.0	0	0
Acoustical board	5.0	17.8	3.5	14.6
Red Oak	19.5@5:40	80.2	19.5 @5:29	73.5
Heptane (310 g)		92.6		95.2

[3] Units: %-obscuration-minutes (area beneath the plot of % smoke obscuration vs. time)

TABLE 3.3
PHASE 2: NFPA 255 MEASUREMENTS ON THREE CABLES, AS RECEIVED,AT BOTH LABORATORIES

	Laboratory 1		Laboratory 2	
	Flame travel, ft.	SDI	Flame travel, ft.	SDI
A	2.8 ± 0.3	542 ±30	3.0 ± 0.5	455 ± 17
C	2.5 ± 0.0	53 ± 11	0.5 ± 0.0	114 ± 19
E	0.8 ± 0.3	40 ± 15	0.0 ± 0.0	48 ± 0.3

TABLE 3.4
PHASE 2: NFPA 255 RESULTS FOR CABLES BEFORE AND AFTER AGING AT 100°C FOR 56 DAYS

	Before		**After**	
Cable	Flame travel, ft.	SDI	Flame travel, ft.	SDI
A	2.8 ± 0.3	542 ±30	2.5 ± 0.5	472 ± 55
C	2.5 ± 0.0	53 ±11	2.3 ± 0.3	67 ± 25
E	0.8 ± 0.3	40 ± 15	1.5 ± 0.0	102 ± 43

TABLE 3.5
PHASE 2: NFPA 255 RESULTS BEFORE AND AFTER SLITTING

	Unslit cable		Slit cable	
Cable	Flame travel, ft.	SDI	Flame travel, ft.	SDI
A	3.0 ± 0.5	455 ± 17	2.5 ± 0.5	611 ± 49
C	0.5 ± 0.0	114 ± 19	0.0[4]	72[4]
E	0.0 ± 0.0	48 ± 0.3	0.0 ± 0.0	23 ± 3

[4] Single determination, no standard deviation calculated

3.2 Phase 2, Aging Studies

It was initially intended to simulate long-term aging of cables by storage at 121° C for a period of two weeks. This approach was constrained, however, by the fact that this temperature was in several cases sufficient to risk irreversible thermal damage to the cables, an occurrence which would have invalidated the exercise. It was decided that the cables would be stored at 100° C for 56 days, which is roughly equivalent to 14 days at 121° C, and then tested in NFPA 255. There was a concern, however, that some cables stored on their original spools at the elevated temperature could not subsequently be made to lie flat on the tunnel ceiling, as they could when tested as received.

The results of testing the aged cables in NFPA 255 are presented in Table 3.4. Also shown are the results of testing unaged (i.e., stored as received) cables from the same lot. With one exception, the SDI of Cable E, aging had little effect on the cables, which could be tested with a degree of repeatability comparable but somewhat less than that for unaged samples.

It was originally intended to investigate the suitablility of a smaller-scale test, the cone calorimeter, ASTM E1354, as a surrogate for the Tunnel in the aging studies, since much smaller sample sizes are required. The results of the cone calorimetry studies are presented in Appendix 8 and they, like the NFPA 255 results, show little change with thermal aging.

3.3 Slitting of Cable

Three cables were tested under NFPA 255 after having all their jackets slit and the underlying insulation exposed. This proved to be a workable technique and although the data, presented in Table 3.5, are somewhat meagre, it appears that this can be accomplished with reasonable repeatability

3.4 NFPA 259 to Measure Potential Heat

The results of the investigations of potential heat carried out at each laboratory are summarized in Table 3.6 (more detail can be found in Appendix 9). Measurements were obtained on the bulk cable as received (Column 1) and on the bulk cable from which the copper had been removed (Column 2). Column 3 is the result of correcting the values of Column 2 for the potential heat contribution of copper, which was measured once by Laboratory 2, and the same value used to correct all the data in Column 2, both laboratories. Column 4 is the calculated potential heat of the whole cable based on the weighted sum of the potential heat of each of its components.

Laboratory 1 carried out a less extensive program on NFPA 259 than did Laboratory 2 and did not obtain some data, notably the potential heats of each component, so there is only one set of values for the "calculated" potential heat (Column 4, Table 3.6).

TABLE 3.6
POTENTIAL HEAT (BTU/LB) OF CABLES AS MEASURED BY NFPA 259

	Laboratory 2				Laboratory 1			
Cable	1. Measured on bulk cable	2. Measured on bulk cable, no Cu	3. Col. 2. corrected for Cu contribution	4. Calc. from pot. heat of components	1. Measured on bulk cable	2. Measured on bulk cable, no Cu	3. Col. 2. corrected for Cu contribution	4. Calc. from pot. heat of components
A	3268 ± 5	5306 ± 19	3274 ± 10	3247 ± 60	3104 ± 54	4528[5]	2810[5]	ND
B	2652 ± 31	4597 ± 21	2701 ± 10	2564 ± 40	2570[5]	ND[6]	ND	ND
C	1987 ± 273	3750 ± 201	2075 ± 91	2137 ± 110	1717 ± 100	3645[5]	2026[5]	ND
D	2525 ± 41	4774 ± 263	2856 ± 142	2535 ± 190	2945 ± 132	4351 ± 171	2345 ± 90	ND
E	1315 ± 50	2068 ± 18	1287 ± 9	1299 ± 76	1364 ± 128	1842 ± 44	1512 ± 20	ND

[5] Single determination; no standard deviation calculated
[6] ND = Not determined

4. DISCUSSION OF RESULTS

4.1 NFPA 262 and NFPA 255

4.1.1 Background

The geometry, burner and airflow are the same in both NFPA 255 and 262. There are at least three major differences, however, in the setup and conduct of the two tests:

- Sample size – The cable bed is wider in NFPA 255 than in NFPA 262 (typically 100 4-pr. cables in the former vs. 55 in the latter).
- Sample mounting – The cables in NFPA 255 are mounted against the tunnel ceiling while those in NFPA 262 are in a tray 3.75 inches below the ceiling, so the thermal environment of the sample in the two tests may be different.
- Test duration – NFPA 255 is a ten-minute test while NFPA 262 is run for twenty minutes.

Furthermore, there is difference the smoke measurements. In NFPA 255, a 10-minute profile of the percent smoke obscuration is recorded. The reported SDI is the ratio (expressed as a percent) of the area under the smoke profile of the sample (A_s) to the area under the smoke profile of red oak for the same period (A_r), or:

$$\mathrm{SDI} = 100\frac{A_s}{A_r} \qquad (1).$$

NFPA 262 does not use an indexing material like red oak. Instead, a 20-minute profile of the optical density is recorded and the peak and average values for that period are reported. The optical density measured in NFPA 262 and the SDI measured in NFPA 255 can be approximately related (see Appendix 7):

$$\mathrm{SDI} \approx \frac{10^5(1-10^{-1.8z})}{A_r} \qquad (2),$$

where z is the average OD of the smoke for the first ten minutes in NFPA 262. Measured values of A_r are typically in the neighborhood of 100 [3], which means that the average optical density in the first ten minutes of NFPA 262 must be of the order of 0.01 to have a reasonable expectation of showing an SDI of 50 or less.

4.1.2 Repeatability and Reproducibility

The work in Phase 1 of this project showed the flame spread and smoke measurements in NFPA 255 to have good repeatability but, in comparison, relatively poor reproducibility. In other words, the result obtained at a given laboratory for a given cable could be more closely replicated in that laboratory than it could be when the cable was tested in the other laboratory. A number of harmonizing adjustments were made at both labs during Phase 2 and, indeed, considerable improvement was realized.

The interlaboratory NFPA 255 results of the three cables samples in Phase 2 can be compared with the reproducibility possible when the Tunnel is really well-tuned for cable testing, such as the data in the FPRF report on the NFPA 262/UL 910 International Harmonization Project[5].

The reproducibility, R, is the upper limit of the range in which differences in measurements between two laboratories will fall with 95% probability. In the NFPA 262 Harmonization Study, values of R were determined for flame travel distance, average optical density and peak optical density. As is often the case, the reproducibility parameters in the Harmonization Project Report were found to be related to the magnitude of the measurement. Using the regression relationships for the expected R values which appear in the Harmonization Project Report,[7] R can be estimated for any value of flame travel and smoke optical density in the range studied.

The values of NFPA 255 flame travel measured in each laboratory for the 5 cables in Phase 1 are shown in Table 4.1, along with a comparison of the interlaboratory difference with the value of R expected from the NFPA 262 Harmonization Project results. As can be seen, the interlaboratory differences in NFPA 255 flame travel measurements fall well within the limits of R for NFPA 262 for four of the five cables. The exception, for no known reason, is Cable D. Cable D was not re-tested in Phase 2.

It is possible to calculate the10-minute average smoke optical density which corresponds to the measured smoke density index (SDI) measurements of NFPA 255 using the equation:[8]

$$\text{Average OD} = -\log_{10}[1-(7.12\times10^{-4}\times\text{SDI})]$$

This calculation was done for the Phase 2 interlaboratory smoke data which appeared in Table 3.3 The differences in optical density values are compared with the reproducibility for average optical density which would be expected if the same cables were tested in NFPA 262 under conditions prescribed by the results of the Harmonization Project – see Table 4.2.

There are two caveats to applying this approach to SDI reproducibility. One is that the cables in Phase 2 had smoke densities which, strictly speaking, fell somewhat outside the range (0.07 to 0.15) in which the reproducibility of NFPA 262 was studied in the Harmonization Project. The other is that NFPA 262 parameter is a 20-minute average OD, while NFPA 255 measures the average for only half that period. Nevertheless, the comparison in Table 4.2 suggests that the interlaboratory diffferences in measured SDI in Phase 2 are well within the expected limits of reproducibility on the basis of the Harmonization Study for NFPA 262.

The slitting and aging studies were carried out at only one laboratory, so reproducibility data are not available. The limited amount of information available suggests that their

---

[7] From reference 5:
For flame propagation distance, R = 0.74 x (average flame propagation distance) + 0.41.
For average optical density, R = 0.19 x (average optical density) + 0.03

[8] This expression is from Appendix 8, using as a value for A_r the average of the two labs' normalization values, 71.2 %-obscuration-minutes.

repeatability is in the same range as, although poorer than, NFPA 255 results on the as-received cables.

4.2 NFPA 259

4.2.1 Background

The potential heat of a material is the heat produced by a sample when burned under the conditions used to test materials for noncombustibility [6], i.e., combustion in a Setchkin furnace at 750° C. It is determined in NFPA 259 by means of a three-step process: (1) burning a sample of the test material in the furnace as prescribed for the noncombustibility test; (2) burning a second sample in an oxygen bomb calorimeter; and then (3) combusting any residue from the furnace burn in the calorimeter as well. The calorimeter produces complete combustion and measures the heat produced in the process, so the difference between the total heat of combustion of the material (Step 1) and any heat produced by combustion of the post-furnace residue (Step 3) is the heat produced when the material is burned in the furnace.

NFPA 259 has traditionally been carried out on individual materials, and so the potential heat of a finished product like a cable would be calculated as the sum of the contributions of each component, each contribution being the potential heat of the component multiplied by the mass fraction of that component in the cable. To produce such a measurement it would be necessary to disassemble the cable into its different components -- insulation, jacket, shielding, rip cord and the like -- and measure the potential heat of each component

An obvious question is whether such a cumbersome procedure is necessary; it would be much simpler if the bulk cable sample could be tested all at once. Complete combustion, however, requires that the sample be in a finely divided state. Early results at Laboratory 2 showed that this was most readily accomplished by grinding or chopping each component separately and then reconstituting the bulk sample by combining the components in the proportions in which they appear in the cable. These studies therefore concentrated on determining: first, how such a bulk testing procedure compares to testing each component separately and, second, how the testing of the metallic copper component is best handled.

4.2.2 Repeatability and Reproducibility

Comparison of the data in Table 3.2, Column 1 under each laboratory, with the data in Column 4, Laboratory 2, shows agreement within about 7%. This is comparable to the average precision of the measurement when it is made on pure materials [6], and suggests that measuring the potential heat of the bulk cable is an acceptable alternative to measuring the potential heat for each component separately and then calculating the quantity for the bulk cable.

TABLE 4.1
COMPARISON OF INTERLABORATORY DIFFERENCES IN AVERAGE FLAME TRAVEL DISTANCES IN NFPA 255 WITH THE EXPECTED REPRODUCIBILITY, R, OF THE SAME MEASUREMENT IN NFPA 262

Cable	Flame travel (ft), Lab 1	Flame travel (ft), Lab 2	Difference, Δ	Expected R
1	2.9	2.0	0.9	2.3
2	1.6	0.9	0.7	1.3
3	0.7	0.1	0.6	0.7
4	2.4	0.4	2.0	1.3
5	0.7	0.0	0.7	0.7

TABLE 4.2
CONVERSION OF MEASURED SMOKE DENSITY INDEX (SDI) IN NFPA 255 TO THE CORRESPONDING 10-MINUTE AVERAGE OPTICAL DENSITY AND COMPARISON OF DIFFERENCES IN AVERAGE 10-MINUTE OPTICAL DENSITY WITH R, THE EXPECTED REPRODUCIBILITY BASED ON HARMONIZED NFPA 262 TUNNELS

Cable	SDI	Avg. OD[8]	SDI	Avg. OD[9]	Difference, Δ	Expected R
A	542 ± 30	.211 ± .013	455 ± 17	.171 ± .007	.04	.07
C	53 ± 11	.017 ± .003	114 ± 19	.037 ± .006	.02	.06
E	40 ± 15	.013 ± .005	48 ± .3	.015 ± .001	.002	.05

[9] Average OD = $-\log_{10}[1-(7.1 \times 10^{-4} \times SDI)]$

One of the labs (Laboratory 2) had both more experience and more advanced equipment, so any conclusions resulting from interlaboratory comparisons should be made with these facts in mind. Even so, the results compare reasonably well. For measurements on the bulk cable samples (Column 1, both laboratories) the interlaboratory results agreed within about 400 Btu/lb, well within the expected reproducibility [5] of 500 Btu/lb. For measurements on the samples which did not contain copper (Column 2, both laboratories), all but one agreed within the expected reproducibility.

What data are available in Column 3, both laboratories, agree within expected experimental error with that in column 4, Laboratory 2. This means that it is not necessary to include the copper in the mix of the bulk sample in every test. Rather, an archival value can be used for the copper's potential heat. The total potential heat for the cable is then the potential heat of the copper times the mass fraction of copper in the cable plus the measured potential heat of the copper-free bulk sample times (1- the mass fraction of copper).

For constructions in which the copper conductors are plated with another metal, or where other metals may be used, the archival value cannot be assumed to be appropriate. In such cases, the potential heat of each type of metallic component used in the construction must be measured.

4.2.3 The Procedure Used in this Study for Determining the Potential Heat of Wire and Cable (based on 4-pair UTP plenum cable)

Although the existing text of NFPA 259 addresses composite and layered materials, some modifications specifically aimed at wire and cable suggest themselves as a result of this work. The procedure followed was NFPA 259, *Standard Test Method for Potential Heat of Building Materials, 1998 Edition*, with modifications to the following sections:

> **§3-1 Specimens.** (precedes text of existing §3-1 in the standard) A length of wire or cable was chosen sufficient to provide 0.044 lb (20 g) of material in addition to the copper conductors. The wire or cable was weighed to the nearest 2.2×10^{-5} lb (0.01 g) and then disassembled into its components: jacket, primary insulation of each type, copper conductors, rip cord and wrapping films. The weight of each component of the wire or cable, including the conductors, was also determined to the nearest 2.2×10^{-5} lb (0.01 g). The proportion of each component in the cable, p_i, was calculated from the formula
>
> $$p_i = \text{(weight of component)/(weight of cable – weight of conductors)}$$
>
> Each component except the conductors was pulverized or otherwise made into powder form capable of passing through a 60-mesh (0. 25-mm) screen. Exactly 0.02203 lb (10.00 g) of a test mixture was prepared by combining all the powdered/pulverized components of the wire or cable (i.e., all the components except the conductors). The amount of each component in the mixture was determined from the formula:
>
> $$\text{Amount of component} = 10.00 \times p_i$$

Test specimens were taken from the test mixture, which was well-blended but then used without further grinding or powdering, in the procedure of Chapter 4, ignoring §4-1.1, §4-1.2 and §4.1.3 and beginning with §4-1.4.

§5-1 Specimen Preparation. For each specimen, a length of wire or cable was chosen sufficient to provide approximately 0.033 lb (15 g) of material in addition to the copper conductors. The copper conductors were removed from the specimen.

§6-3 Potential heat of the assembled cable. The potential heat of the assembled cable, PH_a, was calculated as follows:

$$PH_a = \frac{(PH_m)(W - W_c) + (PH_c)W_c}{W},$$

where: PH_a = potential heat of the assembled cable, Btu/lb;
PH_m = measured potential heat of the test mixture calculated in accord with the calorimetric procedures referenced in §4-2,2 and reported (Btu/lb) in accordance with §6-4;
W_c = weight of conductors in wire or cable;
W = total weight of cable;
PH_c = the potential heat of the metallic conductors (equal to 614Btu/lb[10] for untinned copper conductors)

This modification should be viewed provisionally since it so far has only been tested on 4-pair unshielded twisted pair (UTP) plenum cable.

5. CONCLUSIONS[11]

1. This work has shown that the methodology under study (NFPA 255 and NFPA 259) can be used to test cables to the basic rule for plenum materials as specified in NFPA 90-A.
2. NFPA 255, although not designed originally for testing cables, can be used for this purpose.
3. The cables tested in this program show similar flame spread properties whether tested by NFPA 255 or NFPA 262.
4. All the cables tested showed very low flame spread values; they are below the range where a small change could result in meeting or failing to meet the requirements of NFPA 90A.
5. In NFPA 255, the most effective mounting of the cables was accomplished in accord with Appendix B7 of NFPA 255 and by supporting the cables on steel rods at one-foot intervals. When this mounting procedure was followed and Tunnel conditions were closely controlled, the repeatability and reproducibility of the results compared very favorably with those of NFPA 262.
6. The available data do not permit a conclusion to be drawn as to the use of ASTM E1354 for determining aging effects on the fire performance of wire and cable in NFPA 255.
7. Cables can be slit to expose the interior insulation and then tested in that configuration in NFPA 255.

[10] As measured and reported by Laboratory 2

[11] Conclusions are known to apply only to 4-pair unshielded twisted-pair copper constructions.

8. NFPA 259, although usually used to measure the potential heat of homogeneous materials, can be applied to the bulk cable if the cable's metallic components are removed before testing. The potential heat of the finished cable can then calculated by multiplying the measured potential heat by the non-metallic mass fraction of the cable and adding the mass fraction of conductor multiplied its measured potential heat.
9. The results in such cases, on the basis of limited data, have a repeatability comparable to that reported when the method is used for homogeneous materials.

6. REFERENCES

1. NFPA 90A, *Standard for the Installation of Air Conditioning and Ventilation Systems, 1999 Edition.* National Fire Protection Association, Quincy, MA (1999).

2. ASTM E1354-97, *Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter, 1997 Edition.* ASTM, West Conshohocken, PA (1997).

3. NFPA 255, *Standard Method of Test of Surface Burning Characteristics of Building Materials, 1996 Edition,* National Fire Protection Association, Quincy, MA (1996).

4. ASTM E136-96a, Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750°C, 1996 Edition. ASTM, West Conshohocken, PA (1996).

5. Chapin, T. and Gandhi, P., International NFPA 262 Fire Test Harmonization Project, a Horizontal Integrated Frie Test: Technical Report, Fire Protection Reserch Foundation, National Fire Protection Association, Quincy, MA (2000)

6. NFPA 259, *Standard Test Method for Potential Heat of Building Materials, 1998 Edition.* National Fire Protection Association, Quincy, MA (1998).

7. APPENDIX – DEFINITIONS – NFPA 90A

Flame Spread Index.* A number obtained according to NFPA 255, *Standard Method of Test of Surface Burning Characteristics of Building Materials.*

Limited-Combustible Material. A building construction material not complying with the definition of noncombustible material that in the form in which it is used, has a potential heat value not exceeding 3500 Btu/lb (8141 kJ/kg) where tested in accordance with NFPA 259, *Standard Test Method for Potential Heat of Building Materials*, and complies with (a) or (b):

(a) Materials having a structural base of noncombustible material, with a surfacing not exceeding a thickness of 1/8 in. (3.2 mm), that has a flame spread index not greater than 50; (b) Materials, in the form and thickness used, other than as described in (a), having neither a flame spread index greater than 25 nor evidence of continued progressive combustion, and of such composition that surfaces that would be exposed by cutting through the material on any plane would have neither a flame spread index greater than 25 nor evidence of continued progressive combustion. Materials subject to increase in combustibility or flame spread index beyond the limits herein established through the effects of age, moisture, or other atmospheric condition shall be considered combustible.

Noncombustible Material. A material that, in the form in which it is used and under the conditions anticipated, will not ignite, burn, support combustion, or release flammable vapors when subjected to fire or heat. Materials that are reported as passing ASTM E 136, *Standard Test Method for Behavior of Materials in a Vertical Tube Furnace at 750 Degrees C,* shall be considered noncombustible materials.

Smoke Developed Index.* A number indicating a comparative measure derived from smoke obscuration data collected during the test for surface burning characteristics in accordance with NFPA 255, *Standard Method of Test of Surface Burning Characteristics of Building Materials,* that measures visible smoke.

8. APPENDIX – DERIVATION OF THE RELATIONSHIP BETWEEN THE SMOKE PARAMETERS MEASURED IN NFPA 255 AND NFPA 262

In NFPA 255, a 10-minute profile of the percent smoke obscuration is recorded. The reported SDI is the ratio (expressed as a percent) of the area under the smoke profile of the sample (A_s) to the area under the smoke profile of red oak for the same period (A_r), or:

$$\mathrm{SDI} = 100\frac{A_s}{A_r}.$$

A_s can be is approximated by an average percent obscuration, $\overline{P}_s$, times the time interval Δt, over which the average is measured. So:

$$\text{SDI} \approx 100 \frac{\overline{P}_s \Delta t}{A_r}.$$

In contrast to NFPA 255, NFPA 262 does not use an indexing material like red oak. Instead, a 20-minute profile of the optical density is recorded and the peak and average values for that period are reported. For any time period, the average optical density, OD, is related to the average percent obscuration, $\overline{P}$, by:

$$\overline{P} = 100(1 - 10^{-OD})$$

Substituting this expression for $\overline{P}_s$ in that for the SDI above, and recalling that Δt, the test period for NFPA 255 is 10 minutes, one obtains:

$$\text{SDI} \approx 10^5 \frac{1 - 10^{-OD}}{A_r}.$$

The equation can be transposed to yield the average optical density in terms of a measured SDI:

$$\text{Average OD} = -\log_{10}[1 - (SDI) \times (A_r)]$$

It is possible to estimate the SDI expected from the cables in NFPA 255 simply on the basis of burning the same cable in NFPA 262 and assuming no difference in thermal conditions:

$$\text{SDI} \approx \frac{10^5 (1 - 10^{-1.8z})}{A_r}$$

where z is the average OD of the smoke for the first ten minutes in NFPA 262. Multiplying z by 1.8 accounts for having 1.8 times as many cables exposed to the burner flame in NFPA 255 as in NFPA 262. Measured values of A_r are typically in the neighborhood of 100 [3]. This means that, in order to have a reasonable expectation of showing an SDI of 50 or less, the average optical density in the first ten minutes of NFPA 262 must be of the order of 0.01.

9. APPENDIX – LABORATORY DATA

- **NFPA 255**

  Tabular results, samples A-E: Laboratory 1

  Tabular results, samples A-E: Laboratory 2

  Tabular results, samples A-E: Laboratory 1

  Tabular results, samples A,C,E: Laboratory 2

  Tabular results, samples A,C,E: Laboratories 1 and 2

  Calibration comparisons: both labs

- **NFPA 262**

  Tabular results, samples A-E: Laboratory 1
  Time profiles of OD, flame travel, duct temperature, and duct flow, samples A-E

  Tabular results, samples A-E: Laboratory 2
  Time profiles of OD and flame travel, samples A-E

- **NFPA 259**

  Tabular results, samples A-E: Laboratory 1
  Tabular results, samples A-E: Laboratory 2

- **ASTM E1354**

  Tabular Results, samples A-E: Laboratory 2

FPRF International Limited Combustible Plenum Cable Fire Test

NFPA 255 Results

	Sample Construction						Flame Spread			Smoke Generation		Cable Damage		
Sample ID	Insulation	Jacket	Test #	No. Lengths	OD (in)	Ignition Time (min:sec)	Flame Spread (ft), max.	Index (FSI) un-rounded	Index (FSI) rounded	Index (SDI) un-rounded	Index (SDI) rounded	Melt (ft-in)	Char (ft-in)	Ash (ft-in)
A	3x1	PVC	A-1	99	0.2045	0:25	2.6	12.00	10	512.00	510	12-0	8-0	0-6
A	3x1	PVC	A-2	99	0.2045	0:30	3.0	12.35	10	457.99	460	10-6	7-6	0-6
A	3x1	PVC	A-3	99	0.2045	0:22	3.0	12.75	15	431.23	430	12-0	8-0	0-6
Average:						0:25	2.9	12.37	12	467.07	467			
Note:	Received enough cable for three (3) NFPA 255 burns only.													
B	4x0	PVC	B-1	98	0.2065	0:20	0.5	2.45	0	373.05	375	15-6	8-0	1-6
B	4x0	PVC	B-2	98	0.2065	0:20	1.8	6.98	5	610.29	610	16-6	8-6	1-6
B	4x0	PVC	B-3	98	0.2065	0:20	2.0	9.12	10	481.14	480	17-0	8-0	2-0
B	4x0	PVC	B-4	98	0.2065	0:20	2.1	9.19	10	406.80	405	16-0	7-6	2-0
Average:						0:20	1.6	6.94	6	467.82	468			
Note:	Received enough cable for four (4) NFPA 255 burns only. UL has shipped more to arrive 9/22.													
C	4x0	PVDF	C-1	109	0.1845	0:36	1.3	4.69	5	126.56	125	18-0	5-0	0-0
C	4x0	PVDF	C-2	109	0.1845	0:40	1.2	4.66	5	42.11	40	19-6	3-0	0-0
C	4x0	PVDF	C-3	109	0.1845	0:33	0.6	2.26	0	57.09	55	18-6	3-0	0-0
C	4x0	PVDF	C-4	109	0.1845	0:40	0.0	0.00	0	56.91	55	18-6	3-6	0-0
C	4x0	PVDF	C-5	109	0.1845	0:30	0.6	2.48	0	91.28	90	19-0	2-6	0-0
Average:						0:35	0.7	2.82	2	74.79	73			
Note:	Material that dripped on floor of chamber from cable contributed to smoke values after approx. 7 minutes into the test.													
D	MFA	ECTFE	D-1	99	0.2035	0:20	2.6	10.62	10	360.95	360	16-6	3-0	0-6
D	MFA	ECTFE	D-2	99	0.2035	0:20	2.6	9.84	10	310.77	310	18-0	4-0	0-6
D	MFA	ECTFE	D-3	99	0.2035	0:20	2.6	10.45	10	310.59	310	16-6	4-0	0-6
D	MFA	ECTFE	D-4	99	0.2035	0:20	1.9	7.29	5	209.71	210	17-0	4-0	0-0
Average:						0:20	2.4	9.55	9	298.01	298			
Note:	Only four (4) burns were completed due to loss of data on 5th burn. No cable remaining.													
E	4x0	FEP	E-1	114	0.1765	0:26	1.2	5.29	5	57.67	60	6-0	1-0	0-0
E	4x0	FEP	E-2	114	0.1765	0:30	0.8	3.44	5	62.35	60	5-6	1-0	0-0
E	4x0	FEP	E-3	114	0.1765	0:30	0.4	1.55	0	54.34	55	5-6	1-0	0-0
E	4x0	FEP	E-4	114	0.1765	0:35	0.5	2.21	0	61.38	60	6-0	1-0	0-0
E	4x0	FEP	E-5	114	0.1765	0:24	0.6	2.43	0	93.59	95	6-6	1-0	0-0
Average:						0:29	0.7	2.98	2	65.87	66			

The Fire Protection Research Foundation
International Limited Combustible Plenum Cable Fire Test Project

NFPA 255 - FLAME SPREAD and SMOKE GENERATION RESULTS

	SAMPLE CONSTRUCTION						FLAME SPREAD			SMOKE GENERATION		CABLE DAMAGE			
Sample ID	Insulation	Jacket	Test No.	Number Lengths	Outside Diameter (inch)	Ignition Time (min:sec)	Max Flame Travel (ft-in)	Calculated Flame Spread (CFS)	Flame Spread Index (FSI)	Calculated Smoke Developed (CSD)	Smoke Developed Index (SDI)	Melt (ft-in)	Char (ft-in)	Ash (ft-in)	Cond (ft-in)
Sample A	3x1	PVC	A-1	99	0.2045	0:23	2.0	7.21	5	875.7	Over 500	11-6	8-6	0-6	1-6
Sample A	3x1	PVC	A-2	99	0.2045	0:20	2.0	6.66	5	792.8	Over 500	9-0	7-0	0-0	1-6
Sample A	3x1	PVC	A-3	99	0.2045	0:12	2.0	6.58	5	899.7	Over 500	11-6	7-0	0-6	1-6
Sample A	3x1	PVC	A-4	99	0.2045	0:18	2.0	6.55	5	934.6	Over 500	9-0	5-6	0-6	1-6
Sample A	3x1	PVC	A-5	99	0.2045	0:18	2.0	6.88	5	972.5	Over 500	9-6	6-6	0-6	2-0
Average						0:18	2.0	6.78	5	895.1	Over 500				
Sample B	4x0	PVC	B-1	98	0.2065	0:15	0.5	2.31	0	843.8	Over 500	10-6	9-0	0-0	1-0
Sample B	4x0	PVC	B-2	98	0.2065	0:21	1.0	4.56	5	798.7	Over 500	11-6	9-0	0-6	1-0
Sample B	4x0	PVC	B-3	98	0.2065	0:21	1.0	4.44	5	913.9	Over 500	12-6	11-6	0-6	1-0
Sample B	4x0	PVC	B-4	98	0.2065	0:12	1.0	10.20	10	883.2	Over 500	14-0	10-6	0-6	1-6
Sample B	4x0	PVC	B-5	98	0.2065	0:14	1.0	4.29	5	846.3	Over 500	12-0	9-6	0-6	1-0
Average						0:17	0.9	5.16	5	857.2	Over 500				
Sample C	4x0	PVDF	C-1	109	0.1845	0:27	0.0	0.00	0	223.8	200	19-6	3-0	0-6	2-0
Sample C	4x0	PVDF	C-2	109	0.1845	0:52	0.5	1.87	0	361.6	350	19-6	4-0	0-0	2-0
Sample C	4x0	PVDF	C-3	109	0.1845	0:34	0.0	0.00	0	216.3	200	17-6	3-6	0-0	1-6
Sample C	4x0	PVDF	C-4	109	0.1845	0:27	0.0	0.00	0	281.7	300	19-6	3-6	0-0	1-6
Sample C	4x0	PVDF	C-5	109	0.1845	0:35	0.0	0.00	0	276.1	300	17-6	4-0	0-0	2-6
Average						0:35	0.1	0.37	0	271.9	270				
Sample D	MFA	ECTFE	D-1	99	0.2035	0:31	0.0	0.00	0	774.3	Over 500	16-0	2-6	0-0	1-6
Sample D	MFA	ECTFE	D-2	99	0.2035	0:28	0.5	1.88	0	799.2	Over 500	16-6	4-0	0-6	2-0
Sample D	MFA	ECTFE	D-3	99	0.2035	0:10	0.5	0.98	0	806.5	Over 500	18-0	4-0	0-6	1-6
Sample D	MFA	ECTFE	D-4	99	0.2035	0:19	0.5	2.06	0	759.1	Over 500	17-0	3-6	0-0	1-6
Sample D	MFA	ECTFE	D-5	99	0.2035	0:20	0.5	2.37	0	870.3	Over 500	16-0	2-0	0-0	1-0
Average						0:22	0.4	1.46	0	801.9	Over 500				
Sample E	4x0	FEP	E-1	114	0.1765	0:47	0.0	0.00	0.0	38.9	40	5-0	N/A	N/A	0-0
Sample E	4x0	FEP	E-2	114	0.1765	0:38	0.0	0.00	0.0	31.2	30	4-0	N/A	N/A	0-0
Sample E	4x0	FEP	E-3	114	0.1765	0:32	0.0	0.00	0.0	42.1	40	3-6	N/A	N/A	0-0
Sample E	4x0	FEP	E-4	114	0.1765	0:38	0.0	0.00	0.0	42.0	40	3-6	N/A	N/A	0-6
Sample E	4x0	FEP	E-5	114	0.1765	0:54	0.0	0.00	0.0	54.6	55	4-6	N/A	N/A	0-6
Average						0:42	0.0	0.00	0.0	41.8	41				

NOTES: 1. The burner flame is approximately 4'-6". The CABLE DAMAGE was determined from the end of the flame produced by the burner.

FPRF International Limited Combustible Plenum Cable Fire Test Project

NFPA 255 Results - Slit vs. Unslit - 1 ft. Rod Spacing

Laboratory 2

Jan-01

ID	Sample Construction Insulation	Jacket	Test #	Lengths	OD (in)	Ignition Time, min:s	Spread, Ft.	Flame Spread un-rounded	rounded	Smoke Generation un-rounded	rounded	(From end of Burner Flame) (ft-in)	(ft-in)	(ft-in)
A1 - Unslit	3x1	PVC	A-1	99	0.2045	:14	2.5	10	10	474.9	450	18-0	4-6	0-6
A2 - Unslit	3x1	PVC	A-2	99	0.2045	:14	3.5	11	10	447.2	450	18-0	4-6	0-0
A3 - Unslit	3x1	PVC	A-3	99	0.2045	:14	3.0	11	10	443.8	450	18-0	6-6	0-0
Average						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	450	[illegible]	[illegible]	[illegible]
A7	3x1	***2 ft. rod spacing***				:08	3.0	11	10	***816.1***	over 500	18-0	8-0	0-0
A4 - Slit	3x1	PVC	A-1	99	0.2045	:18	2.0	7	5	660.5	over 500	19-0	4-6	0-0
A5 - Slit	3x1	PVC	A-2	99	0.2045	:18	3.0	11	10	583.2	over 500	19-0	3-6	0-0
A6 - Slit	3x1	PVC	A-3	99	0.2045	:24	2.5	9	10	608.2	over 500	19-0	5-0	0-0
Average						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	over 500	[illegible]	[illegible]	[illegible]
C1 - Unslit	4x0	PVDF	C-1	109	0.1845	:27	0.5	1	0	92.3	90	16-0	0-6	0-0
C2 - Unslit	4x0	PVDF	C-2	109	0.1845	:21	0.5	0	0	127.5	130	17-0	2-0	0-0
C3 - Unslit	4x0	PVDF	C-3	109	0.1845	:12	0.5	0	0	121.5	120	18-0	0-6	0-0
Average						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C4 - Slit	4x0	PVDF	C-1	109	0.1845	:12	0.0	0	0	71.6	70	18-0	1-6	0-0
C5 - Slit	4x0	PVDF	C-2	109	0.1845	Insufficient sample								
C6 - Slit	4x0	PVDF	C-3	109	0.1845	Insufficient sample								
Average						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	70	[illegible]	[illegible]	[illegible]
E1 - Unslit	4x0	FEP	E-1	114	0.1765	:40	0.0	0	0.0	47.9	50	2-0	0-0	0-0
E2 - Unslit	4x0	FEP	E-2	114	0.1765	:08	0.0	0	0.0	48.4	50	2-6	0-0	0-0
E3 - Unslit	4x0	FEP	E-3	114	0.1765	:27	0.0	0	0.0	47.8	50	2-6	0-0	0-0
Average						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	50	[illegible]	[illegible]	[illegible]
E4 - Slit	4x0	FEP	E-1	114	0.1765	1:25	0.0	0	0	19.9	20	3-0	0-0	0-0
E5 - Slit	4x0	FEP	E-2	114	0.1765	1:52	0.0	0	0	26.2	25	3-6	0-0	0-0
E6 - Slit	4x0	FEP	E-3	114	0.1765	Insufficient sample								
Average						[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FPRF International Limited Combustible Plenum Cable Fire Test Project

Summary of NFPA 255 SDI measurements, both laboratories

Laboratory 1

Cable:	A: a/r	A: aged	C: a/r	C: aged	E: a/r	E: aged
Run 1	545	445	60	70	40	60
Run 2	510	535	n/s	90	25	145
Run 3	570	435	n/s	40	55	100
avge	542	472	60	67	40	102
stddev	30	55		25	15	43

Laboratory 2

Cable:	A: a/r	A: slit	C: a/r	C: slit	E: a/r	E: slit
Run 1	475	661	92.3	71.6	47.9	19.9
Run 2	447	563	128	n/s	48.4	26.2
Run 3	444	608	122	n/s	47.8	n/s
avge	455	611	114	72	48	23.1
stddev	17	49	19		0.32	

a/r = as received
n/s= no sample left
ETL: Red Oak smoke : 71.0 %-min
UL: Red Oak smoke area: 71.4 %-min

FPRF International Limited Combustible Plenum Cable Fire Test Project

NFPA 255 Results

Laboratory 1

	Sample Construction						Flame Spread				Smoke Generation		Cable Damage		
Sample ID	Insulation	Jacket	Test #	No. Lengths	OD (in)	Ignition Time (min:sec)	Flame Spread (ft) max.	Index (FSI) un-rounded	Index (FSI) rounded	Index (SDI) un-rounded	Index (SDI) rounded	Melt (ft-in)	Char (ft-in)	Ash (ft-in)
Unaged Samples - September 1999														
A	3x1	PVC	A-1	99	0.2045	0:25	2.8	12.00	10	757.18	755	12-0	8-0	0-6
A	3x1	PVC	A-2	99	0.2045	0:30	3.0	12.35	10	677.31	680	10-6	7-6	0-6
A	3x1	PVC	A-3	99	0.2045	0:22	3.0	12.75	15	637.73	640	12-0	8-0	0-6
Average:						0:25	2.8	12.37	12	690.74	692			
Unaged Samples - January 2001														
A	3x1	PVC	UA-1	99	0.217	0:15	2.5	10.71	10	506.94	505	19-8	12-0	1-0
A	3x1	PVC	UA-2	99	0.217	0:17	3.0	13.54	15	512.43	510	19-6	12-0	1-0
A	3x1	PVC	UA-3	99	0.217	0:14	3.0	13.44	15	569.92	570	19-6	12-0	1-0
Average:						0:15	2.8	12.56	13	529.76	528			
Aged Samples - January 2001														
A	3x1	PVC	AA-1	99	0.217	0:14	2.0	9.73	10	442.61	445	19-6	11-0	1-0
A	3x1	PVC	AA-2	99	0.217	0:11	2.5	11.36	10	537.04	535	19-6	12-0	1-6
A	3x1	PVC	AA-3	99	0.217	0:24	3.0	12.60	10	436.17	435	19-6	13-0	2-0
Average:						0:16	2.5	11.20	10	471.94	472			
Unaged Samples - September 1999														
B	4x0	PVC	B-1	98	0.2065	0:20	0.5	2.45	0	551.69	550	15-6	6-0	1-6
B	4x0	PVC	B-2	98	0.2065	0:20	1.8	6.88	5	902.54	905	16-6	6-6	1-8
B	4x0	PVC	B-3	98	0.2065	0:20	2.0	9.12	10	711.56	700	17-0	8-0	2-0
B	4x0	PVC	B-4	98	0.2065	0:20	2.1	9.19	10	601.61	600	18-0	7-8	2-0
Average:						0:20	1.6	6.94	6	691.85	689			
Unaged Samples - September 1999														
C	4x0	PVDF	C-1	109	0.1845	0:36	1.3	4.69	5	187.17	185	18-0	5-0	0-0
C	4x0	PVDF	C-2	109	0.1845	0:40	1.2	4.88	5	62.28	60	19-6	3-0	0-0
C	4x0	PVDF	C-3	109	0.1845	0:30	0.6	2.26	0	84.43	85	18-6	3-0	0-0
C	4x0	PVDF	C-4	109	0.1845	0:40	0.0	0.00	0	84.16	85	18-6	3-6	0-0
C	4x0	PVDF	C-5	109	0.1845	0:30	0.6	2.48	0	134.89	135	18-0	2-8	0-0
Average:						0:35	0.7	2.82	2	110.61	110			
Unaged Samples - January 2001														
C	4x0	PVDF	AC-1	109	0.192	1:01	2.5	7.98	10	60.94	60	19-6	2-0	0-0
Average:						1:01	2.5	7.88	10	60.94	60			
Aged Samples - January 2001														
C	4x0	PVDF	AC-1	109	0.192	0:42	2.0	7.37	5	69.91	70	19-6	2-0	0-0
C	4x0	PVDF	AC-2	109	0.192	0:50	2.5	8.54	10	88.82	90	19-6	2-0	0-0
C	4x0	PVDF	AC-3	109	0.182	1:08	2.5	8.83	10	41.09	40	19-6	2-0	0-0
Average:						0:52	2.3	8.25	8	66.61	67			
Unaged Samples - September 1999														
D	MFA	ECTFE	D-1	99	0.2035	0:20	2.6	10.62	10	533.60	535	16-6	3-0	0-6
D	MFA	ECTFE	D-2	99	0.2035	0:20	2.6	9.64	10	458.59	460	18-0	4-0	0-6
D	MFA	ECTFE	D-3	99	0.2035	0:20	2.6	10.45	10	459.32	460	15-6	4-0	0-6
D	MFA	ECTFE	D-4	99	0.2005	0:20	1.9	7.29	5	310.13	310	17-0	4-0	0-0
Average:						0:20	2.4	9.55	9	440.71	441			
Unaged Samples - September 1999														
E	4x0	FEP	E-1	114	0.1765	0:26	1.2	5.29	5	85.29	85	6-0	1-0	0-0
E	4x0	FEP	E-2	114	0.1765	0:30	0.8	3.44	5	92.21	90	5-6	1-0	0-0
E	4x0	FEP	E-3	114	0.1765	0:30	0.4	1.65	0	80.36	80	5-6	1-0	0-0
E	4x0	FEP	E-4	114	0.1765	0:35	0.5	2.21	0	90.77	90	6-0	1-0	0-0
E	4x0	FEP	E-5	114	0.1765	0:24	0.6	2.43	0	138.41	140	6-6	1-0	0-0
Average:						0:29	0.7	2.98	2	97.41	97			
Unaged Samples - January 2001														
E	4x0	FEP	UE-1	114	0.179	0:58	0.5	2.22	0	38.27	40	8-0	0-0	0-0
E	4x0	FEP	UE-2	114	0.178	1:47	1.0	3.36	5	24.90	25	8-0	0-0	0-0
E	4x0	FEP	UE-3	114	0.179	1:05	1.0	4.09	5	54.29	55	8-0	0-0	0-0
Average:						1:15	0.8	3.22	3	39.15	40			
Aged Samples - January 2001														
E	4x0	FEP	AE-1	114	0.179	0:55	1.5	4.90	5	60.90	60	7-0	0-0	0-0
E	4x0	FEP	AE-2	114	0.179	0:40	1.5	6.21	5	145.87	145	7-0	0-0	0-0
E	4x0	FEP	AE-3	114	0.179	0:52	1.5	5.74	5	98.09	100	7-0	0-0	0-0
Average:						0:49	1.5	5.62	5	101.62	102			

TFPRF

NFPA 255 ROUND ROBIN STUDY

	Lab. 2			Lab. 1
	TEST 1	TEST 2	TEST 1	TEST 2
VELOCITY TRAVERSE, FT./MIN	243.9	240.4	242.2	242.2
IRCB				
PRESSURE SETTING, In.H2O	0.88		0.084	
GAS FLOW RATE, CFM	5.01		5.34	
MAX. TEMP, 23 FT.(EXP.)F	559		575	
FLAME FRONT, FT.	0		0	
AVG. DUCT VELOCITY, m/s	2.05		1.77	
SMOKE AREA, %OBS-MIN	0.2		0.2	
SMOKE AREA, (CORR.), %OBS-MIN	0.2		0.3	
SMOKE DEVELOPED	0.3		0.2	
SMOKE DEVELOPED, (CORR)	0.3		0.3	
RED OAK				
PRESSURE SETTING, In.H2O	0.88		0.084	
GAS FLOW RATE, CFM	5.03		5.34	
FLAME OVER, (VISUAL),	5:38		5:42	
FLAME OVER, (980 F),	5:36		5:32	
AVG. DUCT VELOCITY, m/s	2.54		2.00	
SMOKE AREA, %OBS-MIN	81.1		122.8	
SMOKE AREA, (CORR.), %OBS-MIN	81.1		128.6	
SMOKE DEVELOPED	113.7		116.9	
SMOKE DEVELOPED, (CORR)	113.7		122.5	
HEPTANE, 155G				
PRESSURE SETTING, In.H2O	0.088	0.088	0.084	0.084
MAX. TEMP, 23 FT.(EXP.)	349	375	415	403
AVG. DUCT VELOCITY, m/s	1.79	1.82	1.38	1.39
SMOKE AREA, %OBS-MIN	37.9	41.3	38.23	40.0
SMOKE AREA, (CORR.), %OBS-MIN	37.9	41.3	39.95	41.8
SMOKE DEVELOPED	53.2	57.8	29.63	31.0
SMOKE DEVELOPED, (CORR)	53.2	57.8	30.97	32.3
BATT & BLANKET				
STATIC PRESSURE, In.H2O	0.088	0.088	0.084	0.084
GAS FLOW RATE, CFM	5.0	5.0	5.33	5.30
FLAME PROPAGATION, FT	5.5	4.5	1.6	0.9
FLAME SPREAD	27.7	22.7	7.4	3.75
AVG. DUCT VELOCITY, m/s	2.31	2.34	1.77	1.77
SMOKE AREA, %OBS-MIN	37.7	36.3	26.7	41.1
SMOKE AREA, (CORR.), %OBS-MIN	37.7	36,3	27.9	42.9
SMOKE DEVELOPED	52.9	50.9	20.7	31.8
SMOKE DEVELOPED, (CORR)	52.9	50.9	21.7	33.7
ACOUSTICAL MATERIAL				
PRESSURE SETTING, In.H2O	0.088	0.088	0.084	0.084
GAS FLOW RATE, CFM	5.0	5.0	5.33	5.33
FLAME PROPAGATION, FT	4.0	4.0	0.7	1.6
FLAME SPREAD	19.7	19.8	3.4	7.4
AVG. DUCT VELOCITY, m/s	2.31	2.32	1.75	1.79
SMOKE AREA, %OBS-MIN	13.1	13.3	18.3	26.7
SMOKE AREA, (CORR.), %OBS-MIN	13.1	13.3	19.1	27.9
SMOKE DEVELOPED	18.4	18.6	14.2	20.1
SMOKE DEVELOPED, (CORR)	18.4	18.6	14.8	21.6

Note: All #2 SD results based on historical red oak area of 71.4 %obs-min.

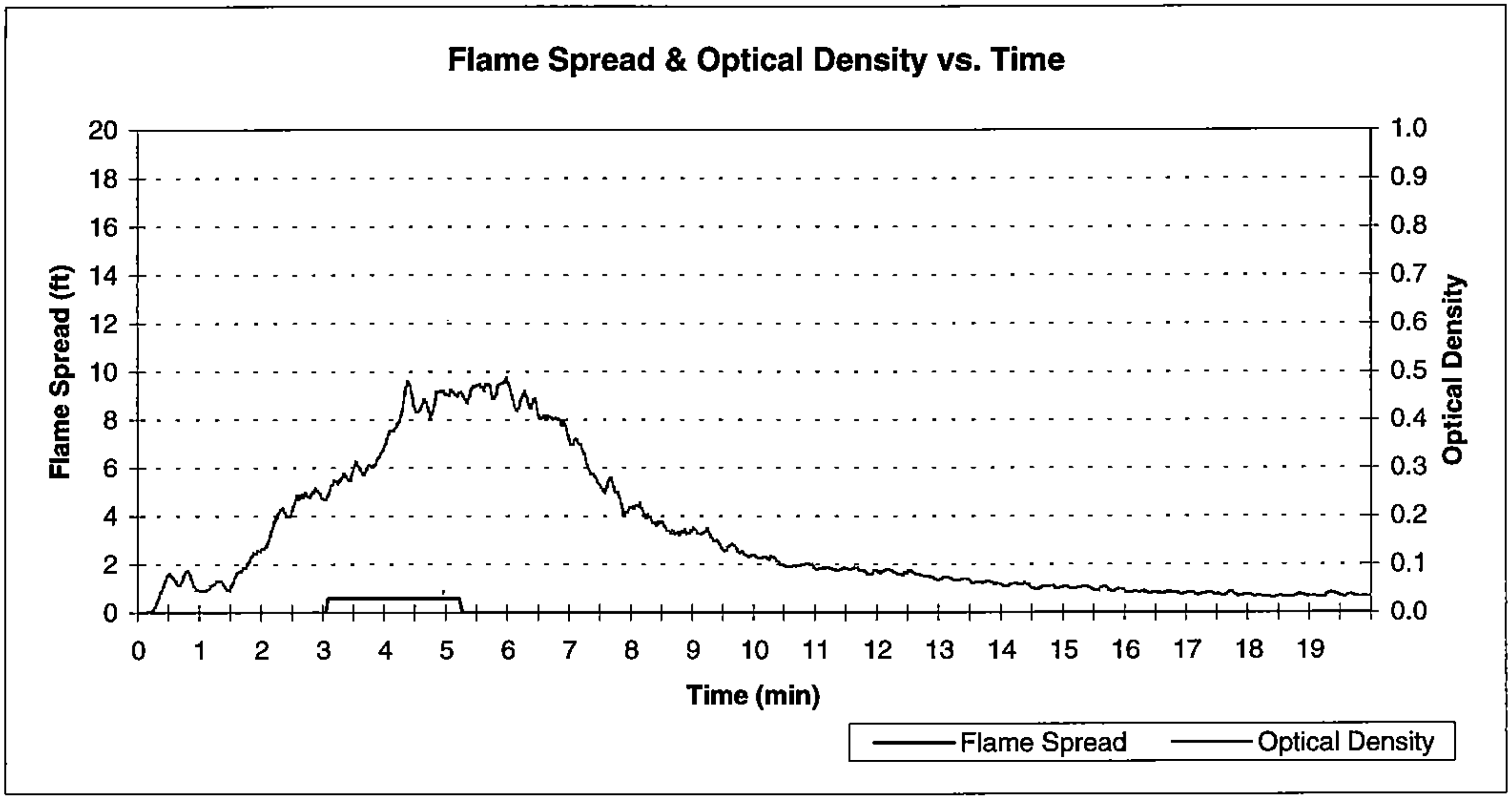
Note: #1 'correction factor of 1.045 applied to smoke results. This is based on linear regression of values obtained from check of neutral density filters. Lamp voltage set at 10V with 40mv cell output, as requested.

FPRF International Limited Combustible Plenum Cable Fire Test Project

NFPA 262

	Sample Construction						Flame Spread	Smoke Generation		Cable Damage		
Sample ID	Insulation	Jacket	Test #	No. Lengths	OD (in)	Ignition Time (min:sec)	Flame Spread (ft), max.	Peak Optical Density	Average Optical Density	Melt (ft-in)	Char (ft-in)	Ash (ft-in)
A	3x1	PVC	A-1	55	0.2045	0:12	0.6	0.49	0.16	19-6	10-0	0-6
B	4x0	PVC	B-1	54	0.2065	0:10	0.5	0.40	0.09	19-6	12-0	0-6
C	4x0	PVDF	C-1	60	0.1845	0:10	0.7	0.22	0.04	19-6	5-0	0-0
D	MFA	ECTFE	D-1	55	0.2035	0:20	1.0	0.23	0.06	17-6	3-0	0-0
E	4x0	FEP	E-1	63	0.1765	0:20	0.0	0.04	0.01	6-0	1-0	0-0

FPRF International Limited Combustible Plenum Cable Fire Test Project
Laboratory 1
NFPA 262

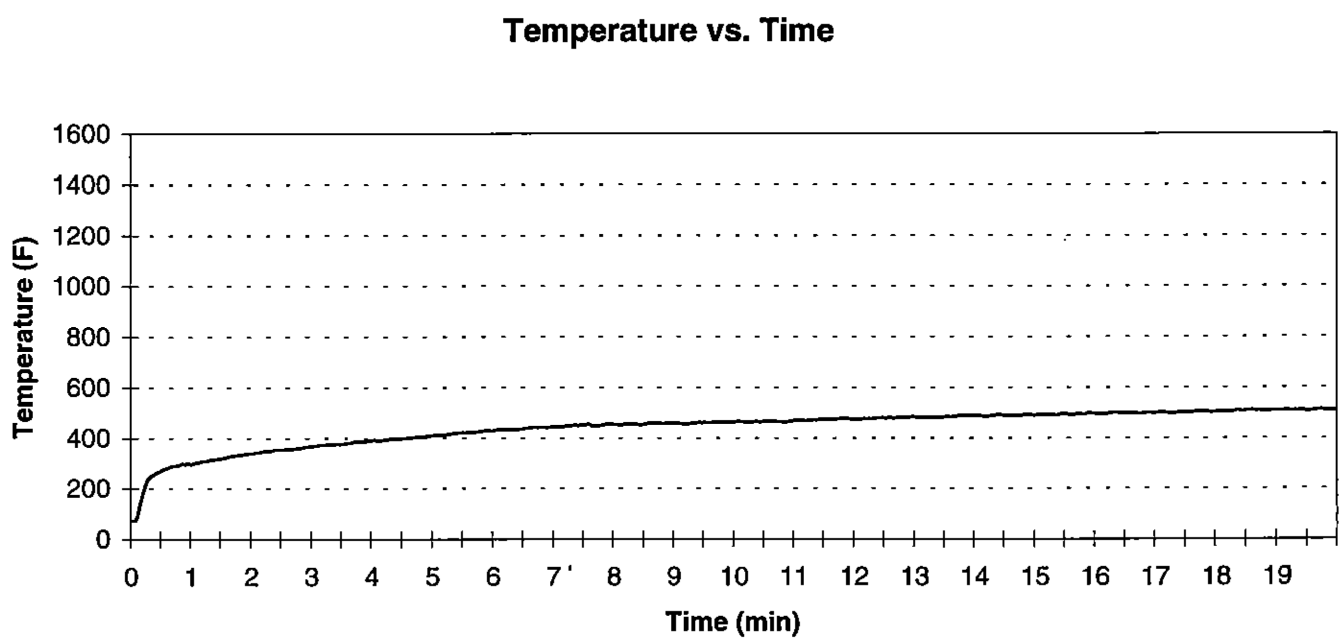


Parameter	Requirement (max.)	Measurement	Result
Peak Flame Spread (ft):	5	0.6	PASS
Peak Optical Density:	0.5	0.49	PASS
Average Optical Density:	0.15	0.16	FAIL

Date: 1999/09/22
Time: 11:36:47.0
File: NFPARF_262_A.xls
Test #: 1

Job No.: J990xxxxx   Desciption : Sample A   Client: NFPARF

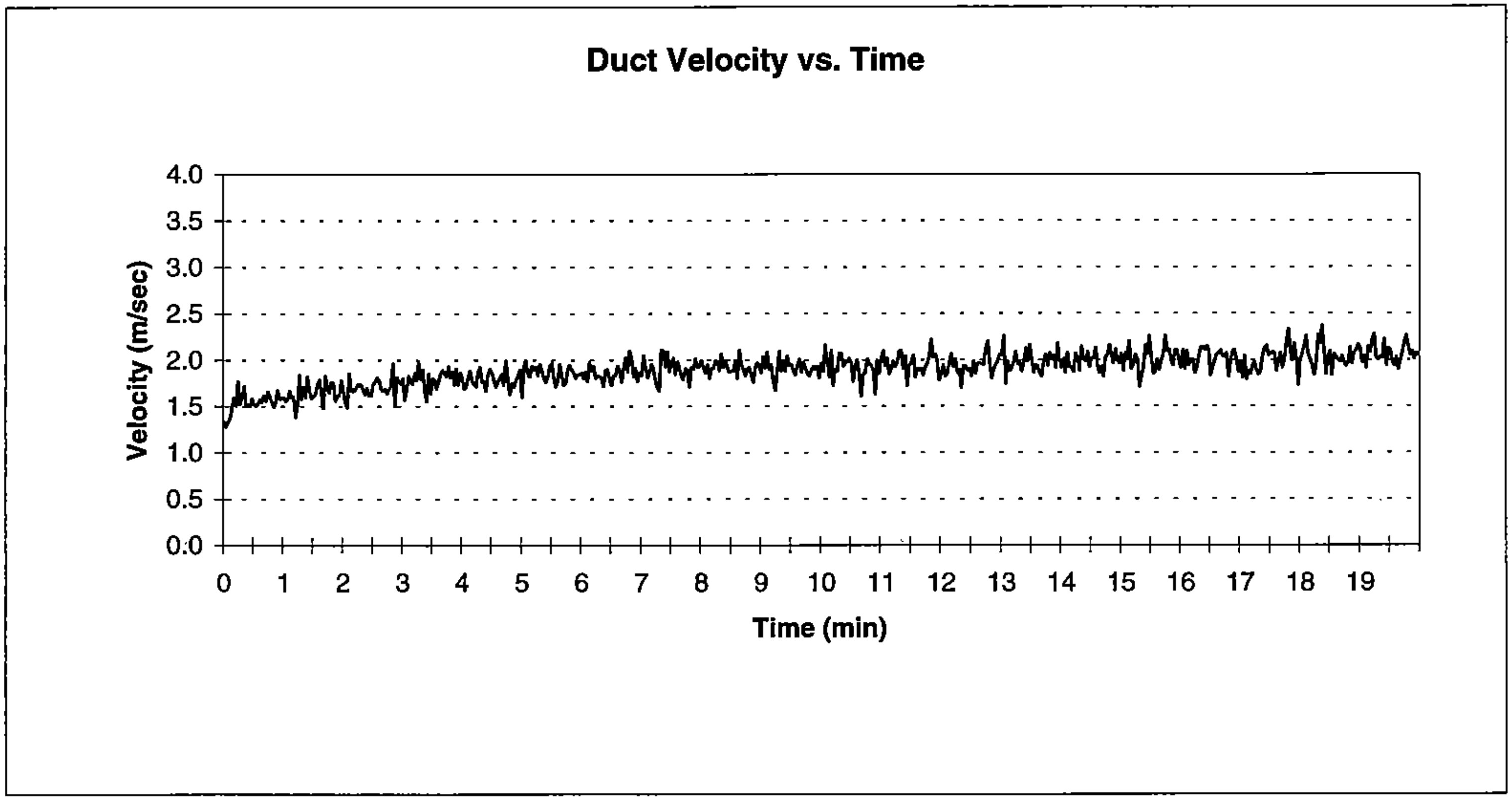
FPRF International Limited Combustible Plenum Cable Fire Test Project
Laboratory 1
NFPA 262



Maximum Temperature (Deg. F):	512.96		Date:	1999/09/22
			Time:	11:36:47.0
			File:	NFPARF_262_A.xls
Total Methane Consumption (ft^3):	82.99		Test #:	1
Consumption Rate (ft^3/min):	4.15			

Job No.: J990xxxxx   Desciption : Sample A   Client: NFPARF

FPRF International Limited Combustible Plenum Cable Fire Test Project
Laboratory 1
NFPA 262

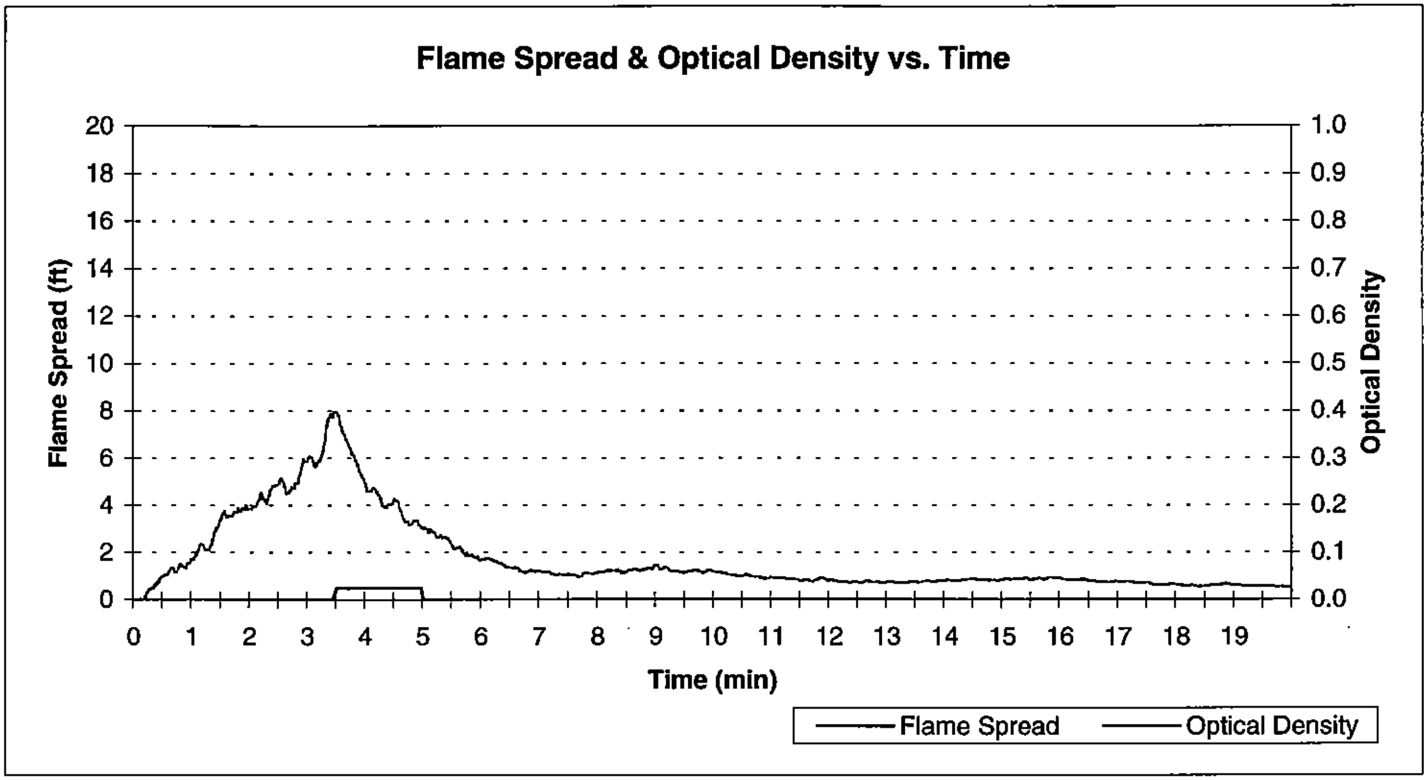


Duct Velocity (max):	2.37	m/s
Duct Velocity (min):	1.28	m/s
Duct Velocity (avg):	1.89	m/s

Date:	1999/09/22
Time:	11:36:47.0
File:	NFPARF_262_A.xls
Test #:	1

Job No.: J990xxxxx   Desciption : Sample A   Client: NFPARF

FPRF International Limited Combustible Plenum Cable Fire Test Project
Laboratory 1
NFPA 262



Parameter	Requirement (max.)	Measurement	Result		
Peak Flame Spread (ft):	5	0.5	PASS	Date:	1999/09/23
Peak Optical Density:	0.5	0.40	PASS	Time:	11:47:19.0
Average Optical Density:	0.15	0.09	PASS	File:	23066
				Test #:	1

Job No.: J99023066 Desciption Cable ID : B Client: NFPA