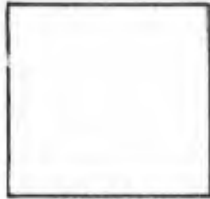


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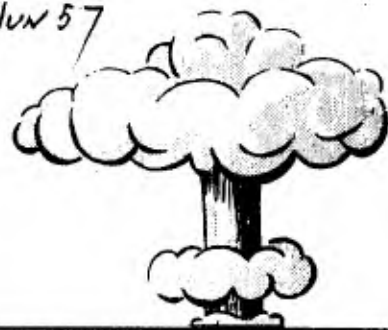
# BUSTER

NEVADA PROVING GROUNDS  
OCTOBER-NOVEMBER 1951

Project 2.4a

PROTECTIVE VALUE AND IGNITION HAZARDS  
OF TEXTILE MATERIALS EXPOSED  
TO THERMAL RADIATION

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OPERATION BUSTER  
PROJECT 2.4a  
PROTECTIVE VALUE AND IGNITION HAZARDS OF TEXTILE MATERIALS  
EXPOSED TO THERMAL RADIATION

By

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Research and Development  
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Major, QMC

26 June 1952

OFFICE OF THE QUARTERMASTER GENERAL  
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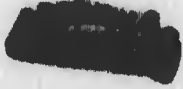
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#### ACKNOWLEDGMENTS

Much of the planning for this test was done by Colonel Frank M. Steadman, OCMG, who also helped carry out the test in the field. Lt. W.W. Goozee, of the Quartermaster Board at Ft. Lee, also assisted in the work in the field.

Many people at the Philadelphia Research and Development Laboratories helped in various ways and a few in particular are mentioned below.

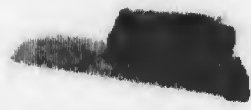
The temperature indicators were developed and furnished by Dr. Joseph D. Loconti and his staff in the Pioneering Research Division.

The samples of fabric were furnished by the Textile & Leather Division, many by Mr. Frank J. Rizzo and his staff in the Textile Dyeing and Finishing Laboratory and others by Mr. Allan J. McQuade of the Functional Finishes Laboratory and Mr. Louis I. Weiner of the Textile Materials Engineering Laboratory.

Measurements of tensile strength, elongation, and stiffness were made by Mr. Constantin J. Monego's staff in the Physical Testing Section of the Textile Materials Engineering Laboratory and optical reflectances by Mr. Samuel P. Cohen's staff in the Pioneering Research Division.

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ABSTRACT


Fabrics, generally uniform types, were exposed to radiation ranging from 1.6 to 27 cal. per sq. cm. to determine resistance to damage and protective value and the effect of method of exposure on these properties. They were exposed flat, in contact with and spaced 1/4 in. from backings varying in reflectance, thermal capacity and thermal conductivity, and also at varying angles of incidence and folded to simulate their use in clothing. Protection was evaluated by using passive thermal indicators and for ignition studies photography was used in an attempt to detect flaming.

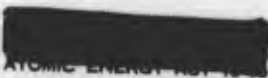
The results are rather complex and difficult to describe concisely and accurately. Damage and protection depend on the energy absorbed and transferred to the skin. Incident radiation is reflected, transmitted and absorbed in varying amounts and in addition to that transmitted thru the fabric, energy is transferred to the skin by conduction, convection and radiation from the hot fabric. In general the results are understandable in terms of these mechanisms. The extent of damage depended on the backing and was generally greater for fabrics with air backing. Relative effects varied with the intensity of radiation. There was no evidence of flaming but there was damage from after-glow.

White fabrics resisted damage but afforded little protection. Military shades were damaged more but afforded more protection, especially if spaced from the backing. Camouflage shades were very little worse than standard OD. Cotton charred and wool melted; at high intensities wool afforded more protection than cotton. Mixtures of 85% wool-15% nylon were about as good as all wool. Heat treated orlon was very resistant but the protective value was not outstanding. Fire retardants improved the resistance to damage only slightly and showed no added protection.

Most ordinary fabrics withstood 5 cal. per sq. cm. without appreciable damage but were very badly charred or melted at 9 cal. per sq. cm. It is difficult to estimate the required protective value from temperature indications but, except for the heavier fabrics, the protection at 5 cal. per sq. cm. likely was not adequate.

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CHAPTER 1

OBJECTIVES

1.1 OBJECTIVES

The objectives of this phase of the test program were to:

- (1) Evaluate the protective value of clothing materials exposed to thermal radiation;
- (2) Evaluate the effects of various types of backing materials in contact with, and spaced away from, the thin material;
- (3) Evaluate the effect of thermal radiation on clothing materials exposed at varying incident angles and the penetration thru such materials;
- (4) Evaluate the hazard of ignition of clothing materials in a standardized exposure conformation intended to simulate conditions of wear.

1.2 PURPOSES

Troops in the field will be primarily dependent upon their uniform clothing for protection from the thermal radiation from atomic bomb air bursts. A knowledge of the thermal effects behind such thin layers is therefore essential to any selective or modification action to provide greater protection to those troops within the thermal hazard range, but beyond the range of ionizing radiation and of blast effects. Minimization of thermal injury of personnel subjected to sub-lethal dosage of ionizing radiation is important to avoid combined effects from resulting in mortalities.

The penetration of thermal radiation through thin layers, direct and scattered, and including that re-radiated from the hot sample, heated by the absorbed energy, has not been adequately investigated. Previous investigation has been directed primarily toward evaluation of the nature and magnitude of the incident radiation, and of its effects on the materials themselves. Those studies have indicated that the choice of backing upon which thin materials are supported for exposure effects the damage to the material itself. An evaluation of the resultant energy behind thin materials of different densities, textures, and thicknesses, under varying conditions of backing is necessary as a



calibration basis from which to initiate laboratory investigations of such effects, in order to reach a valid basis for the evaluation of the protective value of thin materials.

The ignition of clothing being worn would increase and complicate the injury of the wearer. No good evidence has been presented to indicate that such ignition is frequent enough to constitute a real hazard; however, some investigating groups express serious concern as to such a hazard. The emphasis to be placed on the provision of protection from ignition can only be determined after the degrees of ignition hazard are evaluated. The investigation into the incidence of ignition is preliminary only, primarily an evaluation of one possible standardized condition of exposure of thin materials.



[REDACTED]

CHAPTER 2

HISTORY AND PLAN OF TEST

2.1 HISTORY

Thin materials, primarily clothing fabrics, supplied by the Quartermaster Corps have been exposed to thermal radiation at Operations RANGER and GREENHOUSE. Tests have also been conducted on these materials using carbon arc sources at the Naval Material Laboratory (NML), the Naval Radiological Defense Laboratory (NRDL) and the University of Rochester. The work has been primarily concerned with the effects of radiation on the materials themselves.

The generalized results obtained from previous tests are as follows:

(1) Damage to the fabrics is apparently affected by the degree of contact with the backing surface, air backed samples showing more damage than those placed in contact with another surface.

(2) In a single experiment, materials exposed at a high angle of incidence showed considerably less damage than those exposed normal to the radiation. The difference in damage corresponded approximately with that calculated by theoretical computations.

(3) Several synthetic fabric materials, commonly blended with natural fibers in clothing materials, melted at low energies during Operation RANGER.

(4) At Operation RANGER there was little, if any, ignition and flaming of the fabrics.

The Quartermaster Corps is vitally concerned with the effects of thermal radiation on the surface behind the thin clothing materials, i.e., the skin of a person exposed to thermal radiation and protected only by clothing. Considerable difficulty has been encountered in obtaining information of this nature, primarily because of the absence of adequate means of obtaining thermal energy data over an extremely short time period. Recent developments in thermal indicating papers<sup>1</sup> provide at least a partial answer to this problem.

2.2 PLAN OF TEST

[REDACTED]

## 2.2.1 Protective Value of Clothing Fabrics

The primary interest of QM is in the protection afforded the soldier, in this case protection of the skin behind the fabric. Damage to the fabric certainly gives some indication of the protection, but recent experiments, especially those at the University of Rochester<sup>2</sup> show relatively poor protection by some fabrics even with good resistance of the fabric.

For these experiments the fabrics were mounted with a wood backing, both in contact and with a 1/4 in. space. To measure the protection, heat sensitive materials were placed behind the fabrics.

### 2.2.1.1 Thermal Indicators

Two types of indicators were used. One was a temperature device in which the indicating material was an organic compound with a definite melting point. The materials, method of processing and characteristics are described in a report by Dr. Joseph Loconti of the Pioneering Research Division of the Philadelphia Quartermaster Research and Development Laboratories<sup>1</sup>. As sprayed on a black paper backing they present a white or gray appearance. On melting they become transparent and are absorbed in the paper so that the backing becomes and remains visible. As calibrated by contact with hot metal surfaces they show sharp changes, with a range of 1 or 2°C.

Temperature indicators with the following melting points, in °C, were available for this test:

61	93	133	164	224
68	106	143	182	242
86	120	154	205	258

The other indicator was the Chemical Corps vesicant gas detector paint M-5<sup>3</sup> which turns from green (OD) to red on heating. At low temperature a red dye is insoluble in the vehicle and effectively covered by other pigments. As vesicant gases are absorbed the red dye becomes soluble in the vehicle and become visible. Presumably as a thermal detector the action is similar. At higher temperatures the red dye becomes soluble in the vehicle and changes the color.

This is not a sharp change with temperature as with the melting point indicators. The change probably depends on time and temperature and perhaps is some function of the energy absorbed by the paint, but a rather complicated function depending upon the way in which the solubility of the dye depends on temperature. This paint was used on both a white and a black backing.

[REDACTED]

The significance of the indications of these devices depends somewhat on the mechanism of transmission of energy through fabrics and to some extent on the properties of skin. Radiation incident on fabric may be reflected; transmitted to the skin, either directly through interstices or scattered; or may be absorbed. If absorbed it will heat the fabric and in turn some of that heat will be transferred to the skin by conduction, convection or re-radiation. If the amount of all these various kinds of energy are significant, and the results indicate that likely they are, then ideally the thermal indicators should respond to them in the same way the skin does.

The reflectances of a few indicators are given in Table 2.1, measured as described in Section 3.2. The values for M-5 paint are averages for a white and black backing; the two values differ by 10% or less in the visible and somewhat more in the infrared. The curves show a flat response up to about  $.5\mu$ , a rather sharp rise and another plateau to a little more than  $.6\mu$ , another sharp rise and another plateau above  $.7\mu$ . The values for the 86 and 182°C temperature indicators represent the highest and lowest reflectances in that group. The flatness is typical of all of that group except one. The curves for the 133°C indicator start at about 12% at  $.4\mu$  with a fairly steady rise to about 40% at  $1.0\mu$ .

The face of these indicators does not present a desirable or definite radiation absorbing surface, especially considering the change to black or red during exposure. It seemed preferable to use them face down, presenting a high absorbing (95%) or a low absorbing (30%) surface as desired. This method has the disadvantage of a time lag due to the added thermal resistance of the backing but a quick preliminary test showed that likely this was not significant. Accordingly most of the indicators were used face down, generally with a smaller number of indicators face up to provide a check.

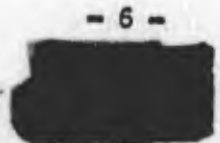
#### 2.2.1.2 Properties of the Skin

Presumably the important properties of the skin in this respect are reflectance, thermal capacity, thermal conductivity and the temperature required for burning. These factors have been studied in various laboratories.

Reflectance has been measured in the U.S. Army Medical Laboratory<sup>4</sup> at Fort Knox. Table 2.1 shows a few results on 71 men and women. The upper figures are for untanned parts of their bodies, the lower figures for the most tanned part. There was considerable variation among subjects; the standard errors were about  $\pm 20\%$  in the visible and  $\pm 10\%$  in the infrared. If radiation from hot fabric is important reflectances at much longer wave lengths are needed. The averages are not very significant without some definite weighting scheme but may be useful for comparisons.

TABLE 2.1  
 Reflectance Properties of Skin and Indicator and Backing Materials

Materials	Thermal Capacity cal/gram	Thermal Conductivity c.g.s. units	Reflectance in Per Cent																	
			0.4 $\mu$	0.5 $\mu$	0.6 $\mu$	0.7 $\mu$	0.8 $\mu$	0.9 $\mu$	1.0 $\mu$	0.4-0.7 $\mu$ Av.	0.7-1.0 $\mu$ Av.									
<b>SKIN</b>																				
Untanned human			107	33	49	61	61	61	57	50	39	58								
Tanned human			57	20	36	52	57	56	49	28	55									
<b>BACKING</b>																				
White pine, nat. max. av.	0.17	0.0003	25	56	78	91	95	97	97	97	64	95								
" " min.			16	46	70	87	92	96	96	96	56	93								
Wh. pine painted wh.			12	34	65	82	89	95	95	95	49	91								
" " stained blk.			89	93	95	96	97	99	99	99	94	98								
Alum. foil on wood			2.5	3	3	3.4	3.5	3.5	3.5	3.5	3	3.5								
Polished aluminum			86	88	88	88	85	88	88	93	88	88								
Navy GSG Fiberglass	0.59	0.53	65	71	75	77	77	82	82	86	72	80								
Silicone Laminate	0.42	0.0007	51	64	67	62	57	53	52	52	63	56								
<b>THERMAL INDICATORS</b>																				
M-5 Paint			5.5	9	13	48	65	65	65	65	14	62								
Face of various temp. indicators 182°C			41	40	40	39	39	39	39	39	40	39								
86°C			17	16	16	16	16	16	16	16	16	16								
Backing, black			4.5	4.5	5	5	5	5	5	5	5	5								
Backing, white			65	70	68	69	69	69	69	68	68	69								



Obviously the thermal indicators, face down with black backing, are better radiation receivers than the skin and to the extent that the radiant energy is important, the indicators will give higher temperatures than would be attained by the skin.

The thermal properties of skin have been measured at the Harvard Medical School. The measurements were on pig skin with considerations of structure to show that the results likely hold for human skin. They found the thermal capacity of the dermis and epidermis to be from 0.77 to 0.86 cal. per gram and the corresponding thermal conductivity from .03 to .05 cal. per sq. cm. per second per °C for a 1 cm. thickness. The effective thermal capacity and thermal conductivity of the thermal indicators depends on the degree of contact with the backing and since generally they were merely held by pressure at the edges it is difficult to estimate these values. There is evidence that the contact was not uniform and the indications varied accordingly.

The relation between time and temperature for contact burning has also been studied in the same laboratory. They found that the time required to produce second and third degree burns depends on the temperature as indicated by the following figures taken from their curve:

TABLE 2.2

Temperature - Time Relation  
for Equivalent Skin Burns.  
Data of Moritz and Henriques

Temperature, °C	Time		
	Hours	Minutes	Seconds
44	7		
48		14	
50		5	
52		1	30
58			10
60			5
65			2
70			1

The lower temperatures are not of much interest here except to show the rapid change with temperatures, nearly a 2-fold decrease in time for an increase of 1°C. At 70°C only 1 second is needed for a severe burn with the time correspondingly shorter at higher temperatures but they did not measure effects at less than 1 second.

In view of the above relation the interpretation of thermal indicator readings is uncertain. The pulse of radiation is very short,

[REDACTED]

probably less than 1/2 second. Back of a sample of fabric the temperature probably shows a short high peak followed by a fairly long period at a temperature appreciably above the original temperature, but considerably below the peak. The latter period may be enough to cause burns but since the burning depends so greatly on the temperature, the peak, even with a very short time, will likely be more important. An indicator which gives the peak temperature will certainly be useful but the time is also needed. Neither indicator has been calibrated with radiation and for contact studies short times are difficult to attain. The use of both types gives more information than either alone but even then the information is not complete. The values given by the indicators will be referred to as a measure of protective value, although it is hardly to be expected that there will be a 1 to 1 correspondence with burning of the skin.

#### 2.2.1.3 Low IR Reflectance Characteristics

QM is developing low infrared reflectance fabrics for camouflage purposes. NML tested some special reflecting materials at GREENHOUSE and some of these were included at RANGER. Generally the difference in direct effect on ordinary and on low infrared reflectance fabrics was not very definite. Calculations also indicate that the effect is not very great. Some of these fabrics have now reached the stage where they already have or soon will be adopted, and it is important to check their performance.

#### 2.2.1.4 Synthetics

The poor performance of nylon at RANGER now is of considerable importance. Because of the wool shortage and to get improved wear resistance, serge and shirting are now being procured with a 15% replacement of wool by nylon. It is essential to know how this material will perform in blends.

At RANGER orlon was somewhat better than nylon, but inferior to wool and cotton. There is now available a specially treated heat resistant orlon which was included in this test.

#### 2.2.1.5 Materials of Various Thicknesses

In past experiments the fabrics were generally standard fabrics or standard fabrics with special modifications. It is obvious from those results that reflectance, thickness or weight and kind of fiber are important, but it is difficult to isolate the effect of each variable. Accordingly, two series of fabrics have been made, one cotton and one wool, with as nearly possible identical construction but varying in

[REDACTED]

weight. These are available in white and OD 7, and for one fabric in a number of shades. In addition, some of the fabric was treated with a variety of fire retardants.

Enough of these were included in the BUSTER program to provide a comparison of materials with the same reflectance but of various weights and thicknesses.

#### 2.2.1.6 Fire Retardants

Results at RANGER indicated good performance of a heavy duck treated for fire resistance. It is realized that other factors may have been important. British laboratory results show little added protection from fire retardants and it is important to check this point. Included here are several treatments on cotton, using Erifon, Martin MEM resin, borax-boric acid and Pyroset D, the latter in various amounts; and two treatments on wool, Pyroset D and duPont CM.

#### 2.2.1.7 Miscellaneous

Cotton fabrics are treated with XX-CC-3 for protection against war gases. This material contains chlorinated compounds and may offer some additional protection in this respect through fire resistance.

#### 2.2.2 Effects of Backing Materials

The importance of the material back of the fabric cannot be neglected. Most experiments have been performed with a backing of air, wood or a silicone-fiberglas laminate. Of greatest interest is a backing that would correspond to the skin in such properties as reflectance, thermal conductivity and heat capacity. This experiment was devised to determine the effect of wide variations in these important properties. One such backing is an open mesh screen which approximates air backing. Another is natural finish in white pine wood. The reflectance of the wood was varied by painting it white and by staining it black with as little change as possible in the other properties. In another modification the wood was covered with aluminum foil which also changes the reflectance without much change in the other properties. Covering the wood with a 1/16 in. sheet of polished aluminum changes the reflectance, heat capacity and thermal conductivity. In another case the wood was covered with a 1/16 in. sheet of Navy type GSG silicone-fiberglas laminate. This was included because many tests have been run with this backing and it is a durable, reproducible material. Possibly it can be modified to correspond more nearly to the human skin.

[REDACTED]

The reflectances of the backings were measured as described in Section 3.2 with the results shown in Table 2.1. The values for natural white pine varied considerably and the high and low values for typical samples are given with the average. For most of the others the values for various samples agreed fairly well and only the average is given. The values for the polished aluminum sheet varied about  $\pm 10\%$  depending on the polish. These values represent fairly clean samples and at the time of the exposure tests all reflectances may have been somewhat lower, especially that of the sheet aluminum.


Values for the thermal properties were taken from several sources. For the fiberglass-silicone laminate, the supplier<sup>7</sup> gave values of 0.007 c.g.s. units for the thermal conductivity and 0.42 cal. per g. for the thermal capacity. For aluminum, a handbook<sup>8</sup> value of the thermal conductivity is 0.53 c.g.s. units and handbook values of the specific heat and density give 0.59 cal. per g. for the thermal capacity. For wood, the handbook<sup>8</sup> value for the thermal conductivity is 0.003 cgs. units. Measured values of density and a handbook<sup>8</sup> value of the specific heat give a thermal capacity of 0.17 cal. per g. Likely painting, staining or coating with foil did not change the values for wood appreciably.

For all modifications except the screen, the fabric was mounted in contact with the backing and with a 1/16 in. space between the fabric and the backing.

An attempt was made to keep the fabric in contact with the backing mainly by using a smooth surface and supplying a little tension. This worked fairly well but there is always some doubt about contact with a flat surface. Accordingly a few experiments were run in which the fabric was mounted on a slightly curved surface. The curvature was not sufficient to change the angle of incidence appreciably, but it aided in maintaining contact.

### 2.2.3 Orientation

In most previous experiments the fabric has been exposed with the radiation normal to the surface. In one experiment at RANGER the effect was greatly reduced by placing the samples at an angle. The effects should follow Lambert's Law with the energy per unit area varying with the cosine of the angle of incidence. No quantitative measurements were made but approximately this was the case. Without experimental evidence it is uncertain whether the rough surfaces of fabrics will follow Lambert's Law. It is of interest to determine this for several reasons. In normal wearing, the exposure will not be normal for much of the fabric. If Lambert's law holds, this may afford a convenient way of controlling the intensity in field tests by varying the angle of incidence, rather



than the distance and this might reduce considerably the manual work required. There is the additional point of applying such information to laboratory experiments, where the direction of radiant energy deviates considerably from the normal.

#### 2.2.4 Incidence of Ignition

At Operation RANGER there was considerable scorching and charring of fabrics, but little evidence that the fabrics had burned with a flame. In view of published statements<sup>9</sup>, this was somewhat surprising. Also there is the contrary evidence of tentage burning at GREENHOUSE at fairly low incident energy. It may be that contact of the fabrics with backing retards combustion, but it is not obvious why this effect should be so great. To increase the possibility of ignition some samples were mounted folded, as shown in Figure 3.6. In this method of exposure, heat loss from the sample should be minimized and perhaps this should promote ignition and flaming. In addition, the fabric is exposed in very much the same condition as when worn as a garment.

#### 2.2.5 Fabrics Used

A list of the fabrics used is given in Appendix A, with identifying nomenclature.

CHAPTER 3

PROCEDURES

3.1 EXPOSURE PROCEDURES

3.1.1 General

Samples were exposed to thermal radiation at four stations on Shot Baker and three stations on Shot Dog. The distances and incident energies as determined from preliminary data are given in Table 3.1.

TABLE 3.1

Distances and Thermal Intensities for Stations Used for Exposure

<u>Station</u>	<u>I</u>	<u>II</u>	<u>III</u>	<u>IV</u>
	Shot Baker - Vertical Distance - 1118 ft			
Intended distance from ground zero, ft.	2000	4000	5000	7000
Actual distance from ground zero, ft.	2140	4140	5140	7140
Slant distance, ft.	2410	4290	5260	7230
Intensity of thermal radiation-cal/sq cm	18	5	3.2	1.6
	Shot Dog - Vertical Distance - 1417 ft			
Intended distance from ground zero, ft.		4000	5000	7000
Actual distance from ground zero, ft.		4060	5060	7060
Slant distance, ft.		4300	5250	7200
Intensity of thermal radiation-cal/sq cm		27	18	9

The samples were mounted on individual holders, described in Sections 3.1.4, 3.1.5 and 3.1.6 and shown in Figures 3.1, 3.2, 3.3, and 3.5 which in turn were mounted on 3/4 in. plywood panels. The panels were 48 in. wide and 24 in. high for parts (1), (2), and (3), protective value of fabrics, effect of backing and orientation and 20 in. wide and 32 in. high for part (4), incidence of ignition. The studies for backing studies were on panels 1 and 2, arranged as shown in Figure 3.4; those for protective value studies on panels 3 and 4, shown in Figure 3.5; those for orientation studies also on panel 3; and those for incidence of ignition on panel 5 shown for both shots in Figure 3.5.

The panels were fastened to 1-1/2 in. angle iron. For Shot Baker, the 8 ft. angle irons were driven 2 ft. into the ground and braced with 2 in. x 2 in. or 2 in. x 4 in. wood struts and guy wires. Panels 1 and 2 were above panels 3 and 4 and panel 5 was separately mounted. The photograph in Fig. 3.7, taken after the exposure, shows the arrangement at Station III. The other three stations were similar. For Shot Dog, the angle irons were fabricated into frames with 4 in. x 4 in. lumber for the base. At Stations III and IV the four large panels were mounted on this frame with panels 1 and 2 below panels 3 and 4, and panel 5 mounted as in Shot Baker. The arrangement at Station IV is shown in the photograph of Figure 3.8, taken after exposure. At Station II the arrangement was similar except all the panels were mounted on the same frame.

Of the fabrics in Appendix A, thirty-three were exposed for Shot Baker and twenty-eight for Shot Dog, as listed below.

### 3.1.2 Thermal Indicators

The thermal indicators described in Section 2.2.1 were placed back of most of the samples. The indicating papers were cut into strips, generally 1/4 in. x 1 in. and assembled in appropriate groups of generally 10 to 12 strips. The grouping is shown in Table 3.2 which also indicates which were face up and which were face down. For this assembly the strips were held with adhesive tape applied to the ends and usually were held against the backing material by the same tape, leaving exposed areas of 1/4 in. x 3/4 in. Further details are given in Sections 3.1.3, 3.1.4 and 3.1.5.

### 3.1.3 Protective Value of Clothing Fabrics

For this study, most of the samples were mounted on holders of type b described in Section 3.1.4. The backing was natural white pine, and the fabric was in contact with the backing over an area of about 6-1/2 in. x 3 in. and spaced 1/4 inch from the backing over a similar area. The fabric was stretched by hand and it was held in position

and in contact with the wood by the 1/2 in. x 1/2 in. wood strips, adhesive tape along the edges and double backed tape along the edge of the thermal indicators on the flat surface. All the fabrics were mounted with the filling yarn in the 6-1/2 in. direction.

The thermal indicators were used according to the following schedule. For Shot Baker, groups A, B and C were used for samples exposed at Stations I and II and groups A, B and D at Stations III and IV. For Shot Dog, groups A, B and C were used at Stations II and III groups A, B and D at Station IV. These indicators were used under both the contact and spaced area of the sample as indicated in the sketch of Figure 3.1. The fabrics exposed at each shot are listed in the Tables of results, for example Tables 4.1 and 4.2. All of these were single layer fabrics except one, which was a combination of the standard 9 oz. per sq. yd. cotton sateen OD-7 over the light weight cotton underwear. This combination was also mounted over the 1/4 in. mesh screen described in more detail in Section 3.1.4.

The arrangement of samples on panels 1 and 2 for both shots is shown in Figure 3.4. The arrangement on panel 3 for Shot Baker is shown in Figure 3.4; for Shot Dog, the arrangement was the same except fabric 26 replaced fabric 14. The arrangement on panel 4 is shown in Figure 3.5, panel 4-B for Shot Baker and Panel 4-D for Shot Dog.

#### 3.1.4 Effect of Backing

Four fabrics were used in the backing study: fabric 1, 9 oz. per sq. yd. sateen, undyed; fabric 2, 9 oz. per sq. yd. sateen OD-7; fabric 3, 9 oz. per sq. yd. wool serge, OD-7; and fabric 4, 5 oz. per sq. yd. sateen OD-7.

They were mounted on the different backing materials described in Section 2.2.2. The holders were of white pine, of the type shown in Figure 3.1, 7-1/2 in. x 8 in. overall, modified as follows:

<u>Code</u>	<u>Surface</u>
b	Natural white pine wood, sanded
c	Wood painted white with a mixture of magnesium oxide and ethyl cellulose in alcohol
d	Stained black. Stain in Handbook of Physics and Chemistry <sup>10</sup> and one coat black drawing ink
e	Wood covered with aluminum foil (Reynold's Wrap)

<u>Code</u>	<u>Surface</u>
f	Wood covered with 1/16 in. polished aluminum sheet
g	Wood covered with 1/16 in. sheet of Navy type GSG silicone-fiberglas laminate

The a holder was similar to the b except that for the spaced part the wood was replaced with 1/4 in. mesh screen to simulate air backing. For each type of holder the fabric was in contact with the backing over an area of about 6-1/2 in. x 3 in. and spaced 1/4 in. from the backing over a similar area.

Thermal indicators were used behind most of these samples. For the b, c, d, e, f, and g holders the groups of indicators were the same as in Section 3.1.3, i.e., groups A, B, C, and D. For Shot Baker, indicators were placed behind all the samples. For Shot Dog, they were placed behind all samples at Station III and behind only those mounted on the natural wood, holder b, at Stations II and IV. For the a holders the arrangement was slightly different. On the screen spaced part the indicators were groups N, O, P and Q corresponding to A, B, C and D. On the contact part of these holders the indicators were face up in groups J and K and L and M J and K were mounted in the usual manner with adhesive tape while L and M were cemented to the backing.

Curved surface holders, h, were used for a few exposures in an attempt to improve the contact between fabric and backing. These holders, shown in Fig. 3.2, were 7 in. x 8 in. overall, with a contact area and a spaced area. Over the former the angle of incidence varied slightly but did not deviate significantly from 0°. Over the latter the spacing varied from zero to 3/16 inch. The thermal indicators were groups E, F and G for the contact areas and A, H and I for the spaced areas, the latter running across the sample to show any effects of variation in spacing. Only two fabrics were used, fabrics 1 and 2 listed above.

The methods of mounting the fabric and holding it in place were as described in the first paragraph of Section 3.1.3. The arrangement of the samples on panels 1 and 2 for both shots is shown in Figure 3.5.

### 3.1.5 Orientation

For studying the effect of orientation or angle of incidence three fabrics were used: fabric 1, 9 oz. per sq. yd. sateen, undyed; fabric 2, 9 oz. per sq. yd. sateen, OD-7; fabric 5, 14.3 oz. per sq. yd. wool blanket, OD-36. The samples were wrapped on white pine half cylinders

7 inches in diameter and 8 inches long, shown in Figure 3.3, with the filling yarn around the cylinder. Mounted with the axis normal to the beam this afforded angles varying from zero to 90°. Thermal indicators were used in the form of 1/4 inch wide strips running from the center toward the edge arranged in groups R and S. Only group R was used at Station IV in Shot Baker; both groups were used in all other samples. The samples were mounted on panel 3 shown in Figure 3.6.

### 3.1.6 Ignition


The samples were 20 inches wide (filling) and 6 inches high (warp) folded to give 5 vertical folds. They were mounted on holders as shown in Figure 3.5. The holders were mounted on the 20 in. x 32 in. plywood to give a 6-inch horizontal spacing and 2 inches between samples vertically. To prevent interaction in case of flaming, sheet metal covers 4 in. x 6 in. were placed over all except the top 3 samples. The samples were arranged on panel 5 as shown in Figure 3.5. The numbers refer to fabric numbers listed in Appendix A. At Station II and IV in Shot Baker and Station IV in Shot Dog, the panels were in the field of view of still cameras with exposures every 1/2 second.

### 3.2 LABORATORY TESTS

Laboratory tests were run on the fabrics and backings for two purposes: first, to measure the properties that determine the exposure effects, and second, to obtain a qualitative measure of the damage to the fabrics on exposure.

Optical reflectance and transmittance of materials were measured with a General Electric Spectrophotometer in the wave length range from 0.4 to 1.0 $\mu$ . For the backing materials reflectance was measured in the usual way. For fabrics preliminary tests showed that the effect of stretch on both transmittance and reflectance was slight and, accordingly, all the measurements were made at no stretch. For undyed fabrics the reflectance depends on the backing and tests were run on a few fabrics with the various backings and at various spacings from contact to 1/2-inch, and on most of the rest under three conditions, with natural wood backing, in contact and spaced 1/4-inch, and with black velvet spaced 1/4 inch. Tests with a few samples showed that the backing has no appreciable effect on the reflectance of dyed fabrics.

The G.E. instrument is not especially adapted for measuring transmittance. With dyed fabrics the transmittance is very low, probably less than 1/2%. For undyed fabrics it is much higher, up to 30% in some cases but the light is mainly scattered. For the usual position of the sample much of the light is lost, but by placing the sample



closer to the sphere more of it enters the port. An improvised holder permitted placing the sample close to the port (position 3) with a subtended solid angle between  $\pi$  and  $2\pi$  steradians, probably closer to the latter. In the usual position (position 2) the angle is about 1.5; the sample can be moved forward (position 1) to give an angle of about .04 steradians. With measurements at the three positions, some estimate can be made of the scattered and direct transmittance.

For quantitative estimates of extent of damage various measurements were made. Change in reflectance is some measure of the degree of scorching and charring and these measurements were made with a standard backing, in this case velvet, 1/4-inch from the fabric. Generally, the samples became stiffer and weaker and these properties were measured by the usual stiffness test on the Olson Stiffness Tester <sup>12</sup> and tensile strength and elongation at break on the Scott Tensile Tester <sup>13</sup>. The stiffness and strength measurements were made under standard atmospheric conditions.



  
CHAPTER 4RESULTS4.1 GENERAL

The operation was generally successful and considerable information was gained about fabrics and methods of testing fabrics, but there were a number of difficulties that interfered with full attainment of the objectives.

For Shot Baker, it rained during the night before the test was scheduled and on the next morning, and the samples were rather thoroughly wet. The panels were taken down and placed indoors to dry. On drying, many of the samples were found to be stained and a number of these were replaced with new fabric. The thermal indicators and the holders were distorted with resulting uncertain contact between the fabric and backing and particularly between the thermal indicators and the fabric and the backing.

In Shot Baker, the supports withstood the blast at Stations II, III, and IV, but at Station I all were blown down. Both the thermal and blast damage were very severe at that station. Not many samples were intact but the thermal indicators showed that the samples provided considerable protection and probably they were damaged more by the blast than by thermal radiation. Since the thermal damage was so great, the failure of the supports was not serious. In Shot Dog, the supports failed at Stations II and III but there was little additional damage from these failures and no loss of results. Here, as in Shot Baker, the thermal effect was over before the shock wave arrived.

Generally, the samples received too little or too much radiation for best evaluation. In Shot Baker, there was little damage at Stations III and IV and nearly complete destruction at Station I. In Shot Dog, most of the samples were rather badly damaged at Station IV and nearly completely destroyed at Stations II and III. Generally, the results at Station II, Shot Baker, and Station IV, Shot Dog, afforded the best comparison of effects and the other data will give the limits of intensity to cause damage.

In many cases, it is difficult to evaluate the thermal damage because the final result is a combination of effects, including thermal damage and blast damage and as part of the latter, abrasion and discoloration by dirt carried by the wind. This is especially true of the spaced

TABLE 4.1

Reflectance of Fabrics Before Exposure  
Measured in Contact with Natural White Pine Wood

No.	Fabric Description	oz/yd <sup>2</sup>	Per Cent Reflectance at Indicated Wave Lengths					Av.
			0.4 $\mu$	0.5 $\mu$	0.6 $\mu$	0.7 $\mu$	0.8 $\mu$	
30	Cloth, Cotton, Sateen, White	4.9	67	72	77	81	74	
29	" " " " " "	8.1	77	79	81	83	80	
1	" " " " " "	8.8	59	68	76	81	71	
31	" " " " " "	10.7	73	78	81	84	79	
34	Cloth, Wool, Serge, White	7.8	38	59	67	76	60	
4	Cloth, Cotton, Sateen, OD-7	5.0	6	8	10.5	9	8.5	
7	" " " " " "	8.1	6	7.5	10	8	8	
2	" " " " " "	9.1	6	7.5	10	8.5	8.5	
8	" " " " " "	9.2	6	7.5	9.5	8	8	
32	" " " " " "	10.5	5.5	7.5	10	8	8	
9	" " " " " "	8.8	4.5	6	8	8.5	8	
10	" " " " " "	9.4	4	5.5	7	8.5	7	
6	" " " " " "	8.5	5	6	8.5	7	6	
39	" " " " " "	8.4	3	2.5	3	4	3	
36	Cloth, Wool, Serge, OD-7	5.9	5	7	9.5	7.5	7.5	
3	" " " " " "	8.3	5	6.5	8.5	7.5	7	
33	" " " " " "	11.2	5	7	7.5	12.5	8	
12	Cloth, Wool, Serge, OD-33	11.4	4	5	6.5	18	7.5	
13	" " " " " "	11.8	3.5	4.5	6.5	13	7.5	
14	" " " " " "	9.9	3.5	5	6.5	18	7.5	
15	" " " " " "	10.3	3	4	5.5	17.5	6.5	
	85% Wool 15% Nylon Serge, OD-33							

TABLE 4.1 (cont'd)

Reflectance of Fabrics Before Exposure  
Measured in Contact with Natural White Pine Wood

No.	Fabric Description	oz/yd <sup>2</sup>	Per Cent Reflectance at Indicated Wave Lengths					Av.
			0.4 $\mu$	0.5 $\mu$	0.6 $\mu$	0.7 $\mu$		
16	Cloth, Wool, Shirting, OG-108	10.3	4	5	7	6	5.5	
17	" 85% Wool 15% Nylon Shirting, OG-108	10.2	4	7	8	24	9.5	
42	Cloth, Rayon, Spinnaker OD-7	2.0	7	9.5	11.5	17	11	
18	" Orlon, Heat Treated, Black	8.7	5	5.5	5	5	5	
21	Cloth, Cotton, Sateen, 15% Pyroset D, White	8.8	73	78	82	84	80	
19	Cloth, Cotton, Sateen 25% XICC 3, OD-7	10.4	9	11	14.5	12.5	12	
22	" " 10% Pyroset D, OD-7	8.4	7	9	12	10	10	
23	Cloth, Cotton, Sateen 15% Pyroset D, OD-7	8.6	7.5	10	12.5	11	10.5	
24	Cloth, Cotton, Sateen 30% Pyroset D, OD-7	10.4	10.5	12.5	16	14	13.5	
25	Cloth, Cotton, Sateen 15% Erifon, OD-7	8.4	10.5	13	15.5	12.5	13.5	
40	Cloth, Cotton, Sateen 15% Boric Acid, OD-7	8.9	7	9	12	10	10	
41	Cloth, Cotton, Sateen 15% Hooper D, OD-7	11.1	11	13	16	13.5	13.5	
26	Cloth, Cotton, HBT Martin HBM Resin, OD-7	10.6	8	10	12.5	14	11	

TABLE 4.1 (cont'd)

Reflectance of Fabrics Before Exposure  
Measured in Contact with Natural White Pine Wood

Fabric		Per Cent Reflectance at Indicated Wave Lengths						
No.	Description	oz/yd <sup>2</sup>	0.4 $\mu$	0.5 $\mu$	0.6 $\mu$	0.7 $\mu$	Av.	
11	Duck, Cotton, FWWMR, OD-7	18.7	4.5	5.5	8	7.5	6.5	
27	Cloth, Wool, Serge, 15% Dupont QM OD-7	8.7	6	8.5	11	9	9	
43	Cloth, Wool, Serge, 15% Pyroset D, OD-7	9.0	6	8.5	11	9.5	9	
No.	Description	oz/yd <sup>2</sup>	0.7 $\mu$	0.8 $\mu$	0.9 $\mu$	1.0 $\mu$	Av.	
30	Cloth, Cotton, Sateen, White	4.9	81	83	84	84	83	
29	" " " " "	8.1	83	85	86	86	85	
1	" " " " "	8.8	81	84	85	85	84	
31	" " " " "	10.7	84	85	86	85	85	
34	Cloth, Wool, Serge, White	7.8	76	80	83	83	80	
4	Cloth, Cotton, Sateen, OD-7	5.0	9	13	23	36	19.5	
7	" " " " "	8.1	8	12	22	36	19	
2	" " " " "	9.1	8.5	13	22	32	18.5	
8	" " " " "	9.2	8	12	22	34	18.5	
32	" " " " "	10.5	8.5	12.5	22	35	18.5	
9	" " " " " OG-107 Vat	8.8	8.5	12	24	40	20	
10	" " " " " OG-107 Org	9.4	7	10	15.5	18.5	13	
6	" " " " " HBT OD-7	8.5	11	22	35	45	28	
39	" " " " " Sateen, Black	8.4	3	15	44	56	30	

TABLE 4.1 (cont'd)

Reflectance of Fabrics Before Exposure  
Measured in Contact with Natural White Pine Wood

No.	Fabric Description	oz/yd <sup>2</sup>	Per Cent Reflectance at Indicated Wave Lengths					Av.
			0.7 $\mu$	0.8 $\mu$	0.9 $\mu$	1.0 $\mu$		
36	Cloth, Wool, Serge, OD-7	5.9	7.5	25	46	51	70	
37	" " " " "	8.3	7.5	28	45	50	29	
38	" " " " "	11.2	12.5	33	43	49	36	
12	Cloth, Wool, Serge, OD-33	11.4	17	42	53	63	45	
13	" " " " "	11.8	13	18.5	19	19	17.5	
14	" " " " "	9.9	9.5	41	52	61	43	
15	" " " " "	10.3	17	43	55	64	43	
16	85% Wool 15% Nylon Serge, OD-33	10.3	6	26	38	44	30	
17	Wool, Shirting, OG-108	10.2	23	49	57	63	50	
	85% Wool 15% Nylon Shirting, OG-108							
42	Cloth, Rayon, Spinnaker OD-7	2.0	16	78	83	83	70	
18	Cloth, Orlon, Heat Treated, Black	8.7	5	5	5.5	6.5	5.5	
21	Cloth, Cotton, Sateen, 15% Pyroset D, White	8.8	84	86	86	86	86	
19	Cloth, Cotton, Sateen 25% XICC 3, OD-7	10.4	12	18	29	41	25	
22	" " " " "	8.4	10.5	15.5	25	38	22	
	10% Pyroset D, OD-7							
23	Cloth, Cotton, Sateen 15% Pyroset D, OD-7	8.6	12	16	26	39	22	

TABLE 4.1 (cont'd)

Reflectance of Fabrics Before Exposure  
Measured in Contact with Natural White Pine Wood

No.	Fabric Description	oz/yd <sup>2</sup>	Per Cent Reflectance at Indicated Wave Lengths				Av.
			0.7 $\mu$	0.8 $\mu$	0.9 $\mu$	1.0 $\mu$	
24	Cloth, Cotton, Sateen 30% Pyroset D, OD-7	10.4	13.5	20	30	44	26
25	Cloth, Cotton, Sateen 15% Erifon, OD-7	8.4	12.5	17	27	43	24
40	Cloth, Cotton, Sateen 15% Boric Acid, OD-7	8.9	10.5	15.5	25	33	21
41	Cloth, Cotton, Sateen 15% Hooper D, OD-7	11.1	13.5	18	28	42	25
26	Cloth, Cotton, HBT Martin HFM Resin, OD-7	10.6	14.5	25	38	52	32
11	Duck, Cotton, FWMR, OD-7	18.7	8	8	7.5	7.5	8
27	Cloth, Wool, Serge, 15% Dupont QM OD-7	8.7	9.5	32	50	55	38
43	Cloth, Wool, Serge, 15% Pyroset D, OD-7	9.0	9	32	50	56	38

TABLE 4.2

Reflectance of Undyed Fabrics with Various Backings  
Average Percent Reflectance in Visible and Near Infrared

No.	Wt. oz/sq yd	Natural White Pine				Black Velvet	
		Contact		1/4 in. space		1/4 in. space	
		0.4 to 0.7 $\mu$	0.7 to 1.0 $\mu$	0.4 to 0.7 $\mu$	0.7 to 1.0 $\mu$	0.4 to 0.7 $\mu$	0.7 to 1.0 $\mu$
30	4.9	74	83	70		65	66
29	8.1	80	85	79	82	77	78
1	8.8	71	84	70		67	75
31	10.7	79	85	75		76	
34	7.8	60	80	57		53	63
21	8.8	80	86	78		77	

part of the flat samples. Generally, it was not possible to determine whether thermal damage weakened the sample and the blast blew it apart or whether thermal damage alone was responsible for complete destruction and disappearance of the whole sample. The final result is important in that it represents the overall effect but it leaves interpretation of the extent of thermal damage alone uncertain.

Reflectance data for the fabrics before exposure are given in Tables 4.1 and 4.2. Table 4.1 gives the reflectance from 0.4 to 1.0 $\mu$  for the fabrics in contact with a backing of natural wood. For the white fabrics the dependence on backing conditions is shown in Table 4.2. The backing had no effect on the reflectance of the dyed fabrics. For the undyed fabrics, the values may not apply directly to the exposure conditions because the sample size may influence the apparent reflectance. Some light is transmitted through the fabric and is reflected, generally diffusely, from the backing and some of that is lost. For the exposure samples, the loss should be less than in the spectrophotometer where the sample is 1-1/4 inches in diameter and should be less for contact than for spaced samples.

Table 4.3 gives the transmittances of eight fabrics, four undyed and four dyed, typical of most of those tested. The values for the dyed fabrics are all low, less than 1/2%, even at position 3 of the spectrophotometer. The undyed fabrics show fairly high transmission, up to 30% for fabric 30 and these values would be still higher if all the scattered light were collected. The direct transmission for fabric 30 is fairly high, but even in this case and certainly for fabrics 1, 29 and 34, nearly all the transmitted light is scattered, i.e., very little of it goes directly thru interstices between fibers and yarns.

TABLE 4.3

Transmittance of Fabrics

No.	Fabric Description	oz/sq yd	Position <sup>a</sup>	Percent Transmittance at Indicated Wave Lengths				
				0.4 $\mu$	0.5 $\mu$	0.6 $\mu$	0.7 $\mu$	Av.
30	Cotton, Sateen, White	4.9	1	1.5	2	2	2	2
			2	10	10.5	11	11	10.5
			3	32	34	35	34	34
29	Cotton, Sateen, White	8.1	1	0.5	0.5	0.5	0.5	0.5
			2	4	5	5.5	6.5	5
			3	14.5	17.5	19.5	20.5	18
1	Cotton, Sateen, White	8.8	1	<0.5	<0.5	0.5	0.5	<0.5
			2	1.5	3	5	5.5	4
			3	5.5	12	17	19	14
34	Wool, Serge, White	7.8	1	0.5	0.5	0.5	0.5	0.5
			2	2.5	7.5	8.5	9	7.5
			3	10.5	25.5	29.5	32.5	26
4	Cotton, Sateen, OD-7	5.0	1	1	1	1	1	1
			2	1.5	1.5	2	2	1.8
			3	2	2	2.5	2	2.3
7	Cotton, Sateen, OD-7	8.1	1	<0.5	<0.5	<0.5	<0.5	<0.5
			2	<0.5	<0.5	<0.5	<0.5	<0.5
			3	<0.5	<0.5	<0.5	<0.5	<0.5
2	Cotton, Sateen, OD-7	9.1	1	<0.5	<0.5	<0.5	<0.5	<0.5
			2	<0.5	<0.5	<0.5	<0.5	<0.5
			3	<0.5	<0.5	<0.5	<0.5	<0.5
3	Wool, Serge, OD-7	8.3	1	<0.5	<0.5	<0.5	<0.5	<0.5
			2	<0.5	<0.5	<0.5	<0.5	<0.5
			3	<0.5	<0.5	<0.5	<0.5	<0.5

<sup>a</sup> Positions described in Section 3.2

[REDACTED]

Temperature and humidity were recorded on a hygro-thermograph located on the main road and converted to site readings by corrections determined by comparisons of data taken on other days. The readings for a period of 6 hours before each shot were as follows:

TABLE 4.4

Weather Conditions

	Shot Baker		Shot Dog	
	Temperature °F	Relative Humidity %	Temperature °F	Relative Humidity %
H-6	44	60	45	53
H-5	44	59	44	55
H-4	44	58	43	59
H-3	43	61	42	57
J-2	42	62	43	59
H-1	42	65	46	59
N	56	65	53	50

4.2 PROTECTIVE VALUE OF FABRICS

4.2.1 General

The protection provided by fabrics depends to some extent on the damage to the fabrics but there is no exact correspondence. In many cases, the fabric was nearly all gone but apparently lasted long enough to provide considerably protection. In other cases, the fabric was intact but apparently provided little protection.

4.2.2 Damage to the Fabric

With such a wide range of effects and especially with small samples where only a limited number of tests can be made, perhaps the best method of evaluation is by visual estimate of the damage. Any attempt to express that estimate concisely is complicated by the variety of ways in which the damage occurs. Cotton first scorches and then chars, going from brown to black; it becomes stiff, brittle and weak. Sometimes material is carbonized throughout the sample as shown by increased transparency. Wool first singes, scorches and then melts, leaving a shiny surface with a metallic lustre. Generally, with white fabrics, at low levels of damage on the face there is scorching on the reverse side. With dyed fabrics appreciable scorching on the reverse side does not occur until the face is rather badly scorched. With wool, usually there are no effects on the reverse side until the melting progresses all the way through.

[REDACTED]

Some of the wool, completely melted and in the form of a hard brittle somewhat blistered layer, was still in place apparently affording some protection to the materials behind it, but of no value as clothing fabric thereafter.

Taking these differences into account, an attempt was made to rate the samples numerically according to the following criteria:

<u>COTTON</u>	<u>RATING</u>	<u>WOOL</u>
<u>Damage to Each Face</u>		
No perceptible change	0	No perceptible change
Barely perceptibly scorched	1	Singed and slightly scorched
Slightly scorched - brown	2	Slightly scorched - brown
Appreciably scorched - dark brown	3	Appreciably scorched and slightly melted
Badly scorched and charred - very dark brown	4	Scorched and melted
Very badly charred - black	5	Melted
<u>Overall Damage</u>		
Intact	0	Intact
Nearly intact - torn slightly or burned through	1	Nearly intact - torn slightly or melted through
Torn or burned appreciably - more than half left	2	Torn or melted appreciably - more than half left
Torn, burned or charred considerably, less than half left	3	Torn or melted considerably less than half left
Very weak, mostly gone	4	Very weak, mostly gone
All or practically all gone	5	All or practically all gone

The evaluation of samples is shown in Table 4.5 for Shot Baker and Table

TABLE 4.5

Visual Estimate of Damage to Fabrics - Shot Baker,  
See Section 4.2.2 for Criteria for Rating

No.	Description	FABRIC	oz/sq_yd	CONTACT		SPACED 1/4 IN.	
				III-1	II-1	III-1	I-1
30	Cotton, Sateen, White		4.9		0 0 0	0 0 0	2 2 0
29	" " " "		8.1		1 0 0	1-1-0	1-1-0
1	" " " "		8.8		1-0 0	1-0 0	1 0 0
31	" " " "		10.7		1 0 0	1-1 0	2 2 0
34	Wool, Serge, White		7.8		0 0 0	5 2 4 <sup>c</sup>	- - -
4	Cotton, Sateen, OD-7		5.0		2 1 0	2 1 0	- - -
7	" " " "		8.1		2 0 0 <sup>a</sup>	2 1 0	- - -
2	" " " "		9.1		1 0 0	1 1 0	- - -
8	" " " "		9.2		1 0 0	1 0 0	- - -
32	" " " "		10.5		1 0 0	1 0 0	- - -
6	Cotton, HBT, OD-7		8.5		1 0 0	1 0 0	- - -
39	" " " "		8.4	1 0 0	2 0 0	2 0 0	- - -
9	" " " "		8.8		1 0 0	1 0 0	- - -
10	" " " "		9.4		1 0 0	1 0 0	- - -
3	Wool, Serge, OD-7		8.3	1-0 0	3 0 0	3 0 0	- - -
5	Wool Blanket, OD-36		14.3	1 0 0	4 0 0	4 0 0	- - -
12	Wool Serge, OD-33		11.4		2 0 0	2 0 0	- - -
13	Wool Serge, OD-33, - Sulfur Top		11.8		2 0 0	2 0 0	- - -
14	Wool Serge, OD-33		9.9	1-0 0	2-0 0	2+1 0	- - -
15	Wool and Nylon, Serge, OD-33		10.3	1-0 0	3 0 0	3 0 0	- - -
16	Wool, Flannel, OG-108		10.3	1-0 0	4 0 0	4 0 0	- - -
17	Wool and Nylon Flannel, OG-108		10.2	1 0 0	4 0 0	4 0 0	- - -
2	Cotton, Sateen, OD - 7		9.1		0 0 0	0 0 0	- - -
28	Underwear, light weight		3.5		0 0 0	0 0 0	4 2 0
42	Rayon, Spinnaker cloth, OD-7		2.0	2 2 1 <sup>f</sup>	- - -	- - -	- - -
18	Orlon, Black		8.7		1 1 0 <sup>e</sup>	1 1 0 <sup>e</sup>	- - -
21	Cotton, Sateen, White-15% Pyroset D		8.8		0 0 0	0 0 0	3 2 2 <sup>b</sup>



TABLE 4.6 (cont'd)

Visual Estimate of Damage to Fabrics - Shot Dog  
See Section 4.2.2 for Criteria for Rating

No.	Description	FABRIC	oz/sq yd	CONTACT			SPACED 1/4 IN.								
				IV1	III1	II1	IV1	III1	II1						
9	Cotton, Sateen, OG-107-V		8.8	5-4	1	-	5	5	4	-	5				
10	" " " " " " " " " " " "		9.4	5-3	0	-	5	5	2	-	5				
6	" " " " " " " " " " " "		8.5	5	4	2	-	-	5	-	5				
34	Wool Serge, White		7.8	0+0	0	3	2	4	0	0	3	3	4		
36	" " " " " " " " " " " "		5.9	-	5	5	5	5	-	5	5	5	5		
3	" " " " " " " " " " " "		8.3	5	5	0	5	5	5	5	5	5	5		
33	" " " " " " " " " " " "		12.2	5	0	0	5	5	5	5	5	5	5		
12	" " " " " " " " " " " "	OD-33	11.4	5	0	0	5	5	4	5	5	4	5		
13	" " " " " " " " " " " "	OD-33 + Sulfur	11.8	5	0	0	5	5	4	5	5	4	5		
16	Wool Flannel, OG-108		10.3	5	1	1	5	5	4	5	3	2	5	4	
17	Wool and Nylon Flannel, OG-68		10.2	5	1+1	5	5	4	5	2	2	5	5	4	
5	Wool Blanket, OD-36		14.3	5	0	1	5	1	4	5	0	1	5	1	2
2	Cotton, Sateen, OD-7		9.1	3	2	1	-	-	5	4	2	4	-	-	5
28	Underwear light weight, white		3.5	2	1	0	3	1	0	3	2	2	4	2	1
18	Orlon, Elack		8.7	1	1	0 <sup>c</sup>	-	-	0 <sup>c</sup>	1	1	0 <sup>c</sup>	-	-	2 <sup>c</sup>
22	Cotton, Sateen, OD-7+10% Pyroset D		8.4	5	4	1	5	5	5	-	5	5	2	5	5
40	" " " " " " " " " " " "	OD-7+15% Borax-Boric Acid	8.9	5	3	2 <sup>a</sup>	5	5	5	5	5	3	5	5	5
41	" " " " " " " " " " " "	OD-7+15% Hooper	11.1	5	3	0	5	5	-	3	5	5	2	-	5
19	" " " " " " " " " " " "	OD-7+25% XGCG3	10.4	5	4	1	5	5	5	-	5	5	2	5	5
26	Cotton, HBT + Martin HEM		10.6	5	4	2	5	5	3	5	5	3	-	-	5
11	Cotton, Duck, OD-7 + FUMMER		18.7	5	1	0	5	4	1	5	2	1	-	-	5
27	Wool Serge, OD-7 + 15% Dupont CM		8.7	4	4	2	5	5	5	-	4	4	3	5	5
43	" " " " " " " " " " " "	" " " " " " " " " " " "	9.0	5	5	4	5	5	5	5	5	4	5	5	5

a - Reverse side variable, 2 to 5.      b - Not uniform.      c - Surface changed - shiny.  
1 - III & IV refer to Stations.

4.6 for Shot Dog. The effect on both surfaces was evaluated, the first figure representing the face and the second the reverse side. In addition, it seemed desirable to give an overall effect to show whether the sample was intact, torn or burned slightly or all gone and that is given by the third figure. In neither case is the scale uniform. Generally, it is not possible to grade samples visually closer than one full step, but by a direct comparison of two samples, it is usually possible to be fairly sure which of the two suffered more damage. For such discrimination, the rating numbers are followed by † or — and although these differences are definite for the particular pair of samples under consideration, they do not necessarily hold for comparisons between groups.

For Shot Baker, at Station IV, the only visible damage was for fabric 42, the 2 oz. per sq. yd. spinnaker cloth, which showed slight scorching. No results are given in the table. Only a few samples were damaged visibly at Station III and only those few are listed in the table. At Station I only a few fabrics were left and only those are listed. For Station II, the list is complete. For Shot Dog at Station II, there were only a few fabrics left. Fabric 18, Orlon, was torn and more than half gone. The combination of fabric 2, 9 oz. per sq. yd. sateen, and fabric 28, lightweight underwear, was badly damaged. The sateen was gone and the underwear charred brown, intact on the contact side and torn slightly on the spaced side. The other fabrics, including the white fabrics, were practically destroyed. The results at Stations III and IV are given in Table 4.6. The tensile strength and stiffness results are erratic partly because of the small number of pieces. For the cases where there was little damage, they add little to the visual estimate of damage. In other cases, the tensile strength and elongation show corresponding changes; the stiffness is perhaps not quite as sensitive to damage. To the extent that a comparison is possible, loss in strength agrees fairly well with the visual estimate of damage. A few individual cases will be considered in Section 5.2.1.

#### 4.2.3 Protection

The temperatures attained by the thermal indicators are given in Tables 4.7 and 4.8 for Shots Baker and Dog. For all cases except the few so indicated, these are the results for the face down (black backing up) indicators. Generally, it was not possible to express the result as a single temperature because there were partial changes over a considerable range of temperatures. The lower figure corresponds to the highest indicator in the series showing complete change. The higher figure corresponds to the highest indicator showing any definite indication of change, either complete blackening in spots or over less than the whole area or a general darkening without any complete change at any point or a combination of these effects. This range of effects makes the

TABLE 4.7  
Temperature Indications Back of Fabrics - Shot Baker

No.	Description	oz/sq yd	CONTACT				I <sup>1</sup>
			IV <sup>1</sup>	III <sup>1</sup>	II <sup>1</sup>	I <sup>1</sup>	
30	Cotton, Sateen, White	4.9	61 <sup>a</sup>	93 <sup>a</sup>	182 <sup>a</sup>	>258	---
29	" " " "	8.1	59	68	93	118	256
1	" " " "	8.8	<59	57	93	---	224
31	" " " "	10.7	<59	68	89	104	242
34	Wool, Serge, White	7.8	68	93	106	180	---
4	Cotton, Sateen, OD-7	5.0	68	72	93	181	---
7	" " " "	8.1	60	68	86	93	133
2	" " " "	9.1	59	---	72	91	182
8	" " " " W.R.	9.2	59	68	86	104	133
32	" " " "	10.5	59	68	72	91	133
39	Black	8.4	61	68	72	131	180
9	OG-107-V, W.R.	8.8	59	68	86	93	133
10	OG-107-O, W.R.	9.4	59	68	72	104	205
6	Cotton, HBT, OD-7	8.5	59	68	86	104	154
3	Wool, Serge, OD-7	8.3	59	68	84	92	120
12	" " " " OD-33	11.4	<59	61	72	91	93
13	" " " " OD-33+Sulfur top	11.8	<59	68	72	93	86
14	" " " " OD-33	9.9	<59	68	85	104	120
15	85 Wool, 15 Nylon, Serge, OD-33	10.3	<59	68	72	91	133
16	Wool, Flannel, OG-108	10.3	<59	61	67	84	93
17	85 Wool, 15 Nylon, Flannel OG-108	10.2	<59	68	72	91	162
5	Wool Blanket, OD	14.3	<59	---	61	66	93

<sup>a</sup> (Face up)

1 I, II, III & IV refer to stations



TABLE 4.7 (cont'd)

Temperature Indications Back of Fabrics - Shot Baker

No.	Description	SPACED 1/4 IN.				
		os/sq yd	IV <sup>1</sup>	III <sup>1</sup>	II <sup>1</sup>	I <sup>1</sup>
2	Cotton, Sateen, OD-7	9.1	<59	72 84	61	182 203
8	" " " W.R.	9.2	<59	<59	61	133 180
32	" " " " "	10.5	<59	<59	67	133 180
39	Black	8.4	<59	<59	<61	205 257
9	OG-107-V, W.R.	8.8	<59	59	<66	133 222
10	OG-107-O, W.R.	9.4	<59	<59	66	182 224
6	Cotton, HBT, OD-7	8.5	<59	<59	86	---
3	Wool, Serge, OD-7	8.3	<59	61 72	86	---
12	" " " OD-33	11.4	<59	<59	60	93 104
13	" " " OD-33+Sulfur top	11.8	<59	61 66	60	93 104
14	" " " OD-33	9.9	<59	<59	72	120 180
15	85 Wool, 15 Nylon, Serge, OD-33	10.2	<59	60	68	154 223
16	Wool, Flannel, OG-108	10.3	59	59	72	143 180
17	85 Wool, 15 Nylon, Flannel OG-108	10.2	<59	61 67	72	---
5	Wool Blanket, OD	14.3	<59	<59	72	133 203
2	Cotton, Sateen, OD-7 and Light Wt	9.1	59	61	60	120 152
and 28	Knit underwear	3.5	---	---	---	---
42	Rayon, Spinnaker Cloth, OD-7	2.0	68 84	93 162	---	---
18	Orlon, Black	8.7	---	---	60	133 180
21	Cotton, Sateen, White 15% Pyroset D	8.8	60 <sup>a</sup> 66 <sup>a</sup>	93 <sup>a</sup> --	93 <sup>a</sup>	162 <sup>a</sup> ---
23	Cotton, Sateen, OD-7, 15% Pyroset D	8.6	<59 <sup>a</sup>	72 <sup>a</sup> --	72 <sup>a</sup>	182 <sup>a</sup> 203 <sup>a</sup>
24	Cotton, Sateen, OD-7, 30% Pyroset D	10.4	<59	<59	---	1337 180

TABLE 4.7 (cont'd)

Temperature Indications Back of Fabrics - Shot Baker

No.	Description	oz/sq yd	SPACED 1/4 IN.			
			IV <sup>1</sup>	III <sup>1</sup>	II <sup>1</sup>	I <sup>1</sup>
25	Cotton, Sateen, OD-7, 15% Brifon	8.4	<59	<59	61	71
19	Cotton, Sateen, OD-7, 25% XICC3	10.4	<59	<59	86	92
26	Cotton, HBT, OD-7, Martin HEM	10.6	<59	<59	60	72
11	Cotton, Duck, FWMR	18.7	<59	<59	60	70

TABLE 4.8

Temperature Indications Back of Fabrics - Shot Dog

No.	Description	oz/sq yd	CONTACT			
			IV <sup>1</sup>	III <sup>1</sup>	II <sup>1</sup>	I <sup>1</sup>
1	Cotton, Sateen, White	8.8	133	203	205	241
34	Wool, Serge, White	7.8	242	256	> 258	> 258?
4	Cotton, Sateen, OD-7	5.0	224	257	> 258	182
7	" " " "	8.1	164	222	242	240
2	" " " "	9.1	164	240	224	241
8	" " " " W.R.	9.2	133	240	182	240
9	" " " " OG-107-V, W.R.	8.8	182	240	224	241
10	" " " " OG-107-O, W.R.	9.4	164	222	182	222
6	" " " " HBT, OD-7	8.5	164	222	242	241
36	Wool, Serge, OD-7	7.6	133	180	93	222
3	" " " "	8.3	106	222	106	180
33	" " " "	12.2	93	180	106	180
12	" " " " OD-33	11.4	106	222	106	180

TABLE 4.8 (cont'd)

Temperature Indications Back of Fabrics - Shot Dog

No.	Description	oz/sq yd	CONTACT			
			IV <sup>1</sup>	III <sup>1</sup>	II <sup>1</sup>	I <sup>1</sup>
13	Wool, Serge, OD-33 + Sulfur Top	11.8	106	93	120	181
16	Wool, Flannel, OG-108	10.3	93	86	106	180
17	85 Wool, 15 Nylon, Flannel, OG-108	10.2	93	93	133	222
5	Wool, Blanket	14.3	72	86	106	180
2	Cotton, Sateen, OD-7	9.1	120	120	106	181
and						
28	Underwear, Light Weight, White	3.5				
18	Orlon, Black	8.7	182		242	257
41	Cotton, Sateen, OD-7, 15% Hooper	11.1	133	143	133	222
22	Cotton, Sateen, OD-7, 10% Pyroset D	8.4	133	224	242	257
40	Cotton, Sateen, OD-7, 15% Borax Boric Acid	8.9	154	>258	>258	—
19	Cotton, Sateen, OD-7, XICC3	10.4	133	224	224	241
26	Cotton, HBT, OD-7, Martin HEM	10.6	133	205	>258	—
11	Cotton, Duck, FWMR	18.7	120	164	133	180
43	Wool, Serge, OD-7, 15% Pyroset D	9.0	120	106	224	240
27	Wool, Serge, OD-7, 15% Du Pont CM	8.7	106	112	143	180

No.	Description	oz/sq yd	SPACED 1/4 IN.	
			IV <sup>1</sup>	III <sup>1</sup>
1	Cotton, Sateen, White	8.8	133	224
34	Wool, Serge, White	7.8	>258	—
				256



TABLE 1.8 (cont'd)

Temperature Indications Back of Fabrics - Shot Dog

No.	Description	FABRIC	oz/sq yd	SPACED 1/4 IN.	
				IV <sup>1</sup>	III <sup>1</sup>
11	Cotton, Duck, FWMR		18.7	68	92
43	Wool, Serge, OD-7, 15% Pyroset D		9.0	133	180
27	Wool, Serge, OD-7, Du Pont CM		8.7	120	162
				133	180
				182	223

[REDACTED]

data inconvenient to handle but the results are valid and useful. It is generally possible to compare a pair of samples and determine definitely for which of the two a higher temperature was indicated.

The highest temperature indicators used in each series were usually 164, 242 or 258°C. Occasionally the temperature was beyond the highest range in which case that is indicated in the table by  $\bar{\sim}$  signs before the temperature reading. At low energies there was sometimes no change in indicators. This is indicated by  $\leq$  signs or ---. In case of extreme damage many of the indicators were damaged or missing and no data could be obtained. This is indicated by ---.

The matter of partial changing and indefinite values for the temperature results partly from variation in contact between the fabric and indicator and between indicator and backing. This, coupled with the size of the steps between indicators, accounts for a large part of the difficulty but evidently there are effects from other causes, possibly from variations in thickness of the coating of sensitive material and variations in specific heat and heat of fusion of the sensitive material.

#### 4.3 EFFECT OF BACKING

The effect of backing on damage to the fabric is shown in Table 4.9 for all cases where the extent of damage was such that differences were evident. The same system of rating the visual estimate of damage was used as in Section 4.2.2.

#### 4.4 ORIENTATION

The effects at varying angles of incidence were about as expected. The fabrics showed more scorching and melting at normal incidence and the thermal indicators showed corresponding effects, but it is difficult to determine the dependence on angle as definitely as desired.

In Shot Baker there was no visible thermal effect on the white or OD sateen at Stations II, III and IV. At Station I the white sateen showed small brown spots near 0° and there was a slight uniform scorching on the face and back near 90°. At that station the OD-7 sateen was burned and torn and mostly missing. The wool blanket showed no effect at Station IV; possibly was slightly singed at Station III; was melted on the surface to nearly 90° at Station II; and was mostly missing at Station I, with no effect on the back of the fabric.

In Shot Dog, the white sateen showed the same type of scorching as

TABLE 4.9

Effect of Backing on Damage to Fabric  
BACKING

Shot	Station	a	b	c	d	e	f	g
<u>Fabric 1 - Cotton, Sateen, Undyed 8.8 oz/ sq yd</u>								
B	I	1 0 0	2 1 0			1-1 0	2 1-0	1+0+0
D	II	4 2+2	3 2 0		3+4 1	4 3 3	4 1 1	4 3 2
D	III	3 2-0	2 1-0		1 2+0	2+2 0	3+1 0	2+1 0
B	I	1 0+0	3-2 0		1 1 0	1 1 0	1 1 0	2-1 0
D	II	- - 5	4 3 4		4 4 4	- - 5	5 4 3	5-3 4-
D	III	3 2+0	2+2 0		1 2 0	1+2 0	1+2-0	1+1+0
<u>Fabric 2 - Cotton, Sateen, OD-7, 9.1 oz/ sq yd</u>								
D	IV	5 2 2	5 2 1-		4-4-1-	4+2-1	2+1-0	2+1 0
D	IV	5 5 4	5 5 3		- - 5	5 5 3	5 5 3	5 5 3
<u>Fabric 4 - Cotton, Sateen, OD-7, 5 oz/ sq yd</u>								
B	II	2 0 0	3-1-0			2 0 0	2 0 0	2-0 0
B	II	3-1+1	3+2 1		- - 5	3 2 0	3 2-0	2-1+0
<u>Fabric 3 - Wool, Serge, OD-7, 8.3 oz/ sq yd</u>								
B	II	2 0 0	2 0 0		2 0 0	2 0 0	2 0 0	2 0 0
D	IV	5 5 1+	5 5 3		5 5 2	5 5 3	5 5 2	5 4 1
B	II	2 0 0	2 0 0		2 0 0	2 0 0	2 0 0	2 0 0
D	IV	5 5 5	5 5 5		5 5 4	5 5 5	5 5 4	5 5 5

above at high angles of incidence. There was no other scorching at Station IV; at Station III there were brown spots at 0° with fewer at higher angles but extending to nearly 90°; at Station II the fabric was charred nearly black with a large area missing near 0° and brown spots extending to large angles. At Station IV, the OD sateen was scorched and charred near 0°, shading off to no visible effect at 90°; at Stations III and II, it was mostly gone. At Station IV, the blanket was melted from 0° to nearly 90°; at Station III the fabric was badly damaged by blast but in place; and at Station II most of it was gone.

In this case, something more than a visual estimate of damage is needed. Generally, tensile strength data agreed with this estimate in showing no effect as indicated above but in cases of considerable damage the figures are too erratic to be of much help. Table 4.10 shows one of the more consistent sets of data, for fabric 2 at Station IV of Shot Dog, 9 cal. per sq. cm. This table also gives the reflectance of this fabric at the indicated angles after exposure. The unexposed fabric shows a peak at 0.57 $\mu$  and values at that wavelength changed the most.

TABLE 4.10

Effect of Angle of Incidence on Damage to  
Fabric 2, 9 oz. per sq. yd. Sateen, OD-7

<u>Angle of Incidence, <math>\theta</math>, in degrees</u>	<u>Cosine <math>\theta</math></u>	<u>Tensile Strength, lb per sq in</u>	<u>Reflectance at 0.57<math>\mu</math>, in %</u>
0	1.00	<5	5
31	.86	6	
37	.80	.	6½
55	.57	62	10
75	.26	84	11½
Unexposed		97	10½

The temperature indicators showed the same type of change as for the flat samples, in this case partial change over a range of angles. This was especially true behind the wool blanket. The more definite results are given in Tables 4.11 and 4.12. The first figure in each column is the largest angle at which the change was complete; i.e., from white to black. The second figure is the largest angle at which any change took place and includes an area where there was a mixture of changed and unchanged indicator; i.e., black and white.

TABLE 4.11

Limiting Angle of Incidence, in Degrees, for Temperature Indicators in Orientation Study, Shot Baker

Temperature °C	IV		III		II		I			
	B <sup>a</sup>	B&W <sup>b</sup>	B	B&W	B	B&W	B	B&W		
<u>Fabric 1, 8.8 oz per sq yd Sateen, White</u>										
61				27	51	58	>	82		
68					49	55	>	82		
86					22	58	>	82		
93						25	>	82		
120								67	80	
133								>	44	
182								>	44	
224								>	44	
242								29	>	44
258									9	
<u>Fabric 2, 9.1 oz per sq yd Sateen, OD-7</u>										
61	20	27	71		>	82	>	82		
68			64		73	78	>	82		
86			25		49	75	>	82		
93					33	44	>	82		
120								51	65	
133								>	44	
182								>	44	
224								>	44	
258									≤	16

a-all black  
b-mixed black and white

TABLE 4.12

Limiting Angle of Incidence, in Degrees for Temperature Indicators in Orientation Study, Shot Dog

Temperature °C	<u>IV</u>		<u>III</u>		<u>II</u>	
	<u>B<sup>a</sup></u>	<u>B&amp;W<sup>b</sup></u>	<u>B</u>	<u>B&amp;W</u>	<u>B</u>	<u>B&amp;W</u>
<u>Fabric 1, 8.8 oz per sq yd Sateen, White</u>						
61	>82		>82		>82	
68	>82		>82		>82	
86	>82		>82		>82	
93	49	53	>82		>82	
120	15	46	>82		>82	
133			>44		>44	
182			15	>44	>44	
224						
242					33	46
258					22	29
<u>Fabric 2, 9.1 oz per sq yd Sateen, OD-7</u>						
61	>82		>82		>82	
68	>82		>82		>82	
86	>82		>82		>82	
93	>82		>82		>82	
120	66	71	82		>44	
133	44		>44		>44	(?)
182	26	35	>44		>44	(?)
242					>44	(?)
258					>44	(?)
<u>Fabric 5, 14.3 oz per sq yd Wool Blanket</u>						
61	69		>82		>82	
68					>82	
86	27	60	60	69	>82	
93		20	49	55	71	74
120						11

a-all black  
b-mixed black and white

#### 4.5 INCIDENCE OF IGNITION

Again there was no direct and obvious evidence of ignition and flaming. A few samples burned in such a way as to suggest that they might have ignited but it is difficult to imagine how flaming could have produced some of the effects. In some cases, there was a black sooty deposit on the sheet metal above the samples but that could have happened without flaming. The still pictures taken at 1/2 second intervals by the Naval Radiological Defense Laboratory show smoke rising from the panels but not in any great amount from the folded samples. In any case, there is nothing that can be identified as flame. Except for a few cases to be considered in detail the damage did not differ in appearance from that of flat samples.

It is difficult to evaluate the damage to a narrow strip of scorched fabric but, as definitely as it could be done, the same method of rating was used as in Section 4.2.2, with one exception. The edge of the fold was considered to be the sample. If it was completely burned through, the third digit in the rating was 5. In a few cases the fabric was burned back toward or to the holder. For these the ratings were 5+ to 5+++ depending on the extent of burning.

For Shot Baker, there was no apparent effect at Station IV. At Station III only two fabrics were affected; fabric 11 was very slightly scorched and fabric 19 was scorched a little more. The results at Stations I and II are given in Table 4.13 in terms of the visual ratings. Also, included are estimates of the decrease in strength for four samples; for the others it was not appreciable. At Station I all the samples were so badly damaged that the strength could not be measured.

For Shot Dog, the ratings are given in Table 4.14 with a few tensile strength results at Station IV. For the others, the damage was so great that tensile measurements could not be made.

TABLE 4.13

Damage to Folded Samples - Shot Baker

<u>FABRIC</u>	<u>No.</u>	<u>Description</u>	<u>Color</u>	<u>Wt oz per sq yd</u>	<u>STATION II</u>		<u>STATION I</u>		<u>Remarks</u>
					<u>Rating</u>	<u>Loss in Strength %</u>	<u>Rating</u>	<u>Variable</u>	
	1	Cotton Sateen	White	8.8	0 0 0		1 0 0		Variable
	4	Cotton Sateen	OD-7	5.0	2 0 0	60	-- 5 †		A few spots burned back from edge
	7	Cotton Sateen	OD-7	8.1	2 0 0		-- 5 † †		All except 1 in. of each end burned back to holder
	2	Cotton Sateen	OD-7	9.1	1 4 0		-- 5		
	6	Cotton HBT	OD-7	8.5	1-0 0		-- 5 † †		All except 1 in. at bottom

TABLE 4.13 (cont'd)

Damage to Folded Samples - Shot Baker

FABRIC

STATION I

STATION II

<u>No.</u>	<u>Description</u>	<u>Color</u>	<u>Wt oz per sq yd</u>	<u>Rating</u>	<u>Loss in Strength %</u>	<u>Rating</u>	<u>Remarks</u>
6	Cotton HBT	OD-7	8.5	1-0 0		-- 5 + +	(cont'd) burned back to holder
5	Wool Blanket	OD-36	14.3	3 0 0		5 0 2	
19	Cotton Sateen, 25% IXCC 3	OD-7	10.4	4 1 0	85	-- 5	
23	Cotton Sateen, 15% Pyroset D	OD-7	8.6	3 0 0	73	-- 5	
24	Cotton Sateen, 30% Pyroset D	OD-7	10.4	1 0 0		-- 5	
25	Cotton Sateen, 15% Krifon	OD-7	8.4	2 0 0	35	-- 5	
26	Cotton HBT, Martin HBM	OD-7	10.6	0+0 0		-- 5	
11	Cotton Duck, FWMR	OD-7	18.7	2 0 0		5 4 4	Part of some folds burned through

TABLE 4.14

Damage to Folded Samples - Shot Dog

No.	Description	Color	Wt oz per sq yd	Rating	Loss in Strength %	STATION III		STATION II	
						Rating	Rating	Rating	Rating
20	Rayon Marquisette	White	1.6	0 0 0			5 5 5†	5 5 5†	
4	Cotton Sateen	OD-7	5.0	- - 5†			- - 5	- - 5†	
7	Cotton Sateen	OD-7	8.1	- - 5††a			- - 5--	- - 5††d	
36	Wool Serge	OD-7	5.9	5 4 5			5 5 5	- - 5†	
3	Wool Serge	OD-7	8.3	5 - 5			5 5 5	5 5 5	
33	Wool Serge	OD-7	12.2	3 0 0	95		5 5 4	5 5 5	
18	Orlon	Black	8.7	3 1 0	75		3 1 1	4 3 3	
19	Cotton Sateen, 25% XIXCC3	OD-7	10.4	- - 5††b			- - 5††c	- - 5†	
40	Cotton Sateen, 15% Boric Acid	OD-7	8.9	5 4 3			5 5 4	5 5 5	
26	Cotton HBT, Martin HEM	OD-7	10.6	5 5 4			5 - 5		
11	Cotton Duck, FWMER	OD-7	18.7	3 0 0	50		5-5†	- - 5††e	
27	Wool Serge, 15% du Pont CM	OD-7	8.7	5 1 1			- - 5		

Remarks: a-Except for 1/2 in. at bottom burned back to holder.  
 b-Burned back to holder, charred fabric in place.  
 c-Except for 1/2 in. at top burned back to holder.  
 d-Practically all burned back to holder.  
 e-All burned. Most of holder burned and charred.  
 Panel charred.

## CHAPTER 5

### DISCUSSION OF RESULTS

#### 5.1 GENERAL

Since damage to the fabrics depends directly on the amount of energy absorbed, a first consideration is the reflectance of the fabrics. For comparisons the most useful figure is the average reflectance, weighted according to the spectral characteristics of the radiation. With information now available, that can be done only approximately. Accordingly, for most of the results, the simpler arithmetical average was used. In the visible region, the average reflectance is about 65% for the undyed fabrics and about 10% for the dyed fabrics. This means that about 90% of the incident energy is absorbed in the dyed fabrics. For the undyed fabrics about 35% is divided between transmission and absorption in varying ratios. With a solid backing most of the transmitted energy is absorbed in one way or another.

#### 5.2 PROTECTIVE VALUE OF FABRICS

##### 5.2.1 Damage to the Fabrics

One striking result is the generally much greater damage to fabrics spaced from a backing than to the same fabrics in contact with wood backing. Of course, unsupported fabrics are subject to greater blast damage and this may account for much of the apparent difference such as tearing and complete disappearance. However, close examination of the degree of charring and melting shows that the samples were actually damaged more thermally, at least the dyed cotton fabrics were. For example, in Table 4.5, fabric 4 at Station II had a rating of 2 1 0 in contact and 5 4 2 spaced, i.e., moderate scorching or less in contact and charred dark brown or black spaced. Other examples are fabrics 7 and 2 in Table 4.6 where at Station IV the ratings are 4 2 1 in contact and 4+4+4 spaced and 5 2 2 in contact and 5 5 3 spaced. These are extreme examples. Many of the others show less difference or the spaced part of the fabric was missing entirely. It is difficult to show qualitative data to support these visual estimates. For slight damage the decrease in strength was no more than the variation between samples; for extreme damage the strength was too low to measure. Although there are a few small discrepancies the tensile strengths generally agree in showing more damage to the spaced samples, but the difference is not as great as the visual



estimate would indicate.

There was another striking effect with the dyed cotton. On the contact side, as described in Section 3.1.3, the fabric was in contact with a strip of double backed adhesive. Over this strip there was much less scorching and charring, on both the face and reverse side, than on adjacent areas.

Both of these results are consistent with the idea that the incident energy is absorbed in the fabric causing a considerable rise in temperature with an appreciable part of the heat carried away by conduction to the contact backing. On the spaced sample, the heat is carried away only by conduction and convection through the air and by re-radiation. Since these are less efficient the fabric reaches a higher temperature and sustains more damage. The conductivity of the adhesive strip may possibly be higher than that of the wood backing, but very likely the greatest difference is in the heat transfer coefficient which should be considerably higher for the adhesive.

With the wool fabrics there was little difference between contact and spaced samples. In only a few extreme cases, such as fabrics 16 and 17 in Table 4.6 was there any difference. The tensile data are in agreement with this. Probably this condition results from the lower thermal conductivity of wool fabrics. The heat cannot be carried away from the surface as readily and the backing is not effective. This is also consistent with the fact that for wool there was no scorching or melting of the reverse side until the process had progressed through the sample.

In a general way the same effects were found with the heavier cottons, such as fabric 32, and the combination of fabrics 2 and 28, which show little difference between contact and spaced samples, and of course, conduct less heat from the surface.

The result with the white fabrics was entirely different. There was little difference between contact and spaced and little difference between the face and the reverse side of the fabric. There is the possibility of direct heating deep in the sample by transmitted energy, and, on the reverse side, by light reflected from the backing and by heat from energy absorbed in the backing. The overall effect depends on the relative magnitudes of the energies arriving in these various ways; it may be that the backing is nearly as hot as the fabric.

The most striking effect was the very slight damage to white fabrics. For example, in Shot Baker they were only slightly scorched at Station I at an intensity of 18 cal. per sq. cm. where almost everything else was practically destroyed. In Shot Dog, at

[REDACTED]

Station II, with 27 cal. per sq. cm. they were almost completely destroyed but stood up very well at Station III with 18 cal. per sq. cm. while corresponding dyed fabrics were very badly damaged at Station IV at 9 cal. per sq. cm. This is about the effect to be expected from the reflectances. The dyed fabrics absorb about 90% and the white fabrics transmit and absorb about 35% of the incident energy, a ratio of about 3/1. Corresponding states of damage occur at intensities of about that ratio. If the white fabrics are damaged a little more than might be expected from this ratio, and that seems to be the case, possibly it is because conditions are not as favorable for dissipating heat.

Fabrics 8, 9 and 10 show that small differences in reflectance are not very important. Fabric 8 is the standard OD-7 and fabrics 9 and 10 are experimental dyes to give low infrared reflectance for night camouflage purposes. In this case a more complete calculation has been made based on the spectral quality of the radiation. It was assumed that the radiation was that of a black body at 6000°K with little ultraviolet below 3000Å. On that basis relative absorptances of fabrics 8, 9, and 10 are 100, 107 and 119. It is difficult to express the experimental results that definitely, but in no case was there appreciably greater damage to fabrics 9 and 10.

The increase in absorptance was carried still further in fabric 39, black, with an average absorptance in the visible of about 97 as compared to 92 for fabric 7. There is no obvious difference in the visual estimate of damage to these two fabrics but the tensile results show slightly greater damage to the black sample. Fabric 13 has a low infrared reflectance compared to fabric 12; the average absorptance in the visible is nearly the same for both but in the infrared the average for fabric 13 is 83 compared to 57 for fabric 12. The visual estimate shows slightly greater damage to fabric 13. The tensile results show little change at Stations IV and III in Shot Baker with possibly 50% greater loss in strength for fabric 13 at Station II. As nearly as can be determined the experimental results agree with the calculations in showing slightly more damage to the low infrared reflecting fabrics but the effect is rather small.

The two fabrics containing nylon to the extent of 15% as a replacement for wool were surprisingly resistant. There was no apparent difference between fabrics 14 and 15 and between fabrics 16 and 17, either in the visual estimate of damage or the loss in strength. Possibly, the nylon melts at low intensities, but apparently the wool supplies a matrix to hold it in place.

The heavier fabrics show less damage than lighter fabrics as shown, for example, by a comparison of cotton fabrics 4, 7 and 32 and wool fabrics 36, 3, and 33, but from the data here the effect can-

not be stated more definitely.

The heat resistant Orlon, although black, was extremely resistant. It was intact at Station II in Shot Baker, 5 cal. per sq. cm., and nearly so at Station III in Shot Dog, 18 cal. per sq. cm., but lost considerable strength, about 25% for Shot Baker and 75% for Shot Dog. At Station IV in Shot Dog, 9 cal. per sq. cm., the loss in strength was nearly as great as at 18 cal. per sq. cm. For all the exposed samples the elongation at break was about 2% compared to 5% originally.

Generally the fire retardant treated fabrics showed little improvement over the corresponding untreated fabrics. They charred brown and black at lower intensities than the untreated fabrics, but possibly retained a little more strength at the higher intensities. The behavior was erratic and it seems that large amounts of retardant are required. Possibly the Martin HPM resin was about the best. The treatments on wool had little effect, but the duPont CM treatment was better than the Pyroset D.

As indicated above, the white fabrics withstood 18 cal. per sq. cm. but were completely destroyed by 27 cal. per sq. cm. The dyed fabrics were destroyed at lower intensities. In Shot Baker, cottons of about 9 oz. per sq. yd. were scarcely affected at 5 cal. per sq. cm. but completely destroyed at 18 cal. per sq. cm. Corresponding wool fabrics were melted on the surface at 5 cal. per sq. cm. and destroyed at 18 cal. per sq. cm. In Shot Dog both the cotton and wool fabrics were very badly damaged at 9 cal. per sq. cm. and completely destroyed at 18 cal. per sq. cm. Any limit that might be set depends on the damage criteria. If 8 to 12 oz. per sq. yd. cotton fabrics are exposed to 5 cal. per sq. cm. they will still be usable. Wool fabrics will not be. Cotton fabrics will likely be unusable after exposure to about 6 cal. per sq. cm. and both wool and cotton will be entirely useless as clothing if exposed to 9 and possibly even to 8 cal. per sq. cm.

### 5.2.2 Temperatures Behind Fabrics

For all of this study the relative effects seem to depend on the intensity of the radiation and sometimes effects are reversed in going from 5 to 9 cal. per sq. cm. or higher. It is possible that for the extremely high energies the fabrics were entirely gone before the exposure was over and there was no protection at all for a very short time. Possibly the fabric burned in some cases and the temperature effects were largely due to the heat of combustion. It is likely that more often the fabric was intact for the whole exposure and the reversal in effects came about from changes in heat dissipation which will become understandable

[REDACTED]

as more data become available.

There were differences in the effect of spacing for various fabrics. For white fabrics, generally, the temperatures were higher for the spaced arrangement than for contact. For example, for fabric 1 at Station III of Shot Baker, the temperature was 93°C in contact and 93 to 162°C spaced. At the same station for fabric 34, the temperature was 106 to 180°C for contact and 182 to 256°C spaced. For Shot Dog the temperature behind fabric 34 was slightly less for contact than spaced, 242 to 256 vs  $\geq 258^\circ\text{C}$  at Station IV. It was also probably less at Station III, but no figure is available for the spaced arrangement. The only discrepancy was for fabric 1 on Shot Dog where the temperatures were nearly the same at Station IV and at Station III, 205 to 241°C for contact and 120 to 163°C spaced.

For the dyed cotton fabrics, at low intensities, the temperatures were definitely lower for the spaced arrangement. Fabric 39, the black sateen, is an extreme example showing at Station II in Shot Baker 72 to 131°C in contact vs. 61 to 72°C spaced. At higher intensities the difference becomes less and in Table 4.8 the temperatures for the spaced arrangement are at least as high as for contact.

For wool either there was little difference or the spaced temperatures were higher throughout.

Perhaps the most striking effect is the lack of protection afforded by the white fabrics. They are very resistant to damage but the temperatures are much higher than for dyed fabrics of the same weight. An appreciable amount of energy is transmitted through these fabrics and it affects the indicators directly.

The difference between the regular OD and camouflage colors is not very great, about what might be expected from the calculations discussed in Section 5.2.2. In Shot Baker, the temperatures for fabrics 9 and 10 were no higher than for fabric 8. In Shot Dog there was little difference at 9 and 18 cal. per sq. cm. but the temperature was definitely higher back of 9 and 10 at 27 cal. per sq. cm. The temperatures were not greatly different for fabrics 7 and 39, OD-7 and black sateen, until an energy of 18 cal. per sq. cm. was reached and then it amounted to 20 to 40°C. There was little difference between fabrics 12 and 13. Generally, the temperature was actually lower for fabric 13, the low IR treatment, but that result probably came about from secondary effects.

At the lower intensities, up to 5 cal. per sq. cm., there was little difference between the temperatures behind wool and cotton but at higher energies, even at 9 cal. per sq. cm., wool provided more

protection.

There was definitely more protection with heavier clothing as can be seen by comparing fabrics 4, 7, 2 and 8 and 32 in Table 4.7 and fabrics 36, 3 and 33 in Table 4.8. The heavier wools, such as fabric 5, the blanket, provided still more protection.

At the lower intensities the blends of wool and nylon were about the same as the all wool fabrics. At higher intensities in Shot Baker the temperatures were a little higher for the blend with some uncertainty because the indicators were all gone for fabric 17; but in Shot Dog, fabric 17 did not seem to be worse than fabric 16.

The temperatures for the combination of fabrics 2 and 28 do not seem to be any lower than a single layer of the same weight. However, there may be some advantage in having layers. For extreme intensities, fabric 28 was badly damaged but generally in place and intact or nearly so while single layer fabrics of about the same weight were gone entirely.

The fire retardant treatments showed little, if any more, protection especially if the added weight is considered. The advantage was generally evident only at the higher energies. The results were erratic, the treated fabrics sometimes showing improvement and in other cases being worse than untreated fabrics. There was evidence of after-flow effects which undoubtedly accounts for some of the variation. This will be discussed further in Section 5.5. Of the various treatments tried, the Martin HEM resin shows some promise.

The heat treated Orlon which resisted damage so well was not particularly good in affording protection. There were some variations, but overall it did not seem to be quite as good as the equivalent weight of cotton.

Since the humidity was somewhat higher for Shot Baker, it might be expected that this would influence the resistance to damage and the protective value. Laboratory tests at the Naval Material Laboratory showed that the critical energy for damage increased with the moisture content of the fabrics. The effect was not particularly evident here, possibly because the materials were not compared at the same energies for the two shots. Most of the useful results were obtained at 5 cal. per sq. cm. in Shot Baker and at 9 cal. per sq. cm. in Shot Dog. In the data at 18 cal. per sq. cm., for both shots, there are individual cases showing higher temperatures in Shot Dog, but no general trend. There is no definite evidence that higher humidity resulted in a lowering of protection.

Most of these results can be explained on the basis of the

reflectance of the fabrics and the manner of transfer of heat from them and to the backing. Other results give some information about the mechanism of transmission of energy through fabric. This comes from the difference between M-5 indicators with black and white backing used face down. For the black backing the absorptance is about 98% and for the white backing about 30%. There were differences between these two for a number of samples. For example, fabric 34, undyed, 9 oz. per sq. yd. wool, has a reflectance of about 60% and a transmittance of at least 26%. In Shot Baker at Station II, 5 cal. per sq. cm., the temperature indicators showed definitely higher temperatures for the spaced sample; Table 4.7 shows 182-256 vs. 106-180°C. There were also definite differences between the M-5 indicators. For contact, the one with white backing was green with a trace of red on one edge and possibly a faint tinge of red throughout; the one with black backing was mostly red, somewhat uneven with a few green spots. For the spaced sample, the white backed indicator was green with a trace of red on one edge only; the black backed sample was red with no trace of green. As nearly as can be determined from these changes, the white backed spaced sample received the least energy; the white backed sample in contact barely perceptibly more; the black backed indicator in contact considerably more and the black backed spaced indicator the most and considerably more than the black backed indicator in contact. Since the major difference between the black and white backed indicators is in their ability to absorb radiation, it seems likely that radiation transmitted through the sample accounts for the difference in color.

With fabric 12 at Station III in Shot Dog, 18 cal. per sq. cm., the results were somewhat similar. In this case the temperature indicators showed about the same temperature for contact and spacing. The M-5 indicators were: white backed spaced, red and green; black backed contact, nearly all red; white backed contact, darker red; black backed, spaced, all red, darker. The white backed spaced indicator received the least energy; the white backed contact and black backed contact, more and about the same; and the black backed spaced indicator the most. Again it seems that an appreciable part of the total energy received by the spaced indicators must have been radiation. In this case, it could not have been transmitted radiation because the transmittance was less than 1/2%. The only other possibility is that the sample was hot enough to lose an appreciable amount of heat by radiating. There were a number of cases like this. A few showed little difference and a few others showed the opposite effect but by far the greater number showed more effect on the black backed indicator.

This evidence is of a negative kind in that the secondary radiation has not been measured directly under conditions that would exclude other possibilities. In addition there is some question as to whether the fabric can be hot enough to radiate enough energy. The

energy radiated per second is

$$E = \sigma T^4$$

where  $\sigma$  is the Stefan-Boltzmann constant,  $5.735 \times 10^{-12}$  watts per sq. cm. per deg<sup>4</sup> and  $T$  is the absolute temperature. Assuming the fabric is at a temperature of 500°C, the radiation amounts to  $5.735 \times 10^{-12} \times (773)^4$  deg<sup>4</sup> about 2 watts or 1/2 cal. per second for each sq. cm. of area. This is rather small but the time is indefinite and moreover, it would not require a very great increase in temperature to raise this value to 1 or 2 cal. per second. Perhaps partly or completely charred and melted samples are that hot. At the above temperature the wave length of maximum intensity is nearly  $4 \mu$ . Even with these uncertainties the experimental evidence strongly suggests that an appreciable part of the heat dissipated by exposed fabrics is in the form of radiation.

The temperatures in Tables 4.7 and 4.8 seem very high, even making allowance for the fact that skin would not attain temperatures as high as the indicators and that the pulse of heat is of very short duration. If 100°C is taken as the limit, then not many of the fabrics tested will protect against even 5 cal. per sq. cm. for skin in contact with the fabric but all the dyed fabrics except the lightest will if spaced from the skin. If the limit is taken as 150°C then some of the undyed fabrics and the lightest dyed fabrics will still not be enough at 5 cal. per sq. cm. Only a few will protect against 18 cal. per sq. cm. possibly the 12 oz. per sq. yd. wool serge, the wool blanket, the heavy duck and the combination of sateen and underwear. The same fabrics might provide barely enough protection at 27 cal. per sq. cm.

### 5.3 EFFECT OF BACKING

There were definite differences in the extent of damage for the various backings. Again the blast effect interfered with interpretation of the results. The overall damage was greatest for spaced samples, and generally for those with screen backing. The relative thermal damage depends on the fabric. For the white fabric, in contact, the sheet aluminum f, seems to be effective in conducting heat away, and the damage was consistently low but not always the lowest. The thermal damage was not always greater for the spaced arrangement. For the dyed cotton the thermal damage was always greater for the spaced condition. For contact, it seems to be low for the sheet aluminum backing, f, but also for others such as for example, g, the silicone fiberglass laminate. For the spaced arrangement the laminate also showed a small amount of damage. The wool serge was affected very little by the backing with one exception. For Shot Dog the material was completely melted for all conditions except contact with the laminate and in this case there was

definitely evidence of fabric structure on the reverse side of the fabric.

The extent of the damage for the different backings varied enough to show the need for a standard backing, but it has not been possible to analyze the damage in terms of the properties of the backing, at least not the properties of thermal capacity, thermal conductivity, and reflectance. The relative effects depend on the intensity of the radiation and vary for the different fabrics. At best, it will probably be necessary to test fabrics with two backing arrangements, contact and spaced, and although this may be satisfactory for single layers, the situation will be further complicated for multi-layer samples.

#### 5.4 ORIENTATION

The results, for damage or protection, are not sufficiently definite to determine the dependence on angle of incidence. Generally, the effects are roughly in agreement with the idea that the energy per unit area varies with the cosine of the angle, at least up to very high angles.

In order to account for the variation in temperature behind the fabrics, it is necessary to know the manner in which the reflectance varies with the angle of incidence and that has not been determined for these fabrics. Some approximate calculations can be made assuming the reflectance does not vary with angle. Even in that case it is not possible to relate the limiting angles of incidence for the various indicators for a single sample at one station. The heat required to melt the indicator material, and the corresponding temperature attained, depends on a number of factors such as the specific heat and thickness of the layer and the degree of contact. Even so, calculations of the relative angles for melting, based on the incident energy, the angle of incidence, the melting point and ambient temperature show fairly good agreement with the limiting values of the angles, but there are so many uncertainties that the results cannot have much significance.

However, comparisons of the incident energy per unit area at the various limiting angles for the same indicator at various stations should be more reliable. In that case the indicators are in corresponding states, and presumably have received the same amount of energy. That energy should be related to the incident energy per unit area, which is given by the product of the incident energy per unit projected area and the cosine of the angle of incidence. Unfortunately with the limited amount of data only a few individual cases can be compared. As shown in Table 4.11, for example, the 61°C indicator behind fabric 2 melted out to 27° at Station III, 3.2 cal. per sq. cm., and out to 58° at Station II, 5 cal. per sq. cm. The corresponding incident energies per unit area are  $3.2 \cos 27^\circ = 2.9$  and  $5 \cos 58^\circ = 2.7$  which agree

within 10%. In some cases, an inequality can be checked. In the same table for fabric 2 at Station I, for 120°C the limiting incident energy per sq. cm. was  $18 \cos 51^\circ = 11$ . The maximum energy at Station II was 5 cal. per sq. cm. which is less than that at Station I, as it should be since the 120°C indicator did not change at Station II. Other similar calculations are shown in the following table for data taken from Tables 4.11 and 4.12.

TABLE 5.1

Comparison of Energy Densities for Corresponding Effects

Fabric	Temperature °C	Incident Energy x Cos $\theta$		Incident Energy x Cos $\theta$
<u>SHOT BAKER</u>				
1	61	3.2 Cos $27^\circ = 2.9$	$\leq$	5 Cos $58^\circ = 2.7$
	120	5 Cos $0^\circ = 5$	$\leq$	18 Cos $67^\circ = 7$
2	61	1.6 Cos $20^\circ = 1.5$	$\leq$	3.2 Cos $71^\circ = 1.1$
	68	3.2 Cos $64^\circ = 1.4$	$\leq$	5 Cos $73^\circ = 1.5$
	86	3.2 Cos $25^\circ = 2.9$	$\leq$	5 Cos $49^\circ = 3.4$
	120	5 Cos $0^\circ = 5$	$\leq$	18 Cos $51^\circ = 11$
<u>SHOT DOG</u>				
1	133	9 Cos $0^\circ = 9$	$\leq$	18 Cos $44^\circ = 13$
2	182	9 Cos $26^\circ = 8$	$\leq$	18 Cos $44^\circ = 13$
5	86	9 Cos $27^\circ = 8$	$\leq$	18 Cos $60^\circ = 9$
	93	9 Cos $20^\circ = 8.5$	$\leq$	18 Cos $55^\circ = 10$
	93	18 Cos $49^\circ = 12$	$\leq$	27 Cos $71^\circ = 9$

For most of the cases, if the angle of incidence is not too large, the agreement is as good as could be expected from the accuracy of determining the limiting angles, but the results are not sufficiently definite to settle the question.

At high angles of incidence the differences are greater and perhaps in that case the reflectance properties vary more. Even here some of the results may be significant. Possibly the scorching of the white fabrics at high angles results from unusually high absorption of incident energy in the very great effective thickness, aided perhaps by reflection from the backing at glancing incidence. If so, the hot fabric would heat the indicators in contact with it and the temperatures would be much higher than expected from geometrical considerations. For example (see Table 4.12) the 120°C indicator behind fabric 1 melted to 15°

at Station IV and the corresponding angle at Station III should have been  $\text{Cos}^{-1} (9 \text{ Cos } 15^\circ/18) = 61^\circ$ . The indicator melted to at least  $82^\circ$  and the inference is that heat was received from another source as suggested above.

### 5.5 INCIDENCE OF IGNITION

As mentioned before there was no definite evidence of ignition of any of the fabrics, but some of them were completely destroyed. An extreme example of this is fabric 11 at Station II in Shot Baker. The whole sample was gone, most of the holder burned, and the panel badly charred. For other samples, particularly fabrics 19, 7, 6, and 4, there was similar burning but not as extreme. There is no apparent reason why fabric 7 should have been damaged more than fabric 4; the result is opposite to the flat sample results. It is possible that many of these materials flamed but since the fire retardant treated materials or similar fabrics showed the greatest damage, this does not seem likely. More probably the fabrics and wood holders were burned as the result of after glow of the fabrics.

Generally, the damage to the folded sample was no greater than for flat samples as a comparison with Tables 4.5 and 4.6 will show. Compared to samples spaced from the backing, the damage may have been a little less. However, this type of mounting does seem to provide a better opportunity to develop after glow, although there is also evidence from a number of flat samples that there may have been combustion of the fabric. It is still important to determine how the fabrics fail but there does not seem to be a way of doing this.

Except for the supposed afterglow effects the fire retardants seemed to show to better advantage here than in the flat samples. With borax-boric acid, Martin HPM and Pyroset D, the edges of the folds burned through, but the charring did not spread appreciably.

## CHAPTER 6

### SUMMARY

#### 6.1 PROTECTIVE VALUE OF FABRICS

The damage to fabrics from intense radiation and the protection they afford to skin behind them depends on the intensity and quality of the radiation, the properties of the fabric and the method of mounting the fabric and exposing it to the radiation. These factors are so inter-related that they can scarcely be discussed separately.

Radiation is reflected from, absorbed in, and transmitted through fabrics in varying amounts. Damage results largely from absorbed radiation which causes a rise in temperature. Radiation transmitted through the fabric and energy from the hot fabric combine to burn the skin. The latter energy is transferred by conduction, convection, and re-radiation; the first mechanism is effective for contact with a solid backing, the first and second less effective, but apparently still significant, for air backing and the third less certain but apparently significant at least for high intensities.

For white fabrics, the reflectance is high, about 65%, and the transmittance is fairly high, up to 30% in some cases, with a corresponding low absorptance. For military shades, OD and OG, the reflectance is low, in the neighborhood of 10%; the transmittance is negligible, less than 1/2%; and the absorptance is accordingly high, about 90%.

White fabrics are very resistant to damage and correspondingly they do not afford much protection to the skin. They have the advantage that the temperature rise from radiation absorbed in them is relatively small but the transmitted radiation is significant. Dyed fabrics become very hot and suffer more damage. Skin in contact with such fabrics becomes very hot; skin spaced away from the fabric is affected much less.

Damage to the fabric depends on the method of mounting and the effect of the backing varies with the fabric. Except for white fabrics, fabrics in contact with a wood backing were damaged less than those spaced from the same backing. In these experiments the overall damage was a combination of thermal and blast effects. The latter was more severe for spaced samples, but making allowance for that, the thermal damage was generally greater. For white fabrics the difference was not

great and may have been reversed, possibly as a result of conduction from a hot backing. For dyed cotton the difference was very definite. For wool the difference was definite but much less, probably because of the lower thermal conductivity of wool.

The temperatures behind the fabrics followed a similar pattern. For white fabrics there was not much difference for contact and spaced samples and in many cases the latter were higher. For OD cotton the temperatures for the spaced arrangement were very definitely lower in general, but the difference decreased at very high intensities. For wool, the differences were in the same direction but lower and decreased for very intense radiation.

With special low infrared reflecting dyes the absorptance in the infrared may be 50 per cent greater than with OD-7 and a few per cent greater in the visible with an overall increase of as much as 20 per cent. It is not possible to assess the damage or the temperature that precisely but as nearly as can be judged both were slightly greater but not to quite that extent.

The resistance to damage and the protective value increased with the weight of the fabric but the data do not provide a way of expressing this more definitely.

The temperatures behind the combination of sateen and underwear were no lower than behind a corresponding weight in a single layer, but there may be some advantage over a single layer in that after exposure to high intensities the sateen was gone but the underwear was nearly intact and would accordingly provide some protection after the blast.

Cotton and wool fail in different ways. Cotton scorches and chars while wool singes and then melts. Wool shows slight effects at lower intensities but withstands very high intensities a little better than cotton. At low intensities the protection afforded by cotton was nearly as good as that by wool, but at extreme intensities, the wool was superior. This results more from its lower thermal conductivity than from its greater resistance to damage.

Mixtures of 85% wool - 15% nylon were about as good as 100% wool, both in resisting damage and in providing protection.

Fabrics treated with fire retardants were only slightly better than untreated fabrics. At low intensities there was very little difference. At extreme intensities the treated fabrics were slightly better in that they retained their shape more completely, but in such cases both untreated and treated fabrics were so badly damaged as to be of no further value as clothing fabrics. There was some evidence that the

treated fabrics were somewhat worse in promoting afterglow and the effects were erratic. Considering the added weight they offered no additional protection.

The heat treated Orlon resisted damage remarkably well, but was not outstanding in providing protection.

It is difficult to state exactly how much radiation any of the fabrics will stand because that depends on the state of damage chosen for comparison; i.e., the first sign of damage, damage to the extent that it might still be useful, damage to the extent that it would no longer be useful, or complete destruction. In the few samples exposed here, not many were in corresponding states of damage. In Shot Baker, only a few of the ordinary fabrics showed significant damage at Station II, 5 cal. per sq. cm. In Shot Dog, all but a few very damaged beyond the point of further usefulness at Station IV, 9 cal. per sq. cm. Lower humidity conditions for Shot Dog may have caused some of the increase in damage. Tentatively, possibly 6 cal. per sq. cm. can be taken as the maximum intensity that will not show appreciable damage. On the same basis 7 or 8 cal. per sq. cm. is probably the maximum that usual fabrics will withstand and still retain any usefulness.

There are even more difficulties in determining the protection fabrics will afford. On the basis of the very short time of exposure, the temperature for burning of the skin will be high, perhaps 100 or 150°C, but the temperatures recorded here are in that neighborhood or higher. Even if 150°C is allowable, none of the single layer cottons will provide sufficient protection at 5 cal. per sq. cm. and none of the ordinary weight wools will provide enough protection at 9 cal per sq. cm.

The temperature indicators performed fairly well. Some of the defects are known and can be corrected. These include uncertainties about contact, color or reflectance and protection from the blast. Correlation with skin burning tests are needed to make the results more useful.

## 6.2 EFFECT OF BACKING

With various backings representing a wide range of reflectance, thermal capacity and thermal conductivity, the relative effects seem to depend on the fabric. With white fabrics there was a fairly wide range in the relative amounts of damage for the different materials and in many cases, the damage was greater for contact than for the spaced arrangement. With wool there was little or no effect. The effect was greatest with dyed cotton and, in this case, the spaced samples always

showed more damage than corresponding samples in contact. The effects varied so widely among the four fabrics tested that it has not been possible to determine the relative importance of the various properties of the backing.

Since the damage does depend on the backing and since significant amounts of energy are transmitted to the skin by conduction and radiation, it seems desirable to select a backing which has properties similar to the skin. None of the ones used here meets all the requirements but presumably the reflectance of the Navy GSG laminate could be changed fairly readily, and it would provide a reproducible backing with other properties in the desired range.

### 6.3 ORIENTATION

The effects of varying the angle of incidence were about as calculated on the basis of incident energy per unit area, i.e., varying with the cosine of the angle of incidence. Up to angles well above  $45^{\circ}$  the agreement was fairly good, but it was not possible to determine the effect as definitely as desired.


There were some exceptions, principally at very high angles. The wool blanket showed appreciable melting up to at least  $80^{\circ}$ . The white sateen showed scorching at very high angles with correspondingly high temperatures, likely resulting from unusually high absorptance because of the very long effective path length. The damage to the OD-7 sateen was more nearly normal, but at high angles the temperatures were also rather high. More exact data are desirable, but these results will be useful in evaluating laboratory results and in estimating the performance of clothing.

### 6.4 INCIDENCE OF IGNITION

There was no definite evidence of ignition and flaming although this may have occurred in a few cases. There was evidence of afterglow, from the charring and burning of samples and holders, for both folded and flat samples, and from very high temperatures in isolated cases. With few exceptions, this was confined to fabrics treated with fire retardants.

With the exception of the cases of afterglow, which of course are rather serious, fire retardants showed to better advantage for folded samples than for flat samples.

Since the folded samples seem to provide a better opportunity for



afterglow or flaming, if that occurred with any of the samples that were completely destroyed, perhaps it is a more realistic simulation of clothing than a flat sample. At least the matter deserves further study with a careful comparison of flat and folded samples.

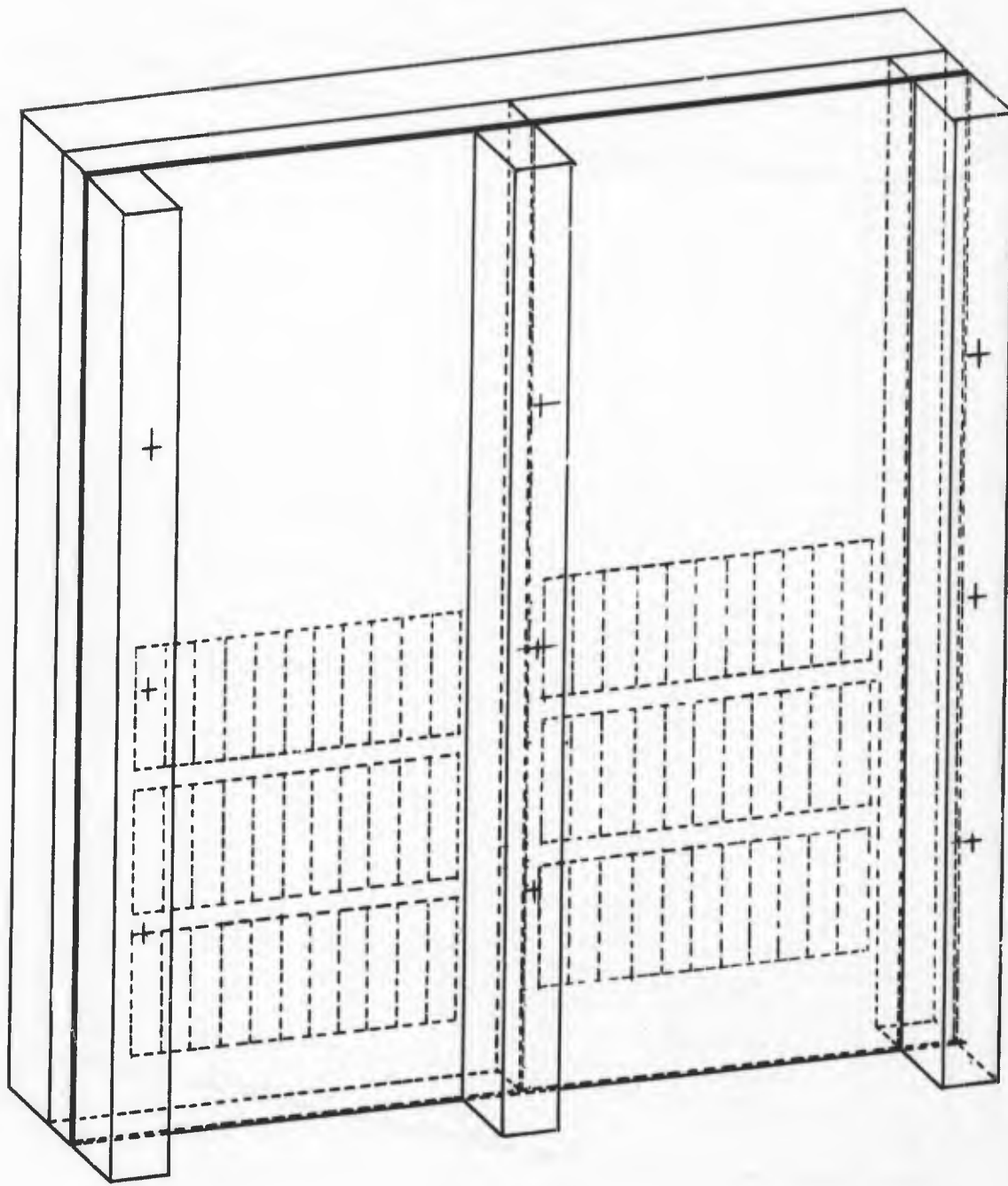


Fig. 3.1 Fabric Holder - Flat - b

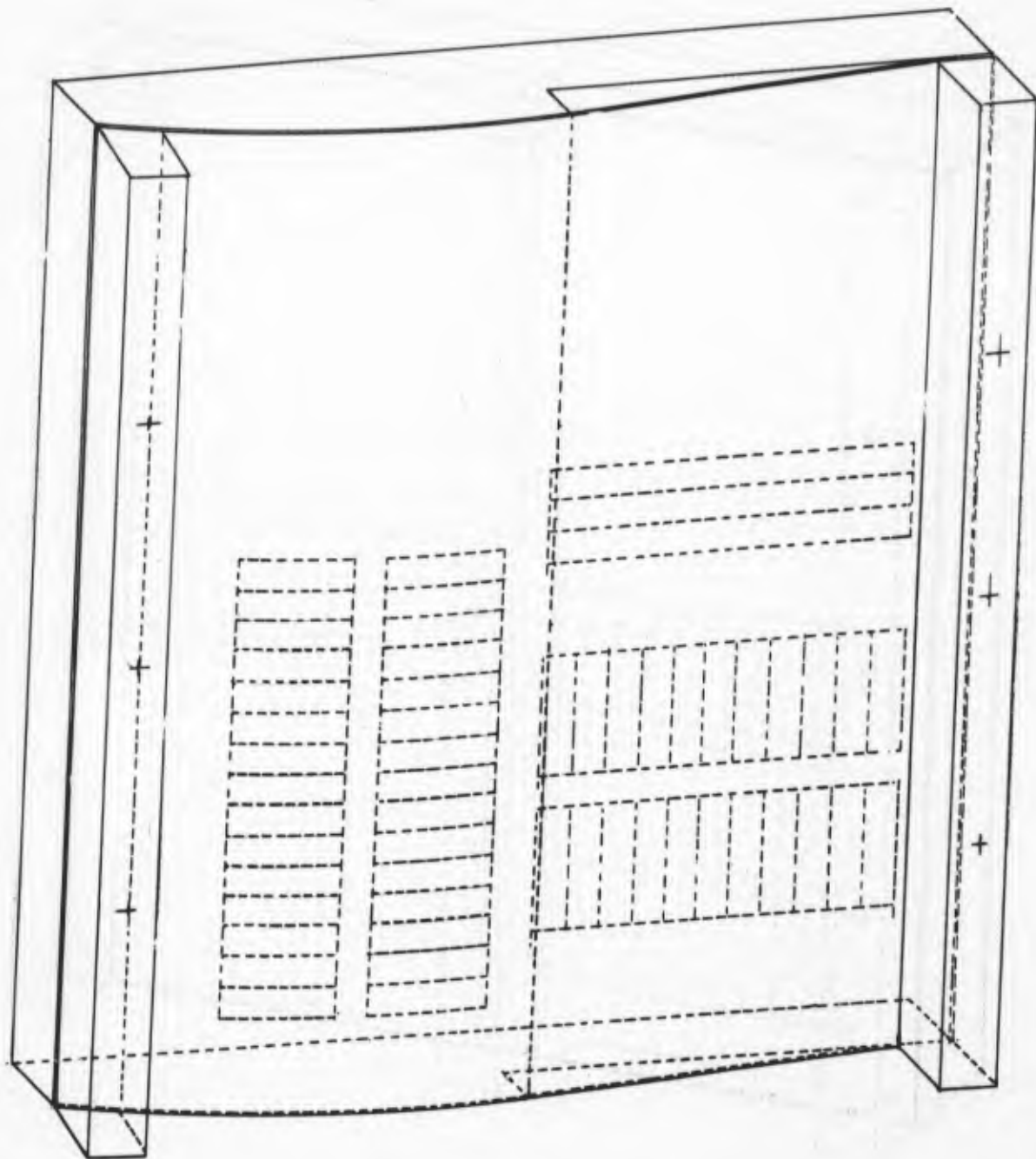


Fig. 3.2 Fabric Holder - Curved - h

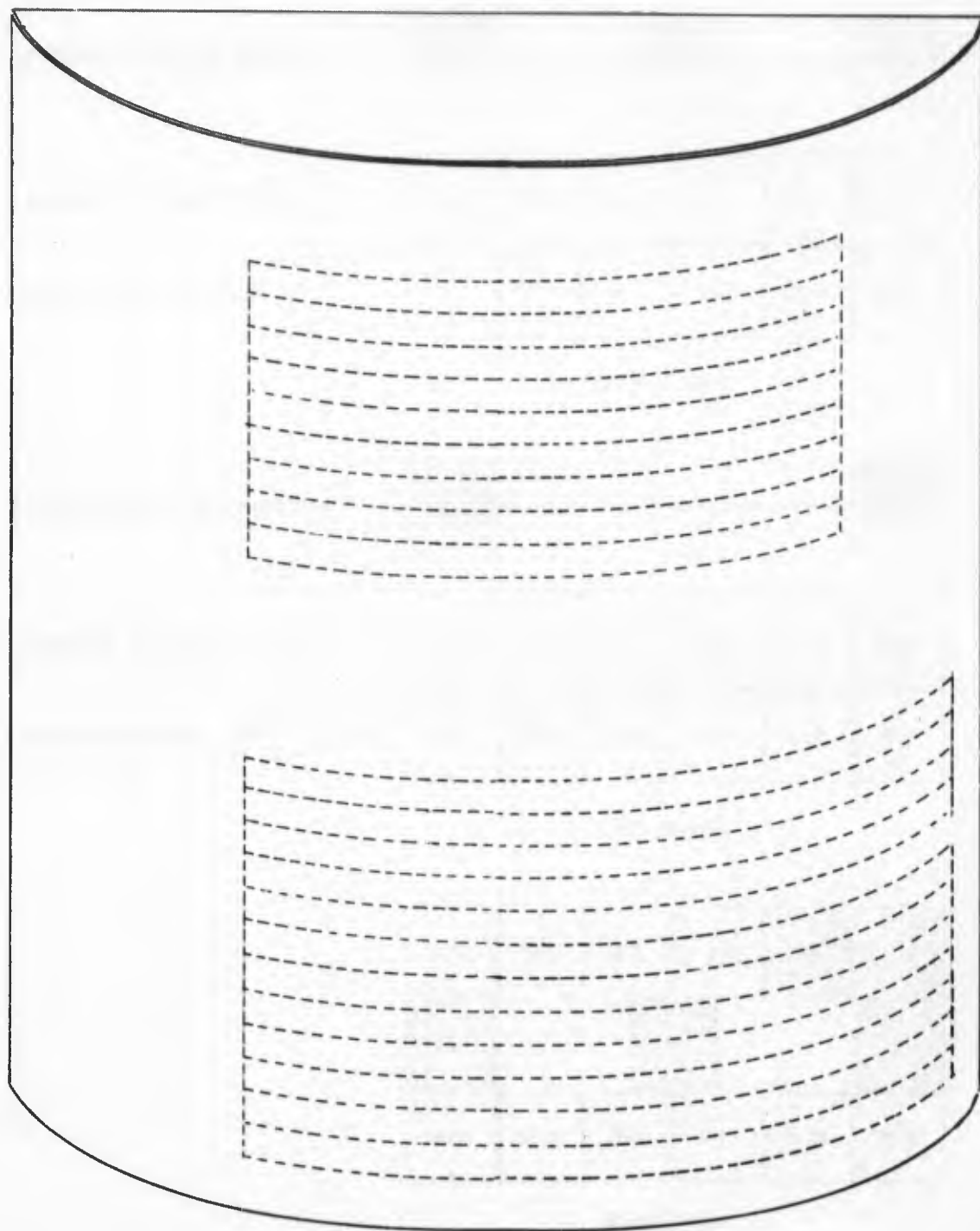
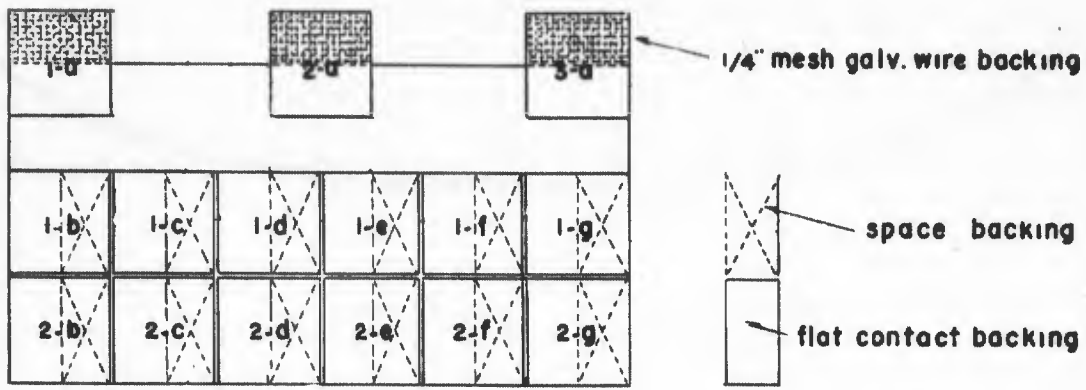
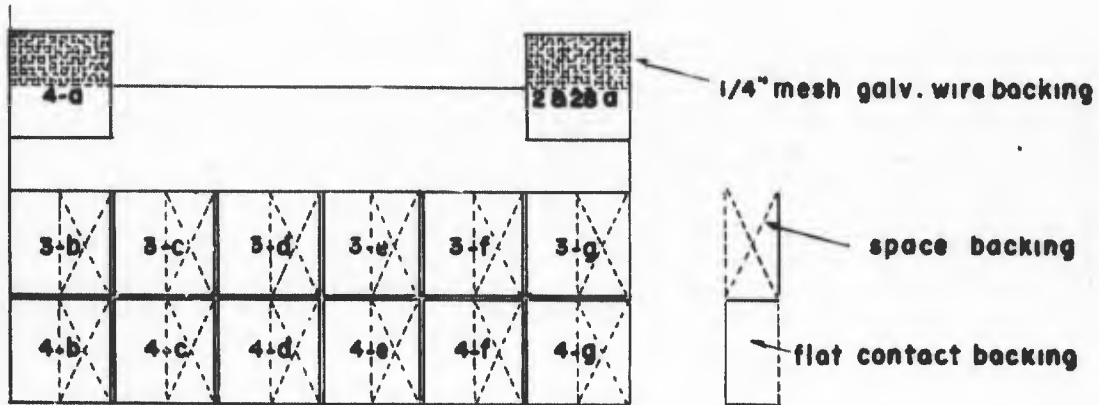


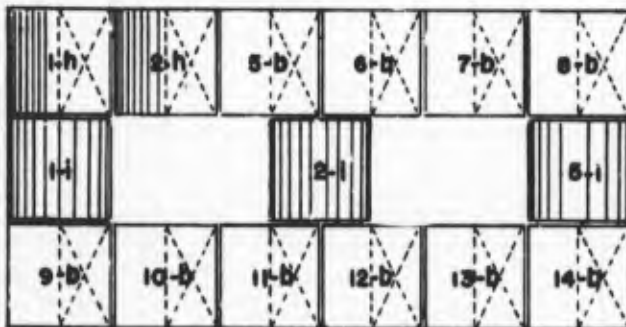
Fig. 3.3 Fabric Holder - Half Cylinder - 1



Panel No.1.

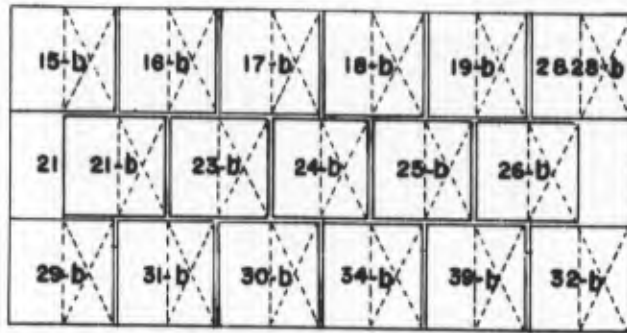


Panel No.2.

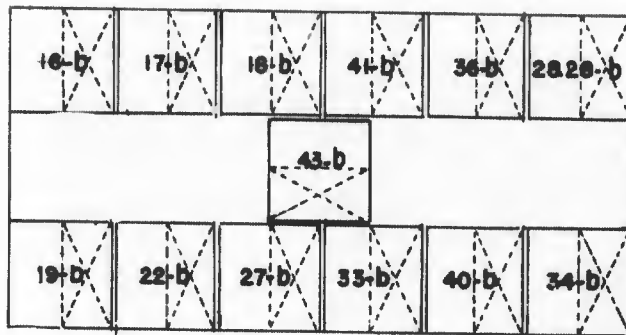


Panel No.3

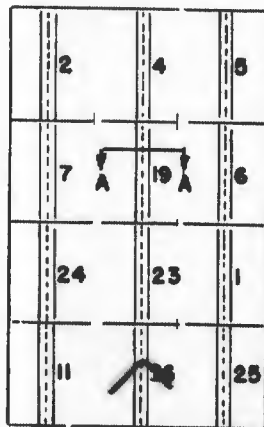
Fig. 3.4 Arrangement of Holders on Panels 1, 2, and 3



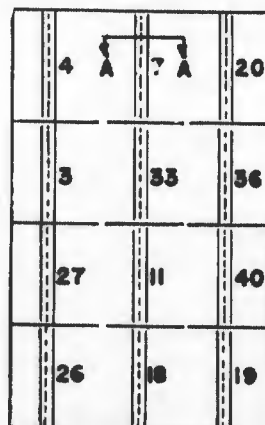
Panel No. 4-B



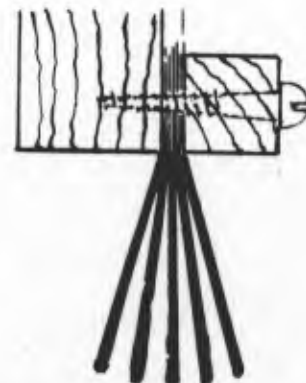
Panel No. 4-D



Panel No. 5  
Shot Baker



Panel No. 5.  
Shot Dog



Section "A-A" typical  
for Panels Nos. 5.

Fig. 3.5 Arrangement of Holders on Panels  
4-B, 4-D and 5



Fig. 3.6 Panels on Supports, Station III, Shot Baker, after Exposure

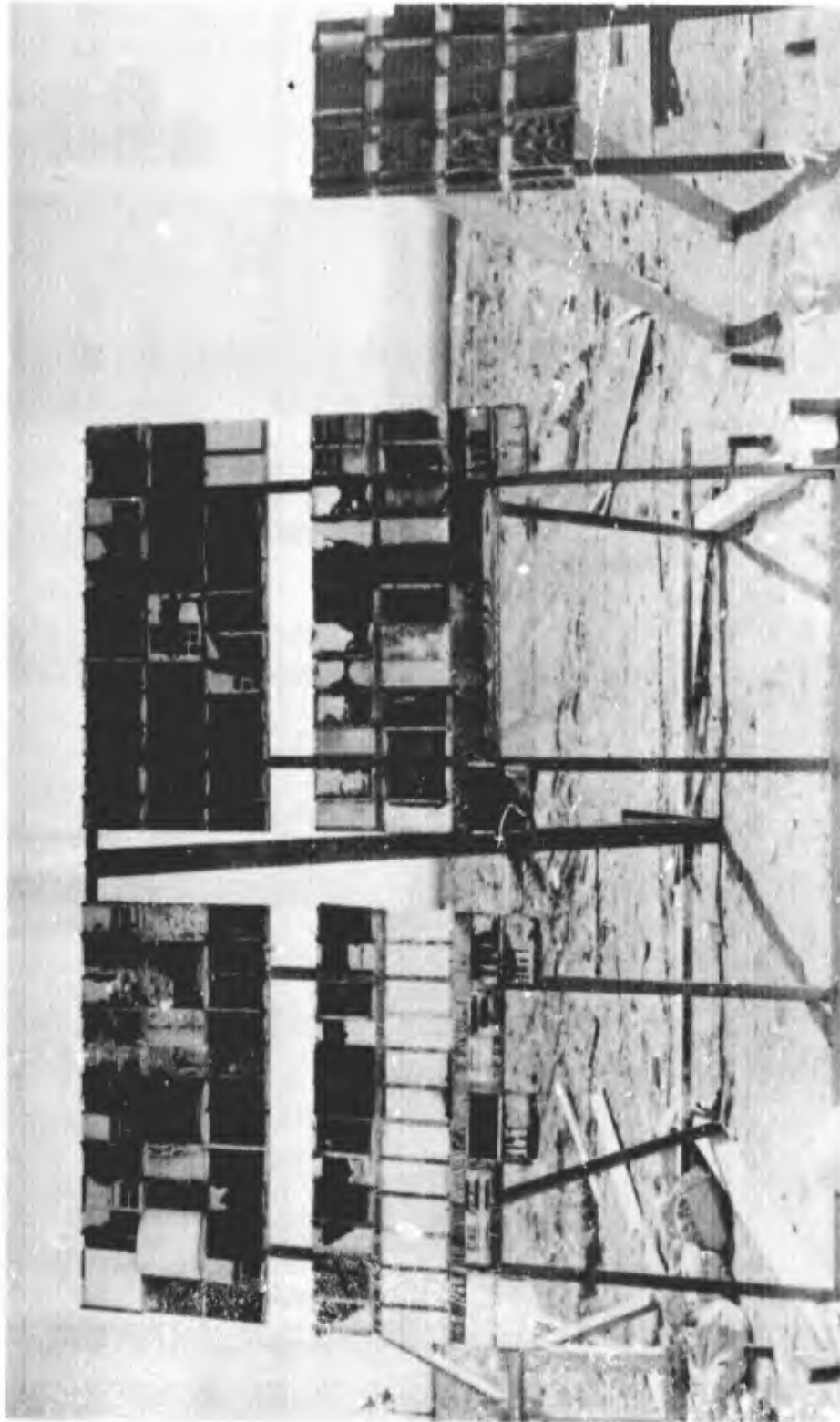


Fig. 3.7 Panels on Supports, Station IV, Shot Dog, after Exposure

APPENDIX A

List of Fabrics

No.	Description	Weight oz per sq yd		Color	Specification or Laboratory Designation
		Nominal	Actual		
1	Cloth, cotton (combed) wind resistant sateen	9	8.8	White	A-4-a
2	Cloth, cotton (combed) wind resistant sateen	9	9.1	OD-7	A-4-b
3	Cloth, wool, serge	9	8.3	OD-7	B-3-b
4	Cloth, cotton, (carded) sateen	5	5.0	OD-7	A-1-b
5	Cloth, wool, napped (blanket)	13.8	14.3	OD-36	MIL-B-844
6	Cloth, cotton, HBT	8.5	8.5	OD-107	Jan-C-154
7	Cloth, cotton, (carded) sateen	8.5	8.1	OD-7	A-3-b
8	Cloth, cotton, (combed) wind resistant sateen water repellent	9	9.2	OD-7	Jan-C-557
9	Cloth, cotton, (combed) wind resistant sateen	9	8.8	OG-107-vat	Roll 625
10	Cloth, cotton, (combed) wind resistant sateen	9	9.4	OG-107-org	Roll 626
11	Duck, cotton, FWDAR		18.7	OD-7	USA-6-342&
					USA-6-345
12	Cloth, wool, serge (18 oz.)	13	11.4	OD-33	USA-8-94-c <sup>a</sup>
13	Cloth, wool, serge (18 oz.) (#12 treated)	13	11.8	OD-33 sul- fur topped	
14	Cloth, wool, serge (16 oz.)	10	9.9	OD-33	MIL-C-11305 QMC
15	Cloth, 85% wool, 15% nylon, serge	10	10.3	OD-33	Experi- mental <sup>a</sup>
16	Cloth, wool, shirting, shrink resistant (16 oz.)	10	10.3	OG-108	MIL-C-10752 QMC

<sup>a</sup> Present Spec. MIL-C-11305 QMC

APPENDIX A (cont'd)

List of Fabrics

No.	Description	Weight oz per sq yd		Color	Specification or Laboratory Designation
		Nominal	Actual		
17	Cloth, 85% wool, 15% nylon, shirting (16 oz.)	10	10.2	OG-108	Experimental Peerless Woolen <sup>b</sup> Experimental from du Pont
18	Cloth, orlon, heat treated		8.7	black	
19	Cloth, cotton, (carded) sateen, treated with 25% XCC3 (#7 treated)	8.5	10.4	OD-7	
20	Cloth, rayon, marquisette		1.6	white	Experimental from D. Statler
21	Cloth, cotton (carded) sateen, with 15% Pyroset D (#29 treated)	8.5	8.9	white	A-3-k
22	Cotton, sateen (carded) treated with 10% Pyroset D (#7 treated)		8.4	OD-7	A-3-n
23	Cloth, cotton (carded) sateen, treated with 15% Pyroset D (#7 treated)	8.5	8.6	OD-7	A-3-l
24	Cloth, cotton (carded) sateen, treated with 30% Pyroset D (#7 treated)	8.5	10.4	OD-7	A-3-p
25	Cloth, cotton (carded) sateen, treated with 15% Erifon D (#7 treated)	8.5	8.4	OD-7	A-3-r
26	Cloth, cotton, HBT, Martin IHM resin (#6 treated)	8.5	10.6	OD-7	
27	Cloth, wool, serge, with 15% du Pont QM (#3 treated)		8.7	OD-7	B-3-i
28	Cloth, cotton, knitted underwear, quarter sleeve, lightweight	3	9.1	White	JAN-U-797

<sup>b</sup> Present Spec. MIL-C-11065 QMC

APPENDIX A (cont'd)

List of Fabrics

No.	Description	Weight oz per sq yd		Color	Specification or Laboratory Designation
		Nominal	Actual		
29	Cloth, cotton (carded) sateen	8.5	8.1	White	A-3-a
30	Cloth, cotton (carded) sateen	5	4.9	White	A-1-a
31	Cloth, cotton (carded) sateen	12	10.7	White	A-2-a
32	Cloth, cotton (carded) sateen	12	10.5	OD-7	A-2-b
33	Cloth, wool, serge	13	11.2	OD-7	B-2-b
34	Cloth, wool, serge	9	7.8	White	B-3-a
36	Cloth, wool, serge	5	5.9	OD-7	B-1-b
39	Cloth, cotton, (carded) sateen	8.5	8.4	Black	A-3-j
40	Cloth, cotton (carded) sateen, treated with 15% Boric Acid (#7 treated)	8.5	8.9	OD-7	A-3-x
41	Cloth, cotton (carded) sateen, treated with 15% Hooper D (#7 treated)	8.5	11.1	OD-7	A-3-t
42	Cloth, rayon (Fortisan) Spinnaker cloth	1.9	2.0	OD-7	Experimental from Amer. Pad & Text.
43	Cloth, wool, serge, with 15% Pyroset D (#3 treated)		9.0	OD-7	B-3-j

  
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