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BURN INJURY POTENTIAL OF NAVY SHIPBOARD WORK CLOTHING

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NAVY CLOTHING AND TEXTILE RESEARCH FACILITY
NATICK, MASSACHUSETTS

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Shipboard work/utility clothing was evaluated to determine the potential of standard clothing (officer and enlisted personnel) for burn injury. Sixteen fabrics made from cotton, polyester, wool, and blends of these fibers and of nylon/cotton were used in shipboard clothing and were heat tested along with two fire-retardant (FR) materials of Nomex/Kevlar and 100-percent FR-treated cotton (THPOH-NH_3) and four underwear materials of cotton and polyester cotton. (U)

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Materials were subjected to radiant heat exposures of 0.2 to 0.6 g cal/cm^2/sec. The FR materials were also impinged by flame. Time to burn injury (TBI) values were established for all tested fabrics using the Stoll-Derksen curve with the measuring calorimeter in contact and 1/2 inch from the specimens. For the flame impingement tests the flame temperature was 2000°F and the TBI and total heat values were measured 1/8 inch from the fabrics. (U)

Experimental methods were established which could differentiate between heat protection assemblies exposed to modest and high heat exposure. Data were obtained for TBI and total heat (TH) transmitted. Visual inspection of the material was also noted. Results showed that, at radiant heat flux levels of 0.2 g cal/cm^2/sec, protection was related to fabric weight and not fiber type. At higher heat exposures, the type of fiber used becomes significant, with thermoplastic fibers providing the least protection. Data on the Nomex/Kevlar and FR cotton fabrics showed that the aramids were superior to the FR cotton at the higher flux values of 0.6 g cal/cm^2/sec, but neither would provide reliable protection from jet fuel fires for more than a few seconds. Differences in protection afforded by polyester/cotton and all cotton underwear were insignificant in terms of TH transferred. However, when tested under the FR materials at the 0.6 gcal/cm^2/sec radiant flux level, cotton underwear tended to ignite more easily than the polyester/cotton blend. (U)

TABLE OF CONTENTS

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DTIC TAB
Unannounced
Justification
By
Distribution /
Availability Codes
Dist | Avail and/or Special
A-1

LIST OF ILLUSTRATIONS

LIST OF TABLES

BURN INJURY POTENTIAL OF NAVY SHIPBOARD WORK CLOTHING

INTRODUCTION

The work described in this report was undertaken to assist the Navy Clothing and Textile Research Facility (NCTRF) in choosing a work clothing fabric for shipboard personnel which would offer some protection against heat from accidental fires. It compares the heat protective characteristics of flame-retardant (FR) fabrics with those of the ordinary fabrics presently worn. It also compares two major types of FR fabrics, aramid and FR cotton, under a variety of radiant heat and flame exposures.

The fabrics included outerwear fabrics (100% cotton, polyester, wool, and blends containing polyester/cotton, polyester/rayon, and polyester/wool as well as nylon/cotton), four underwear fabrics (100% cotton and polyester/cotton undershirt and drawer fabrics), and several FR (aramid and FR cotton) fabrics. All fabrics were exposed to radiant heat, and some of the FR fabrics were also exposed to a gas flame. Based on preliminary test results, the exact exposure conditions were arranged with NCTRF during the course of the experiments. NCTRF also furnished the data on fabric construction. The National Bureau of Standards (NBS) measured the heat behind the exposed fabrics as a function of time, as an indication of how soon a skin burn may occur and of the severity of the burn injury to a wearer. The deterioration of the fabric integrity--shrinkage, melting, charring--at various exposures was also reported.

EXPERIMENTAL

Exposure to Radiation

The specimens were exposed to the apparatus shown in Figure 1, consisting essentially of a quartz radiant panel, a specimen holder, a heat sensor, and a shutter to regulate time of heat exposure. The apparatus and the results obtained on a variety of fabrics were described in previous publications (1-5). The radiant energy was supplied by an electrically heated quartz radiant panel (31 x 31 cm), vertically mounted and operating at about 910°C with peak energy occuring at a wavelength of 2.6μm. Heat transfer through the fabrics was measured with a commercial, water-cooled, total heat flux meter that was flush mounted in a 1.3-cm-thick calcium-silicate board plate (10.7 x 10.7 cm). Fabric specimens (15.2 x 15.2 cm) were clipped onto a holder and placed in a vertical position, with the face side towards the radiant heat source. The sensor was either in contact with the fabric specimen or at some distance from it to simulate heat transfer through loose clothing which would not touch the skin.

Two parameters were chosen to express the insulative properties of the fabrics. One was the time to burn injury (TBI), the duration of exposure to heat at which a skin burn might be estimated to occur. This time is determined from the Derksen curve which shows the TBI as a function of time of exposure and the rate at which the heat is delivered (6, 7).

Another parameter measured during each test was the total heat (TH) received by the sensor through the fabric at various times during the test. Printouts of the TH were obtained every 5 seconds. The heat flux, averaged every 5 seconds, was also printed. Typical graphs and accompanying printouts are shown in Figures 2 and 3. Also shown in Figure 2 (broken line) is the Derksen curve. The part of the time vs. TH curve which lies below the Derksen curve indicates no burn injury; the part above, second degree or deeper. The time at which the two curves cross is the TBI.

It should be borne in mind that the TBI serves mainly as a means of comparing various fabric assemblies, <u>but not as a means to predict actual time to burn injury in real-life fire exposures</u>. The Derksen curve was established with exposure of real skin, while the present measurements utilize a heat flux meter of different thermal response. Skin characteristics and susceptibility to burn injury also vary widely among individuals and over any individual's body. Finally, the Derksen curve and our data were produced by square pulses of radiant energy, while in "real life," radiant heat from a fire would fluctuate. As discussed in reference 2, however, a fair correlation has been established between the results from this apparatus and feeling of pain due to heat.

Specimens were generally exposed to the radiant heat source for 2 minutes. After this period, the measurements were recorded for another minute to establish the effect of the heat stored in the fabric on the burn injury potential. Levels of radiant exposure varied from 0.2 to 0.6 $cal/cm^2/s$ (0.84 to 2.52 $J/cm^2/s$ or 0.74 to 2.22 $BTU/ft^2/s$). In some cases, specimens were exposed to various radiant heat levels for a given time and then the heated side was impinged by an approximately 25-mm-long methane flame for

15 seconds, to establish the flammability of the specimens while they were at elevated temperatures and, presumably, at low moisture content.

Flame Exposure

Fabric specimens were also exposed in an apparatus consisting essentially of a Meeker burner, a horizontal specimen holder, and a heat sensor (Figure 4). This apparatus, using pure methane, is proposed in an ASTM method for thermal protective performance of materials for protective clothing (8). However, the present project required exposure to flames at the approximate temperature of jet fuel fires--1090°C (2000°F). This was attained by using a Meeker natural gas burner with a 1.0 to 0.7 mixture of methane and nitrogen.

Fabrics

Two groups of fabrics were investigated: flame-retardant fabrics and non-flame-retardant fabrics. Other FR fabrics--aramid and FR cotton--were under consideration for use in shipboard work uniforms. Two shipments of these fabrics were received. The first consisted of a 100-percent Nomex and an FR cotton fabric; the second consisted of a 95/5 Nomex/Kevlar fabric and an FR cotton fabric. These are described in Table 1. The test protocol for the second shipment was more severe than that for the first because low-level exposures showed less difference between the aramid and FR cotton fabric than high-level exposures.

The other group consisted of fabrics presently used on shipboard, none of them flame-retardant or intended to protect against heat in fire situations. These are described in Table 2 (data provided by NCTRF).

RESULTS AND DISCUSSION

Comparison of FR Cotton and Nomex/Kevlar Fabrics

An FR cotton twill and the Nomex/Kevlar were submitted to NBS in January 1981. They were the fabrics of more immediate interest than the previously submitted FR cotton fabrics and 100% Nomex. Based on the earlier work, it was agreed to subject these fabrics to relatively high heat loads, 0.4 and 0.6 cal/cm^2.s radiant heat and the 1090°C flame, since lower exposures had not indicated large differences between the fabrics. The results are shown in Figures 5 through 8 and Tables 3 through 5.

Figure 5 illustrates the TBI at 0.4 and 0.6 cal/cm^2/s radiant exposure, with the sensor 13 mm behind the fabric. In TBI graphs, a long bar indicates a desirable characteristic, a long TBI. The top of each bar indicates TBI at 0.4 cal/cm^2/s, and the top of the shaded, lower part of the bar, the TBI for 0.6 cal/cm^2/s exposure. The TBI for the FR cotton was higher than that for the Nomex/Kevlar fabric when the specimens were exposed without underwear fabric at 0.4 cal/cm^2/s, presumably because the FR cotton fabric was heavier. At 0.6 cal/cm^2/s, however, the situation was reversed indicating, perhaps, the greater degree of deterioriation of the FR cotton under this heat exposure. In combination with the underwear fabrics, the Nomex/Kevlar outer fabric produced longer TBI results under both exposures.

In the TH graph, Figure 6, a long bar indicates an undesirable characteristic, a great amount of heat transferred through the fabric in a given time. Here the top of each bar indicates the TH at 0.6 cal/cm^2/s, and the top of the lower, shaded part of the bar, the TH at 0.4 cal/cm^2/s exposure. Three bars are drawn for each outer fabric/underwear combination--one each for TH after 60 and 120 seconds exposure, and the third bar for 60 seconds after exposure stopped. Again, the Nomex/Kevlar fabric was superior to the FR cotton fabric. Underwear specimens behind the Nomex/Kevlar fabric were generally less charred than those behind the FR cotton.

There was little difference in the TH results obtained with the four different underwear fabrics in these exposures, except that the 100% cotton T-shirt fabric behind the Nomex/Kevlar fabrics ignited in all 0.6 cal/cm^2/s exposures. The specimens were removed as soon as ignition was observed, and no results are shown in Figure 6 for an exposure of 120 seconds and 60 seconds after exposure stopped. Other underwear fabric occasionally ignited at 0.6 cal/cm^2/s with the FR cotton fabric but no pattern of ignition could be established. These ignitions generally occurred some time after the TBI was reached.

The results obtained when the outerwear-underwear combinations were exposed to 1090°C (2000°F) flame are shown in Figures 7 (TBI)and 8 (TH). The fabrics were exposed for 20 seconds, and the heat behind them plotted for this time and for 10 seconds beyond it. Exposure was with the specimens in contact with the sensor and with a 3.2 mm distance between specimen and sensor.

In Figure 7, the open, upper end of the bar indicates the results obtained with the fabric 3.2 mm below the sensor, and the shaded bar, the results with the fabric in contact with the sensor. In this test mode, the Nomex/Kevlar clearly produced a longer TBI than the FR cotton fabric. A possible explanation is the stronger off-gasing from the FR cotton fabrics which may transfer heat more effectively to the sensor with horizontal specimens and sensor orientation than when both are vertical. Differences between the results obtained for the different underwear fabrics were again small.

In Figure 8, showing the TH results at 10 and 20 seconds in the flame, and 10 seconds after the flame was removed, the top of the open bar shows the contact situation, and the top of the shaded bar the less severe situation of a 3.2 mm distance between specimen and sensor. Less heat was transferred through the Nomex/Kevlar than through the FR cotton fabric in the first 10 seconds of the test, alone and in combination with the underwear fabrics. After 20 seconds exposure, and 10 seconds after the flame had been removed, the FR cotton fabric generally produced lower TH results (second and third bar in each set). All specimens showed considerable charring after these tests. The polyester/cotton underwear fabrics stuck to the Nomex/Kevlar but not the FR cotton fabrics.

All of these tests were performed with the fabrics mounted so that they could not move during the tests. When the specimens were mounted so that they could relax, the Nomex/Kevlar shrank considerably even during a 2-second exposure, while the FR cotton did not shrink. The TBI and TH results in the relaxed condition were quite irreproducible but the Nomex/Kevlar in its puckered and shrunken state seemed to permit less heat transfer.

Additional specimens were exposed to 0.4 $cal/cm^2/s$ for 120 seconds, and a 25 mm flame was applied to them for 15 seconds after 60 seconds of radiant exposure. The results are shown in Table 3. The specimens ignited in some cases, but not in others. In such cases, the average TH of the ignited and unignited specimens is listed.

In general, the differences between the FR cotton and the Nomex/Kevlar fabrics were minor. As expected, ignition of the specimens greatly increased the TH at 180 seconds.

Comparison of FR Cotton and Nomex Fabrics

Because these fabrics were received from NCTRF in August 1980, they represent earlier samples than the FR cotton and the Nomex/Kevlar fabrics discussed above. They were also tested under somewhat different conditions: under radiative exposures of 0.2, 0.3, and 0.4 $cal/cm^2/s$ with the specimens in contact with the heat sensor and at 13 mm (1/2 in) from the sensor.

The results are shown in Tables 6A through 6E and summarized in Figures 9 and 10. At the 0.2 $cal/cm^2/s$ exposure, the TBI results for the Nomex and FR cotton fabrics--alone and in combination with the four underwear fabrics--were quite similar. The same held for the 0.4 $cal/cm^2/s$ exposure with the specimens in contact with the sensor. However, at 0.3 and 0.4 $cal/cm^2/s$ with the specimens at a 13-mm distance from the sensor, the Nomex fabric recorded a consistently longer TBI than the FR cotton fabric when exposed with the underwear. Without the underwear, the two fabrics were roughly equal. The FR cotton charred severely during the 2-minute 0.4 $cal/cm^2/s$ exposure, less severely at 0.3 $cal/cm^2/s$, and not at all at 0.2 $cal/cm^2/s$. the Nomex fabric did not change in appearance in any of the exposures.

The TH data were similar for the Nomex and the FR cotton fabrics when the specimens were in contact with the sensor, for both the 0.2 and 0.4 $cal/cm^2/s$ exposures. When the specimens were 13 mm from the sensor, the single-layer TH results were similar at 0.2 and 0.3 $cal/cm^2/s$, but the FR cotton exhibited higher total heat at 0.4 $cal/cm^2/s$. In combination with the four underwear fabrics, the FR cotton had lower TH at 0.2 $cal/cm^2/s$, was similar at 0.3 $cal/cm^2/s$, and had higher TH at 0.4 $cal/cm^2/s$. This perhaps indicates a breakdown or development of pyrolysis gases which increase heat transfer to the sensor at the more severe exposure in the case of the FR cotton but not the Nomex fabrics.

The specimens were also exposed to 0.2 $cal/cm^2/s$ for 120 seconds, and then a 25-mm-long methane flame was applied to them, with the radiant heat exposure continued (Table 6B). All the specimen combinations containing the cotton-drawer-underwear fabric ignited. Sporadic ignitions occurred with the other combinations, following no recognizable pattern. In cases of such combinations, both the average TH and the TH for the ignited specimens are shown in the table. The TH for ignited specimens is two to three times that of unignited specimens. There was little difference in the TH of the Nomex and FR Cotton fabrics at 120 and 135 (the completion of the flame contact) seconds, but at 180 seconds, the FR cotton had a lower TH.

Non-FR Fabrics

A cross section of the fabrics presently worn aboard ship was received from NCTRF. The fabrics described in Table 2 were tested under four conditions: at 0.2 and 0.4 $cal/cm^2/s$ radiant heat exposure, with the specimens 13 mm in front of the sensor, and with the specimens in contact with the sensor. The results are shown in Figures 11 and 12.

Despite substantial differences in construction, the ranges in TBI are relatively small, as follows:

0.2 $cal/cm^2/s$, 13 mm	: 62 to 105 seconds
0.2 $cal/cm^2/s$, in contact	: 21 to 35 seconds
0.4 $cal/cm^2/s$, 13 mm	: 23 to 48 seconds
0.4 $cal/cm^2/s$, in contact	: 11 to 19 seconds

In general, the thicker or heavier the fabric is, the longer the TBI. At the 0.4 $cal/cm^2/s$ exposure, the difference between individual specimens of one fabric tended to be quite large. Because of melting, charring, and shrinking, the specimens wrinkled and moved away from the heat sensor and thus showed longer TBI. These specimens also showed more damage, in terms of melting and/or charring, because they were not in direct contact with the plate holding the sensor. Attempts were made to hold the specimens in a reproducible manner; however, holding them too tightly would be unrealistic because they are not held tightly against the body when worn by a person.

Because many specimens were essentially destroyed during the 0.4 $cal/cm^2/s$ exposure, total heat after 120 seconds or 180 seconds (i.e., 60 seconds after exposure stopped), as reported for the FR fabrics, is not descriptive of the protective characteristics of the non-FR fabrics. The polyester/cellulosic blends charred and melted to various degrees but generally retained their integrity, as did the heavier cotton fabric. As shown in the attached chart, the 100% polyester specimens melted and shrank, and though the molten sheet may have protected the sensor, the shrunken fabric may not cover a wearer completely, and/or the molten area may open up under even slight stress during wear. Similarly, the wool fabric and the wool/polyester blends became very brittle, and would disintegrate during actual wear, but the charred area still protected the sensor.

CONCLUSIONS

Experimental methods were established which could differentiate between heat protective fabric assemblies at modest and high heat exposures. Numerical values can be obtained for such protective values as TBI and TH transmitted through the specimens at various conditions of exposure. Equally important, however, may be the visual inspection of the specimens after exposure. Shrinkage due to heat could leave the wearer partially exposed, as could formation of melt holes and charring leading to embrittlement and breaking open of the fabric due to wearer movement.

At the relatively low radiation exposure of 0.2 $cal/cm^2/s$, protection very roughly increased with increasing fabric weight, as it had in previous studies (1-5), regardless of fiber content. There may be secondary effects, such as rough weave or fuzzy fabric surface, which reduce specimen-sensor contact and the heat registered by the sensor. Differences in optical density, color, etc., could affect the results, but no systematically varied series of fabrics was available to study such effects in this or earlier work.

At higher heat exposures, the fiber content of the fabrics becomes important. One hundred percent thermoplastics probably rank lowest, because they shrank, then formed melt holes, and tended to make close contact and adhered to the skin. Blends of thermoplastic and cellulosic or wool fibers shrank much less, and formed chars. The thermoplastic/cellulose blend chars seemed to form more slowly and seemed less embrittled than the thermoplastic fiber/wool chars. Wool also formed weaker chars than cotton fabrics in the same exposure. The 100-percent natural fiber fabrics, wool and cotton, had the lowest heat shrinkage.

Among the FR fabrics, the FR cotton fabric charred and lost strength at lower heat exposures than the aramids. On the other hand, the FR cotton was stable when held in the relaxed condition in a 1090°C (2000°F) flame, while the Nomex/Kevlar blend shrank. Both types of fabrics charred under these conditions. Thus, in general, one may say that the aramids provide protection into a higher heat range, but neither fabric would provide reliable protection at temperatures comparable to those of a jet fuel fire for more than a few seconds.

Heat transfer to the sensor was measured for some time after heat exposure was discontinued, to record the effect of heat stored in the fabric. No consistent difference was found between the FR cotton and aramid fabrics, through the aramid fabrics were lighter than the FR cotton fabrics.

APPENDIX A. ILLUSTRATIONS

SCHEMATIC DIAGRAM OF APPARATUS TO MEASURE HEAT FLUX RESISTANCE

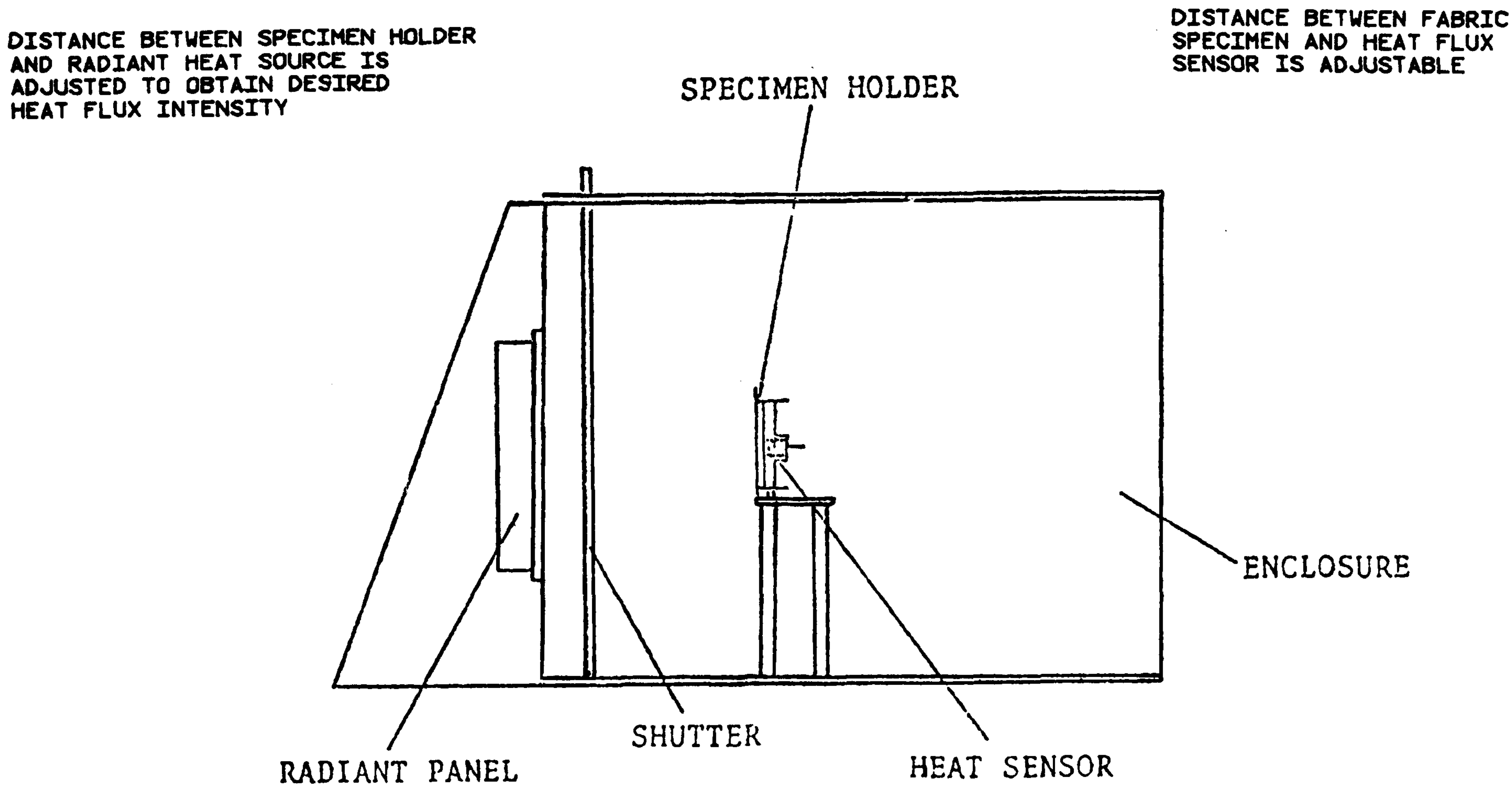
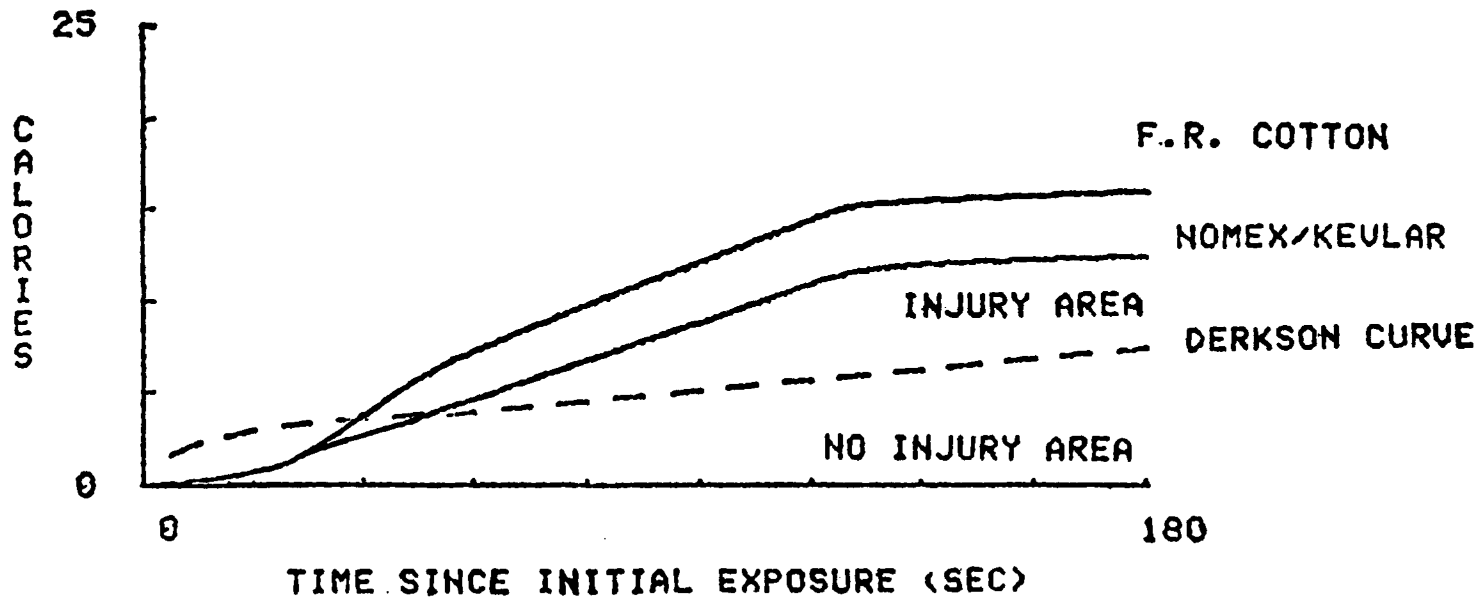


FIGURE 1

TOTAL HEAT GRAPH FOR 95/5 NOMEX/KEVLAR AND 100% F.R. COTTON
OUTER FABRICS WITH COTTON T-SHIRT
AT 0.4 CAL/SQ CM-S AND 13 mm SPECIMEN-SENSOR DISTANCE



TOTAL HEAT FOR F.R. COTTON SPECIMEN EXCEEDED DERKSON CURVE AT 38.4 SEC
TOTAL HEAT FOR NOMEX/KEVLAR SPECIMEN EXCEEDED DERKSON CURVE AT 50.3 SEC

FIGURE 2

100% F.R. COTTON & COTTON T-SHIRT - 1/2" FROM SENSOR, 0.4 CAL/SQ CM-S

TIME SEC	HEAT FLUX CAL/CM2-SEC	TOTAL HEAT CAL/CM2 EVERY 5.00 SEC
0	0	0
5	0.02072	0.0518
10	0.02737	0.172025
15	0.04654	0.3568
20	0.06497	0.635575
25	0.08508	1.0107
30	0.19037	1.699325
35	0.20844	2.69635
40	0.20264	3.72405
45	0.19849	4.726875
50	0.17276	5.655
55	0.14561	6.453425
60	0.12943	7.143525
65	0.12183	7.771675
70	0.12109	8.378975
75	0.11985	8.979325
80	0.11615	9.567325
85	0.11493	10.145025
90	0.11627	10.723025
95	0.11404	11.2988
100	0.11481	11.870925
105	0.11053	12.434275
110	0.1131	12.99335
115	0.11044	13.5522
120	0.11108	14.106
125	0.07611	14.573975
130	0.03192	14.84405
135	0.0181	14.9891
140	0.01297	15.046775
145	0.01172	15.1085
150	0.01193	15.167625
155	0.00943	15.221025
160	0.00969	15.267325
165	0.00836	15.31995
170	0.00803	15.351925
175	0.09983	15.396575
100	0.00815	15.441525

FIGURE 3A.

95/5 NOMEX/KEVLAR & COTTON T-SHIRT - 1/2" FROM SENSOR, 0.4 CAL/SQ CM-S

TIME SEC	HEAT FLUX CAL/CM2-SEC	TOTAL HEAT CAL/CM2 EVERY 5.00 SEC
0	0	0
5	0.02222	0.05555
10	0.03738	0.20455
15	0.05881	0.445025
20	0.07736	0.78545
25	0.08047	1.200025
30	0.09521	1.659225
35	0.09799	2.142225
40	0.09842	2.63325
45	0.09888	3.1265
50	0.10117	3.626625
55	0.10132	4.13285
60	0.10239	4.642125
65	0.10486	5.16025
70	0.10571	5.686675
75	0.1058	6.21545
80	0.10571	6.744225
85	0.10559	7.272475
90	0.10498	7.7989
95	0.10287	8.318525
100	0.10242	8.83175
105	0.10126	9.34095
110	0.10208	9.8493
115	0.10364	10.3636
120	0.10883	10.874775
125	0.07111	11.304625
130	0.04593	11.597225
135	0.02939	11.785525
140	0.02005	11.989125
145	0.01642	12.0003
150	0.01294	12.0737
155	0.01147	12.134725
160	0.00977	12.187825
165	0.00803	12.232325
170	0.00803	12.272475
175	0.00787	12.312225
100	0.00667	12.349075

FIGURE 3B.

SCHEMATIC DRAWING OF FLAME APPARATUS

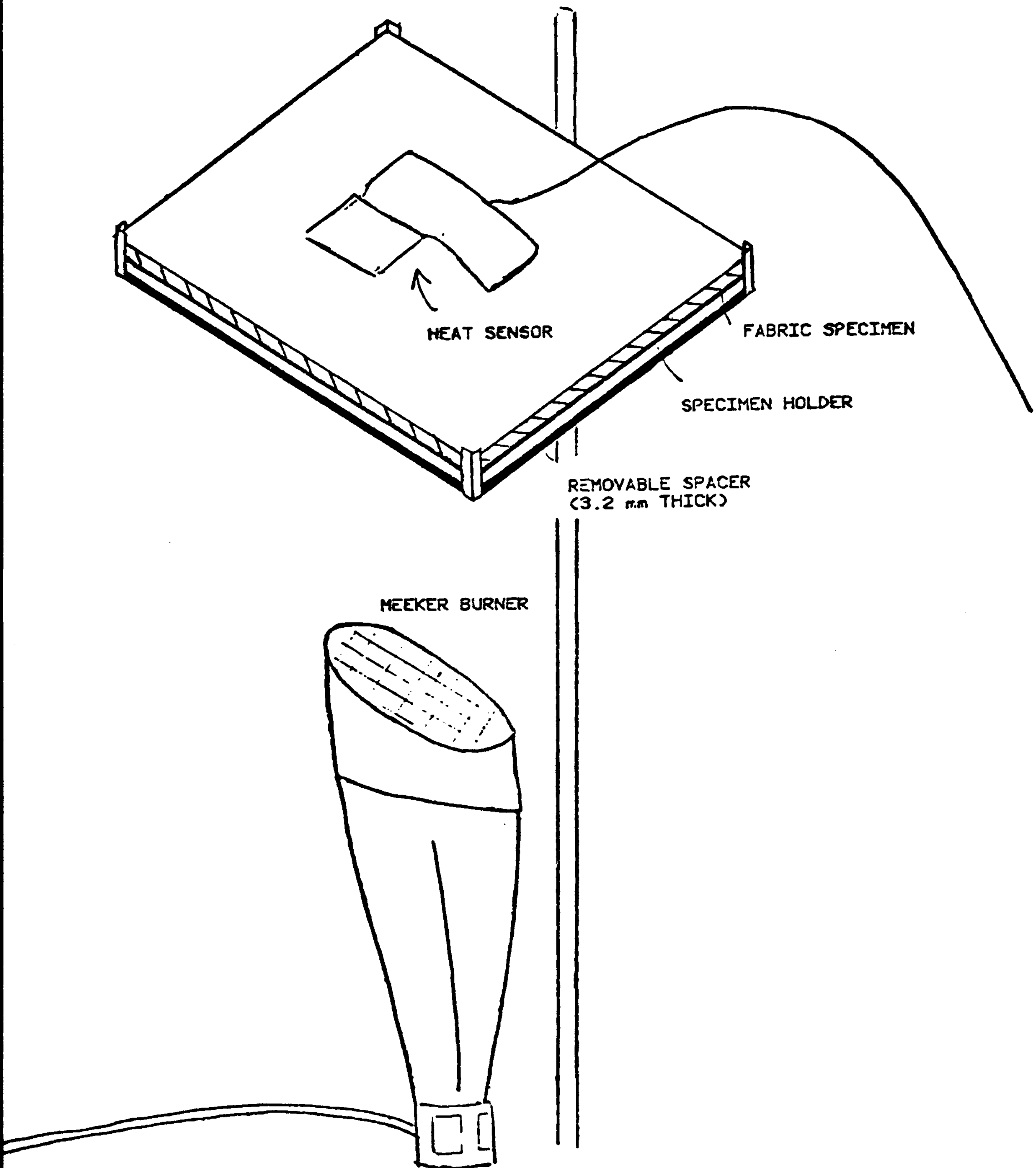


FIGURE 4

TIME TO BURN INJURY: KEVLAR/NOMEX AND FR COTTON OUTER FABRICS AND UNDERWEAR
(specimen-sensor distance 13 mm)

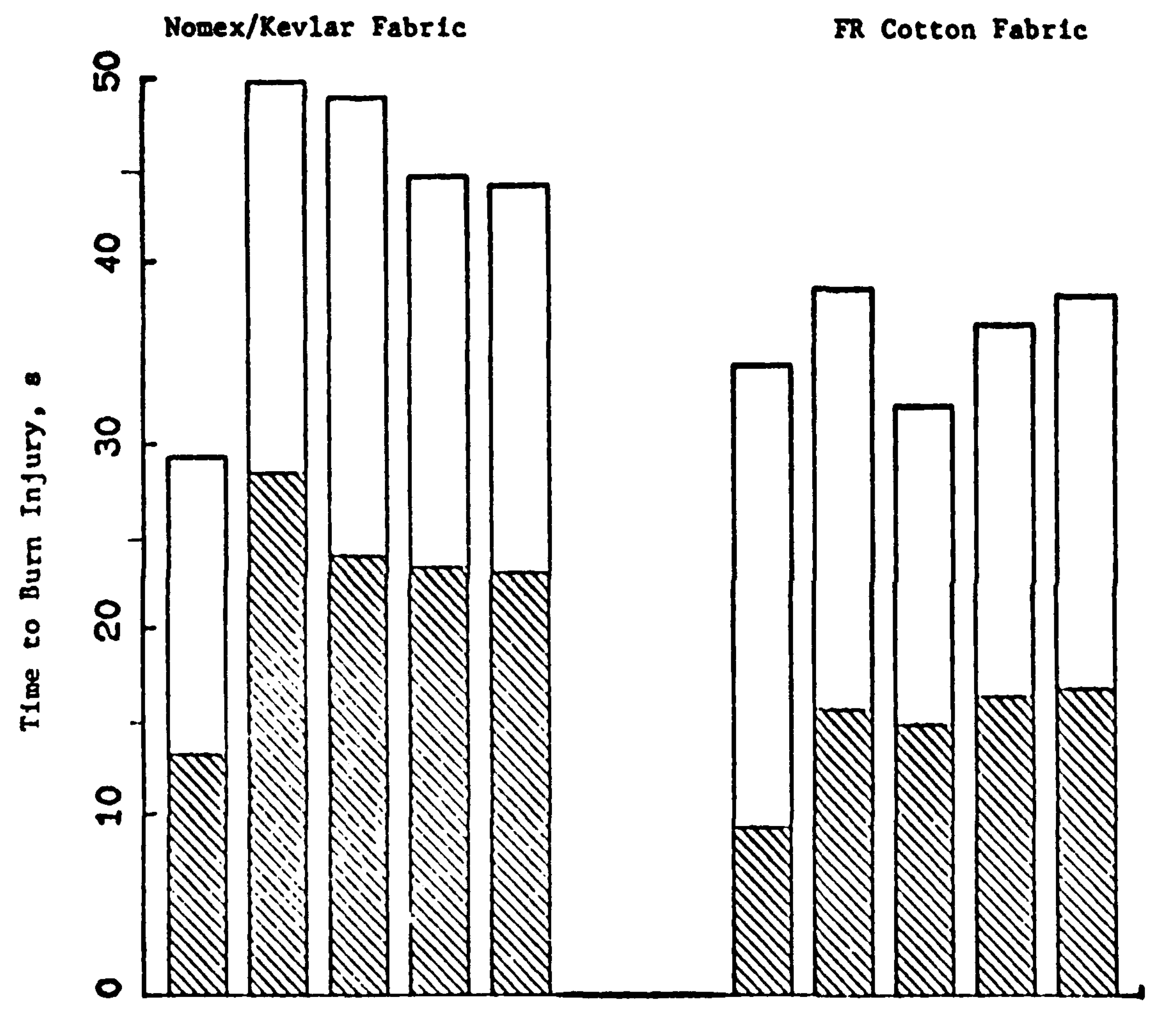


FIGURE 5

TOTAL HEAT TRANSMITTED THROUGH NOMEX/KEVLAR and
FR COTTON OUTER FABRICS AND UNDERWEAR
(specimen-sensor distance 13 mm)

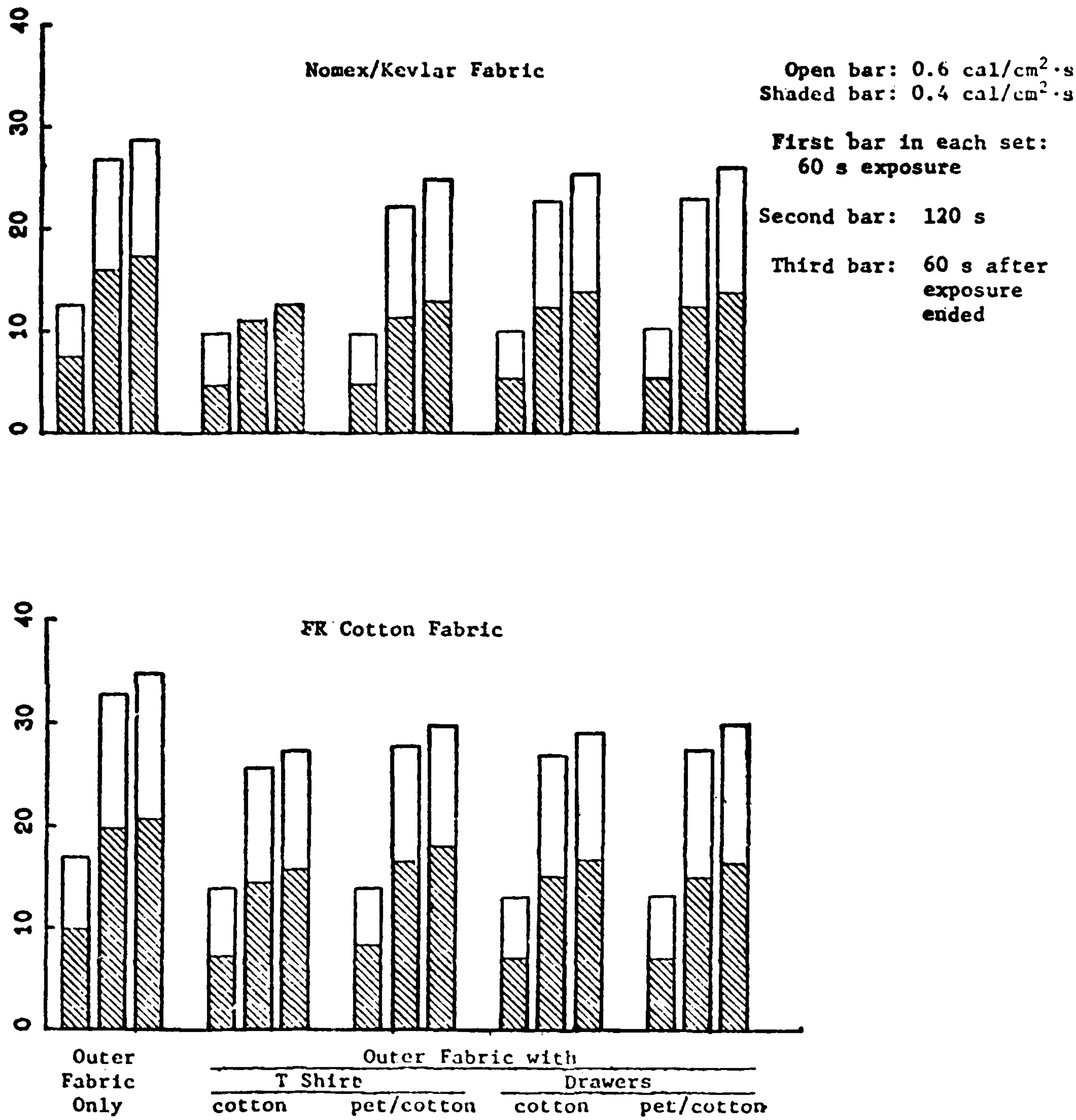
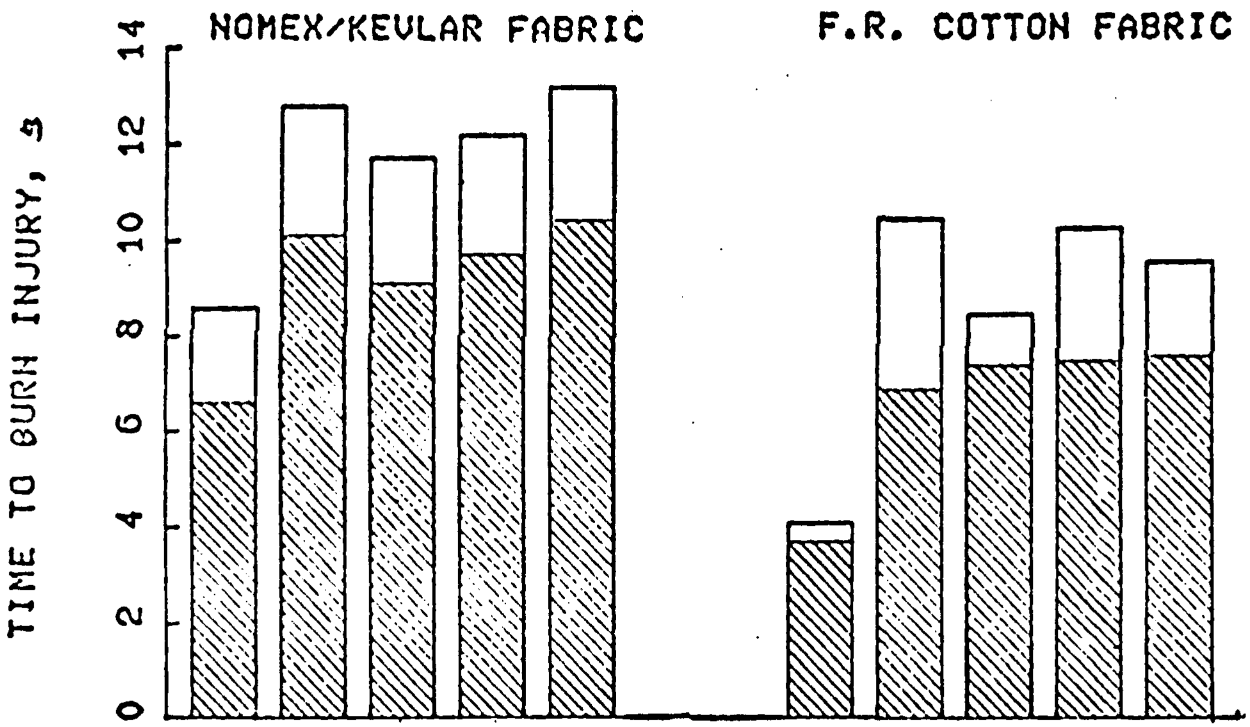


FIGURE 6

TIME TO BURN INJURY: NOMEX/KEVLAR AND F.R. COTTON OUTER FABRICS AND UNDERWEAR (flame temperature 1090 °C)



Open bar: 3.2 mm specimen-sensor distance
Closed bar: specimen-sensor in contact

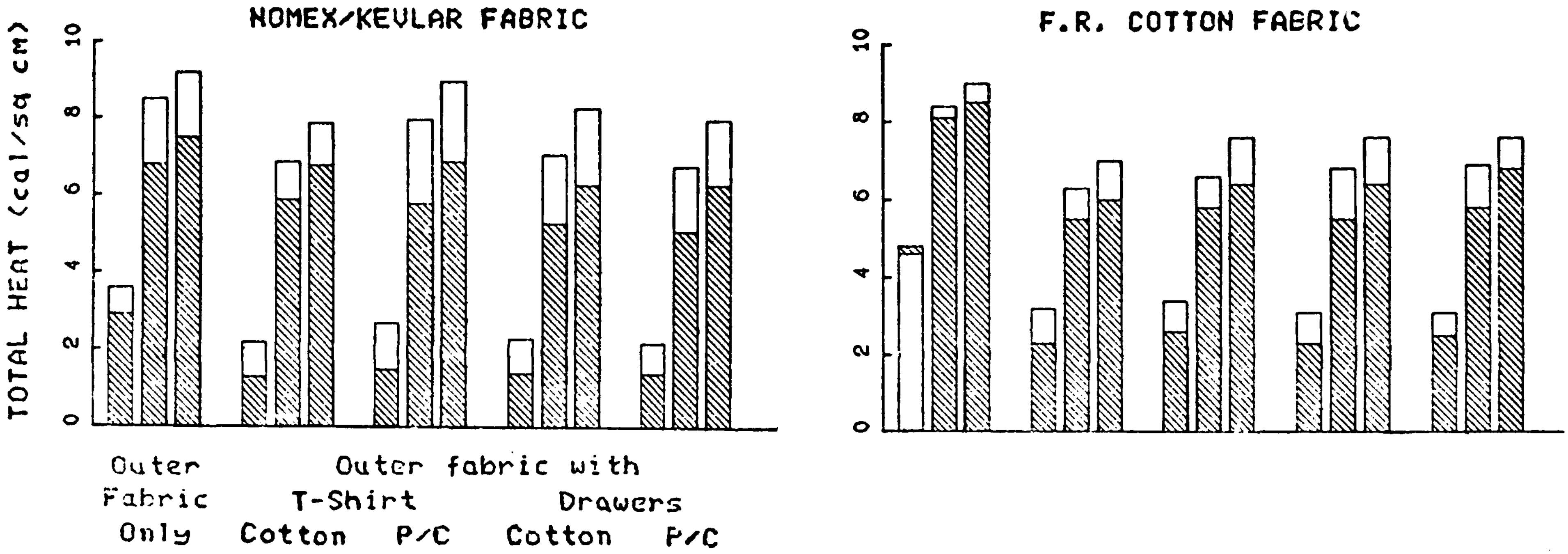
First bar: outer fabric only

Outer Fabric With

Second bar: Cotton T-shirt
Third bar: P/C t-shirt
Fourth bar: Cotton drawers
Fifth bar: P/C drawers

FIGURE 7

TOTAL HEAT TRANSMITTED THROUGH NOMEX/KEVLAR AND F.R. COTTON
OUTER FABRICS AND UNDERWEAR
(flame temperature 1090 °C)



Open bar: specimen-sensor in contact
Closed bar: 3.2 mm specimen-sensor distance

First bar in each set: 10 s exposure
Second bar: 20 s exposure
Third bar: 10 s after exposure ended

FIGURE 8

TIME TO BURN INJURY: NOMEX AND F.R. COTTON OUTER FABRICS AND UNDERWEAR
(Specimen in Contact with Heat Sensor)

Open Bar: TBI at 0.2 cal/cm^2
Closed Bar: TBI at 0.4 cal/cm^2

First Bar: Outer Fabric Only

Outer Fabric With

Second Bar: Cotton T-Shirt
Third Bar: P/C T-Shirt
Fourth Bar: Cotton Drawers
Fifth Bar: P/C Drawers

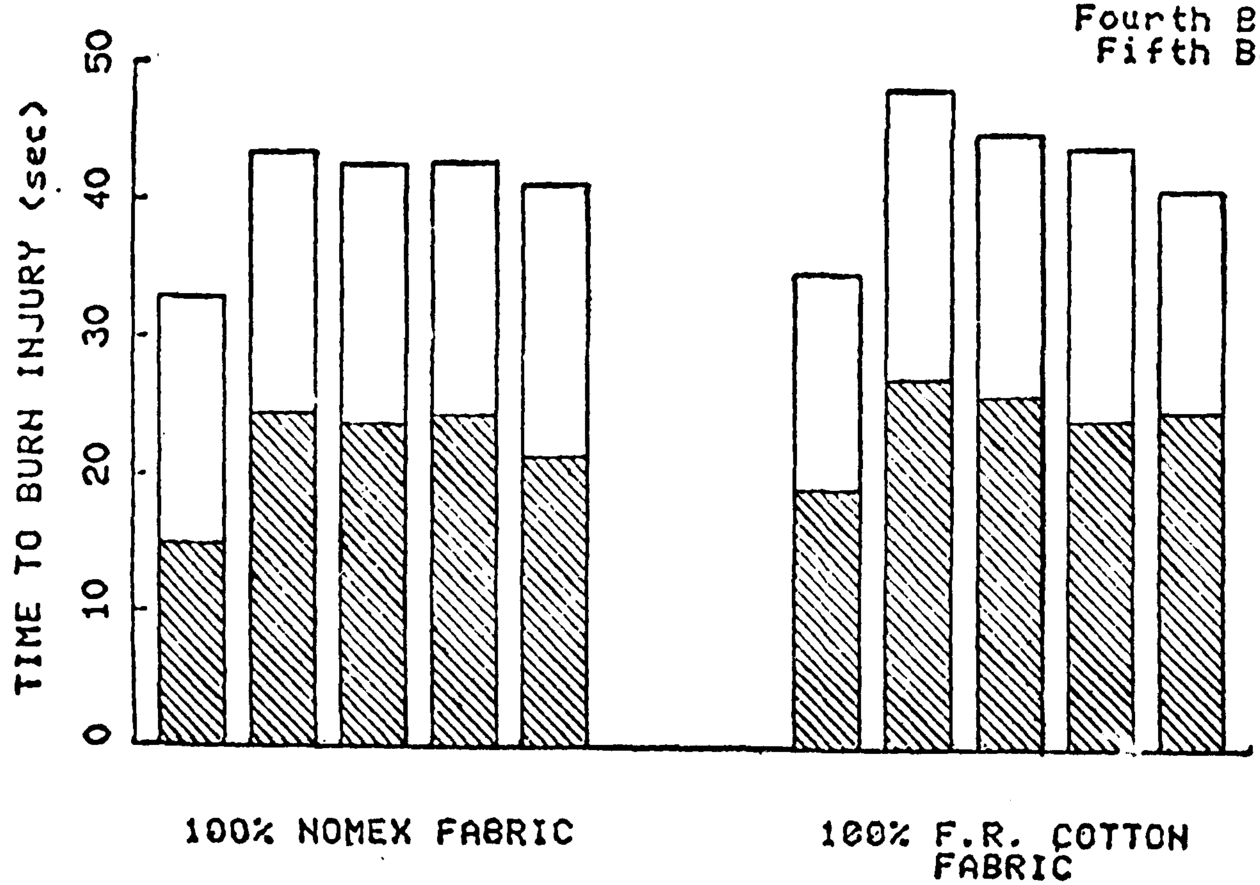


FIGURE 9

TOTAL HEAT TRANSMITTED THROUGH NOMEX AND F.R. COTTON
OUTER FABRICS AND UNDERWEAR
(Specimen in Contact with Heat Sensor)

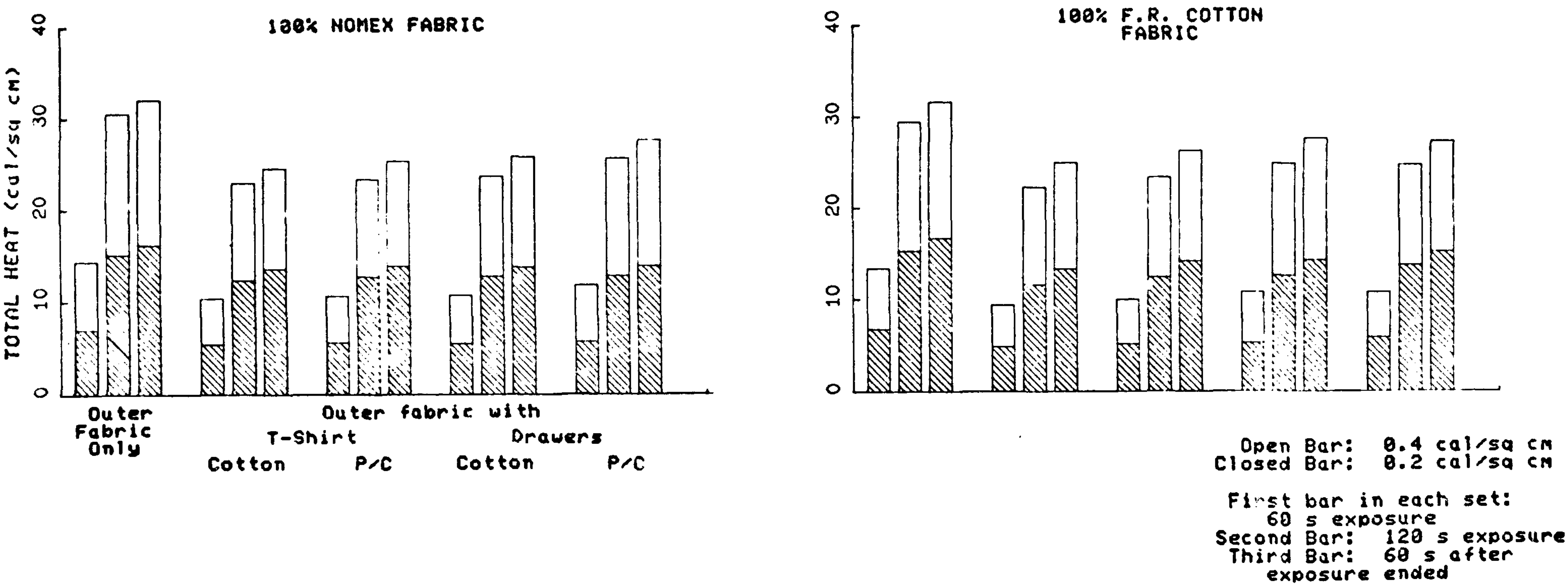
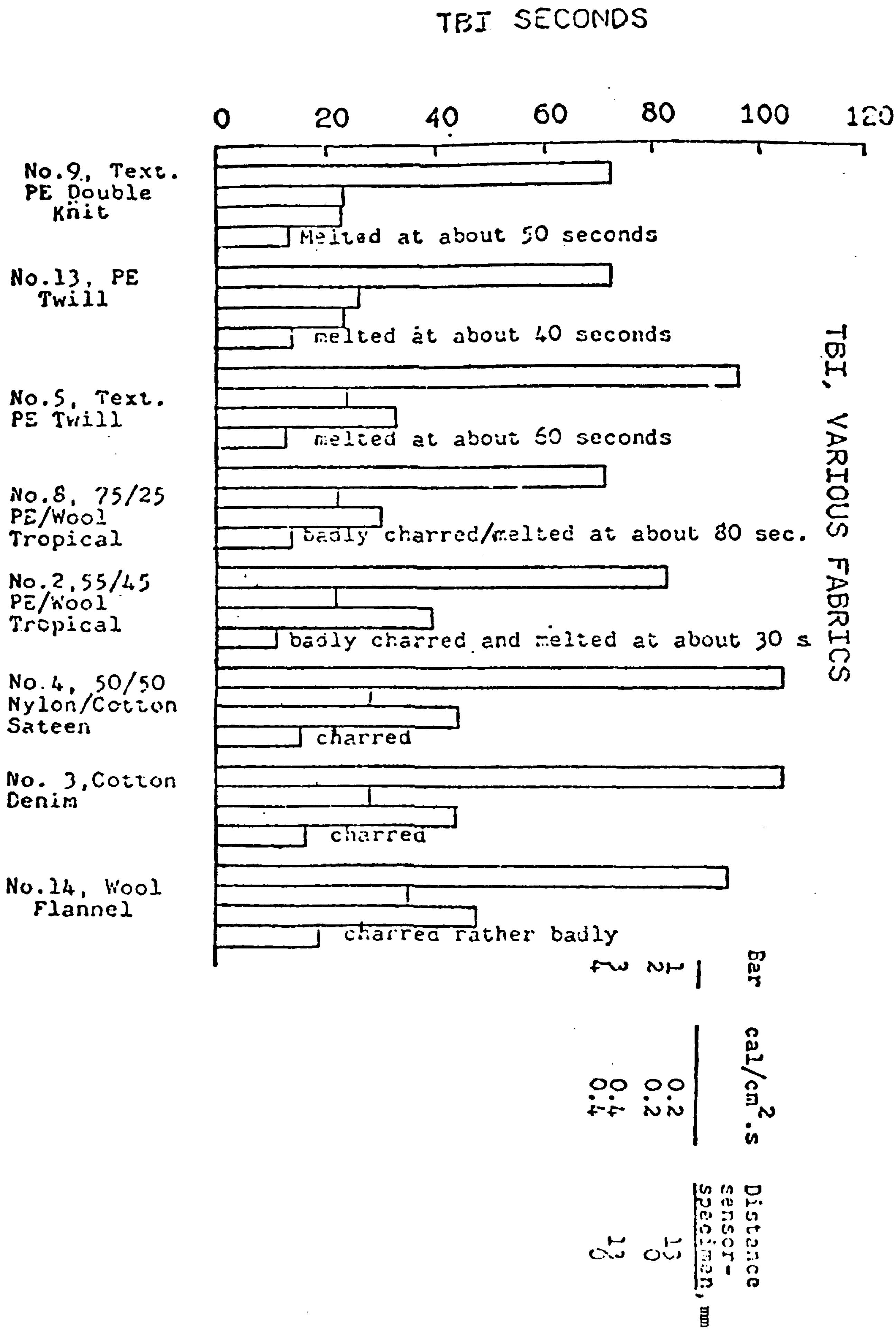
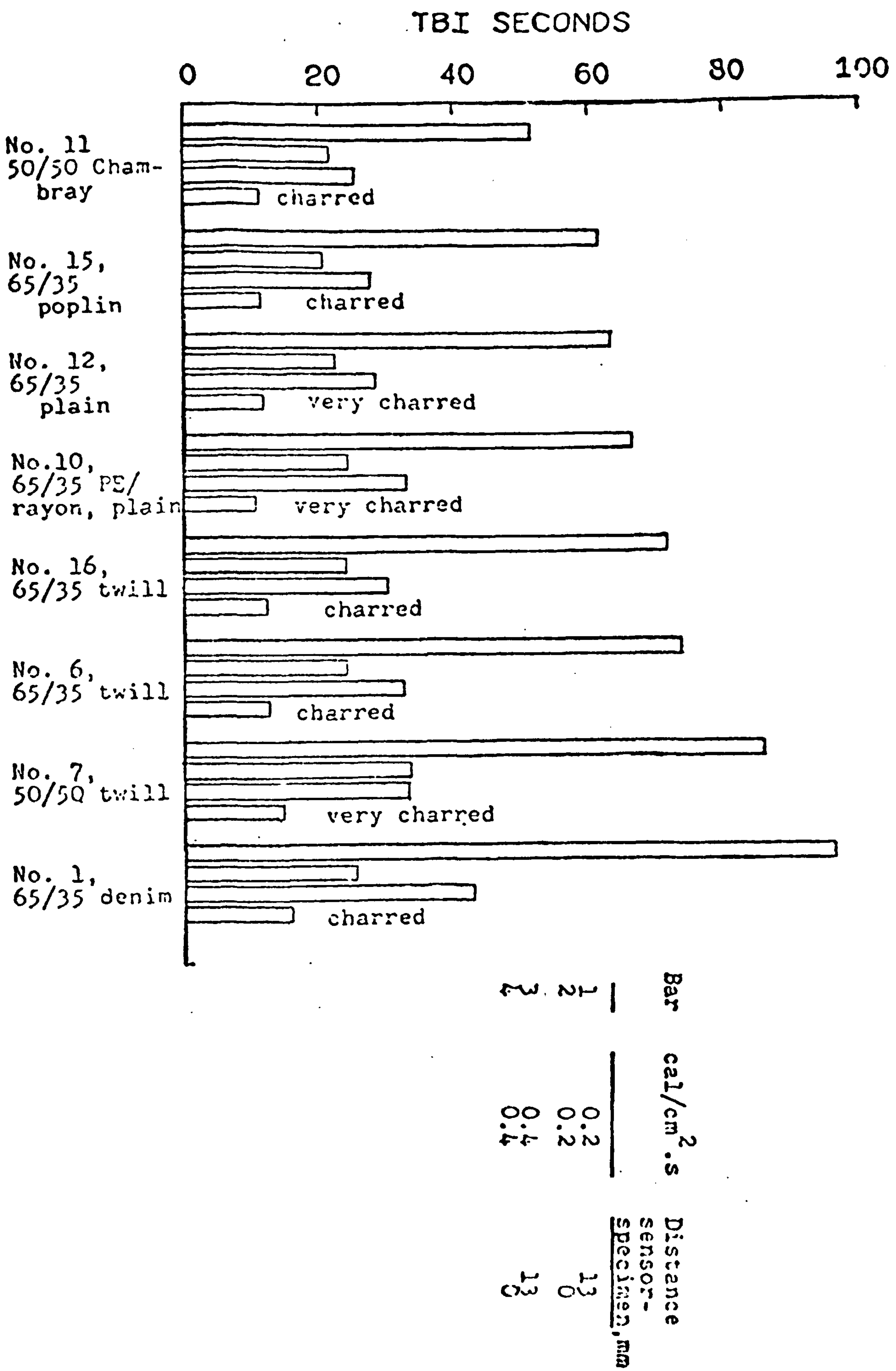


FIGURE 10



TBI SECONDS
0
20
40
60
80
100
120
No.9, Text. PE Double Knit
Melted at about 50 seconds
No.13, PE Twill
melted at about 40 seconds
No.5, Text. PE Twill
melted at about 60 seconds
No.8, 75/25 PE/Wool Tropical
badly charred/melted at about 80 sec.
No.2, 55/45 PE/Wool Tropical
badly charred and melted at about 30 s
No.4, 50/50 Nylon/Cotton Sateen
charred
No. 3, Cotton Denim
charred
No.14, Wool Flannel
charred rather badly
TBI, VARIOUS FABRICS
Bar
1
2
3
4
cal/cm2.s
0.2
0.2
0.4
0.4
Distance sensor-specimen, mm
13
0
13
0

FIGURE 11



TBI, POLYESTER/COTTON AND POLYESTER/RAYON FABRICS

FIGURE 12

APPENDIX B. TABLES

TABLE 1. DESCRIPTION OF TREATED FABRICS PRESENTLY USED ON SHIPBOARD (DATA SUPPLIED BY NCTRF)

FIBER CONTENT	COLOR	WEIGHT g/sq m	WEIGHT oz/sq yd	ENDS/PICKS /m	ENDS/PICKS /in	THICKNESS $m \times 10^4$	THICKNESS in	AIR PERMEABILITY $\frac{m^3/min}{m^2}$	AIR PERMEABILITY $\frac{ft^3/min}{ft^2}$
SHIPMENT: 8/80									
100% NOMEX	OLIVE GREEN	165	4.8	3150/2050	80/52	3.8	.015	22.0	72.2
100% F.R. COTTON	DARK BLUE	235	6.9	4880/2200	124/56	4.6	.018	9.27	30.4
SHIPMENT: 1/81									
95/5 NOMEX KEVLAR	OLIVE GREEN	165	4.8						
100% F.R. COTTON	DARK BLUE	240	7.1						

TABLE 2. DESCRIPTION OF FABRICS PRESENTLY USED ON SHIPBOARD
(DATA SUPPLIED BY NCTRF)

A. OUTERWEAR

NUMBER	FIBER CONTENT	COLOR	WEIGHT g/m^2	WEIGHT oz/yd^2	ENDS/PICKS /m	ENDS/PICKS /in	THICKNESS $m \times 10^4$	THICKNESS in	AIR PERMEABILITY $m^3/min/m^2$	AIR PERMEABILITY $ft^3/min/ft^2$
1	65/35 C/P DENIM	BLUE	350	10.3	2760/1730	70/44	7.4	.029	9.27	30.4
2	55/45 P/W TROPICAL	BLACK	220	6.5	2440/2050	62/52	4.6	.018	10.4	34
3	100% COTTON DENIM	BLUE	340	10.0	2680/1650	68/42	7.9	.029	7.04	23.1
4	50/50 N/C SATEEN	BLUE	315	9.3	4410/2990	112/76	5.8	.023	1.67	5.48
5	100% TEXT. POLY. TWILL	DARK BLUE	270	8.0	2600/2280	66/58	6.4	.025	5.5	18
6	65/35 P/C TWILL	TAN	240	7.0	3310/2200	84/56	4.1	.016	13.8	45.2
7	50/50 P/C TWILL	WHITE	235	6.9	4250/2200	108/56	4.3	.017	5.27	17.3
8	75/25 P/W TROPICAL	DARK BLUE	215	6.4	2050/1730	52/44	4.3	.017	13.5	44.2
9	100% POLY. DOUBLE KNIT	DARK BLUE	205	6.0	1420/940	36/24	9.1	.036	64	210
10	65/35 P/R	BLACK	200	5.9	2200/1890	56/48	4.3	.017	31.7	104
11	50/50 P/C CHAMBRAY	LIGHT BLUE	120	3.5	2834/1890	72/48	3.0	.012	73	240
12	65/35 P/C TWILL	BLUE	160	4.8	3622/2834	92/72	3.3	.013	27.9	91.4
13	100% POLY. TWILL	DARK BLUE	205	6.0	2716/2360	69/60	6.4	.025	17	57
14	100% WOOL FLANNEL	DARK BLUE	295	8.4			10.1	.040	21.1	69.2
15	65/35 P/C POPLIN	TAN	150	4.4	4250/2050	108/52	2.8	.011	27.3	89.6
16	65/35 P/C TWILL	DARK BLUE	195	5.8	4920/2130	125/54	4.1	.016	11.8	38.8

TABLE 2. CONT. DESCRIPTION OF UNDERWEAR FABRICS PRESENTLY USED ON SHIPBOARD (DATA SUPPLIED BY NCTRF)

B. UNDERWEAR

FIBER CONTENT	WEIGHT g/m^2	WEIGHT oz/yd^2	ENDS/PICKS /m	ENDS/PICKS /in	THICKNESS $m \times 10^4$	THICKNESS in	AIR PERMEABILITY $\frac{m^3/min}{m^2}$	AIR PERMEABILITY $\frac{ft^3/min}{ft^2}$
100% COTTON T-SHIRT	140	4.2	1260/1180	32/30	4.8	.019	268	81.7
P/C T-SHIRT	115	3.4	1260/1260	32/32	4.6	.018	581	177
100% COTTON DRAWERS	100	3.0	5350/2630	136/72	2.3	.009	75.1	22.9
P/C DRAWERS	100	3.0	5670/5670	144/144	2.0	.008	120	36.6

TABLE 3.

PROTECTIVE CHARACTERISTICS OF NOMEX/KEVLAR AND F.R. COTTON OUTER FABRICS AND UNDERWEAR AT 13 mm SPECIMEN-SENSOR DISTANCE AND 0.4 CAL/SQ CM-S

	TBI s.	TOTAL HEAT (CAL/SQ CM)					
		NO FLAME EXPOSURE			FLAME EXPOSURE		
		60 s	120 s	180 s	60 s	120 s	180 s
NOMEX/ KEVLAR							
ALONE	29.3	7.5	16.0	17.3	7.6 I) 7.3	16.0 28.9	18.0 30.7
& COTTON T-SHIRT	49.8	4.7	11.0	12.6	5.0	13.0	14.4
& P/C T-SHIRT	48.9	4.8	11.3	12.9	5.4	12.0	13.3
& COTTON DRAWERS	44.6	5.4	12.3	13.7	5.3	12.8	13.9
& P/C DRAWERS	44.1	5.4	12.3	13.8	5.4 I) 7.5	12.7 25.9	13.9 36.9
F.R. COTTON							
ALONE	34.2	9.9	19.3	20.7	10.3	21.5	23.1
& COTTON T-SHIRT	38.4	7.3	14.5	15.8	7.4 I) 8.2	18.6 20.1	19.6 21.3
& P/C T-SHIRT	32.7	8.4	16.6	18.1	7.3 I) 7.1	14.6 23.2	15.8 23.9
& COTTON DRAWERS	36.4	7.2	15.2	16.8	I) 8.1	28.9	30.2
& P/C DRAWERS	38.0	7.1	15.1	16.5	6.7 I) 7.5	14.3 25.9	15.4 26.9

I) SPECIMEN WAS IGNITED WHEN EXPOSED TO FLAME

* EXPOSED FOR 15 SEC TO 25 mm METHANE FLAME AT 60 SEC.

TABLE 4.

PROTECTIVE CHARACTERISTICS OF NOMEX/KEVLAR AND F.R. COTTON OUTER FABRICS AND UNDERWEAR AT 13 mm SPECIMEN-SENSOR DISTANCE AND 0.6 CAL/SQ CM-S

	TBI (SEC)	TOTAL HEAT (CAL/SQ CM) 60 SEC	120 SEC	180 SEC
95/5 NOMEX KEVLAR				
ALONE	13.2	12.7	26.9	29.0
& COTTON* T-SHIRT	28.4	9.8	16.7	
& P/C T-SHIRT	23.9	9.7	22.1	24.7
& COTTON DRAWERS	23.3	10.0	22.6	25.2
& P/C DRAWERS	23.0	10.2	22.8	25.8
100% F.R. COTTON				
ALONE	9.2	17.0	32.8	34.8
& COTTON T-SHIRT	15.6	14.0	25.7	27.3
& P/C+ T-SHIRT	14.8	14.0	27.8	29.8
& COTTON+ DRAWERS	16.3	13.2	27.0	29.1
& P/C DRAWERS	16.7	13.3	27.5	30.0

* THE COTTON T-SHIRT IN EACH SAMPLE WAS IGNITED
\+ IN ONE SAMPLE THE UNDERGARMENT WAS IGNITED
ALL VALUES ARE AN AVERAGE OF 3 TESTS

TABLE 5.

TIME TO BURN INJURY AND TOTAL HEAT VALUES FOR NAVY FABRICS EXPOSED TO A 2000°F (1089°C) FLAME AT 3.2 MM DISTANCE

SPECIMEN	TIME TO BURN INJURY* (SEC)	TOTAL HEAT (CAL/SQ CM)+ 10 SEC	20 SEC	30 SEC
95/5 NOMEX/KEVLAR	8.6	2.9	6.8	7.5
95/5 NOMEX/KEVLAR WITH CT	12.8	1.3	5.9	6.8
95/5 NOMEX KEVLAR WITH PCT	11.7	1.5	5.8	6.9
95/5 NOMEX/KEVLAR WITH CD	12.2	1.4	5.3	6.3
95/5 NOMEX/KEVLAR WITH PCD	13.2	1.4	5.1	6.3
100% F.R. COTTON	4.3	4.7	8.1	8.8
100% F.R. COTTON WITH CT	10.1	2.3	5.5	6.8
100% F.R. COTTON WITH PCT	8.5	2.6	5.8	6.4
100% F.R. COTTON WITH CD	10.3	2.3	5.5	6.4
100% F.R. COTTON WITH PCD	9.6	2.5	5.8	6.8

* AVERAGE VALUE FROM 3 SAMPLES

+ AVERAGE VALUE FROM 2 SAMPLES

CT - COTTON T-SHIRT
PCT - POLYESTER/COTTON T-SHIRT
CD - COTTON DRAWERS
PCD - POLYESTER/COTTON DRAWERS

PROTECTIVE CHARACTERISTICS OF EXPERIMENTAL UNIFORM FABRICS AND UNDERWEAR

SPECIMEN IN CONTACT WITH HEAT SENSOR

EXPOSURE: 0.2 CAL/SQ CM-S

	TBI (SEC)		TOTAL HEAT (CAL/SQ CM)					
			60 SEC		120 SEC		180 SEC	
	NOMEX	FR C	NOMEX	FR C	NOMEX	FR C	NOMEX	FR C
ALONE	32.9	34.8	7.0	6.8	15.1	15.3	16.2	16.7
WITH COTTON T-SHIRT	43.5	48.3	5.4	4.9	12.3	11.6	13.6	13.3
WITH P/C T-SHIRT	42.6	45.1	5.6	5.2	12.7	12.4	13.9	14.2
WITH COTTON DRAWERS	42.8	44.1	5.5	5.3	12.8	12.6	13.8	14.3
WITH P/C DRAWERS	41.2	41.0	5.7	5.9	12.8	13.7	13.9	15.2

ALL VALUES ARE AN AVERAGE OF 3 TESTS
P/C - POLYESTER / COTTON
FR C - FLAME RETARDANT COTTON 6.9 OZ/SQ YD WEIGHT
NOMEX 4.8 OZ/SQ YD WEIGHT

TABLE 6A.

PROTECTIVE CHARACTERISTICS OF EXPERIMENTAL UNIFORM FABRICS AND UNDERWEAR

SPECIMEN 1/2 IN. IN FRONT OF SENSOR

EXPOSURE: 0.2 CAL/SQ CM-S FOR 120 SEC.

THEN ALSO EXPOSURE TO METHANE FLAME FOR 15 SEC. KEPT IN RADIANT FIELD

	TBI (SEC)		TOTAL HEAT (CAL/SQ CM)					
			120 SEC		135 SEC		180 SEC	
	NOMEX	FR C	NOMEX	FR C	NOMEX	FR C	NOMEX	FR C
ALONE	69.9	85.9	7.7	7.0	12.0	9.8	17.5	13.7
WITH COTTON T-SHIRT	131.4	131.9	5.1	4.9	6.7	6.9	13.0 *29.1	10.3 *33.0
WITH P/C T-SHIRT	128.7	129.3	5.3	5.1	6.9	7.1	13.5 *31.9	11.3 *33.1
WITH COTTON DRAWERS	131.5	131.4	5.1	4.9	6.5	7.5	*28.5	*27.9
WITH P/C DRAWERS	122.2	130.0	5.6	5.1	7.9	6.8	11.3 *30.9	10.2

*MEANS IGNITION OF THE FABRICS
ALL VALUES ARE AN AVERAGE OF 3 TESTS
P/C - POLYESTER / COTTON
FR C - FLAME RETARDANT COTTON 6.9 OZ/SQ YD, NOMEX 4.8 OZ/SQ YD

TABLE 6B.

PROTECTIVE CHARACTERISTICS OF EXPERIMENTAL UNIFORM FABRICS AND UNDERWEAR

SPECIMEN 1/2 IN. IN FRONT OF SENSOR

EXPOSURE: 0.3 CAL/SQ CM-S

	TBI (SEC)		TOTAL HEAT (CAL/SQ CM)					
			60 SEC		120 SEC		180 SEC	
	NOMEX	FR C	NOMEX	FR C*	NOMEX	FR C	NOMEX	FR C
ALONE	40.5	43.9	5.6	5.4	12.2	12.3	13.2	13.8
WITH COTTON T-SHIRT	68.7	58.4	3.5	4.2	8.3	12.6	9.8	13.8
WITH P/C T-SHIRT	65.1	53.8	3.6	5.3	8.6	13.0	10.0	14.6
WITH COTTON DRAWERS	57.9	50.7	4.0	5.5	9.4	12.6	10.8	14.0
WITH P/C DRAWERS	55.9	54.3	4.2	4.8	9.7	12.6	11.0	14.0

ALL VALUES ARE AN AVERAGE OF 3 TESTS
P/C - POLYESTER / COTTON
FR C - FLAME RETARDANT COTTON 6.9 OZ/SQ YD WEIGHT
NOMEX 4.8 OZ/SQ YD WEIGHT
* AFTER EXPOSURE THESE SPECIMENS WERE CHARRED

TABLE 6C.

PROTECTIVE CHARACTERISTICS OF EXPERIMENTAL UNIFORM FABRICS AND UNDERWEAR

SPECIMEN 1/2 IN. IN FRONT OF SENSOR

EXPOSURE: 0.4 CAL/SQ CM-S

	TBI (SEC)		TOTAL HEAT (CAL/SQ CM)					
			60 SEC		120 SEC		180 SEC	
	NOMEX	FR C	NOMEX	FR C*	NOMEX	FR C	NOMEX	FR C
ALONE	28.6	29.8	7.8	10.7	16.9	21.0	18.4	22.5
WITH COTTON T-SHIRT	48.2	36.8	4.9	8.6	11.7	16.7	13.4	18.0
WITH P/C T-SHIRT	48.9	32.4	4.9	8.5	11.8	17.3	13.9	19.4
WITH COTTON DRAWERS	44.0	32.2	5.5	9.0	12.8	18.8	14.6	20.8
WITH P/C DRAWERS	43.6	33.4	5.5	8.6	12.7	17.1	14.5	18.9

ALL VALUES ARE AN AVERAGE OF 3 TESTS
P/C - POLYESTER / COTTON
FR C - FLAME RETARDANT COTTON 6.9 OZ/SQ YD WEIGHT
NOMEX 4.8 OZ/SQ YD WEIGHT
* AFTER EXPOSURE THESE SPECIMENS WERE VERY CHARRED

TABLE 6D.

PROTECTIVE CHARACTERISTICS OF EXPERIMENTAL UNIFORM FABRICS AND UNDERWEAR

SPECIMEN IN CONTACT WITH HEAT SENSOR

EXPOSURE: 0.4 CAL/SQ CM-S

	TBI (SEC)		TOTAL HEAT (CAL/SQ CM)					
			60 SEC		120 SEC		180 SEC	
	NOMEX	FR C	NOMEX	FR C	NOMEX	FR C	NOMEX	FR C
ALONE	15.0	19.1	14.4	13.4	30.5	29.5	32.0	31.7
WITH COTTON T-SHIRT	24.5	27.1	10.3	9.4	23.0	22.3	24.6	25.0
WITH P/C T-SHIRT	23.7	25.9	10.6	10.0	23.4	23.4	25.4	26.3
WITH COTTON DRAWERS	24.4	24.2	10.7	10.8	23.8	24.9	25.9	27.7
WITH P/C DRAWERS	21.4	24.9	11.8	10.8	25.7	24.7	27.7	27.3

ALL VALUES ARE AN AVERAGE OF 3 TESTS
P/C - POLYESTER / COTTON
FR C - FLAME RETARDANT COTTON 6.9 OZ/SQ YD WEIGHT
NOMEX 4.8 OZ/SQ YD WEIGHT

TABLE 6E.

APPENDIX C. REFERENCES

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