NBSIR 76-1072

Back-Up Report for the Proposed Standard for the Flammability of General Wearing Apparel

E. Braun, V. B. Cobble, S. Helzer,
J. F. Krasny, R. D. Peacock and A. K. Stratton

Center for Fire Research
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National Bureau of Standards
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Final Report

Prepared for
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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, *Secretary*
Dr. Betsy Ancker-Johnson, *Assistant Secretary for Science and Technology*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Acting Director*

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Abstract

A "Proposed Standard for the Flammability of General Wearing Apparel" was submitted to the Consumer Product Safety Commission in February 1976. This report discusses the reasons for the choices of experimental arrangement for the flammability test and the choices of pass-fail criteria. The specimen is cylindrical, to simulate a garment, and to eliminate framed specimens which often burn differently from garments. Criteria for the fire hazard of fabrics are the time to ignite with a specified gas flame and the heat transferred to sensors inside the burning specimen. The proposed standard specifies that fabrics which transfer little heat to the inside of the specimens could be used in all garments but would have to be used in garments which cover most of the body and/or fit loosely. They would also have to be used in children's dresses and skirts (children's nightwear is covered by an earlier standard). Fabrics which transfer larger amounts of heat, and thus have larger injury potential, could be used in garments with normal or tight fit such as most present-day shirts, slacks, etc. If such fabrics ignite in one-half second or less, they would be excluded from use in garments. These provisions in the proposed standard were based on the need to reduce the number and severity of apparel fires with miminum economic and technological impact on the fiber, textile, and apparel industry. The present report summarizes the available knowledge in the area covered by the standard, and points out areas in which additional work is indicated.

Key words: Apparel; burn injury; ease of ignition; fabrics; fire; flammability tests; garments; heat transfer; standards.

1. INTRODUCTION

This report discusses work by the National Bureau of Standards (NBS) for the Consumer Product Safety Commission (CPSC) on the development of a draft proposed general wearing apparel flammability standard. This draft proposed standard would provide an alternative to the extension of a modified FF 5-74 standard [1][1] to additional garment categories. A copy of the "Proposed Standard for the Flammability of General Wearing Apparel" is attached which will be called the "Draft Proposed Standard" in this report. This draft is currently the subject of numerous comments and suggestions by CPSC and industry, and is under revision at the time of this writing. It should be emphasized that CPSC will make the decision whether to publish the draft proposed standard in the Federal Register for public comment. Only after analyzing such comments, CPSC will decide whether to promulgate the standard, with the appropriate revisions.

A previous report to CPSC [2] dealt with the possible modification of existing apparel flammability standards, FF 5-74 and CS 191-53 [3], for use as general apparel flammability standards. It concluded that a new test concept was indicated and recommended the following features:

- a vertical, cylindrical specimen closed on top, to simulate, as closely as possible in a laboratory test, the configuration and conditions during burning of real-life garments;

- ignition in the body of the fabric rather than at or near the botton edge, to allow the flames to spread in all directions;

- pass-fail criteria based on the ease of ignition and the rate of heat transfer to the inside of the specimen;

- and a fabric and garment classification scheme so that the relatively hazardous garments (those which cover a large part of the body and/or fit loosely) would be made from relatively safe fabrics, and less hazardous garments (which cover roughly half of the body and/or fit relatively tight) could be made from those fabrics which transfer more heat to the inside of the specimen and are considered to have a greater injury potential. Present technology does not permit exclusion of such fabrics from the market.

An apparatus which combines these features is described in detail in the draft proposed standard. It consists of a cylindrical core with a circular plate of larger diameter on top. The specimen is suspended from the top plate, ignited, and the time to ignite and the heat transfer rate to the cylindrical core and the top plate measured. The apparatus has been called the "Mushroom Apparel Flammability Tester" (MAFT).

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[1] Numbers in brackets correspond with the literature references listed at the end of this paper.

The present report describes in detail the considerations which led to the choice of the test parameters and methods. The results of ignition and heat transfer tests on a large number of commercial and experimental fabrics are discussed in the framework of the proposed fabric and garment classification. The results are also compared with those of apparel fire accident simulation and fabric extinguishability experiments. These experiments were carried out at NBS and under CPSC and NBS grants at the Massachusetts Institute of Technology (MIT) and the University of Maryland, as well as in an industrial laboratory.

NBS has had frequent and intensive discussions with industry about the general concepts and details of the MAFT and draft proposed standard. Formal presentations were made to various industrial groups, representing the fiber, textile, converting, and apparel industries; to AATCC, ASTM, ICFF, and similar groups; and to an ad-hoc committee set up by the American Textile Manufacturing Institute. Throughout the development of this test, there has been a steady stream of visitors to the NBS laboratories. Many of them tested commercial and experimental FR fabrics which they furnished; others merely came to observe, make comments, or compare results obtained with MAFTs in their own laboratories. NBS personnel have also visited textile and garment plants and the two major U.S. textile and garment retailers, as well as the facilities of Consumers Union. All suggestions have been considered in the development of the apparatus, test methods, pass-fail criteria, and other provisions of the draft proposed standard.

It is emphasized that this is a progress report. It outlines work which has been completed, as well as work in progress. It indicates where, in the opinion of NBS, additional work may lead to alternate provisions in the draft standard. This report, as well as the draft proposed standard, is offered as a basis for discussion of the technical merits and economic impact of this entirely new concept for reducing apparel flammability casualties.

2. MAFT APPARATUS AND TEST METHOD

Engineering drawings of the MAFT are shown in the attached draft proposed standard. The parameters of the apparatus were chosen to combine simulation of real-life garment fires and a practical, simple, routine laboratory method. The work leading to the major parameter choices is described; in some cases, need for further data or exploration of alternatives is indicated.

2.1. Specimen

The specimen configuration and size were chosen to simulate a garment. The specimen is a cylinder closed on top. It drapes before and during burning much like actual garments; i.e., it is able to shrink, curl, or wither in much the same manner as observed with garments on mannequins [4]. The specimen is a cylinder 18 cm (7 in) in diameter and 30.5 cm (12 in) high. Four replicates require about 0.75 m^2 (0.90 yd^2) of fabric. This is less than needed to conduct the present AATCC test for durable press appearance of fabrics and seams [5]. The diameter of the specimen is considerably less than that of skirts but about that of pants.

The height of the specimen was chosen to allow reasonable development of flames, both upward and downward. It is recognized that some fabrics do not develop a stable flame within the upward distance available in the MAFT [6,7]. However, it does not seem that this would affect the classification of these fabrics since they are likely to be in the high heat transfer rate classes, not on the borderline between classes.

Experimentation with smaller specimen sizes has been given a low priority but will be undertaken as time permits. If reasonable results are obtained, an alternative method will be submitted to CPSC.

Buchbinder [8], using an early version of the MAFT, compared results obtained with cylindrical and truncated cone specimens. The truncated cone simulated skirts with drape ratios of 1:2 and 1:3. She found significant differences in the resulting heat transfer rates between the two sample configurations for some fabrics. However, the fabrics with heat transfer rates near the limit of Class 1, 0.40 $J/(cm^2 \cdot s)$, showed no difference due to specimen shape. The experiments did not indicate better repeatability for the truncated specimens than for the cylindrical specimens. The cylindrical specimen was then specified in the draft proposed standard. It is easier to cut and requires less fabric.

The draft proposed standard specifies that half of the required number of specimens be cut with the warp (wale, machine) direction in the 30.5 cm (12 in), vertical dimension and half in the direction opposite to it. This requirement is based on the finding that the heat transfer rates of some fabrics vary depending on specimen orientation.

2.2. Ignition

The ignition source is a methane, diffusion flame, with the methane supplied at a rate of 110 cm^3/min. The orifice is a No. 18 hypodermic needle; near it is a small pilot flame. The flame is about 2.2 cm (7/8 in) long, bent upward at the end. The ignition source is positioned so that the fabric touches a hook extending 0.9 cm (3/8 in) beyond the orifice. A solenoid valve automatically regulates gas flow for the required ignition time.

Point of flame impingement is 10 cm (4 in) above the bottom edge. In this manner, the flames can spread in all directions, not only upward as in many other tests. The flame impinges for a predetermined time; during and after this time, the specimen can shrink or otherwise move, much as during ignition of full-size garments on mannequins.

For the ignition test, the surface of the fabric is exposed for 1/2 second and 1 second. Surface ignition has been chosen because it is much more likely to occur in real-life than edge ignition [9].

The operating characteristics of the ignition source were established as follows: A thermocouple was attached to a blackened copper plate, 5 cm (2 in) in diameter and 0.11 cm (0.043 in) thick. The ignition source was made to impinge on this plate and the temperature increase measured. Figure 1 shows the results of experiments in which the impingement time and the rate of methane flow was varied. The results were not sensitive to gas flow within the accuracy of setting of an ordinary flow meter. The standard error for five replicates was of the order of 5 percent. Figure 2 shows a typical set of data obtained for the effect of distance between the orifice of the ignition source and the sensor. It indicates that deviation of 1 mm (.039 in) from the prescribed distance of 9 mm (.35 in) would result in an error in energy received by the sensor of about 0.03 J/($cm^2 \cdot s$), or 2 percent.

For the heat transfer test, a small hole is cut into the fabric and the flame aligned with it. The reason for the hole is as follows: Some fabrics, such as heavy cotton and cotton-containing fabrics with FR treatments at levels which permitted limited burning, burned only on the outside and formed chars when ignited on the fabric surface. The heat transfer rates measured on the insides of specimens were low. However, when the chars were broken, these fabrics burned on both sides, and the heat transfer rates were high. In real-life apparel fires, the brittle chars could easily be broken due to the stresses imposed on garments by the movement of the victims. Consequently, this situation was simulated by ignition at a hole. Experiments were conducted which showed that the hole size is not critical between 3.2 x 3.2 mm (1/8 x 1/8 in) and 1.2 x 1.2 cm (1/2 x 1/2 in).

Time of ignition for the heat transfer test is 3 seconds. If the specimen does not ignite, ignition is again attempted in a different area for 12 seconds. The reason for two exposure times is that it has been shown that certain FR treated fabrics had longer char length when exposed to the flame for 3 seconds than when exposed for 12 seconds [10]. The opposite holds for certain wool and acrylic fabrics. Fabrics which fail to ignite in 12 seconds are considered sufficiently safe to be placed into the low hazard Class 1.

The flame size was chosen so that the theoretical rate of heat output is somewhat larger than that of a paper match. The rate of heat output of a paper match was calculated to be approximately 40 J/s, that of the burner was 65 J/s. This is based on the assumption of complete combustion of the fuel. The heat of combustion of matches was measured at NBS on an oxygen bomb calorimeter [11]. How much of the heat developed by a match or the burner is actually transferred to either the garments in real-life accidents or the specimen in the test can be determined by experiments which will be conducted as time permits. It should be emphasized that no single flame is optimum for ignition of all fabrics. Small flames have been reported to be more likely to ignite thermoplastic fabrics, while cellulosics and other fabrics ignite more rapidly with larger flames [12].

The effect of the flame parameters on the heat transfer rates has been given low priority until now but will be investigated in due course. It is possible that a larger flame would pre-dry relatively large areas in wool fabrics and FR treated cellulosics and that this would affect the heat transfer rates. It remains to be seen whether this affects fabric classification in a manner which warrants use of two ignition sources of different sizes.

2.3. Sensors

The sensors consist of a vertical cylinder and a copper ring embedded in a plate mounted on top of the cylinder. Experiments were carried out with cylinders with diameters of 12.5 and 7.6 cm (5 and 3 in). The cylinder diameter apparently did not affect fabric classification. More fabrics which shrank touched the larger cylinder, and the polymer deposits had to be cleaned off. It was therefore decided to use the smaller cylinder in the standard test. To further reduce the need for cleaning, the cylinder is surrounded by eight 3.2 mm (.125 in) diameter metal rods located 2.5 cm (1 in) from the cylinder.

Sixteen thermocouples are installed inside the cylinder, in four rows of four thermocouples each. The thermocouples are 30-gage chromel-alumel and peened into 0.075 cm (0.030 in) deep holes in the cylinder. No problem with this attachment has been found in use by NBS.

Miller at the Textile Research Institute (TRI) conducted experiments in which he eliminated thermocouples at various locations. He recommends retention of the present arrangement [13].

Two major variants of the top plate were investigated. One was made from Transite, an asbestos-concrete mix, with a 0.16 cm (1/16 in) thick, 1.25 cm (1/2 in) wide copper ring embedded. The other variant used was an aluminum top plate with cooling vanes, again, with a copper ring embedded and insulated from the aluminum by asbestos. In each case, four thermocouples were attached to the ring at 90° intervals. Comparable results were obtained with both types of plates.

The Transite plate has the advantage that the attachment of the copper ring does not require insulation. However, it requires significantly more cooling time between heat transfer rate measurements than the aluminum top plate.

A suggestion was made [13] to use a solid copper plate as top sensor, with the thermocouples attached, and to eliminate a separate sensor ring. This would be a simpler construction than the sensor ring, but the sensitivity would be reduced, due to the larger thickness of the plate which must not warp in continued use. In addition, the rings which hold the specimens and which are mounted on the top plate would either have to be of closely controlled mass and be made part of the system to be calibrated or be insulated from the top plate. It does not appear that this presents a simpler solution. NBS proposes to specify the aluminum top plate with the cooling vanes, as shown in the draft proposed standard.

Both the top plate sensors and the cylinder are blackened with dull black spray paint. The draft proposed standard specifies an emissivity of at least 95 percent. This is attained by using such spray paints as 3M Nextel velvet. The top sensor, and, to a lesser degree, the cylinder, accumulate soot and must be cleaned periodically and then repainted. The need for this will become apparent during the daily calibration.

The sensors must be cooled to near room temperature between heat transfer tests. At present, this is done by air jets. Cooling time after tests of specimens which are on the borderline of Class 1 (the only ones which would be routinely tested) are 2 to 5 minutes. Time permitting, NBS will be working on a water cooling system for the top (which receives most of the heat). The top would be shaped like a bowl, with water flowing through it at a controlled rate. The temperature difference between the inflowing and outflowing water could be used to measure the heat transfer rate. For the cooling mode between tests, the water flow rate could be increased. If this method proves feasible, it will be suggested as an alternate method at a later date.

The 16 thermocouples in the cylinder are connected electrically in parallel, as are the four thermocouples in the top sensor. The leads are all the same length to the connection point. This parallel connection averages the temperature readings of each set of thermocouples. The average reading is then fed to a recorder.

For the purpose of analyzing the operational characteristics of the MAFT, outputs of the top plate and cylinder were recorded separately, on a two-pen recorder. The rates are calculated from the slopes of the time-millivolt traces, using the appropriate constants. The results are expressed in $J/(cm^2 \cdot s)$ or $cal/cm^2 \cdot sec$ where 1 J = 0.24 cal; the latter notation is more familiar to the textile and related industries.

A circuit was designed to electronically sum the maximum heat transfer rates measured on the top plate and cylinder. It can present the results in the form of a single time-heat transfer rate trace or could be modified to show the maximum slope digitally. This circuit averages the individual slopes over approximately 8 seconds. Some fabrics, especially knitted acetate, polyester and nylon fabrics, often exhibit spurts of high heat. The averaging in the circuitry produces maximum heat transfer rate classifications for such fabrics more in accord with the injury potential of these materials as derived from apparel burn simulation experiments, as discussed below.

Daily calibration of the heat output rate by means of the photographic flood lamps, as outlined in the draft proposed standard, resulted in a range of results of only 0.008 $J/(cm^2 \cdot s)$ over 6 days. This indicates that the heat sensing and electronic recording apparatus of the MAFT gives highly repeatable results.

The heat transfer rates to the top plate were 50 to 85 percent of the total. The standard errors for total heat transfer and for top only heat transfer rates were similar for a given fabric. More specifically, setting the criterion of a fabric class at 0.40 J/(cm^2 · s) for the total and 0.25 J/(cm^2 · s) for the top only would generally not affect the classification of the fabrics tested thus far.

Based on this finding, one could eliminate the cylinder results and base the fabric classifications in the draft proposed standard on top plate measurements only. This would somewhat simplify the apparatus. On the other hand, omitting the cylinder heat transfer rate measurements may have disadvantages. Fabrics which separate during burning, fall to the bottom of the cabinet, and continue burning would probably not be evaluated properly, especially if they burn with a smokey flame, and relatively little heat would be received by the top sensor. This could cause an industry trend toward treating fabrics, not to control total heat release rate, but to minimize heat transfer to the top by decreasing melt viscosity, and consequently, increasing ablation. Such a trend has already been started by the arrangement in FF 5-74, which measures only upward char length and disregards sideward and downward burning, thereby, promoting ablation as a means for passing the test. The relationship of this trend to real hazard cannot be readily explored by garment fire simulation in the laboratory. If large portions of the fabric ablate or if melting polymer runs down the garment, they may contact the lower body of the victim or his lower garments and cause injury or spread the fire. Because of this uncertainty, NBS has chosen to maintain the provision for measuring the heat transfer rate to both the cylinder and top in the draft proposed standard. The effect of fabric ablation and burning at the foot of the cylinder will be more fully investigated.

Miller [13] suggested raising the cylinder by means of a nonflammable block, to avoid heat flux readings due to ablated material. NBS feels that this material does present a hazard and should not be eliminated from heat flux measurements.

2.4. Conditioning

Many fabrics have been shown to ignite in shorter exposures to ignition sources, and burn with higher flame spread rates when oven dried, than when tested at a higher relative humidity (RH) [14,15]. The effect of moisture content of the fabrics on heat transfer is not known but can be expected to be in the same direction as ignition time and flame spread rate. A NBS report [16] showed that fabrics dry to the level of oven drying in a few minutes when exposed in front of a space heater. The same report showed that many U.S. homes have low RH, expecially in winter, and that garments are in equilibrium with the ambient atmosphere when they are more than about 3.7 cm (1-1/2 in) from the skin, as in most dresses and similar garments. At closer distances, perspiration may increase the moisture content of the garments. For these and other reasons, CPSC has maintained the oven drying requirement for the children's sleepwear tests, in which prevention of injury took preference over test simplicity.

However, specifying longer ignition time pass-fail criteria and higher RH during conditioning and testing will presumably provide results equivalent to specifying slightly less stringent criteria and oven dried specimens. Oven drying of the specimens used for the MAFT would require considerable oven and desiccator space. On the other hand, rooms held at the standard textile testing conditions, 21 ± 1.1 °C (70 ± 2 °F) and 65 ± 2 percent RH are available in many textile mills. To obviate the need for special facilities for flammability testing, the draft proposed standard specifies that conditioning and testing can be conducted at temperatures down to 16 °C (60 °F) and up to 67 percent RH. CPSC would have to have at least one laboratory capable of maintaining these conditions for the testing of borderline specimens.

2.5. Cabinet

A cabinet, 51 x 51 x 51 cm (20 x 20 x 20 in), for the MAFT is specified in the draft proposed standard, to permit use of the apparatus regardless of the draft conditions in the test room. During the early part of the work, tests were conducted in an enclosure with similar dimensions but open at the top and 6.25 cm (2.5 in) above the base of the MAFT. No major effect of the type of enclosure on the results was found, and no further experimentation with varying enclosure geometries is anticipated.

2.6. Hood Draft and Safety

The draft proposed standard recommends a low draft in the hood during testing. No experiments with the effect of hood draft have been conducted but this will be given priority in future experimentation. If necessary, a maximum air speed for the hood will be included in addition to the draft proposed standard. A hood with provisions for bottom exhaust may be more efficient in removing pyrolysis products after the test than up-drafts.

In practice, no extensive fabric burns are expected in testing on the MAFT. Heat transfer rate tests would be carried out only on fabrics which would be expected to be in Class 1 and burn tenuously. Fabrics can be extinguished in ignition testing as soon as the flame base spreads 10 cm (4 in) in any direction beyond the point of ignition.

2.7. Calibration

The timing of the exposure to ignition relies on electrical timing devices. A timer/counter combination with a counter accuracy of 0.5 ± 0.05 seconds would provide sufficient control to insure accurate timing at all ignition times provided in the draft proposed standard (0.5, 1, 3, and 12 seconds).

A satisfactory calibration procedure for heat transfer rate employs two tungsten lights used for movie making (3,400 K). The position and angle of the lights are described in the draft proposed standard. An aging study was performed on such movie lights, for a total of 446 hours time, with 20 seconds on-time, 90 seconds off-time. The lamps became nonfunctional after this trial, but there was no gradual deterioration in output. However, heat output was found to be sensitive to the line voltage, and the draft proposed standard requires use of a volt meter-transformer combination to attain a constant voltage of 120 volts.

An alternate calibration method, using a special gas burner, is under investigation.

3. FABRIC AND GARMENT CLASSIFICATION

3.1. Classification Scheme

The fabric and garment classification scheme is shown in table 1. It directs the available supply of low-hazard "Class 1 fabrics" into high-hazard "Class 1 garments." Higher-hazard fabrics can still be used in lower-hazard garments (Classes 2 and 3). Fabrics which ignite in a very short exposure to an ignition source, and generate substantial amounts of heat, are in Class 4 and cannot be used in garments. The draft proposed standard is thus intended to replace CS 191-53 for the purpose of eliminating extremely hazardous fabrics from the apparel market, as well as to further reduce frequency and severity of garment fire burn injuries.

Table 1. Fabric and Garment Classification

Class	Maft Criteria		Garments Required to be in Class	Fabrics Found to be in Class
	Heat Transfer Rate ($J/cm^2 \cdot s$)	Time to Ignite (s)		
1	≤ 0.40	3 or 12	Loose-fitting, full-cover garments except raincoats, overcoats Loose-fitting, half-cover garments All dresses, skirts through children's size 14	Many 100% nylon, polyester, some wool, modacrylics, FR cellulosics, acetate
2	>0.40	>1	Tight-fitting, full-cover garments Tight-fitting, half-cover garments for the lower body All garments through children's size 14 except those required to be in Class 1 Raincoats and overcoats	Heavy and medium weight cellulosics and their blends: acrylics, acetate
3	>0.40	1>1/2	Tight-fitting, half-cover garments for the upper body	Cellulosics and their blends, 120-150 g/m^2 (3.5-4.5 oz/sq yd
4	>0.40	$\leq 1/2$	Excluded from use in any garment	Cellulosics and their blends, 70-120 g/m^2 (2.0-3.5 oz/sq yd)

Notes: Full-cover and half-cover garments are defined by shoulder seam-botton hem distance, and loose-fitting and tight-fitting garments are defined by waist, sweep, sleeve width, and pants leg width dimensions shown in tables in the draft proposed standard.

3.1.1. Hazard Criteria

The draft proposed standard is based on fabric and garment classification according to probability of ignition and probability of extensive burn injury. The criteria for probability of ignition are the time to ignite for fabrics and the looseness of fit for garments. The criterion for probability of extensive injury is the rate of heat transfer from the burning fabric specimen to the sensors in the MAFT.

The choices of hazard criteria, and of the pass-fail levels in the draft proposed standard, were based on analysis of injury patterns in real-life garment burn accidents (see 3.2.) and of garment fire accident simulations (see 3.3.). Practical considerations also entered into the setting of the pass-fail levels; e.g., safety would require as long as possible ignition times. However, NBS has found that requiring ignition times of more than one-half second could have severe economic and technological impact on certain markets; e.g., shirts and blouses. Similarly, the choice of garment dimensions is based on tight fit consistent with comfort, ease of movement, and ease of putting on and taking off the garment. The pass-fail value for heat transfer rate is based on the results of a variety of laboratory garment fire simulation experiments. The compromise with economics and technology here lies within the fact that tenuous burning is allowed. Insistence on self-extinguishment, as in the children's sleepwear standards, would severely limit fabric choice and could cause substantial price increases.

Heat transfer rate, as measured in the MAFT, was chosen as one of the criteria for fabric classification because it is the heat transferred to the body inside a burning garment which causes injury. Flame spread rate has been one of the traditional measures of fabric flammability but was not used for the following reasons: linear flame spread rate would not be a good measure of the hazard of such fabrics as acetate and polyester, which burn sidewards and downwards, as well as upwards. Measurement of the area flame spread rate would be more appropriate, but is experimentally quite difficult. Flame spread rate is also no guide to heat output because heavy fabrics have low flame spread rates but produce considerable amounts of heat per unit area. This heat can rise inside garments and cause injury in areas not near the actual burning surface [18]. Finally, no well defined relationship between a measure of flame spread rate and the extent of injury in real-life fire accidents was established (see 3.2.2.).

Fabrics with low heat transfer rate are in Class 1. Fabrics not in Class 1 are classified into Classes 2, 3, and 4 by time to ignite. This criterion was chosen because fabrics which require long exposure to an ignition source for ignition are less likely to be involved in a garment burn than those which ignite rapidly.

The classification of garments according to flammability hazard is based on length and width dimensions of the garments in relation to their body measurements (see 3.1.3.). Investigation of real-life garment fire injury patterns indicates that larger burn injuries are generally associated with garments which cover most of the body (e.g., nightgowns, robes, dresses) than with half-cover garments (e.g., shirts, pants) (see 3.2.3.). Loose garments are more likely to ignite than tight fitting ones and have been shown to be more likely to cause extensive burns in mannequin experiments (17,18,26). The draft proposed standard, consequently, classifies garments into full-cover and halfcover garments (table 1 of draft proposed standard and 3.1.3.1.). For each group, it classifies by width dimensions. Tighter fit is specified for Class 2 full-cover garments (table 2) than for half-cover garments in Classes 2 and 3 (tables 3 and 4).

The limiting garment dimensions for Classes 1, 2, and 3 were chosen to assure maximum safety compatible with comfort, ease of movement, and ease of putting on and taking off the garments. The dimensions which assure the latter characteristics were determined from discussions with stylists, studies of garment patterns, and observations of garments varying in fit on models. The limitations they place on the garment manufacturer are, thus, primarily in the area of styling for appearance. No styling feature is eliminated as long as Class 1 fabrics are used.

Stricter requirements are applied to children's garments, up to children's size 14, than to larger garments. This is based on the frequent involvement of children in this age group (up to 12 years) in fire accidents (see 3.2.1.).

The draft proposed standard assigns the responsibility for fabric classification to the fabric manufacturer or finisher. The garment manufacturer receives a fabric labeled with the appropriate class designation. He can use Class 1 fabrics in all garments but has to control the length and lateral dimensions when using Class 2 and 3 fabrics. For some garment manufacturers, this will mean increased effort in sizing control. On the other hand, improved control of sizing may benefit consumers, making it easier to buy according to labeled size rather than trying on garments in the store.

Table 2. Age Distribution by Garment Type for First-to-Ignite Garments

No Flammable Liquid Contamination

FFACTS Data Base, November 1975

Item Type	Age						Total Number*
	0-5		6-12		13+		
	No.	%	No.	%	No.	%	
Percentage of U.S. Population		10		14		76	
Pants	20	16	26	21	80	63	126
Shirts and Blouses	44	14	61	19	216	67	321
Pajamas	80	38	64	31	65	31	209
Robes	14	9	13	8	135	83	162
Dresses	41	29	38	27	63	44	142
Nightgowns	53	28	59	32	74	40	186
Total	252	22	261	23	633	55	1,146

*Number of cases in FFACTS where the age of the persons involved is known.

Table 3. Relationship Between CS 191-53 Burn Time and Area of Body Burned

Non-Contaminated, First-to-Ignite Garments, FFACTS, Nov. 1975

Garment Type	Spearman's Correlation Coefficient	Number of Garments
	A. 100% Cotton	
Pajamas	-0.07	117
Nightgowns	-0.03	87
Shirts and Blouses	-0.08	83
Robes	-0.02	52
Dresses	-0.07	45
Pants	-0.09	22
	B. Polyester/Cotton Blends	
Shirts and Blouses	0.01	65
Pants	0.35	19
Dresses	0.26	16

Table 4. Fatalities by Garment Type for First-to-Ignite Garments

No Flammable Liquid Contamination

FFACTS Data Base, November 1975

Item Type	A. All Cases			B. Victims $\geq$ 13 Years of Age		
	Number of Cases*	Number of Fatalities	Percentage of Fatalities	Number of Cases*	Number of Fatalities	Percentage of Fatalities
Pants	120	11	9	76	10	13
Shirts and Blouses	289	14	5	190	14	7
Pajamas	193	23	12	62	18	29
Robes	147	47	32	123	44	36
Dresses	122	24	20	57	22	39
Nightgowns	153	29	19	54	17	32
Total	1,024	148	14	562	125	22

*Includes only those cases for which information on recovery or death of victims is available in FFACTS.

3.1.2. Classes

3.1.2.1. Class 1

Class 1 includes the safest fabrics, those which either do not ignite or self-extinguish after 3 or 12-second exposure to the MAFT ignition source; or, if they ignite, burn tenuously, transfer little heat to their surroundings and have been found to be relatively easily extinguished. Such fabrics have been found to have heat transfer rates of 0.40 $J/(cm^2 \cdot s)$ or below (see 3.3.).

However, such fabrics are not self-extinguishing in the sense of the children's sleepwear standards, FF 3-71 and FF 5-74. These standards eliminate so many fabrics from the market that their extension to other garments could result in severe economic and technological impact.

There is a possibility that a fabric passing FF 3-71 or FF 5-74 is not in Class 1 of the draft proposed standard. Fabrics which burn downward and sideward could transfer heat to the MAFT sensors at a high rate. They could, however, have a low char length in the FF 3 or FF 5 tests. In these tests, they are ignited at the bottom edge, and the upward char length is measured.

Class 1 fabrics can be used in all garments, except children's sleepwear, regardless of configuration. Examples of fabrics which usually meet the criterion of Class 1 include many 100 percent nylon, polyester, modacrylic, and wool fabrics; and FR treated cotton, polyester/cottons, polyester/rayons, acetate, triacetate, etc.

Table 1 shows that Class 1 garments include all children's dresses and skirts because of the high fire accident rate for this age group (see 3.2.1.). Class 1 also includes all loose-fitting garments except overcoats and raincoats. It is felt that such coats are probably worn less frequently near sources of ignition than many other garments. No Class 1 material (except some wool fabrics) could be readily substituted for fabrics in present use in most coats.

3.1.2.2. Classes 2 and 3

Class 2 and 3 fabrics have heat transfer rates in excess of 0.40 $J/(cm^2 \cdot s)$. That means they continue to burn in the MAFT until at least a substantial part of the specimen is consumed, with considerable rate of heat transfer to the sensors. They show similar behavior in garment fire simulation experiments (see 3.3.1. and 3.3.2.). Such fabrics also have been found generally to be relatively difficult to extinguish (see 3.3.3.). They have considerable injury potential but cannot be eliminated from the market because of technological and economic impact. Without them, there simply may not be enough fabric to clothe the population adequately. The draft proposed standard limits such fabrics to use in garments with a relatively low likelihood of ignition; i.e., relatively tight-fitting garments. Tight-fitting garments can be visualized to have one or more fire stops. If such garments ignite, heat can presumably be felt sooner by the victim because of the low garment-body distance. Attempts to extinguish or remove the garment would generally start earlier in tight-fitting than in loose-fitting garments because the victim is generally aware of the fire sooner when wearing tight-fitting garments.

Class 2 fabrics do not ignite during a one-second exposure to the MAFT ignition source. Class 3 fabrics ignite within one second but not within one-half second.

Fabrics which usually meet the criteria of Class 2 include many acetate, acrylic, and lightweight wool fabrics, as well as smooth surface, medium and heavyweight fabrics containing cellulose (100 percent cotton or rayon and their blends with polyester, nylon, or acrylics). Among the fabrics tested thus far, the borderline weight range for cellulosic Class 2 fabrics was 135 to 170 g/m^2 (4 to 5 oz/sq yd). It appears that some cotton flannels are in this class. The draft proposed standard permits testing after laundering and tumble drying and does not require brushing up of pile as does CS 191-53. It is doubtful that flannel pile or nap is in the brushed-up condition any time during use.

Table 1 lists the garments which must be made from Class 2 (or Class 1) fabrics but cannot be made from Class 3 fabrics. This includes all children's garments, up to children's size 14, except dresses and skirts which are Class 1. It includes full-cover garments, provided they fit tightly; looser full-cover garments are in Class 1. However, raincoats and overcoats are in Class 2, regardless of fit. Class 2 also includes tight-fitting garments covering only the lower body.

Class 3 fabrics ignite in one second but not in one-half second. This includes many lightweight cotton, rayon, acetate, and triacetate fabrics and their blends with polyester or nylon. Such fabrics are used in a portion of the shirts, blouses, dresses, nightgowns, robes, pajamas, etc., presently in production. The draft proposed standard removes them, because of their short ignition time and high heat transfer rate, from all full-cover garments, all children's garments, and from half-cover garments covering the lower half of the body. Elimination of Class 3 fabrics from half-garments covering the upper half of the body, primarily shirts and blouses, appears impractical because of the severe economic and technological impact of such a step. However, elimination of garments which ignite in one-half second may be desirable from a safety point of view, and can perhaps be accomplished in a few years.

3.1.2.3. Class 4

Class 4 fabrics ignite within one-half second exposure to the MAFT ignition source. This includes lightweight cellulosic fabrics, with the upper limit in the 70 to 100 g/m^2 (2 to 3 oz/sq yd) range. It also includes heavier cellulosic fabrics with piles, such as some cotton terry and the infamous brushed rayon, torch sweater fabric. The draft proposed standard eliminates such fabrics from use in garments.

3.1.2.4. Effect of Classification on Fabric Market

CPSC and the textile and garment industries will undoubtedly conduct intensive studies of the economic and technological impact of the draft proposed standard. According to preliminary discussion with industry representatives the following major market changes could probably be caused by its adoption as written:

> The major impact would be on cotton and polyester/cotton fabrics which have an important share of the nightgown, dress, blouse, and pajama markets. Many garment producers would switch to 100 percent nylon or polyester fabrics. This trend already exists but would probably be accelerated. The other possibility is greater use of the existing FR treatments for cotton and commercialization of the experimental FR treatments for polyester/cotton. A number of such treatments have been evaluated on the MAFT. It was found that phosphorus concentration had little effect on the MAFT heat transfer rate until a concentration of 1/2 to 3/4 of that needed to pass the children's sleepwear tests was reached. At this level, a small increase in phosphorus content brought the fabric into Class 1. The actual concentration depended on the fabric construction, polyester content, and type of treatment. It should be mentioned that all these results were obtained on experimental fabrics, and commercialization of these treatments, as well as combination with the popular durable

press treatments, may still be some time away. The lower concentration, as compared to that needed to pass the children's sleepwear standards, should result in small savings in cost, less stiffening of the hand due to treatment, and easier quality control in the mill.

Acetate may now account for 5 to 6 percent of the apparel market, much of it in Class 1 garments. A commercial treatment is available for acetate, but the increase in price may make it less competitive with 100 percent polyester or nylon, which generally do not require treatments. No commercial treatment is available for the popular 80/20 acetate/nylon blends.

The effect of the ignition time requirements would primarily be an increase of the weight of some of the polyester/cotton and cotton fabrics for use in Class 2 and Class 3 garment configurations. It may also eliminate some cotton terry fabrics from the garment market. These fabrics now pass the CS 191-53 test, but many of them ignite in one-half second on the MAFT.

3.1.3. Garment Dimensions

Body measurements for children and adults are listed in a series of voluntary and commercial standards [19]. The fit requirements for garments which can be made from Class 1, 2, or 3 fabrics are shown in tables 1 through 4 of the draft proposed standard. They are based on the body dimensions given in the standards plus an "oversize" or "ease." The magnitude of this oversize was chosen on the basis of fire safety as well as of comfort, ease of movement, and ease of donning the garments. The details are given below.

3.1.3.1. Classification Into Full- and Half-Cover Garments

Dimension A in figure 3 is the garment length. It is determined by laying the garment flat and measuring the distance from the highest point of the shoulder straight down the front, parallel to the center front of the garment. All garments which cover the upper body and have a length dimension exceeding

$$\frac{\text{vertical trunk girth given in the sizing standards}}{2} + 10 \text{ cm (4 in)}$$

are considered full-cover garments. Division of the measurement given by the sizing standards by 2 is necessary because the vertical trunk girth body dimensions in the sizing standards are measured from the shoulder through the crotch and back to the shoulder. Full-cover garments, according to this formula, reach somewhat less than 10 cm below the crotch. Ten centimeters were chosen so that most shirts, blouses, vests, sweaters, sport coats, shirt jackets, and similar items presently on the market would be classified as half-garments. Full-cover garments would be dresses, nightgowns, robes, etc.

For children's garments, up to children's size 6X, maximum half-garment length is vertical trunk girth/2. These garments are approximately crotch length. An allowance of 10 cm below the crotch would permit garments to approximately the knee for some of the smaller sizes. This would provide little protection for this population group which is frequently involved in burn accidents, with particularly severe consequences.

Skirt and pant-type garments are exempted from the length requirements because of the fire stop at the waist. They are classified by sweep measurements which attempt to lower the probability of ignition.

3.1.3.2. Lateral Garment Fit

3.1.3.2.1. Waist Dimensions

Dimension B in figure 3 is the waist measurement. This measurement, as well as the sweep and sleeve measurements, determine whether full-length garments can be made from Class 1 or 2 fabrics. Class 3 fabrics are excluded from full-length garments because of their higher injury potential in such garments and availability of sufficient Class 1 and 2 fabric for this market.

Ten centimeters (4 in) oversize is required at the waist for comfort, freedom of movement, and ease of putting on the garment. Full-length garments exceeding or equaling this oversize must be made from Class 1 fabric. Full-length garments with less than 10 cm oversize can be made from Class 2 fabrics, provided they do not exceed the sweep and/or sleeve requirements. If the waist fit is achieved by use of a belt, the belt must be permanently attached to the garment, lest it not be used.

The draft proposed standard does not have a waist specification for half-garments which cover the upper part of the body and relies on the sweep measurement for specifying fit.

3.1.3.2.2. Sweep Dimensions

Sweep dimensions, shown as C in figure 3, are specified in tables 2 through 4 of the draft proposed standard, for various garments. The dimensions chosen are based on the need to keep sweep at a minimum to reduce danger of ignition, consistent with the need for freedom of movement, particularly the ability to walk comfortably. This requires that the sweep increase with distance from the waist downward; e.g., floor-length garments require about 25 cm (10 in) more sweep than knee-length garments. Sweep dimensions are, consequently, specified for measurement in the knee region as well as below. The permissible sweep dimensions given in the tables were based on actual measurements on garments worn by models and represent sweeps at which the models could walk freely. It is considered the lower limit of "moderate flare" by stylists and in descriptions of garments on home sewing patterns. Sweep dimensions for half-garments covering the upper body were chosen on the basis of similar considerations.

The draft proposed standard also includes provisions for the sweep of pant-like garments, Dimension E, figure 3. It specifies that very wide pants; e.g., wide pajamas or palazzo pants, be made from Class 1 fabrics. Class 2 fabrics can be used in all other pants.

3.1.3.2.3. Sleeve Dimensions

Sleeve dimensions should be kept at a minimum to prevent ignition from kitchen ranges, etc. All too many robes, which are frequently worn for cooking, are made with wide, sweeping sleeves. The size standards do not give wrist sizes for all garment types; however, upper arm girth is listed in all standards. Wrist size is always smaller than upper arm girth. A small oversize over the upper arm girth was chosen to allow easy putting on and taking off of the garments and to still result in low likelihood of inadvertent ignition of the sleeve. The sleeve dimension, D in figure 3, applies to anywhere below the elbow, even if the sleeves are gathered at the wrist.

3.1.3.3. Garment Layers

According to stylists and garment patterns, a reasonable oversize for garments intended to be worn over other outer garments, e.g., suit coats, blazers, etc., in 5 cm (2 in) more than the inner-layer garment. This has been considered in the draft proposed standard.

Certain garments like overcoats, which are intended to be worn over one or two layers of outer garments, can be made from Class 2 fabrics regardless of length and fit dimensions. This was based on the low likelihood of exposure of such garments to many ignition sources and on the ease with which they usually can be taken off.

3.2. Analysis of Real-Life Garment Fire Accidents (FFACTS Data)

The Flammable Fabrics Accident Case and Testing System (FFACTS) is a collection of in-depth reports on fire accidents involving fabric products. The reported accidents were not selected on a statistical basis, and they do not constitute a statistically representative sample of all fabric fire accidents in the United States. Nevertheless, they represent events investigated without known preference.

Processing of the reports and fabric samples received by NBS included reviewing and screening of the accident reports, laboratory testing and characterization of the fabric products involved, data encoding, formatting, editing, and entry into a computer masterfile for retrieval. Some 130 different data elements can be coded for each accident. They include time and location of the accident; personal and socio-economic facts about the victim; ignition sequence; the victim's reaction; and garment type, fabric construction, weight, and results of flammability tests carried out on remnants of the garments involved in the accident, when they are supplied. For most of these cases, FFACTS also provides the percent "total area of body burned." This data element is used to estimate injury severity. This is the approximate percentage of the body which suffered first, second, and third-degree burns. This area is related to mortality as well as morbidity.

The total area of body burned depends on an interaction of human behavioral factors and of the physical flammability characteristics of garments and fabrics. The most important human behavioral factors are exposure to an ignition source and the effectiveness of defensive action after a garment ignites. Such action varies greatly, from increasing the level of fire; e.g., by running, to very effective attempts at extinguishing or removing the garment [9]. The effect of garment and fabric flammability characteristics on the total area of the body burned is, thus, somewhat masked by the effects of the human response to the fire. However, the analysis of FFACTS still demonstrates certain phenomena which can be ascribed to physical flammability factors. These will be discussed on the following page.

A preliminary analysis of FFACTS, with respect to injury severity, was published in 1973 [20]. This analysis has been expanded to use all cases entered into FFACTS by November 1975. There were 1,373 garment fire cases in which a specific garment was known to be the first item to ignite and in which the garment was not contaminated by flammable liquids. In the following discussions, the cases are categorized by the first-to-ignite garment. Other garments were frequently involved during later stages of the accident.

3.2.1. Age of Victim

The draft proposed standard requires that all dresses and skirts up to children's size 14 (covering children from 0 to 12 years of age) be made from Class 1 fabrics. (Larger sizes can be made from Class 1 or 2 fabrics, depending on fit.) Other children's clothing; e.g., pants and shirts, can be made from Class 2 but not Class 3 fabric. The reasons are discussed below.

Approximately 24 percent of the U.S. population is under 13 years of age [21]. However, 45 percent of FFACTS cases involve children under 13, as shown in table 2. More specifically, children under 13 were involved in 60 percent of the nightgown cases, 66 percent of the pajama cases, and 17 percent of the robe cases. This led to the children's sleepwear standards, FF 3-71 and FF 5-74, which should minimize this toll. However, children under 13 were also involved in 56 percent of the dress cases, 33 percent of the shirt and blouse cases, and 37 percent of the pants cases. Consequently, the draft proposed standard requirements for children's garments up to size 14 are more severe than those for the general population, to provide special protection for this apparently more vulnerable part of the population.

3.2.2. Fabric Burn Time

The flammability characteristics of the garments in FFACTS were tested whenever sufficient fabric was retrieved from the burn accident. The flammability was measured in the CS 191-53 tester and expressed by the "burn time." This is the sum of the time to ignite by forced ignition plus the time it took to break a trip thread 12.7 cm (5 in) from the point of ignition. In figure 4, the burn times were divided into four groups and the area of the body burned into four groups. The distribution of cases by percent of area of body burned is shown for each of the six major garment types in FFACTS. No relationship between burn time and size of burn injuries in real-life accidents is indicated. The same is shown by table 3, listing the Spearman Correlation

Coefficients for the relationship between the burn time and the total area burned.

Accordingly, the criterion used in the draft proposed standard for differentiation between Class 1 and the other classes is the rate of heat transfer from the burning specimen to the sensors. This is independent of flame spread rate and fabric weight. Other reasons for this choice have been discussed previously in 3.1.1. However, the other criterion for classification, time to ignite, is inversely related to fabric weight for most fabrics. Fabric weight thus affects classification of the fabrics into Classes 2, 3, and 4, and heavier fabrics still appear safer from an overall point of view.

3.2.2.1. Garment Configuration

The garment classification of the draft proposed standard is based on the concept that long and/or loose garments are more hazardous than tight-fitting garments which cover only half of the body. This section discusses findings in FFACTS which appear to support this concept. Additional support of the concept is derived in the analysis of garment fire simulation experiments (section 3.3.).

Buchbinder [9] and Vickers [20], using FFACTS data, showed that fires of garments which covered over half of the body are associated with more extensive burn injuries than fires involving half-cover garments. This is also shown in figure 5, where the total area of the body burned has been divided into four categories, for the six major garment categories represented in FFACTS.

Full-cover garments — nightgowns, robes (including housecoats), and dresses — appear to have more injury potential than half-cover garments — pants, shirts, blouses, and pajamas. For example, more than 45 percent of the cases involving these half-cover garments resulted in burns to less than 10 percent of the body. However, only about 35 percent of the cases involving robes and dresses and only about 25 percent of the cases involving nightgowns resulted in burns to less than 10 percent of the body. Furthermore, less than 10 percent of the cases involving half-garments resulted in burns to at least 50 percent of the body; whereas, more than 15 percent of the dress cases and more than 20 percent of the robe and nightgown cases resulted in such large burns. There are also many more cases with burns to more than 20 percent of the body in the full-cover garments than in the half-cover garments.

Many of the nightgown, robe, and pajama cases, represented by the bars in figure 5, involved children under 13 years of age, as discussed earlier. These garments have been covered by the children's sleepwear standards and no longer present a flammability hazard. Figure 6 includes only those FFACTS cases involving persons 13 years or older. Again, full-cover garments caused more severe injuries than half-cover garments at each level.

Table 3 shows the fatality data from FFACTS for the six garment types. The fatality data contained in FFACTS are probably conservative because the reports were generally written soon after the accident, and death may occur weeks or months later. Such late deaths were probably not noted in FFACTS.

Part A of table 4 gives the data for all FFACTS cases where fatality information was available, Part B for victims 13 years or older. The tables, again, indicate that full-cover garments are more hazardous than half-cover garments. There is a higher precentage of fatalities for each of the full-cover garments than there is for each of the half-cover garments. The percentage of fatalities is higher for ages 13 and above, than for all ages. The reason is the greater susceptibility of victims over 65 to serious burn injuries [22] and the higher mortality rate of such victims for a given size burn injury [23].

3.2.2.2. Garment Fit

FFACTS does not contain data on the actual fit and configuration of the various garment types. However, the full-cover garments — nightgowns, robes, and dresses — in general, fit more loosely than the half-cover garments — pants, shirts, and blouses. FFACTS does not permit conclusions as to whether the higher injury potential of the full-cover garments is due to their length or their looser fit. However, burning of dresses with and without belts on mannequins indicated that the beltless dresses would cause larger injuries [18]. Figures 5 and 6 show that pajamas which can be considered loose-fitting half-garments inflicted larger injuries than the generally more tight-fitting blouses, shirts, and pants.

Buchbinder [9] found that, in most FFACTS cases, ignition occurred in the loosest area of the garment. Hayes [24] analyzed FFACTS for garment fires caused by space heaters. He found 77 cases in which the space heater contacted the garments, without involvement of any intermediary material or flammable liquid. Nightgowns, dresses, and robes accounted for 82 percent of these garments. Again, to eliminate the possible bias introduced by including children's sleepwear, Hayes' data on direct ignition involving persons 13 years of age and over were analyzed. There were 27 cases of this type, of which, 24 cases (89 percent) involved dresses, nightgown, and robes. It seems reasonable to conclude that loose garments are more likely to contact this type of ignition source than more tight-fitting garments. Experimental work with sleeves exposed over a range has shown that for any one fabric, time to ignite depends primarily on sleeve width [25]. While time did not permit similar studies for other ignition sources, there is no reason to believe that the same effect of fit would not also apply to other ignition sources.

3.3. Garment Fire Simulation Experiments

The draft proposed standard specifies that Class 1 fabrics have a heat transfer rate not exceeding 0.40 J/(cm^2 · s). This pass-fail level has been chosen because a variety of garment fire simulation experiments indicated that fabrics in this class have low injury potential. They either self-extinguish or burn tenuously and are easily extinguished. The experiments are described below.

3.3.1. Mannequin Burns

Many garment fire simulation experiments consist of burning of garments on mannequins. Procedures for such mannequin burns and some results can be found in the literature [18,26]. Optimum procedure requires that the mannequin surface be instrumented for heat flux measurements. Then the area which receives sufficient heat to cause a second-degree or deeper burn in skin can be determined as a function of time since ignition. It has been found that the early time period of garment fires on mannequins show the largest differences due to fabric fiber content and construction. If garments are allowed to burn to completion, similar mannequin areas receive potentially injurious amounts of heat, and in many cases, relatively little difference between fabrics is observed. Exceptions are, of course, fabrics which self-extinguish.

The most sophisticated mannequin available is "Thermoman," a full-size [approximately 185 cm (6 ft, 1 in)] male mannequin, used primarily by the armed forces to measure the effectiveness of heat protective clothing. The Textile Research Laboratories of E. I. du Pont de Nemours and Company, Inc., uses one of these mannequins for the evaluation of garments [26]. The output from approximately 120 sensors on the mannequin surface is measured every 2 seconds. The injury potential is expressed in the form of the "B" value. It is a function of the area of the mannequin receiving at least 10.5 J/cm^2, weighted by higher heat flux, in 80 seconds. Most of the garments burned, to date, were fairly tight-fitting A-line dresses, and they were ignited at the hem near the knee. Other garment geometries and other ignition points can produce results quite different from those found in A-line dresses [27]. However, there is little doubt that "Thermoman" is among the best means for garment fire simulations.

Figure 7 compares "B" values with MAFT heat transfer rate results. The two experiments measure very different flammability characteristics, and no 1:1 correlation should be expected. However, it is important to choose the Class 1 pass-fail heat transfer rate criteria so that no fabric with a high injury potential, as illustrated by the "Thermoman" and other garment fire simulations, is in Class 1. The figure shows that Class 1 fabrics had, indeed, very low "B" values. An analysis of the "Thermoman" areas subjected to a total heat value of 10.5 J/cm^2 or more, 15, 30, 45, and 60 seconds after ignition, does not indicate major changes in the ranking of the fabrics as compared to "B" values.

There are, however, four fabrics which are not in Class 1 but have low "B" values. One fabric is a lightweight wool; the others are a knitted and a woven acetate and a 80/20 acetate/nylon knit fabric. These fabrics apparently self-extinguished on "Thermoman" before a significant amount of heat was transferred to the sensors. It must be remembered that the sensors are some distance from the area of the dress where the burn starts, and any heat generated which travels upward inside the garment is distributed over a relatively large area. The same fabrics showed more injury potential in a different type of garment fire simulation, as discussed below.

3.3.2. Movement Simulation Experiments

Interpretation of mannequin fire results is often difficult because it depends, among other things, on the initial distance between the complex configuration of the mannequin. This distance can, of course, change in real-life due to movement of the wearer and turbulence effects. It has been observed that burns slow down and often extinguish when the burning garments touch the mannequin. Similar observations have been made when burning fabrics touch animal skin [18]. Actual heat flux to sensors of a mannequin thus depends, in a very complex manner, on point of ignition, initial garment fit, drape, fabric wrinkling, turbulence, and their changes during the burn.

NBS constructed the apparatus shown in figure 8 in order to be able to simulate the effects of movement and thus contact of fabric and body during the fire. It also attempted to eliminate many of the difficulties encountered with burning of garments on such complex forms as mannequins by using a semi-cylinder as the simulated body and a well defined specimen configuration. The work was carried out by the Research Associate sponsored by the Man-Made Fiber Producers Association, who is writing a detailed report [28].

The simulated body is a semicylinder, 20 cm (8 in) in diameter and 46 cm (18 in) high. It is almost completely covered by 54 copper sensors. In most experiments carried out to date, the fabrics hang freely at first. The body was tilted to make contact with the burning fabric when the flame base reached 23 cm (9 in) from the point of ignition. Experiments in which tilting occurs at a specified heat flux are in progress.

The approximate level of heat at which second-degree burns occur is 8.4 J/cm^2 or somewhat above, depending on the rate at which the heat is delivered [29]. (E. I. du Pont de Nemours and Company, Inc., uses 10.5 J/cm^2 in their calculations, as discussed above.) The round symbols in figure 7 show the results of the movement simulation experiments, in terms of percent area of the simulated body which received 8.4 J/cm^2. Again, no Class 1 fabric transferred heat over more than 5 percent of the area of the simulated body. In addition, all fabrics not in Class 1, including those which had low "B" values in the "Thermoman" experiments, transferred heat at the potential burn injury level to more than 25 percent of the simulated body. It should be noted that the total area of the simulated body of the movement simulation apparatus is about 0.145 m^2 and that of "Thermoman" is more than 10 times as much. The other major difference between the movement simulation and "Thermoman" experiments is, that in the former, the heat delivered is that during the burn of the free-hanging specimen plus that delivered during contact until extinguishment, while "Thermoman" "B" values are given for 80 seconds whether extinguishment occurs or not. In fact, some of the garments continue to burn and cover large areas after 80 seconds [27]. It is, of course, impossible to predict the course of a real-life accident with the same garment because the human reaction cannot be predicted for any individual case. The two garment simulation experiments represent two extremes: simulation of the effect of movement relatively early during the burn and of a garment burn without movement.

Figure 9, again, shows the relationship between MAFT heat transfer rate results and the results of the movement simulation experiments for a wider range of fabrics. Again, the Class 1 fabrics transferred very small amounts of heat to the simulated body. All of them extinguished upon contact. The fabrics beyond the Class 1 limit transferred heat in amounts assumed to cause burn injuries to at least 25 percent of the simulated body. Figure 9 also shows the percentage of the simulated body subjected to this heat level at 90 seconds after ignition, in the form of a small black symbol connected to the larger open circle, indicating total area. Once could stipulate that after that time, the garment may be removed from the skin in many accidents. The graph shows that much of the heat from the acetate and acrylic fabrics was transferred after 90 seconds. The heat transfer from the cotton and polyester/cotton fabrics was essentially complete before that time, presumably because of the good contact they made with the simulated body. An exception is the cotton terry which continued burning after contact.

The movement simulation experiments showed that some of the acetate knits transferred heat over similar areas as the cotton and polyester/cotton fabrics. Other acetate knits, and especially woven acetates, transferred heat to larger areas. Edges of the acetates tended to curl away from the surface after contact and burn. Acrylic knits and wovens generally covered the largest area; they continued to burn more after contact than other fabrics except the cotton terry.

Figure 10 shows the results of the same experiments, except that the areas of the simulated body which received various heat levels are shown by the shading of various portions of the bars. Again, the woven acetate and acrylic fabrics tend to show larger areas of high heat levels than cotton and polyester/cotton fabrics with the same MAFT heat transfer rate. While this information does not affect the classification scheme, it is presented here as an aid in understanding the burn phenomena associated with the various fabrics.

3.4. Extinguishability

Until recently, very few experiments have been carried out to explore the extinguishability of fabrics. Extinguishability should, however, have a large effect on the size of burn injuries in real-life accidents because it relates to the time a garment will burn and deliver heat to the body. CPSC and NBS have provided grants to the University of Maryland and the Massachusetts Institute of Technology to explore various aspects of extinguishability. Figure 11 summarizes the results of such experiments performed at Maryland on the same fabrics as used in the "Thermoman" and movement simulation experiments. Extinguishability is expressed as (a) the heat transferred from a burning fabric, which is slapped by a solid surface and a screen, to a heat sensor in the solid plate, (b) the air currents at which the fabrics extinguished, and (c) the lowest oxygen concentration at which the fabrics extinguished at the 1:30 position of a TRI wheel apparatus [30,31]. Again, no correlation with the MAFT can be expected. However, again, none of the Class 1 fabrics are among those with unfavorable extinguishability characteristics.

The choice of 0.40 $J/(cm^2 \cdot s)$ as the upper limit of Class 1 fabrics thus seems reasonable, on the basis of a variety of garment fire simulation experiments. Such experiments are being continued.

The University of Maryland also attempted to separate the effects of the presence of a heat sink and of oxygen exclusion on the extinction of burning fabrics. As expected, this basic investigation proved to be difficult but provided considerable insight on methods and measurements which could be used for this purpose. At present, the results indicate that oxygen exclusion is the more important of these factors [32].

4. CONCLUSIONS

This report explains the choices made in specifying technical parameters and pass-fail criteria in the draft proposed standard for the flammability of general apparel. These choices were made on the basis of analyses of real-life garment fire accidents, of laboratory experimentation, and considerations of economic and technological impact. Some laboratory experimentation continues and may lead to alternate procedures in the operation of the test. However, the work has progressed to the point where an interlaboratory evaluation of the test method seems in order. NBS is attempting to organize such an evaluation through the appropriate ASTM committee.

In the opinion of NBS, publication of the draft proposed standard in the Federal Register at an early date would give all of the interested organizations in fiber, fabric, and garment manufacturing and in retailing, as well as various segments of the consuming public, an opportunity to study the proposed standard and make comments and suggestions. Comments and suggestions have been received from members of these groups which have taken the initiative to contact NBS. A broader spectrum of participation may be desirable at this point in development of the draft proposed standard.

5. REFERENCES

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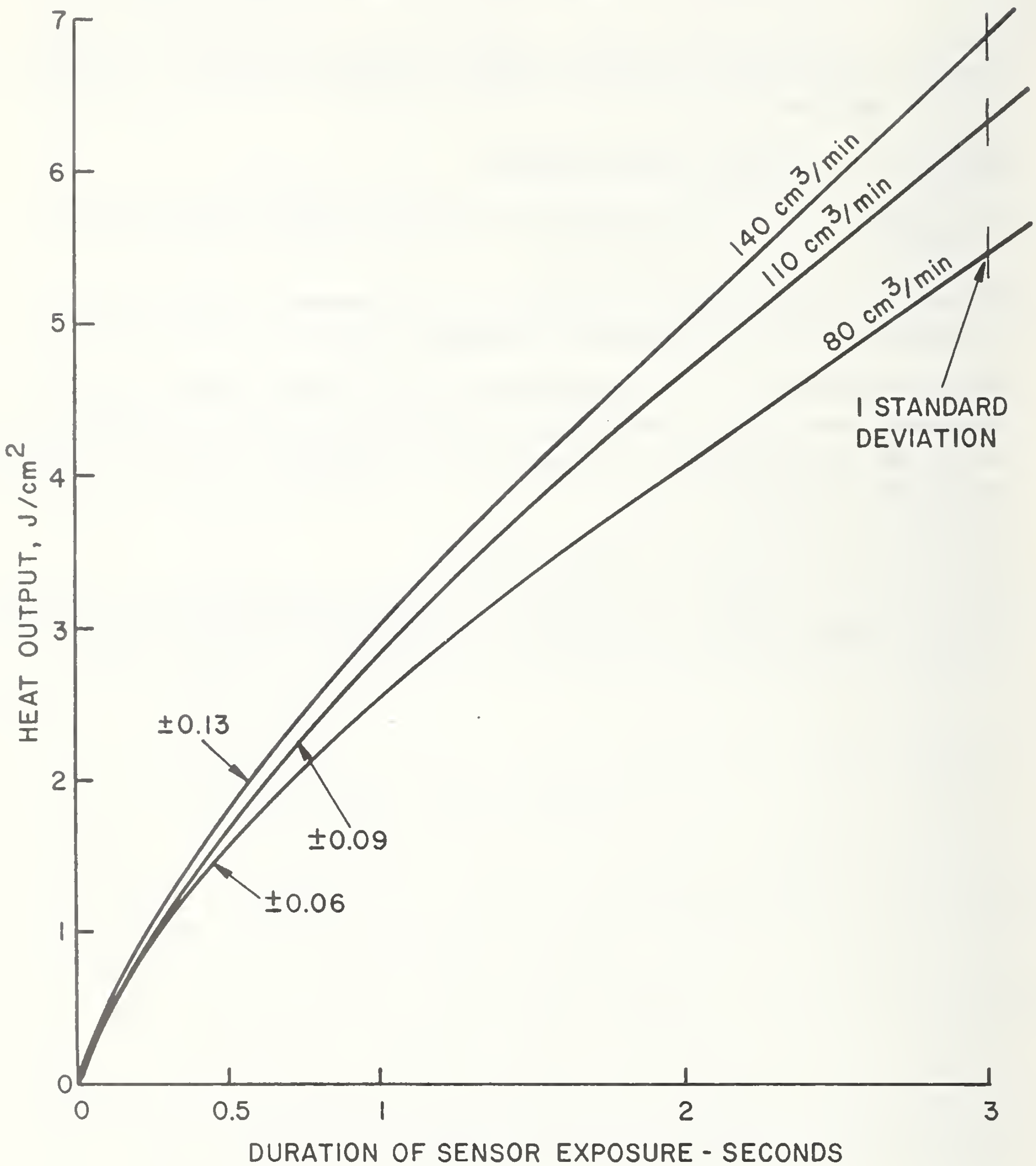


Figure 1. Heat Output of Ignition Source: Effect of Gas Flow Rate

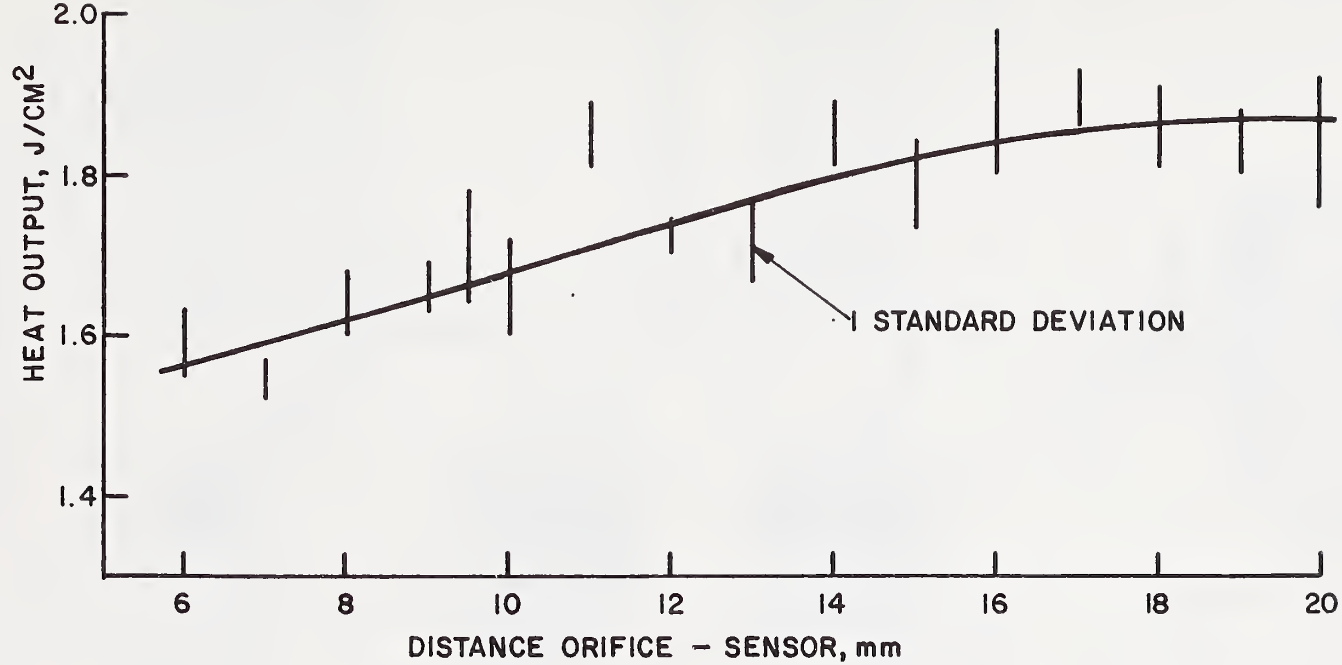


Figure 2. Heat Output of MAFT Ignition Source at Various Points within the Flame

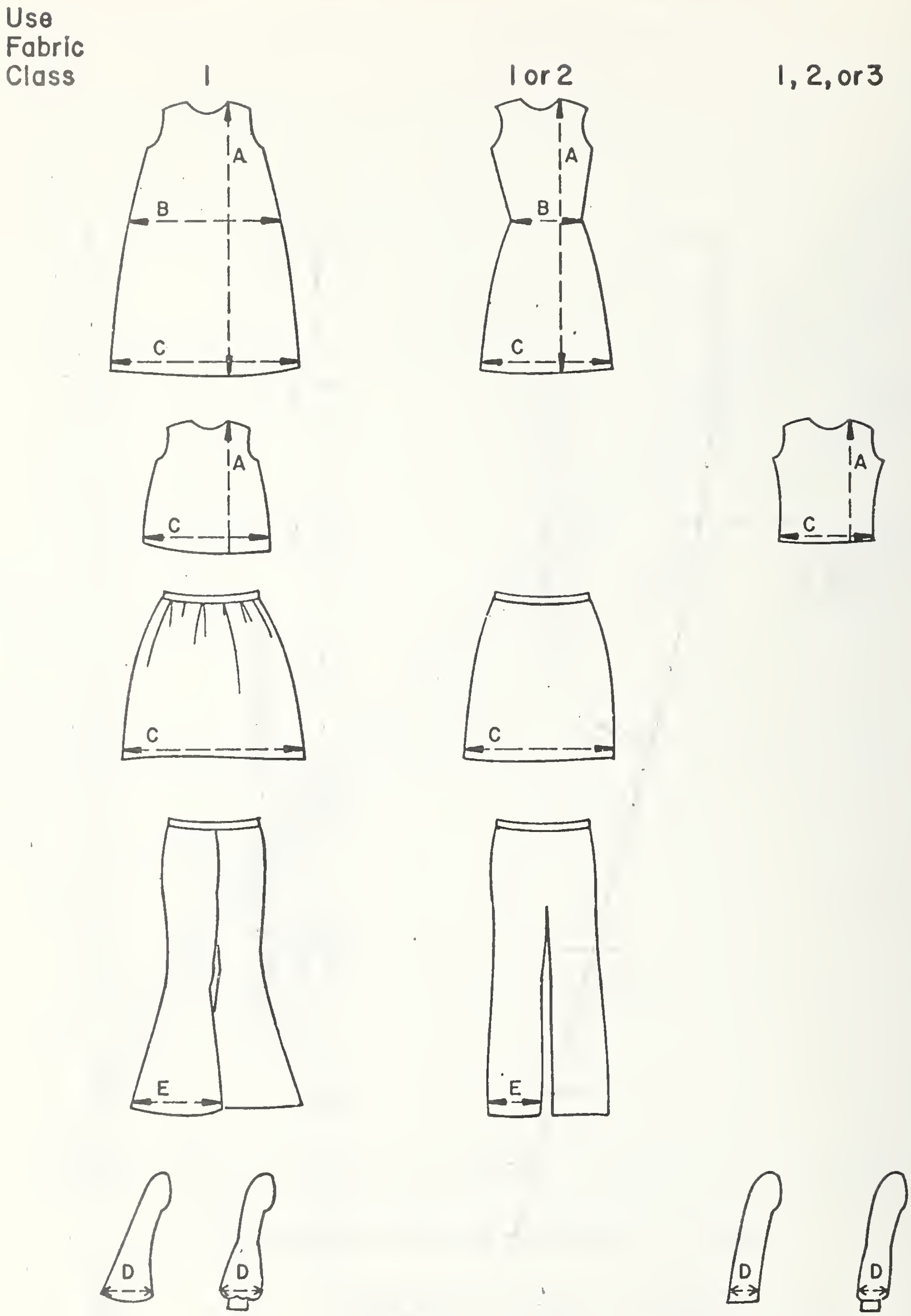


Figure 3. Garment Classification

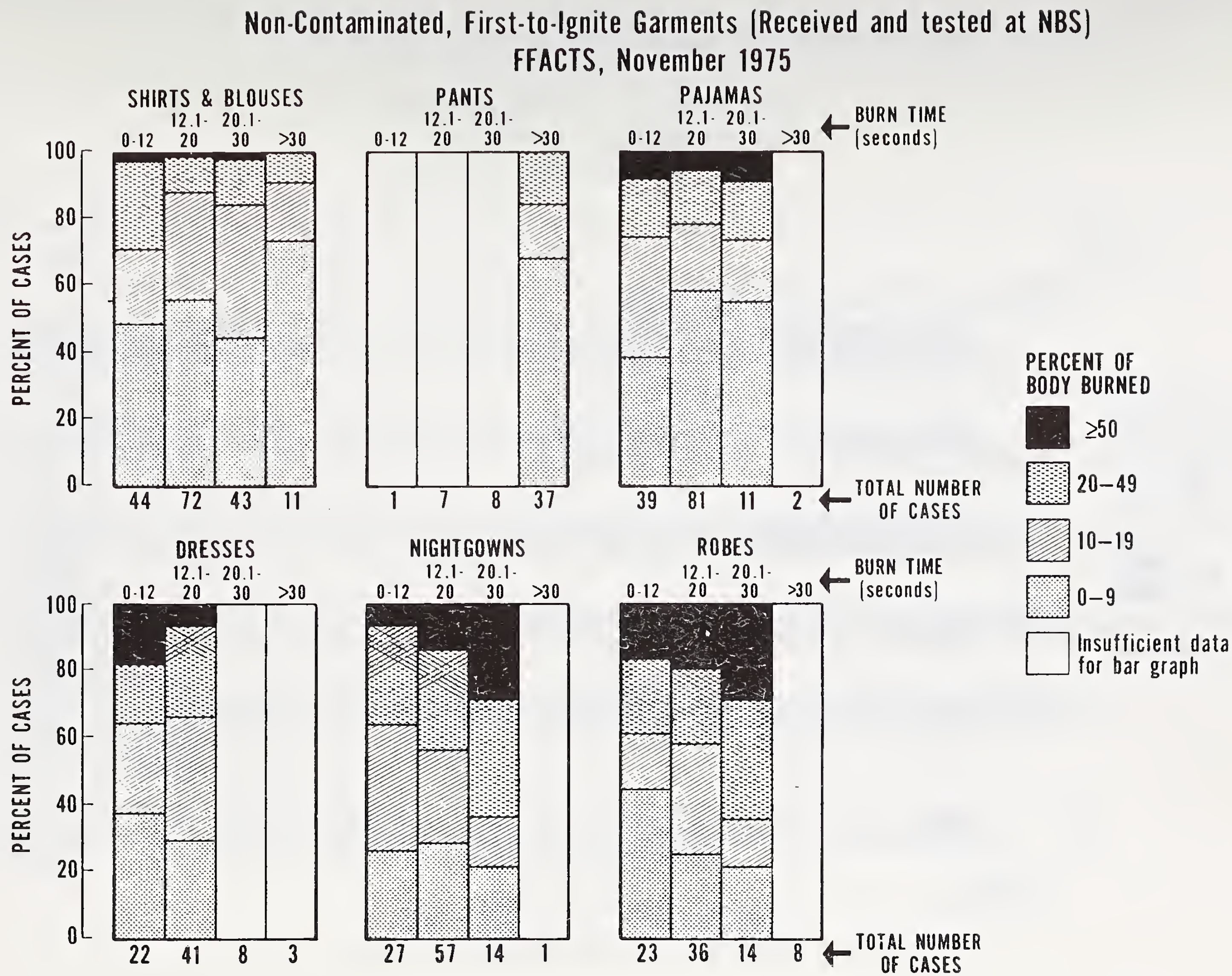


Figure 4. Area of Body Burned for CS 191-53 Burn Time Groups, within Garment Types

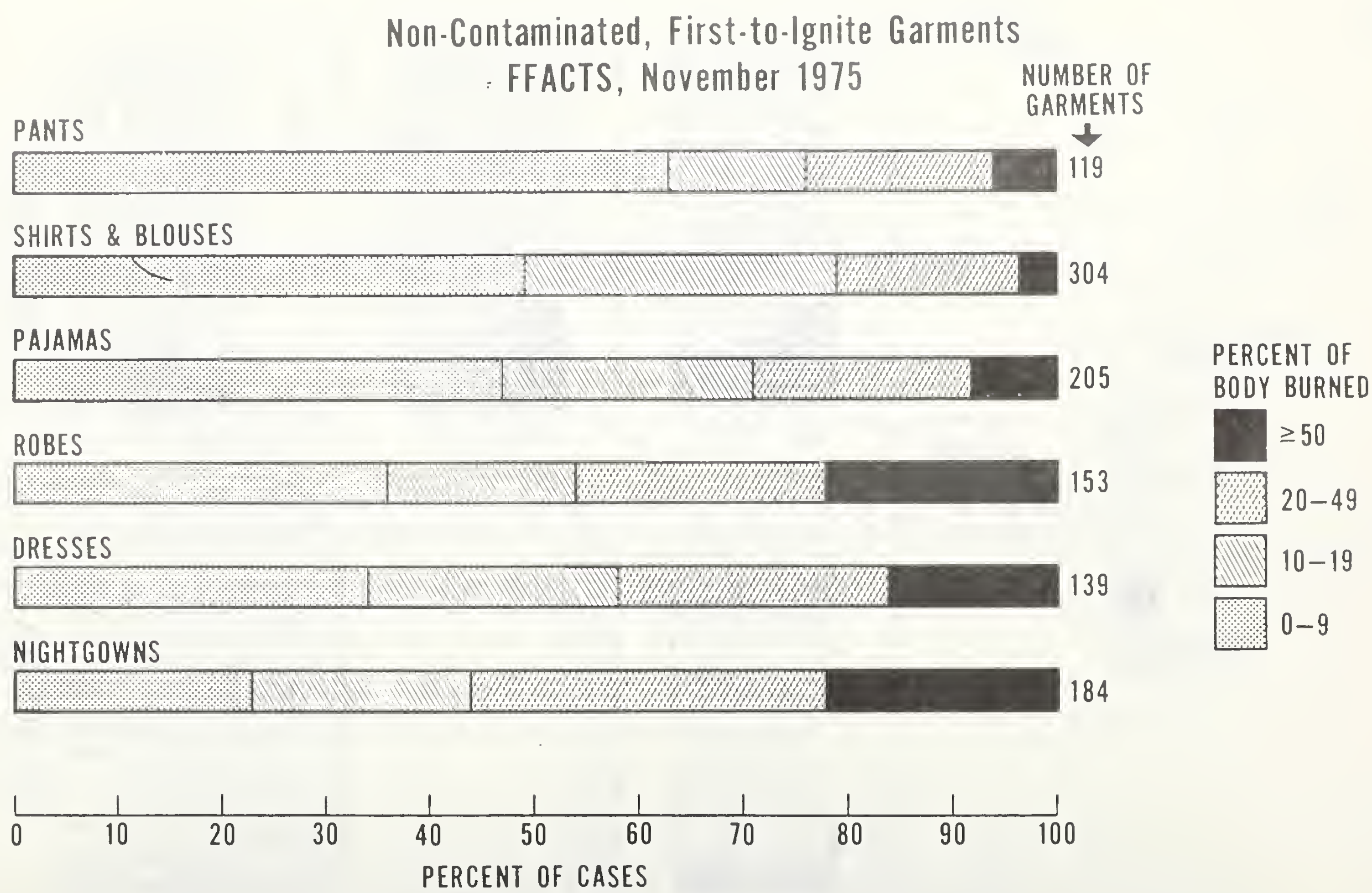


Figure 5. Area of Body Burned for Garment Types

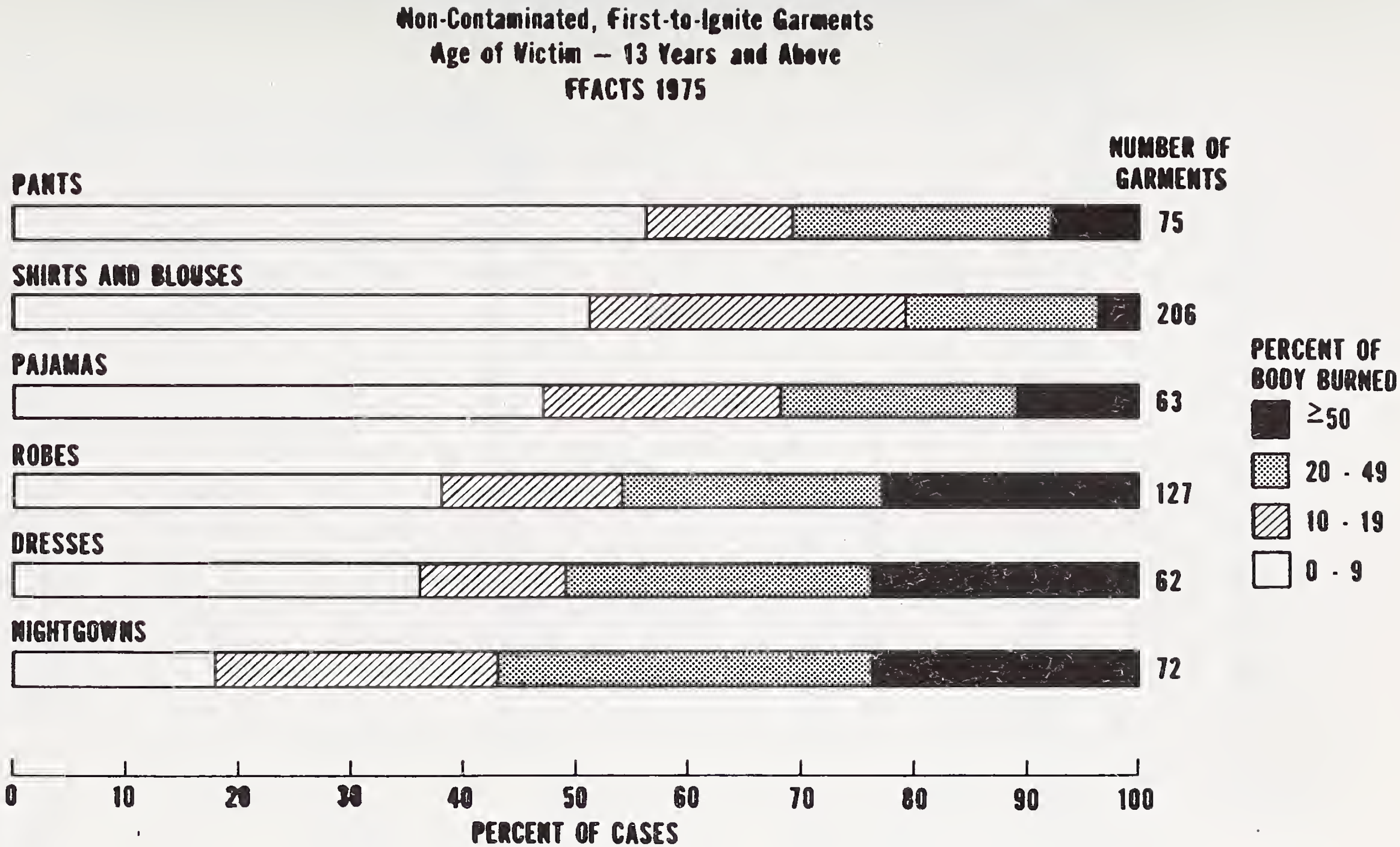
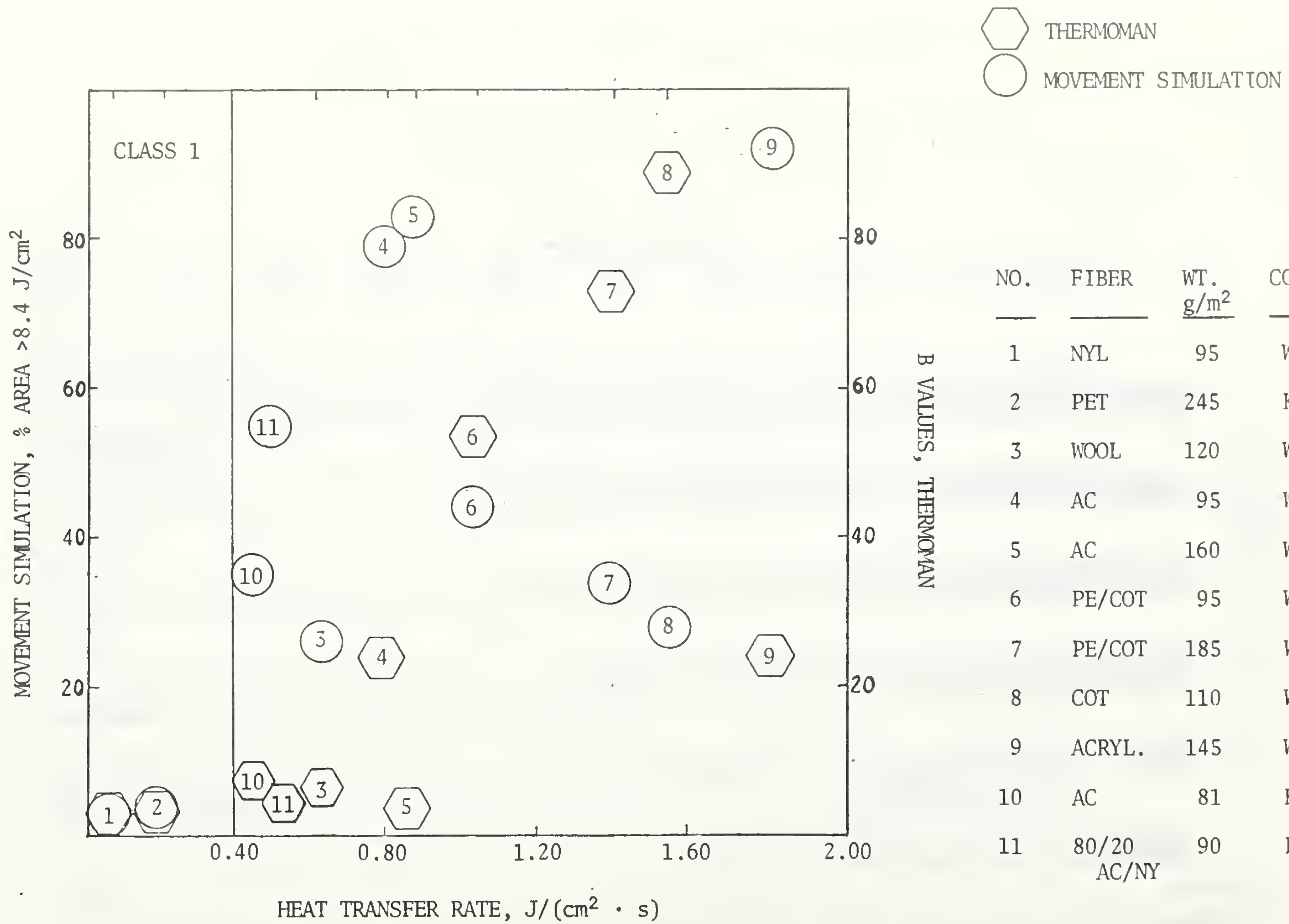


Figure 6. Area of Body Burned for Garment Types



NO.	FIBER	WT. g/m²	CONSTR.
1	NYL	95	WOV.
2	PET	245	KNIT
3	WOOL	120	WOV.
4	AC	95	WOV.
5	AC	160	WOV.
6	PE/COT	95	WOV.
7	PE/COT	185	WOV.
8	COT	110	WOV.
9	ACRYL.	145	WOV.
10	AC	81	KNIT
11	80/20 AC/NY	90	KNIT

Figure 7. Relationship between MAFT Heat Transfer Rate and Results of Mannequin and Movement Simulation Experiments

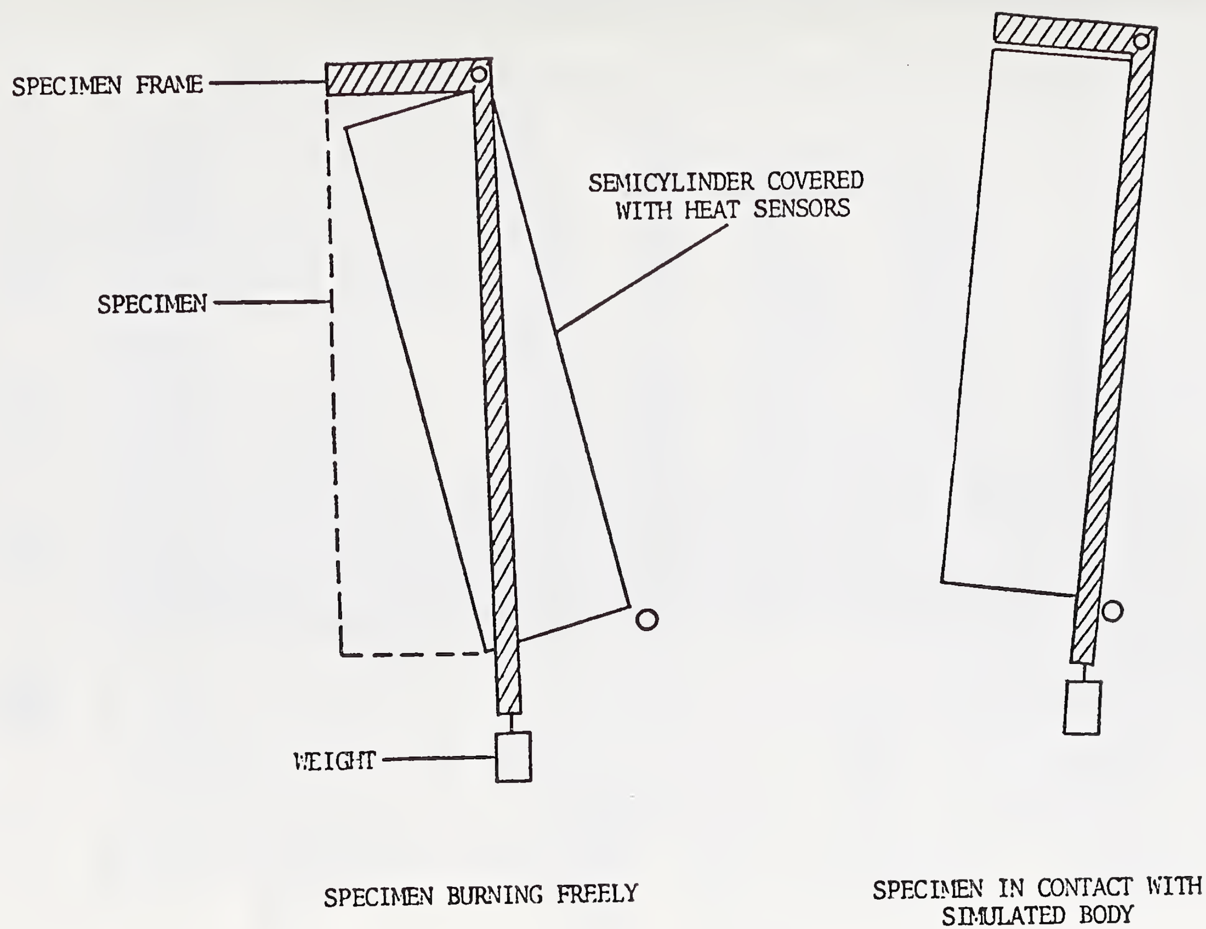


Figure 8. Apparatus for Modeling of Body Movement During Apparel Fires

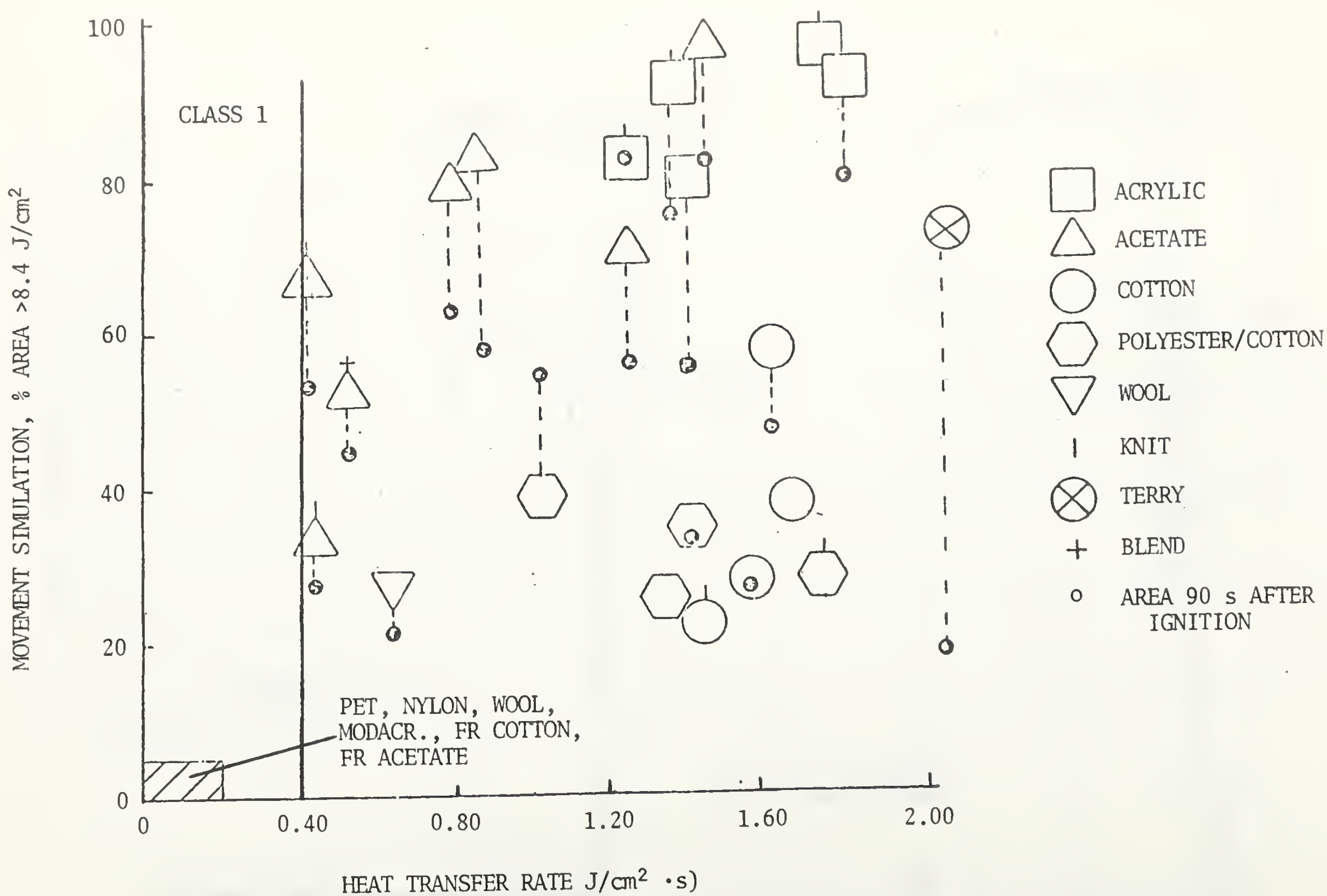


Figure 9. Relationship between MAFT Heat Transfer Rate and Results of Movement Simulation Experiments

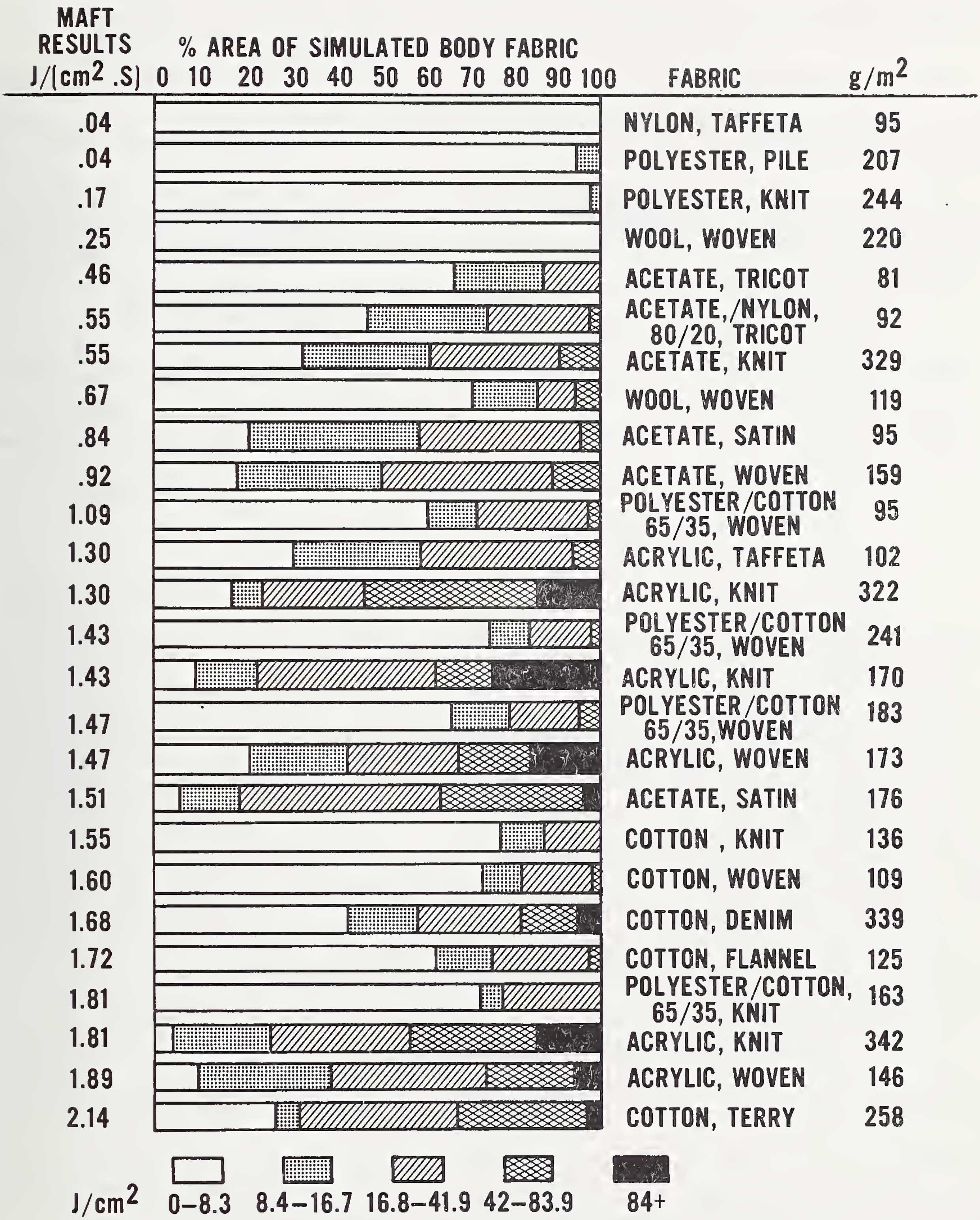
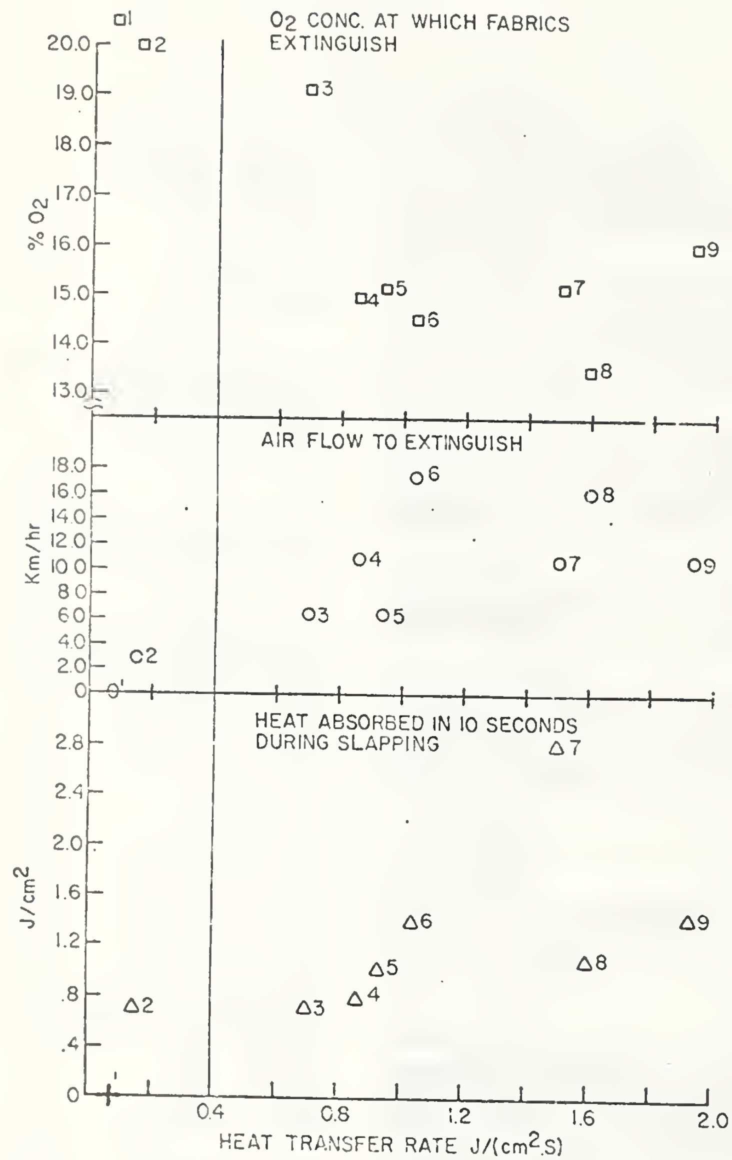


Figure 10. Comparison of MAFT and Movement Simulation Results



NO.	FIBER	WT. OZ/YD^2	CONSTR.
1	NYL	2.8	WOV.
2	PET	7.2	KNIT
3	WOOL	3.5	WOV.
4	AC	2.8	WOV.
5	AC	4.7	WOV.
6	PE/COT	2.8	WOV.
7	PE/COT	5.4	WOV.
8	COT.	3.2	WOV.
9	ACRYL.	4.3	WOV.

Figure 11. Relationship between MAFT Heat Transfer Rate and Three Measurement Related to Extinguishability of Fabrics

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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.)*

A "Proposed Standard for the Flammability of General Wearing Apparel" was submitted to the Consumer Product Safety Commission in February 1976. This report discusses the reasons for the choices of experimental arrangement for the flammability test and the choices of pass-fail criteria. The specimen is cylindrical, to simulate a garment, and to eliminate framed specimens which often burn differently from garments. Criteria for the fire hazard of fabrics are the time to ignite with a specified gas flame and the heat transferred to sensors inside the burning specimen. The proposed standard specifies that fabrics which transfer little heat to the inside of the specimens could be used in all garments but would have to be used in garments which cover most of the body and/or fit loosely. They would also have to be used in children's dresses and skirts (children's nightwear is covered by an earlier standard). Fabrics which transfer larger amounts of heat, and thus have larger injury potential, could be used in garments with normal or tight fit such as most present-day shirts, slacks, etc. If such fabrics ignite in 1/2 second or less, they would be excluded from use in garments. These provisions in the proposed standard were based on the need to reduce the number and severity of apparel fires with minimum economic and technological impact on the fiber, textile, and apparel industry. The present report summarizes the available knowledge in the area covered by the standard, and points out areas in which additional work is indicated.

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)*

Apparel; burn injury; ease of ignition; fabrics; fire; flammability tests; garments; heat transfer; standards

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