Determination of Fire Exposure Heat Flux in Cable Fire Tests

PRAVINRAY D. GANDHI
Underwriters Laboratories Inc.
333 Pfingsten Rd.
Northbrook, IL 60062, USA

LOREN CAUDILL and JAMES HOOVER
Du Pont, Chestnut Run Plaza
Wilmington, DE 19880 USA

TOM CHAPIN
Lucent Technologies Inc.
2000 N.E. Expressway
Norcross, GA 30071, USA

ABSTRACT

In the US, tests are conducted on cables based upon the usage and installation practices. For example, cables, installed in air handling spaces without a conduit, are tested in accordance in UL 910[1] test method. Cables used in high rise building and installed in riser shafts or installed from floor-to-floor are tested in accordance with UL 1666[2]. Cables used in installations other than the air handling space or floor-to-floor may be tested in accordance with UL 1685[3]. All these tests are product-scale tests requiring sample lengths from 25 ft. (for the UL 910 test) to 8 ft. (for the UL 1685 test).

With the advancement in small-scale heat release calorimetry technology, there has been a strong interest in developing small-scale tests that would permit screening of materials to be used for the appropriate applications. However, heat flux exposure from the fire tests needs to be defined to assist in determining the test parameters in the small-scale tests.

In this paper, tests conducted to determine the heat flux exposure provided in the three cable fire tests are discussed. The tests were conducted using Gardon type gauges to measure the total heat flux from the ignition burners of three cable tests.

Results of the UL 910 tests from this investigation compared well with existing data obtained by Parker[4]. The heat flux data were then scaled with respect to the flame lengths of each of the burners. The scaled data were shown to coalesce for the scaled parameter, x/l_f, greater than 0.4. With the scaling it was possible to approximate the total heat flux from the ignition burners with a single equation.

KEYWORDS: cable fire tests, fire exposure heat flux, fire modeling

INTRODUCTION

In the US, tests are conducted on cables based upon the usage and installation practices. These practices are guided by the National Electrical Code[5] in the US. The methods for conducting these tests are described herein.

<u>UL 910 Test Method</u>

Cables installed in air handling spaces without a conduit are tested in accordance with UL 910[1] test method. These tests are applicable to low-power cables such as optical fiber and copper communication cables.

The test apparatus consists of a 25 ft. long, 1.5 ft. wide, 1.0 ft. deep firebrick lined chamber. A cross-section schematic of the apparatus is depicted Figure 1 showing the details of the gas burner and its position relative to the cable tray. The ignition source is a methane gas burner which produces approximately 300 BTU (87.9 kW) located at one end of the chamber. Individual cable lengths in a single layer are supported on steel racks (11-1/4 in. wide) positioned 8 in. above the chamber floor. Air flow is established in the chamber such that the average velocity in the chamber is 240 feet per minute.

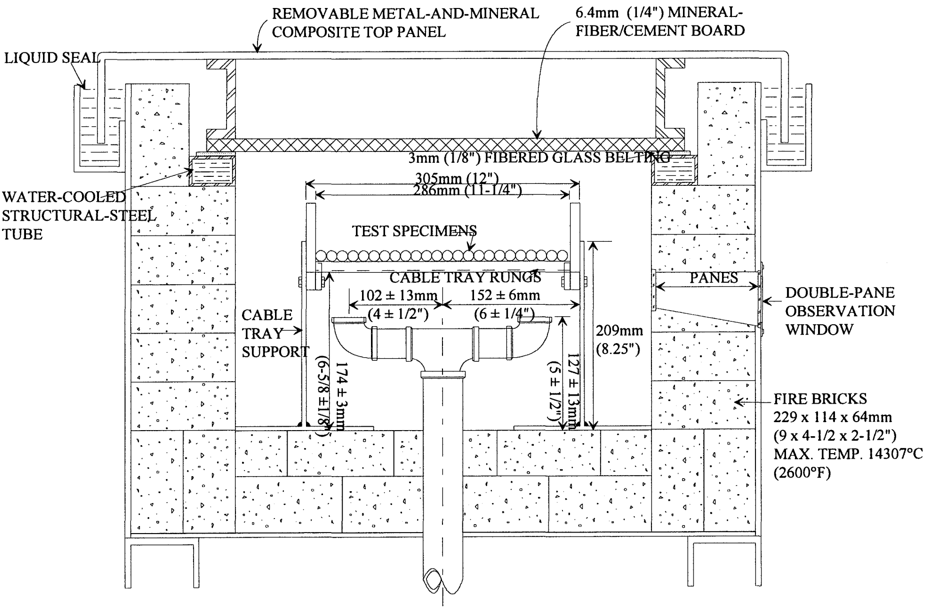

FIGURE 1. Schematic of the UL 910 Tunnel Apparatus

<u>UL 1666 Test Method</u>

Cables used in high rise building and installed in riser shafts, or from installed floor to floor of a building are tested in accordance with UL 1666[2]. These tests are applicable to optical fiber and copper communication cables.

The test apparatus, consists of a 20 ft. tall assembly, constructed of concrete masonry unit walls, reinforced concrete floors with an upper and lower chamber, interior dimensions of 4 ft. wide by 8 ft. long. The first floor chamber height is 11 ft. - 6 in. and the second floor chamber height is 7 feet. The ignition source is a propane gas burner which produces approximately 527,500 BTU per hour (154.5 kW). The burner consists of piping and a steel diffusion plate that directs the flame towards the cable sample. The schematic of the gas burner is depicted in Figure 2 showing the position of the burner relative to the test cable sample. Air flow is established in the chamber such that the air velocity in the entrance slot is 11.5 ± 1.6 ft/s (3.5 ± 0.5 m/s).

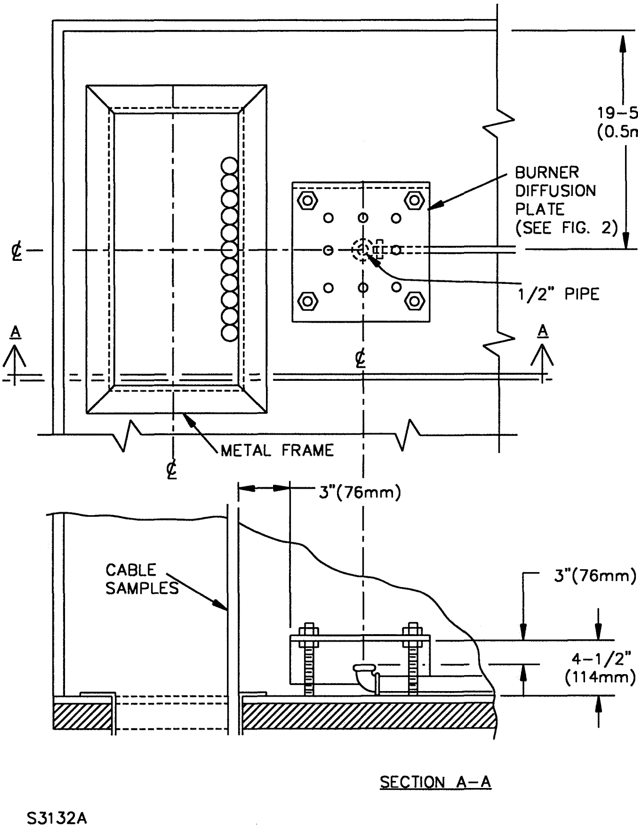

FIGURE 2. UL 1666 Test Facility

UL 1685 (FT-4) Test Method

For installations other than the air handling space or from floor-to-floor, the flammability of cables may be determined using the UL 1685[3] test method.

The UL 1685 test apparatus consists of an concrete masonry unit enclosure which measures 8 ft wide by 8 ft deep by 11 ft tall (2.4 m by 2.4 m by 3.4 m). The ignition source for the UL 1685 (FT-4) method is a propane gas/ air mixture burner which produces approximately 70,000 Btu per hour (20.5 kW) and is placed at an angle of 20° to the horizontal, and 3 in. away from the test sample. A schematic of the vertical tray apparatus is depicted in Figure 3 showing the position of the gas burner with respect to the test cable sample.

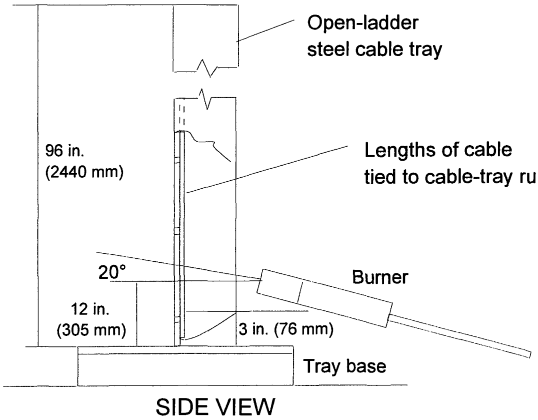

FIGURE 3. Schematic of UL 1685 Test Apparatus

The test sample consist of multiple lengths of 8 ft. long cables. Depending upon the diameter of the cable, the sample may either be separate lengths or bundles of individual lengths.

Defining the Fire Exposure Heat Flux

With the advancement in small-scale testing and improvements in heat release calorimetry technology, there has been a strong interest in developing small-scale tests that would permit screening of materials to be used for the appropriate applications. Specifically of interest to researchers is the use of the Cone Calorimeter[6] in determining the important flammability parameters for use in material screening and development. However, since the material flammability is dependent on the fire exposure, it is important to define the fire exposure heat flux provided by the cable fire tests. The fire exposure may then be used to determine the heat flux setting on the Cone Calorimeter for obtaining the flammability properties.

In this paper, tests were conducted to determine the heat flux exposure from the ignition burner fires in the three cable fire tests that are described. The heat flux results are then analyzed and scaled with respect to the flame lengths.

EXPERIMENTAL

For determining the total heat flux from the burner for each test apparatus, six heat flux gauges were mounted on a 1/2 in. thick by 8 ft. long inorganic board. For the UL 910 test method the board was 11 in. wide. For the UL 1685 and UL 1666 test methods the board was 9 in. wide. The gauges were spaced 12 inches on center along the length of the inorganic board. The gauges were water cooled Gardon type with a range of 0 - 100 W/cm^2. These were calibrated and checked for linearity in the range of fluxes expected in the tests.

UL 910 Tests

Two test sequences were performed to determine the heat flux of the UL 910 test burner. The inorganic board was positioned horizontally on the rungs of the steel ladder cable trays. The heat flux gauges were mounted in holes drilled through the inorganic board so that the face of each gauge was flush with the underside of the inorganic board. In the first sequence, the first heat flux gauge was located 5 inches downstream from the burner. In the second sequence, the inorganic board was positioned on the cable tray, and the first heat flux gauge was located 77 inches downstream from the burner.

UL 1685, and UL 1666 Tests

One test each was performed to determine the heat flux of the UL 1685 (FT-4), and UL 1666 test burners. The inorganic board was positioned vertically in the test chambers at the location of cable specimen location. The heat flux gauges were mounted in holes drilled through the inorganic board so that the face of each gauge was flush with the underside of the inorganic board. The position of the “bottom” gauge was perpendicular to the burner elevation. The first heat flux gauge for each test was located very close to elevation of the burner and the center of the gauge was estimated to be 0.25 in. away from the burner.

RESULTS AND DISCUSSION

The total heat flux results obtained from the three test apparatuses are presented and discussed herein.

The typical heat flux data using the total heat flux gauges are shown graphically in Figure 4 for the one of the two UL 910 tests.

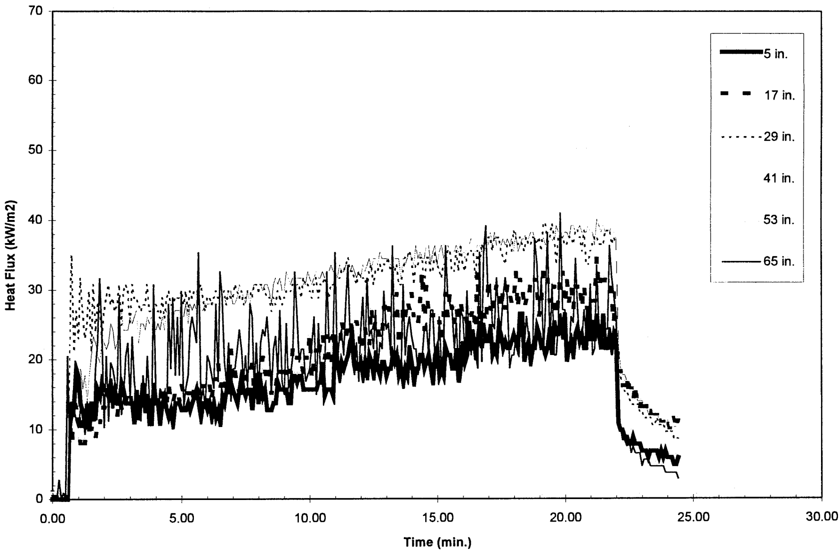

FIGURE 4. Burner Heat Flux in UL 910 Test Method (5in. to 65 in.)

The average heat fluxes, averaged from 1 minute to 19 minutes into the test, for each heat flux gauge location are provided in TABLE 1.

TABLE 1. UL 910 Average Burner Heat Flux

Test Sequence	Distance From the Burner (in.)	Average Heat Flux (kW/m²)
	5	17.1
	17	20.8
1	29	31.2
	41	48.9
	53	30.8
	65	21.8
	77	10.8
	89	10.5
2	101	12.4
	113	8.2
	125	9.7
	137	7.7

The data are presented graphically in Figure 5. Also shown are the data obtained by Parker in an earlier investigation for the ASTM E-84 test method. Both the UL 910 and ASTM E84 apparatus have identical burners and test apparatus. However, the location of the test sample during the test is slightly different.

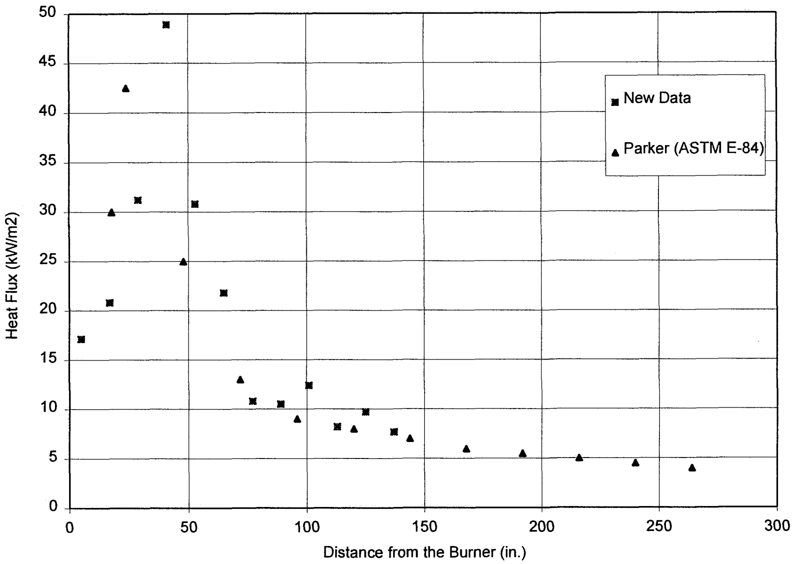

FIGURE 5. UL 910 Total Heat Flux Profile Comparison

The new data obtained in this investigation are in general agreement with Parker's results. However, Parker's data show that the peak heat flux to be closer to the burner than the new data. This may be due to the location of the heat flux gauges used in the measurements as well as the differences in the sample location.

UL 1685 (FT-4) Test

The average heat flux profile, with the heat fluxes averaged from 1 minute to 19 minutes into the test, for the UL 1685 (FT-4) is shown graphically in Figure 6.

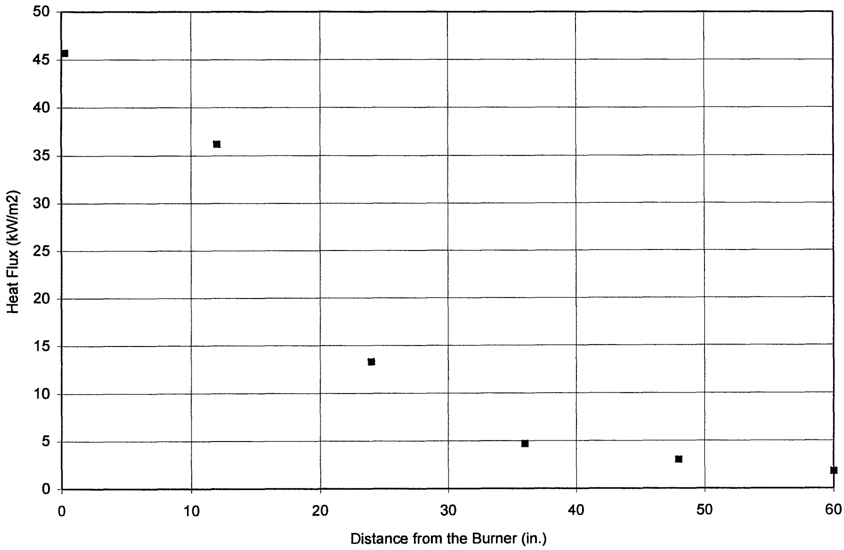

FIGURE 6. Average Burner Heat Flux Profile in UL 1685 (FT-4) Test Method

The average heat flux data are tabulated in TABLE 2.

TABLE 2. UL 1685 (FT-4) Average Burner Heat Flux

Distance From the Burner (in.)	Average Heat Flux (kW/m^2)
0.25	45.7
12	36.2
24	13.3
36	4.7
48	3.0
60	1.8

UL 1666 Test

The average heat flux profile, with the heat fluxes averaged from 1 minute to 29 minutes into the test, for the UL 1666 is shown graphically in Figure 7.

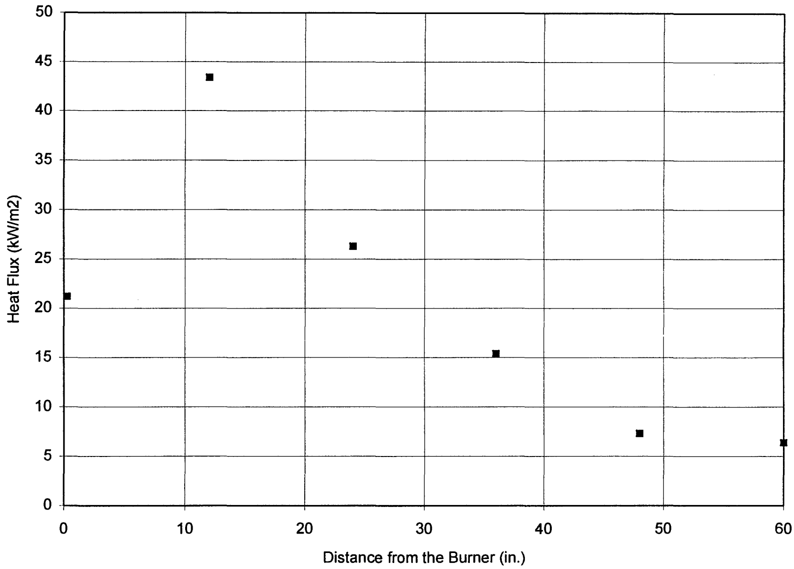

FIGURE 7. Average Burner Heat Flux Profile in UL 1666 Test Method

The average heat fluxes for each heat flux gauge location are tabulated in TABLE 3.

TABLE 3. UL 1666 Average Burner Heat Flux

Distance From the Burner (in.)	**Average Heat Flux (kW/m^2)**
0.25	21.2
12	43.4
24	26.3
36	15.4
48	7.3
60	6.4

Heat flux data from flames to vertical surfaces analyzed by Quintiere and Cleary[7] showed that the heat flux data may be scaled with flame lengths. The advantage of such scaling is that heat flux data from the different apparatuses may be combined. A similar approach was used with the heat flux data collected for the three apparatuses. The flame lengths in the three methods using the standard ignition sources are shown in TABLE 4.

TABLE 4. Flame Lengths

Test method	Flame Length, l_f (ft.)
UL 910	4.5
UL 1666	3.0
UL 1685	1.33

Using these flame lengths, the non-dimensional distance from the burner were calculated as x/l_f; where x is the distance from the burner, and l_f is the flame length.

The heat flux data from the three methods are presented in Figure 8. The figure also shows the type of ignition burner used in each test. Also included in the figure are measurements conducted by Parker.

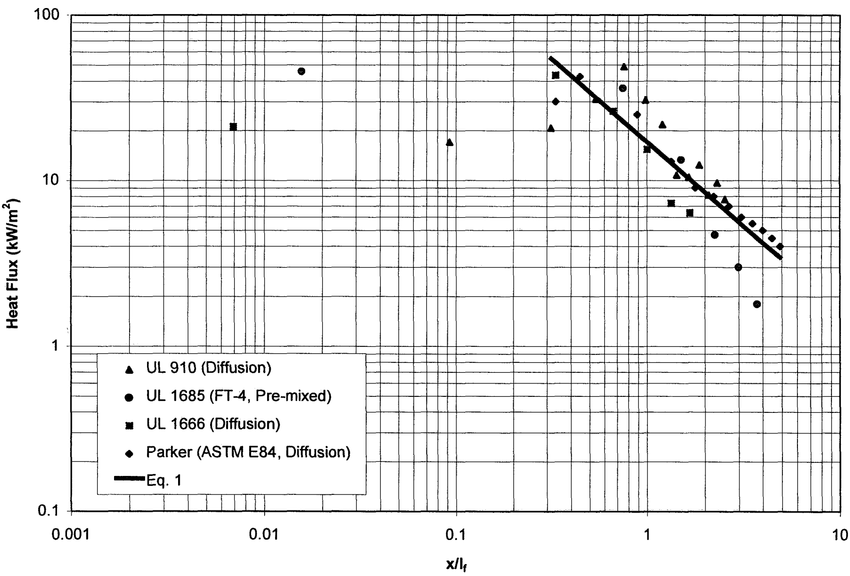

FIGURE 8. Scaled Total Heat Flux Data

The figure shows that for $x/l_f > 0.4$, heat flux data coalesce. It is interesting to observe that the heat flux data from the different test burners coalesce despite the differences in the burners, and, and the burner gas used. The deviation of the data for $x/l_f < 0.4$ may be due to the nature of flame impingement over the surface.

For $x/l_f > 0.4$, the heat total heat flux may be approximated using a least-squares fit shown in equation 1.

$$\dot{q}''_{tot} = \mathbf{17.1}(x / l_f)^{-1.0} \tag{1}$$

where $\dot{q}''_{tot}$ is the total heat flux, x is the distance from the burner, and l_f is the flame length.

SUMMARY

In this paper experimental data on the heat flux exposure provided by the burners in three fire tests used in the U.S. were presented. Results of the UL 910 tests in this investigation compared well with existing data obtained by Parker. The heat flux data were then scaled with respect to the flame lengths of each of the burners. The scaled data were shown to coalesce for the scaled parameter, x/l_f, greater than 0.4. An equation to approximate the total heat flux from the ignition burners was developed.

The data developed in this investigation will be useful in selecting the heat flux when conducting small-scale screening tests such as the Cone Calorimeter.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the guidance provided by Art Fine (AT&T Corporation) in conceptualizing the project. The authors express their thanks to Robert Backstrom and Dan Powers (Underwriters Laboratories Inc.) for conducting the experiments reported in this paper.

REFERENCES:

[1] UL 910 - Test Method for Fire and Smoke Characteristics of Electrical and Optical-fiber Cables Used in Air-Handling Spaces, Underwriters Laboratories Inc., 333 Pfingsten Road, IL 60062, USA.
[2] UL 1666 - Test for Flame Propagation Height of Electrical and Optical-Fiber Cables Installed Vertically in Shafts, Underwriters Laboratories Inc., 333 Pfingsten Road, IL 60062, USA.
[3] UL 1685 - Vertical-Tray Fire-Propagation and Smoke-Release Test for Electrical and Optical-Fiber Cables, Underwriters Laboratories Inc., 333 Pfingsten Road, IL 60062, USA.
[4] Parker, W. J., "An Investigation of the Fire Environment in the ASTM E-84 Tunnel Test, NBS Technical Note 945, U.S. Department of Commerce, National Bureau of Standards (now NIST), Washington D. C., USA, (1977).
[5] National Electric Code, National Fire Protection Association, One Batterymarch Park, Quincy, MA 02269, USA.

6 ASTM E1354 -Standard Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter, (1992), American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA, 19428, USA.
7 Quintiere, J. G., Cleary, T. G., "Heat Flux from Flames to Vertical Surfaces", Fire Technology, Second Quarter, (1994), pp. 208-229.