NBSIR 78-1448

Full-Scale Burning Behavior of Curtains and Draperies

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Center for Fire Research
Institute for Applied Technology
National Bureau of Standards
Washington, D.C. 20234

March 1978

Final Report

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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CONTENTS

Page

LIST OF FIGURES iv

LIST OF TABLES. v

ABSTRACT. 1

1. INTRODUCTION. 1

2. SCOPE OF EXPERIMENTS. 2

3. TEST OF INSTRUMENTATION AND CONDITIONS. 2

4. RESULTS AND DISCUSSION. 3

4.1. Burning Rate. 4
4.2. Burning Time. 4
4.3. Ignition of Wall and Ceiling Panels 4
4.4. Air Temperatures in Room and Doorway. 6
4.5. Total Heat Flux and Radiant Flux. 7
4.6. Smoke Generation. 7
4.7. Gas Analysis. 8
4.8. Draperies as Flashover Promoters. 8
4.9. Test Results. 9

5. CONCLUSIONS 10

5.1. Ignition of Wall and Ceiling Materials. 10
5.2. Smoke Generation. 10
5.3. Gas Analysis. 10
5.4. Drapery Ignition - Open Versus Closed 11

6. ACKNOWLEDGMENTS 11

7. REFERENCES. 11

LIST OF FIGURES

		Page
Figure 1.	C/D Hazard Analysis	29
Figure 2.	Instrumentation of Wall behind Drape.	29
Figure 3.	Exp. S16 (100% Cotton Print 3.64 oz/yd^2) - 16 Seconds after Ignition.	30
Figure 4.	Exp. S16 - 23 Seconds	30
Figure 5.	Exp. S16 - 27 Seconds	31
Figure 6.	Exp. S16 - 44 Seconds	31
Figure 7.	Exp. S16 - 76 Seconds	32
Figure 8.	Exp. S16 - 89 Seconds	32
Figure 9.	Exp. S16 100% Cotton 3.64 oz/yd^2 (Light) Closed Position.	33
Figure 10.	Ceiling Tile and Wall Paneling Layout for Verification Experiments No. 21, 22, 23 & 24	33
Figure 11.	Center of Room Temperatures versus Time - Exp. S17 9.65 oz/yd^2 50% Cotton/50% Polyester	34
Figure 12.	Heat Flux versus Time - Exp. S17.	34
Figure 13.	Radiant Flux versus Time - Exp. S17	35
Figure 14.	Exp. S17 - 78 Seconds	35
Figure 15.	Exp. S17 - 103 Seconds.	36
Figure 16.	Exp. S17 - 116 Seconds.	36
Figure 17.	Drapery Consumption and Smoke Generation - Exp. S17 50% Cotton/50% Polyester.	37
Figure 18.	CO at Top of Door (ppm) versus Time - Exp. S17.	37
Figure 19.	CO_2 at Top of Door versus Time - Exp. S17	38

LIST OF TABLES

		Page
Table 1.	Fabric Selection for 5 x 2 x 2 Factorial Experimental Design	12
Table 2.	Wall and Ceiling Test Panels	12
Table 3.	Weight of Curtains and Draperies Burned	13
Table 4.	Burning Time: Aerial and Mass Burning Rates	14
Table 5.	Heat of Combustion of Various Fabrics by Oxygen Bomb Method	15
Table 6.	Energy to Wall and Number of Test Panels Ignited	16
Table 7.	Ranking of Samples According to Area under Heat Flux Meter Curves	17
Table 8.	Number of High and Low Panels Ignited by Heavy and Light Draperies	18
Table 9.	Verification of Panel Ignitions	19
Table 10.	Doorway and Center of Room Temperatures	20
Table 11.	Physiological Effects of Elevated Temperatures	21
Table 12.	Peak Radiant Flux Generated by Drape (Measured 5 Feet above Floor and 5 Inches from Drape) Total Peak Heat Flux Measured above Drape	22
Table 13.	Peak Smoke Generation	23
Table 14.	Toxic Gas and Oxygen Depletion Produced by Burning Draperies — Peak Concentrations	24
Table 15.	Effect of Carbon Monoxide Exposure on Humans	25
Table 16.	Effect of Carbon Dioxide Exposure on Humans	25
Table 17.	Effects of Oxygen Depletion on Humans	26
Table 18.	Physiological Response to Various Concentrations of Hydrogen Cyanide in Air - Mass	26
Table 19.	Weight Losses in Chair — Drapery Burns (Exp. 16 and 20)	27
Table 20.	Time to Ignition and Flashover in Chair Test	27
Table 21.	Comparison of Chair and Drapery Experiments - Temperature, Heat Flux Measurements, Toxic Gases	28

LIST OF TABLES

		Page
Table 1.	Fabric Selection for 5 x 2 x 2 Factorial [illegible] Design	[illegible]
Table 2.	Wall and Ceiling Test Panels	[illegible]
Table 3.	Weight of Curtains and Draperies Burned	13
Table 4.	Burning Time: Aerial and Mass Burning Rate	14
Table 5.	Heat of Combustion of Various Fabrics by Oxygen Bomb Method	15
Table 6.	Energy to Wall and Number of Test Panels Ignited	[illegible]
Table 7.	Ranking of Samples According to Area under Heat Flux Meter Curves	[illegible]
Table 8.	Number of High and Low Panels Ignited by Heavy and Light Draperies	18
Table 9.	Verification of Panel Ignitions	19
Table 10.	Doorway and Center of Room Temperatures	20
Table 11.	Physiological Effects of Elevated Temperatures	21
Table 12.	Peak Radiant Flux Generated by Drape (Measured 5 Feet above Floor and 5 Inches from Drape) Total Peak Heat Flux Measured above Drape	22
Table 13.	Peak Smoke Generation	23
Table 14.	Toxic Gas and Oxygen Depletion Produced by Burning Draperies — Peak Concentrations	24
Table 15.	Effect of Carbon Monoxide Exposure on Humans	25
Table 16.	Effect of Carbon Dioxide Exposure on Humans	25
Table 17.	Effects of Oxygen Depletion on Humans	26
Table 18.	Physiological Response to Various Concentrations of Hydrogen Cyanide in Air - Mass	26
Table 19.	Weight Losses in Chair — Drapery Burns (Exp. 16 and 20)	27
Table 20.	Time to Ignition and Flashover in Chair Test	27
Table 21.	Comparison of Chair and Drapery Experiments - Temperature, Heat Flux Measurements, Toxic Gases	28

FULL-SCALE BURNING BEHAVIOR OF CURTAINS AND DRAPERIES

L. Dow Moore[1]

To better understand the burning in room fire development, 38 full-scale drapery and curtain burn experiments were conducted in a 3 x 4.9 m (10 x 16 ft) room. The variables investigated included fabric and lining type, fabric weight, and position of the draperies (open vs closed). As each burning experiment progressed a number of conditions were continuously monitored such as rate of drapery consumption, air temperature increase, smoke and toxic gas generation, and radiant energy developed. Ignition of sample wall and ceiling panels was also monitored.

Key words: Curtains; draperies; flammable fabrics; full-scale fires.

1. INTRODUCTION

A recent report [1][2] by Moore and Vickers surveyed 286 fire accidents in which curtains and/or draperies (C/Ds) were involved. The case history records in the Flammable Fabrics Accident Case and Testing System (FFACTS) file at the National Bureau of Standards (NBS) contained 147 cases, those at the National Fire Protection Association (NFPA) 73 cases, the Consumer Product Safety Commission (CPSC) 52 cases, and a literature survey 14.

The cases were analyzed in detail attempting to ascertain the extent to which these products represented potential fire hazards. In the FFACTS file, when C/Ds were involved in a fire, 63.5% of the time they were the first object to be ignited. Matches headed the list of ignition sources and the fires started most frequently in the living room. When the fire spread sequence was known, burning C/Ds most frequently ignited ceiling and wall materials of the house, thereby facilitating spread to other rooms of the house. Death incidence per case ranged from 0.23 to 0.84 depending on the set of case history records. The average for all cases that recorded property and contents financial losses was $8000 per incident.

To answer some of the questions generated by the survey a series of pilot studies was conducted in which full sized draperies were burned in a 3 x 4.9 m (10 x 16 ft) room. Answers to the following questions were sought:

1. What type of wall and ceiling materials were ignited by flaming C/Ds?

2. Would the radiant energy from a burning drapery represent a risk to a person entering the room?

3. What level of air temperature would be reached in a room and what would be the gradient from floor to ceiling?

4. How much carbon monoxide would a C/D produce? Would the amount of smoke vary with type of fiber?

5. Would the presence of a C/D in a room where other furnishings are burning decrease the flashover time by carrying the flame to the ceiling area where combustible gases are collecting?

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[1] When this work was in progress the author was a Research Associate at the National Bureau of Standards, Washington, D.C.

[2] Numbers in brackets refer to the references listed under section 7 of this paper.

2. SCOPE OF EXPERIMENTS

In the selection of typical curtains and draperies to be used in the accident simulation tests, there were many variables to consider. The C/D configurations ranged from 0.034 kg/m^2 (~1 oz/yd^2) sheers to short cottage curtains, to open weave casements, to heavy lined pinch pleated draperies weighing 0.371 kg/m^2 (10.9 oz/yd^2) — draped vertically and tied back. There are many types of fabric weaves and types of fibers and blends. Common linings range from separate layers of cotton fabric to acrylic foam backing.

From the previous survey report the largest portion of C/D fires occurred in the living room and was ignited by a match. For this reason it was decided to select full length 2.13 m (84 in) long pinch draperies as the configuration to be tested as they would most likely be found in the living room. A nominal 1.22 to 1.27 m (48 to 50 in) wide drapery was selected because this was the size most frequently sold in the U.S. according to marketing data. This width is tailored to fit curtain rods 0.86 to 1.02 m (34 to 40 in). With one exception, Experiment No. 15 — the rayon/polyester sheer, all draperies were composed of a pair of panels.

To derive the maximum amount of information from the set of experiments, a statistical design was utilized. After reviewing estimated future market trends of types of fibers to be used in C/D fabrics, five fabrics were chosen (see table 1). Two weights of each fabric, i.e., light and heavy, were included. In addition, the draperies were tested in the closed as well as the open position, thus making a total of 5 x 2 x 2 or 20 experiments. Randomization procedures were used to select the burn sequence. As these fabrics in two different weights were not readily available in ready-made draperies, they were custom made.

In addition, 12 other ready-made C/Ds were burned to get some knowledge of the behavior of sheers, fiberglass flocked with rayon, casements, foam-backed draperies, etc. To test the theory that when a C/D burns in a flaming room environment, the flashover time is decreased, two additional experiments were performed.

The statistically designed experiments were numbered S1 thru S20 and the others 7 thru 20.

3. TEST INSTRUMENTATION AND CONDITIONS[3]

To simulate real life accident conditions, full-scale C/Ds were burned in a 3 x 4.9 m (10 x 16 ft) room totally closed except for one doorway directly opposite the C/D (see fig. 1). The top of the open 0.76 x 2.0 m (30 x 79 in) doorway was 0.33 m (13 in) below the 2.34 m (92 in) ceiling. To enable the installation of test wall panels and lines of thermocouples behind the drapery a window was not installed. The ceiling was composed of Class A mineral fiber tile and the walls of 16 mm (5/8 in) Type X (fire resistant) gypsum board except for the panel behind the drapery. This panel was 1.2 x 2.3 m (48 x 92 in) by 16 mm of asbestos sheet, with 15 x 15 cm (6 x 6 in) hole cut-outs for insertion of various wall panels (see table 2) at two heights above the floor (see fig. 2). The first line of test panels was located 1.1 m (3 ft 6 in) from the ceiling and the second 10 cm (4 in). To eliminate the edge effects the crack between the specimen and the board was filled with white non-burning caulking and allowed to dry.

A 0.9 m (3 ft) length of 5.7 cm (2-1/4 in) wide white pine window molding coated with two layers of white latex paint was nailed to the asbestos board as shown in figure 2.

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[3] The identification of commercial products is made in order to specify adequately the experimental procedure, and does not imply recommendation or endorsement by the National Bureau of Standards.

To measure the shape effect a 10 cm x 2 m (4 in x 80 in) piece of Panel No. 3 (see table 2) was nailed to the surface of the asbestos sheet also shown in the figure.

Test ceiling panels 15 cm by 15 cm (6 x 6 in) were inserted in the ceiling 20.3 cm (8 in) from the wall and caulked (see table 2).

The test drapery was hung with short hooks on a curtain rod 10 cm (4 in) from the wall with the top of the drapery approximately 13 cm (5 in) below the ceiling. The curtain rod was attached to two flexible wires leading through the ceiling over two low friction pulleys and horizontally to a single load cell.

The two-panel drape was arranged on the rod so the horizontal coverage was 1 m (40 in). This gave an overlap of the right panel over the left of 8 to 10 cm (3 to 4 in). For the closed draperies the fabric to wall surface ratio was 2.1 to 1 and in the open position it averaged 4.1 to 1. In all tests the bottom center edge of the right panel was ignited with a "book type" match.

Vertical thermocouple "trees" were placed (1) 1.2 m (4 ft) from the back wall and 46 cm (18 in) to the left of the door — drape centerline, and (2) in the center of the doorway.

A total heat flux transducer whose range was 0-10 W/cm^2 of the Gardon type was placed flush in the ceiling on the drape centerline and 25 cm (10 in) from the wall. The radiant flux meter (0-2 W/cm range) used the Schmidt-Boelter thermopile and was faced with an Intran 2 window with a view angle of 150 degrees. It was placed 1.5 m (5 ft) above the floor, 1.5 m (5 ft) from the back wall, 84 cm (33 in) to the right of drape — door centerline, and pointed at the top center of the drapery.

Smoke was measured by a vertical light beam and photocell placed in the center of, and just inside, the doorway. The beam was 2.34 m (92 in) long. The photocell was inset in a hole in the ceiling approximately 12.7 cm (5 in) deep thus keeping smoke film contamination of the lens during the latter part of the run at a minimum.

The evolution of toxic gases was continuously monitored near the vertical centerline of the doorway in two locations. M.S.A. Model 300 and Model 303 Lira units were used to monitor CO_2 and CO respectively. Oxygen was measured by an O_2 cell (Part #514010) supplied by Bacharach Instrument Division of Ambac Industries Inc.

Output from instruments were recorded every four seconds for each data point and printed on paper as well as magnetic tape. The mag tape was then processed by computer.

Visual records of the burning draperies were made using 16 mm film and 35 mm slides. Both were taken through the open doorway with the photographer approximately 3 m (10 ft) outside the room. Both sweep second and digital clocks were used to provide a visual record of the time elapse.

4. RESULTS AND DISCUSSION

The 18 different types of fabric burned had almost 18 different burning characteristics. This was not necessarily evident by visual observation but was evident by examination of the rate of burning curves, smoke generation and room temperature distribution curves. Time clocks were started after the bottom right panel edge was lit with a match with the lighting process requiring from 2-4 seconds actual time. Heavy drapes required the longest ignition time. Ten to 30 seconds were then usually required for the flame to make some headway and start its rapid rise to the ceiling. Figures 3 thru 8 are a photographic record of test S16, 100% cotton print 0.12 kg/m^2 (3.64 oz/yd^2), closed position, showing the typical V-shaped burning pattern. Figure 9 is a copy of the computer printout curve showing the drapery consumption rate and smoke generation. Again these curves, especially the drapery consumption curve, cannot be considered average or typical; however, they are given as examples.

4.1. Burning Rate

When a vertically hung fabric is ignited at the bottom, the flame travels vertically very rapidly for at least three reasons: (1) there is ready access to oxygen, (2) hot air has a bouyancy effect which carries the flame upward, and (3) fabric above the flame is being preheated which increases its burning rate. Referring again to figure 9, the first part of the drapery consumption curve, with a slope of 1.46 %/s, represents the right-hand panel burning rate. As soon as this panel is essentially consumed and flame advances to the left and down the left panel (see fig. 6 at 44 s) the burning rate drops to about half at a rate of 0.72 %/s. In some of the other experiments this change in slope is not always so clear cut as some fabrics burned faster in the fill direction (horizontal in this case) then the 0.1233 kg/m^2 cotton. Also, some fabrics burned 1/2 or 3/4 of the way to the top and parts fell off affecting the rate of burning of the left panel.

4.2. Burning Time

Considering the uniform burning curve of the lightweight cotton drapery, figure 9, it is easy to estimate a total burning time of 80 seconds. In some experiments, however, when the flame travels part way to the ceiling and a portion of the panel drops to the floor, it is impossible to judge an accurate burning time. The mass burning rate in most all cases reached a uniform value (slope) and was therefore used to calculate a theorical burning time for the right panel. Theorical burning times for right panels are listed in table 4 and these values were obtained by dividing 1/2 the drapery weight by the mass burning rate provided by the load cell.

For lightweight draperies the burning time for the right panel (ignited at the bottom) ranged from 11 to 42 seconds. For the heavyweights the range was from 22 to 138 seconds. In the statistical group of 20 experiments the lightweight fabrics burned 2 to 4 times as fast as the heavier materials. This was with the exception of the heavy acrylic with a calculated burn time of 31 seconds. This fabric melted and dripped so profusely that the accuracy of this time calculation is questionable.

4.3. Ignition of Wall and Ceiling Panels

One of the findings in the survey report [1] was that some types of curtains or draperies ignited walls or ceilings and thus could aid in the spread of fire throughout a dwelling. Some items such as wall paneling cannot be readily ignited with a match or momentary electrical arc, but are susceptible to a large ignition source (a drapery could be considered a large ignition source). Lie [2] indicates the probability of ignition is a function of both heat flux and time of exposure. In other words the residence time of the flame playing on each cm^2 is one of the main controlling factors in the ignition of the surface. For example, a match will usually ignite a heavy drapery if allowed to be in contact with a heavy drapery for 3-8 seconds; however, no ignition will take place if the contact time is 1 or 2 seconds.

What was the relationship of the energy input to the number of test panels ignited? The test panels are listed in table 2 and their locations in figure 2. After each burn all panels were examined for areas that had been ignited. In the test panel "count" the long panel, number three, was not included as often since it was ignited on the bottom end by part of a drapery falling to the floor. Another exception was panel five (the Class A ceiling tile) which was never ignited in any tests. Thus the total number of panels that could ignite in any test would be 10.

A method of ranking the C/Ds with respect to number of panels ignited would be the use of the total heat-flux data. A typical curve of the output of the meter located in the ceiling is illustrated by figure 12. Integrating under the curves produced the total heat measured by the meter ($W \cdot s/cm^2$ or J/cm^2). This integrated value for each experiment is listed in table 7 with the number of panels ignited. The value ranges from 28 J/cm^2 for the number 15 polyester sheer to 483 for the S18 heavy acrylic drapery. The ranking here is apparently a range of 180-190 J/cm^2 below which very few wall or ceiling panels were ignited. In other words, the lightweight C/Ds did not ignite the wall or ceiling panels, whereas the heavy draperies which produced areas under the heat flux meter curves of approximately 200 or above ignited as many as 8 of the 10 panels.

In addition, it was hypothesized that as the flame moved up the wall, its intensity would increase and possibly the ceiling as well as the wall panels near the ceiling would be ignited, whereas the lower wall panels would not. This was true for the heavyweight draperies (see table 8). Only two ceiling panels were ignited by the lightweight curtains.

Is it possible to extrapolate from the ignition of 15.2 x 15.2 cm (5 x 5 in) specimens to full wall and ceiling covered conditions? A number of factors such as heat conductivity and raw edge exposure would vary. To check on the validity of this extrapolation four additional experiments (Nos. 21-24) were conducted using the arrangement indicated in figure 10. The room size and drapery position were the same as used previously. The wall was composed of two sheets of "chestnut finished" Class C plywood paneling (Panel No. 3, see table 2). The Class D tile (low density cellulosic ceiling tile) (Panel No. 6) was installed to cover a suspended ceiling area of 2.44 m (8 ft) by 1.22 m (4 ft). A 2.5 cm (1 in) cove molding covered the junction of wall and ceiling and the window trim molding (Panel No. 1) was painted and installed as indicated. All wall materials were nailed to Type X gypsum board and the gypsum board showing through the window opening was painted black. Thus, four "items" could be ignited, i.e., the wall paneling, window molding, cove molding, and ceiling tile.

Instrumentation consisted of duplicating some of the previous installations — namely the load cell, heat flux meter in the ceiling, and the "center" of room thermocouple tree.

To test the hypothesis two heavy and two lightweight draperies were chosen. They were identical to those previously burned. The lightweights had not ignited any of the ten 15 x 15 cm panels and of the heavyweight draperies, one had ignited 7 and the other 8 panels.

Table No. 9 lists the results of these four experiments and the data obtained from the comparison test made with 15 x 15 cm panels. As may be noted the room temperatures, peak heat fluxes, and total energy deviate from previous results and not always in the same direction. For example, an increase in peak heat flux does not necessarily mean a total energy increase. However, three out of the four experiments did verify the previous ignition tests. The heavy draperies (Exp. 21 and 22) ignited all four of the items in the full-scale tests. The lightweight acetate drapery did not ignite any of the items; however, the lightweight 50% rayon/50% cotton ignited all four.

Comparing Experiment 23 with S1 reveals the energy as "seen" by the ceiling meter increased from 119 to 217 J/cm^2 — almost doubled. (Why should this value double for the same drapery? In Experiment 25 the new sheets of "chestnut finished" plywood presented a smooth reflective surface to the burning drapery, whereas, the darkened asbestos board in S1 absorbed considerable energy.) This probably explains the ignition of the four items as the break point from non-ignitor to ignitor in table 7 appears to occur near 180 to 190 J/cm^2.

4.4. Air Temperatures in Room and Doorway

As the C/Ds began to burn, hot combustion gases and heated air collected near the ceiling. Vertical temperature gradients were measured for each test. Figure 11 shows Experiment S17 (heavy, 50% cotton/50% polyester) where the peak temperature 25 mm (1 in) below the ceiling was 445°C. Other tests produced a high of 662°C for Exp. S9 (heavy 100% acrylic-open) and a low of 118°C (Exp. 15 sheer, 70% rayon/30% polyester). Table 10 lists doorway and center of room temperatures 1.65 m (65 in) above the floor — a position related to a possible hazard to a person in the room. This temperature ranged from a low of 44°C for the lightweight 100% polyester to 288°C for the heavy acrylic. In general the heavy fabrics produced increased temperatures than the lighter by a factor ranging from 1.4 to 2.5 times.

Is this air temperature high enough to cause physiological damage to the mucus membranes, lungs and to the skin of humans? Some of the physiological effects of air temperatures published by Pryor et al. [8] are listed in table 11. Six of the 1.65 m (65 in) above the floor temperatures listed in table 9 are in the 150°C danger zone. At 150°C, mouth breathing is difficult and it is considered the temperature limit for escape. In Experiment No. S17 (see fig. 11) the temperature 760 mm (2-1/2 ft) above the floor peaked at 57°C (135°F) which is tolerable for a few minutes if a person choses to escape along the floor. For all of the samples tested the maximum temperature reached at this "crawl level" was in Exp. S18 (100% acrylic) where the peak was 75°C (167°F).

As expected, in general the doorway temperatures were slightly lower than corresponding temperatures in the center of the room. The time-temperature profiles for all tests (curves) for the doorway were very similar to that in figure 11.

Is the room temperature high enough to cause a flashover, i.e., complete involvement of everything in the room? The maximum upper room temperature listed in table 10 is the average of the peak temperature 25 mm (1 in) below the ceiling and the corresponding mid-height temperature. These values range from a low of 76°C to a high of 392°C. Fang [4] indicates that an upper room temperature of 450-650°C is required for flashover. Only a few of these temperatures approached this range. The two experiments with heavy 100% acrylic fabric generated 371 and 392°C.

Another measure of impending flashover is the rate of heat generation. In the NBS testing of fire in Navy compartments, [12] a heat generation of 40 x 10^6 J/min (38 000 Btu/min) was found to cause flashover in a 3 x 3 x 3 m (10 x 10 x 10 ft) compartment. This value projected [4] to the 3 x 4.9 m (10 x 16 ft) room used for C/Ds is 64 x 10^6 J/min (55 500 Btu/min). One drape as indicated in table 6 had a heat generation higher than this critical value, i.e., Exp. S18 with 70.6 x 10^6 J/min (61 200 Btu/min). Flashover was not reached in this experiment, however, as the maximum burning rate lasted for only 12 seconds and was interrupted by part of the panel falling to the floor.

4.5. Total Heat Flux and Radiant Flux

Figures 12 and 13 show flux curves that are typical of all experiments. The total heat flux meter was located directly above the drapery and was acted on by hot combustion gases, flame impingement and radiant energy from the flame and smoke. In table 12 peak value ranged from 1.30 W/cm^2 for the 100% acetate drapery (Exp. 12) to 14.37 for the 100% acrylic (Exp. S18). In these tests the wall panels were exposed to flame fronts from 0.8 to 10 seconds — minimum duration — using the right-hand panel burning time.

The radiometer located 1.5 m (5 ft) from the wall was aimed at the centertops of the draperies. It measured peak values ranging from 0.11 to 1.91 W/cm^2 and in all cases the heavier weights produced the highest radiant flux for any one type of fabric.

The maximum rate of increase in total heat or radiant flux was calculated from the slope of the line drawn through points A and B in figs. 12 and 13. Although the utility of this rate data is questionable, the data are included for completeness in table 12.

4.6. Smoke Generation

The amount of smoke developed was measured by using a photometer based on the light attenuation principle. The flux was determined by measuring the decrease in emf from a photodetector cell corresponding to the decrease in transmittance from a collimated light beam passing through the smoke. The quantity of smoke is proportional to the optical density of the smoke per unit path length or

$$OD/L = \frac{1}{L} \mathrm{Log}_{10} \frac{I_o}{I}$$

where I_o = Incident Flux

I = Transmitted Flux

L = Path Length

OD/L = Optical Density per Unit Length.

The photometer was positioned vertically just inside the door on its centerline and had an effective path length of 2.34 m (7 ft). As was the case with hot gases, visual smoke started accumulating at the ceiling level, and as the quantity increased, the smoke layer stratified. When the smoke layer reached the top of the doorway 0.33 m (13 in) below the ceiling, exhausting through the doorway became more rapid. Figures 14, 15, and 16 show the buildup of smoke that occurred in Experiment S17. These photographs may also be related to the curves of optical density and drapery consumption in figure 17.

Table 13 indicates the lightweight 100% acetate drape (Exp. 12) produced the least amount of smoke while the S3 test with the 50% cotton/50% polyester produced the most.

King [5] burned various plastics and wood in the NBS smoke density chamber and measured the gravimetric concentration, i.e., grams of smoke per cubic meter. When all burning conditions were kept constant, this particulate smoke mass divided by the optical density approached a constant. Then, if the smoke concentration is doubled, the OD value measured should be twice as large. Reviewing the OD values in table 13, this principle would imply the heavy 50% cotton/50% polyester (Exp. S17 at $OD/L = 0.79\ m^{-1}$) peaked at

4.6 times the amount of smoke of Exp. S16 at OD/L = 0.17 m^{-1}. An examination of photographs, figures 8 and 16, verifies this trend.

In spite of high smoke concentration, i.e., OD/L in the range of 0.50 m^{-1} and above, the smoke was stratified and there was a visually clear path near the floor. This path generally ranged from 0.60 to 1.2 m (2 to 4 feet) high and was always present.

It was evident that within the group of 20 tests in the experimental design, heavier draperies produced more smoke than lightweight fabrics. The cotton/polyester blend and the acrylic also generated more than other fabrics of the same weight.

4.7. Gas Analysis

During the initial stages of planning the experiments, i.e., with respect to toxic gas exposure, it was decided to consider the potential risk to a person entering the doorway. Within the doorway it was surmised the CO and CO_2 concentrations might not be high enough to measure by the instrumentation available — except at the very top of the door opening. This should be the point of highest concentration. Later in the series of experiments a second suction tube was installed 14 cm (5-1/2 in) below the first tube to investigate the vertical distribution of these toxic gases.

Examination of figures 18 and 19 indicate the CO and CO_2 concentrations continuously monitored at the top of the door build up very rapidly to a peak value. As the fire subsides dilution occurs and the concentrations slowly decrease. The shapes of the curves of concentrations measured 14 cm (5-1/2 in) below the doorway top were very similar except for lower values. Table 14 lists peak concentrations for each experiment. Measured at the top of the doorway, CO concentrations ranged from 200 ppm for the rayon/polyester sheet (Exp. 15) to 7400 ppm for Exp. S3-100% acrylic. The CO curve for S3 had a pinnacle type peak which dropped from 7400 ppm to 2200 ppm in 10 seconds. The CO_2 peak concentrations varied from a low of 1.8% to a high of 9.60% with the major number of draperies producing 5-7% at the top of the doorway.

Concentrations of CO and CO_2 at the point 14 cm (5-1/2 in) below the door top were not consistently lower than those at the door top. This was likely due to differences in turbulence and gas velocities which made accurate extrapolation to lower elevations, i.e., nose level of the average human, difficult.

As would be expected, the amount of oxygen in the gases expelled from the room decreased as the CO_2 and CO increased. At low concentrations of CO the volume percentages of CO_2 and O_2 should total 20.9% or the normal O_2 concentration in air. (A volume of O_2 used in burning will produce an equal volume of CO_2.) This was generally true indicating the accuracy of the gas concentration measurements.

When the four 100% acrylic draperies were burned, chromatographic color tubes were employed at the 14-cm location to measure hydrogen cyanide concentration. Values ranged from 15 to 40 parts per million.

4.8. Draperies as Flashover Promoters

In 1971 [6] fire tests were conducted in one of the rooms of the defunct Pioneer International Hotel in Tucson, Arizona. They involved typical hotel furniture, primarily a sofa, end table and a drapery hanging behind the sofa. At 10 minutes from ignition time only the end of the sofa and end table were burning and the fire could be approached quite closely. Hot gases were collecting and stratifying at the ceiling. At 10:12 the fire flashed up the preheated draperies and a flashover occurred. It was suggested the flashover time would have been delayed if the drapery had not carried the flame to the ceiling. Emmons [7] following a full-scale burn test conducted in a bedroom, also suggests that the presence of draperies or curtains materially decreases the time to flashover.

To test this theory a small upholstered chair with urethane cushion and back was burned with and without a drapery. (Two identical chairs were purchased.) The 3.0 x 4.9 m (10 x 16 ft) room, figure 1, was used for conducting the tests. However, the addition of a gypsum board wall down the center of the room decreased the room to 2.4 x 3.0 m (8 x 10 ft). It was opined that the small chair, being the major source of fuel, would not create a flashover condition in the large room. In both experiments the chair was placed 21.6 cm (8-1/2 in) from the back wall facing the left front of the room at 45°. The back corner of the chair was 18 cm (7 in) to the right of the drapery rod centerline. The ignition source in both cases was a polyethylene wastepaper basket containing 20 dismantled quart-sized milk containers. It was placed 11.4 cm (4-1/2 in) to the right of the chair. To insure ignition of the chair by the flaming waste container a 61 x 84 cm (24 x 33 in) aluminum sheet metal reflector was placed in a vertical plane and 10 cm (4 in) to the right of the wastebasket. In Experiment No. 16 one panel of the same 100% cotton drapery used in previous Experiment No. 7 was hung directly behind the chair. There was approximately 8 cm (3 in) of clearance between the drape and chair.

Examination of the movie film and the digatal clock gave the ignition and flashover times listed in table 20. As full ignition of fires have a wide range of preflashover times "striking of the match" is not considered a reliable starting point. In these two trials ignition of the chair seats more nearly represents full involvement and is considered the start point for measuring time to flashover. In Experiment 20, i.e., without the drape, the time to flashover was 3 minutes 25 seconds; whereas, with the drape it occurred in 2 min 7 s — difference of 1 min 18 s. In Experiment No. 7 when this same drapery was ignited alone the right-hand panel burned in 22 seconds. In Exp. 16 the panel, preheated by the burning chair, was consumed in 2 to 3 seconds.

Because of the variability of burns no definite conclusions should be drawn from these two trials except that a trend is indicated.

Table 21 lists data obtained from the two experiments. At the time of flashover, temperatures in the center of the room and doorway were in the range of 837°C (1540°F) to 998°C (1830°F). The maximum total heat flux reached 13.37 W/cm^2 in the chair experiment — not as high as the peak of Exp. 18, 100% acrylic drape, which was 14.37 W/cm^2. Radiant energy at 9 and 11 W/cm^2 was much higher than obtained in the drapery experiments as were the carbon monoxide and carbon dioxide concentrations.

4.9. Test Results

1. Theorical burning times for the lightweight C/Ds 1.56 to 3.70 oz/yd^2 varied from 11 to 42 seconds and from 22 to 138 seconds for the heavy draperies 7.64 to 10.9 oz/yd^2. Corresponding mass burning rates were 0.45 to 0.91 kg/min for lightweight C/Ds and 0.40 to 2.29 for heavies.

2. Areas under the heat flux meter curves indicate lightweight C/Ds gave values from 28 to 227 J/cm^2; whereas, heavy draperies ranged from 177 to 483 J/cm^2.

3. Of the 12 lightweight C/Ds tested 10 failed to ignite any of the 10 test panels. The other two ignited one each. Excluding the two foam back draperies, Exp. 18 and 19, the heavy draperies ignited an average of 5.5 panels out of 10.

4. Samples S18 (100% acrylic) and #11 (73% rayon/27% cotton) produced the greatest number of ignitions (8 panels ignited).

5. A lined drapery #7 (100% cotton) and foam backed draperies #18 (63% cotton/37% polyester), #19 (60% rayon/40% cotton) by producing 3, 1 and 0 ignitions in the test panels gave an indication that lined or backed draperies are less of a hazard than unlined draperies of the same weight.

6. On the basis of panels ignited, it appears that no judgment can be made concerning whether closed or open draperies are more hazardous.

7. Peak radiant flux varied from 0.11 to 0.74 for lightweight C/Ds and .20 to 1.86 for heavy draperies.

8. Peak smoke generation as optical density was 0.14 to 1.19 for lightweight C/Ds and 0.23 to infinite for heavyweight draperies.

9. Peak carbon monoxide measured at the top of the doorway opening had a range of 200 to 2400 ppm for lightweight samples and 1000 to 7400 for heavyweight materials.

5. CONCLUSIONS

The following conclusions have been drawn from this research.

5.1. Ignition of Wall and Ceiling Materials

1. Heavyweight wall hangings ignited wall and ceiling material, whereas lightweight ones usually did not.

2. Two test burns indicate a C/D may provide a fire path to the combustible gases collecting at the ceiling and thus may decrease the time to flashover; thus a person would have less time to escape from the room. After flashover, fire may spread rapidly throughout a house.

5.2. Smoke Generation

Heavyweight draperies produced more smoke than lightweight materials. In addition, fabrics containing significant quantities of polyester and acrylic fibers generated more smoke than cottons, rayons, and acetates. In the early stages of a fire, smoke accumulates near the ceiling and, again, a person can escape the room of fire origin by exiting at the floor level.

5.3. Gas Analysis

As expected, heavy draperies produced high air temperatures, more smoke, and higher levels of toxic gases. No consistency was found between types of fiber and the amount of toxic gases produced. Gas concentrations measured near the top of the doorway were found low enough for exit before flashover.

5.4. Drapery Ignition — Open Versus Closed

In all cases that were compared, draperies in the open position generated more heat than when closed as measured by the total heat flux meter.

6. ACKNOWLEDGMENTS

The author wishes to thank Douglas Bostian, William Bailey, Thomas Maher and others for their assistance in performing the experiments, Samuel Steel and Sue Alderson for consultation on instrumentation, and James Slater and Margaret Hackleroad for computer programming and many others for consultation.

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Table 1. Fabric Selection for 5 x 2 x 2 Factorial Experimental Design

5 FABRICS	
100% Cotton	
50% Cotton/50% Polyester	
100% Acrylic	
59% Rayon/41% Cotton	
100% Polyester	
2 FABRIC WEIGHT	
Heavy:	Range 0.25 to 0.35 kg/m^2 (7.3 to 10.4 oz/yd^2)
Light:	Range 0.10 to 0.13 kg/m^2 (2.9 to 3.7 oz/yd^2)
2 DRAPE POSITIONS	
Closed	
Open	
Total Experiments: 5 x 2 x 2 = 20	
Supplemental Experiments: 18	

Table 2. Wall and Ceiling Test Panels

Panel No. 1 -	White pine window molding 1.6 cm x 5.7 cm x 91 cm (5/8 in x 2-1/4 in x 36 in) painted with 2 coats of white latex
Panel No. 3 -	"Chestnut finished" 4 mm (5/32 in) untreated plywood, Class C, flame spread 200, fuel contribution 125, smoke rating 200
Panel No. 4 -	Common 13 mm (1/2 in) wallboard - white surfaced
Panel No. 5 -	White textured ceiling tile, 13 mm (1/2 in) Class A
Panel No. 6 -	White screen finish ceiling tile, 13 mm (1/2 in), Class D
Panel No. 7 -	6 mm (1/4 in) Masonite smooth both sides (oil treated)

Table 3. Weight of Curtains and Draperies Burned

Type Fiber	Experiment Number	Position	Weight	Weight Fabric (oz/yd^2)*	Drape Weight (kg)
100% Cotton	S16	Closed	Light	3.64	.773
	S 8		Heavy	7.64	1.475
	S13	Open	Light	3.64	.754
	S 5		Heavy	7.64	1.460
50% Cotton/ 50% Polyester	S20	Closed	Light	3.45	.836
	S17		Heavy	9.65	1.764
	S19	Open	Light	3.45	.810
	S 3		Heavy	9.65	1.751
100% Acrylic	S 4	Closed	Light	2.92	.631
	S18		Heavy	10.42	2.366
	S11	Open	Light	2.92	.631
	S 9		Heavy	10.42	2.344
59% Rayon/ 41% Cotton	S 1	Closed	Light	3.70	.725
	S15		Heavy	8.47	1.612
	S 2	Open	Light	3.70	.720
	S10		Heavy	8.47	1.582
100% Polyester	S14	Closed	Light**	3.17	.612
	S12		Heavy	7.33	-
	S 7	Open	Light	3.17	.601
	S 6		Heavy	7.33	-
100% Cotton Cotton Lining	7	Closed		9.20	1.566
Rayon Flocking	8	Closed		10.80	1.90
on Rayon/ Polyester	14	Closed		7.87	1.50
87% R/13% Acetate	9	Closed		8.70	1.776
73% R/27% Cotton	11	Closed		9.12	2.01
100% Acetate	12	Closed		3.42	.640
100% Fiber-glass***	13	Closed		5.24	.970
70% R/30% Polyester E. (sheer)	15	Closed		1.56	.276
63% C/37% Polyester E. & Foam†	18	Closed		8.97	1.575
60% R/40% Polyester & Foam†	19	Closed		8.35	1.376
60% R. Flocking	10	Closed		10.9	1.860
on Fiberglass	17	Closed		10.9	1.887

* To correct to kilograms/meter^2 multiply by 0.034

** Flame would not propagate upward for more than a few inches

*** Would not ignite with a match

† Corrected for filler in foam backing

Table 4. Burning Time: Aerial and Mass Burning Rates

Type Fiber	Exp. No.	Position	Weight	Theorical R. Panel Burning* Time (s)	Mass Burning Rate (Max) (kg/min)
100% Cotton	S16	Closed	Light	34	.68
	S 8		Heavy	94	.47
	S13	Open	Light	40	.57
	S 5		Heavy	80	.55
50% Cotton/ 50% Polyester	S20	Closed	Light	30	.84
	S17		Heavy	50	1.06
	S19	Open	Light	26	.95
	S 3		Heavy	71	.74
100% Acrylic	S 4	Closed	Light	42	.45
	S18		Heavy	31	2.29
	S11	Open	Light	27	.70
	S 9		Heavy	-	-
54% Rayon/ 41% Cotton	S 1	Closed	Light	27	.80
	S15		Heavy	97	.50
	S 2	Open	Light	33	.66
	S10		Heavy	66	.72
100% Polyester	S14	Closed	Light	33	.56
	S12		Heavy**	-	-
	S 7	Open	Light	20	.91
	S 6		Heavy	-	-
100% Cotton Cotton Lining	7	All Closed		22	2.17
Rayon Flocking on Rayon/Polyester	8			26	2.23
	14			41	1.10
87% R/13% Acetate	9			133	.40
73% R/27% Cotton	11			89	.68
100% Acetate	12			37	.52
100% Fiberglass†	13			-	-
70% R/30% Poly E (Sheer)	15			11	.76
63% C/37% Poly E & Foam	18			40	1.18
60% R/40% Poly E & Foam	19			41	1.01
60% R. Flocking on Fiberglass	10	All Closed		111	.50
	17			138	.41

* Burning time of right panel at maximum burning rate.

** Flame would not propagate upward for more than a few inches.

† Would not ignite with a match.

Table 5. Heat of Combustion of Various Fabrics by Oxygen Bomb Method [3]*

Type Fabric	J/kg x (10^6)	Btu/lb
Acrylic	30.76	13254
Modacrylic	24.72	10650
Polyester	21.59	9300
Rayon	15.43	6650
Acetate	17.78	7660
Triacetate	18.10	7800
Nylon 6	30.14	12989
Spandex	31.43	13540
Cotton	16.53	7122
Wool	20.82	8972
Ethyl Acrylate **	29.81	12500

*Not corrected for water vapor.

**Reference: NBS Journal of Research, Vol. 2, p. 359 (1929) assumed close in value to 4 or 5 other $C_5H_8O_2$ compounds. (Et. Acrylate used as foam backing on drapes - experiment 18 and 19)

Table 6. Energy to Wall and Number of Test Panels Ignited

Type Fiber	Exp. No.	Curtain Configu- ration	Weight	Max Rate of Heat Generation ($x10^6$, J/min)	Number of Wall and Ceiling Panels Ignited
100% Cotton	S16	Closed	Light	11.27	1
	S 8		Heavy	7.79	7
	S13	Open	Light	9.44	0
	S 5		Heavy	9.11	7
50% Cotton/ 50% Polyester	S20	Closed	Light	16.04	1
	S17		Heavy	20.25	5
	S19	Open	Light	18.15	0
	S 3		Heavy	14.13	7
100% Acrylic	S 4	Closed	Light	13.87	0
	S18		Heavy	70.60	8
	S11	Open	Light	21.58	0
	S 9		Heavy	-	7
59% Rayon/ 41% Cotton	S 1	Closed	Light	12.82	0
	S15		Heavy	7.96	6
	S 2	Open	Light	10.57	0
	S10		Heavy	11.46	2
100% Polyester	S14	Closed	Light	12.11	0
	S12		Heavy	-	-
	S 7	Open	Light	-	-
	S 6		Heavy	-	-
100% Cotton Cotton Lining	7	Closed		35.96	3
Rayon Flocking on Rayon/ Polyester	8	Closed		39.45	2
	14	Closed		19.76	7
87% R/13% Acetate	9	Closed		6.31	4
73% R/27% Cotton (case)	11	Closed		10.72	8
100% Acetate	12	Closed		9.27	0
70% R/30% Poly E. (Sheer)	15	Closed		13.16	0
63% C/37% Poly E. & Foam	18	Closed		23.12	1
60% R/40% Poly E. & Foam	19	Closed		19.55	0
60% R. Flocking on Fiberglass	10	Closed		7.74	5
	17	Closed		6.34	5

Table 7. Ranking of Samples According to Area Under Heat Flux Meter Curves

Experiment Number	Fabric Weight+ (oz/yd^2)	Area Under Heat Flux Curve (J/cm^2)	Number 6" x 6" Panels Ignited
15	1.56	28	0
12 (#24)*	3.42	36	0
S14	3.17	67	0
S 7	3.17	71	0
S 2	3.70	73	0
S 4	2.92	78	0
S13	3.64	91	0
S19	3.45	113	0
S11	2.92	115	0
S 1 (#23)	3.70	119	0
S16	3.64	168	1
19	8.35	177	0
18	8.97	197	1
S10	8.47	197	2
S 5	7.64	225	7
S20	3.45	227	1
S 3	9.65	264	7
S17	9.65	277	5
7	9.20	306	3
11 (#21)	9.12	313	8
9	8.70	314	4
17	10.90	359	5
S 9	10.42	359	7
S 8 (#22)	7.64	365	7
8	10.80	396	2
S15	8.47	406	6
10	10.90	408	5
14	7.87	416	7
S18	10.42	483	8

+To convert to kilograms/meter^2 multiply by 0.034.

*Verification experiments (full panels and ceiling area).

Table 8. Number of High and Low Panels Ignited by Heavy and Light Draperies

	Heavyweight		Lightweight	
	Closed	Open	Closed	Open
CEILING SAMPLES				
4C Wallboard	4	3	1	-
7C Hardboard - Oil Treated	4	3	1	-
5C Ceiling Tile (Class A)	-	-	-	-
6C Ceiling Tile (Class D)	4	4	-	-
WALL SAMPLES (HIGH POSITION)				
4H Wallboard	3	3	-	-
7H Hardboard - Oil Treated	4	3	-	-
3H Plywood Paneling (Class C)	3	2	-	-
1 Window Molding	3	4	-	-
WALL SAMPLES (LOW POSITION)				
4L Wallboard	-	-	-	-
7L Hardboard - Oil Treated	-	-	-	-
3L Plywood Paneling (Class C)	1	1	-	-

Table 9. Verification of Panel Ignitions

Experiment Number: Full Panel / 15 x 15 cm	Fabric	Center of Room Temp. (°C)	Peak Heat Flux (W/cm^2)	Area Under Heat Flux Curve (J/cm^2)	Item Ignited: Full, 4 possible	Item Ignited: 6"x6", 10 possible
21	73% Rayon/	89	4.33	257	4	
	27% Cotton					
11	9.12 oz/yd^2+	114	3.80	313		8
22	100% Cotton	111	5.07	369	4	
S 8	7.64 oz/yd^2	93	6.19	365		7
23	50% Rayon/	79	4.14	217	4	
	50% Cotton					
S 1	3.70 oz/yd^2	82	4.59	119		0
24	100% Acetate	74	2.74	67	0	
12	3.42 oz/yd^2	75	1.30	36		0

*1.65 m (65^4) above floor.

+To convert to kilograms/meter^2 multiply by 0.034

Table 10. Doorway and Center of Room Temperatures*

Type Fiber	Exp. No.	Position	Weight	Peak Doorway Temp.** (°C)	Peak Center of Room Temp.** (°C)	Max. Upper Room Temp.*** (°C)
100% Cotton	S16	Closed	Light	52	64	166
	S 8		Heavy	86	93	220
	S13	Open	Light	41	49	168
	S 5		Heavy	75	69	238
50% Cotton/ 50% Polyester						
	S20	Closed	Light	134	113	196
	S17		Heavy	171	158	261
	S19	Open	Light	44	59	225
	S 3		Heavy	122	115	333
100% Acrylic						
	S 4	Closed	Light	124	116	159
	S18		Heavy	306	288	371
	S11	Open	Light	91	90	131
	S 9		Heavy	249	253	392
59% Rayon/41% Cotton						
	S 1	Closed	Light	83	82	179
	S15		Heavy	121	130	188
	S 2	Open	Light	39	45	184
	S10		Heavy	41	58	209
100% Polyester						
	S14	Closed	Light	116	95	145
	S12		Heavy	-	-	-
	S 7	Open	Light	39	44	152
	S 6		Heavy	-	-	-
100% Cotton/ Cotton Lining	7	Closed		125	249	353
Rayon Flocking on Rayon Backing	8	Closed		221	230	319
	14	Closed		167	151	295
87% R/13% Acetate	9	Closed		83	76	166
73% R/27% Cotton (Case)	11	Closed		140	114	234
100% Acetate	12	Closed		82	75	88
70% R/30% Poly E. (Sheer)	15	Closed		53	48	76
63% C/37% Poly E. & Foam	18	Closed		142	131	223
60% R/40% Poly E. & Foam	19	Closed		153	149	209
60% R. Flocking on Fiberglass	10	Closed		90	101	223
	17	Closed		108	118	189

*Flame would not propagate upward for more than a few inches before melting and dripping caused extinguishment.

**Measured 1.65 m (65") above floor.

***Average of temperatures 25 mm (1") below ceiling and at midpoint in room.

Table 11. Physiological Effects of Elevated Temperatures [8]

60°C (140°F)	Heat stroke possible
82°C (180°F)	49 min tolerance time
100°C (212°F)	Very rapid skin burns in humid air
115°F (240°F)	20 min tolerance time
125°C (260°F)	Nasal breathing difficult
150°C (300°F)	Mouth breathing difficult - Temperature limit for escape
160°C (320°F)	Rapid unbearable pain to dry skin
200°C (390°F)	Tolerance time less than 4 min with wet skin - Respiratory system threshold 200°C)

Table 12. Peak Radiant Flux Generated by Drape (Measured 5 Feet above Floor and 5 Inches from Drape) Total Peak Heat Flux Measured above Drape

Type Fiber	Exp. No.	Position	Weight	Peak Radiant (W/cm^2)	Rate to Peak Radiant Flux (W/cm^{2}min)	Peak Total Heat Flux (W/cm^2)	Rate to Peak Total Heat Flux (W/cm^{2}min)
100% Cotton	S16	Closed	Light	.34	.84	4.70	24.5
	S 8		Heavy	.34	.42	6.19	4.1
	S13	Open	Light	.32	1.73	5.44	33.3
	S 5		Heavy	.46	1.02	6.21	16.8
50% Cotton/ 50% Polyester	S20	Closed	Light	.63	3.45	8.82	40.4
	S17		Heavy	.76	3.45	9.19	31.1
	S19	Open	Light	.74	6.75	8.69	68.9
	S 3		Heavy	1.32	4.35	7.79	19.8
100% Acrylic	S 4	Closed	Light	.27	.35	1.45	2.1
	S18		Heavy	1.86	5.65	14.37	62.1
	S11	Open	Light	.28	1.00	2.30	7.8
	S 9		Heavy	1.91	7.90	11.45	30.6
59% Rayon/41% Cotton	S 1	Closed	Light	.30	.75	4.59	12.6
	S15		Heavy	.39	.75	5.61	22.0
	S 2	Open	Light	.36	2.18	4.04	27.7
	S10		Heavy	.40	1.09	5.36	23.9
100% Polyester	S14	Closed	Light	.25	3.30	3.41	43.1
	S12		Heavy	-	-	-	-
	S 7	Open	Light	.38	1.70	6.77	87.3
	S 6		Heavy	-	-	-	-
100% Cotton Cotton Lining	7	Closed		1.12	1.54	8.02	12.6
Rayon Flocking on Rayon/ Polyester	8	Closed		.97	5.18	8.91	39.5
	14	Closed		.89	2.18	10.29	36.2
87% R/13% Acetate	9	Closed		.20	-	3.16	5.8
73% R/27% Cotton (Case)	11	Closed		-	-	3.80	16.8
100% Acetate	12	Closed		.11	.32	1.30	4.3
70% R/30% Poly E. (Sheer)	15	Closed		.12	1.2	1.70	11.3
63% C/37% Poly E. & Foam	18	Closed		.94	3.60	10.00	57.0
60% R/40% Poly E. & Foam	19	Closed		.83	5.30	9.58	51.2
60% R. Flocking on Fiberglass	10	Closed		.56	2.50	7.14	27.9
	17	Closed		.50	2.63	8.50	47.8

*Flame would not propagate upward for more than a few inches before melting and dripping caused extinguishment.

Table 13. Peak Smoke Generation

Type Fiber	Experiment Number	Position	Weight	Minimum Light Transmission	Peak Smoke Optical Density, OD/m
100% Cotton	S16	Closed	Light	40.1	.17
	S 8		Heavy	30.7	.22
	S13	Open	Light	59.9	.10
	S 5		Heavy	37.1	.18
50% Cotton/50% Polyester	S20	Closed	Light	17.4	.32
	S17		Heavy	1.4	.79
	S19	Open	Light	11.0	.41
	S 3		Heavy	< 0.01	> 2.00*
100 Acrylic	S 4	Closed	Light	13.7	.37
	S18		Heavy	1.8	.75
	S11	Open	Light	17.0	.33
	S 9		Heavy	0.9	.87
59% Rayon/41% Cotton	S 1	Closed	Light	48.2	.14
	S15		Heavy	58.3	.10
	S 2	Open	Light	42.8	.16
	S10		Heavy	28.3	.23
100% Polyester	S14	Closed	Light**	6.6	.51
	S12		Heavy	-	-
	S 7	Open	Light**	27.7	.24
	S 6		Heavy	-	-
100% Cotton Cotton Lining	7	Closed		30.7	.22
Rayon Flocking on Rayon/ Polyester	8	Closed		5.5	.54
	14	Closed		3.5	.62
87% R/13% Acetate	9	Closed		19.8	.30
73% R/27% Cotton (Case)	11	Closed		21.6	.28
100% Acetate	12	Closed		73.8	.06
70% R/30% Poly E. (Sheer)	15	Closed		62.9	.09
63% C/37% Poly E. & Foam	18	Closed		23.1	.27
60% R/40% Poly E. & Foam	19	Closed		22.3	.28
60% R. Flocking on Fiberglass	10	Closed		12.4	.39
	17	Closed		22.3	.28

* Estimate

** Flame would not propagate upward for more than a few inches before melting and dripping caused extinguishment.

Table 14. Toxic Gas and Oxygen Depletion Produced by Burning Draperies — Peak Concentrations

Type Fiber	Experiment Number	Position	Weight	Carbon Monoxide		Carbon Dioxide		Oxygen	Hydrogen Cyanide
				Top Doorway (ppm)	14 cm Below Door Top (ppm)	Top Doorway (%)	14 cm Below Door Top (%)	Top Doorway (%)	14 cm Below Door Top (ppm)
100% Cotton	S16	Closed	Light	2400	1200	4.91	4.20	17.68	
	S 8		Heavy	2700	1800	5.49	4.7 *	15.69	
	S13	Open	Light	1800	600	5.58	-	15.98	
	S 5		Heavy	2400	-	5.85	4.6 *	-	
50% Cotton/ 50% Polyester	S20	Closed	Light	1100	900	5.96	2.90	15.47	
	S17		Heavy	2900	2500	6.96	6.15	14.56	
	S19	Open	Light	2100	700	6.97	1.97	15.30	
	S 3		Heavy	7400	-	9.60	5.4 *	10.68	
100% Acrylic	S 4	Closed	Light	400	500	2.11	3.2 *	18.25	35
	S18		Heavy	1100	1600	6.31	5.14	17.39	28
	S11	Open	Light	200	-	2.67	-	17.38	15
	S 9		Heavy	2800	-	7.03	-	12.03	40
59% Rayon%/ 41% Cotton	S 1	Closed	Light	700	-	4.26	2.7 *	16.61	
	S15		Heavy	1300	1300	4.58	4.22	16.18	
	S 2	Open	Light	900	-	5.75	1.7 *	15.04	
	S10		Heavy	2000	600	6.87	-	14.59	
100% Polyester	S14	Closed	Light	500	-	2.73	2.10	18.34	
	S12		Heavy**	-	-	-	-	-	
	S 7	Open	Light	800	-	2.65	2.3 *	18.09	
	S 6		Heavy**	-	-	-	-	-	
100% Cotton Cotton Lining	7	Closed		4500	-	8.06	8.0 *	13.02	
Rayon Flocking on Rayon/Polyester	8	Closed		2500	-	7.80	7.8 *	13.53	
	14	Closed		3300	-	6.29	6.12	15.90	
87% R/13% Acetate	9	Closed		1200	-	3.30	-	17.33	
73% R/27% Cotton (Case)	11	Closed		-	-	-	6.2 *	-	
100% Acetate	12	Closed		300	200	1.81	1.33	19.27	
70% R/30% Poly E. (Sheer)	15	Closed		200	-	1.84	.99	19.94	
63% C/37% Poly E. & Foam	18	Closed		1000	800	6.16	-	-	
60% R/40% Poly E. & Foam	19	Closed		1400	600	6.60	-	16.45	
60% R. Flocking on Fiberglass	10	Closed		1400	-	4.72	5.8 *	15.22	
	17	Closed		1100	1000	5.40	-	16.03	

* One liter grab samples taken at or near visual peak of smoke generation.

** Flame would not propagate upward for more than a few inches before melting and dripping caused extinguishment.

** One liter grab samples taken at or near visual peak of smoke generation.

Table 15. Effect of Carbon Monoxide Exposure on Humans [9]

Parts per Million	Time	Effects
200	2 - 3 hr.	Mild headache
800	45 min	Mild headache
	2 hr.	Death possible
3200	10 - 15 min	Dizziness
	30 min	Death
6900	1 - 2 min	Dizziness
	10 - 15 min	Death
12800	2 - 3 Breaths	Unconscious
	1 - 3 min	Death

Table 16. Effect of Carbon Dioxide Exposure on Humans [9]

Percent Concentration	Effects
0.5	Increase depth of breathing
3.0	Breathing rate doubles
5.0	300% increase in breathing rate
10.0	Possible death even with sufficient atmospheric oxygen

Table 17. Effects of Oxygen Depletion on Humans* [10]

Percent	Time	Effect
21 - 17	Indefinite	Respiration volume decreases, loss of coordination and difficulty in thinking
17 - 14	2 hr.	Rapid pulse and dizziness
14 - 11	30 min	Nausea, vomiting and paralysis
9	5 min	Unconsciousness
6	1 - 2 min	Death within a few minutes

*These figures are only approximate as there are some variations in the literature.

Table 18. Physiological Response to Various Concentrations of Hydrogen Cyanide in Air - Mass [11]

Parts per Million	Effects
18 - 36	Slight symptoms for several hours
45 - 54	Tolerated for 1/2 to 1 hr. Without immediate or late effects.
110 - 135	Fatal for 1/2 to 1 hr. or later, or dangerous to life.
135	Fatal after 30 minutes
181	Fatal after 10 minutes
270	Immediately fatal

Table 19. Weight Losses in Chair — Drapery Burns (Exp. 16 and 20)

	Waste Basket	Chair	1/2 Drape	Total Wt. of Combustible
Exp. 20				
Wt. Before	1.4 kg (3.2 lb)	19.3 kg (42.5 lb)	--	
Wt. After	0	16.1 kg (35.5 lb)	--	
Wt. Loss	1.4 kg (3.2 lb)	3.2 kg (7.0 lb)	--	4.6 kg (10.2 lb)
Exp. 16				
Wt. Before	1.4 kg (3.2 lb)	19.3 kg (42.5 lb)	.8 kg (1.8 lb)	
Wt. After	0	15.2 kg (33.5 lb)	0	
Wt. Loss	1.4 kg (3.2 lb)	4.1 kg (9.0 lb)	.8 kg (1.8 lb)	6.3 kg (14.0 lb)

Table 20. Time to Ignition and Flashover in Chair Test

Material	Basket/Chair Exp. 20 min sec	Basket/Chair/Drape Exp. 16 min sec
Waste basket	0 - 0	0 - 0
Chair Arm	3 - 15	3 - 20
Chair Seat	3 - 30	3 - 30
Flashover	6 - 55	5 - 32 to 5 - 43

Table 21. Comparison of Chair and Drapery Experiments - Temperature, Heat Flux Measurements, Toxic Gases

	Maximum Values	
	Exp. 20	Exp. 16 1/2 Drape
Doorway Temperature *	837 °C	893 °C
Center Room Temperature *	928 °C	998 °C
Upper Room Temperature **	866 °C	932 °C
Total Heat Flux ***	13.37 W/cm^2	10.47 W/cm^2
Radiant Flux ***	11.28 W/cm^2	9.06 W/cm^2
Smoke	.78 OD/m	--
Carbon Monoxide - Door Top	35,000 ppm	33,000 ppm
14 mm (5-1/2") Below Top	21,000 ppm	20,000 ppm
Carbon Dioxide - Door Top	15.0%	14.8%
14 mm (5-1/2") Below Top	15.6%	13.2%

*Measured 1.65 m (65") above floor.

**See table 7.

***Same locations as previous experiments except radiometer aimed horizontally.

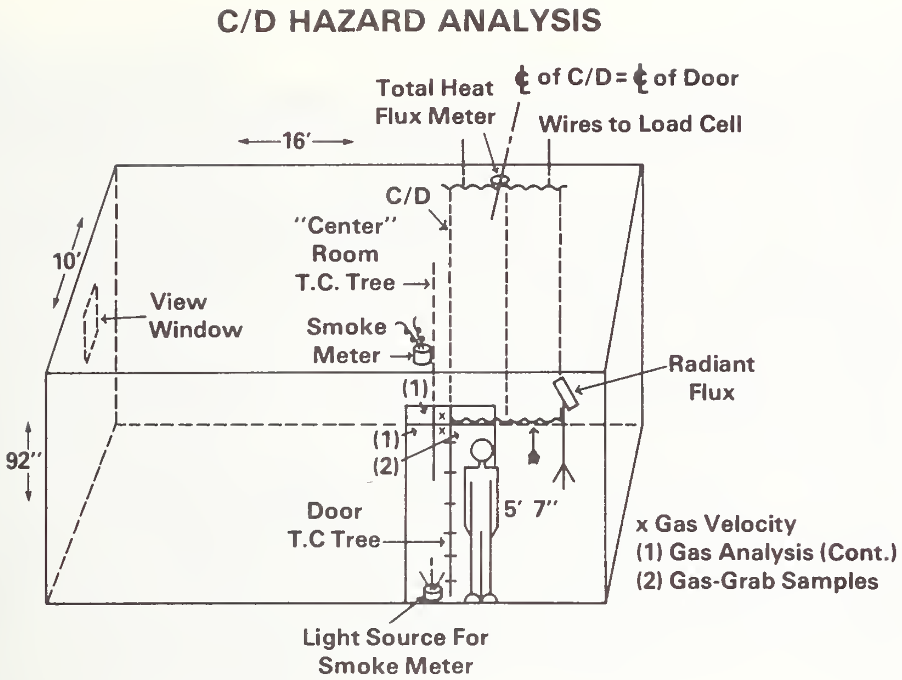


Figure 1. C/D Hazard Analysis

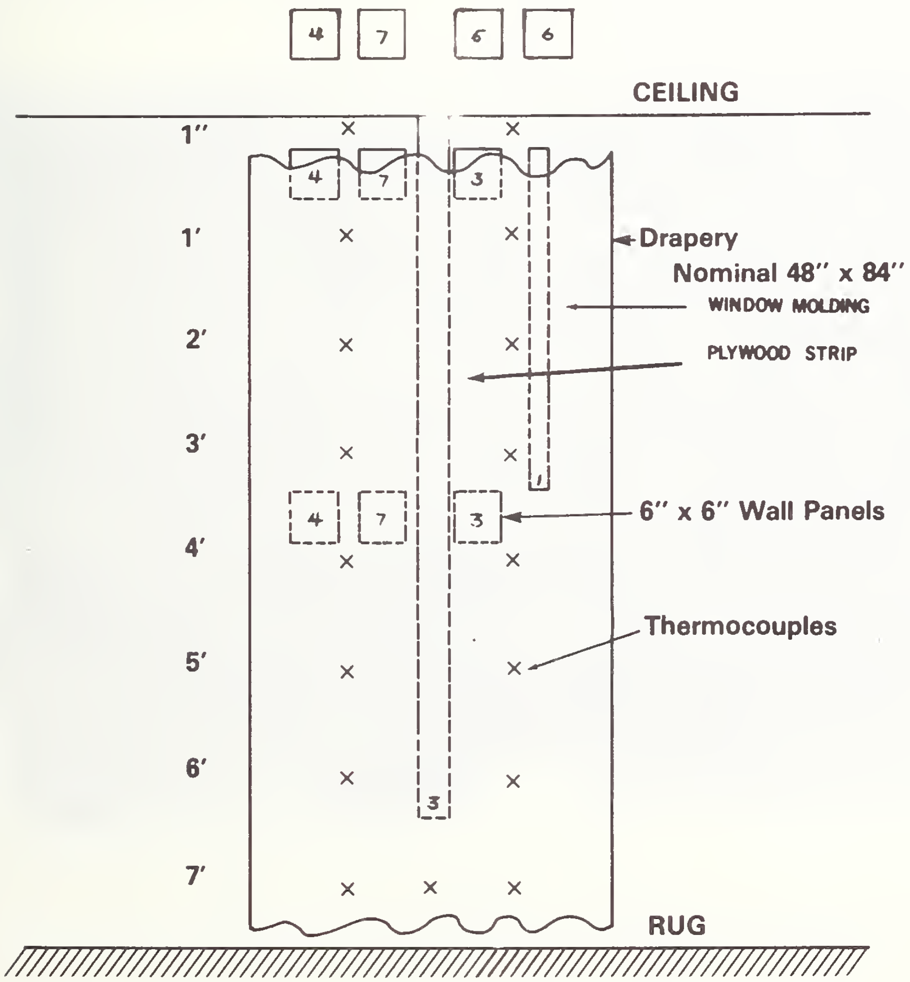


Figure 2. Instrumentation of Wall Behind Drape

Figure 3. Exp. S16 (100% Cotton Print 3.64 oz/yd^2) - 16 Seconds after Ignition

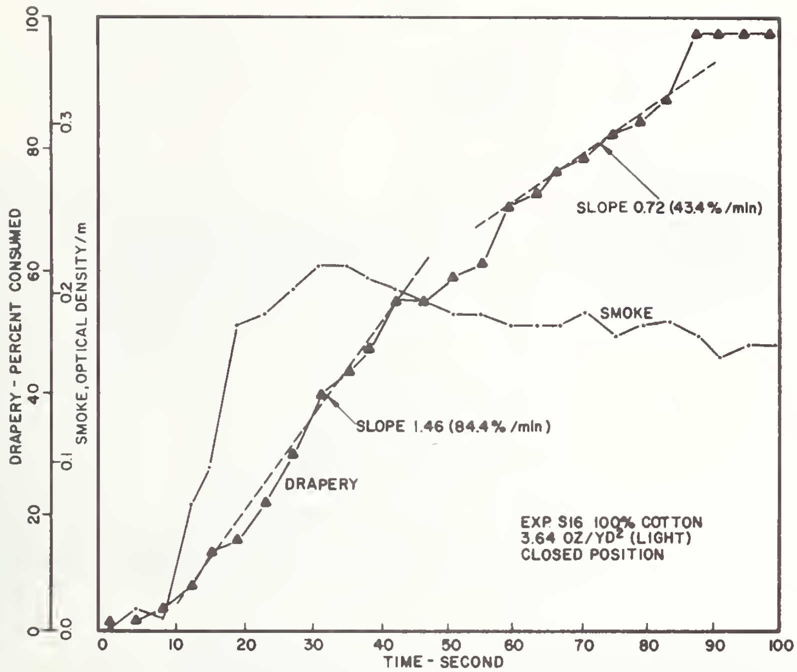
Figure 4. Exp. S16 - 23 Seconds

Figure 5. Exp. S16 - 27 Seconds

Figure 6. Exp. S16 - 44 Seconds

Figure 7. Exp. S16 - 76 Seconds

Figure 8. Exp. S16 - 89 Seconds



Time	Smoke OD/M
4	.009
8	.005
12	.044
16	.060
20	.130
24	.144
28	.152
32	.170
36	.179
40	.162
44	.154
52	.144
60	.132
68	.136
76	.122
84	.136
92	.110
100	.116

Figure 9. Exp. S16 100% Cotton 3.64 oz/yd^2 (Light) Closed Position

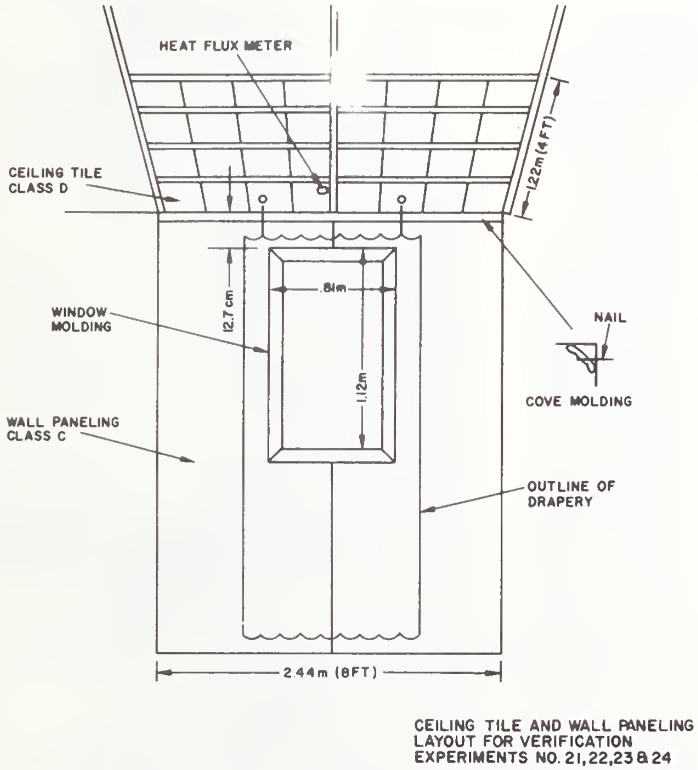


Figure 10. Ceiling Tile and Wall Paneling Layout for Verification Experiments No. 21, 22, 23 & 24

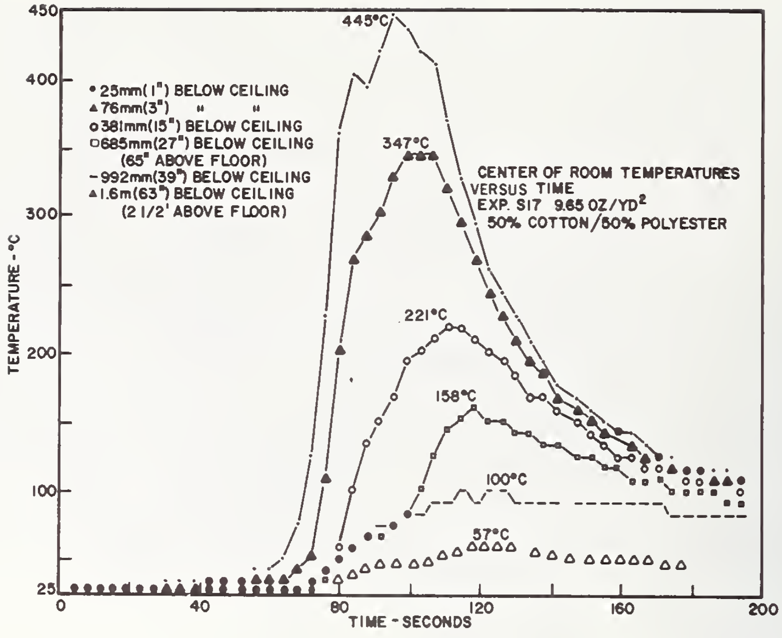


Figure 11. Center of Room Temperature versus Time - Exp. S17 9.65 oz/yd^2 50% Cotton/50% Polyester

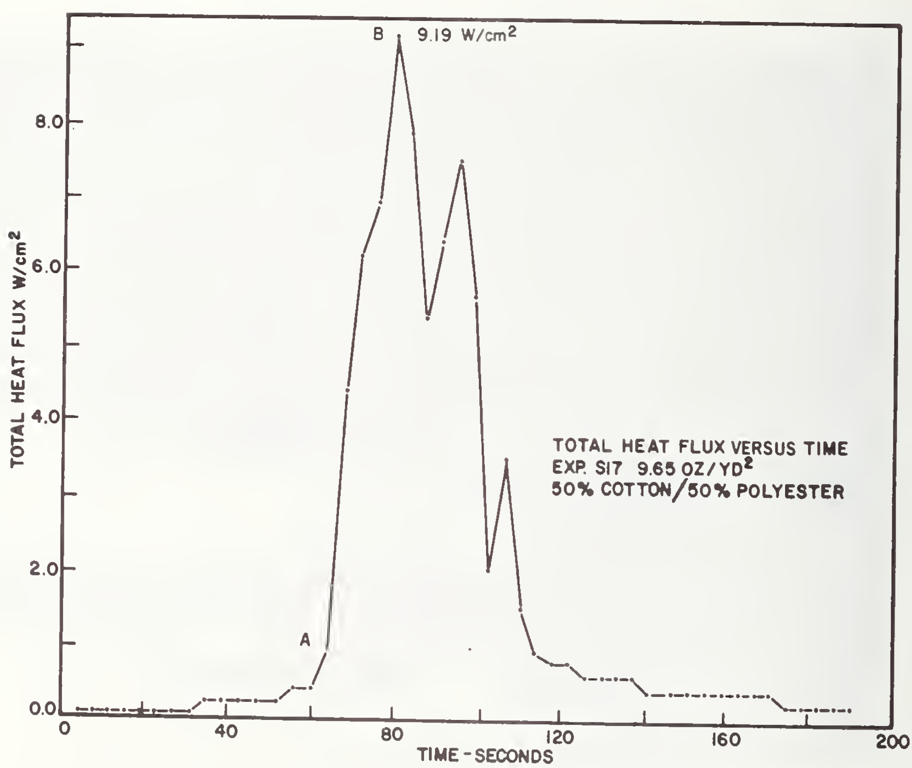


Figure 12. Heat Flux versus Time - Exp. S17

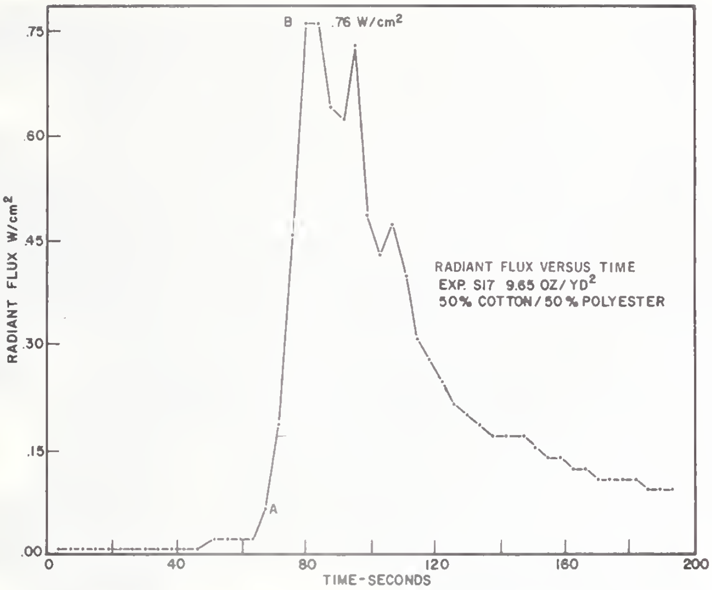
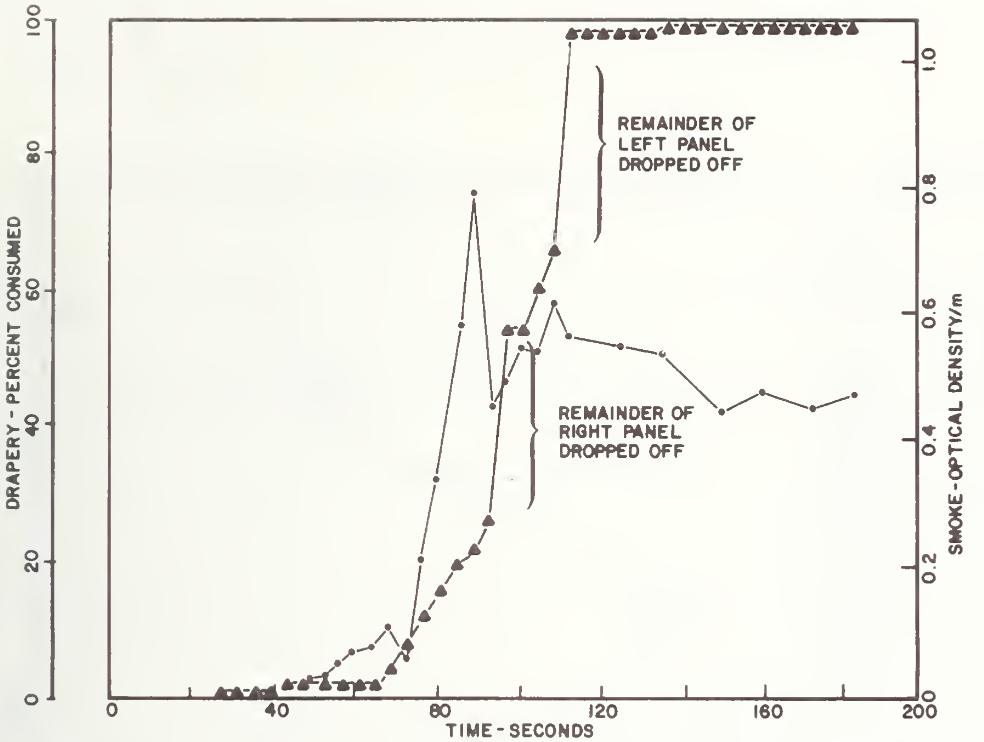


Figure 13. Radiant Flux versus Time - Exp. S17

Figure 14. Exp. S17 - 78 Seconds

Figure 15. Exp. S17 - 103 Seconds

Figure 16. Exp. S17 - 116 Seconds



Sec.	OD/m
52	.038
56	.054
60	.065
64	.071
68	.113
72	.062
76	.21
80	.38
84	.59
88	.79
92	.45
96	.49
100	.56
104	.54
108	.62
112	.57
124	.54
136	.53
148	.44
160	.47
172	.45
184	.47

Figure 17. Drapery Consumption and Smoke Generation - Exp. S17 50% Cotton/50% Polyester.

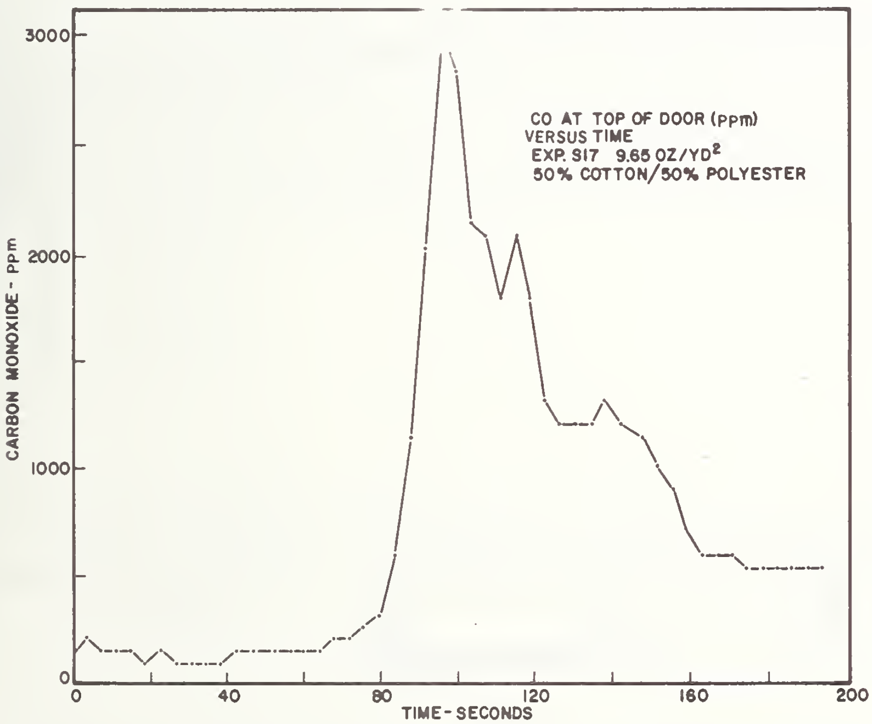


Figure 18. CO at Top of Door (ppm) versus Time - Exp. S17

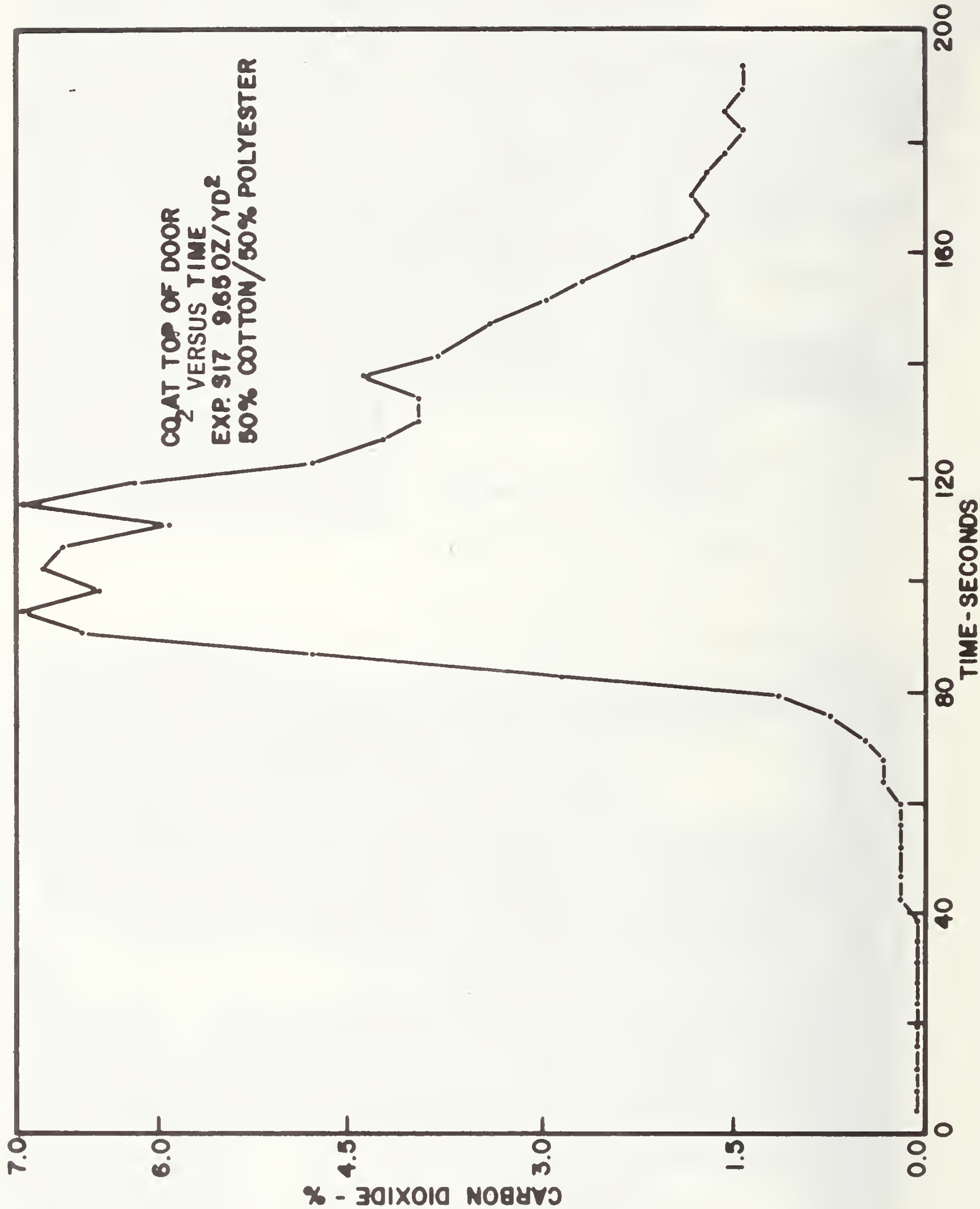


Figure 19. CO_2 at Top of Door versus Time - Exp. S17

NBS-114A (REV. 7-73)

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET	1. PUBLICATION OR REPORT NO. NBSIR 78-1448	2. Gov't Accession No.	3. Recipient's Accession No.

4. TITLE AND SUBTITLE

FULL-SCALE BURNING BEHAVIOR OF CURTAINS AND DRAPERIES

5. Publication Date March 1978

6. Performing Organization Code

7. AUTHOR(S)

L. Dow Moore

8. Performing Organ. Report No.

9. PERFORMING ORGANIZATION NAME AND ADDRESS

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

10. Project/Task/Work Unit No. 4900900

11. Contract/Grant No.

12. Sponsoring Organization Name and Complete Address *(Street, City, State, ZIP)*

Same as No. 9

13. Type of Report & Period Covered Final Report

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

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

To better understand the burning in room fire development, 38 full-scale drapery and curtain burn experiments were conducted in a 3 x 4.9 m (10 x 16 ft) room. The variables investigated included fabric and lining type, fabric weight, and position of the draperies (open vs closed). As each burning experiment progressed a number of conditions were continuously monitored such as rate of drapery consumption, air temperature increase, smoke and toxic gas generation, and radiant energy developed. Ignition of sample wall and ceiling panels was also monitored.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Curtains; draperies; flammable fabrics; full-scale fires.

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[X] Order From National Technical Information Service (NTIS) Springfield, Virginia 22151

19. SECURITY CLASS (THIS REPORT)	21. NO. OF PAGES
UNCLASSIFIED	40
20. SECURITY CLASS (THIS PAGE)	**22. Price**
UNCLASSIFIED	$4.50