AN INVESTIGATION INTO THE USE OF HEAT RELEASE RATE CALORIMETERY FOR ELECTRICAL CABLES

by

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ABSTRACT

Fire tests used to investigate the fire propagation characteristics of electrical cables are dependent upon use of the cable (type and designation) and also the installation. In these fire tests, fire propagation characteristics are either determined by the travel of the luminous flame along the sample or the extent of fire damage to the sample as determined by measurement after the test. Recent advancements in oxygen consumption calorimetery has enabled the use of heat release rate as supplemental information for vertical tray flame test described in UL1581. Additionally, calorimetery data can be developed for electrical cables using the Cone Calorimeter (ASTM E1354) to obtain fire performance factors not easliy determined from product-scale tests.

This paper describes an investigation consisting of several fire test experiments to obtain heat release rate data on communication and power cables using a modified UL1581 vertical cable tray test and ASTM E1354 test to determine correlation between these tests and fire propagation characteristics.

INTRODUCTION

Fire tests used to investigate the fire propagation characteristics of electrical cables are dependent upon the use of the cable (National Electrical Code[1] type designation) and the installation. The vertical tray test described in UL1581[2] is used to investigate the extent of damage due to flame propagation for TC cable, communication cables for general use (designated as CM cables) and various other cable types and intended installations. Recent advancements in oxygen calorimetery have provided the capability to measure heat release rate as supplemental information for UL1581 tests. Interest in obtaining this supplemental heat release data for cables has evolved from similar research on heat release rates of building materials and other products in conjunction with fire modeling and hazard analysis. In addition to these product-scale tests, oxygen calorimetery is also increasingly used in small-scale tests such as the Cone Calorimeter[3]. The Cone Calorimeter provides data on the burning behavior of materials and products under controlled heating conditions and also allows determination of fire performance factors not easily obtained from large-scale tests. These data then may be employed to develop a model that describes the burning behavior of larger assemblies. This has been demonstrated by Babrauskas[4] who developed a method correlating the heat release rate of furniture determined in a large-scale test to heat release rate from the Cone Calorimeter. Similarly Gorranson and Wickstrom[5] showed that heat release rate data from the Cone Calorimeter may be modeled to predict the behavior of products in a room fire.

In this paper, an investigation consisting of UL1581 fire tests modified to obtain heat release rate data for communication and power cables is presented. The test data were analyzed to obtain relationships between heat release rate and UL1581 vertical tray test flame damage results. Data were also obtained from specimens of cables using the Cone Calorimeter to obtain additional information on fire performance factors of the cables. The results from the Cone Calorimeter tests were analyzed and compared to the performance of cables in UL1581 tests.

EXPERIMENTAL

UL1581 TESTS

The vertical tray flame test is described in Reference Standard for Electrical Wires, Cables, and

Flexible Cords - UL1581. Lengths of cables are used as test specimens and are placed into an open ladder cable tray that is 0.30m wide and 2.44m high with horizontal rungs at 0.23m intervals. The cable specimens are installed in the tray, half diameter apart and filling the center 0.15m of the tray. The cables are fastened to the tray by means of metallic wires at the upper and lower ends and at the third points. The tray can be placed over a weigh frame to monitor the weight loss during the test. A nominal 20 kW propane burner is used as an ignition source. The propane burner produces a flame height of about 0.36-41m and has a peak total heat flux of 35 kW/m^2 at approximately 0.15m above the centerline of the burner. The flux is approximately 20-25 kW/m^2 at flame tips, and reduces to 5 kW/m^2 at a distance of 1.22m. The total heat flux from the burner measured as a function of distance[6] along the center line of the burner is depicted in Fig. 1.

Fire tests were conducted on power and communication cables[7] in accordance with UL1581 with the ignition flame applied for 20 min. Oxygen consumption technique[8] was used for measurement of heat release rate by collecting the products of combustion through the hood over an enclosure as shown in Fig. 2, and sampling the gases at an instrumented duct section. Heat release rate data were obtained during the tests at 5s intervals. After each test, maximum damage to the cables was recorded.

CONE CALORIMETER TESTS

Cone Calorimeter tests were conducted using the test procedure described in "Standard Test Method for Heat and Visible Smoke Release Rate for Materials and Products Using an Oxygen Consumption Technique - ASTM E1354". A schematic of the Cone Calorimeter is shown in Fig. 3. The calorimeter consists of a cone shaped radiant heater, an electric spark ignitor, a load cell, a He-Ne (632.8 nm) laser for measuring light obscuration, and gas sampling system to determine the heat release rate using the oxygen consumption technique. The test sample may be oriented horizontally or vertically, and the radiant flux to the sample surface may be varied from 0-100 kW/m^2.

The Cone Calorimeter tests were conducted on three types of cables tested in accordance with UL1581. The selected cables, designated as A, B, and C, provided a range of performance in the UL1581 tests as shown in Table 1. Cable A had damage exceeding 2.44m; Cable B had damage of 1.68m; and Cable C had a damage of 1.07m. The peak heat release rate for each cable as determined from the modified UL1581 tests is also shown in Table 1.

Based upon the heat flux characteristics (Fig. 2) of the UL1581 propane burner ignition source, the Cone Calorimeter tests were conducted at 20, 25, 30, and 40 kW/m^2. The cables were tested in the vertical orientation with a grid to restrain the cables in a sample holder. A refractory board was used behind the cables, and was retained in place by a spring. Schematics of the sample holder, grid, and retainer spring are shown in Fig. 4. The cable lengths used in the test were 0.1m long and were placed adjoining each other to fill the 0.1m square sample holder. The number of lengths for each type of cable employed in the tests are shown in Table 2. Heat release rate, and weight loss data were obtained during the tests at 5s intervals.

DISCUSSION OF RESULTS

UL1581 TESTS

Experimental data developed by Delichatsios [9] for turbulent wall flames show that flame height, ℓ_f, and heat release rate per unit flame width, HRR', are related as follows:

$$\ell_f \propto (\mathrm{HRR'})^{2/3} \qquad (1)$$

Since in the UL1581 fire test, the flame width is invariant (approximately 0.15m), it is expected that damage height of the cables would also be related to heat release rate. The results of peak heat release rate were plotted against flame damage for those tests with a flame damage of less than 2.44m and are presented in Fig. 5. From the limited data, there appears to be a linear relationship between the peak heat release rate and the flame damage. The exponent differs from that developed by Delichatsios (1 instead of 2/3) and may be due to the fact that exponent 2/3 was developed for flame heights over flat surfaces whereas the cables have a definite curvature. An important observation that may be made from the figure is that the flame damage exceeds 2.44m if the peak heat release rate is greater than approximately 90 kW.

CONE CALORIMETER TESTS

The Cone Calorimeter data were analyzed to determine the additional fire performance factors, and to compare these factors with the performace of cables in UL1581 tests.

Heat of combustion

The heat of combustion was determined from the heat release rate and weight loss data as follows:

$$h_c = \int HRR/\Delta m \qquad (2)$$

where h_c is the heat of combustion; $\int HRR$ is total heat released during the test; and Δm is weight loss. Fig. 6 is a bar chart comparison of the heat of combustion obtained from the UL1581 cable tests with the Cone Calorimeter. For all the three cables the heat of combustion in UL1581 tests was in reasonable agreement with the Cone Calorimeter results. The data from the Cone Calorimeter tests show that heat of combustion is insensitive to radiant flux. This behavior is expected unless the test is conducted close to the critical flux for ignition, where significant smoldering may lower the average heat of combustion.

Heat release rate

The heat release rate data obtained during the the test were plotted against time with radiant heat flux as the parameter. The heat release rate curves for the cable A are depicted in Fig. 7. This cable did not ignite at 20 kW/m^2. It may be observed that peak heat release rate increased with the radiant flux. The influence of the jacketing material was more clearly evident at the lower flux as seen by a slight leveling of the heat release rate curve. It was observed that the leveling occurred because the ignition of the insulating material nearly coincided with the peak burning of the jacketing material. Fig. 8 shows the heat release rate curves for cable B. The initial peaks correspond to the ignition of jacket material. It is interesting that the maximum peak heat release rate occurred at a radiant flux of 30 kW/m^2 and not 40 kW/m^2. However, there was more vigorous burning near the peak value at 40 kW/m^2 than at 30 kW/m^2. The reason for this behavior appears to be due to the interaction of burning between jacketing and insulating materials. As before, the ignition of jacket material was more clearly defined at lower radiant fluxes. Fig. 9 depicts the heat release rate data for cable C. The peak heat release rate increased with the radiant flux. A summary of the peak heat release rate data obtained from the three cables tested at the four radiant fluxes is shown in Fig. 10.

Fig. 11 shows a correlation between the peak heat release rate from UL1581 tests and the Cone Calorimeter tests at 25 kW/m^2 and 30 kW/m^2. The data appear to correlate reasonably well at both fluxes. The figure also shows that if the peak heat release rate using the Cone Calorimeter is greater than 200 kW/m^2 (at a radiant flux of 30 kW/m^2), then the UL1581 heat release rate would exceed 90 kW. It may be recalled from UL1581 results of the trend of peak heat relase rate vs. flame damage (Fig. 3) that the flame damage would exceed 2.44m if heat release rate was greater than 90 kW. It should be emphasized that this correlation is preliminary since it is based upon only three Cone Calorimeter tests and limited cable construction types. More test data with varying cable materials (jacketing and insulating) and constructions are required to refine the correlation.

Another important fire performance factor may be determined by considering the relationship between heat release rate and the applied external radiant flux. The heat release rate from a burning material may written as a product of heat of combustion and mass burning rate as follows:

$$HRR = h_c \dot{m}'' \qquad (3)$$

where HRR is the heat release rate, h_c is heat of combustion, and $\dot{m}''$ is mass burning rate per unit area. The mass burning rate per unit area of the test sample may be approximated by the relation

$$\dot{m}'' = (\dot{q}''_r + \dot{q}''_{rf+cf} - \dot{q}''_{r\infty})/L \qquad (4)$$

where $\dot{q}''_r$ is the external radiant flux; $\dot{q}''_{rf+cf}$ is the combined radiant and convective feedback heat fluxes; $\dot{q}''_{r\infty}$ is the radiant heat loss from the surface to the ambient; and L is heat of gasification. The heat of gasification as expressed in Eq. (4) is the energy required to bring the material to its gasification temperature.

Substituting Eq. (4) in Eq. (3) yields a relationship between the applied radiant flux and heat release rate as given by Eq. (5).

$$HRR=(h_c/L)((\dot{q}''_r + \dot{q}''_{rf+cf} - \dot{q}''_{r\infty}) \qquad (5)$$

The term (h_c/L) is the ratio of energy released and the energy consumed per unit mass of material consumed. Thus higher is the ratio, greater will be the heat release rate. This ratio may be obtained from Cone Calorimeter data by plotting peak heat release rate against the radiant flux as shown in Fig. 12. The ratio (h_c/L) for each cable is then determined by the slope of the best-fit line for that cable. Since heat of combustion was determined by the heat release rate and mass loss data (Eq. (2)), the heat of gasification can be calculated and is presented in Table 3. From the ratios obtained for the three cables it may be discerned that cable A has the highest potential for burning, followed by the cable B and cable C respectively. These results are in agreement with cable performance in the UL1581 tests.

SUMMARY

An investigation was conducted to study performance of cables in UL1581 fire tests modified to measure heat release rate using oxygen consumption calorimetery. The study showed that there was a

linear trend between the peak heat release rate and flame damage in the UL1581 tests. Cone Calorimeter tests were performed on three types of cables tested in accordance with UL1581. Based on the limited data, there appears to be a relationship between the peak heat release rate in the Cone Calorimeter and the peak heat release rate from UL1581. However, more test data are needed with varying materials and constructions to refine this correlation. The heat of combustion from the Cone Calorimeter were compared with the values determined from UL1581 tests and were found to be in reasonable agreement. The fire performance factor (h_c/L) was determined for each cable and the values were found to be consistent with the fire performance of the cables in UL1581 tests.

REFERENCES

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3. ASTM 1354- Standard Test Method For Heat and Visible Smoke Release Rates For Materials and Products Using an Oxygen Consumption Calorimeter, American Society for Testing and Materials, 1916, Race Road, Philadelphia, PA.

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TABLE 1

Performace of Selected Cables in UL1581 Test

	Cable		
	A	B	C
Char Damage (m.)	> 2.44	1.68	1.07
Peak hrr (kW)	114	60	31

TABLE 2

Cable Lengths in the Cone Calorimeter Tests

Cable	Number of Lengths
A	25
B	5
C	10

TABLE 3

Heat of Gasification

Cable	h_c/L	h_c* MJ/kg	L MJ/kg
A	33.6	31	0.92
B	4.3	22	5.1
C	1.8	10	5.6

* - Average heat of combustion calculated from Cone Calorimeter tests.

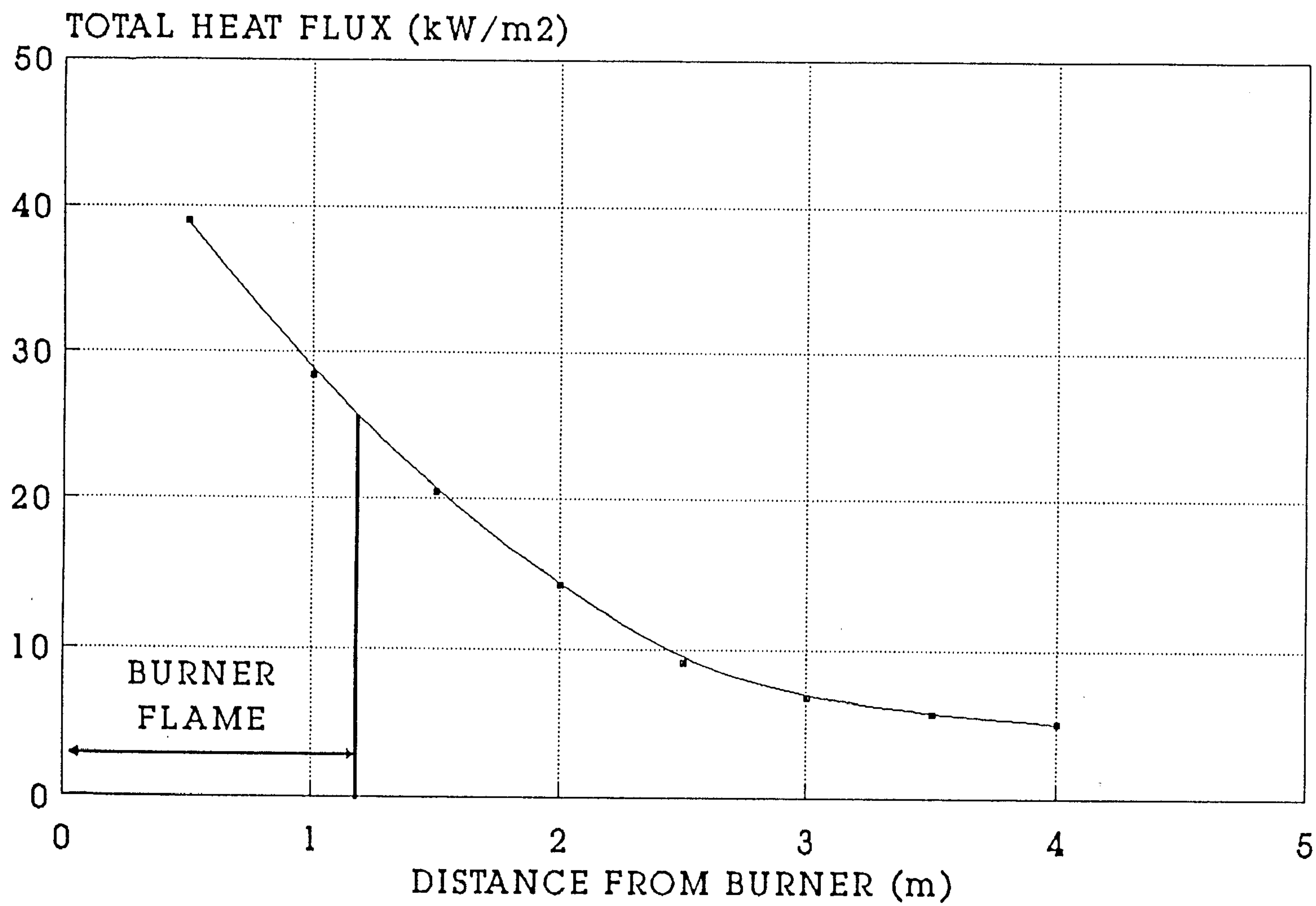

Fig. 1. Total Heat Flux at Burner Center Line VS Distance Along the Cable Tray

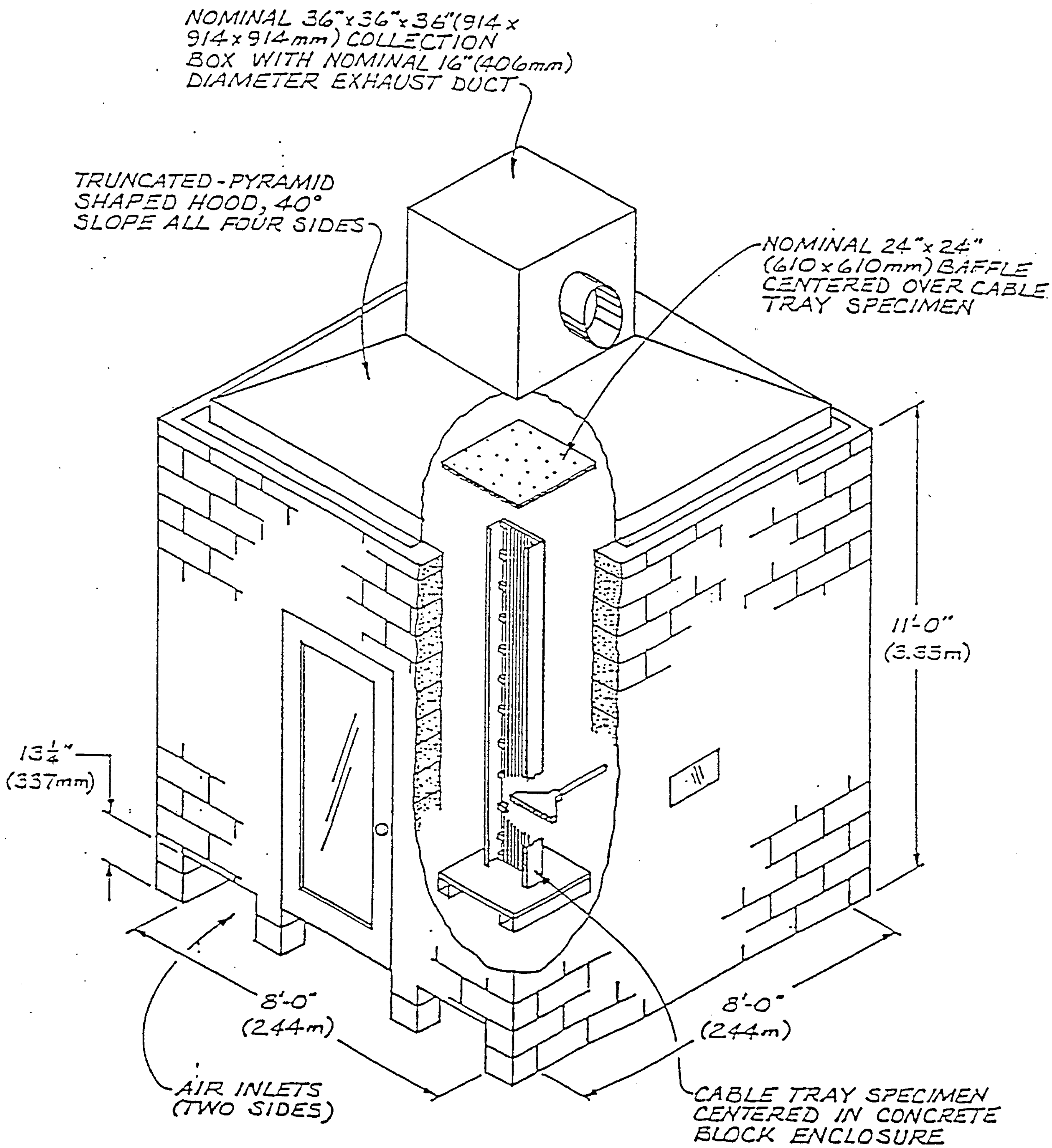

Fig. 2. Schematic of UL1581 Test Facility

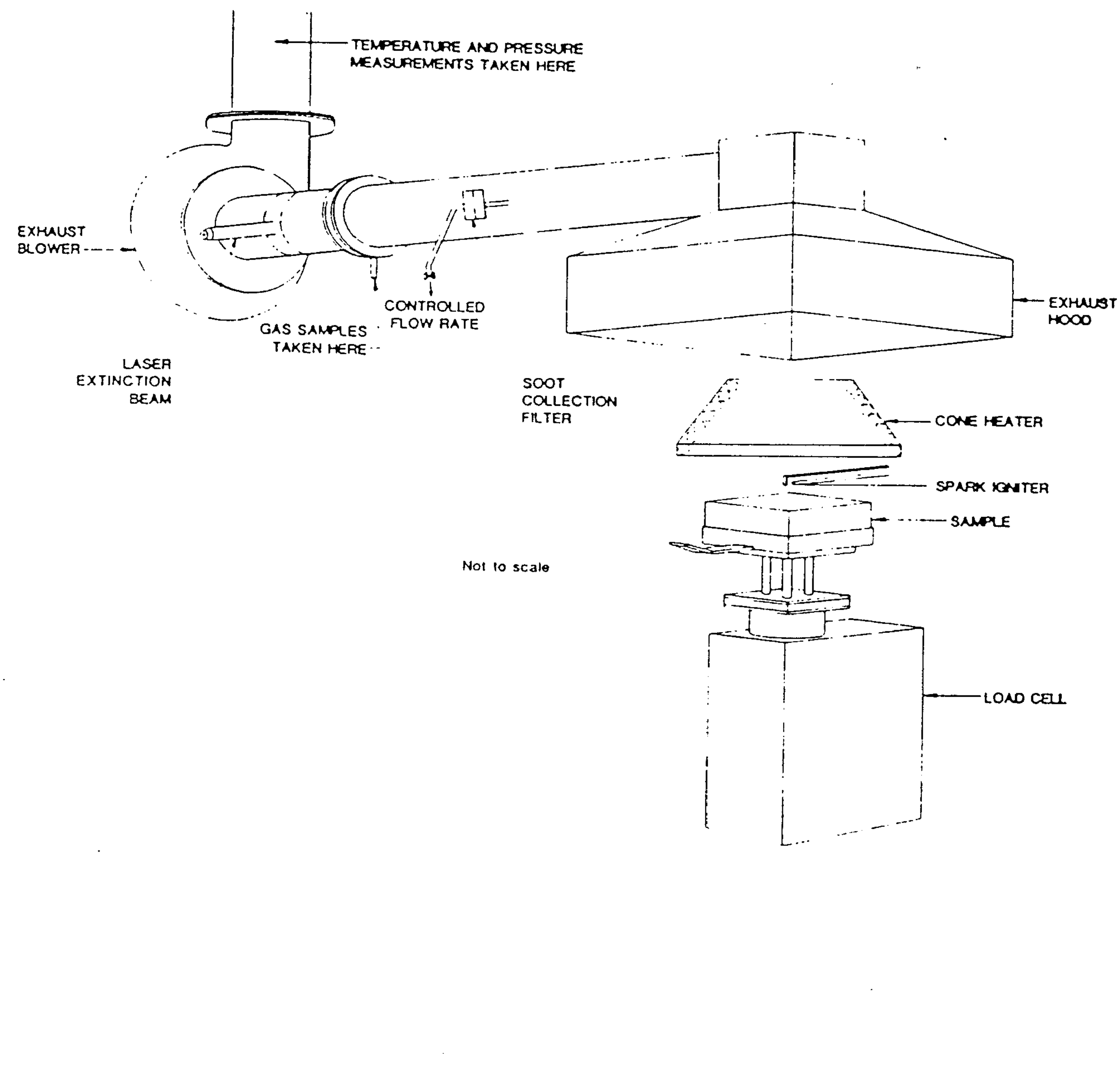

Fig. 3. Schematic of the Cone Calorimeter

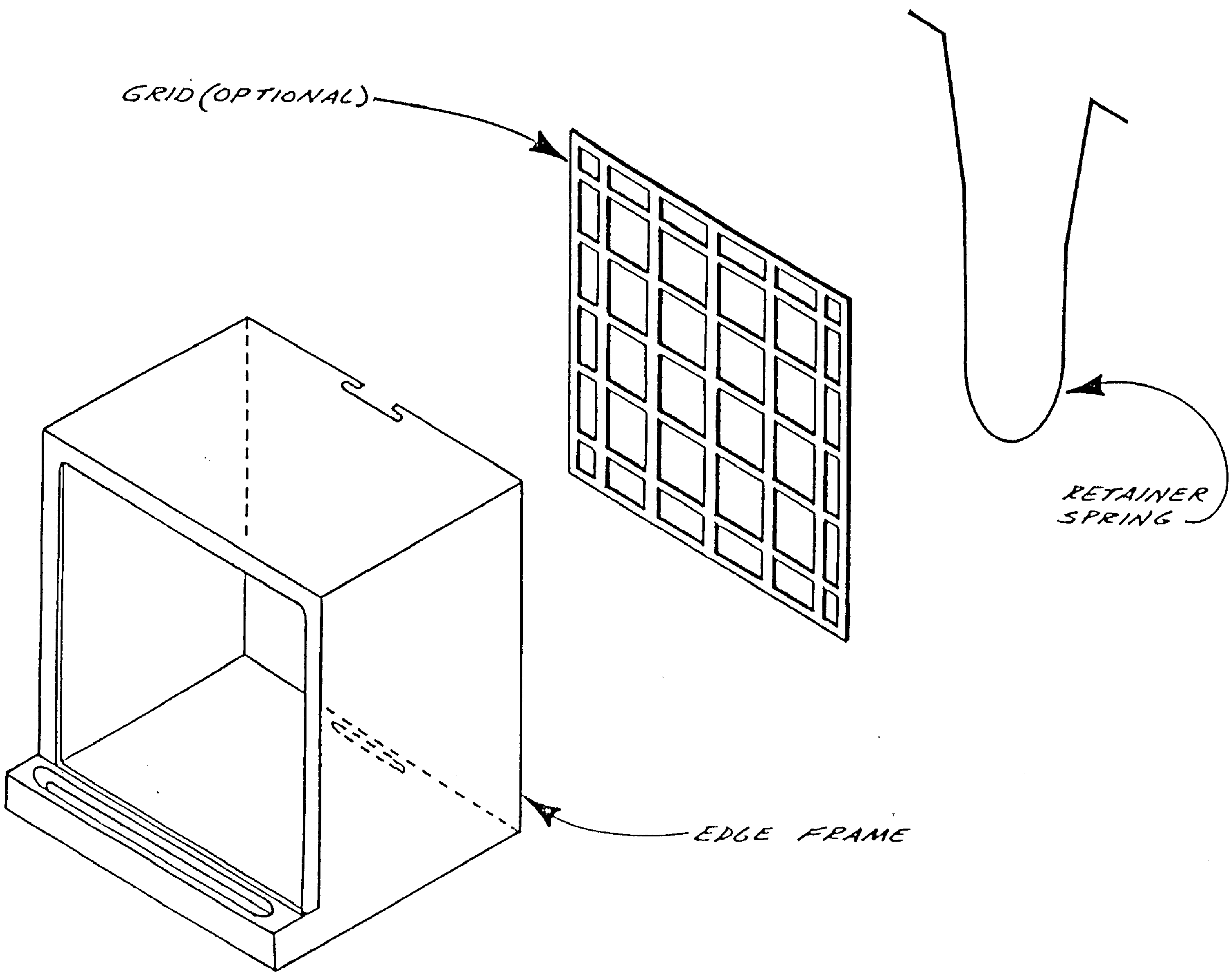

Fig. 4. Cone Calorimeter Sample Holder, Grid, and Retainer Ring

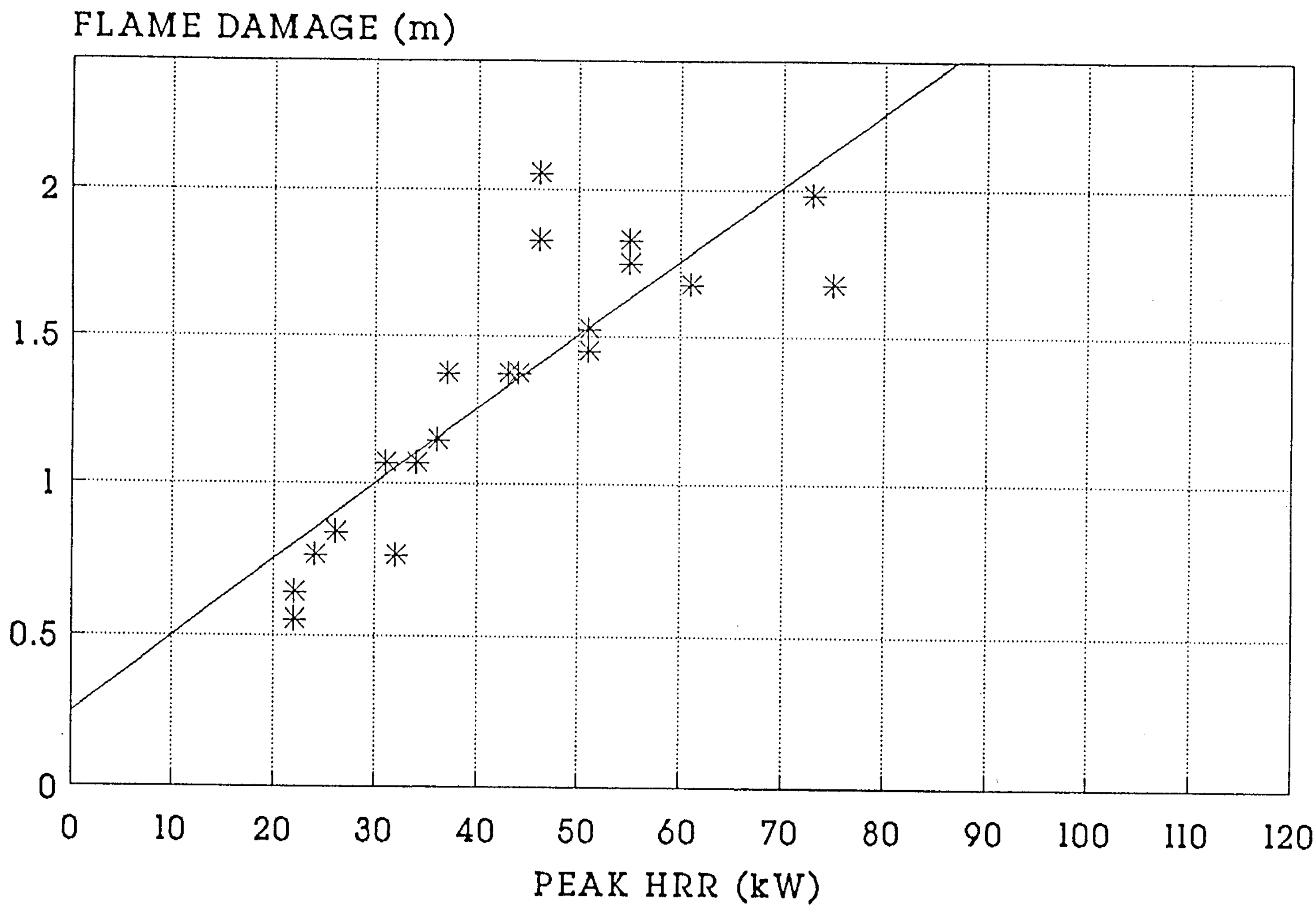

Fig. 5. Peak Heat Release Rate from UL1581 Tests VS Flame Damage

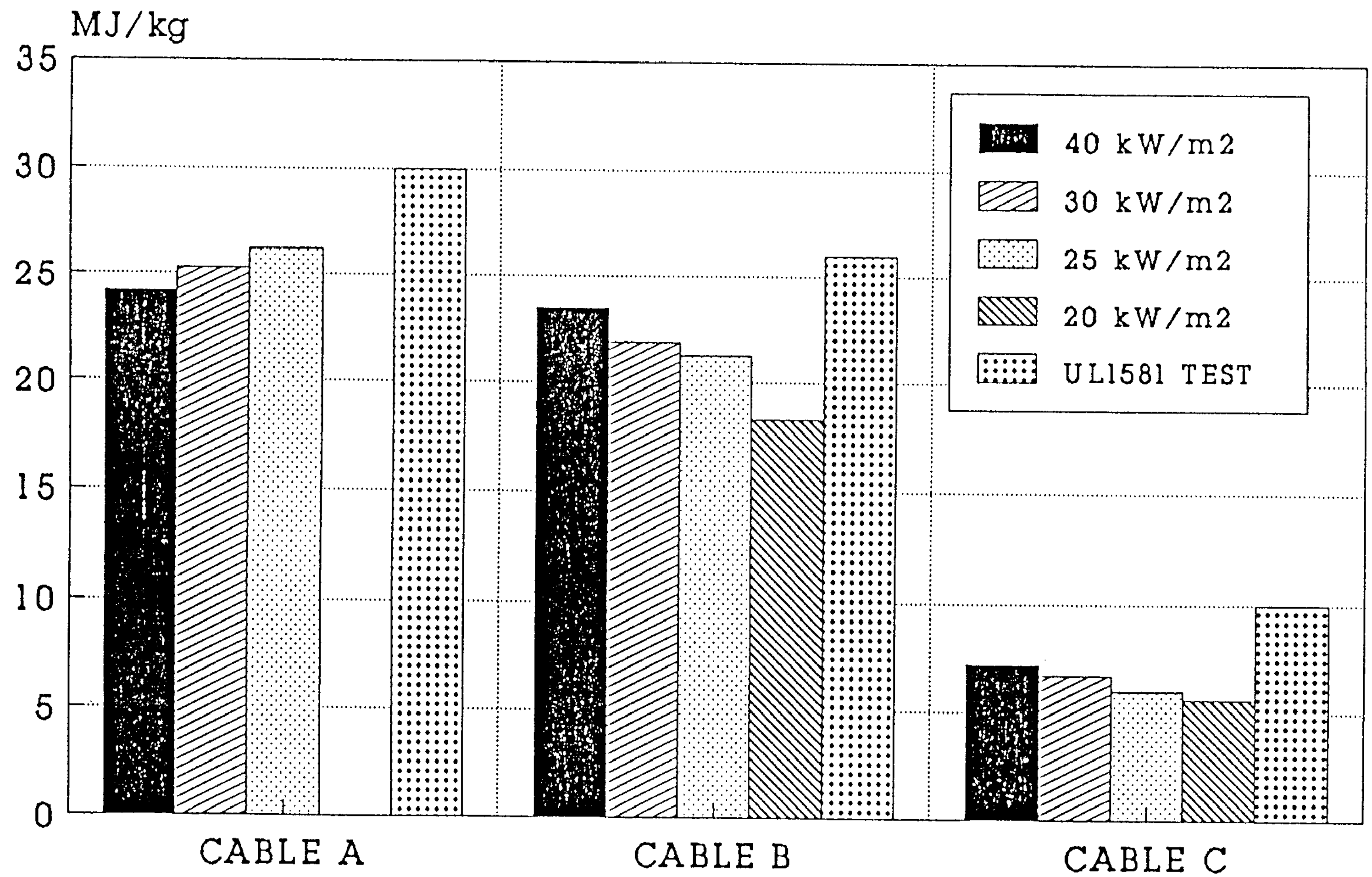

Fig. 6. Correlation of Heat of Combustion

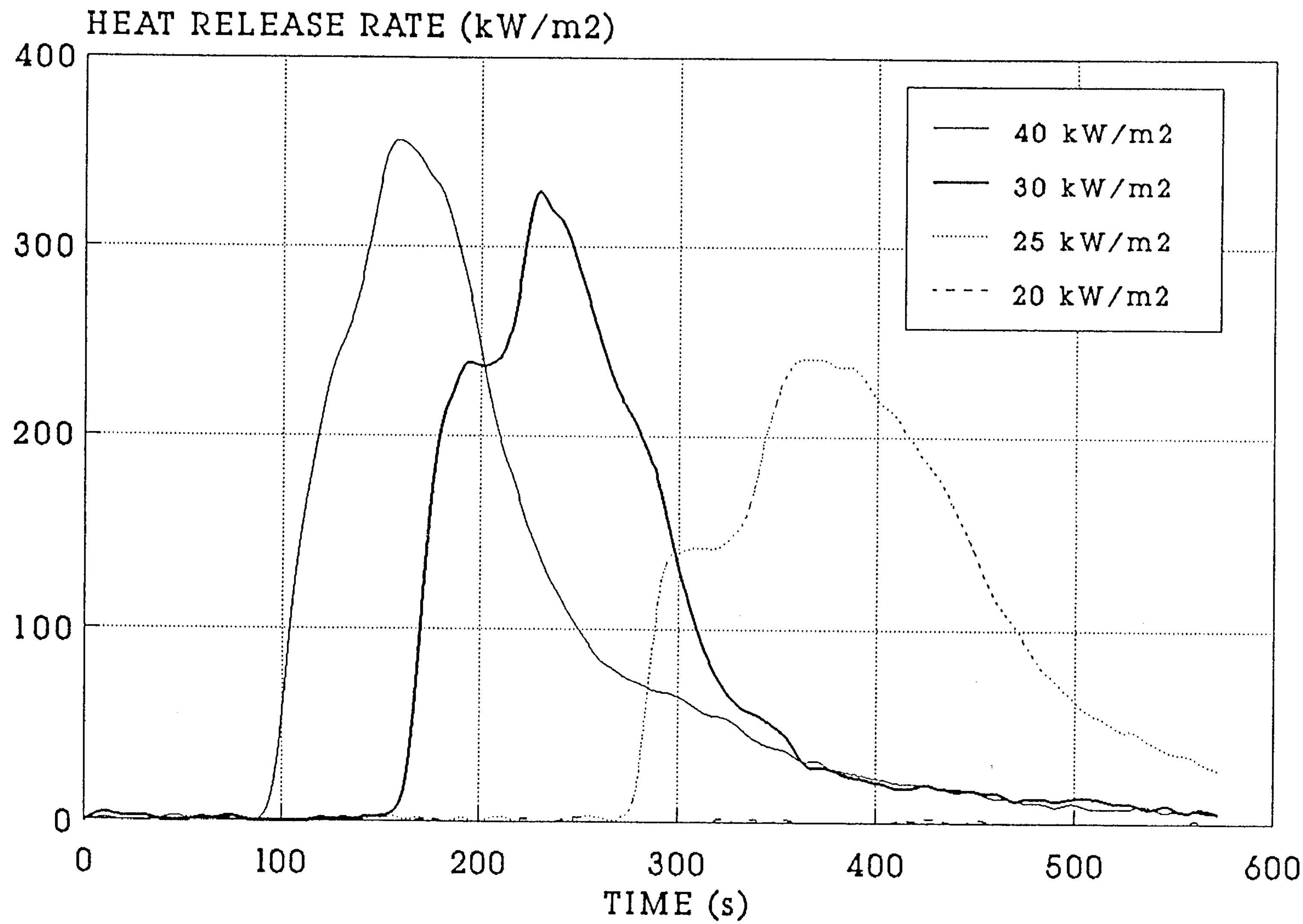

Fig. 7. Heat Release Rate - Cable A

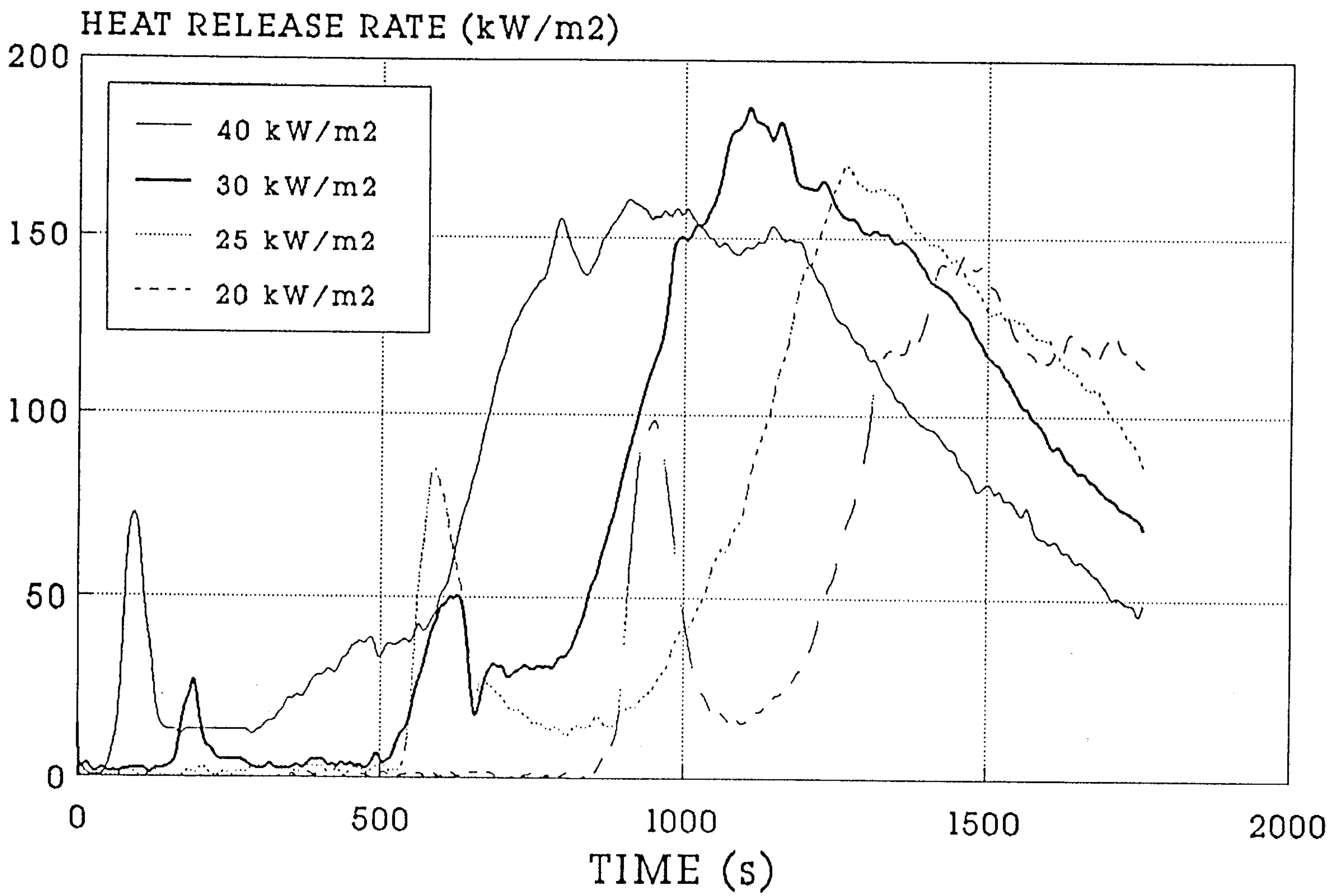

Fig. 8. Heat Release Rate-Cable B

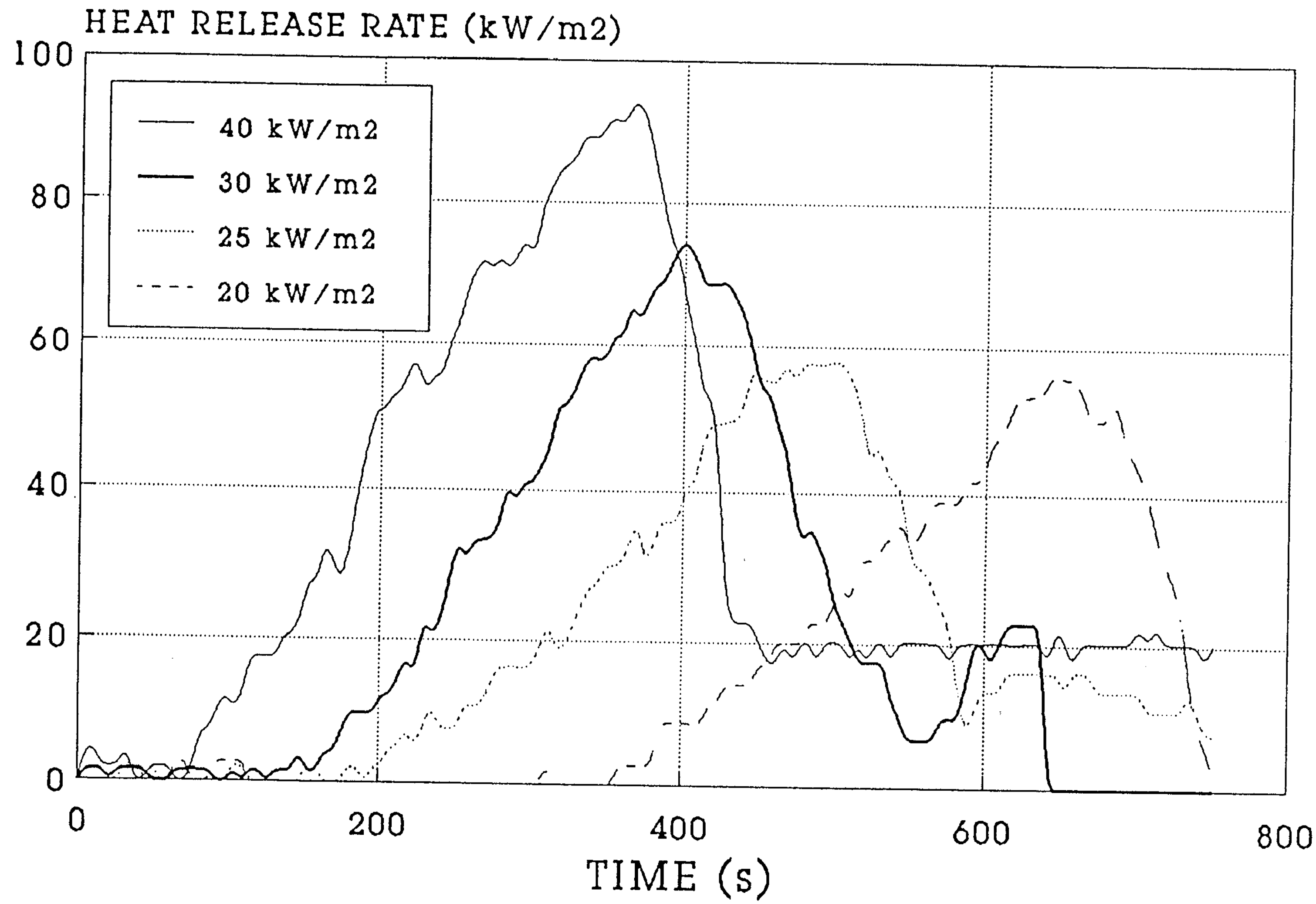

Fig. 9. Heat Release Rate - Cable C

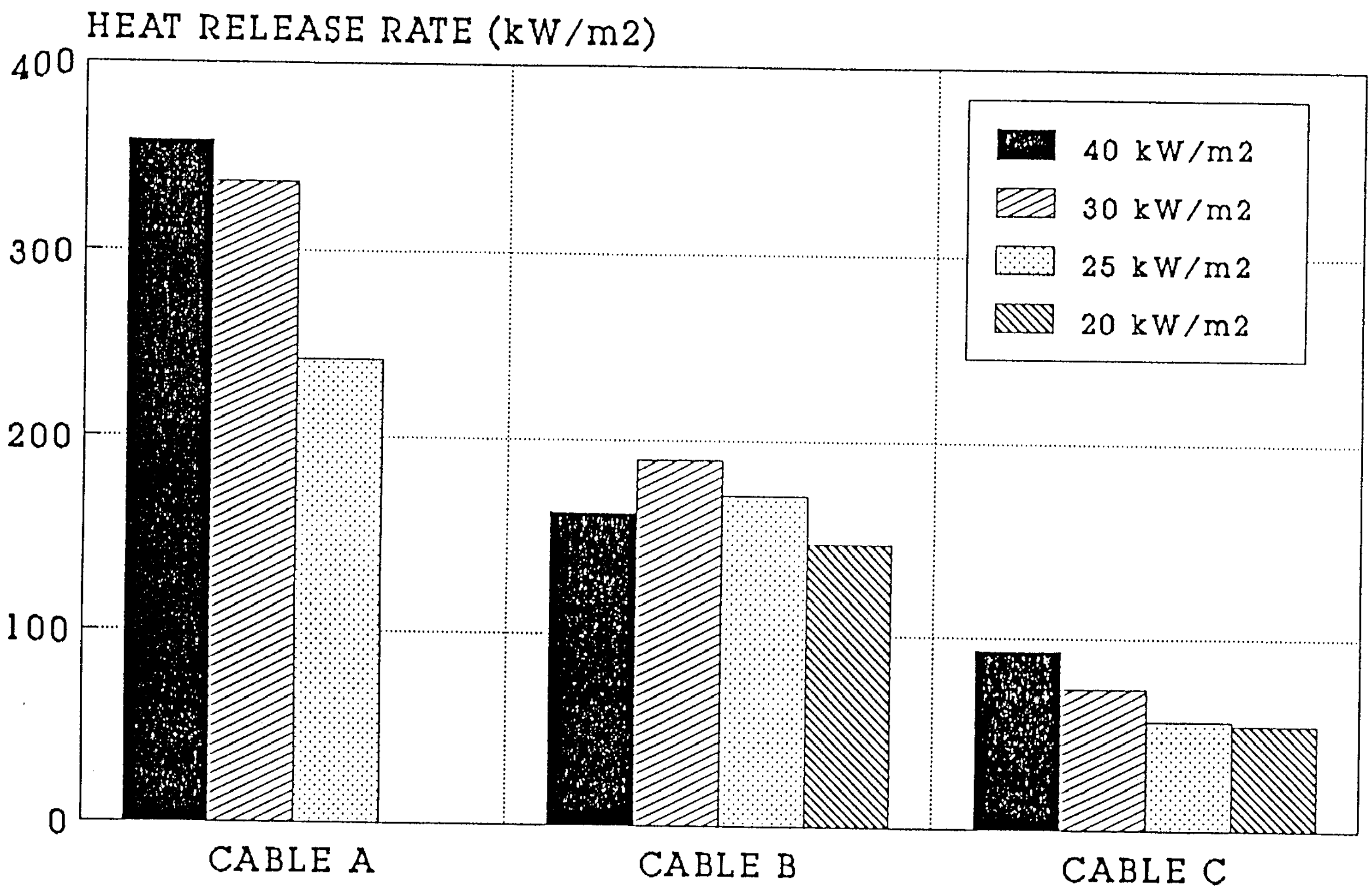

Fig. 10. Summary of Peak Heat Release Rates in Cone Calorimeter

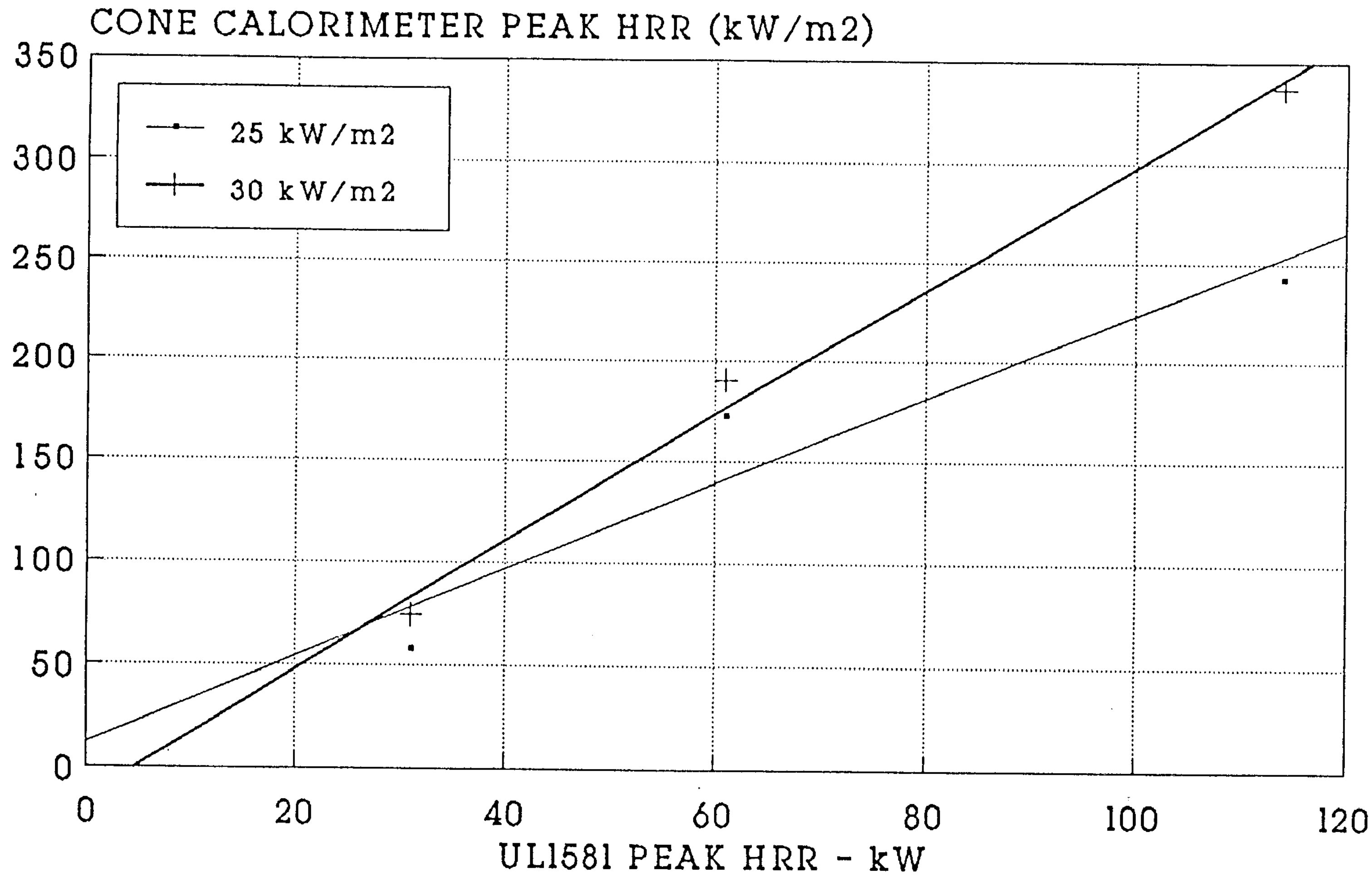

Fig. 11. Correlation of Peak Heat Release Rates
UL1581 vs Cone Calorimeter

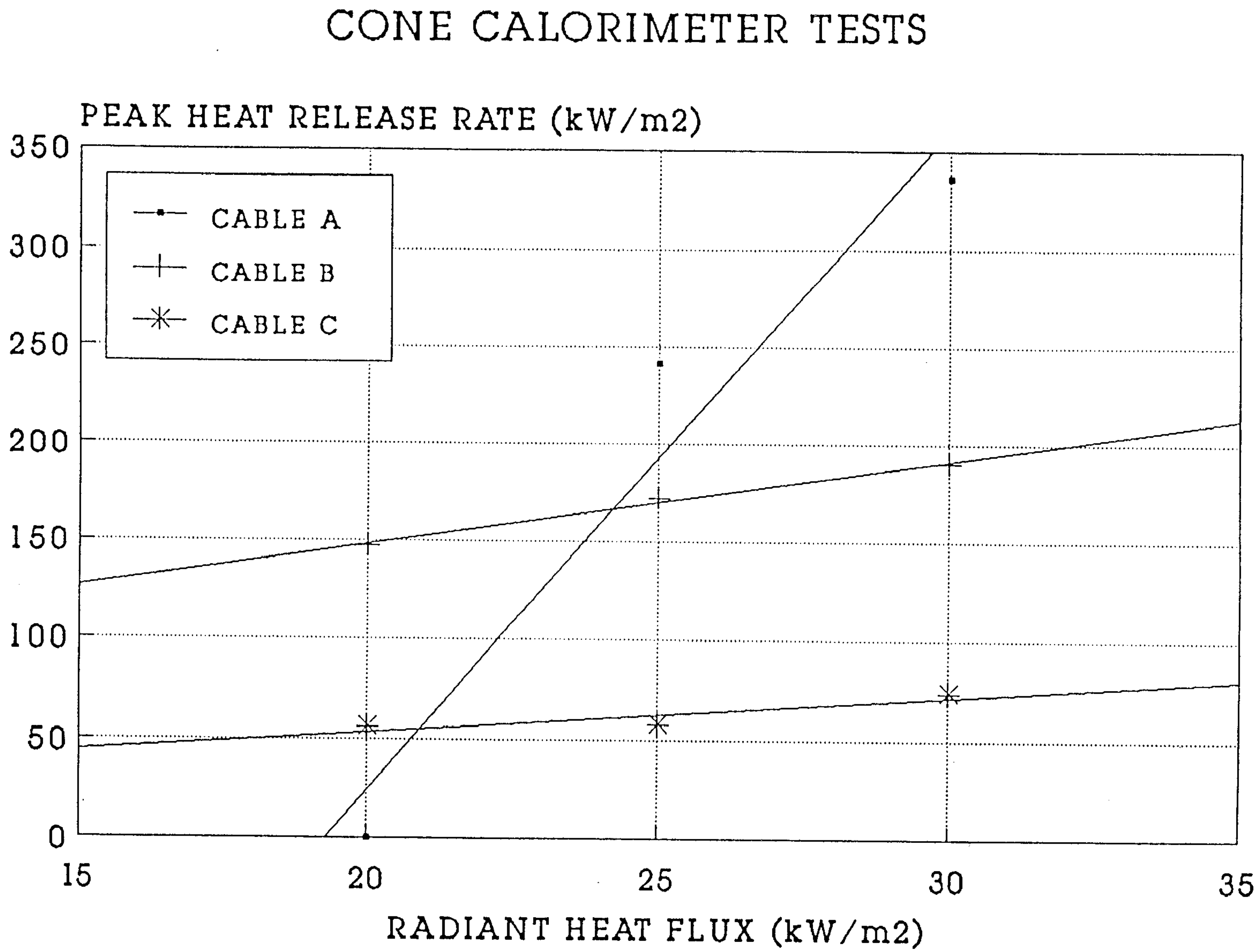

Fig. 12. Influence of Radiant Heat Flux on Peak Heat Release Rate