NISTIR 89-4065

Fire Properties Database for Textile Wall Coverings

Margaret F. Harkleroad

U.S. DEPARTMENT OF COMMERCE
National Institute of Standards and Technology
(Formerly National Bureau of Standards)
National Engineering Laboratory
Center for Fire Research
Gaithersburg, MD 20899

March 1989

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NOMENCLATURE

b	($s^{-1/2}$)	ignition parameter in eq. 2
C	$(s/mm)^{1/2}$ (cm^2/W)	parameter, slope of correlated flame spread data
c	(kJ/kgK)	specific heat
F(t)		thermal-time response function
h_c	(W/m^2 K)	convective heat transfer coefficient
h_e	(W/m^2 K)	effective heat transfer coefficient
k	(kW/mK)	thermal conductivity
$\dot{q}''_{o,ig}$	(kW/m^2)	critical flux for ignition
$\dot{q}''_e$	(kW/m^2)	external radiant flux
$\dot{q}''_e$ (50)	(kW/m^2)	external radiant flux measured at the 50 mm position
t	(s)	time
t^*	(s)	characteristic equilibrium or thermal steady state time
t_b	(s)	burn time
T_{ig}	(K)	ignition temperature
T_s	(K)	surface temperature before flame effects
V	(m/s)	flame velocity
x	(m)	distance along sample
x_f	(m)	flame front position along sample
$k\rho c$	($(kW/m^2K)^2s$)	thermal inertia
ρ	kg/m^3	density
ϵ		emissivity
σ	(5.67×10^{-11} kW/m^2K^4)	Stefan-Boltzmann constant
Φ	(kW^2/m^3)	flame heating parameter

ABSTRACT

A technical basis for linking small scale fire property test data to realistic performance has been initiated by the establishment of a small scale fire property database for some textile wall covering materials. The properties are obtained from experimental small-scale tests of materials in a vertical orientation. They include ignition and flame spread properties based on measurements from the Lateral Ignition and Flame spread Test (LIFT) apparatus and energy release rate and ignition measurements from the Cone Calorimeter. The wall covering materials database includes fire properties for: woven, knit, and needle punched polyesters; woven cotton/rayon and wool/nylon blends; nylon; and polypropylene.

Key words: ignition; flame spread; heat release rate; textile wall coverings; material properties; thermoplastics; char formation

1. INTRODUCTION

1.1 PURPOSE.

This study was initiated by the American Textile Manufacturers Institute for the purpose of identifying inexpensive small scale tests that can be used in accurately predicting the flammability characteristics of textile wall covering materials. It was the purpose of this study to initiate the establishment of a technical basis for determining fire properties of materials using data from small scale laboratory fire property test methods. It is intended that these properties will be utilized in fire models for comparison with results obtained in full scale tests. This phase of the study was to provide a database of small scale fire properties that relates to the fire growth of interior wall covering materials.

1.2 BACKGROUND.

Most surface flammability tests in use today assess the hazard of a material based on ratings, classifications or indices that are apparatus dependent. One of the more widely used U.S. flammability tests, the ASTM E84, has produced results for some materials that differ from those in room fire tests. Some textile wall coverings with ASTM E84 flame spread index ratings as low as 15 have shown flashover conditions in room fire experiments conducted at the University of California Fire Research Laboratory in Berkeley [1]. As a result some codes have adopted a full scale room corner test to more realistically measure the fire hazard of textile wall coverings.

A major concern in any fire situation is the rapid spread of flame along the surface of materials. The rate at which fire will grow depends on the ease with which a material can be ignited and flame can spread over its surface. These factors are influenced by the incident heat flux and the rate, duration and self augmentation of heat energy released by the material in a given configuration. Much research has been and is being devoted to the study of the fire growth process on one of the more simple configurations - that of a vertical surface or wall. Small scale fire property test methods that can easily test materials in a vertical orientation are under development [2-8]. The NIST Center for Fire Research is pursuing the development of a computational model to simulate fire growth on a wall in a room which utilizes the information from newly developed small scale fire property tests.

1.3 OBJECTIVE.

The ultimate objective of this study is to demonstrate the ability of small scale tests to accurately predict the flammability performance of wall lining materials. Three steps are required to accomplish this objective: the establishment of a property database for a wide range of materials; the development of an experimental strategy that identifies the pieces of fire growth and links those pieces in the appropriate relationships with fire property data; and validation of these property data correlations in corner room tests scenarios.

This report examines small scale test measurements of selected textile wall covering materials for their ignition, flame spread and energy release behavior and establishes a property database which can provide information toward assessing the relationships between small scale test results and room fire test such as those conducted at the UC Berkeley laboratory.

2. EXPERIMENTAL PROCEDURE

2.1 APPARATUS

Two small scale test apparatus were selected for measuring fire properties of ten wall covering materials from the UC Berkeley room fire tests [1]. Since the test procedures and their theoretical analysis for the LIFT apparatus have been fully described by Quintiere, et al. [2-4] and for the Cone Calorimeter apparatus by Babrauskas, et al. [5-8], Parker [9-10] and Huggett [11], only a brief overview will be presented here.

The LIFT apparatus [2-4] was used for determining the ignition and flame spread properties. A schematic of the apparatus is shown in figure 1. It consists of a pre-mixed methane-air radiant heat source, a sample holder, and a pilot flame to promote ignition. The sample is backed by an inert insulating material and the pilot flame is positioned above the sample adjacent to a contiguous wall such that it interrupts the escaping mixture containing the pyrolyzed gases generated at the sample surface. The normalized radiant heat flux distribution to the sample surface is shown in figure 2.

The Cone Calorimeter [5-8] apparatus was used for rate of heat release measurements. The apparatus utilizes the oxygen consumption principle [9-11] for determining the rate of heat release values of materials. It consists of an electrical cone shaped radiant heat source, a sample holder, a spark ignition pilot and appropriate instrumentation for measuring gas flows and oxygen depletion from the fuel exhaust stream. Schematics of the apparatus are shown in figures 3,4. It was used with the specimen and heater in the vertical orientation.

2.2 MATERIALS

The wall coverings were selected to cover the high, medium and low ranges of heat release rate values measured in the U.C. Berkeley room fire test. Some were made from thermoplastics; others were char forming fiber polyesters. One wall covering was tested with and without the application of a fire retardant and two different weaves of the same fiber material were also tested. Table 1 lists the materials with the heat release rate observed in the room fire tests, and ASTM E84 flame spread index values from reference [1].

2.3 PREPARATION OF MATERIALS

The textile wall coverings were mounted on 12.7 mm (½ inch) ordinary core gypsum wallboard using noncombustible Sairmix-7[1] adhesive [12]. The wallboards were cut to the dimensions specified in the apparatus test procedures: for the LIFT apparatus the ignition test specimens were 155 x 155 mm, and the flame spread specimens were 155 x 800 mm; for the cone calorimeter the specimens were 100 x 100 mm. Sairmix-7 was applied to the finish side of the wallboard with a carpenters trowel, the wall covering placed on the adhesive covered surface and then hand rolled until a secure bond was established between the textile and the wallboard. The textile specimens, thus mounted, were conditioned at 23 ± 3 C and 50 ± 5% RH for a minimum of two weeks prior to testing. In all tests the backs and edges of the wall covering/wallboard unit were covered with aluminum foil.

2.4 IGNITION

Ignition tests in the LIFT apparatus were conducted by exposing the conditioned wall coverings to constant and uniform incident heat fluxes that varied from 15 to 65 kW/m^2 and recording the times to ignition: ignition time is defined as the time the flame becomes attached to the specimen. The results are shown in figures A1-A10. Ignition times measured in the cone calorimeter at 30 and 50 kW/m^2 irradiances are included for purposes of comparison. The minimum flux necessary for ignition $\dot{q}''_{o,ig}$ was experimentally determined as the limit at which no ignition occurred. These critical ignition fluxes are indicated by the dashed lines in figures A1-A10. The solid lines are derived from the data correlation described below.

Effective ignition temperatures T_{ig} were found from the curve of figure 5 which expresses the surface temperature of a material, under long heating periods in the apparatus, as a function of the external radiant flux [2-4]. The approach used in the ignition temperature analysis is based on a steady state energy balance which holds after a long heating period [2,4,13] and is represented by the expression

$$\dot{q}''_{o,ig} = h_c(T_{ig} - T_\infty) + \epsilon\sigma(T^4_{ig} - T^4_\infty) = h_e(T_{ig} - T_\infty) \tag{1}$$

where T_{ig} represents the ignition temperature, T_∞ the local surface temperature, h_c the convective heat transfer coefficient, h_e a linearized effective heat transfer coefficient including the thermal radiation, σ the Stefan-Boltzmann constant and ϵ the emissivity.

The ignition time t, for the cases in which the incident flux is great enough to ignite the material, is expressed in terms of

$$\frac{\dot{q}''_{o,ig}}{\dot{q}''_e} = F(t) \begin{cases} b\sqrt{t}, & t \le t^* \\ 1, & t \ge t^* \end{cases} \tag{2}$$

---

[1]The use of trade names are for descriptive purposes only and should not be construed as endorsement by the National Institute of Standards and Technology.

where F(t) is a time-response function representing the thermal response of the material to external radiation, b is a material constant and t^* is a characteristic time at which the rear surface temperature starts to rise and is indicative of the thermal equilibrium time [3,4]. The heat losses are neglected in this development.

The data are shown in figures B1-B10. By ignoring data at the low heat fluxes where convective heat loses might erroneously influence the results, a fit of eq. 2 is represented by the solid lines.

From eq. 2, the time to ignition for any given flux $\dot{q}''_e$ is given by

$$t = \left(\frac{\dot{q}''_{o,ig}}{b} \right)^2 \frac{1}{\dot{q}''^{\,2}_e} \qquad \text{for } t \le t^* \tag{3}$$

It has been shown [3] that the parameter b can be used to compute an effective material $k\rho c$ from the expression

$$k\rho c = \frac{4}{\pi} \left(\frac{h_e}{b} \right)^2 \tag{4}$$

where h_e, a heat transfer coefficient, is determined at the ignition temperature T_{ig}. Ignition properties for the ten wall covering materials are listed in Table 2.

It should be noted that it would have been possible to determine these ignition properties using the Cone Calorimeter by making more measurements over a greater range of incident radiant fluxes and applying the same analysis. Since a complete set of ignition measurements in the LIFT apparatus is an integral part of the procedure for obtaining the flame spread properties, it was not necessary to make the additional measurements with the Cone Calorimeter.

2.5 FLAME SPREAD

The flame spread results were obtained from tests conducted in the LIFT apparatus with the 150 X 800 mm specimen mounted as shown in figure 1. The specimen was exposed to an external gradient heat flux whose high value, measured at the 50 mm position $\dot{q}''_e(50)$, was slightly higher than the minimum flux required for ignition $\dot{q}''_{o,ig}$ that was determined from the experimental ignition data. The specimen was subjected to this heat flux until it reached a state of thermal equilibrium. This pre-heating time t^* was determined from the ignition data derived in terms of eq. 2, i.e., when the minimum flux for ignition $\dot{q}''_{o,ig}$ and the external flux $\dot{q}''_e$ were equal. It is identified in figures B1-B10 by the solid line fit to the data at the point where F(t) is equal to 1. When the specimen had been pre-heated for the time t^*, it was ignited by a pilot flame and the lateral flame spread position x_f as a function of time t was noted. Table 3 lists the incident fluxes measured at the 50 mm position $\dot{q}''_e(50)$ for each of the materials in the flame spread tests.

A three-point running least-squares fit was used to find the velocity V as a function of $\dot{q}''_e(x)$. The results are shown in figures C1-C9. The critical flux for ignition from the ignition tests is indicated by the dotted line. The solid line is the velocity curve according to the values of $\dot{q}''_{o,ig}$, C, etc. deduced on the analysis described below. This calculation was based on the arrival times of the flame front at 25 mm increments along the surface of the specimen.

It has been shown [2-4,13] that flame spread velocity can be expressed by

$$V^{-\frac{1}{2}} = C\{(\dot{q}''_{o,ig} - \dot{q}''_e)F(t)\}; \quad \text{for } \dot{q}''_{o,s} \le \dot{q}''_e\ F(t) \le \dot{q}''_{ig}. \tag{5}$$

By plotting $V^{-\frac{1}{2}}$ vs $\dot{q}''_e\ F(t)$ in figures D1-D9, the slope C, the x-intercept $\dot{q}''_{oig}$ and the minimum flux for flame spread $\dot{q}''_{o,s}$ were found. Using the relationship between T_s and $\dot{q}''_e$ in figure 5, the critical temperature for flame spread was determined from $\dot{q}''_{o,s}$. These derived values of the minimum flux and temperature for spread are listed in Table 2.

In general the flame spread velocities can also be represented by the expression [2-4,13]

$$V = \frac{\Phi}{k\rho c(T_{ig} - T_s)^2} \tag{6}$$

where Φ is a material flame spread property. It includes the effects of the gas phase properties, flame temperature, opposed flow gas velocity and chemical kinetics.[4] It is determined from the expression

$$\Phi = \frac{4}{\pi} / (Cb)^2. \tag{7}$$

Values of Φ for the ten wall covering fabrics are tabulated in Table 2.

2.6 RATE OF HEAT RELEASE

While the properties included in Table 2 are associated with lateral spread on vertical surfaces, Quintiere [13] has demonstrated that some of these same properties are applicable to upward flame spread where the flame heat transfer is a function of time that depends on the energy release rate over the burning time of the fabric. The Cone Calorimeter [5,6] was used for obtaining the rate of heat release with its associated burn time for the fabrics in the vertical position. Mass loss rates and effective heats of combustion were also determined. The rate of heat release values are based on oxygen consumption as determined by the oxygen concentration and the flow rate in the combustion products stream; the heat of combustion is determined from the rate of mass loss and rate of heat release measurements and the burn time is the time associated with the peak rate of heat release. The peak rate of heat release, the heat of combustion, the total heat released, the peak mass loss rate and the burn time are tabulated in Table 4. Figures E1-E19 show the measured rate of heat release as a function of time.

3. DISCUSSION

The fire performance of a material is related to its fire properties. From two small scale test apparatus, some of these properties have been determined for ten wall covering fabrics. They include the thermal inertia, a parameter used to calculate time to piloted ignition under known irradiances, critical flux and temperature for ignition, critical flux and temperature for flame spread, a flame heat parameter, rate of heat release at 30 kW/m^2 and 50 kW/m^2 and heat of combustion.

The ignition test results indicated that the polyesters (B, Q, Q_{FR}, G), the wool/nylon blend (H) and the nylon with backing (R) fabrics required a higher heat flux for ignition and that the loosely woven polyester fabric (B) performed better than the more tightly woven needle punched polyester fabric (G). Similarly, the loosely woven cotton/rayon blend fabric showed a slightly better ignition performance than the more tightly woven cotton/rayon blend fabric: it required a higher heat flux for ignition to occur. The polypropylene fabric (PP-PF) and the acrylic/wool blend (AA) had the lowest ignition temperatures.

The experimentally determined minimum ignition fluxes and temperatures are listed in Table 2. These values can also be inferred from the flame spread data from the x-axis intercept of the solid line fit to the correlated data, figures D1-D9. There seems to be lack of agreement between the ignition and flame spread data results for fabrics Q, Q_{FR}, B, PP-PF and R that can not be justified in terms of data scatter. The correlated flame spread data for these materials indicate minimum fluxes for ignition to be 8 to 20 kW/m^2 higher than those from the ignition tests. For the tests conducted with a maximum surface flux $\dot{q}''_e(50)$ of 40 kW/m^2 or less, various degrees of melting, shrinking and vaporization were observed prior to piloted ignition. It is reasonable to assume that this resulted in changes in the thermal inertia properties of any remaining fabric and the correlated results therefore no longer represented the original fabric, but rather the thermal behavior of a composite - that of an altered fabric, the adhesive and/or the gypsum board backing. Four fabrics (H, C, Q, and R) were tested with the heat flux $\dot{q}''_e(50)$ at 50 kW/m^2 and these flame spread values show good agreement with the measured ignition data. Here melting and vaporization were not observed and the flame spread data can be assumed to representative of the fabric prior to any effective decomposition.

The flame parameter Φ is included for each set of data. The data for the higher $\dot{q}''_e(50)$ tests, represent spread properties that are perhaps indicative of the pyrolyzing char forming fiber behavior that might be expected in fire situations where the fabric is exposed to heat fluxes high enough to cause ignition before melting would occur. The parameters derived from tests where $\dot{q}''_e(50)$ was less than 40 kW/m^2 might be required for predicting fabric behavior under low flux exposures that induce melting and vaporization. As noted earlier, ASTM E-84 flame spread ratings of 15 have been measured for some of these thermoplastic fabrics yet they have been shown to support flashover conditions in room fire tests. Measurements and calculation by Parker [22] of the heat flux distribution along an asbestos millboard specimen in the E-84 tunnel show a peak value of approximately 40 kW/m^2 at the burner flame that rapidly drops to around 15 kW/m^2 at the six foot location and decreases to approximately 5 kW/m^2 at the end of the tunnel. The LIFT test results indicate that melting and vaporization would be expected to occur at these flux levels. While other factors may be involved, this could help explain the difference between the full scale and E 84 test results. In view of this, further analysis and comparison of these data with the room fire test might prove useful.

At the lower flux levels, it was difficult to identify the flame front of wall covering H and the parameters listed are from the higher flux level tests. Except for fabric R, the critical flux for flame spread was independent of the selected flux at $q_e(50)$; the critical flux for spread at the lower $\dot{q}''_e(50)$ corresponds to the measured minimum flux for ignition.

For all fabrics, the peak rate of heat release values listed in Table 4 show lower values at 30 kW/m^2 than at 50 kW/m^2 flux levels. The energy release rate was greatest for the nylon with backing fabric (R) at 50 kW/m^2 and the smallest energy release rate was measured for the same fabric at 30 kW/m^2. The polypropylene (PP-PF) and acrylic/wool fabrics (AA) also indicated high rate of heat release values as well as long burn times at both external heat flux values.

It is emphasized that while individually these properties provide useful information regarding a material's fire behavior, they more completely describe the material's fire behavior when used collectively in the appropriate scientific analysis. A logical extension of this work is to use these data in current models for flame spread to predict the total energy release rate for wall configurations. Limited attempts have shown promise. A final challenge would be the prediction of the UC Berkeley full scale room tests. However, all the necessary data may not be available from those test to use a room fire model.

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Table 1. Description of Textile Wallcoverings[1]

ATMI Code	Material Type	Weight (Oz/Yd^2)	Weight (kg/m^2)	Construction	ASTM E84 Flame Spread Index	Rate of Heat Release^x (kW)
PP-PF	100% Poly-propylene	18.0	0.61	Non-Woven	-	1166$^+$
R	100% Nylon	12.6	0.43	Woven	15	590$^+$
Q	100% Polyester	12.8	0.43	Knit Plush	15	497$^+$ 474$^+$
B	100% Polyester	9.8	0.33	Woven Panel Fabric	-	298$^+$
H	85% Wool/ 15% Nylon	9.6	0.33	Woven Flannel	-	160$^+$
C	55% Cotton/ 45% Rayon	11.5	0.40	Dobby Woven Loose Complex Weave with Floating Yarn	-	119$^+$
AA	70% Acrylic 30% Wool	22P-38T	0.75P 1.29T	Tufted	25	684$^\#$
R	100% Nylon	12.6	0.43	Woven	15	587$^\#$
Q_{fr}	100% Polyester	12.8	0.43	Knit Plush	15	310$^\#$
Q	100% Polyester	12.8	0.43	Knit Plush	15	207$^\#$
B	100% Polyester	9.8	0.33	Woven Panel Fabric	-	207$^\#$
G	100% Polyester	20.0	0.68	Needle Punched	-	83$^\#$
C	55% Cotton/ 45% Rayon	11.5	0.40	Dobby Woven Loose Complex Weave with Floating Yarn	-	62$^\#$
H	85% Wool/ 15% Nylon	9.6	0.33	Woven Flannel	-	46$^\#$
Q	100% Polyester	12.8	0.43	Knit Plush	15	5771*
Q	100% Polyester	12.8	0.43	Knit Plush	15	297*

^{x} peak total heat release rate measured in room fire test at UC Berkeley
$^\#$ 1 ft wide test specimen
$^+$ 2 ft wide test specimen
$*$ fully lined room fire test
P pile weight
T total weight

TABLE 2. Wallcovering Ignition and Flame Spread Parameters
LIFT Apparatus

Wallcovering Code Material	Critical Flux for Ignition $\dot{q}''_{o,ig}$** (kW/m²)	Ignition Temperature T_{ig} (C)	Thermal Inertia $k\rho c$ $(kW/m^2K)^2 s$	Critical Flux for Spread $\dot{q}''_{o,s}$ (kW/m²)	Critical Temperature for Spread $T_{s,min}$ (C)	Flame Heating Parameter Φ (kW^2/m^3)	Ignition Parameter b $(s^{-1/2})$
B polyester (woven)	26.0	491	0.82	12.5	340	33.5	0.068
H 85% wool 15% nylon	24.7	480	0.47	16.7	397	15.3*	0.089
Q polyester (plush)	24.0	473	0.84	6.6	235	25.3 5.1*	0.065
Q_{fr} polyester (FR, plush)	24.0	473	0.86	10.7	305	35.0	0.064
R nylon with backing	24.0	473	0.87	6.8 2.4*	240 110*	15.7 11.1*	0.064
C 55% cotton 45% rayon (loose complex weave)	20.5	440	0.68	9.9	300	20.6 8.0*	0.072
G polyester (needle point)	20.0	434	1.04	-	-	-	0.054
C 55% cotton 45% rayon (tight complex weave)	18.7	420	0.65	7.0	245	9.7	0.065
AA 70% acrylic 30% wool	18.1	414	0.98	7.8	260	20.9	0.053
PP-PF polypropylene	16.0	386	0.85	7.2	248	27.9	0.053

** ignition test data
* $\dot{q}''_e(50)$ = 50 kW/m²

TABLE 3. Surface Flux at 50 mm Position ($\dot{q}''_e(50)$) for Flame Spread Tests. LIFT Apparatus

Code	Wallcovering Material	specimen	$\dot{q}''_e(50)$ (kW/m²)
B	polyester (woven)	1	30
		2	36
		3	36
Q	polyester (plush)	1	38
		2	38
		3	38
		4	50
		5	50
		6	50
Q_{fr}	polyester (FR, plush)	1	35
		2	35
		3	35
G	polyester (needle point)	1	30 no flame spread
		2	30 no flame spread
		3	50
C	55% cotton / 45% rayon (tight complex weave)	1	30
		2	36
		3	36
C	55% cotton / 45% rayon (loose complex weave)	1	35
		2	35
		3	35
		4	50
		5	50
		6	50
H	85% wool/ 15% nylon	1	35 } *not enough*
		2	40 } spread for
		3	40 } analysis
		4	50
		5	50
		6	50
AA	70% acrylic / 30% wool	1	30
		2	30
		3	30
R	nylon with backing	1	37
		2	40
		3	40
		4	50
		5	50
		6	50
PP-PF	polypropylene	1	27
		2	30
		3	30

TABLE 4. Wallcovering Heat Release Rate Parameters. Cone Calorimeter

Wallcovering Code Material	External Heat Flux (kW/m^2)	Peak Rate of Heat Release (kW/m^2)	Total Heat Release (MJ/m^2)	Peak Rate of Mass Loss ($g/s\text{-}m^2$)	Heat of Combustion at Peak RHR (kJ/kg)	Peak Burn Time (s)
B polyester (woven)	30	137	2	9	20	23
	50	247	6	8	25	27
Q polyester (plush)	30	140	3	8	12	28
	50	225	7	16	14	35
Q_{fr} polyester (FR, plush)	30	169	3	10	18	25
	50	213	8	12	19	42
G polyester (needle point)	30	70	2	9	8	15
	50	73	2	7	9	22
C 55% cotton 45% rayon (tight complex weave)	30	120	5	11	11	23
	50	132	5	9	15	25
C 55% cotton 45% rayon (loose complex weave)	30	108	4	10	11	20
	50	124	5	11	12	23
H 85% wool 15% nylon	50	105	4	6	17	30
AA 70% acrylic 30% wool	30	233	21	12	29	152
	50	252	25	8	31	132
R nylon with backing	30	43	3	4	12	43
	50	288	9	12	23	52
PP-PF polypropylene	30	209	8	9	24	113
	50	262	17	8	35	78

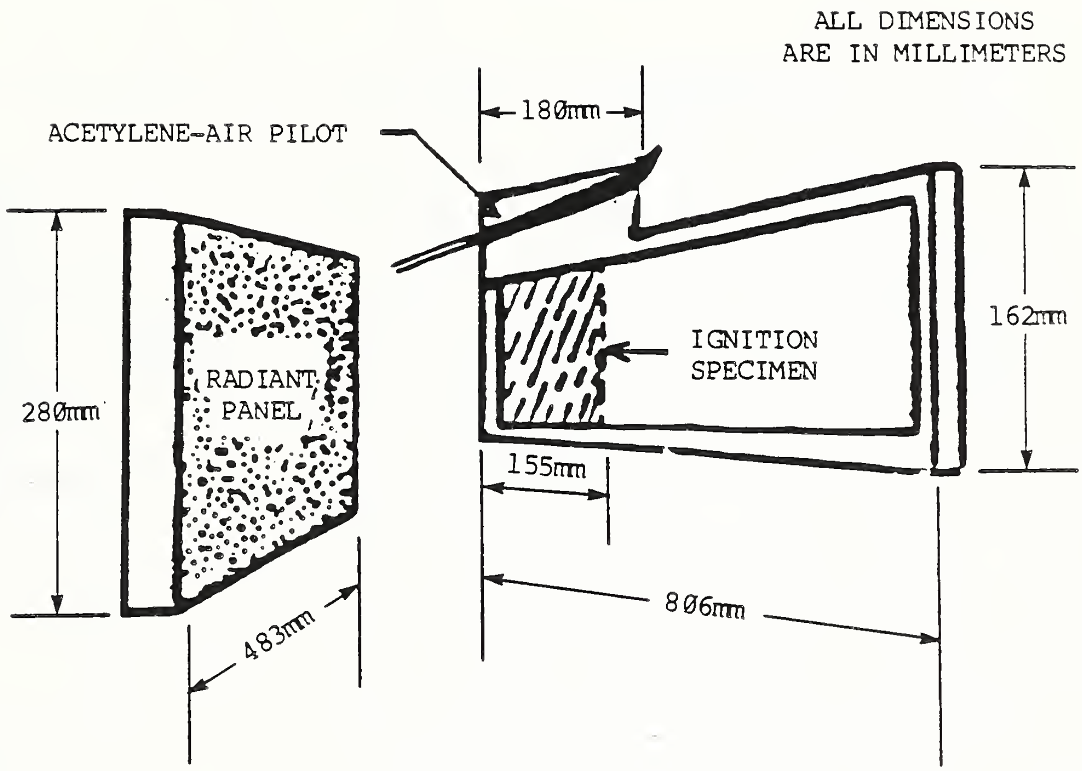


Figure 1. Schematic of ignition and flame spread (LIFT) apparatus

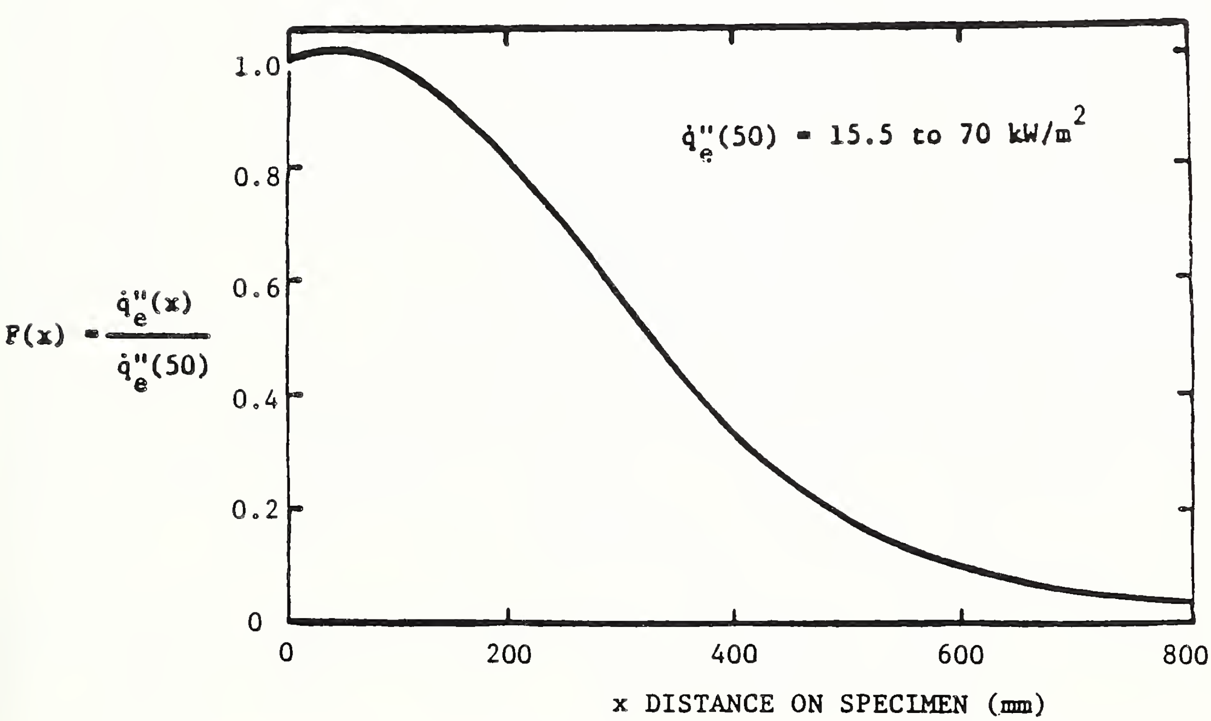


Figure 2. Normalized heat flux over the specimen surface

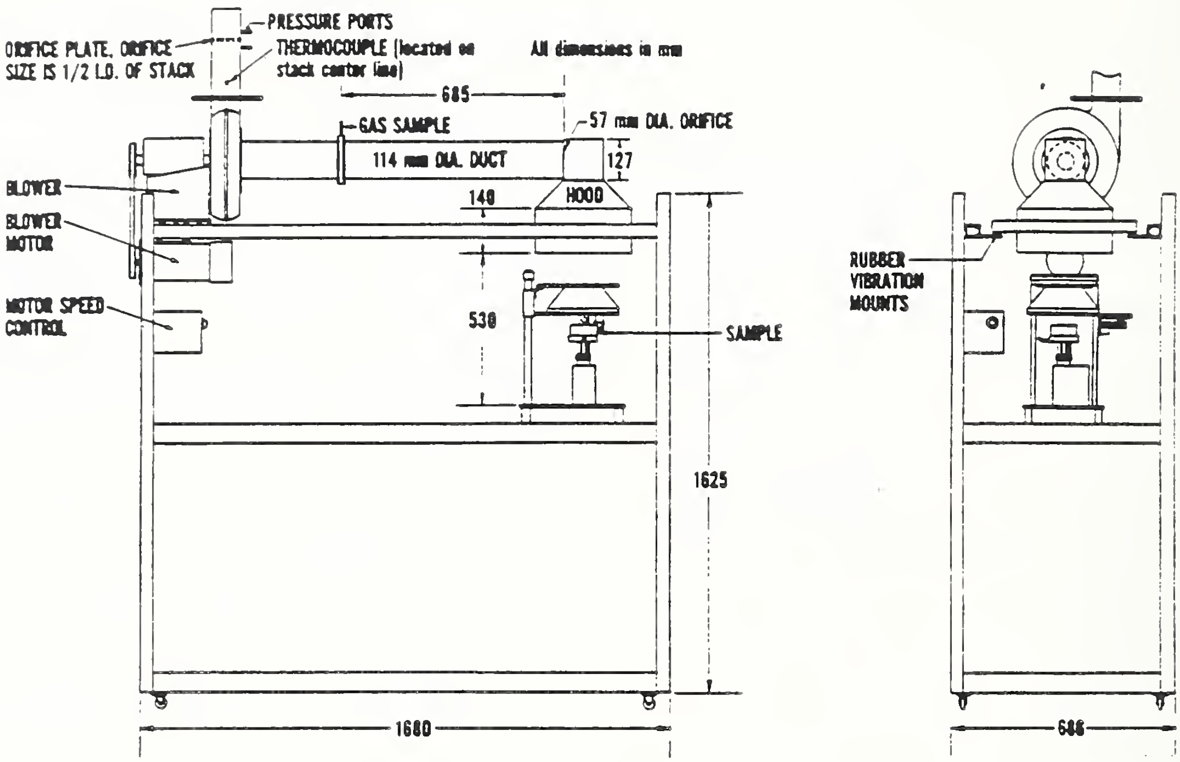


Figure 3. Schematic of rate of heat release (CONE) apparatus

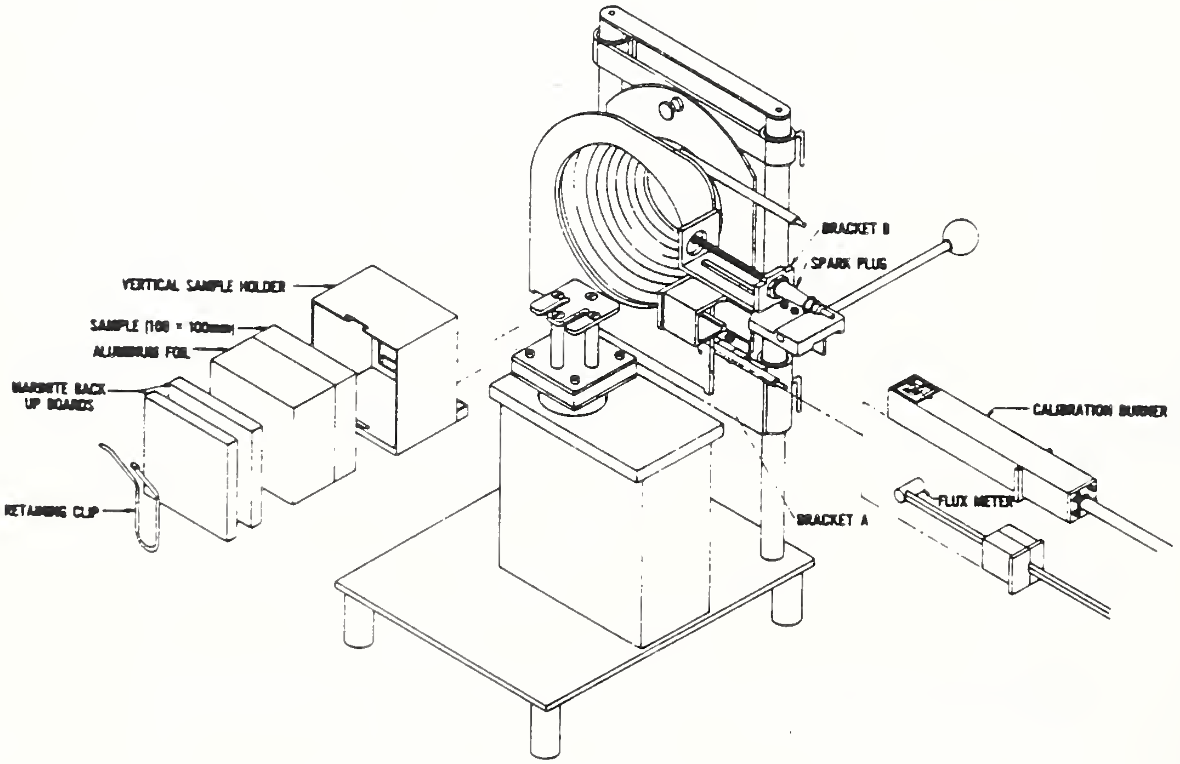


Figure 4. Schematic of CONE radiant heat source and specimen holder

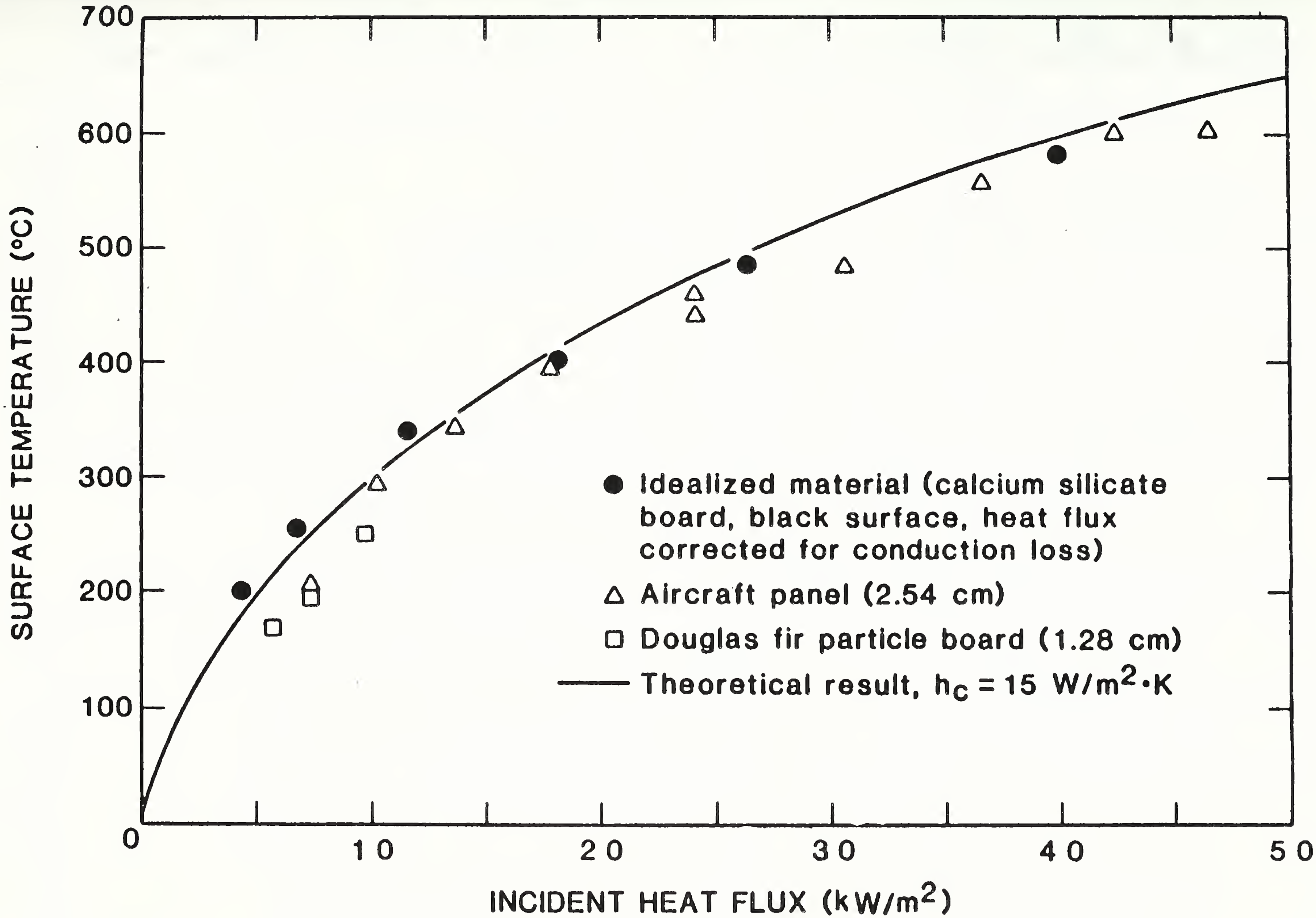


Figure 5. Equilibrium surface temperature as a function of external heating (LIFT apparatus)

Appendix A. Ignition Results

Ignition results were conducted for the ten wall covering materials. The time to ignition vs external flux profiles are shown in figures A1-A10. The experimentally determined minimum fluxes for ignition are indicated by the dashed lines. The solid lines represent analytical curves based on the derive value of the parameter b of eq. 2. Ignition times measured in the cone calorimeter at 30 and 50 kW/m^2 are included.

Figure A1. Ignition time vs external flux, fabric Q

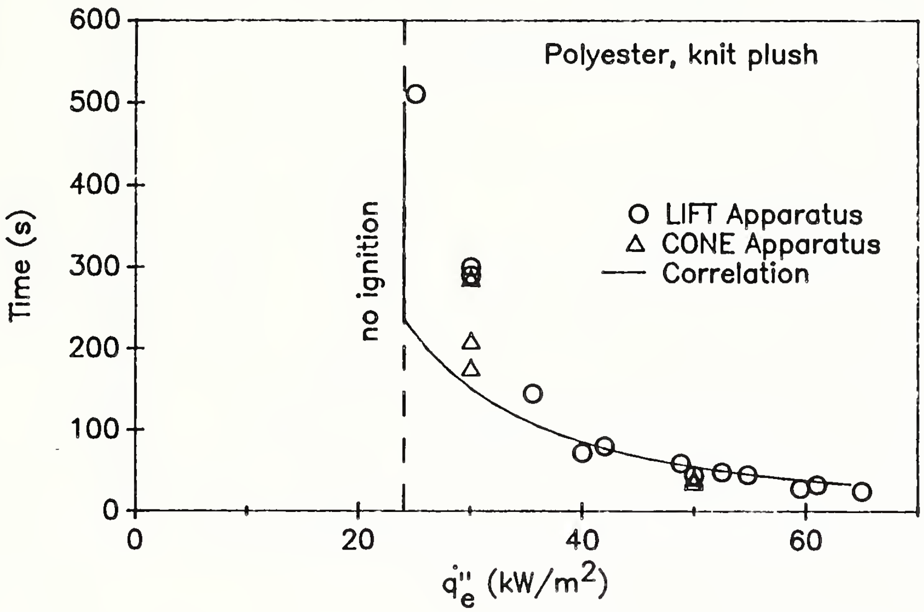


Figure A2. Ignition time vs external flux, fabric Q_{FR}

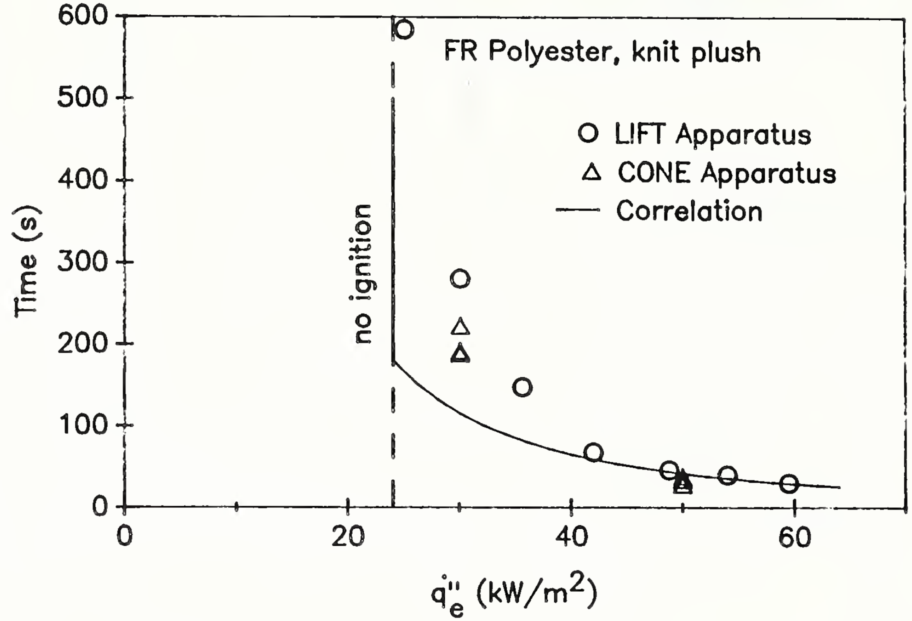


Figure A3. Ignition time vs external flux, fabric B

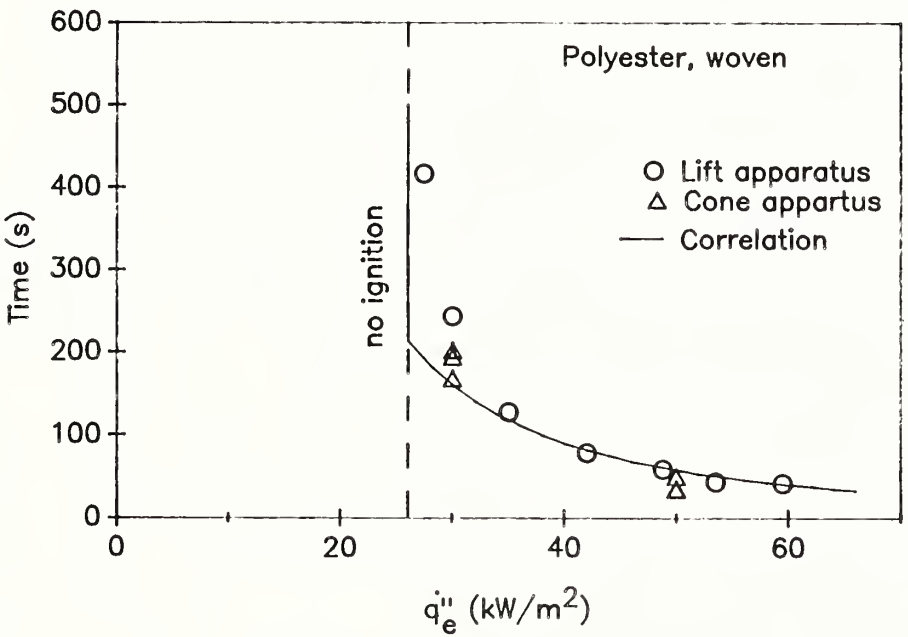


Figure A4. Ignition time vs external flux, fabric G

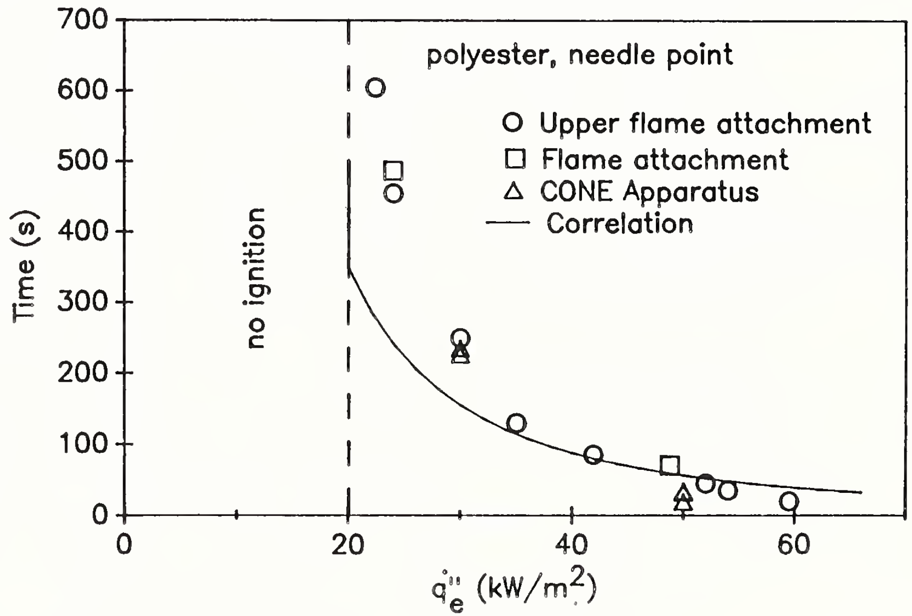


Figure A5. Ignition time vs external flux, fabric C

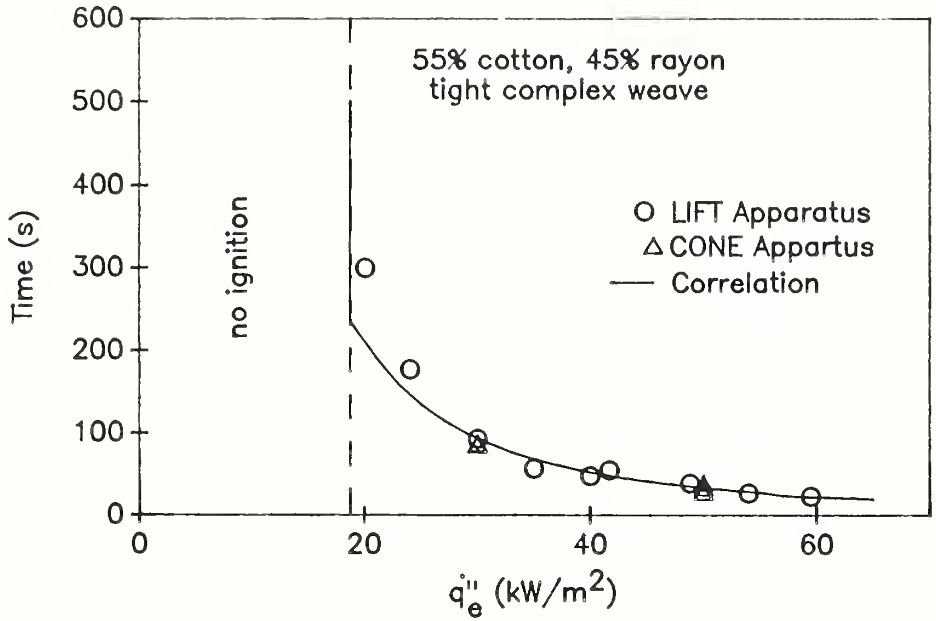


Figure A6. Ignition time vs external flux, fabric C

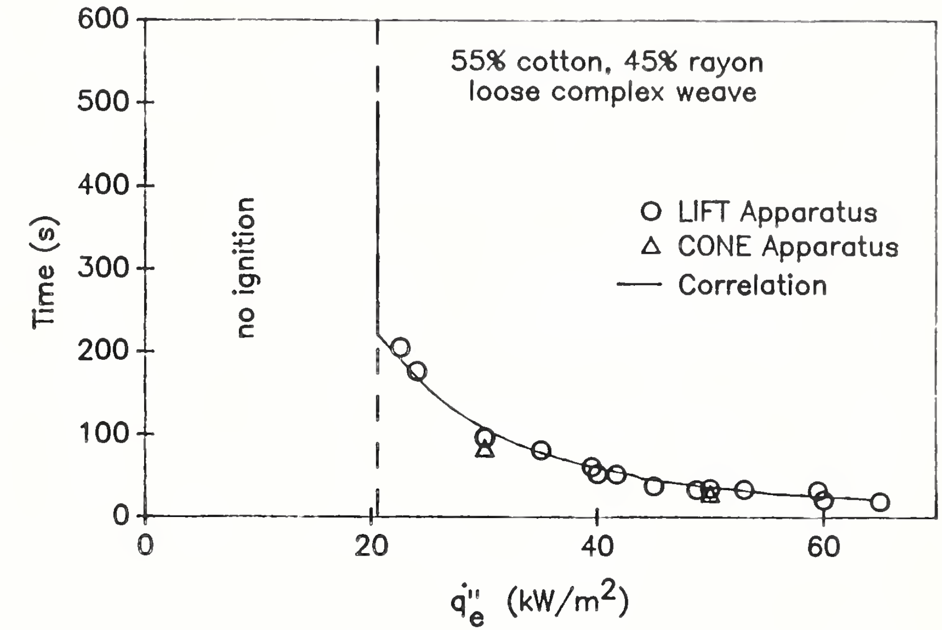


Figure A7. Ignition time vs external flux, fabric H

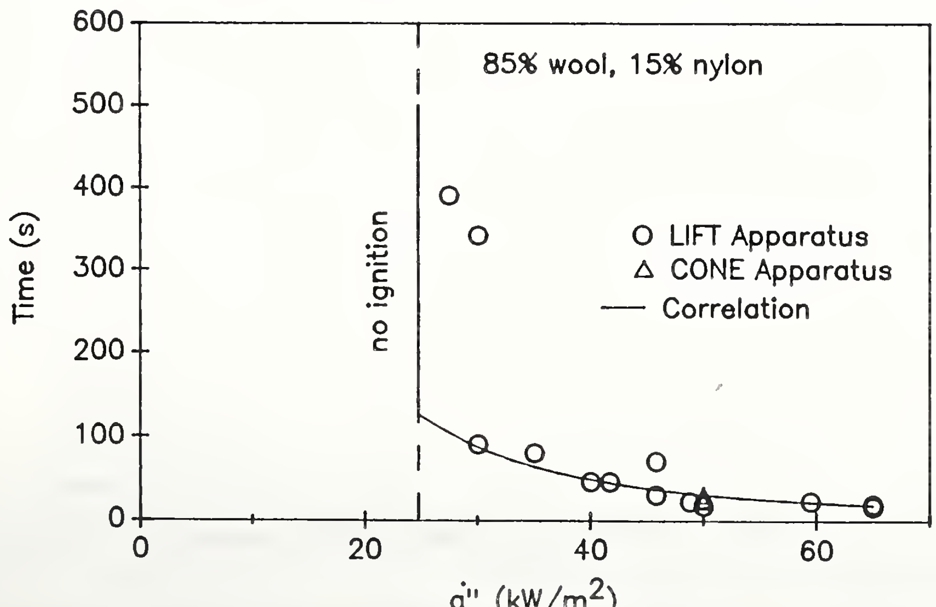


Figure A8. Ignition time vs external flux, fabric R

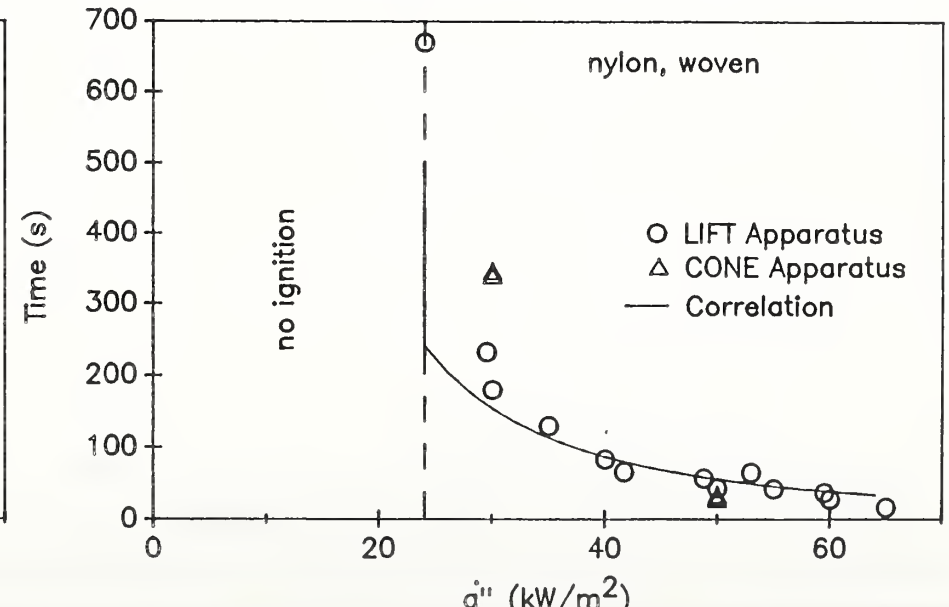


Figure A9. Ignition time vs external flux, fabric AA

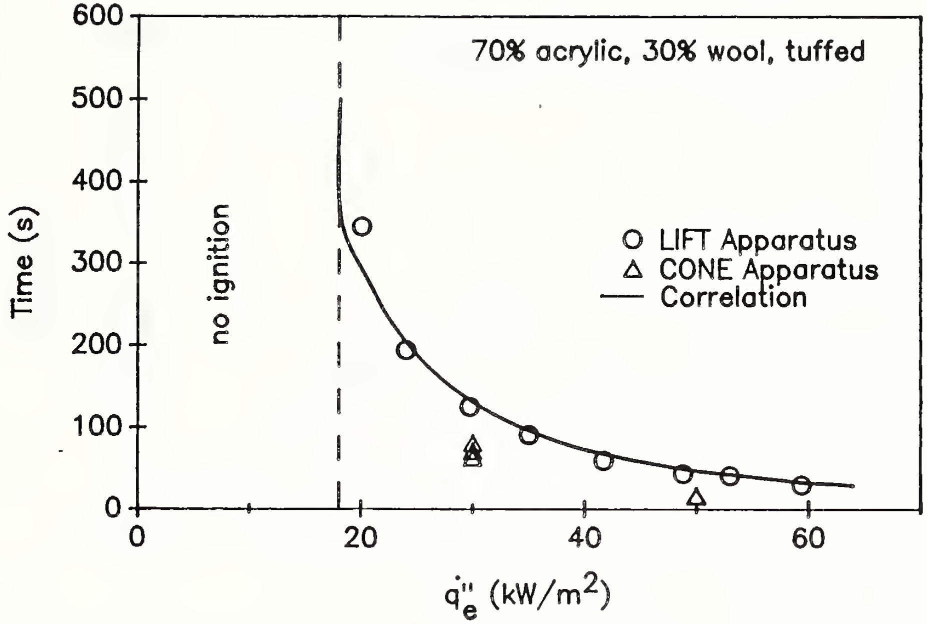
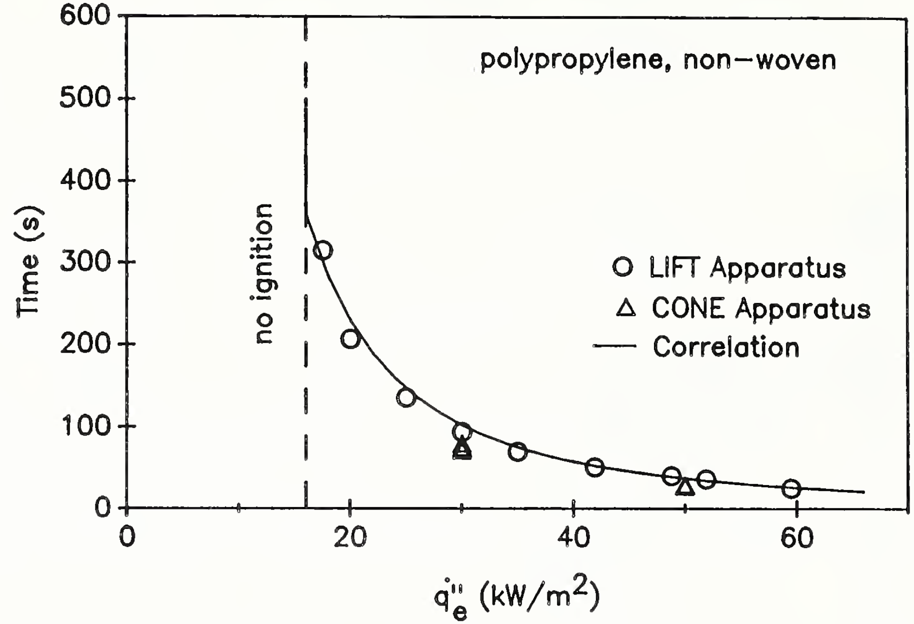


Figure A10. Ignition time vs external flux, fabric PP–PF



Appendix B. Correlation of Ignition Results

Ignition results for the ten wallcoverings correlated in terms of eq. 2. are shown in figures B1-B10. The illustrated solid line represents a least square fit that favors the data at the shorter time.

Figure B1. Ignition correlation, fabric Q

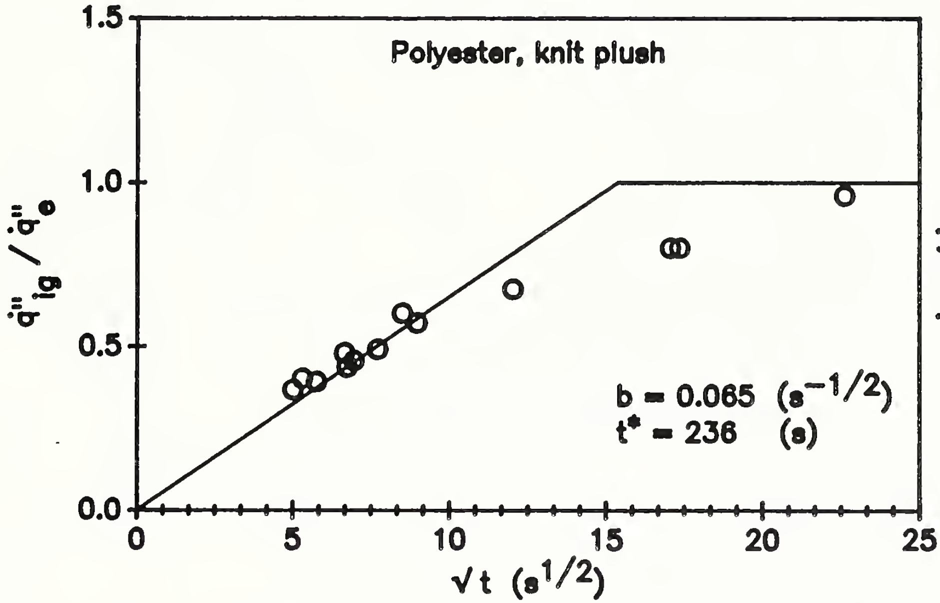


Figure B2. Ignition correlation, fabric Q_{FR}

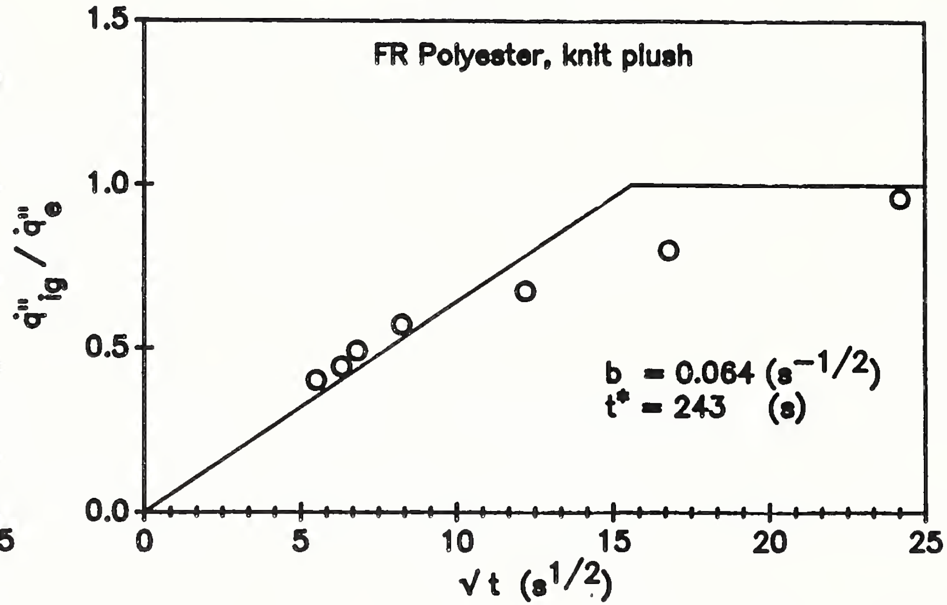


Figure B3. Ignition correlation, fabric B

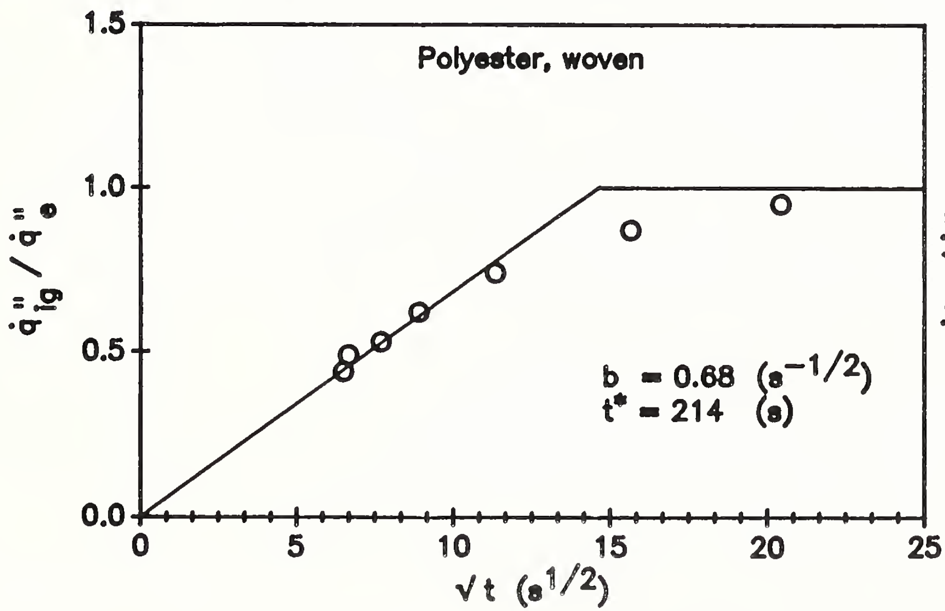


Figure B4. Ignition correlation, fabric G

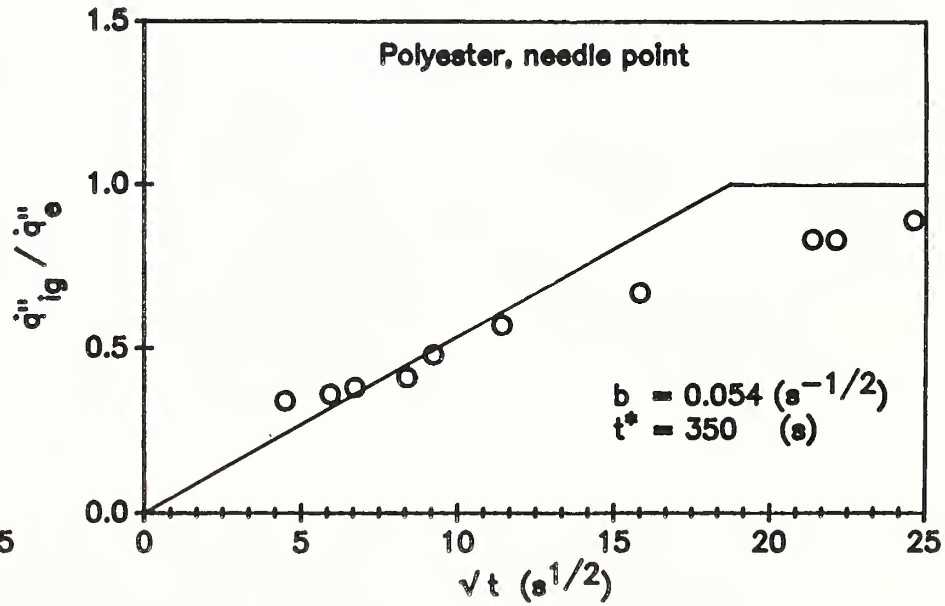


Figure B5. Ignition correlation, fabric C

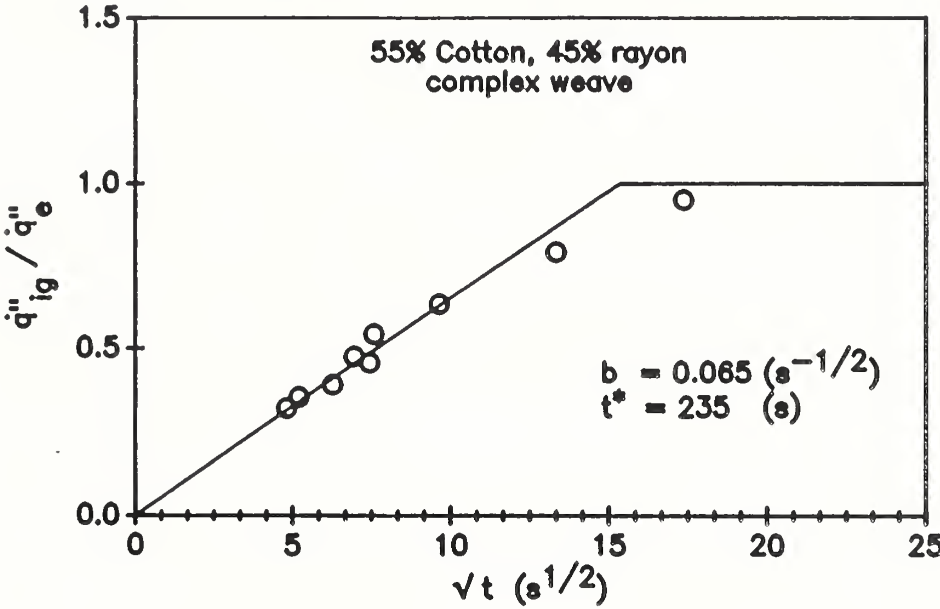


Figure B6. Ignition correlation, fabric C

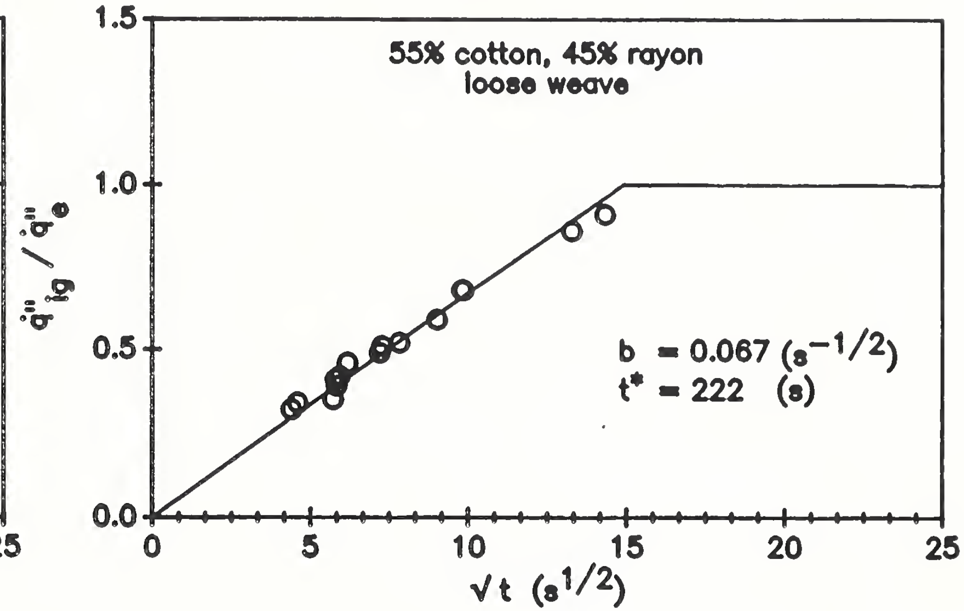


Figure B7. Ignition correlation, fabric H

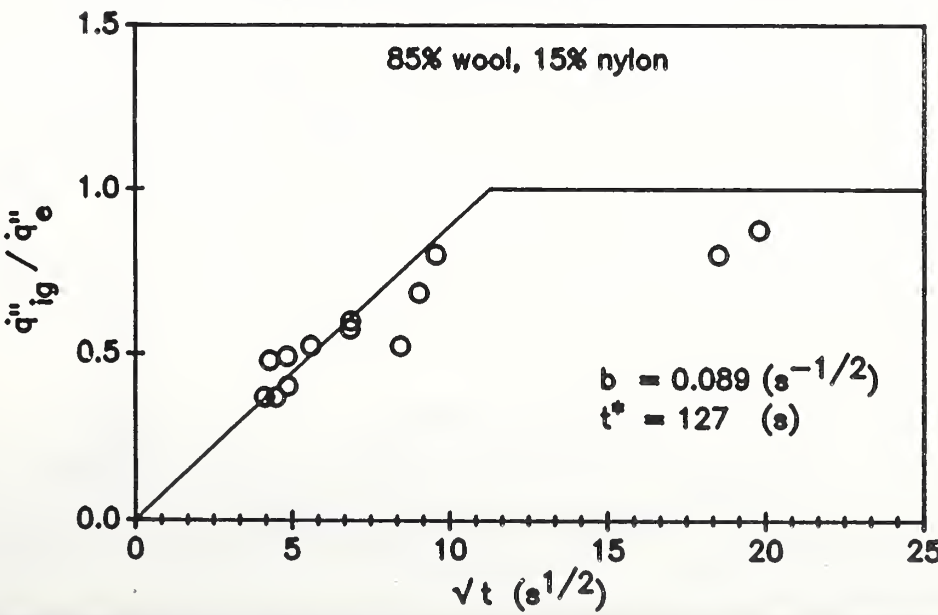


Figure B8. Ignition correlation, fabric R

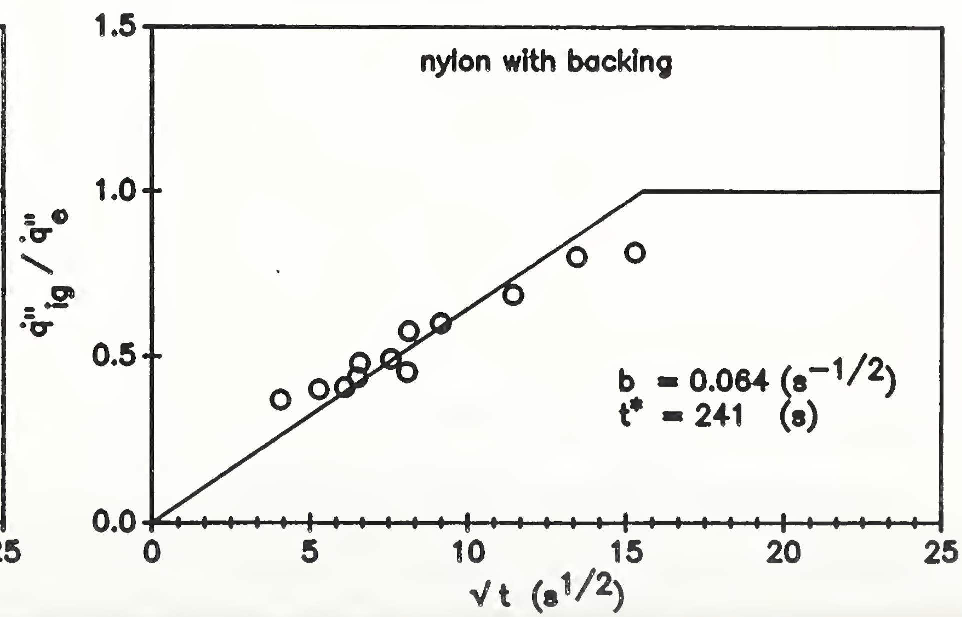


Figure B9. Ignition correlation, fabric AA

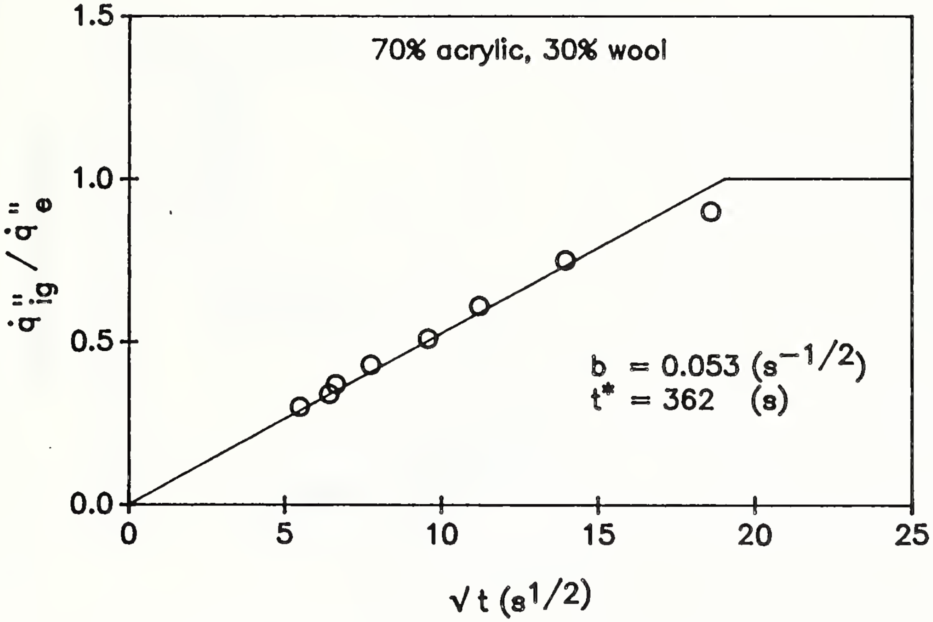
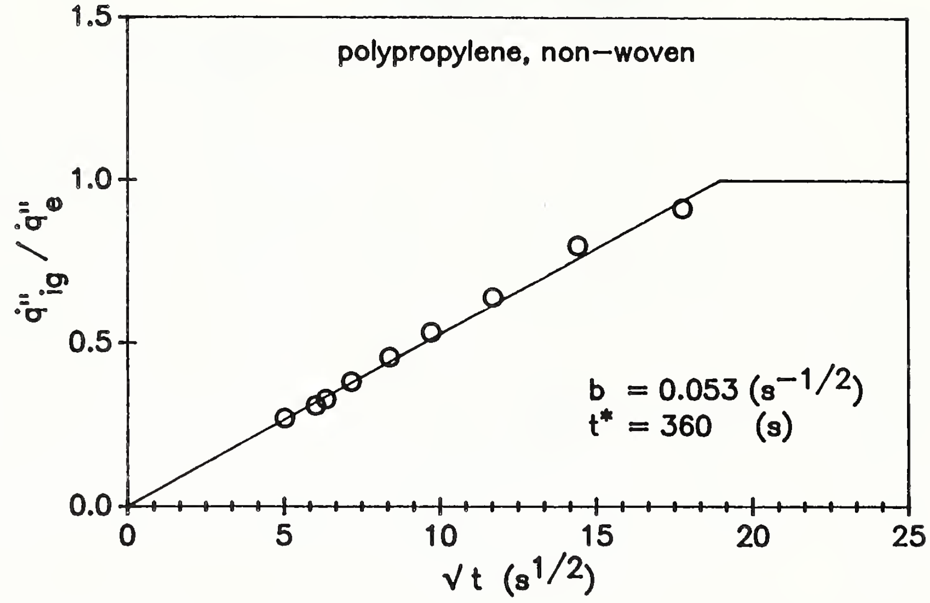


Figure B10. Ignition correlation, fabric PP–PF



Appendix C. Flame Spread Results

Flammability diagrams, which plot the velocity as a function of time, are shown in figures C1-C9. The velocities represent a running 3-point least square fit of the slope of the flame front position-time data. Fabric G did not propagate flame spread. The analytical curves represented by the solid lines are based on the derived values of the parameter C, eq. 5. The dotted lines represent the experimentally determined minimum flux for ignition.

Figure C1. Flame spread results for fabric Q
Polyester, knit plush

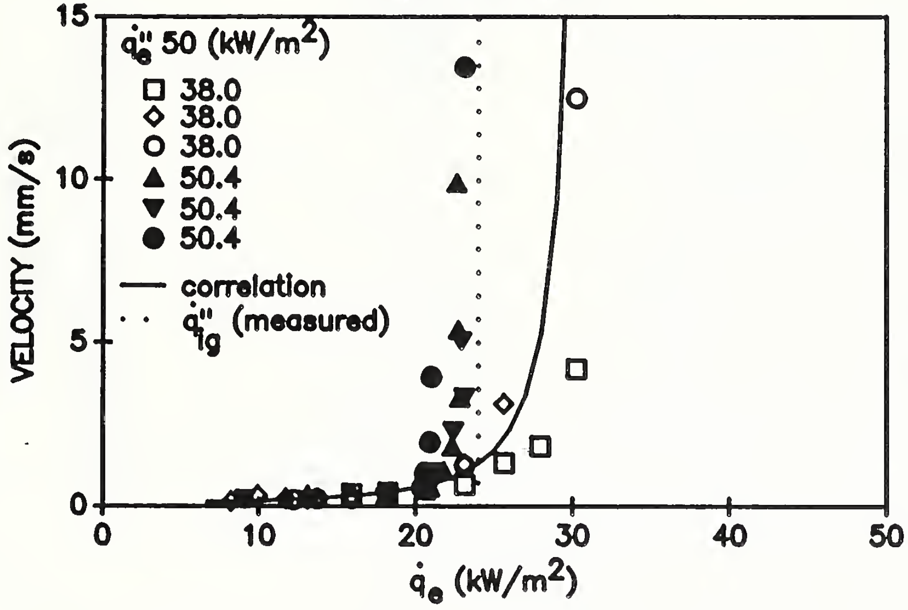


Figure C2. Flame spread results for fabric Q_{FR}
FR Polyester, knit plush

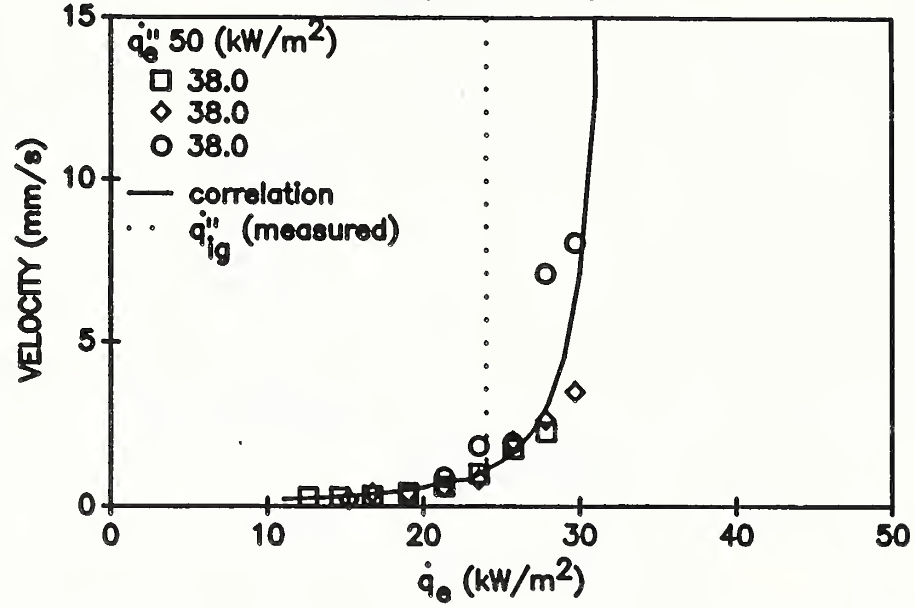


Figure C3. Flame spread results for fabric B
Polyester, woven

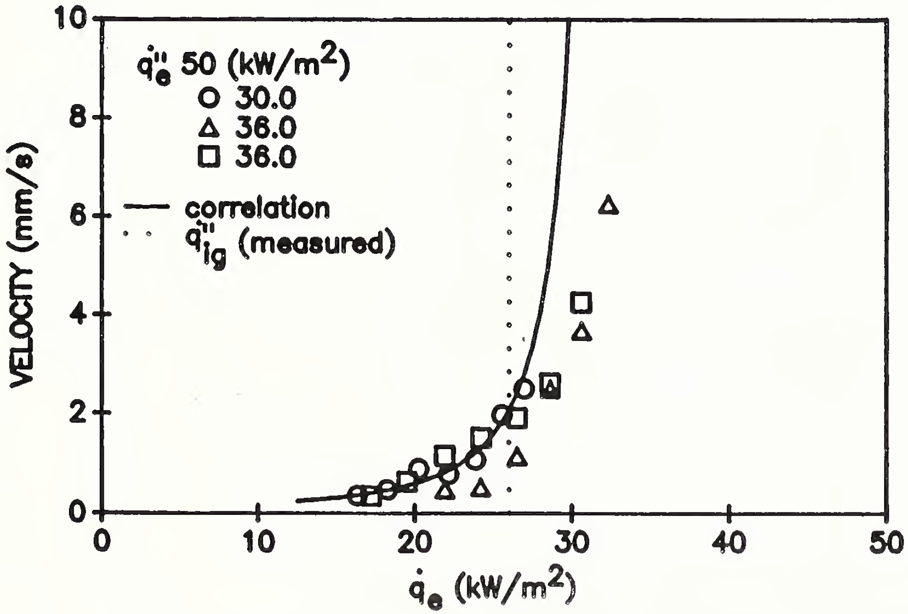


Figure C4. Flame spread results, fabric PP—PF
Polypropylene

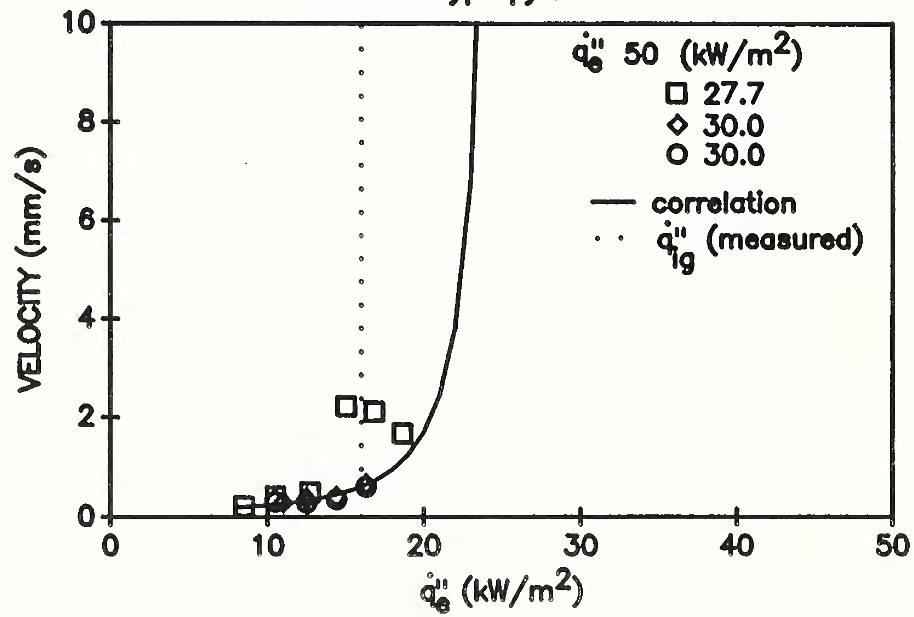


Figure C5. Flame spread results, fabric C
55% cotton, 45% rayon, complex weave

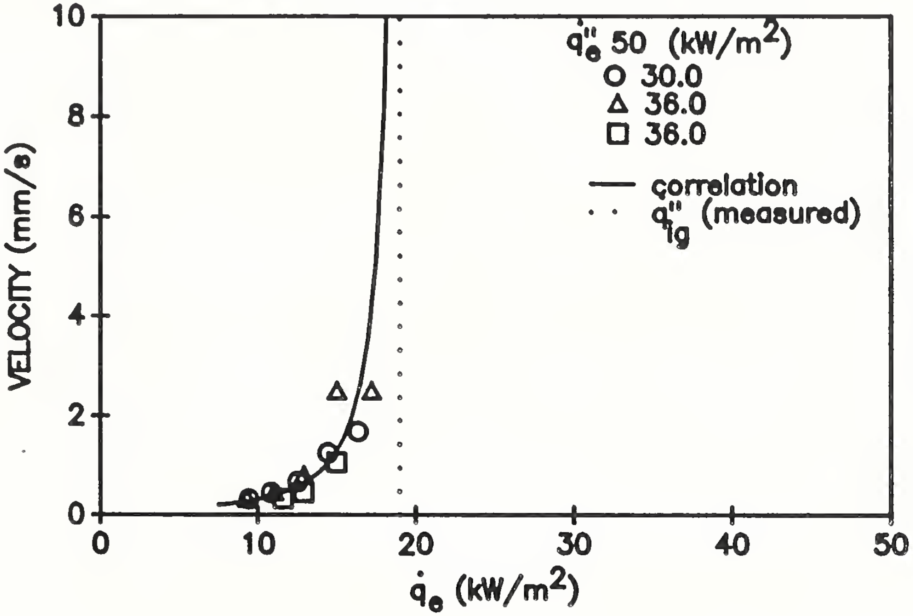


Figure C6. Flame spread results, fabric C
55% cotton, 45% rayon, loose weave

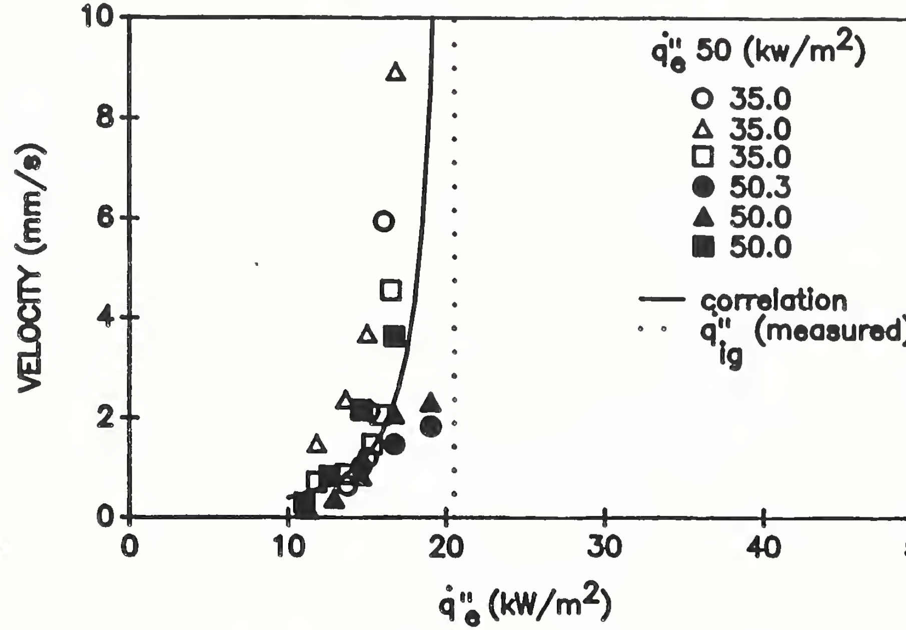


Figure C7. Flame spread results, fabric H
85% cotton, 15% wool, woven flannel

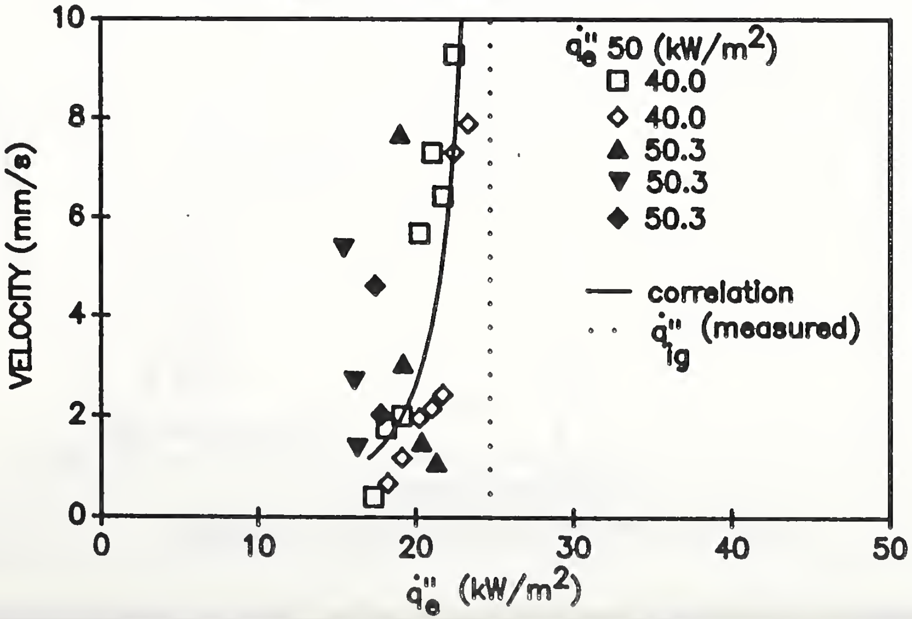


Figure C8. Flame spread results, fabric R
Nylon, with backing

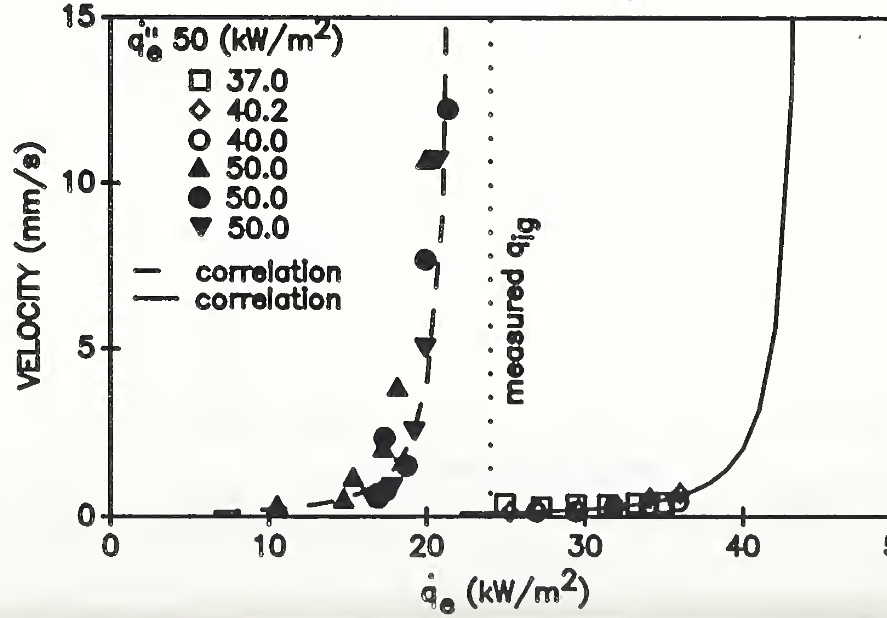
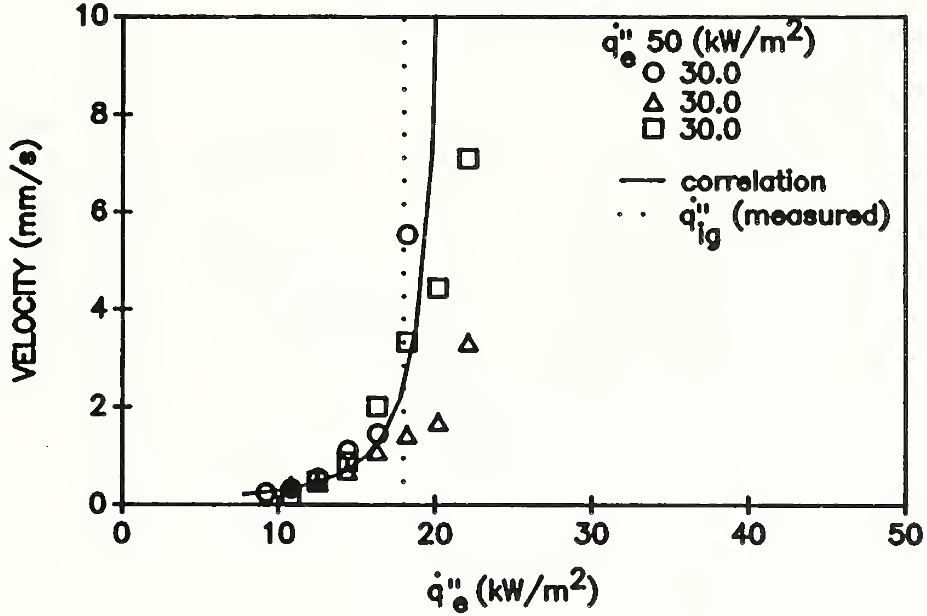


Figure C9. Flame spread results, fabric AA
70% acrylic, 30% wool



Appendix D. Correlated Flame spread Results

The computed velocities of figures C1-C9, correlated in terms of eq. 5, are plotted as $V^{-\frac{1}{2}}$ vs $\dot{q}_e''$ F(t) in figures D1-D9. The solid line, indicating the slope, represents a least square fit of the core-data set, i.e., data at the ends which represents the high and low $\dot{q}_e''$ F(t) values has been ignored. The low end is near extinction where other phenomena are suspected to influence flame spread. The high end is near ignition where velocities are high and ignition phenomena can influence this spread.

Figure D1. Correlated spread results, fabric Q
Polyester, plush

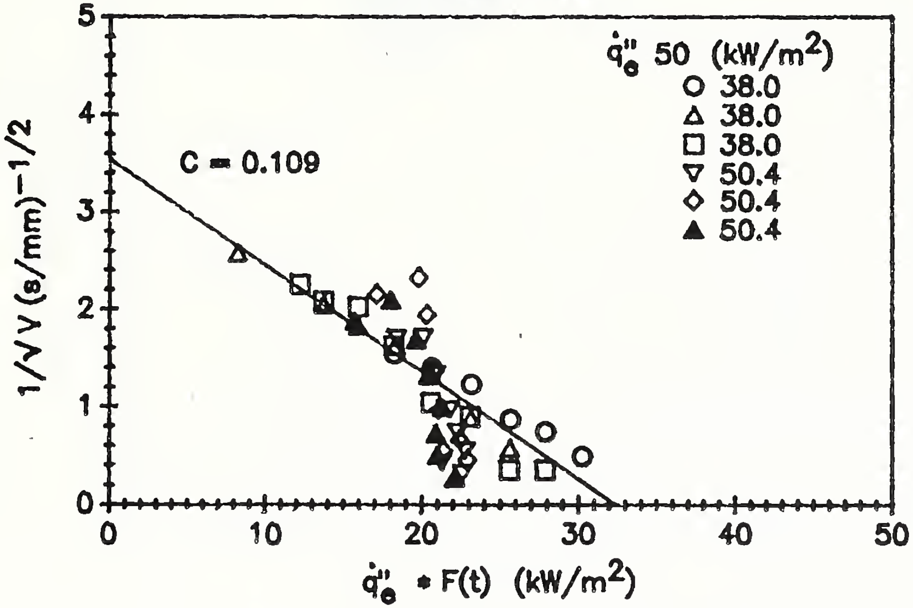


Figure D2. Correlated spread velocity, fabric Q_{FR}
Polyester, plush

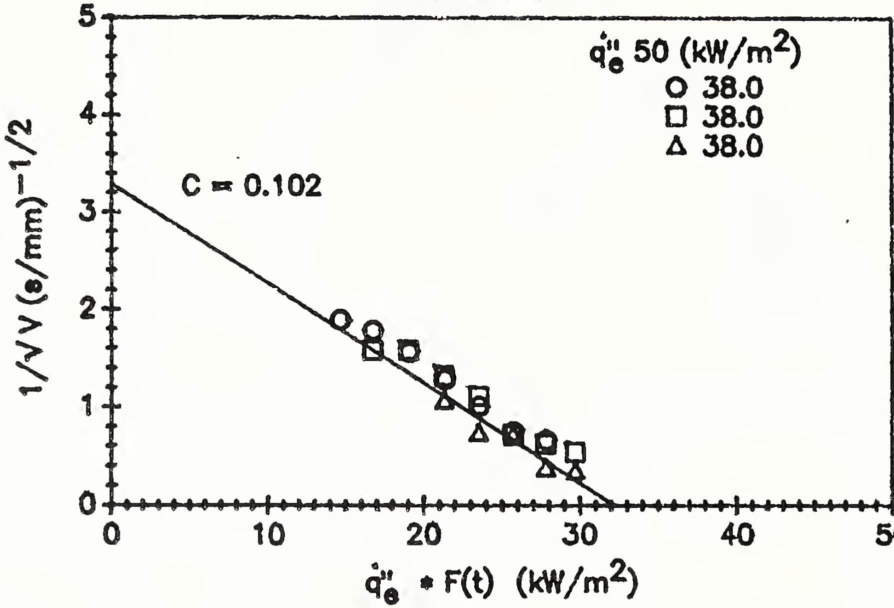


Figure D3. Correlated spread velocity, fabric B
Polyester, woven

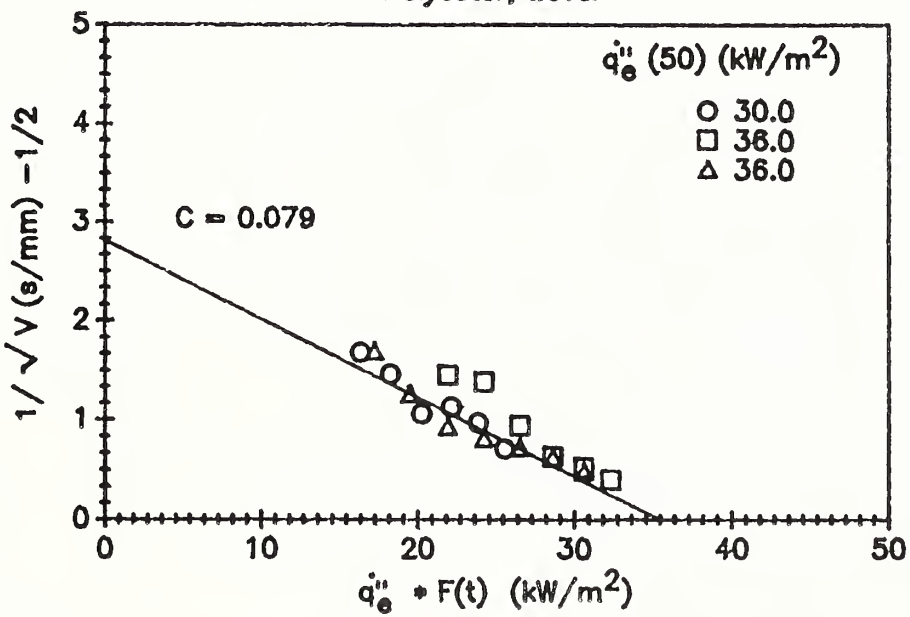


Figure D4. Correlated spread velocity, fabric PP–PF
Polypropylene

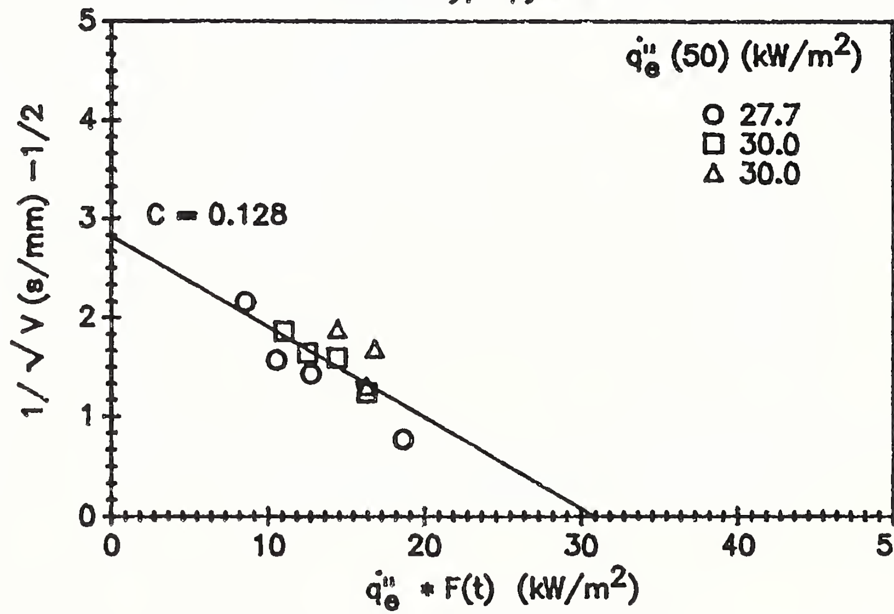


Figure D5. Correlated spread velocity, fabric C
55% cotton, 45 rayon, complex weave

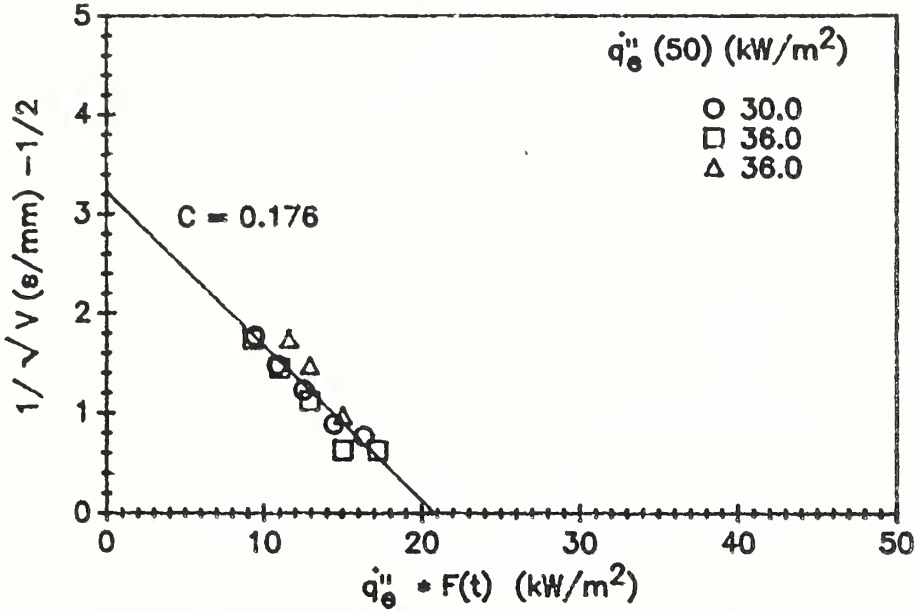


Figure D6. Correlated spread velocity, fabric C
55% cotton, 45% rayon, loose weave

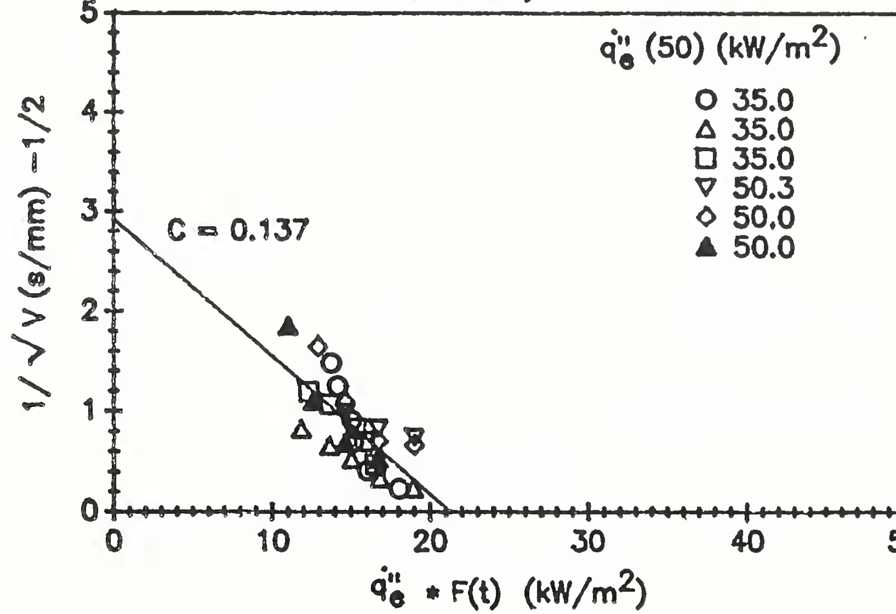


Figure D7. Correlated spread velocity, fabric H
85% wool, 15% nylon,

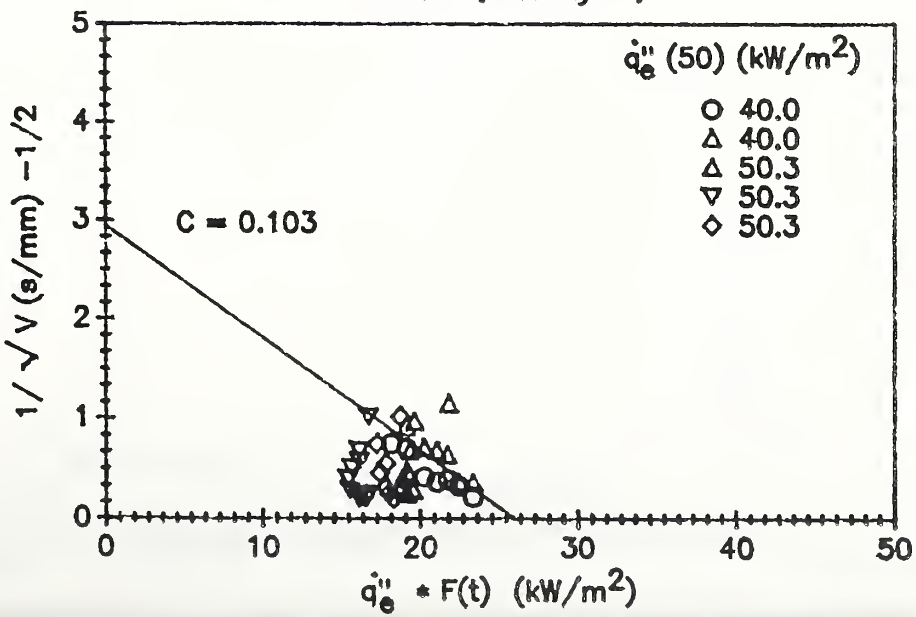


Figure D8. Correlated spread velocity, fabric R
Nylon, with backing

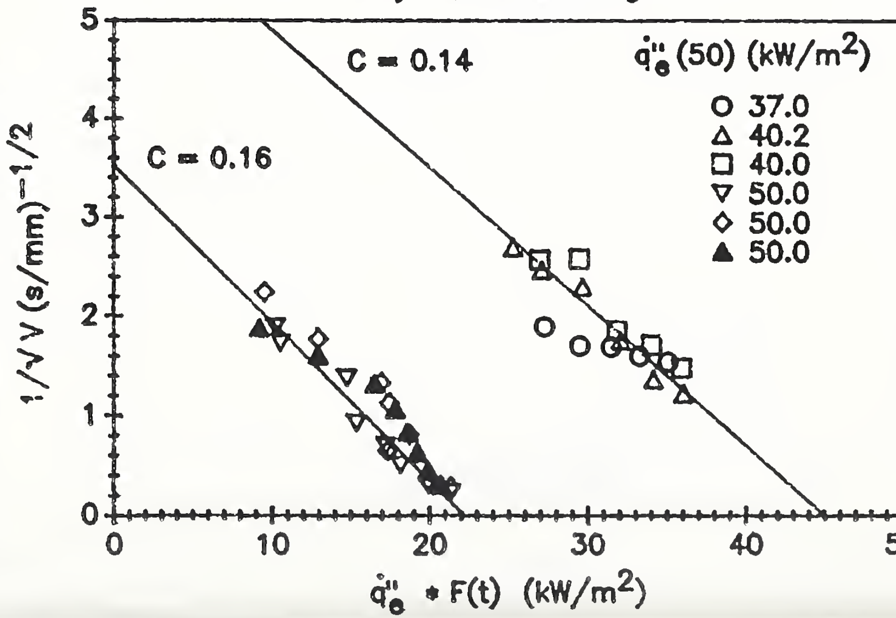
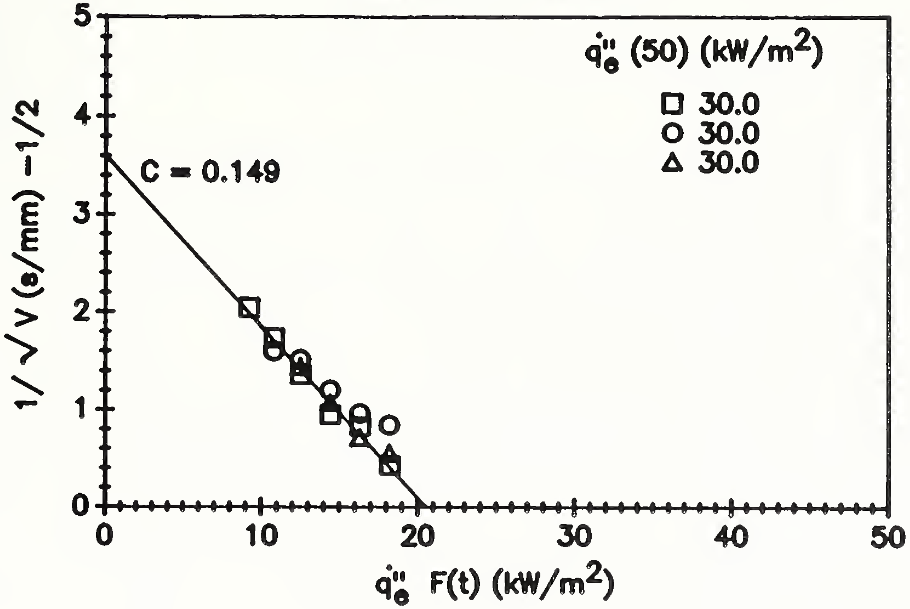


Figure D9. Correlation of spread velocity, fabric AA
70% acrylic, 30% wool



Appendix E. Rate of Heat Release Results

Rate of heat release values, based on the theories of oxygen consumption, vs time are shown in figures E1-E10. The graphs represent repeat test at 30 and 50 kW/m^2.

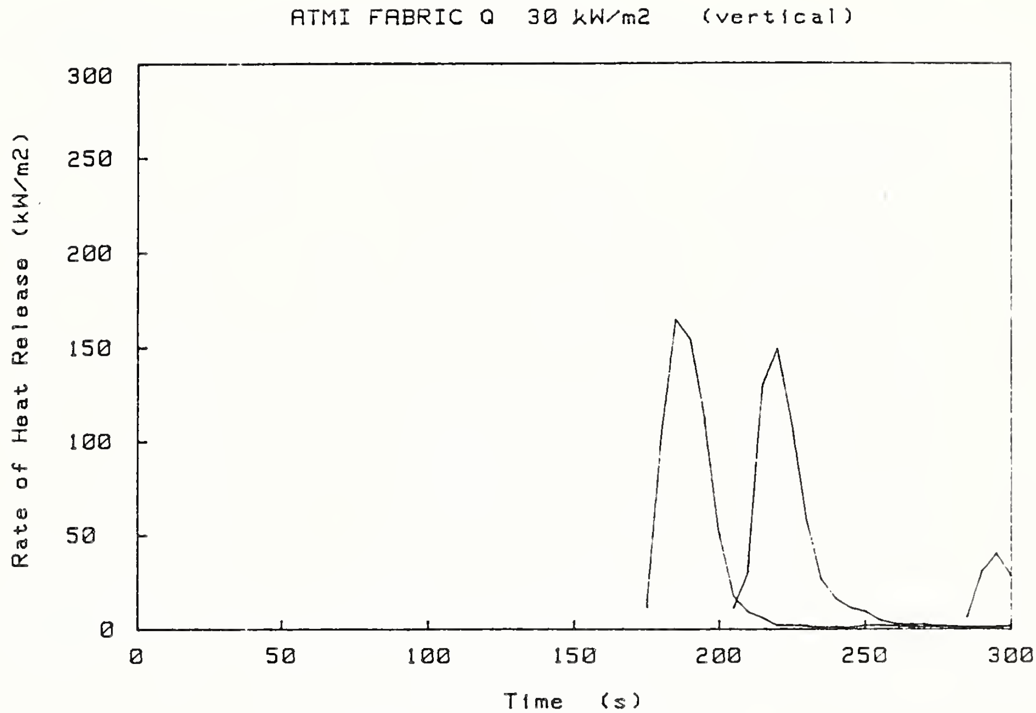


Figure E1. Fabric Q, (polyester, knit plush) rate of heat release at 30 kW/m^2 irradiance.

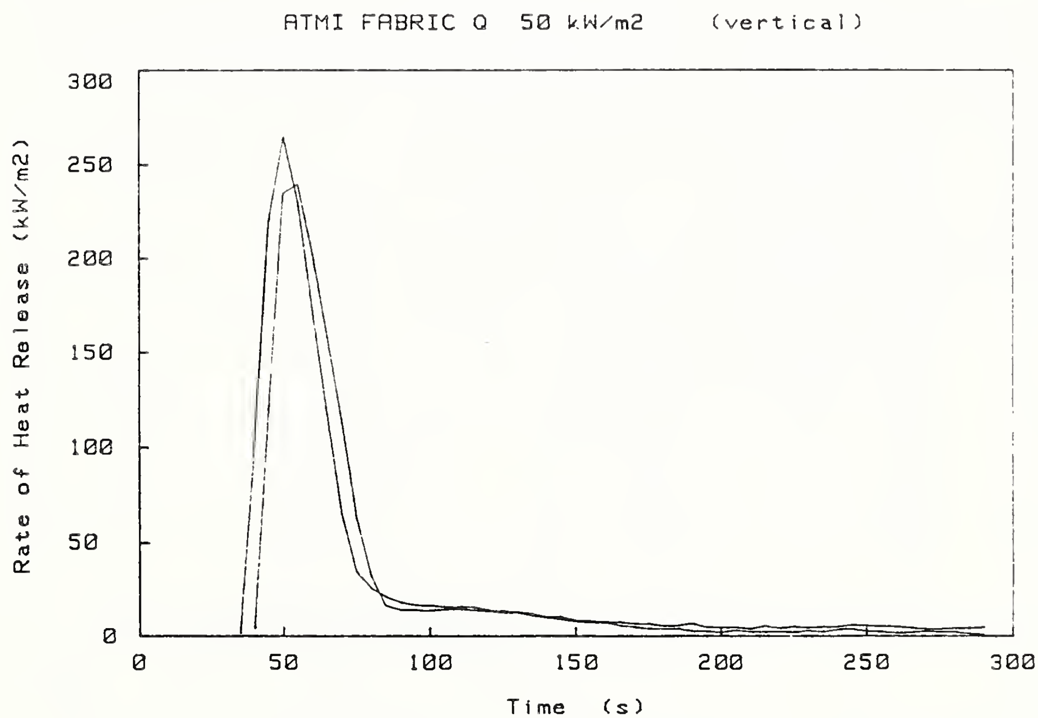


Figure E2. Fabric Q, (polyester, knit plush) rate of heat release at 50 kW/m^2 irradiance.

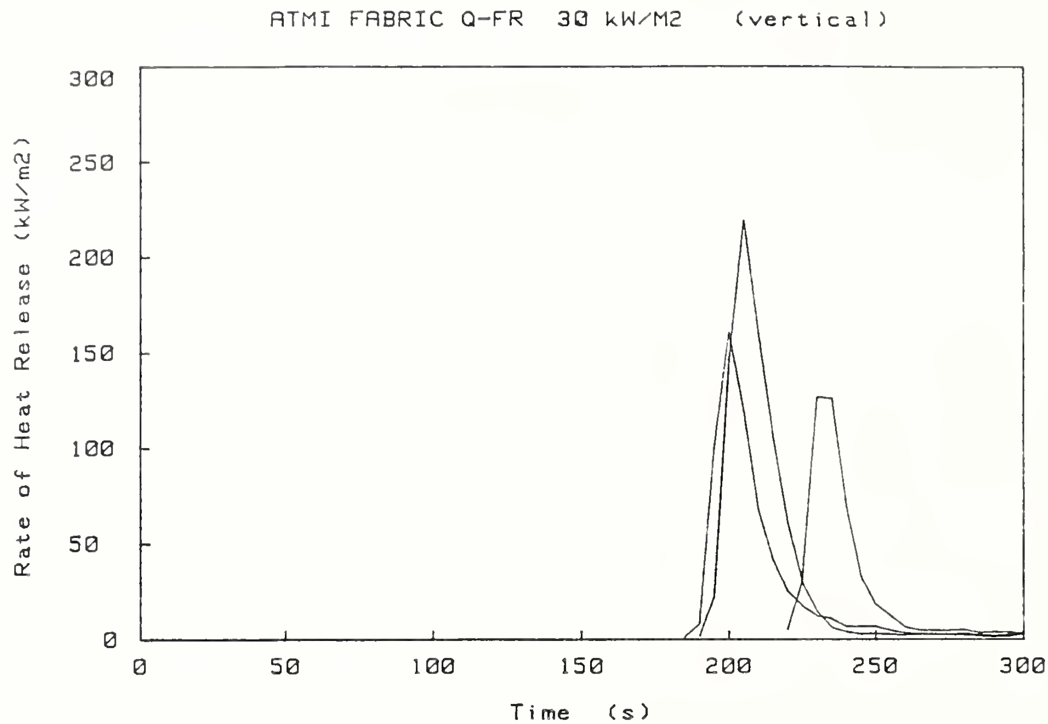


Figure E3. Fabric Q_{FR}, (FR polyester, knit plush) rate of heat release at 30 kW/m^2 irradinace.

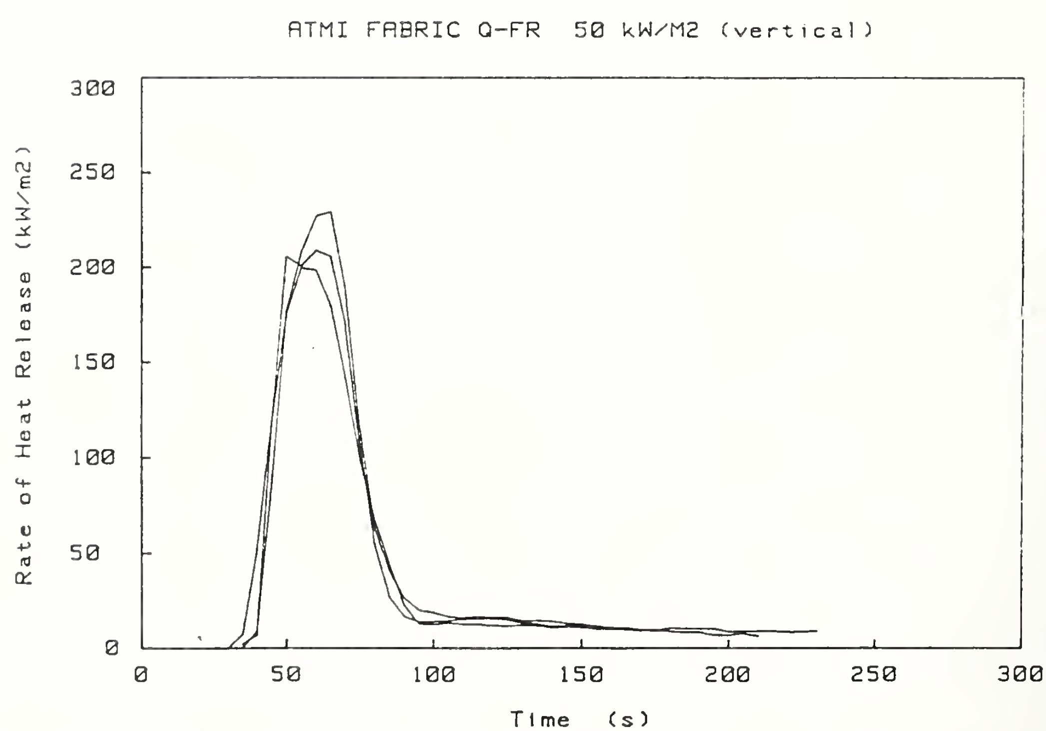


Figure E4. Fabric Q_{FR}, (FR polyester, knit plush) rate of heat release at 50 kW/m^2 irradinace.

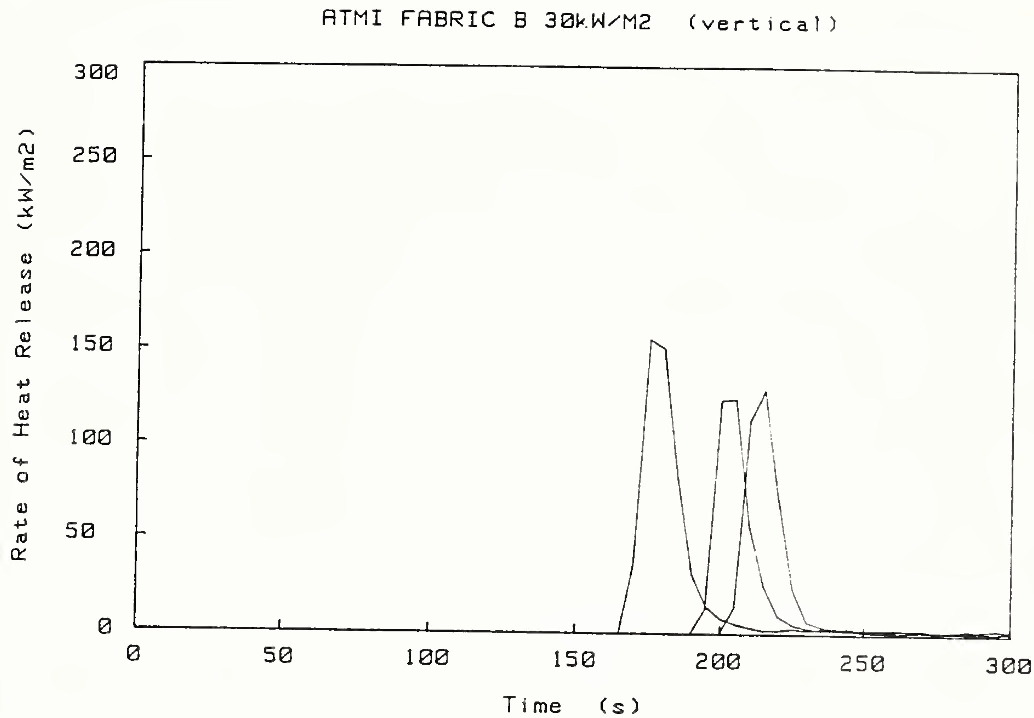


Figure E5. Fabric B, (polyester, woven) rate of heat release at 30 kW/m^2 irradiance.

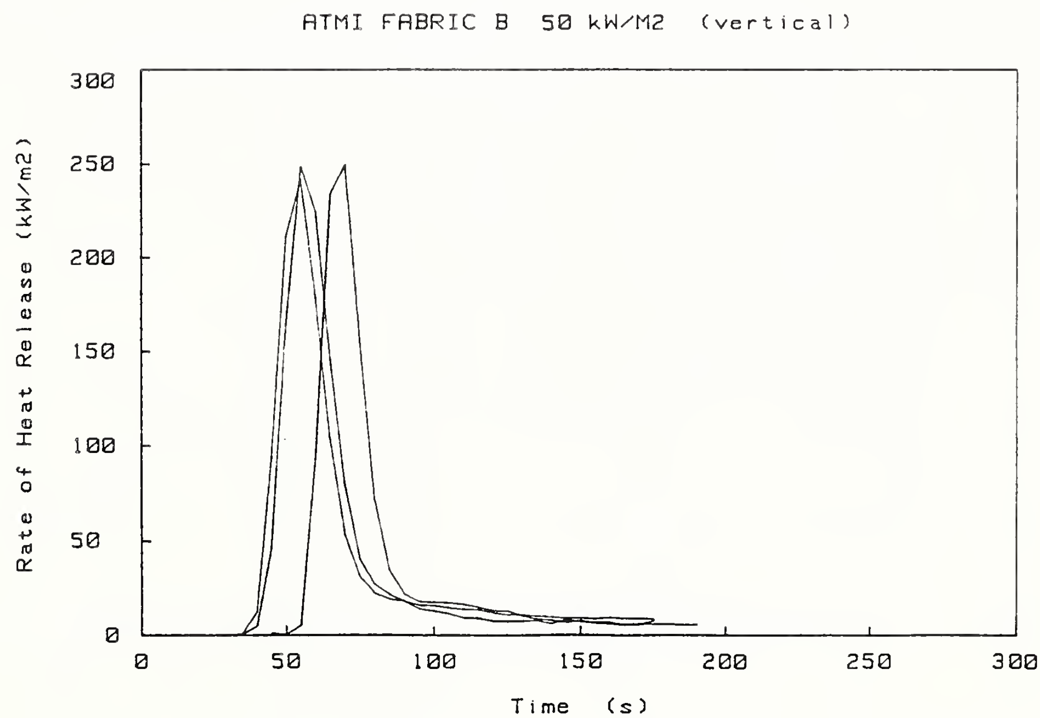


Figure E6. Fabric B, (polyester, woven) rate of heat release at 50 kW/m^2 irradiance.

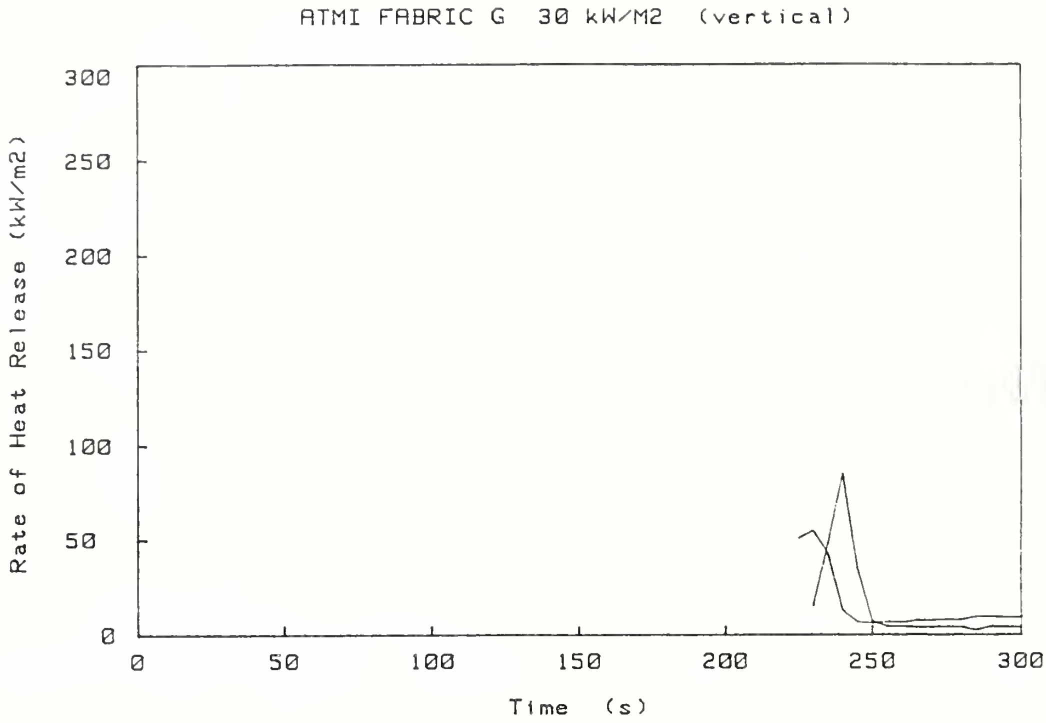


Figure E7. Fabric G, (polyester, needle point) rate of heat release at 30 kW/m^2 irradiance.

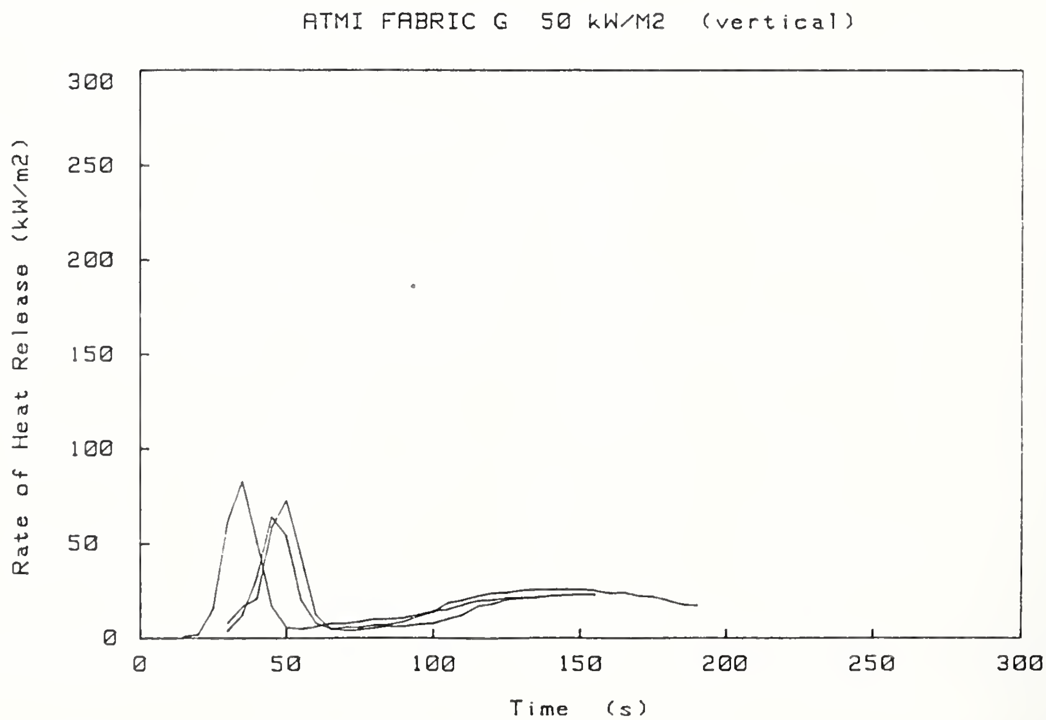


Figure E8. Fabric G, (polyester, needle point) rate of heat release at 50 kW/m^2 irradiance.

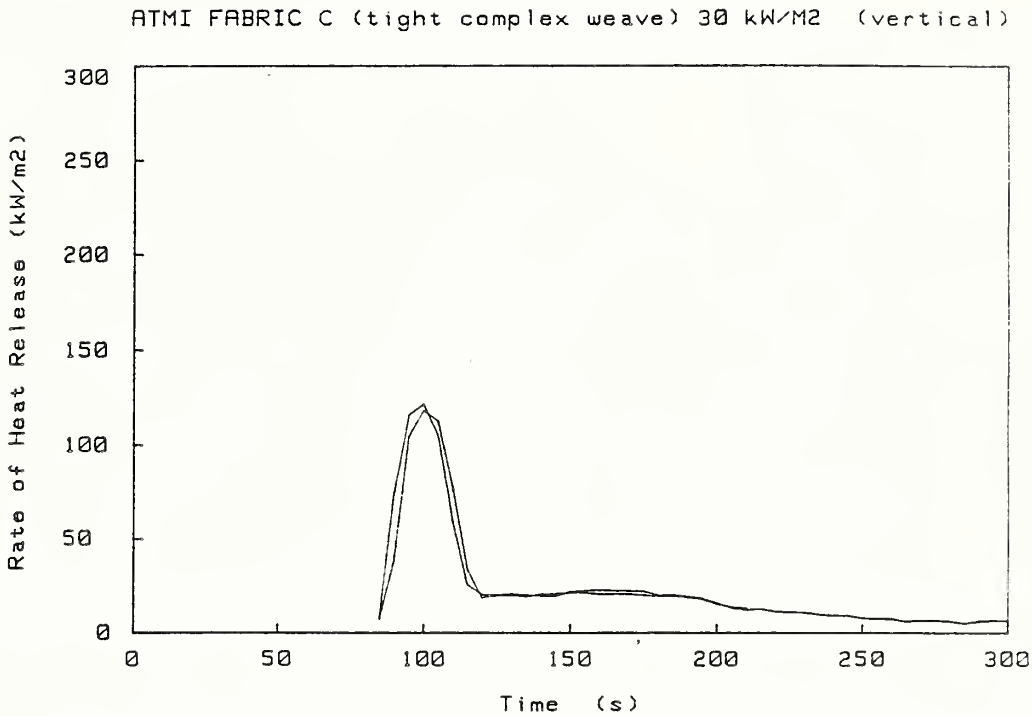


Figure E9. Fabric C, (55% cotton, 45% rayon, complex weave) rate of heat release at 30 kW/m^2 irradiance.

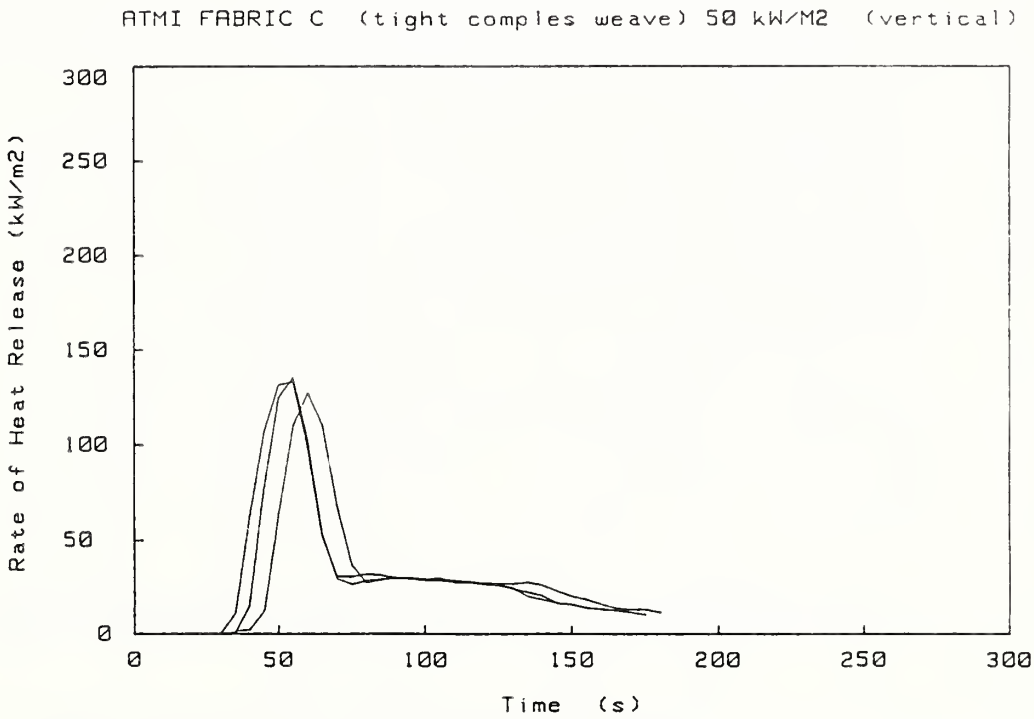


Figure E10. Fabric C, (55% cotton, 45% rayon, complex weave) rate of heat release at 50 kW/m^2 irradiance.

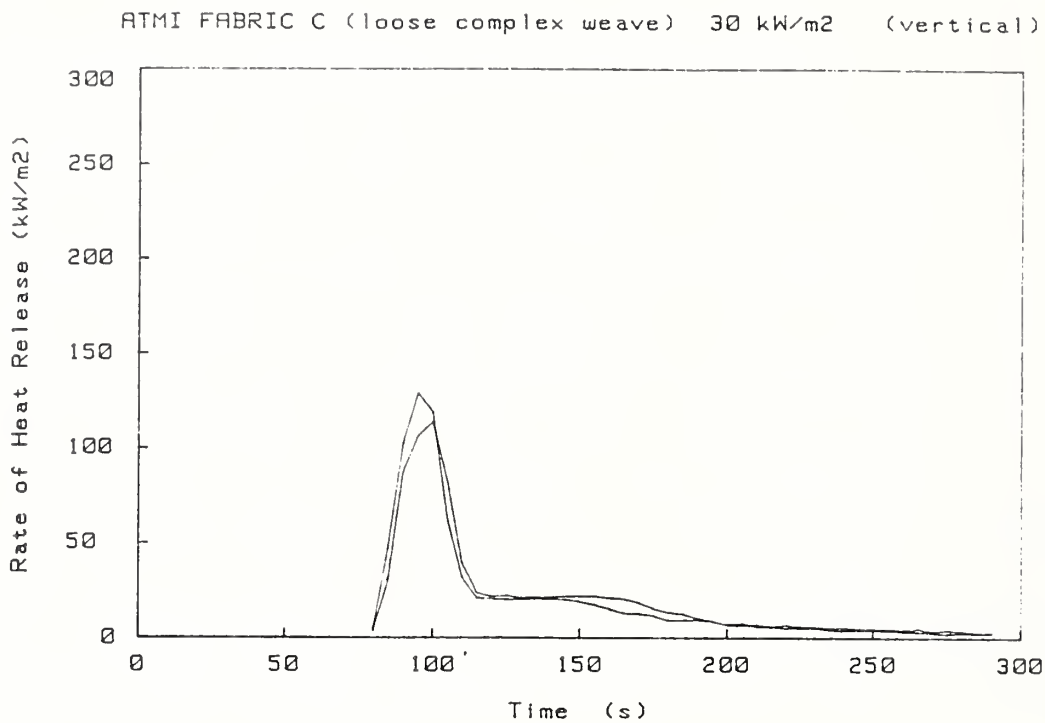


Figure E11. Fabric C, (55% cotton, 45% rayon, loose weave) rate of heat release at 30 kW/m^2 irradiance.

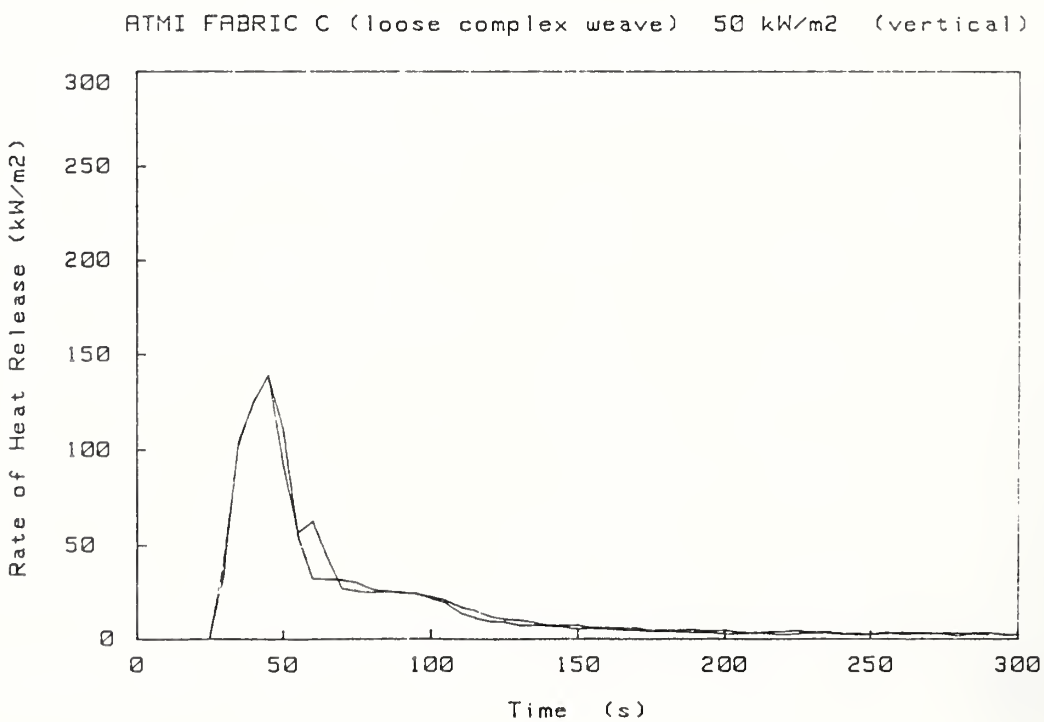


Figure E12. Fabric C, (55% cotton, 45% rayon, loose weave) rate of heat release at 50 kW/m^2 irradiance.

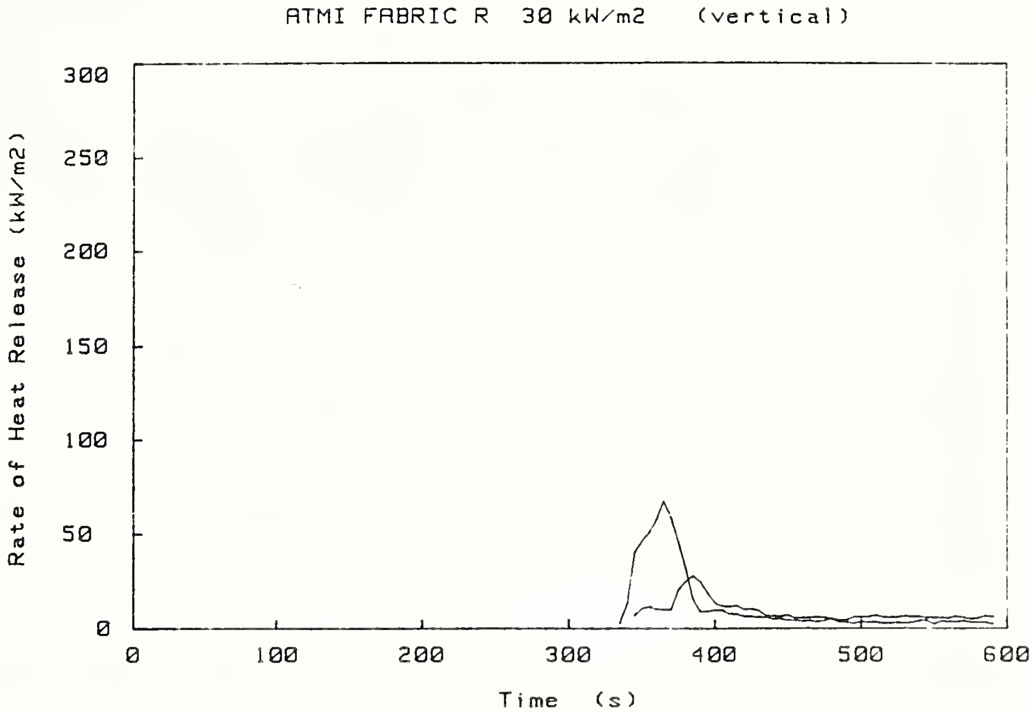


Figure E13. Fabric H, (85% wool, 15% nylon) rate of heat release at 30 kW/m^2 irradiance.

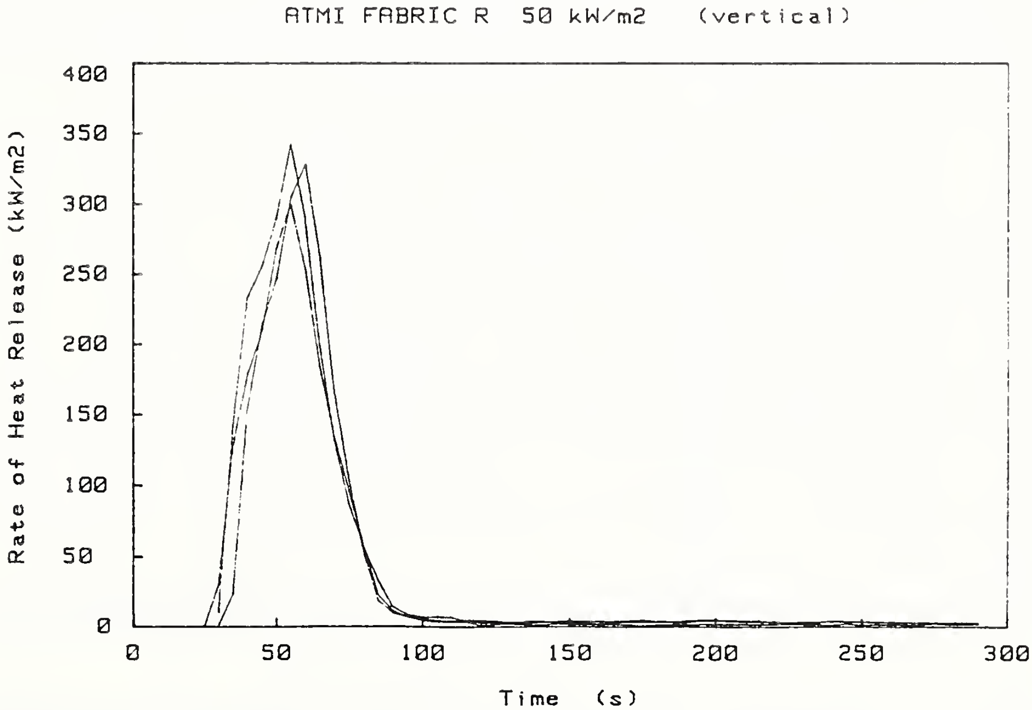


Figure E14. Fabric R, (nylon, with backing) rate of heat release at 50 kW/m^2 irradiance.

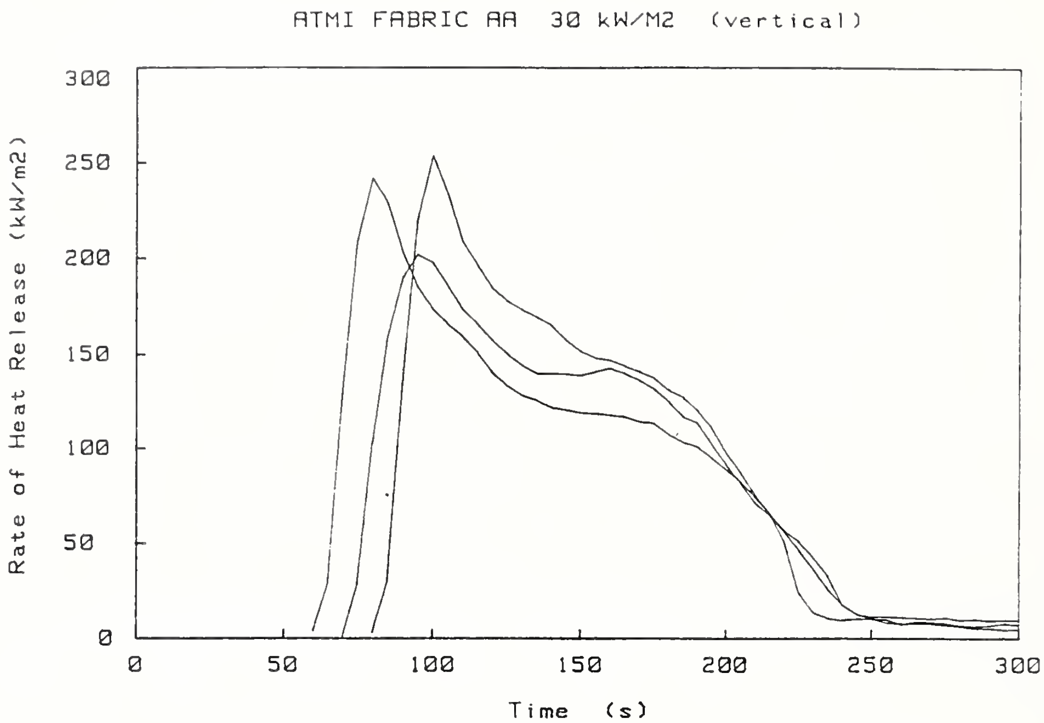


Figure E15. Fabric R (nylon, with backing) rate of heat release at 30 kW/m^2 irradiance.

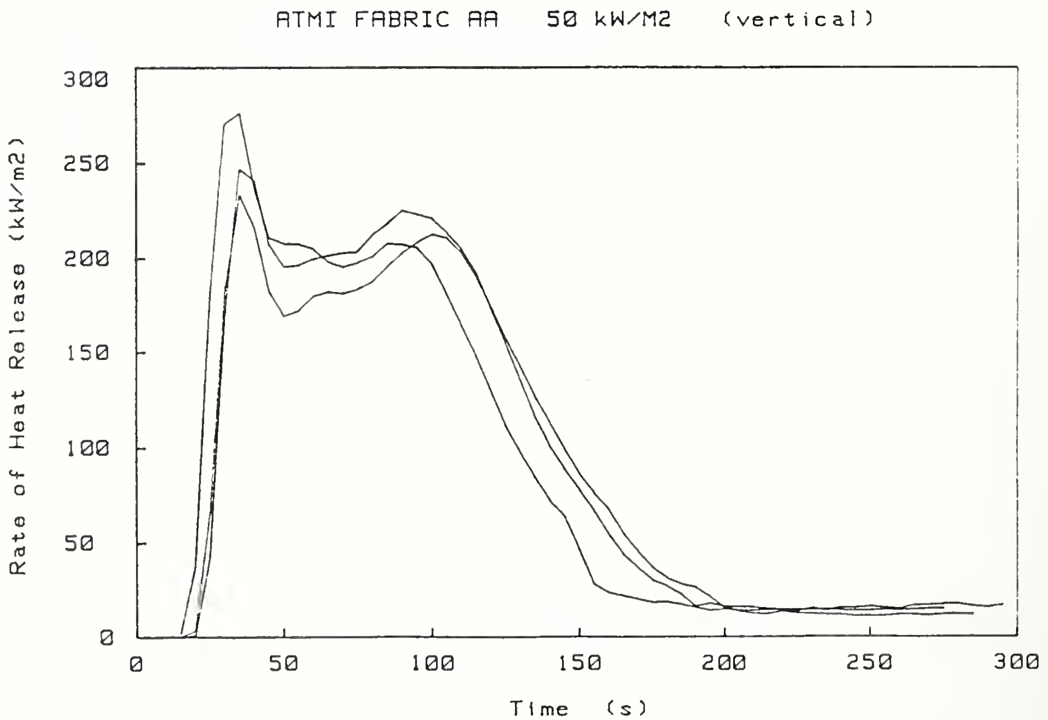


Figure E16 Fabric AA, (70% acrylic, 30% wool, tuffed) rate of heat release at 50 kW/m^2 irradiance.

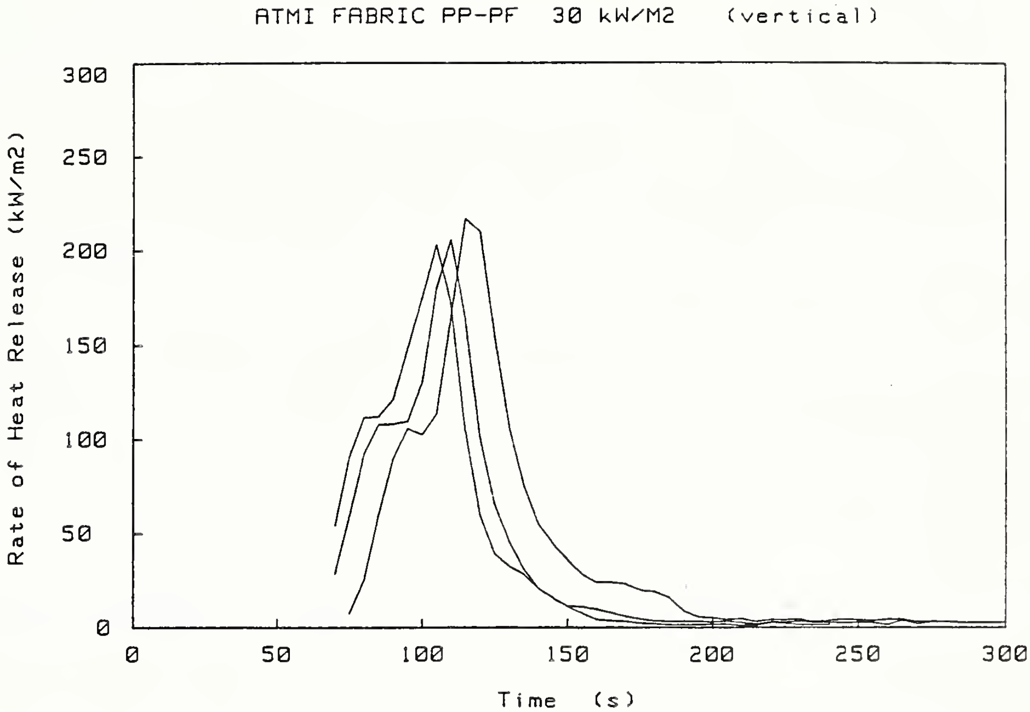


Figure E17. Fabric AA, (70% acrylic, 30% wool, tuffed) rate of heat release at 30 kW/m^2 irradiance.

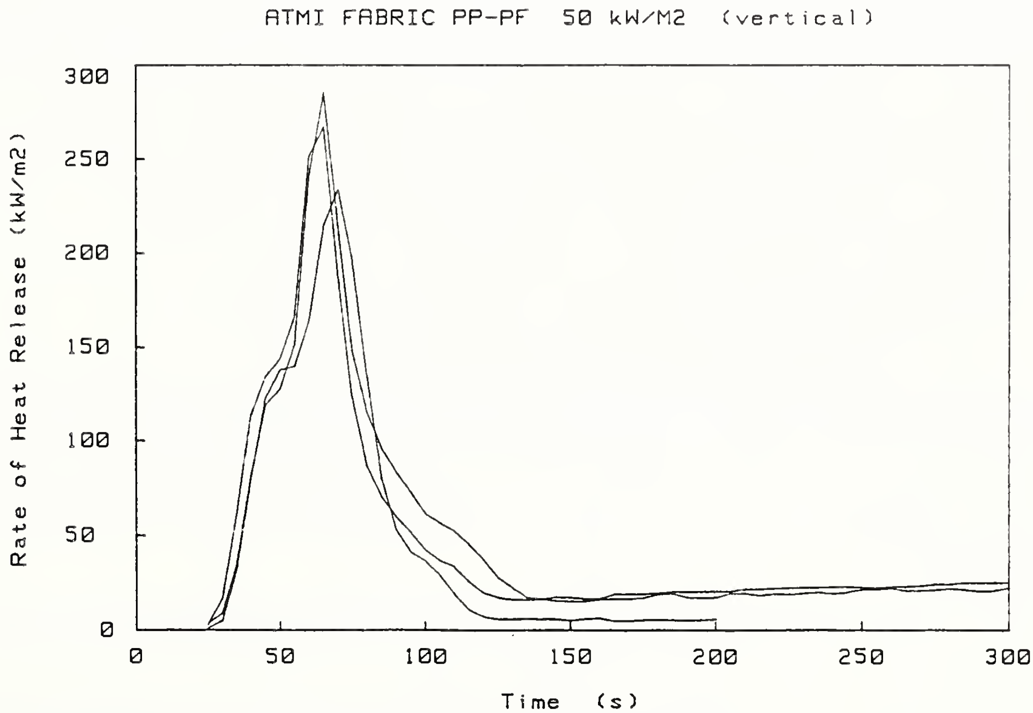


Figure E18. Fabric PP-PF, (polypropylene) rate of heat release at 50 kW/m^2 irradiance.

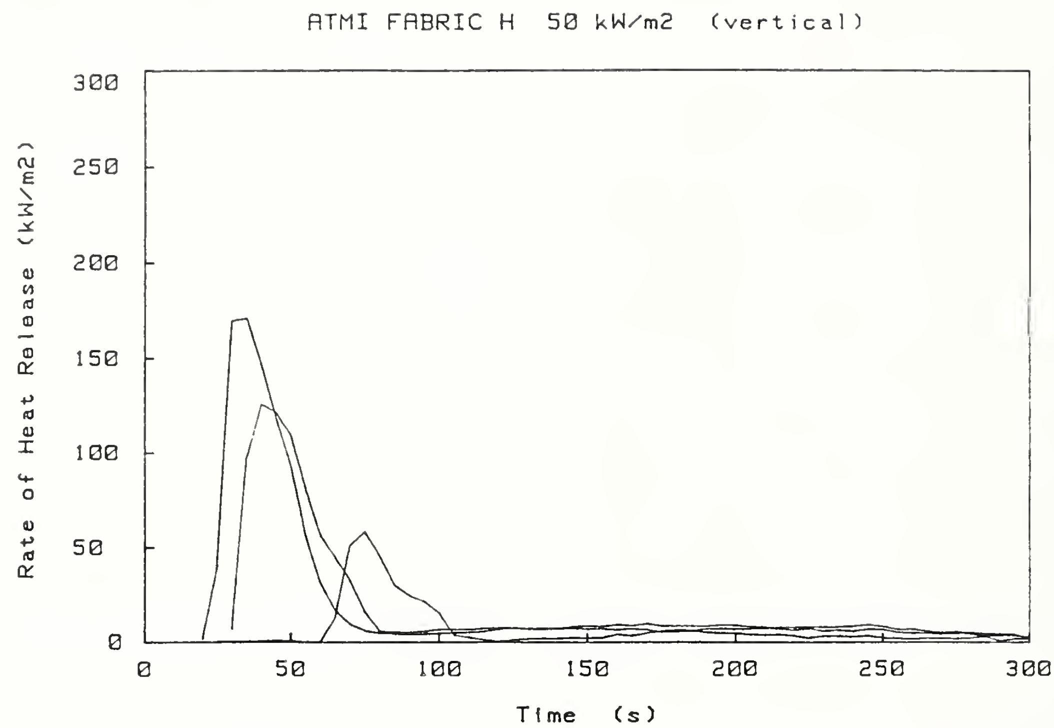


Figure E19. Fabric PP-PF, (polypropylene) rate of heat release at 50 kW/m^2 irradiance.

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10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

A technical basis for linking small scale fire property test data to realistic performance has been initiated by the establishment of a small scale fire property database for some textile wall covering materials. The properties are obtained from experimental small-scale tests of materials in a vertical orientation. They include ignition and flame spread properties based on measurements from the Lateral Ignition and Flame spread Test (LIFT) apparatus and energy release rate measurements from the Cone Calorimeter. The database includes fire properties for woven, knit and needle punched polyesters, woven cotton/rayon and wool/nylon blends, nylon and polypropylene wall covering materials.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

ignition; flame spread; heat release rate; textile wall coverings; material properties; thermoplastics; char formation

13. AVAILABILITY

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