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# Operation UPSHOT-KNOTHOLE

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March - June 1953

Project 8.6

## PERFORMANCE CHARACTERISTICS OF CLOTHING MATERIALS EXPOSED TO THERMAL RADIATION

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(21) Report on OPERATION UPSHOT-KNOTHOLE - Project 8.6.

Project 8.6

# (6) PERFORMANCE CHARACTERISTICS OF CLOTHING MATERIALS TO THERMAL RADIATION,

REPORT TO THE TEST DIRECTOR

(10) by

David Feldman and J. Fred Oesterling,

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## ABSTRACT

Tests were conducted at UPSHOT-KNOTHOLE, Shots 9 and 10, in which various fabric systems as used in U. S. Army clothing were exposed to the effects of atomic weapons. Samples were exposed to energies ranging from approximately 9 cal/cm$^2$ to 75 cal/cm$^2$.

Three of the fabric assemblies, each with and without a fire resistant treatment, corresponded to the same fabric systems on the animals used in Project 8.5. These assemblies were (1) the "Temperate" (a four-layer assembly identical with the standard Army cold-wet uniform without the frieze liner) which provided the greatest resistance to thermal transfer and damage in this group at all levels of energy to which it was exposed, i.e., up to 75 cal/cm$^2$, (2) the hot-wet 50/50 assembly (5.2 oz oxford over 10.5 oz 50 per cent wool/50 per cent cotton underwear fabric) which offered very good protection up to the highest energy level to which it was exposed (40.5 cal/cm$^2$) for both the treated and untreated assemblies, and (3) the hot-wet assembly (5.2 oz oxford over 3.2 oz cotton underwear fabric) which offered very little in the way of thermal protection at any energy level to which it was exposed (9.5 to 26.0 cal/cm$^2$) whether or not it was fire resistant treated. The fire resistant treatment did not enhance the resistance of the fabric to thermal transfer when the assemblies were in contact with the backing but was definitely superior to the untreated assembly when the combination was spaced away from the backing.

In addition, other clothing fabrics, assemblies, and parameters were studied. The cold-dry and cold-wet assemblies offered the best protection against thermal transfer of any combination tested. In a comparative test of three underwear fabrics, the 50 per cent wool/50 per cent cotton was much better than an all cotton fabric of approximately the same weight. Both were very superior to the lightweight cotton underwear fabric.

The wool/synthetic blended fabrics showed that for 15 per cent synthetic fiber there was very little or no difference from the all wool fabric regardless of the synthetic. With higher percentage blends the differentiation became greater. The higher the per cent of synthetic the poorer the resistance to thermal damage and heat transfer. The all synthetic fabrics showed Dynel to be the best with Orlon next and Acrilan a poor third.

Reflectance and spacing studies involving systems consisting of three fabric layers and a backing material yielded results complicated by sustained glowing of the fabric layers. A system with the two outer layers in contact with each other and with a space between these and the under layer was much more susceptible to glow phenomenon than two other spacing systems in which one had all three layers in contact with each other and the second had the outer layer spaced away from the inner two layers which were in contact with each other. In addition, a system with a more highly reflectant outer layer was more susceptible to this glow effect than a system with a less reflectant outer layer. In general, the system with a space between the outer and middle layer yielded the lowest beneath fabric temperatures and one with a space between the middle and under layer yielded the higher backing temperatures.

Results of the tests demonstrated that flaming and glowing of fabrics can occur. Fire resistant treating of the outer layer eliminated this effect.

The area of exposure studies showed that for protective layers of fabric there is a minimum exposure area below which lateral heat losses become significantly greater with decreasing area size. It appears that more heat is transmitted per unit area through the larger areas than through the smaller area.

It is recommended that studies be carried out in the laboratory to determine the primary mechanisms of heat transfer through fabric systems and that the effects of reflectance, spacing, fabric construction and fiber combinations be studied in the laboratory to determine the interrelationships involved. The over-all results are to be checked in future field exercises.

## FOREWORD

This report is one of the reports presenting the results of the 78 projects participating in the Military Effects Tests Program of Operation UPSHOT-KNOTHOLE, which included 11 test detonations. For readers interested in other pertinent test information, reference is made to WT-782, Summary Report of the Technical Director, Military Effects Program. This summary report includes the following information of possible general interest.

a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the 11 shots.

b. Compilation and correlation of all project results on the basic measurements of blast and shock, thermal radiation, and nuclear radiation.

c. Compilation and correlation of the various project results on weapons effects.

d. A summary of each project, including objectives and results.

e. A complete listing of all reports covering the Military Effects Tests Program.

## ACKNOWLEDGEMENT

In the course of the investigations reported herein many people contributed to the planning, preparation and conduct of the test. To all parties associated with this project the authors wish to express their sincere appreciation. The invaluable help of Mr. John Davies in planning the test is acknowledged; to Mr. William A. Caskie, who designed and supervised the construction and field installation of the exposure frames, our special thanks. Special thanks are also due Mr. Allan J. McQuade for his invaluable assistance in the planning and conduct of the test.

The authors gratefully acknowledge the help received from personnel of the University of Rochester, Walter Reed Medical Center, Quartermaster Field Evaluation Agency, Reno Quartermaster Remount Service, and Bureau of Medicine who contributed of their time and energy in the field preparations. Appreciation is expressed to LCDR. Roger G. Preston and LT. R. M. Casson, Director and Assistant Director of Program 8, for their counsel and assistance in the preparation and field conduct of the tests. Thanks are also due to AFSWP personnel in general and to the support groups who made possible the orderly conduct of the entire operation.

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# CHAPTER 1

# INTRODUCTION

## 1.1 OBJECTIVE

The providing of protection against flame and thermal agents is an integral part of the over-all requirement for protection of the individual against environmental and special hazards. A program to provide protection against flame and thermal agents was initiated during World War II, with particular emphasis on protection against flame. However, the development of other munitions has broadened this problem to include protection against the thermal effects of phosphorous, flame throwers, napalm, and atomic weapons.

Field tests at UPSHOT-KNOTHOLE, Shots 9 and 10, on performance characteristics of clothing materials exposed to thermal radiation were designed and conducted:

(1) To yield information on field performance characteristics of standard Armed Services clothing and experimental fabric assemblies when exposed to the thermal radiation of a nuclear weapon.

(2) To relate the data obtained in (1) to the burn injury sustained by pigs (Project 8.5) subjected to the same conditions of thermal radiation and wearing the same fabric combinations in the form of specially designed garments.

(3) To determine the performance characteristics of blended fabrics containing various percentages of wool and different synthetic fibers to the thermal effects of a nuclear detonation.

(4) To provide data on the minimum area of exposure required to give realistic thermal radiation transfer data. This information is needed for evaluation of laboratory work since existing instrumentation concentrates the energy in a small area in order to approach field levels.

(5) To obtain information on the effect of fabric reflectance and spacing on the transfer of thermal energy to the backing material.

(6) To determine whether flaming or other exothermic reactions occur in fabrics as a result of a nuclear explosion, and if so, during what phase of the explosion they take place, and how long they persist.

(7) To utilize these data in establishing laboratory evaluation methods which can be used as screening techniques for determining the

relative thermal characteristics of protective barriers which may be used in the development of combat or field uniforms.

Thus, it was desired to obtain information through data developed in this project and data of other interested agencies which would make possible valid laboratory evaluations of protective barriers without the need for extensive and costly field studies involving the use of clothed animals.

In order to accomplish the objectives as outlined above, it was necessary to obtain field data which would fill in gaps on previous tests.

(8) In addition, a very limited number of Chemical Corps items and Quartermaster Corps packaged materials were exposed to obtain some indication of thermal effects upon the former and blast and thermal effects upon the latter.

## 1.2 BACKGROUND

In several previous exercises including Operations CROSSROADS, SANDSTONE, GREENHOUSE, RANGER, BUSTER and TUMBLER-SNAPPER, the Quartermaster Corps exposed fabrics, a limited number of clothing and packaged items, and some other miscellaneous materials to the effects of atomic explosions.

From the standpoint of clothing fabrics the most important of these were RANGER,(1) TUMBLER-SNAPPER,(2) and BUSTER(3). Whereas, the energy levels of exposure for the UPSHOT-KNOTHOLE series ranged from 9.5 cal/cm$^2$ to 75.0 cal/cm$^2$, those for the previous tests were considerably lower, being 0.5 to 12.0 cal/cm$^2$ in RANGER, 1.6 to 27.0 cal/cm$^2$ in BUSTER, and 4.0 to 13.0 cal/cm$^2$ in TUMBLER-SNAPPER. The results of these early tests indicated that reflectance, fabric thickness, weight, special finishes, and position of the fabric (i.e., spaced away from or in contact with the backing material) influence the thermal characteristics of fabric assemblies.

Early work in this field was directed toward the determination of the degree of fabric destruction or burn. However, it soon became apparent that the critical factors were the amount and rate of thermal energy reaching the backing material and that the degree of burn or scorching of a fabric was not necessarily a good index of the heat transmitted from the outer to the inner surface of a fabric system. The criterion of whether a fabric did or did not burn gave no conclusive indication of how much heat was transferred to the backing.

In these earlier tests based on beneath-fabric temperatures, as measured with passive indicators, and thermal damage to underneath fabric layers, heavier fabrics (whether the added weight was a function of thickness or the addition of fabric layers) were found to give better protection than fabrics of lighter weight. White fabrics transmitted more heat than those dyed an olive drab color, but were more resistant to damage by thermal energy. Light colored fabrics appeared to give better thermal protection than dark ones. The temperature behind camouflage fabrics designed to absorb infrared rays was somewhat, but not seriously, higher than that behind regular olive drab materials. At RANGER, an aluminized fabric was tested which, by virtue of its high reflectance, was expected to give superior thermal protection. Such was not the case, however, when another sample aluminized in a different manner was tested at TUMBLER-SNAPPER, it was superior to all fabrics evaluated.

Wool and cotton fabrics were found to be thermally degraded in different ways, the cotton charring and the wool tending to melt and form a cellular char. At low intensities of thermal energy, the cotton was as good as the wool in protective value and perhaps slightly better, but at higher energy levels the superiority of the wool was indicated. The synthetics, in general, were found to be worse in both thermal resistance and protection than the natural fibers. A 70/30 wool/nylon fabric at TUMBLER-SNAPPER was considerably damaged but the performance of an 85/15 wool/nylon sample was not found to be comparable to all wool fabric. Heat treated Orlon when tested at BUSTER was shown to be resistant to thermal damage, but not outstanding in reducing heat transfer to the backing.

Some of the fabrics tested at BUSTER were treated for fire-resistance with several different compounds. The results of the experiment indicated that the treated fabrics were only slightly better than the untreated in thermal resistance and that they were no better in protective value considering their added weight. No evidence of flaming was noted in any of the samples included in this test.

Not only the materials themselves, but the way in which they were exposed was shown to be important in these earlier tests. Fabrics spaced away from the backing gave much better protection (as measured by passive indicators), but were less resistant to thermal degradation than fabrics exposed in close contact with the backing. In TUMBLER-SNAPPER exposures it was noted that a 1/2 in. space provided more protection than a 1/16 in. space. There did not appear to be much difference in a two-layer assembly whether the space was between the two layers or between the backing and the bottom layer.

At TUMBLER-SNAPPER some complete uniforms were exposed on torso forms with passive temperature indicators beneath the uniforms. Here it was found that the temperatures beneath the uniforms were lower than those beneath the same fabrics exposed on panels.

These field tests and other work with fire bombs have established that from the standpoint of thermal protection, the important consideration is the amount of heat transmitted through a barrier system to the backing, not the extent to which the protective barrier itself is damaged. In view of this, the objective of most laboratory work has changed from determination of fabric damage to determination of thermal transfer through fabrics. In the tests at UPSHOT-KNOTHOLE, while fabric damage was noted, primary consideration was given to the temperatures attained beneath the fabrics as a criterion of their protective value.

## 1.3 EXPERIMENT DESIGN

### 1.3.1 General

There were several different phases to the exposures carried out on Project 8.6 as follows:

(1) This phase concerned the evaluation of military clothing assemblies of various weights and numbers of layers.

(2) The second phase was an evaluation of 15, 30, and 50 per cent synthetic-wool blends as compared to all-synthetic and all-wool fabrics. These fabrics were mostly serges and the principal blend fibers were the newer synthetics, Dynel, Orlon, and Acrilan. An 85/15 wool/nylon blend was also included.

(3) A third phase combined a preliminary study of the surface reflectance with spacing. Two cotton fabrics were exposed in this phase, one dyed so as to give an infrared reflectance of 7 per cent and the other of 65 per cent. Samples of these fabrics were exposed on specially constructed panels in superimposed layers, each set of layers so arranged that a space was provided between two of them while the balance were in contact with each other, the position of the space, i.e., whether it was between the second and third layers, between the bottom layer and the panel backing, or other was systematically varied from panel to panel.

(4) The fourth phase was planned to yield information on the effect of exposure area size on thermal transfer. In this phase, fabrics were exposed behind aluminum shields in which holes of various sizes from 1/8 in. to 4 in. in diameter had been cut. These exposures were designed to bridge the gap between laboratory tests where existing equipment required the concentration of energy over a small area, and field tests where the area of exposure can be very much larger. The specific purpose of this work was to determine how large an area must be exposed in the laboratory to give results that can be correlated with large-area field exposures.

(5) A fifth phase was designed to demonstrate whether fabrics can be set on fire by the thermal energy from an atomic bomb. In this study fabric strips were suspended vertically on a special rack, the lower part of the strips exposed to the radiant energy and the upper part shielded by a cylindrical cover. It was expected that if the fabric strips flamed, the fire would extend up into the protected portions and continue burning though the flaming below the shield might be extinguished by the blast wave. On the other hand, if no flaming occurred, damage or destruction of the samples would be sharply limited to the unprotected portion.

(6) A final phase concerned the exposure of a number of miscellaneous items of military interest including packaged rations, baled clothing, and certain Chemical Corps items of issue.

## 1.4 DESCRIPTION OF EXPOSURE EQUIPMENT

The basic panel used in this test was made from 1/4 in. oak veneer and is detailed in Fig. 1.1. The actual exposure area was 9 in. x 12 in., with one-half of the wood backing in contact with the overlaying test material and one-half spaced 1/4 in. away. The fabrics were placed on the panel with just enough tension to keep them in contact with the one side of the panel and properly spaced from the other half. The panels for the "effect of area studies" were the same as the basic panel except that aluminum shields (Fig. 1.2) with circular openings varying from 1/8 in. to 4 in. in diameter were placed over the test fabrics.

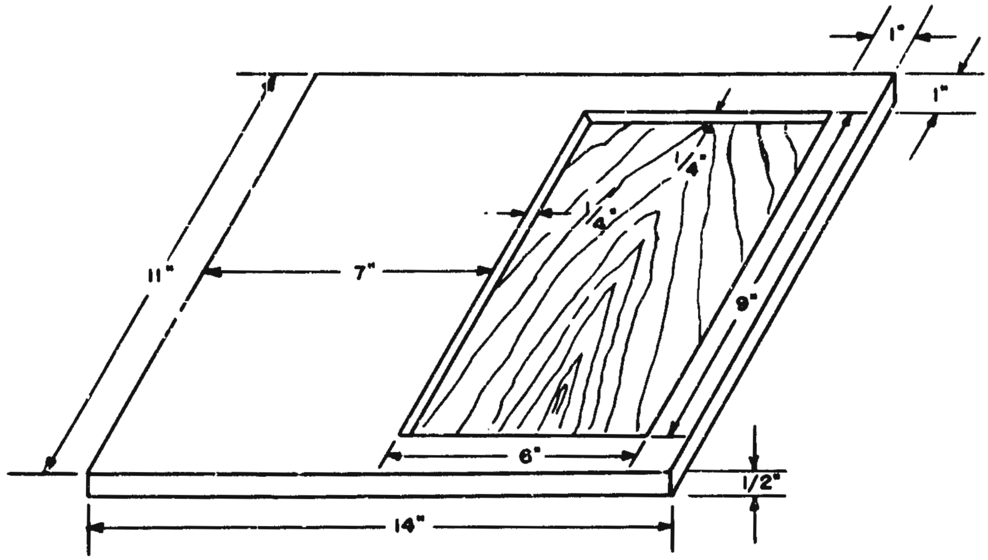


Fig. 1.1 Exposure Panel

The racks and cylinders used in the flaming study have been mentioned (1.3) and are described in more detail in Chapter 5.

Fifteen individual panels were placed in a metal rack designed to permit the fabrics to be positioned perpendicular to the incident radiation. This was accomplished by placing hinges at the point where the upper portion of the rack and the A frame met. By the end of the thermal pulse or on arrival of the blast wave the panel portion was released and descended to a position horizontal with the ground. This was done in order to reduce the destructive action of the blast wave and the abrasive action of the particles carried by the blast wave. The racks were well anchored with metal stakes and guy wires. (Fig. 1.3).

The exposure racks were positioned as close to ground zero as 75.0 cal/cm$^2$ and extended out to 8.7 cal/cm$^2$. Table 1.1 shows the distribution and number of racks at each station.

## 1.5 TEMPERATURE INDICATORS (Paper Thermometers)

While time-temperature curves showing the history of the thermal transfer would have been most desirable, the necessary instrumentation for the use of thermocouples could not be provided due to lack of available circuity for such an operation. In addition, the cost of the large number of multi-channel high speed recorders was almost prohibitive. In view of this, temperature indicators or paper thermometers as developed by the Research and Development Laboratory of the Quartermaster Corps were used. These indicators had been used in previous weapons tests and also in work involving fire bombs.

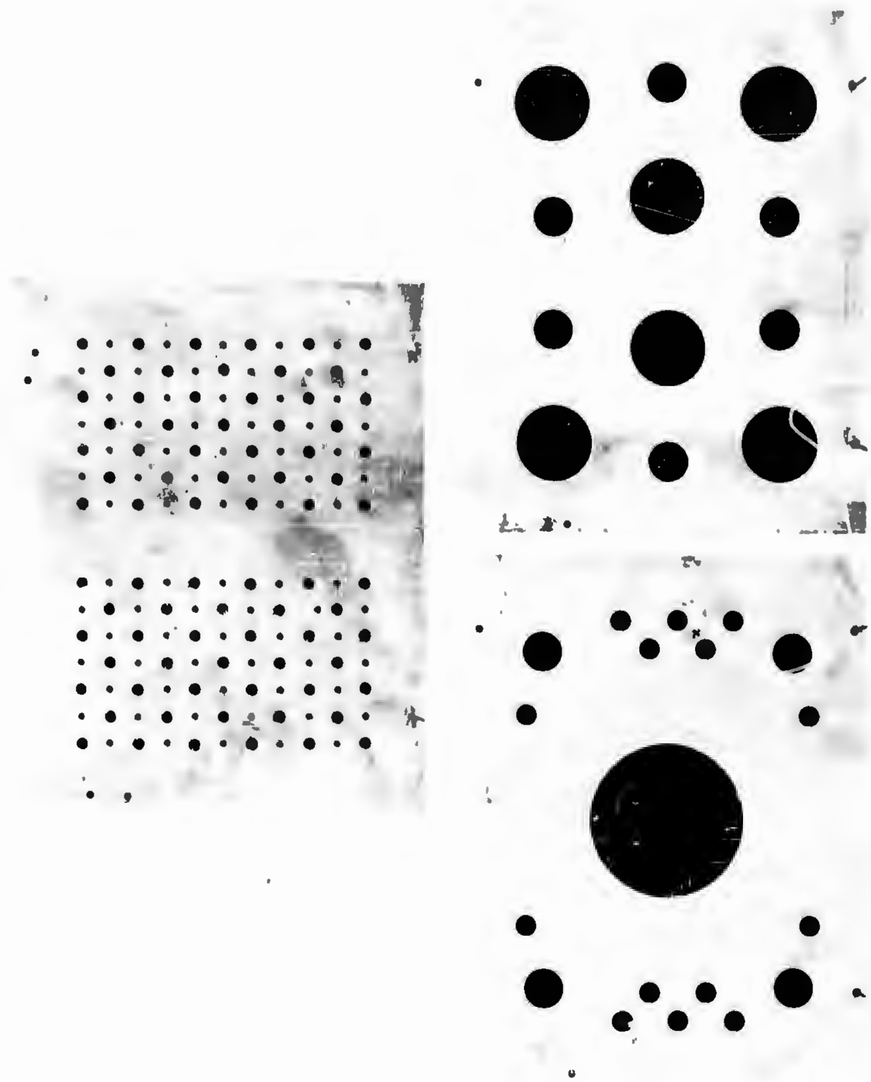

Fig. 1.2 Shields Used in Area Study

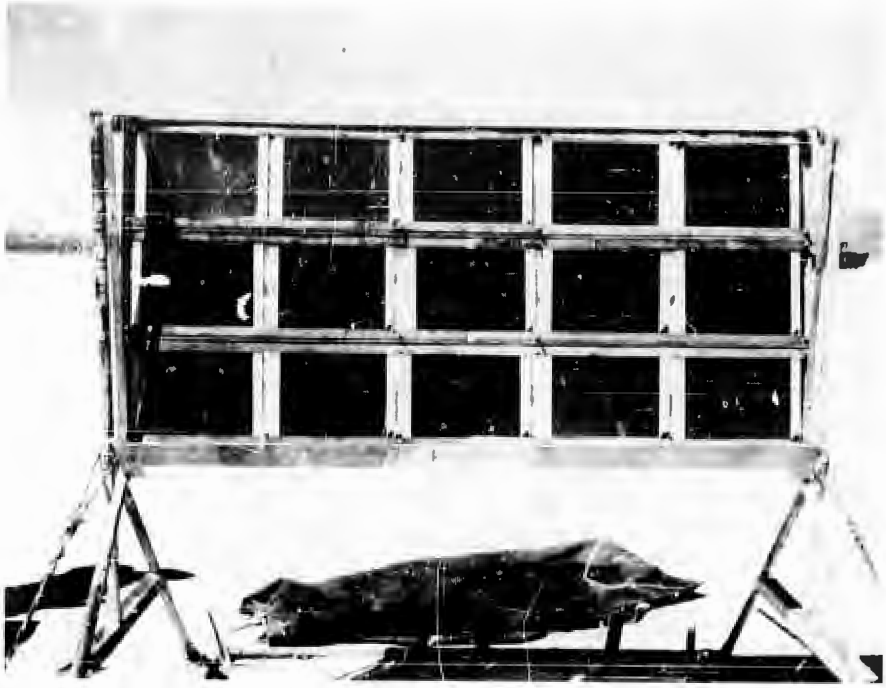

Fig. 1.3 Exposure Rack with Panels

The indicators consisted of a black absorbent paper coated with a thin layer of a suitable pure organic chemical. Each chemical used as a coating has a specific melting point. This coating gives the paper a greyish to white appearance. On melting, the chemical is absorbed by the paper exposing its black color. Thus, when a paper turns black, it is positive proof that the organic coating had attained a temperature at least equal to that of its melting point. The effective temperature and active ingredient of the indicator papers are listed in Table 1.2.

Pieces 1/4 in. x 1 in. of each of the 20 temperature indicators were mounted on very thin transparent, double coated, pressure sensitive tape. These in turn were adhered to the contact and spaced side of the oak veneer panels as shown in Fig. 1.4. In this photograph the 54°C and 62°C indicators on the left or contact side and the 54°C indicator on the right or spaced side have changed. The indicator papers revealed only one fact relative to the thermal energy transferred through the fabric; this fact being that a beneath-fabric temperature equal to at least the melting point of the highest indicator change had been attained.

TABLE 1.1 - Distribution of the Exposure Racks

| Shot | Thermal Energy (cal/cm²) | Uniform Fabrics | Synthetic Wool Blends | Reflectance & Spacing | Area Study | Flammability |
|---|---|---|---|---|---|---|
| 9 | 9.5 | 1 | | | | |
| 10 | 9.0 | | | | | 1 |
| 9 | 12.5 | 1 | | | 1 | |
| 10 | 12.5 | 1 | | | 1 | 2 |
| 9 | 16.0 | 1 | | | 1 | 1 |
| 10 | 17.0 | 1 | 2 | 1 | | 1 |
| 9 | 21.5 | 1 | | | 1 | |
| 10 | 26.0 | 1 | | 1 | | |
| 9 | 29.5 | 1 | | | 1 | |
| 10 | 33.5 | 1 | 2 | | | |
| 9 | 41.0 | 1 | | | 1 | |
| 10 | 40.5 | 1 | 2 | | | |
| 9 | 50.0 | 1 | | | 1 | |
| 10 | 60.0 | 1 | | | | |
| 9 | 75.0 | 1 | | | 1 | |
| Total | | 14 | 6 | 2 | 8 | 5 |

Note: Some racks included panels other than those which are shown as a heading for a rack.

TABLE 1.2 - Temperature Indicators

| | Temp. °C | Compound |
|---|---|---|
| 1. | 54 | Triphenylthiophosphate |
| 2. | 62 | S-Di-n-Butylthiourea |
| 3. | 69 | Stearic Acid |
| 4. | 77 | Sucrose Octaacetate |
| 5. | 85 | n-Diphenylbenzene |
| 6. | 94 | Sorbitol Hexaacetate |
| 7. | 101 | a-Dextrose Pentaacetate |
| 8. | 107 | Dichloro-diphenyl-tetramethyl ethane |
| 9. | 115 | Mannitol Hexaacetate |
| 10. | 121 | Phenyl-p-Tolylsulfone |
| 11. | 127 | Hydroquinone Dibenzyl Ether |
| 12. | 142 | Adipic Acid |
| 13. | 163 | Benzanilide |
| 14. | 172 | S-Di-o-tolythiourea |
| 15. | 196 | p-ethoxybenzoic Acid |
| 16. | 205 | Dicyandiamide |
| 17. | 228 | Hexachlorobenzene |
| 18. | 239 | Carbanilide |
| 19. | 254 | Phenolphthalien |
| 20. | 305 | Theobromine |

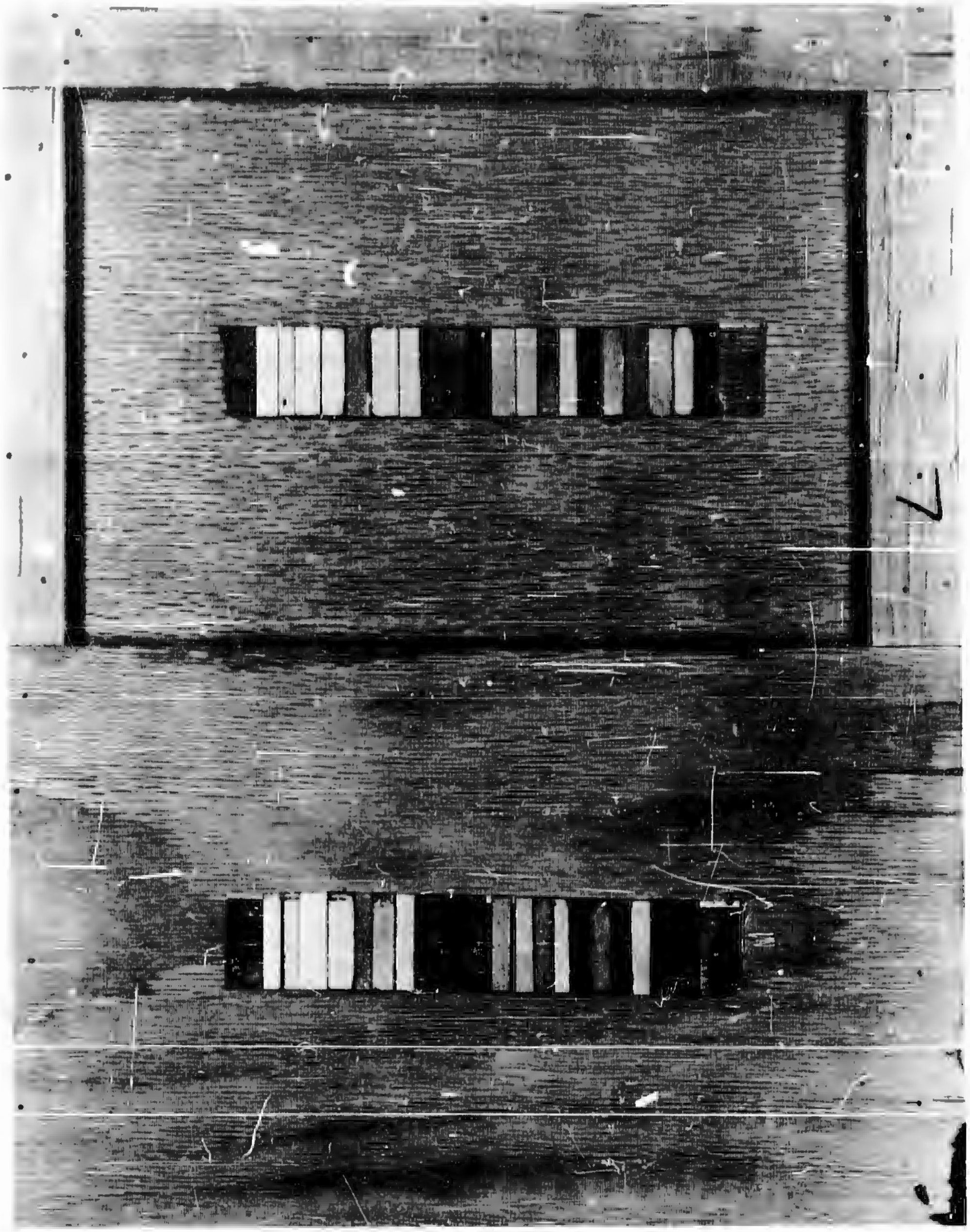

Fig. 1.4 Panel with Temperature Indicators

## CHAPTER 2

## MILITARY CLOTHING ASSEMBLIES

### 2.1 GENERAL

This phase of the investigation, undertaken to provide data on the performance characteristics of complete assemblies and component parts of military clothing, was divided into two sub-phases. The first sub-phase was in effect a supplement to the clothed pig experiment (Project 8.5) and included the same fabric assemblies at the same stations as used for the clothed animals. The second portion of the test included other military clothing items. These latter materials were not exposed in the pig experiment. An experimental aluminized duck fabric was also included in the second sub-phase. All the specimens were exposed to the thermal effects of nuclear detonations in the form of test panels with temperature indicators beneath the materials as described in Chapter 1.

The specimens were positioned at distances from ground zero corresponding to estimates of the maximum energy levels against which they would provide protection. These estimates were based on laboratory data obtained by the University of Rochester.(4) Other specimens were exposed at the next nearer and next farther stations. In addition, some exposures were made to study certain effects manifested at energy levels lower than those found to be critical from the protection standpoint. Some of the uniform assemblies, for example, were exposed at the more distant stations to observe their tendency to glow or flame, although they were known to perform satisfactorily close to ground zero. Table 2.1 summarizes the uniform panel exposures for both shots. As indicated previously the purpose of the panel exposure of uniform assemblies was to provide data, especially on beneath-fabric temperatures, that might be associated with burns sustained by the pigs (Project 8.5) exposed at the same time to the same conditions wearing the same fabric combinations.

### 2.2 UNIFORM FABRIC ASSEMBLIES

#### 2.2.1 Experiment Design

Five different assemblies of fabrics were exposed to the thermal effects of nuclear explosions on Shots 9 and 10. The energy levels to which they were subjected varied from 9.0 to 75.0 cal/cm$^2$, as indicated

TABLE 2.1 - Summary of Uniform Fabric Panel Exposures

| Energy (cal/cm$^2$) | 75.0 | 60.0* | 50.0 | 40.5* | 41.0 | 33.5* | 29.5 | 26.0* | 21.5 | 17.0* | 16.0* | 12.5* | 12.5 | 9.5 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Assembly | | | | | | | | | | | | | | | |
| HW | | | | | | | | 2 | 3 | 2 | 3 | 2 | 3 | 3 | 18 |
| HWFR | | | | | | | | 1 | 3 | 2 | 3 | 1 | 3 | 3 | 16 |
| HW 50/50 | | 2 | | 2 | | 2 | 2 | 2 | 3 | 2 | 3 | | 3 | 3 | 24 |
| HWFR 50/50 | | 1 | | 1 | | 2 | | 2 | | 2 | | 2 | | | 10 |
| Temperate | 4 | | 4 | | 5 | | 5 | 2 | | 2 | | 2 | | | 24 |

*Shot 10 (all others Shot 9)

in Table 2.1. The five assemblies included the fabrics composing the Hot-Wet uniform with cotton underwear; the Hot-Wet (HW) uniform with 50 per cent wool/50 per cent cotton underwear (HW 50/50); each of these combinations with the outer layer treated with a fire retardant (HWFR and HWFR 50/50); and the Temperate uniform (T) which was not treated for fire resistance. This latter uniform assembly is the same as the standard Cold-Wet, but without the frieze liner.

The fabrics composing each of these uniform assemblies are as follows, starting in each case from the outer layer:

1. Hot-Wet (HW)
   a. Cloth, Cotton, Permeable, 5.2 oz, Shade 116
   b. Cloth, Cotton, Knit, 3.5 oz
2. Hot-Wet 50/50 (HW 50/50)
   a. Cloth, Cotton, Permeable, 5.2 oz, Shade 116
   b. Cloth, 50% wool/50% cotton, Knit, 10.5 oz
3. Hot-Wet, Fire Resistant (HWFR)
   a. Cloth, Cotton, Permeable, 5.2 oz, Shade 116 Fire Resistant Treated
   b. Cloth, Cotton, Knit, 3.5 oz
4. Hot-Wet, 50/50, Fire Resistant (HWFR 50/50 FR)
   a. Cloth, Cotton, Permeable, 5.2 oz, Shade 116, Fire Resistant Treated
   b. Cloth, 50% wool/50% cotton, Knit, 10.5 oz
5. Temperate (T)
   a. Cloth, Cotton, Wind Resistant, Sateen, 9 oz, Water Repellent, OG107
   b. Cloth, Cotton, Wind Resistant, Oxford, 5.5 oz, Water Repellent, OG107

c. Cloth, 85% wool/15% nylon, Shirting, 16 oz, OG108

d. Cloth, 50% wool/50% cotton, Knit, 10.5 oz

### 2.2.2 Results

#### 2.2.2.1 Temperatures Attained Beneath Fabrics

The temperatures beneath the various fabric assemblies as recorded by the passive indicators are shown in Table 2.2. These are averages of the temperatures under the two or three replicate specimens of each assembly exposed at each location. As can be seen in Appendix Table A.1 the variation among the replicate specimens in most cases was not very great.

The results of these tests may be summarized as follows:

(1) Based on T-Max, beneath-fabric temperatures, it may be seen from the data in Table 2.2 that the four layer Temperate uniform assembly was superior to the Hot-Wet 50/50, with the Hot-Wet 50/50 being much better than the Hot-Wet. Roughly, the order of magnitude for the beneath-fabric temperatures in contact with the backing was 54°C or less for the Temperate, 127° - 142°C for the Hot-Wet 50/50 and 205° - 254°C for the Hot-Wet.

(2) In 24 out of 27 cases, involving HW, HWFR, HW 50/50 and HWFR 50/50, both in contact and spaced from the backing, significantly lower temperatures were recorded on the spaced side of the panels as against the contact; these temperature differentials being of the order of 11° to 127°C. Maximum contact and spaced temperature differences were noted for those assemblies where the highest contact temperatures were observed, that is for the lighter weight fabric combinations. The lighter in weight a fabric assembly the greater appeared to be the effect of spacing. The four layers of the Temperate combination offered such a high degree of protection (maintaining the beneath-fabric temperatures at a very low level) that essentially no differences were observed for conditions of contact and spaced. Where slight differences were noted these were in favor of the spaced fabrics.

(3) For 12 cases of fire resistant treated fabrics (HWFR and HWFR 50/50) in no single instant was the beneath-fabric temperature as high for the spaced portion as for the contact portion.

(4) The non-fire resistant fabrics versus the fire resistant treated fabrics performed about the same in contact with respect to beneath-fabric temperatures. However, when these fabrics were spaced away from the backing the superiority of the fire-resistant treated fabrics was indicated. Out of a total of 10 cases one was equal, 2 were somewhat poorer, and 7 were found to be markedly better than the non-fire resistant fabrics.

(5) From the nearest to the most distant station the quantity of thermal radiation received did not influence to a marked degree the temperatures recorded beneath any one fabric combination. Some gradual decline in the temperature could be noted with distance from ground zero, but it was not commensurate with the decline in thermal energy received.

#### 2.2.2.2 Visual Evidence of Fabric Damage

Comparison of the appearance of the exposed samples as an indication of relative thermal damage was in virtually all cases limited to the second layer of each assembly, since the top layers were destroyed in over 90 per cent of the test specimens.

For the purpose of comparison damage to the second layer has been arbitrarily divided into five categories as determined visually from "slight scorch" to "destroyed." (Fig. 2.1.) The least damage was sustained by the second layer of the temperate assemblies except for those exposed at the most distant station (12.5 cal/cm$^2$) which will be discussed below. The most severely damaged fabrics were those of the Hot-Wet assemblies, both with and without fire resistant treatment, while those of the Hot-Wet 50/50 assemblies were intermediate in extent of damage.

Also as expected, the panel fabrics exposed at the nearest stations usually sustained somewhat more damage than those at the farther stations. However, the extent of fabric damage at the close-in stations was not in proportion to the increased thermal energy of the exposure. In the third and fourth layers of the Temperate assemblies it is noteworthy that the trend of slightly more damage at the stations nearer to ground zero was reversed. These layers were undamaged at 75.0 and 50.0 cal/cm$^2$ but at 41.0 cal/cm$^2$ and less the third layer was scroched and discolored and the fourth yellowed.

Of special interest is the damage sustained by the temperate ensemble exposed at the farthest station on Shot 10 (12.5 cal/cm$^2$). This assembly was expected to be spared any severe damage. Instead, the outer layer of sateen was destroyed (although some char remained) and the second layer of oxford was heavily scorched on the contact side of the panel and heavily charred, with glow holes, on the spaced side. Under the spaced portion of the specimen there was charring in the third and fourth layers beneath the glow holes in the second layer.

A change in color on the wood backing was noted on the temperate panles at the very nearest station. Those behind the Hot-Wet and, to a much lesser extent, behind the Hot-Wet 50/50 assemblies (untreated) showed a green color. This green stain also appeared on the underwear layer of the HW 50/50 ensembles. A deep brown stain, quite different in appearance from the brown discoloration noted above, appeared consistently on the backing and underwear layers of the fire resistant treated assemblies. The fact that green and brown stains appeared on the surface of the wood backing was evidence that hot gases from the decomposition of the outer layers penetrated through the fabric system.

### 2.2.3 Discussion

#### 2.2.3.1 Effect of Fabric Assembly Weight on Beneath-Fabric Temperatures

The relative protection afforded by the various uniform fabric assemblies as indicated by their beneath-fabric temperatures appears to be a function of their weight, the heaviest (Temperate) giving the most protection and the lightest (Hot-Wet) giving the least. When the total weight (ounces per square yard) of each assembly is computed and plotted

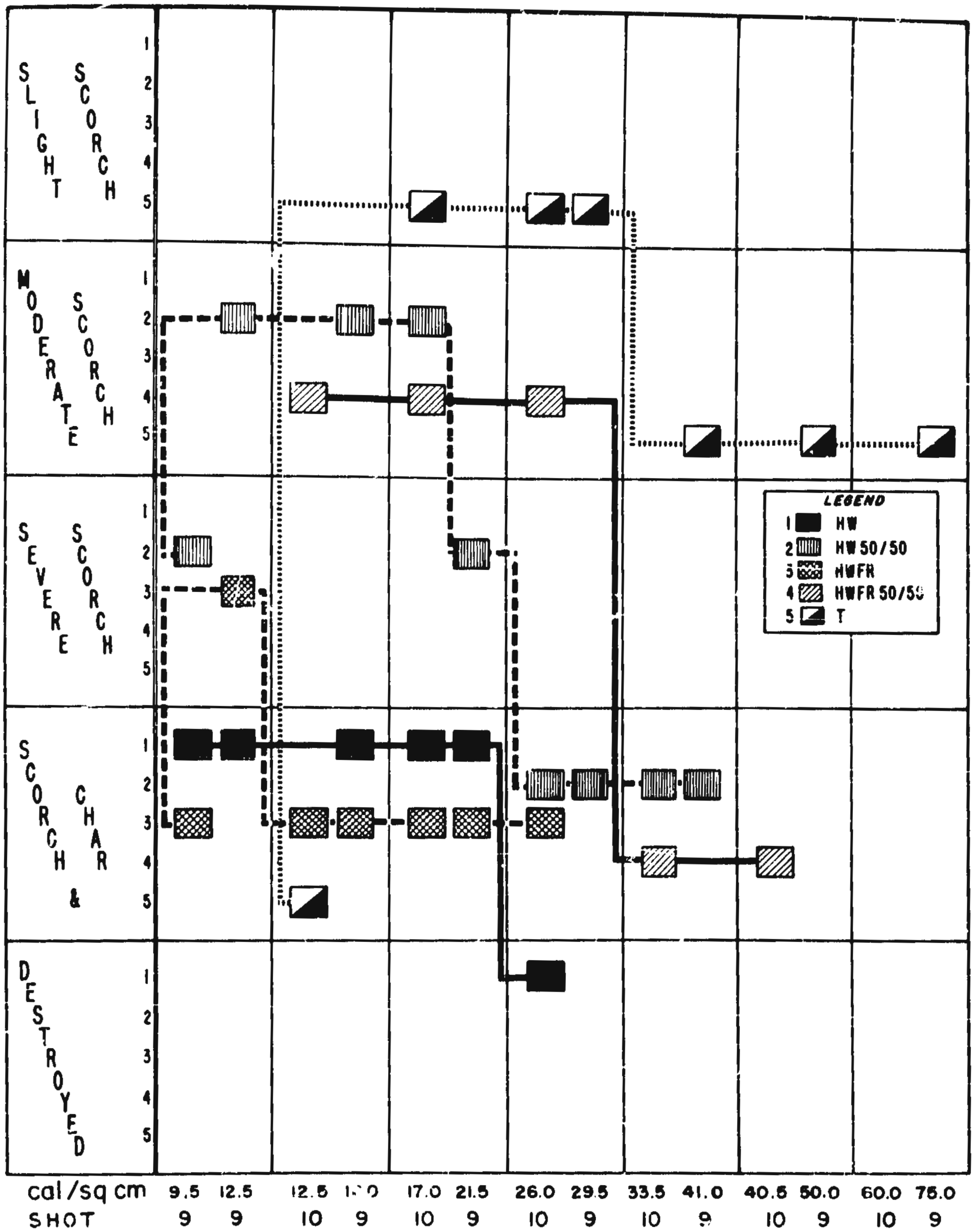


Fig. 2.1 Visual Evidence of Damage Sustained by Second Layers of Hot-Wet and Temperate Assemblies

against the average maximum beneath-fabric temperature for all exposure stations the curves shown in Fig. 2.2 are obtained for contact and spaced temperatures and averages of the two.* It will be noted that all the points (except for the combination of sateen and heavy cotton underwear which will be discussed in 2.4) fall reasonably close to the curve, representing a decline in beneath-fabric temperature with an increase in weight.

2.2.3.2 <u>Effect of Fire Resistant Treatment on Temperature Data</u>

As stated in paragraph 2.2.2.1 the beneath-fabric contact temperatures were about the same for the fire resistant and non-fire resistant fabrics. However, when the fabrics were spaced away from the backing the superiority of the fire resistant treated fabrics was indicated. There are several mechanisms that may play a role in either increasing or decreasing thermal transfer through fire resistant treated fabrics as compared to untreated. The most important of these from a practical standpoint is that the treated materials do not support a continuing flame or glow. Especially for fabrics in close skin contact, such flaming or glowing can cause a severe burn as shown in many of the pigs in Project 8.5 [5] that wore untreated uniforms.

In addition, the fire resistant treatment adds to the weight of the fabric. In computing the total weights of the fire resistant assemblies in Fig. 2.2, approximately 25 per cent was added in each case to the outer layer of the corresponding untreated assembly.** When the spaced and contact temperatures are averaged, the HWFR has some advantages over the HW and the HWFR 50/50 over the HW 50/50. This advantage may in some degree be due to the additional weight, but this appears to be a relatively unimportant factor, since the additional protection found in many cases was much more than could be accounted for for by the extra weight alone.

More important is a mechanism that might work to the disadvantage of the fire resistant treated fabrics. This is that a fire resistant treatment increases the rate at which gases and tars are evolved from the decomposing fabrics.[6] This fact has been advanced to explain laboratory indications that a fabric in contact with a backing transmits more heat to that backing if the fabric is fire resistant treated than if it is untreated. It is hypothesized that, with more gases and tars being evolved, there is a greater chance that some of these may not escape but go into the fabric where their heat would be made more readily available to the backing. The dark brown coloration noted on the contact side of the wood backing under the

*To the data obtained on the full uniform fabric assemblies have been added, in Fig. 2.2, the data obtained similarly for two-fabric combinations of sateen with three different underwear fabrics, 3.5 and 10-oz cotton, and 10.5-oz 50/50 wool/cotton. These will be discussed in 2.4.

**The weight add-on of the brominated triallyl phosphate treatment used in these tests is approximately 25 per cent.

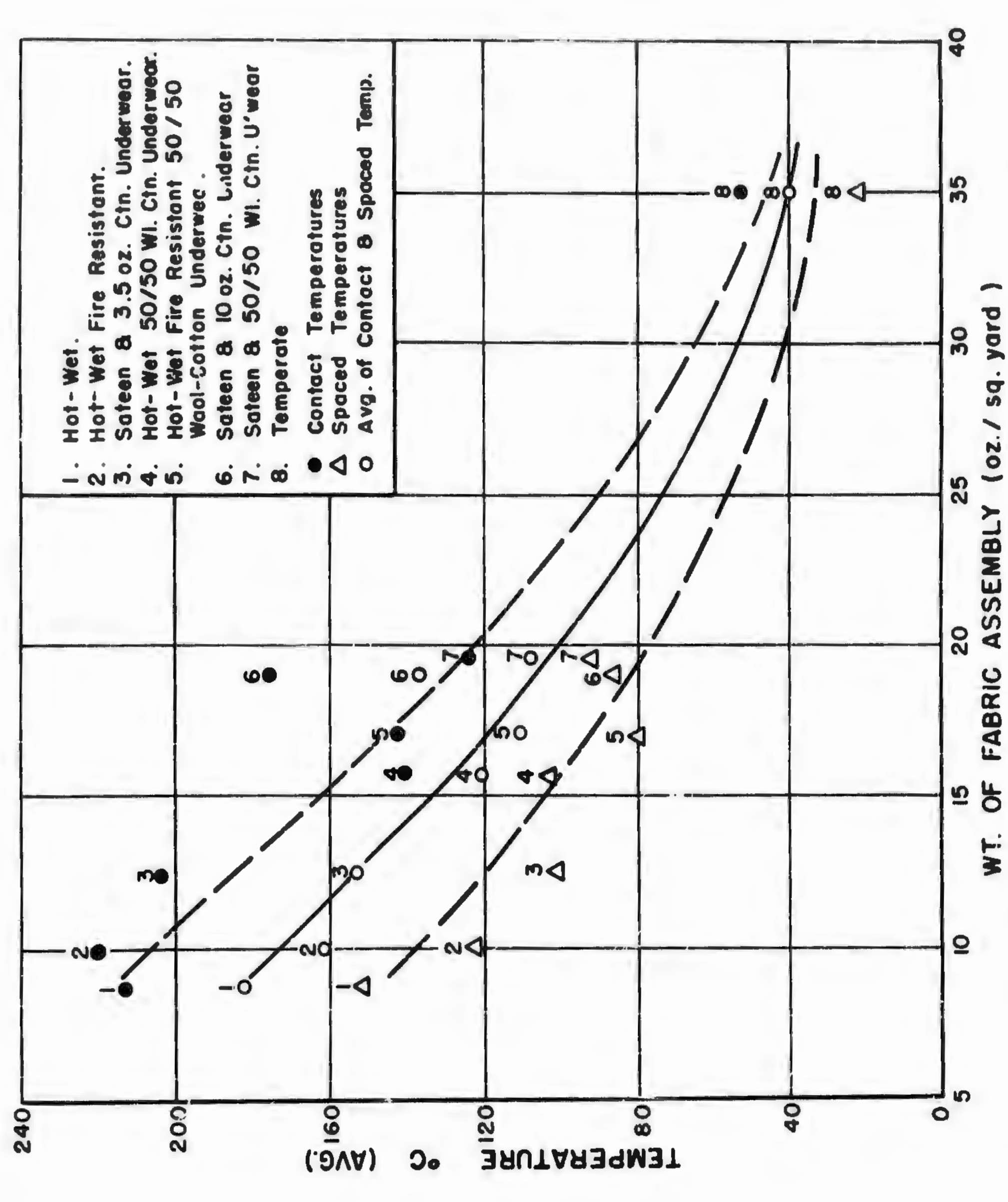


Fig. 2.2 Effect of Weight of Clothing Assemblies on Beneath-Fabric Temperatures

treated fabric panels is evidence that these tars condensed on the backing, raising the temperature by releasing their heat of vaporization.

2.2.3.3 Effect of Spacing on Temperature Data

Figure 2.2 shows that the average contact temperatures were consistently higher than the spaced temperatures. This is easy to understand, since the air space between fabrics and backing acts as an effective insulating layer.

Spacing has emerged from this and other studies on the subject as an extremely important consideration. It is especially true with fire resistant clothing that the degree of protection afforded is to a large extent dependent upon whether or not the garment is loose or tight fitting. Referring again to Fig. 2.2, the average contact temperatures are slightly higher for the fire resistant treated assemblies than for the corresponding untreated assemblies. The average spaced temperatures, on the other hand, are much lower for the treated fabric assemblies than for their untreated counterparts.

2.2.3.4 Effect of Thermal Energy Received on Temperature Data

All other things being equal, it is reasonable to assume that the samples exposed nearest ground zero (those exposed to the most intense thermal radiation) would develop the highest beneath-fabric temperatures. Generally it can be said that the temperatures beneath the assemblies exposed at the close stations were slightly higher than beneath like assemblies exposed at the far stations. By no means, however, was there anything approaching a straight-line relationship between energy and temperatures. Table 2.2 shows that in many instances the same assembly showed no change in beneath-fabric temperatures for several successive exposure stations.

In other cases, particularly for the HW 50/50 combinations, a plot of maximum temperatures versus energy would result in a U-shaped curve, with the highest temperatures recorded at the extremely near and far stations and the lowest temperatures at the intermediate stations. Such behavior has been noted in laboratory work, and has been explained by less extensive destruction at lower energy levels, allowing more fabric to remain and act as a heat reservoir transferring its energy through the system. At intermediate levels the energy may be sufficient to destroy the fabric and thus remove this heat reservoir. At the highest levels the energy may be more than sufficient for complete destruction of the outer layer and the energy in excess of that required for such destruction may be absorbed by the under layers. These fabrics in turn may act as a heat reservoir, thus further raising the temperature beneath them.

The failure of the reciprocity law to hold in the case of radiant exposure versus beneath-fabric temperature and total fabric destroyed is worth considering. At the close-in stations where the thermal energy was extremely high (being of the order of 75.0 $cal/cm^2$) it was expected that total fabric damage, in terms of the number of layers destroyed, would be considerable and that beneath-fabric temperatures would be much higher than at the more distant stations. As stated

TABLE 2.2 -- Average Maximum Temperatures Attained (Deg C) Under Fabric Assemblies

| Fabric Assembly | Shot 9 Thermal Energy (cal/cm²) 75.0 | | 50.0 | | 41.0 | | 29.5 | | 21.5 | | 16.0 | | 12.5 | | 9.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | S | C | S | C | S | C | S | C | S | C | S | C | S | C | S |
| HW | | | | | | | | | 205 | 121 | 205 | 94 | 205 | 107 | 205 | 205 |
| HW 50/50 | | | | | | | 142 | 115 | 142 | 77 | 119 | 77 | 115 | 77 | 163 | 77 |
| HWFR | | | | | | | | | 205 | 121 | 205 | 121 | 205 | 130 | 205 | 121 |
| T | 54 | 54 | 54 | 54 | 54 | 54 | 54 | 54 | | | | | | | | |

| Fabric Assembly | Shot 10 Thermal Energy (cal/cm²) 40.5 | | 33.5 | | 26.0 | | 17.0 | | 12.5 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | C | S | C | S | C | S | C | S | C | S | |
| HW | | | | | 254 | 254 | 172 | 127 | | | |
| HW 50/50 | 142 | 142 | 142 | 131 | 142 | 107 | 121 | 85 | | | |
| HWFR | | | | | 254 | 127 | 205 | 121 | 205 | 121 | |
| HWFR 50/50 | 142 | 94 | 142 | 77 | 121 | 77 | 127 | 77 | 127 | 77 | |
| | | | | | 54 | 54 | 54 | 54 | 54 | 54 | |

C = Contact
S = Spaced

previously, for a given assembly, neither fabric damage nor backing temperatures were commensurate with increased energy. There are a number of factors which may contribute to this phenomenon; delivery time of the thermal pulse; obscuration of the full primary thermal effect by smoke arising from the test fabric or surrounding samples; and blast arrival time.

2.2.3.5 Comparison of Panel Data with Results on Clothed Pigs (Project 8.5)

Comparison of the results of this phase of the panel studies with those observed for the clothed pig experiment (Project 8.5) shows that a parallelism exists for the two sets of data. While it is not possible, because of limited data, to establish a correlation between the two experiments the over-all trends appear to bear a close relationship. The relative protective value of the various fabric assemblies was found to be the same in the panel study as in the animal study; the Temperate being best, the Hot-Wet worst, and the Hot-Wet 50/50 intermediate but much better than the Hot-Wet.

When the results of the panel tests are compared with those on the uniformed pigs some light is thrown on the mechanism whereby the pigs were burned.

For example, some severe burns were noted on pigs wearing fire resistant uniforms where the fabric was in close contact with the skin. The dark brown stain on the contact side of the panels with the fire resistant assemblies was evidence that these pig burns might have been caused in part by condensation of gases and tars which are known to be evolved at a faster rate when the fire retardant is present.

The advantage of the fire resistant treatment was indicated in both studies in that high temperatures under the panels and severe burns on the pigs often occurred on the untreated assemblies at the far stations. That high temperatures and severe burns were noted at the far stations suggests that flaming or glowing of non-fire resistant fabrics was more serious because it was given greater opportunity to proceed before the decomposing fabric was removed by the arrival of the blast wave.

The consistently higher temperatures on the contact sides of the panels than on the spaced sides help explain why more severe burns were encountered in areas such as those adjacent to the drawstring where the fabric was held tightly against the skin. Both studies pointed to the importance of spacing from the standpoint of thermal protection, especially where fire resistant fabrics were involved.

A correlation of panel temperature data with the over-all burn injury to the animals is not warranted. The data, however, do show a broad association between the panel temperatures and animal injury. In the following discussion the maximum temperatures and most severe large area burns on the pigs were considered.

Beneath-fabric temperatures, of assemblies corresponding to those worn by the pigs, were divided into three broad ranges. These were: (1) less than 100°C, (2) 101 to 200°C, and (3) over 201°C. Each of 36 animals (where comparisons could be made) were then listed as to major burn type. The fabric panel temperature was then listed next to its animal counterpart. This sort of tabulation showed that of the 36 animals 24 had 2+ burns,* 9 had 1+, and 3 had no burns. It also showed that of the 24 with 2+ burns 21 matched up with panels indicating backing temperatures over 201°C. Nine of those with 1+ burns fell into the 101° to 200°C range (more specifically a range of 101 to 150°C), and 1 of the 3 with no burns was in the less than 100°C range (Table 2.3).

For the conditions of this particular test the data indicate that for a 2+ pig burn a beneath-fabric panel temperature of over 200°C had to be attained. Temperatures of 100 to 150°C were indicative of 1+ burns.

TABLE 2.3 - Association of Panel Temperature and Animal Burn

| Panels | Clothed Pigs | | | |
|---|---|---|---|---|
| Beneath-Fabric Temp. Range °C | Burn Type | | | |
| | 0 | 1+ | 2+ | |
| 100 | 1 | | | |
| 101-200 | 1 | 9* | 3 | |
| 201 | 1 | | 21 | |
| Total | 3 | 9 | 24 | 36 |

*Actually these 9 were between 101 and 150°C.

It is believed that one is not justified in attempting to extrapolate the observed relationship (between panel data and pig burns) beyond the conditions of this test. It should be remembered that panel temperatures are not necessarily the same as the animal skin temperature. Beneath-fabric temperatures of 200°C and over were observed only for the HW and HWFR assemblies; 100° to 150°C for the HW 50/50 and HWFR 50/50; and below 100°C for the Temperate. Inasmuch as heavier fabric assemblies, such as the four layer temperate, would act as better heat reservoirs than two thin fabric layers, it is reasonable to believe that 2+ burns might be sustained for this uniform at beneath-fabric temperatures of less than 200°C. The time element as well as T-max must be taken into consideration.

The results of panel temperatures versus pig burns indicate that for a fixed set of conditions of humidity, ambient temperature, fabric assembly, rate of delivery, and total thermal energy a correlation between T-max, inanimate backing, and pig burn might be established.

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* 0 - No burn
1+ - Erythema (persistent reddening)
2+ - Patchy coagulation (spotty whiteness). (For more detailed description of burn rating see Project 8.5)

2.3 MILITARY CLOTHING ITEMS (Other than those in the Clothed Animal Experiment, Project 8.5)

2.3.1 Experiment Design, General

Four different cold weather assemblies, three types of underwear fabrics, two boot materials, body armor, rainwear, and aluminized duck were exposed on Shots 9 and 10 as indicated in Table 2.4.

2.3.2 Cold Weather Uniform Fabric Assemblies

2.3.2.1 Experiment Design

Four different cold weather assemblies, three standard, and one experimental, were exposed on Shot 9 at 75.0, 50.0, and 41.0 cal/cm$^2$ stations. The three standard Quartermaster fabric assemblies included two Cold-Dry assemblies (one with parka over-white and one without) and the Cold-Wet ensemble. The fourth assembly consisted of the materials comprising the experimental Coldbar suit.

1. The conventional Cold-Dry uniform with parka consists of the following fabrics listed in the order in which they are worn and in which they were exposed. From the outer to the inner layer these are:

a. Cloth, Cotton Warp, Nylon Filling, 5.5 oz, Water Repellent, White.
b. Cloth, Cotton Warp, Nylon Filling, 5.5 oz, Water Repellent, OG 107.
c. Cloth, Mohair, Frieze, 16 oz, White.
d. Cloth, Rayon, Acetate, Saponified, Rip-Stop, 1.9 oz, OG 106.
e. Cloth, Cotton, Wind Resistant, Sateen, 9 oz, Water Repellent, OG 107.
f. Cloth, Cotton, Wind Resistant, Oxford, 5.5 oz, Water Repellent, OG 107.
g. Cloth, Mohair, Frieze, 16 oz, White.
h. Cloth, Rayon Acetate, Saponified, Rip-Stop, 1.9 oz, OG 106.
i. Cloth, 85% Wool/15% Nylon, Shirting, 16 oz, OG 108.
j. Cloth, 50% Wool/50% Cotton, Knit, 10.5 oz.

2. The same assembly as above was also exposed without layer a, which represents the parka over-white.

3. The Cold-Wet assembly consisted of the same fabrics as 1, but without layers a, b, c, and d.

4. The Coldbar assembly consisted of the following:

a. Cloth, Cotton, Wind Resistant, Sateen, 9 oz, Water Repellent, OG 107.
b. Expanded Vinyl-Synthetic Rubber Compound.

All these cold weather assemblies were exposed on Shot 9, the Cold-Dry with parka to 75.0 cal/cm$^2$, and the Cold-Wet to 41.0, 50.0, and 75.0 cal/cm$^2$.

TABLE 2.4 -- Summary of Fabric Panel Exposures

| Energy (cal/cm$^2$) | 75.0 | 60.0* | 50.0 | 41.0 | 40.5* | 33.5* | 29.5 | 26* | 21.5 | 17.0* | 16.0 | 12.5* | 12.5 | 9.5 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cold-Wet | 5 | | 5 | 5 | | | | | | | | | | |
| Cold-Dry | 2 | | | | | | | | | | | | | |
| Cold-Dry with Parka Over-White | 2 | | | | | | | | | | | | | |
| Cold B[illegible] | 2 | | 2 | | | | | | | | | | | |
| Temperate with Cotton Underwear | | | | 2 | | | 2 | | 2 | | | | | |
| Body Armor, USA | | 2 | 2 | | | | | | | | | | | |
| Body Armor, USMC | | 2 | 2 | | | | | | | | | | | |
| Sateen over Light Cotton Underwear | | | | | | | | | | | 2 | | 2 | 2 |
| Sateen over Heavy Cotton Underwear | | | | | | | | | | | 2 | | 2 | 2 |
| Sateen over 50/50 Wool/ Cotton Underwear | | | | | | | 2 | | 2 | | 2 | | 2 | 2 |
| Leather | 2 | | 2 | 2 | | | | | | | | | | |
| Insulated Boot | 2 | | 2 | 2 | | | | | | | | | | |
| Aluminized Duck | | | | 2 | 2 | | 1 | | 1 | | | | | |

* Shot 10 - All others Shot 9.

2.3.2.2 Results and Discussion

The two Cold-Dry uniforms (with and without parka) survived the thermal pulse with about the same type and extent of damage. The cotton-nylon layer was destroyed and along with it, the white parka fabric where this was included in the assembly. Heavy scorching and charring on the upper pile surface of the frieze was noted, and the acetate ripstop layer of the outer liner was discolored. The layers beneath this lining fabric were undamaged. None of the temperature indicators under these assemblies changed, indicating complete protection (i.e., temperatures below 54°C) at energies as high as 75.0 cal/cm$^2$.

In the Cold-Wet assembly, which was exposed at 75.0, 50.0, and 41.0 cal/cm$^2$, the most severe damage occurred at the farthest of these three stations. Here, the sateen was destroyed, the oxford heavily scorched with light char in some areas, the pile of the frieze was heavily scorched, and the acetate ripstop fabric discolored. At the nearer stations (50.0 and 75.0 cal/cm$^2$) the sateen was likewise destroyed, but the oxford only heavily scorched, and the frieze undamaged except for a marked discoloration. Below the frieze there was no damage. The appearance of small glow holes on the oxford and upper pile of the frieze gave a clue as to the reason for the more extensive damage at the farther station. It is believed to be an action similar to the phenomenon noted in connection with the Hot-Wet assemblies (untreated) where an exothermic reaction (in the case of the Cold-Wet assembly, glowing) proceeds for an appreciable period of time before it is extinguished. In spite of the damage to the outer layer, none of the temperature indicators under the Cold-Wet assemblies changed, indicating good thermal protection up to 75.0 cal/cm$^2$.

In the Coldbar assembly the outer sateen layer was destroyed as in the case of the other cold weather assemblies. There was a heavy surface char on the expanded plastic layer, but the depth of the char was not very great. Temperatures under the Coldbar assembly were 107°C on the contact side and from 62.0 to 107°C on the spaced side of the panels. Thus, the thermal protection afforded by this combination of materials would probably be in the range of that provided by the Temperate ensemble (see 2.2). The Coldbar assembly, however, was not as effective as the Cold-Dry or Cold-Wet fabric combinations. Since only very slight burns were noted on pigs wearing the Temperate assembly in Project 8.5, it is reasonable to believe that the Coldbar uniform would provide adequate thermal protection to well within the lethal nuclear radiation zone.

2.3.3 Underwear Fabrics

2.3.3.1 Experiment Design

Three different types of underwear fabrics were exposed on Shot 9, each under a layer of Cloth, Cotton, Wind Resistant, Sateen, 9 oz, OG 107. The fabrics, which were exposed to 9.0, 12.5, and 16.0 cal/cm$^2$, were as follows:

1. Cloth, 50% Wool/50% Cotton, Knit, 10.5 oz.
2. Cloth, Cotton, Knit, 3.5 oz, ("T" shirt material).
3. Cloth, Cotton, Knit, 10 oz.

2.3.3.2 Results and Discussion

In all these panels the outer layer of sateen was destroyed, and the underwear fabrics scorched to various degrees. The samples exposed to 12.5 cal/cm$^2$ of radiation showed evidence of glowing in the outer layer, as a result of which the fabrics beneath were charred.

In general, damage to the wool/cotton fabric was less than that of the heavy cotton, despite the similarity of their weights. This heavy cotton fabric showed less damage than the light cotton, as expected. The temperature data shown in Table 2.5 likewise show that best thermal protection was provided by the wool/cotton fabric. The difference in beneath-fabric temperatures for the two knit cotton fabrics was not as great as might have been expected on the basis of fabric weight. Differences beneath the contact and spaced temperatures were less for the wool/cotton samples than for the all-cotton samples. This phenomenon of more pronounced effect of spacing for light weight fabrics and fabric assemblies of poorer heat insulative value was also observed in the case of the HW and HW 50/50 assemblies (see section 2.2.2.1).

The additional protective value observed for 50 per cent wool/50 per cent cotton admixture as against a like fabric of 100 per cent cotton, while significant, is not fully understood at this time. That the addition of wool enhances the thermal protective value of cotton fabrics has been shown not only in these exposures, but also in previous tests with other flame and thermal weapons. The fact that wool does not flame as readily as cotton, the admixture of less flammable gaseous decomposition products of wool with those of cotton, and the formation of a protective wool char may contribute to the better thermal insulative properties of the 50/50 wool-cotton mixture. This characteristic of wool-cotton blends is under study as part of an investigation being conducted at Rhode Island University on the decomposition products of thermally degraded fabrics.

TABLE 2.5 - Average Maximum Temperatures (Deg. C)
Attained on Underwear Fabric Panels

| | Energy (cal/cm$^2$) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 29.5 | | 21.5 | | 16.0 | | 12.5 | | 9.5 | |
| | C | S | C | S | C | S | C | S | C | S |
| Lightweight Cotton | | | | | 205 | 111 | 205 | 101 | 205 | 98 |
| Heavy Cotton | | | | | 169 | 105 | 230* | 110* | 118 | 94 |
| 50/50 Wool/Cotton | 142 | 101 | 113 | 85 | 99 | 85 | 99 | 77 | 124 | 94 |

*Underwear layer shows much evidence of glow.

Fig. 2.3 Leather Panel After Exposure to 50.0 cal/$cm^2$

### 2.3.4 Boot Materials

#### 2.3.4.1 Experiment Design

Two boot materials were exposed on Shot 9 to radiant energies of 41.0, 50.0, and 75.0 cal/$cm^2$. These were the upper from the Boot, Combat, Leather, and the upper from the Boot, Combat, Rubber, Insulated. Each was exposed over the rib-knit wool fabric which is used for the leg portion of the Sock, Wool, Cushion Sole. Samples were exposed on panels in contact with the wood backing. For these materials it was unnecessary to make any exposures spaced away from the backing since boots and shoes, unlike clothing, are for the most part close fitting.

#### 2.3.4.2 Results and Discussion

Two replicates of the leather exposed to 41.0 cal/$cm^2$ were recovered. Both were heavily scorched, charred, and shrunk by the heat. One of the samples which became detached from the backing on three sides, showed a temperature of over 205°C. The other sample, which remained firmly attached to the panel, showed a backing temperature of 62°C. At the two nearer stations only one replicate of the leather at each station was recovered. The one exposed at 50.0 cal/$cm^2$ was almost completely destroyed by glow, the remaining portions under the protecting wood frame being severely charred, as shown in Fig. 2.3. At 75.0 cal/$cm^2$ the leather was heavily charred, but it protected the sock fabric beneath it from any damage whatsoever. The temperature recorded beneath this sample was 62°C. Samples of the insulated boot material were recovered only from the 41.0 cal/$cm^2$ station. The surface of the samples was wrinkled and roughened by the thermal effects. The temperature beneath the samples was 54°C.

The scope of this test was too limited to permit any definite statements to be made, but the indications are that both the leather and the rubber in conjunction with the sock wool cushion sole provide fair protection from relatively large amounts of thermal energy.

The leather was chrome-tanned, and the method used is thought to be responsible for the glowing noted. Chromes evidently catalyze the thermal degradation of leathers and actually help propagate glow. It appears advisable in future laboratory tests to compare the thermal resistance of chrome-tanned leather to that of vegetable or synthetic-tanned leathers.

How serious the shrinkage of the leather might be cannot be stated at this time because of the fact that the samples were fastened to the panels thus impeding the full shrinkage that might have occurred otherwise. However, the shrinkage in one of the samples, as noted above, was enough to pull it loose from its backing on three sides. If such shrinkage took place in boots, and was extensive enough to destroy the fit, it may be a serious consideration.

The rubber samples recovered withstood the thermal effects of the bomb remarkably well except for slight damage to their outer surface.

2.3.5 Body Armor Panels

2.3.5.1 Experiment Design

Panels made from two types of body armor, U. S. Army and U. S. Marine Corps, were exposed to 50.0 cal/$cm^2$ on Shot 9 and 60.0 cal/$cm^2$ on Shot 10. Each type was exposed over the Temperate uniform assembly.

The Army body armor consisted of multi-layer laminated nylon oxford encased in thin vinyl plastic and covered with an outer layer of light weight nylon oxford. The Marine type consisted of extremely hard plates of glass fabric laminated plastic assembled in overlapping positions and set in fabric pockets, the whole being covered with a light weight nylon fabric.

2.3.5.2 Results and Discussion

The outer nylon fabric and vinyl film of the Army body armor were destroyed by the explosion. In some small areas the first layer of the armor proper was destroyed and in others it was melted. In a few other small areas the second and third layers were also melted. In the Marine armor the outer fabric layers and a number of the fabric pockets holding the armor plates were destroyed and melted, allowing the plates to fall out or be carried away by the blast wave. One vest section which originally consisted of five plates was recovered with three of its plates missing. No temperature under the vests and clothing fabric assemblies with which they were exposed exceeded 54°C.

These tests indicated that the Army body armor could continue to function as a ballistic protective garment after subjection to the thermal effects of a nuclear blast. Whether this could be said of the Marine armor would depend upon the ability of the armor plates to be retained within the garment. The loss of plates in this test was sufficient to make the Marine armor unserviceable.

2.3.6 Poncho Materials

2.3.6.1 Experiment Design

Two types of poncho materials were exposed on Shot 10 to 40.5 cal/$cm^2$. These consisted of the standard vinyl coated light weight fabric and an experimental vinyl coated material known as "Fiberthin." Both base fabrics are nylon, with the "Fiberthin" being distinguished from the standard by being made of extremely low-twist monofilaments. Its tear resistance and abrasion resistance are better than those of the standard, and it is also more satisfactory from the standpoint of adhesion of the vinyl coating.

Both the standard and the "Fiberthin" fabrics were exposed over the Temperate uniform assembly of fabrics described in 2.2.1.

2.3.6.2 Results and Discussion

Although both the poncho materials were destroyed, they provided the Temperate assembly some additional protection and reduced slightly the heat transferred to the backing For the assemblies not covered by any poncho material the sateen layer was destroyed, the oxford fabric and shirting scorched, and the underwear layer slightly discolored. Under the standard poncho fabric the sateen was only partially destroyed and heavily scorched and torn on one side. The oxford was scorched under both poncho fabrics (only lightly under the "Fiberthin"). Neither the shirting nor the underwear fabric was damaged when either of the two poncho materials was used. The temperatures were less than 54°C where the coated nylon fabrics were present; where they were not, some temperatures of 62°C were recorded.

2.3.7 Aluminized Duck Fabric

2.3.7.1 Experiment Design

The purpose of this test was to evaluate the thermal resistance of an experimental fabric designed for use in the firemens' coats and trousers. The fabric was an 8.25 oz cotton duck treated with a commercial fire retardant, and coated on the face with aluminum and on the back with a low temperature neoprene rubber. It was exposed over a layer of 50 per cent wool/50 per cent cotton underwear fabric to 40.5 $cal/cm^2$ on Shot 10 and to 29.5 and 41.0 $cal/cm^2$ on Shot 9.

2.3.7.2 Results and Discussion

The results on these samples demonstrated the value of a continuous reflectant surface in resisting thermal transfer. None of the underwear fabrics under these aluminized materials were damaged and the temperatures beneath them were kept below 54°C. At 29.5 $cal/cm^2$ the only damage to the samples was a slight dulling of the aluminum surface. At 41.0 and 40.5 $cal/cm^2$ some small areas of the aluminum coating were destroyed in addition to the dulling. Under these areas the duck fabric was charred and scorched. A few small holes appeared in the neoprene backing at the 40.5 $cal/cm^2$ station, but there was not sufficient thermal transfer through these holes to damage the layer of underwear fabric.

The indications of this test are that men wearing a garment of this aluminized fabric would be protected from severe burning by the thermal radiation of a nuclear blast, and that the usefulness of this garment for environmental protection would not be greatly impaired, although its effectiveness as a protective barrier against thermal radiation would be reduced by virtue of its dulling.

2.4 Recommendations

It is recommended that further work be carried out in the laboratory to resolve and define the critical parameters involved in heat transfer through multi-layered fabric assemblies.

It is further recommended that studies be continued in both the field and the laboratory to fill in the gaps in our present knowledge of damage to materials by thermal radiation.

CHAPTER 3

# THE THERMAL AND BLAST EFFECTS UPON WOOL/SYNTHETIC FIBER BLENDS

## 3.1 OBJECTIVE

This phase of Project 8.6 was carried out to obtain information on the performance characteristics of blended fabrics containing various percentages of wool and different synthetic fibers to the thermal effects of a nuclear detonation.

## 3.2 EXPERIMENT DESIGN

Exposures of serge fabrics of three synthetic fibers each of which were blended in varying percentages with wool were made on panels similar to those used in the clothing studies (1.4). These panels were exposed to 17.0, 33.5, and 40.5 cal/cm$^2$ on Shot 10. The syntehtic fibers used were Dynel, Orlon, and Acrilan, each being blended with wool in the following percentages: 15, 30, 50, and 100. A 100 per cent wool serge was exposed as a control fabric. In addition, an 85 per cent wool/15 per cent nylon serge was exposed at 17.0, 33.5 and 40.5 cal/cm$^2$, an 85 per cent wool/15 per cent nylon shirting, at 33.5 and 40.5 cal/cm$^2$, and all-wool shirting at 26.0 and 33.5 cal/cm$^2$.

All test samples were exposed as two layer systems with a 50 per cent wool/50 per cent cotton underwear fabric as the under layer for each fabric.

## 3.3 RESULTS AND DISCUSSION

### 3.3.1 Beneath-Fabric Temperatures and Fabric Damage

The temperatures attained beneath each fabric combination are tabulated in Table A.2 of the Appendix and shown graphically in Fig. 3.1. Fabric damage as determined by visual examination is recorded in Fig. 3.2 and illustrated pictorially in Figs. 3.3, 3.4, 3.5, and 3.6.

On the basis of beneath-fabric temperatures and damage to the first and second layers of the test samples, gross results for the blended fabrics were found to be as follows:

(1) Blends up to 15% of synthetic with wool were equal to 100% wool in protective value.

(2) Blends of 30% Dynel and 30% Orlon with wool were border line cases with the over-all results favoring 100% wool.

(3) Blends of 30% Acrilan, and 50% and 100% Dynel, Orlon, and Acrilan were definitely inferior in protective value to counterpart fabrics of 100% wool.

(4) Whereas spacing of wool, cotton, and wool/cotton mixtures away from the backing has been found to increase their thermal protective value, a reversal of spacing and contact results (especially for the higher synthetic concentrations) was observed in this test. As may be seen from Table A.2 and Fig. 3.1 spacing of the blended fabric away from the backing afforded less protection than when in contact. This situation had never been observed before with wool or cotton fabrics.

(5) For this test the gross order of protection afforded by the blends of synthetic with wool was Dynel first, Orlon a close second, and Acrilan the least effective.

(6) The blends of 85/15 wool/nylon performed equally as well as their 100% wool counterparts.

In addition to the empirical data obtained relative to the protective value of blended fabrics, the results also indicate that the manner in which fabrics respond to thermal stimuli is dependent to a large extent upon the chemical and physicochemical properties of their fiber make up, all other conditions being equal.

If one eliminates such factors as reflectance and transmission and considers only the thermal energy absorbed by a fabric, such energy may be utilized in a number of possible ways. These are: (1) raising the temperature of the fiber; (2) endothermic and exothermic decomposition of the fiber below its ignition point; (3) endothermic and exothermic destruction of the fiber above its ignition point; (4) melting of the fiber; and (5) heating of the molten mass from the melting temperature of the fiber to any point up to decomposition or ignition.

Cotton does not melt but decomposes either endothermically or exothermically on the application of heat. Wool shows a tendency to melt and will also char during the application of thermal energy. The synthetic fibers, especially those tested, melt before decomposing. If the decomposition temperature is high enough the melt can act as a reservoir for considerable thermal energy with subsequent transfer of this energy to the backing.

The results of these tests on blends of synthetic with wool point to the need for a study of the manner in which heat is absorbed and dissipated by different fibers. Such information could be used as a basis for selecting fiber and fabric combinations which, weight for weight, will yield the most protection against thermal radiation.

## 3.4 SUMMARY

From the standpoint of beneath-fabric temperatures and damage to both the first and second fabric layers, all-wool fabrics afforded better protection against thermal radiation than any of the blends in which the synthetic fiber exceeded 15 per cent. The 15 per cent blend was equal to the all-wool.

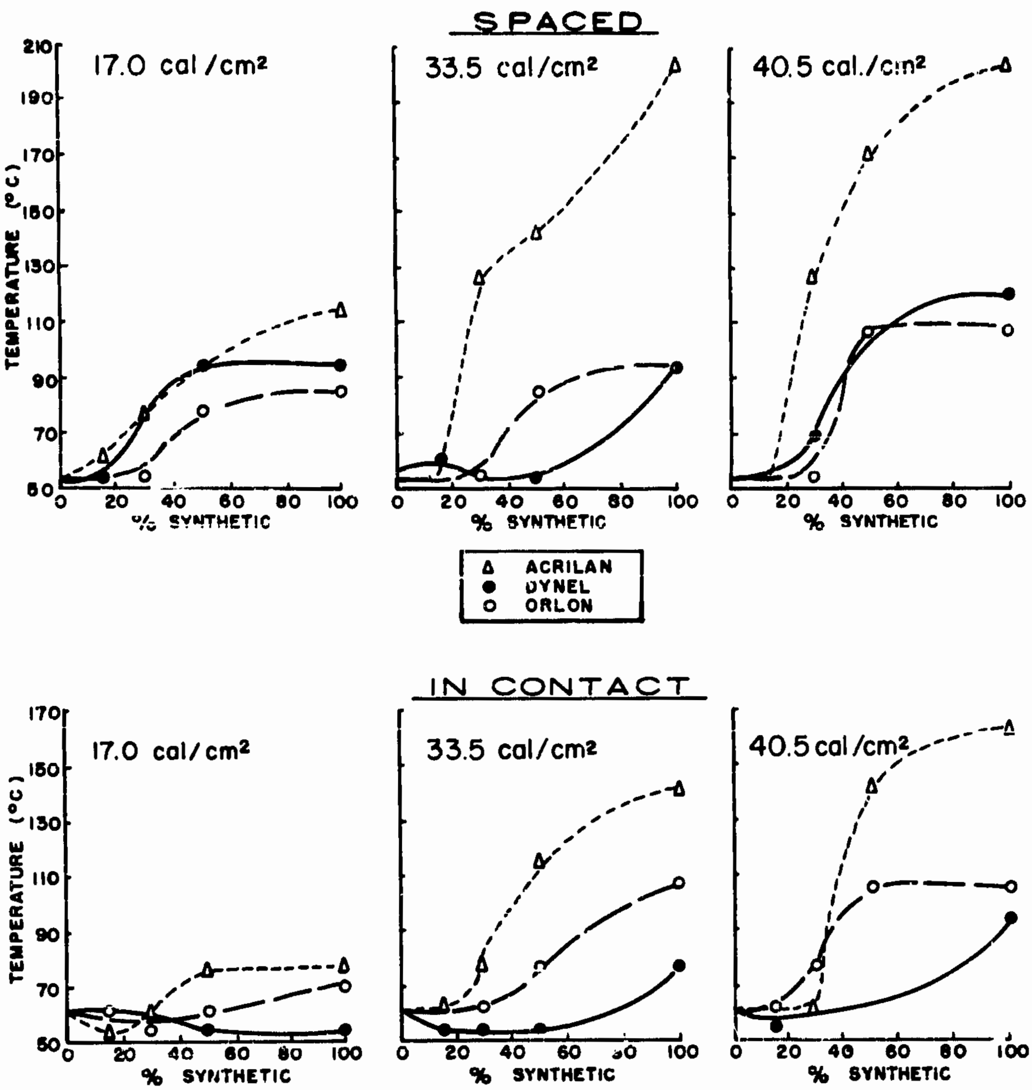


Fig. 3.1 Temperatures Attained under Wool Synthetic Blended Serges

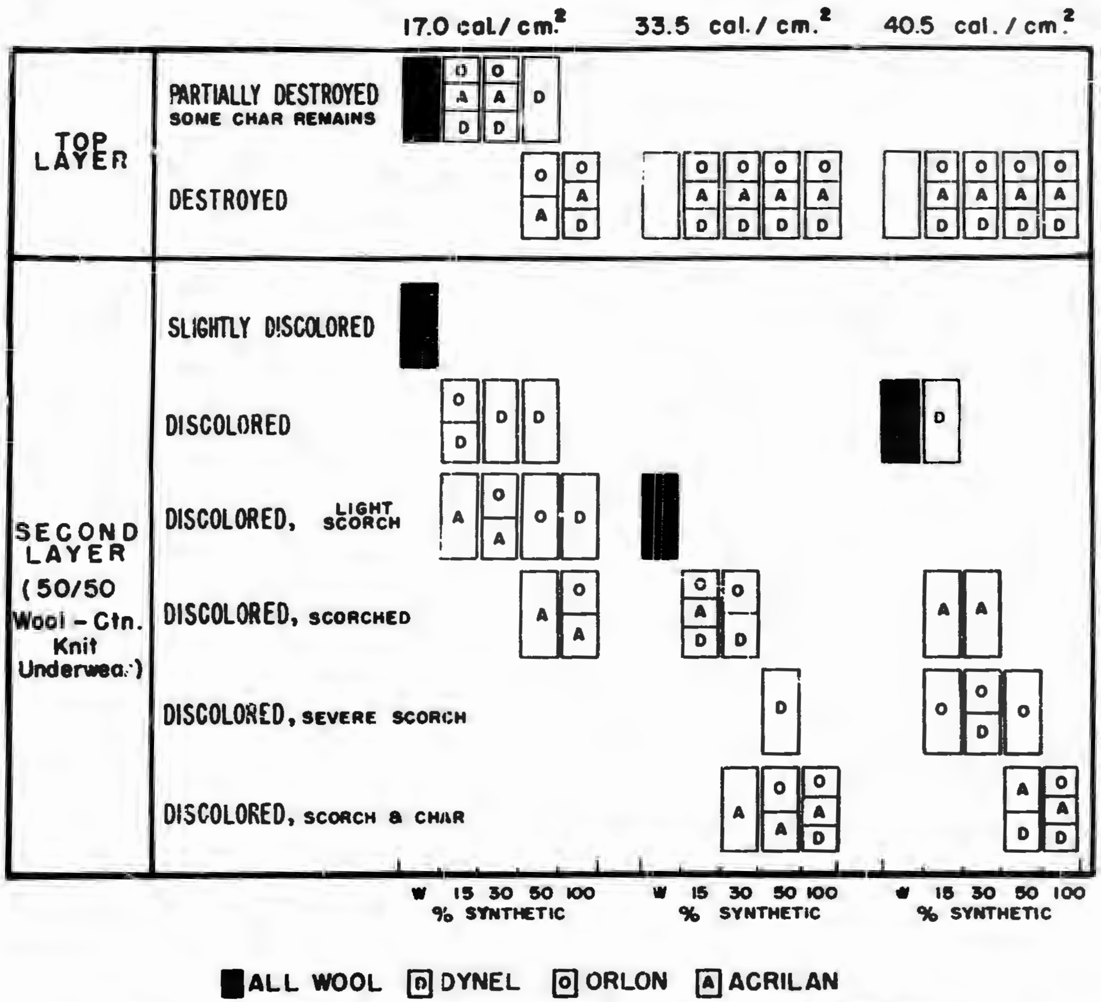


Fig. 3.2 Thermal Damage Sustained by Wool/Synthetic Combinations

Of the three synthetic fibers tested Dynel yielded the best results, Orlon next, and Acrilan the poorest.

In general for the blends having the higher percentage of synthetic (50 and 100%) spacing of the fabric away from the backing resulted in higher beneath-fabric temperatures than were observed for the fabrics in contact with the backing material. This was in direct contrast to results obtained with wool or cotton where spacing had a marked beneficial effect upon the thermal protective value of the fabrics.


Fig. 3.3 Per Cent Dynel Panel

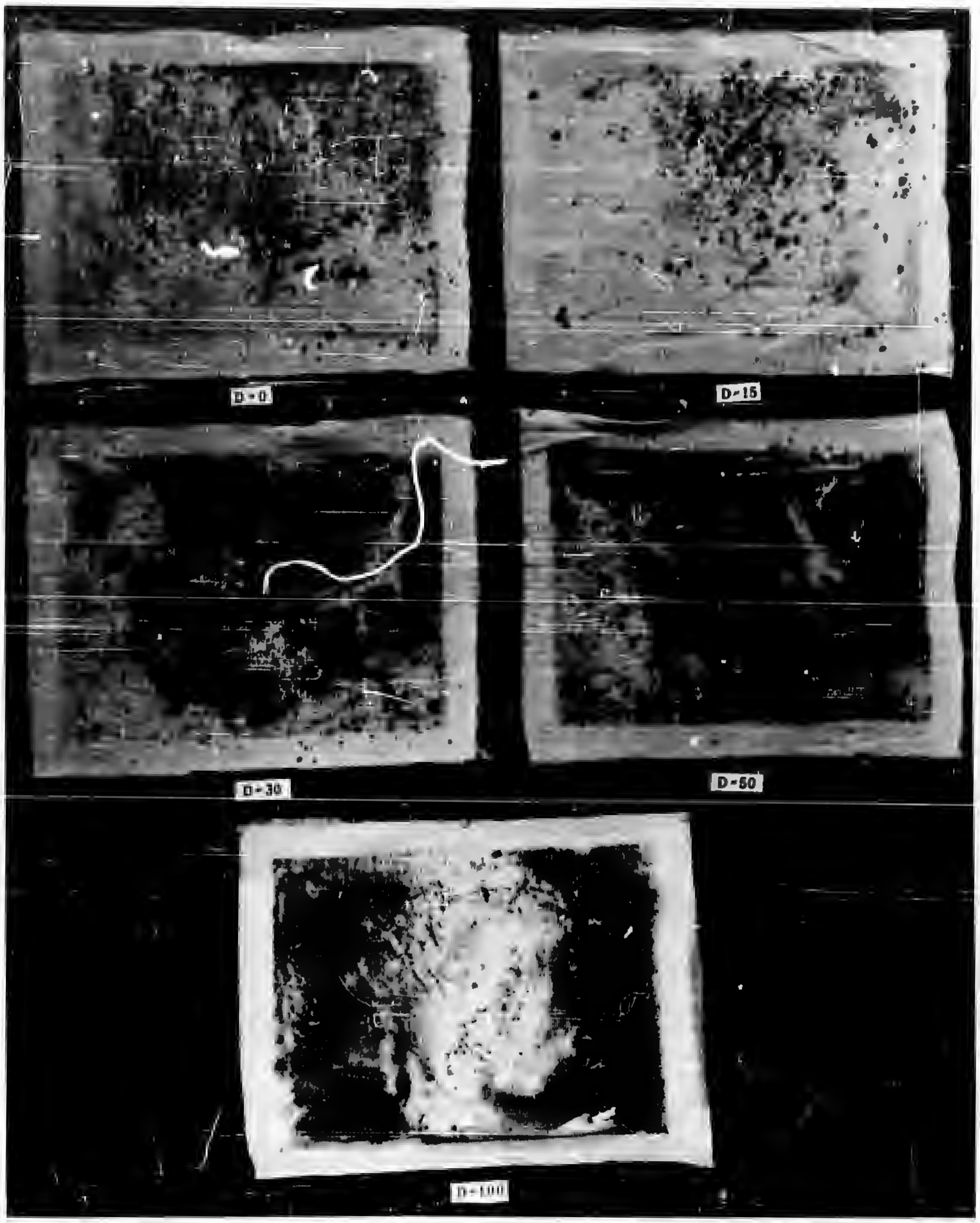


Fig. 3.4 S.cond Layers of Dynel Series

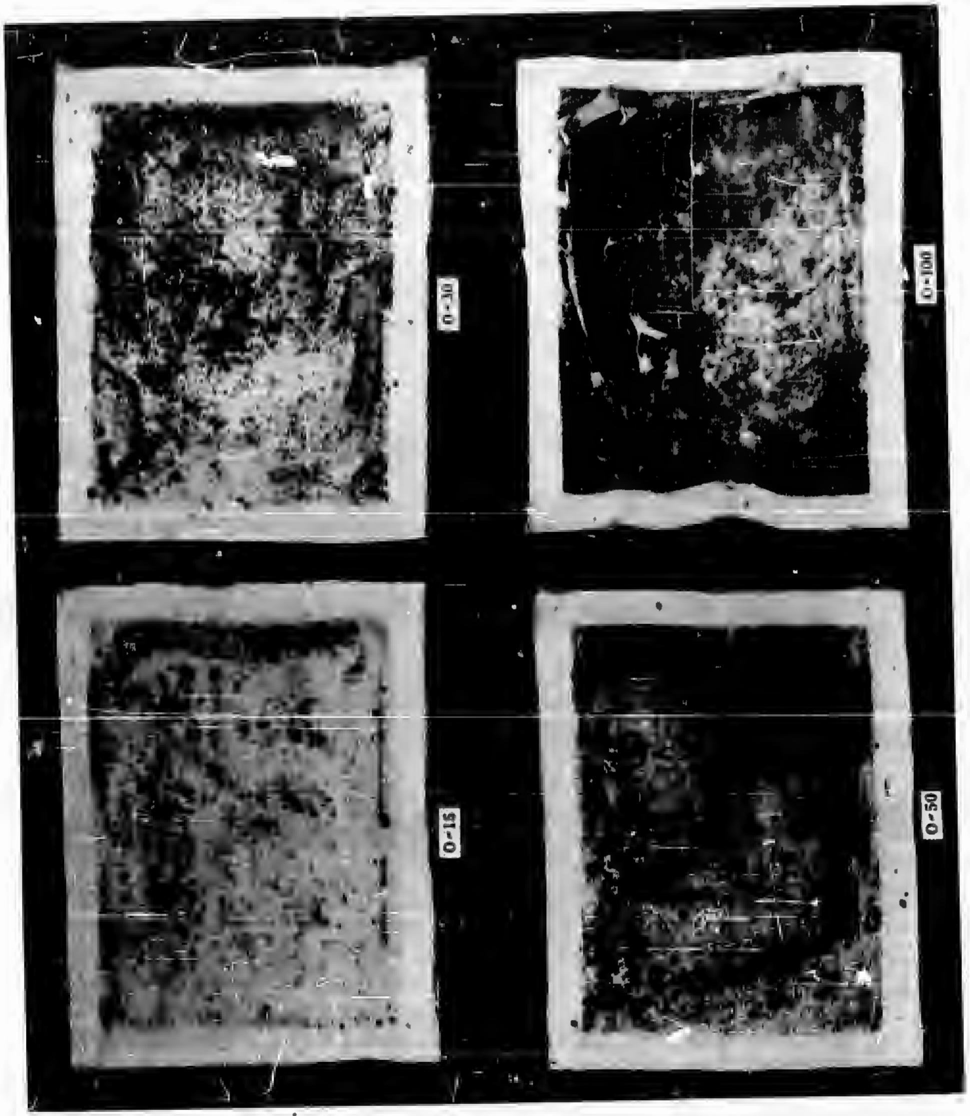


Fig. 3.5 Second Layers of Orlon Series

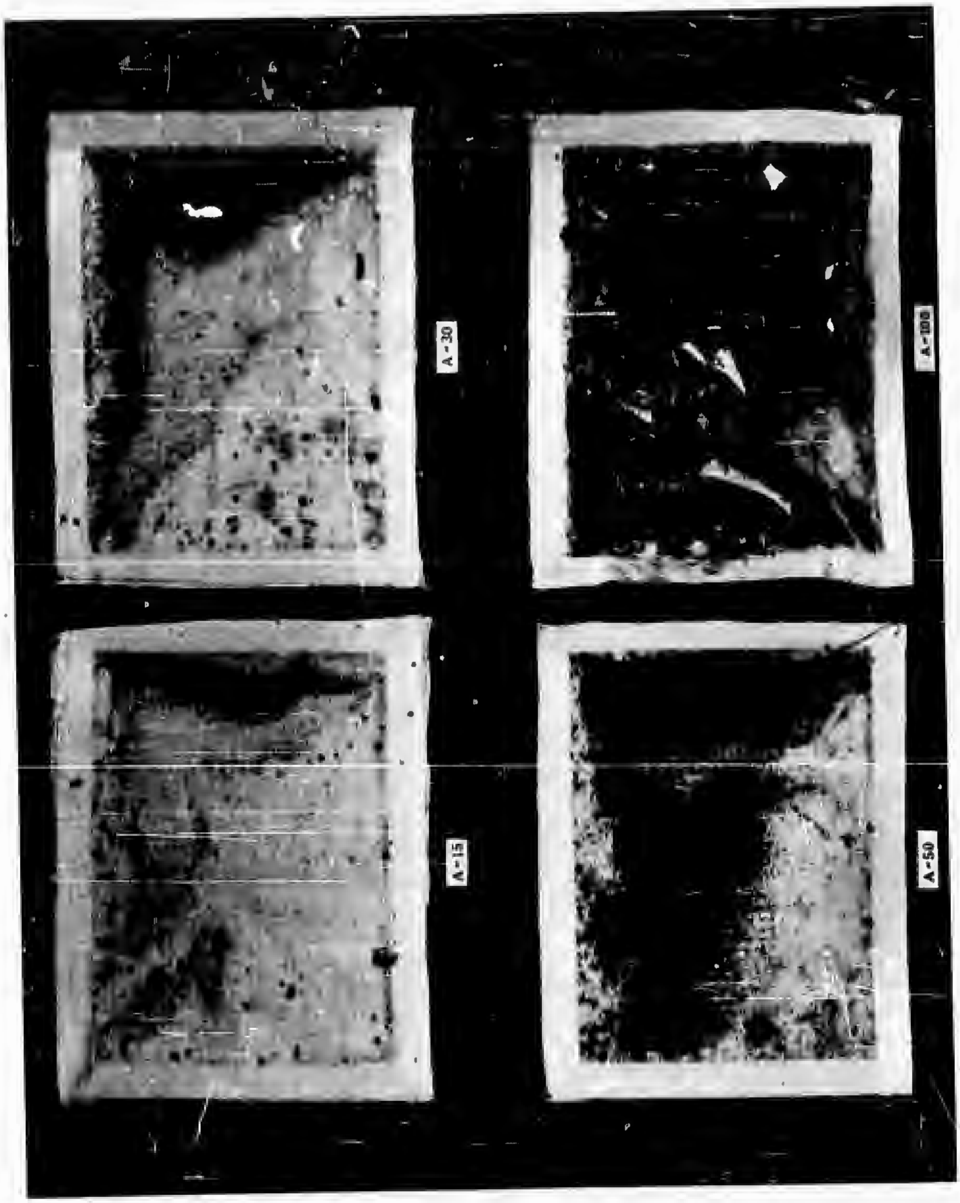


Fig. 3.6 Second Layers of Acrilan Series

CHAPTER 4

EFFECT OF REFLECTANCE AND SPACING OF FABRIC LAYERS UPON TRANSMISSION OF THERMAL RADIATION

## 4.1 OBJECTIVE

Previous tests (1, 2, 3) have shown that the reflectance characteristics of a fabric have a definite influence upon the protection the fabric affords against radiant thermal energy. Spacing (1, 2, 3) of cotton and wool fabrics away from the backing material has also been found to reduce the transfer of thermal energy to the backing.

The reflectance and spacing test had as its objective a two-fold purpose: (1) to yield additional information on the protective effect of fabric reflectance; and (2) to demonstrate whether the position of spacing among fabric layers has a bearing on the heat transferred through the system.

## 4.2 EXPERIMENT DESIGN

### 4.2.1 Reflectance

This portion of the test, as planned initially, was to include four dark gray to very light gray fabrics having reflectance values of approximately 2, 7, 35, and 65 per cent in the infrared range of 0.7 to 1.1 microns. The visual reflectances were to be of the same order of magnitude. Space limitations at the test site necessitated the elimination of two of the reflectance materials. The 7 and 65 per cent fabrics were selected. The basic fabric used was the 9 oz sateen. The desired reflectances were obtained by impregnating bleached fabric with carbon black pigment using carboxymethyl cellulose as the binding agent. Spectrophotometric curves for the fabrics are shown in Fig. 4.1.

### 4.2.2 Spacing

In the spacing phase the same fabrics as used for reflectancy studies were exposed on panels (Figs. 1.1 and 1.4). Three layer systems were used with the inner two layers being the 7 per cent reflectant fabric in all cases. The outer layer was either the 7 per cent or 65

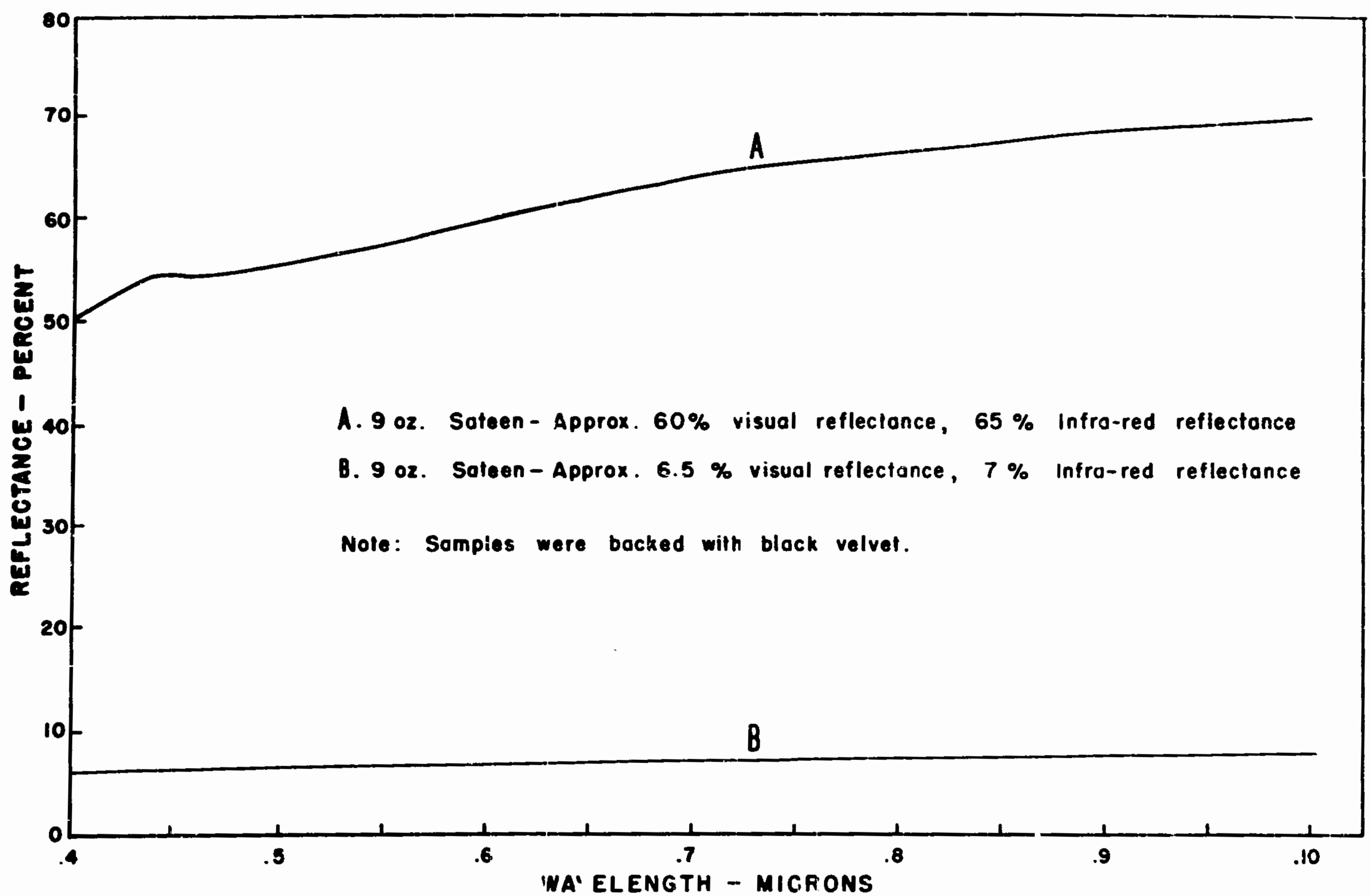


Fig. 4.1 Reflectance Curves of Carbon Black Treated Cotton Sateen

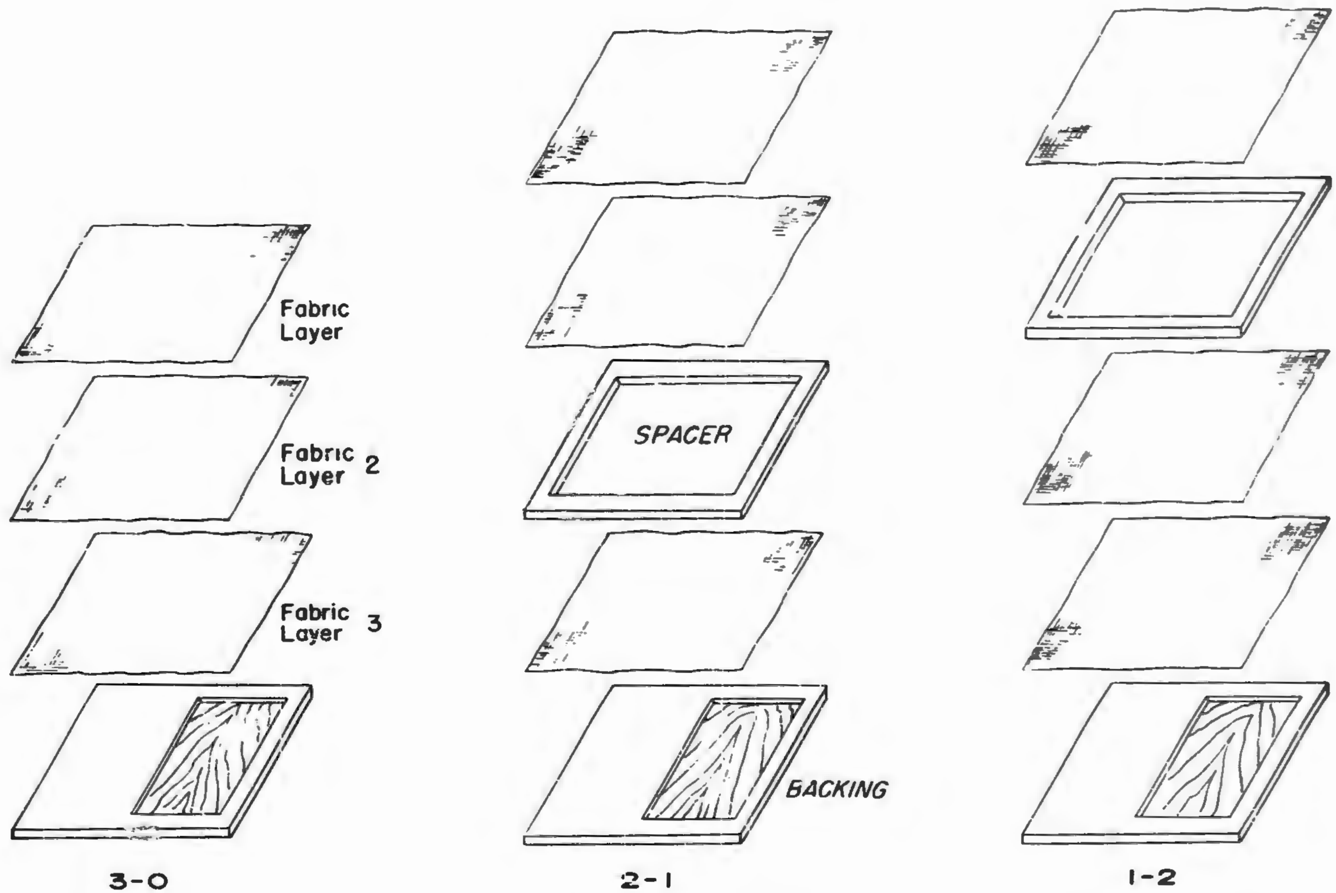


Fig. 4.2 Exploded View of Exposure Panels for Spacing Study

TABLE 4.1 - Reflectance & Spacing Study - Temperatures Beneath Fabrics (°C)

| Energy (cal/cm²) | | | 12.5 | | 12.5* | | 16.0 | | 17.0* | | 21.5 | | 26.0* | | 29.5 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Re-flectance | System | No | C | S | C | S | C | S | C | S | C | S | C | S | C | S |
| 7 | 3-0 | 1 | | | | | | | 101 | 77 | | | 77 | 54 | 305 | 305 |
| | | 2 | | | | | | | 101 | 228 | | | 77 | 54 | | |
| | | 3 | | | | | | | 101 | 205 | | | 62 | 54 | | |
| | 2-1 | 1 | | | | | | | 54 | 228 | | | 54 | 54 | | |
| | | 2 | | | | | | | 69 | 54 | | | 54 | 54 | | |
| | | 3 | | | | | | | 54 | 85 | | | 62 | 121 | | |
| | 1-2 | 1 | | | | | | | -54 | 54 | | | -54 | 54 | | |
| | | 2 | | | | | | | -54 | 54 | | | 54 | 54 | | |
| | | 3 | | | | | | | 54 | 54 | | | -54 | 54 | | |
| | 2-0 | 1 | 172 | 121 | 305 | 305 | 172 | 142 | 172 | 77 | | | | | | |
| | | 2 | 205 | 305 | 305 | 305 | 172 | 305 | 142 | 94 | | | | | | |
| | | 3 | | | | | | | 142 | 77 | | | | | | |
| | 1-1 | 1 | 94 | 77 | | | 121 | 85 | | | | | | | | |
| | | 2 | 94 | 94 | | | 127 | 94 | | | | | | | | |
| | | 3 | | | | | | | | | | | | | | |
| 65 | 3-0 | 1 | | | | | | | 77 | 254 | 77 | 54 | 54 | 54 | 101 | 77 |
| | | 2 | | | | | | | 94 | 228 | | | 54 | 54 | | |
| | | 3 | | | | | | | | | | | | | | |
| | 2-1 | 1 | | | | | | | 228 | 305 | — | 254 | — | 205 | 85 | 54 |
| | | 2 | | | | | | | 239 | 305 | | | 142 | 172 | | |
| | | 3 | | | | | | | | | | | | | | |
| | 1-2 | 1 | | | | | | | 54 | 228 | 77 | 54 | 54 | 54 | 77 | 62 |
| | | 2 | | | | | | | 121 | 239 | | | 54 | 305 | | |
| | | 3 | | | | | | | | | | | | | | |
| | 2-0 | 1 | | | | | | | | | | | | | | |
| | | 2 | | | | | | | | | | | | | | |
| | | 3 | | | | | | | | | | | | | | |
| | 1-1 | 1 | | | | | | | | | | | | | | |
| | | 2 | | | | | | | | | | | | | | |
| | | 3 | | | | | | | | | | | | | | |

*Shot 10 - All others Shot 9

C=Contact
S=Spaced

per cent reflectant fabric. The spacing combinations used were: (1) three layers in contact with each other; (2) the top layer of fabric separated by 1/4 in. air space from the inner two layers which were in contact with each other; and (3) the outer two layers in contact with each other but separated from the bottom layer by 1/4 in. air space. (Fig. 4.2.) Fabric reflectances and spacing arrangements (reading from left to right, i.e., top, middle, and bottom layer), were as follows:

a. 7%, 7%, 7% b. 65%, 7%, 7%
c. 7%, space, 7%, 7% d. 65%, space, 7%, 7%
e. 7%, 7%, space, 7% f. 65%, 7%, space, 7%

Combinations a and b will be referred to as 3-0, c and d as 1-2, and e and f as 2-1.

It is to be noted that in effect the reflectance and spacing within fabric phases were combined as one experiment. A vertical examination of a, c, e, and b, d, f, will include spacing effect, while a horizontal consideration encompasses the effect of reflectance.

Principal exposures of these fabrics were carried out at 17.0 and 26.0 cal/cm$^2$ on Shot 10, with some exposures at 21.5 and 29.5 cal/cm$^2$ on Shot 9.

In addition, two layer systems of 7 per cent IR reflectant fabrics were exposed at 12.5 and 17.0 cal/cm$^2$ on Shot 10 and to 12.5 cal/cm$^2$ on Shot 9. A three layer system with all layers in contact with each other but spaced 1/8 in. and 1/2 in. from the wood backing was exposed to 26.0 cal/cm$^2$ on Shot 10. This was done in order to obtain an indication of the effect of varying the space between the fabric and the backing.

## 4.3 RESULTS AND DISCUSSION

The results of the tests in terms of backing temperatures are listed in Table 4.1 and shown graphically in Figs. 4.3 and 4.4. Fabric damage to the various layers is depicted in Fig. 4.5. The occurrence of glow in the various layers is indicated in Table 4.2.

The top layers of the samples were destroyed by the primary effects of the thermal pulse. This occurred in all cases except one set of samples at 21.5 cal/cm$^2$ in which the outer layer was a 65 per cent reflectant fabric. The underneath layers suffered damaging effects varying from partial destruction and heavy scorch to very light scorch or no damage. The pattern of damage and beneath-fabric temperatures was not consistent. A complicating factor of induced glow, as a secondary thermal effect, resulted in fabric damage and backing temperatures which were not indicative of the protective effect of either reflectance or spacing against the thermal radiation of the bomb. Out of a total of 51 specimens exposed 36 of the recovered panels showed positive evidence of sustained exothermic fabric decomposition as glow. In some instances, as shown by Fig. 4.6, fabric destruction of the third layer occurred directly under a second layer area which remained intact.

On a gross basis less fabric damage and slightly lower beneath-fabric temperatures were observed for the three layer systems in which the outer layer was 7 per cent reflectant than where it was 65 per cent reflectant. On the same basis the over-all results favored the 1-2 system of spacing with the 3-0 next, and the 2-1 combination the poorest.

TABLE 4.2 - Reflectance and Spacing Study - Occurrence of Glow

| Energy | (cal/cm²) | | 12.5 | | 12.5* | | 16.0 | | 17.0* | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | C | S | C | S | C | S | C | S |
| Layer | | | 1 2 3 | 1 2 3 | 1 2 3 | 1 2 3 | 1 2 3 | 1 2 3 | 1 2 3 | 1 2 3 |
| Reflectance | System | No | | | | | | | | |
| 7 | 3-0 | 1 | | | | | | | - - - | - ⁄ ⁄ |
| | | 2 | | | | | | | - - - | - - - |
| | | 3 | | | | | | | - - - | - ⁄ ⁄ |
| | 2-1 | 1 | | | | | | | - ⁄ ⁄ | ⁄ ⁄ ⁄ |
| | | 2 | | | | | | | - ⁄ ⁄ | ⁄ ⁄ ⁄ |
| | | 3 | | | | | | | - ⁄ ⁄ | - ⁄ ⁄ |
| | 1-2 | 1 | | | | | | | - - - | - - - |
| | | 2 | | | | | | | - - - | - - - |
| | | 3 | | | | | | | - - - | - - - |
| | 2-0 | 1 | - ⁄ | - ⁄ | - ⁄ | - ⁄ | - - | - ⁄ | - - | - ⁄ |
| | | 2 | - ⁄ | - ⁄ | ⁄ ⁄ | ⁄ ⁄ | - ⁄ | - ⁄ | - - | - ⁄ |
| | | 3 | | | ⁄ ⁄ | ⁄ ⁄ | | | - ⁄ | - ⁄ |
| | 1-1 | 1 | - - | - ⁄ | | | - - | - ⁄ | | |
| | | 2 | - - | - ⁄ | | | - - | - ⁄ | | |
| | | 3 | | | | | | | | |
| 65 | 3-0 | 1 | | | | | | | - ⁄ - | ⁄ ⁄ ⁄ |
| | | 2 | | | | | | | - ⁄ ⁄ | ⁄ ⁄ ⁄ |
| | | 3 | | | | | | | | |
| | 2-1 | 1 | | | | | | | ⁄ ⁄ ⁄ | ⁄ ⁄ ⁄ |
| | | 2 | | | | | | | ⁄ ⁄ ⁄ | ⁄ ⁄ ⁄ |
| | | 3 | | | | | | | | |
| | 1-2 | 1 | | | | | | | ⁄ - - | ⁄ ⁄ ⁄ |
| | | 2 | | | | | | | ⁄ - - | ⁄ ⁄ ⁄ |
| | | 3 | | | | | | | | |
| | 2-0 | 1 | | | | | | | | |
| | | 2 | | | | | | | | |
| | | 3 | | | | | | | | |
| | 1-1 | 1 | | | | | | | | |
| | | 2 | | | | | | | | |
| | | 3 | | | | | | | | |

* Shot 10 - All others Shot 9
- No Glow
⁄ Glow
C=Contact
S=Spaced

TABLE 4.2 - Reflectance and Spacing Study - Occurrence of Glow (Con't.)

| Energy | | | 21.5 | | 26.0* | | 29.5 | |
|---|---|---|---|---|---|---|---|---|
| | | | C | S | C | S | C | S |
| Layer | | | 1 2 3 | 1 2 3 | 1 2 3 | 1 2 3 | 1 2 3 | 1 2 3 |
| Reflect-ance | System | No | | | | | | |
| 7 | 3-0 | 1 | | | - - - | - - - | - / / | - / / |
| | | 2 | | | - - - | - - - | | |
| | | 3 | | | - - - | - - - | | |
| | 2-1 | 1 | | | - - - | - - - | | |
| | | 2 | | | - - - | - - - | | |
| | | 3 | | | - / / | - / / | | |
| | 1-2 | 1 | | | - - - | - - - | | |
| | | 2 | | | - - - | - - - | | |
| | | 3 | | | - - - | - - - | | |
| | 2-0 | 1 | | | | | | |
| | | 2 | | | | | | |
| | | 3 | | | | | | |
| | 1-1 | 1 | | | | | | |
| | | 2 | | | | | | |
| | | 3 | | | | | | |
| 65 | 3-0 | 1 | - - - | - - - | / / - | / / / | - / / | - / / |
| | | 2 | | | - - - | - - - | | |
| | | 3 | | | | | | |
| | 2-1 | 1 | - / / | - / / | - / / | / / / | - / / | - / / |
| | | 2 | | | / / / | / / / | | |
| | | 3 | | | | | | |
| | 1-2 | 1 | - - - | - / / | - - - | / - - | / - - | / / - |
| | | 2 | | | / - - | / / / | | |
| | | 3 | | | | | | |
| | 2-0 | 1 | | | | | | |
| | | 2 | | | | | | |
| | | 3 | | | | | | |
| | 1-1 | 1 | | | | | | |
| | | 2 | | | | | | |
| | | 3 | | | | | | |

*Shot 10 - All others Shot 9
- No Glow
/ Glow
C=Contact
S=Spaced

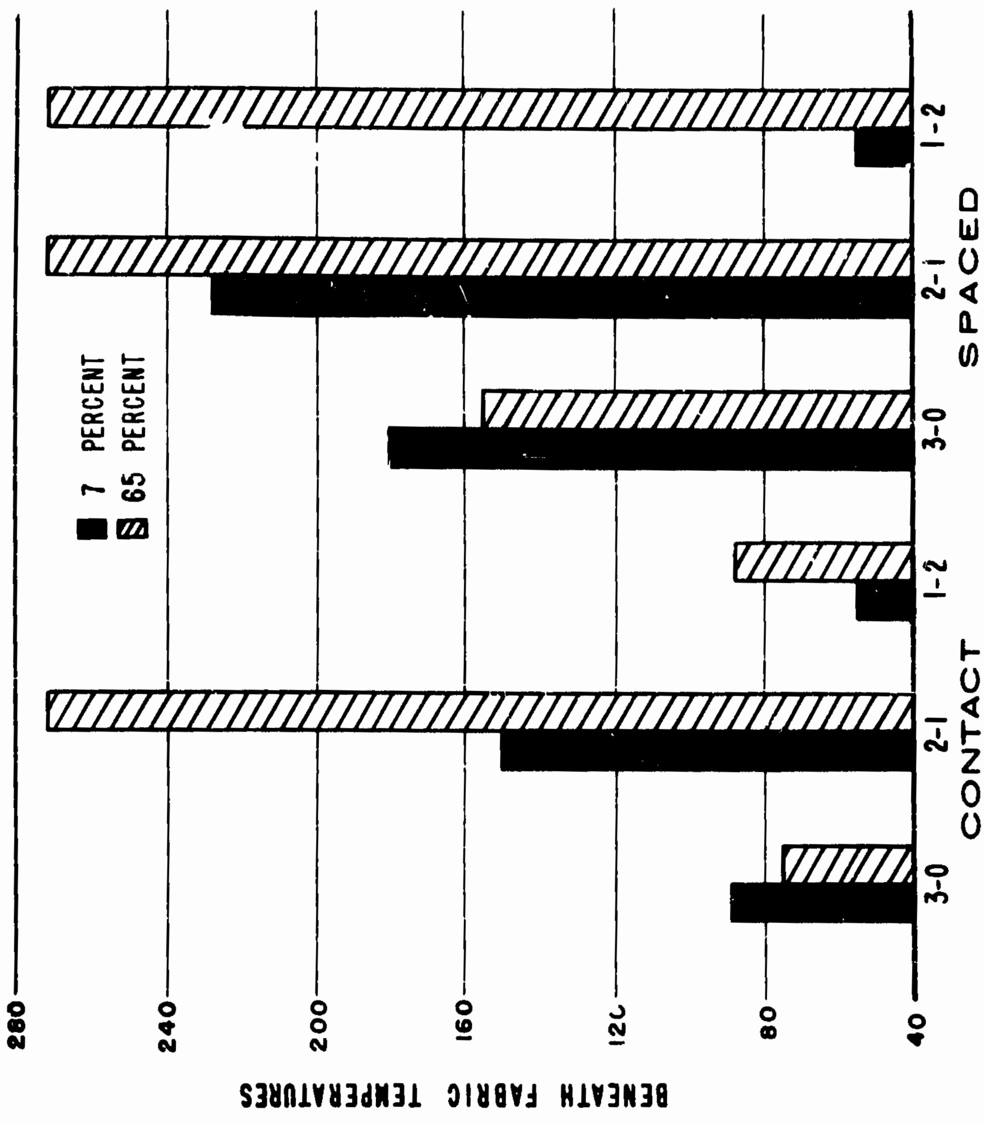


Fig. 4.3 Effect of Reflectance and Spacing on Beneath-Fabric Temperature

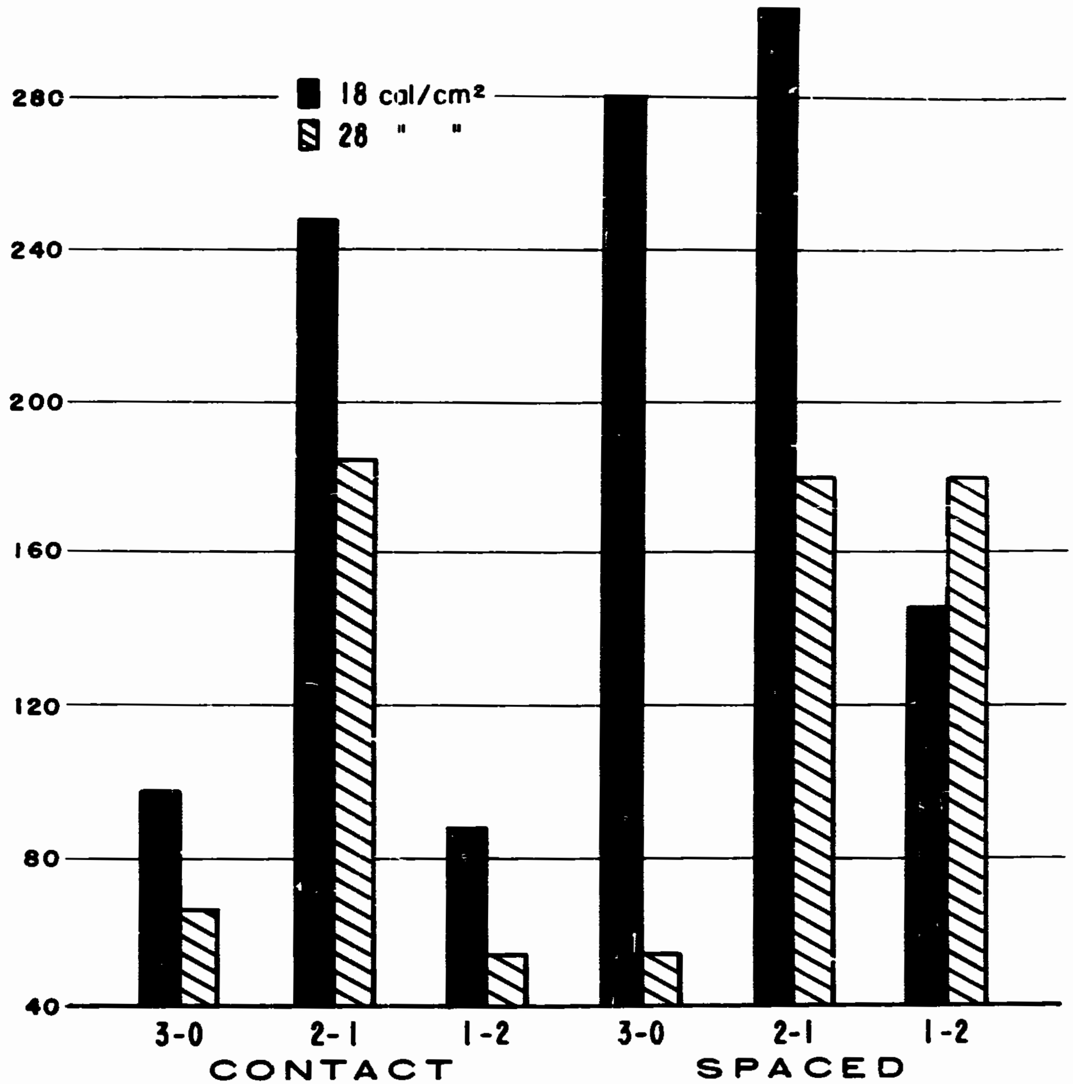


Fig. 4.4 Effect of Spacing and Energy Applied on Beneath-Fabric Temperature

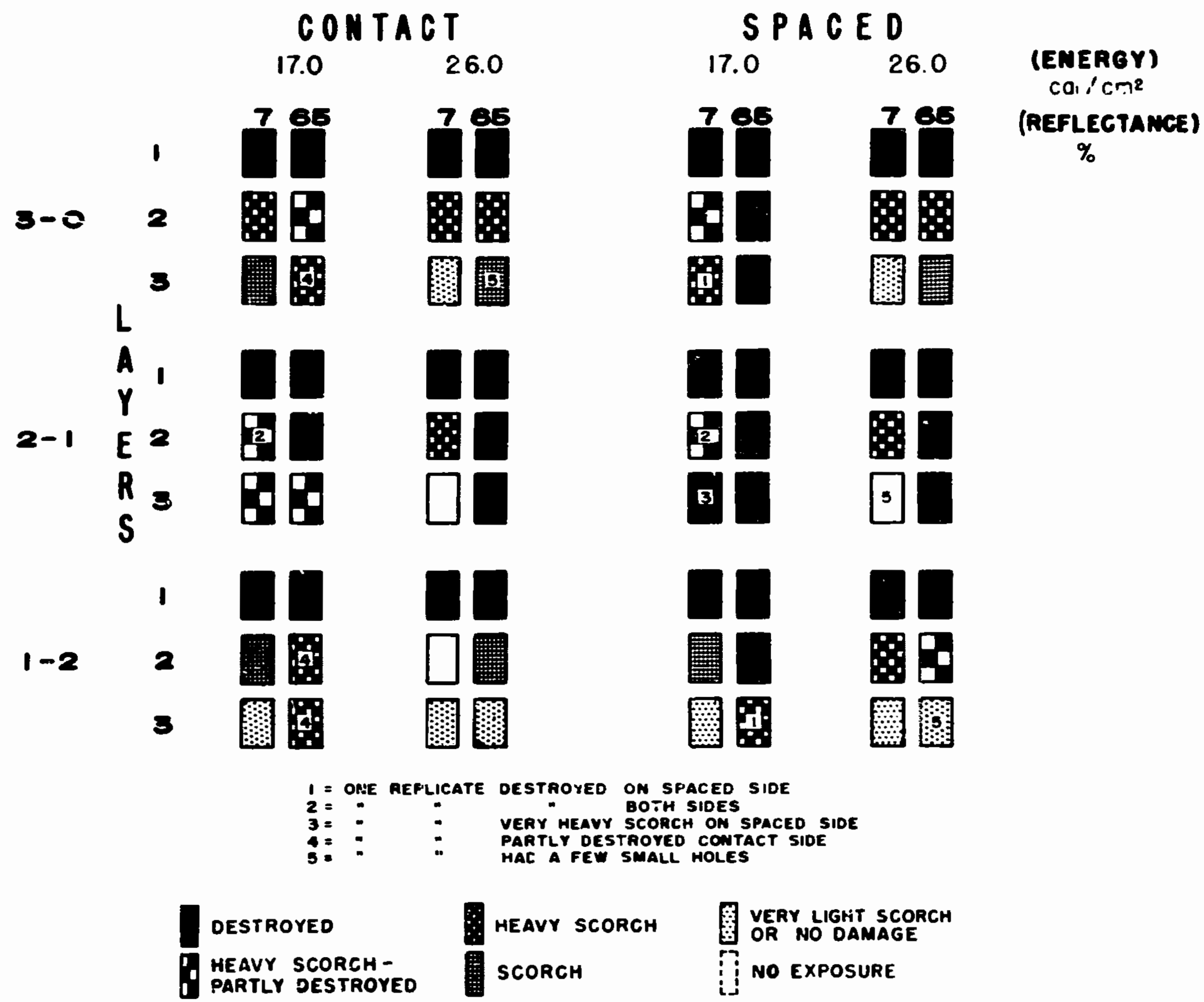


Fig. 4.5 Degree of Damage Sustained by Reflectance - Spacing Panels

Outer Layer

Middle Layer

Bottom Layer

Fig. 4.6 Fabric Destruction Due to Glow Note: This is a 2-1 System

It is interesting to note that for the 65 per cent reflectant outer layer assemblies induced fabric glow occurred in 67 out of a total of 108 fabric layers, whereas only 51 layers out of 170 showed evidence of glow in the 7 per cent outer layer reflectant assemblies. These data were compiled on the basis that each panel consisted of two distinct parts, i.e., spaced and contact (Fig. 1.1).

For the spacing arrangements, 18 instances of glow damage out of a possible 72 cases was recorded for the 1-2 combination, 27 for the 3-0, and 49 for the 2-1 system. Each of the latter two systems involved the same total of fabric specimens as the 1-2 combination, that is 72.

The data also showed more cases of glow for the fabrics which were spaced away fr— the backing than where the bottom layer was in contact with the backing.

The two layer systems of 7 per cent IR 9 oz sateen fabrics exposed at 26.0 and 17.0 cal/$cm^2$ followed much the same pattern as found for the three layer system in that only a limited degree of glow damage was found for the contact with backing side of the panel and extensive damage due to glow on the spaced side of the panel.

Beneath-fabric temperatures for the three layer (3-0) assembly with 1/8 in. and 1/2 in. spacing from the backing material were 101°C and 54°C respectively. The same three layer combination spaced 1/4 in. from the backing showed a beneath-fabric temperature of 54°C.

## 4.4 CONCLUSIONS

No specific conclusion can be drawn from the results of these tests on the roll of reflectance and spacing in the transfer of thermal energy through the fabric system from the primary effects of the bomb. However, it does appear that optical characteristics of non-fire resistant cotton fabrics and spacing arrangements within the fabric layers are inter-related and have a definite bearing on the initiation of sustained glow.

The study of the influence of fabric reflectance and spacing within fabric systems should be further investigated in the laboratory where complications due to sustained exothermic reactions can be eliminated and spacing can be closely controlled.

CHAPTER 5

# FLAMING OR GLOWING OF TEXTILE FABRICS DUE TO RADIANT THERMAL ENERGY

## 5.1 OBJECTIVE

Previous field tests had not demonstrated conclusively whether or not sustained flaming of fabrics occurred when exposed to the thermal energy from an atomic bomb. Such knowledge is required in order to determine what emphasis should be placed on fire resistant fabrics in connection with protection against thermal radiation.

## 5.2 EXPERIMENT DESIGN

Single fabrics and multiple layer fabric assemblies were exposed in the form of 3 in. wide strips mounted in special holders which in turn were placed on a specially designed rack. The fabric holders were designed in such a manner that the upper half (18 in.) of the fabric strip would be shielded from the direct rays of the thermal pulse and from the blast wave. The lower half of the fabric was exposed to the incident energy. The rack and the sample holders were set perpendicular to the center of the burst. The rack with samples in position is illustrated in Fig. 5.1. The samples were secured inside of the cylinder by a pin which passed through the cylinder and through a loop in the fabric strip. The lower portion of the fabric was then clamped to a bar across the bottom of the rack. The purpose of this arrangement was to permit any flame or glow that might be induced on a fabric to travel upwards into the cylinder. Thus, if no flaming occurred there would be a very sharp demarcation between the exposed and protected portions; if there were flaming, a portion of the fabric inside the cylinder would be destroyed or charred and the edge remaining would be irregular. In order to reduce further the effects of the blast wave three specimens had the lower exposed portions encased in cylinders of clear plastic. (Fig. 5.1.)

The fabrics and fabric assemblies exposed on these racks were:

1. Brushed Rayon (of "Torch Sweater" fame).
2. Cloth, Cotton, Percale, 3.2 oz, Unbleached.
3. Cloth, Cotton, Oxford, 5.2 oz, Shade 116, Fire Resistant Treated.

4. Cloth, Cotton, Sateen, 9 oz, OG 107.
5. Cloth, Cotton, Sateen, 9 oz, OG 107, Fire Resistant Treated.
6. Two layer Hot-Wet Assembly (chap. 2, para. 2.2.1).
7. Two layer Hot-Wet 50/50 Assembly (chap. 2, para. 2.2.1).
8. Four layer Temperate Assembly (chap. 2, para. 2.2.1).
9. Hot-Wet, Fire Resistant Assembly (chap. 2, para. 2.2.1).

A total of 70 specimens were exposed to 16.0 cal/cm$^2$ on Shot 9, and to 9.0, 12.5, and 17.0 cal/cm$^2$ on Shot 10. The lower energy values were selected because it was desired to obtain longer time intervals between the end of the thermal pulse and the arrival of the blast wave than would prevail at the closer stations. In this manner, any ignited fabric would be given an opportunity to burn inside the cylinder before the blast wave might extinguish it.

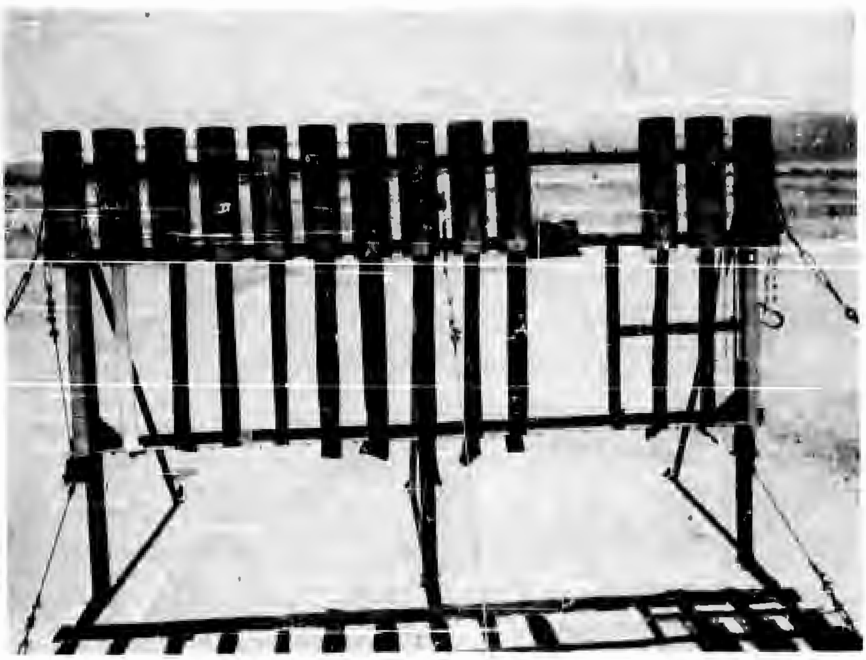

Fig. 5.1 Flammability Rack

## 5.3 RESULTS AND DISCUSSION

All the samples of the brushed rayon exhibited evidence of a flame which burned off the deep nap. This could have been a flash type of flame and would have required a very short period of time to travel over the 18 in. or so of the shielded rayon. This fabric burns at the rate of approximately 6 to 8 in./sec. A total of six samples of the oxford and percale at the 12.5 cal/cm$^2$ station showed charred streaks extending from the exposed portion into the cylinder. These streaks were similar to those observed in the laboratory in the Vertical Flame Resistance Test. At the 9.0 cal/cm$^2$ station some of these samples showed evidence of glowing. Although definite evidence of flame or glow was found in only 16 out of a total 70 specimens exposed the results of the tests demonstrated that sustained exothermic decomposition of non-fire resistant textile fabrics can occur. A valid question, however, might be raised as to the extent and seriousness of persistent flaming or glow in fabrics exposed to thermal radiation of the bomb. This applies particularly to clothing fabrics. For the answer to this question it is necessary to turn to other sources of information.

Thirty-six out of the 51 panels exposed in the Reflectance and Spacing Study (Chapter 4) of this project showed conclusive evidence that flaming or glow, particularly glow, did occur. For example, in the underlayers of the 9 oz sateen (used in this test) glow destruction to areas as much as 6 in. in diameter were observed. This indicated that sustained glow proceeded for at least 12 minutes since glow travels through 9 oz sateen at the rate of approximately 1/4 in./min. Evidence of glow phenomena was also found in 23 of the clothing fabric assemblies (Chap. 2).

Irrefutable evidence of sustained flaming or glow was found in the clothed pig experiment (Project 8.5, conducted concurrently with the panel exposure tests). Colored motion pictures taken on both Shots 9 and 10 at exposures of 12.5, 17.5, 21.5, and 33.5 cal/cm$^2$ showed flaming of the untreated uniform fabrics between the end of the thermal pulse and the arrival of the blast wave. In this same experiment certain of the clothed animals at the more distant stations sustained burns of a type and severity which have only been seen in the laboratory when flaming or glowing fabric was in contact with the skin. Further evidence of sustained flame or glow was found in numerous instances where thermal destruction of the uniforms extended well into those areas which were shadowed from the direct radiation of the bomb.

## 5.4 CONCLUSIONS

On the basis of the shielded fabric experiment alone, no definite conclusions can be drawn as to extent and seriousness of sustained exothermic reactions in exposed textile fabrics. However, the results of this study, that of the Reflectance and Spacing investigation, and Clothing Fabric Panels supports the conclusions reached in Project 8.5 that flame and glow can and do occur and are sufficiently serious to warrant the use of fire retardants in the outer layer of combat uniforms.

CHAPTER 6

EFFECT OF AREA EXPOSED ON THE TRANSFER
OF THERMAL ENERGY THROUGH FABRIC SYSTEMS

## 6.1 OBJECTIVE

This study was made in order to obtain data on how thermal energy transferred through a fabric system varied with the area exposed to the thermal pulse of an atomic weapon.

## 6.2 EXPERIMENT DESIGN

Since existing laboratory sources of radiant thermal energy, having somewhat comparable characteristics to that of a nuclear detonation, have been limited to small area sources it was necessary to investigate the effects of a large area source on larger exposure areas than those obtainable under laboratory conditions.

Circular exposure areas having diameters of 0.125, 0.25, 0.5, 1.0, 2.0, and 4.0 in. were selected for study. These were obtained by using the 9 in. x 12 in. panel (described in Chapter 1) and placing over the test specimens an aluminum shield in which circular holes of the desired diameters had been cut. (Fig. 1.2.) The shields were made of 0.051 in. aluminum sheeting and in the panel assembly were positioned 1/4 in. above the outer layer of fabric. Each shield was designed so that the edge of any one hole would be separated from the edge of an adjacent hole by a distance equal to the sum of their radii. This was done in order to minimize the effects of a possible overlapping of heat from two adjacent holes due to a lateral spreading. Enough panels and shields were made so that at least three replicates of each temperature indicator could be exposed under each size hole at each station. A rack of panel assemblies with shields is illustrated in Fig. 6.1.

The fabric assemblies consisted of an outer layer of 9 oz sateen, OG 107, backed with 1, 2, 3, or 4 layers of 3.9 oz undyed Balloon Cloth depending upon the station at which the panel was exposed. The balloon cloth was treated with diammonium phosphate in order to lower the scorching temperature, thus making it easier to determine lateral heat spread. The diammonium phosphate also acted as a glow retardant. The fabrics in turn were backed with temperature indicators placed so that they coincided with the holes in the shield. It was expected that the

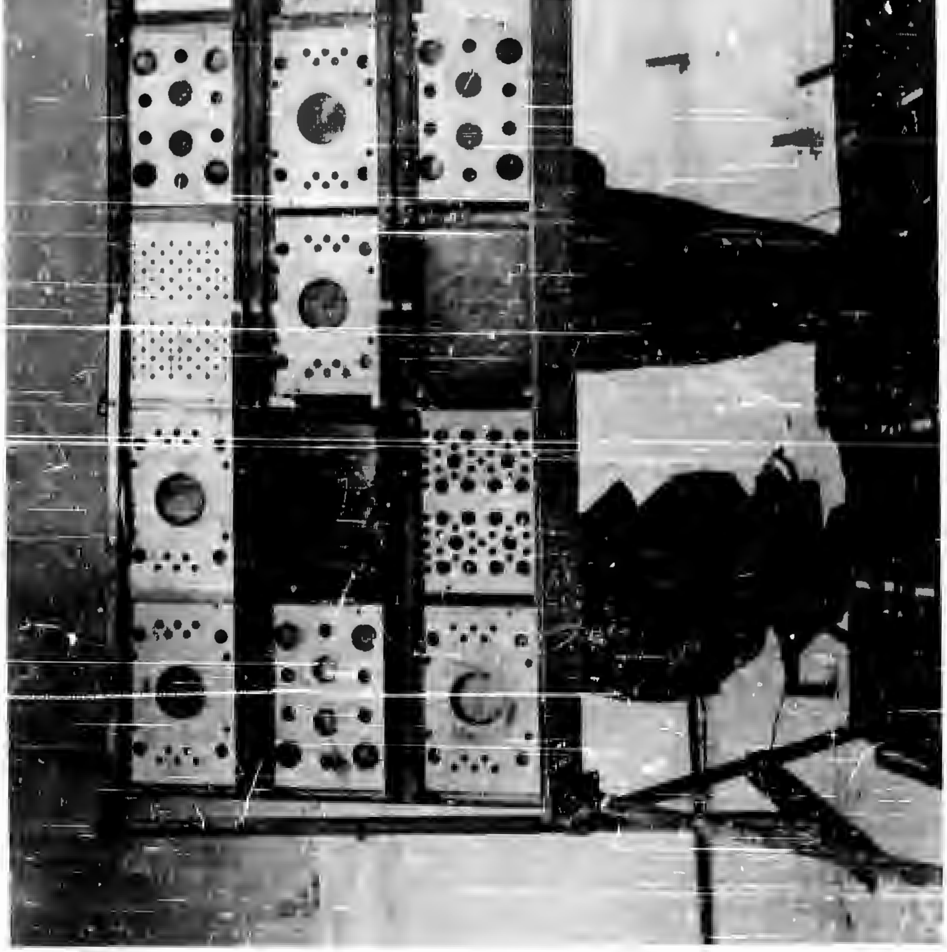

Fig. 6.1 Rack with Area Study Panels

depth of damage and the temperature indicators would serve as a double check on the effect of area exposed upon thermal transfer. Racks with the shielded panels were exposed to 12.5, 16.0, 21.5, 41.0, 50.0, and 75.0 cal/cm² on Shot 9 and to 12.5 cal/cm² on Shot 10 as a check.

## 6.3 RESULTS AND DISCUSSION

The beneath-fabric temperature data for the various stations are given in Table 6.1 and the average temperature over all the stations for each hole size is plotted in Fig. 6.2. There was no pronounced difference from station to station between the beneath-fabric temperatures for a given hole size. Plotting the backing temperature versus hole size data for each exposure station resulted in a family of curves which were of the same shape and differed only slightly from each other with respect to temperature for a given exposure area. Because of this close similarity and because the same conclusions result from the entire family of curves as from one composite curve the latter method was used to express the relationship shown in Fig. 6.2

The data from the 50.0 and 75.0 cal/cm² stations are not included because of the extensive blast damage sustained by the test panels and fabrics at these stations. However, the results of the limited number of test specimens recovered at these forward locations showed the same trend of more heat per unit area being transmitted through the larger exposure areas than through the smaller ones.

Figure 6.2 is essentially self-explanatory. From this it can be seen that for cotton fabrics in contact with the backing an exposure area of between 1 and 2 inches in diameter is required to overcome the effects of lateral heat spread. It should be noted that beneath-fabric temperatures were determined at the center of the circular areas. This loss of thermal energy laterally as against transfer through the fabric or fabrics is readily understood when it is remembered that an irradiated area 0.2 in. in diameter has an area to edge or circumference ratio of 20 to 1 whereas an area 2.0 in. in diameter has a ratio of 2 to 1.

In those cases where the fabric was spaced away from the backing it was found that an area of approximately 2.5 in. was required to overcome the heat losses. This is as would be expected since conditions are more favorable for diffusion of heat to the side by convection and radiation.

In addition to higher beneath-fabric temperatures having been recorded for the large exposure areas, visual examination showed that thermal damage in the form of charred or scorched fabric extended to a greater depth for the larger openings. This is illustrated in Figs. 6.3 to 6.7.

Figure 6.3 illustrates the panel without its shield. Note the sharp circular areas burned out of the outer layer. Figure 6.4 is of the second layer and here the lateral spread of the heat can be seen. With the sharply defined black circular areas of char matching the outline of the holes in the outer layer. Figure 6.5 is of the third layer and shows the beginning of the decrease in depth of penetration. Here the larger holes (4 in. and 1 in.) show rather distinct outlines corresponding to the areas under the holes in the shield, but the half inch diameter areas are not sharp and show less damage. Also it will be noted that the half inch holes show little or no lateral damage

TABLE 6.1 - Area Study - Temperatures under Apertures

| Energy (cal/cm²) | Aperture Diameter (inches) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Contact | | | | | | Spaced | | | | | |
| | 4.0 | 2.0 | 1.0 | 0.5 | 0.25 | 0.125 | 4.0 | 2.0 | 1.0 | 0.5 | 0.25 | 0.125 |
| 12.5 | 205 | 205 | 205 | 117 | 65 | 54 | 142 | 96 | 77 | 54 | 54 | 54 |
| 12.5* | 205 | 184 | 184 | 152 | 72 | 54 | 122 | 98 | 70 | 54 | 54 | 54 |
| 16.0 | 205 | 205 | 205 | 184 | 89 | — | 103 | 83 | 82 | 72 | 54 | 54 |
| 21.5 | 205 | 205 | 205 | 142 | 127 | 54 | 153 | 99 | 77 | 54 | 54 | 54 |
| 29.5 | 205 | 205 | 163 | 121 | 98 | 54 | 108 | 101 | 83 | 60 | 54 | 54 |
| 41.0 | 205 | 205 | 184 | 142 | 75 | 54 | 103 | 93 | 83 | 60 | 54 | 54 |
| Avg. | 205 | 202 | 191 | 143 | 88 | 54 | 122 | 95 | 79 | 58** | 54 | 54 |

* Shot 10
** Estimated

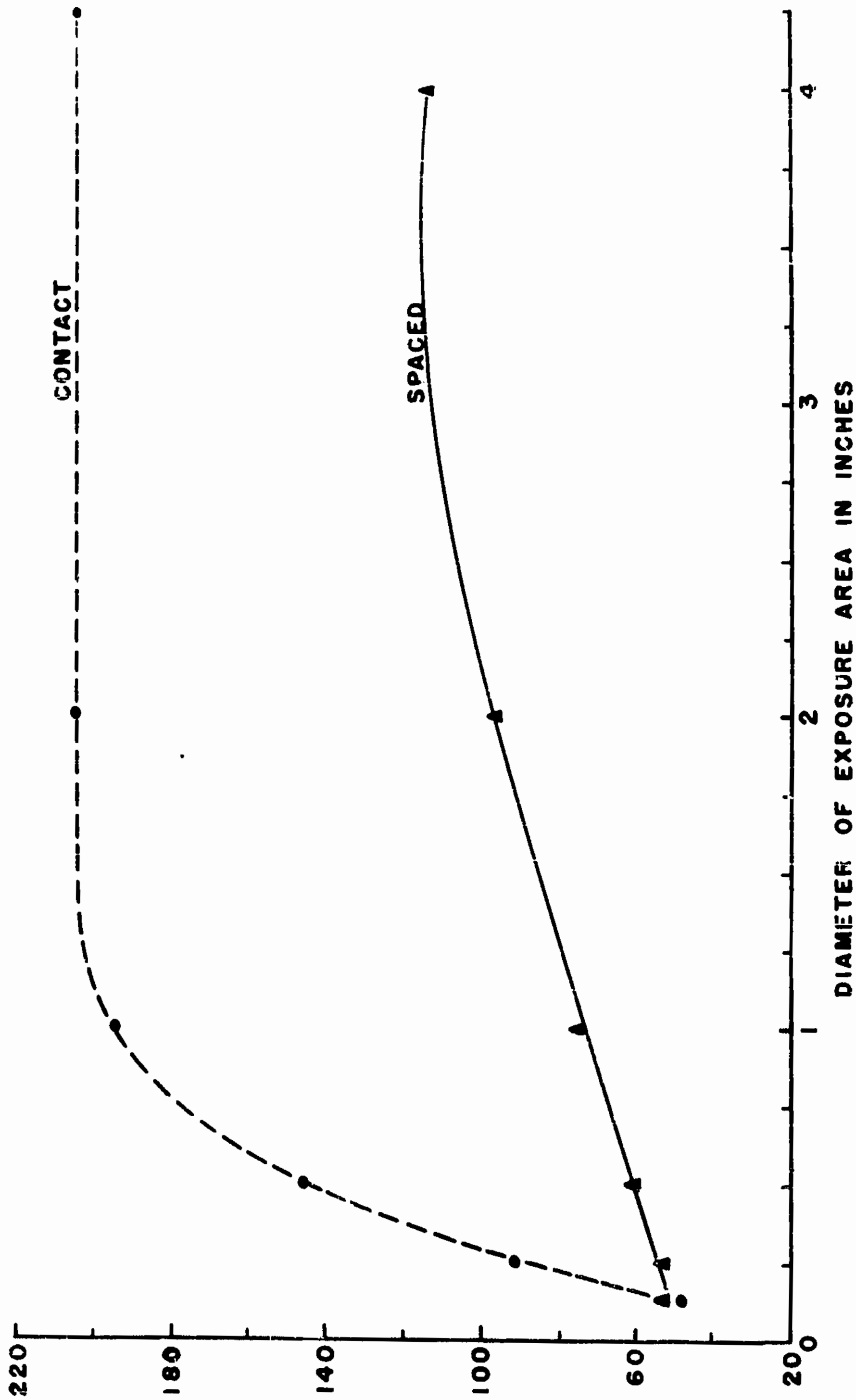


Fig. 6.2 Average Temperature vs Exposure Area

indicating a greater reduction in the quantity of heat penetrating to this depth than for the larger aperatures. Figure 6.6 is of the fourth layer and shows the large area as being more severely scorched than the others, although not clearly visible in the illustration. The 1 in. diameter areas were scorched slightly more than the one half inch diameter areas. Figure 6.7 shows the large area quite distinctly and the 1 in. diameter areas faintly. The one half inch diameter areas are very faint or do not show. The light shaded triangular areas visible are the temperature indicators showing through from the backing. This panel was exposed to 75 cal/cm$^2$ on Shot 10.

The results of this test clearly demonstrated that area of exposure must be taken into consideration in interpreting laboratory results. These findings have also been corroborated by the clothed pig experiment (Project 8.5)[5] where a peculiar type of edematous burn beneath protective layers of fabric was noted for the first time. This type of pig burn had not been observed before in the laboratory although burns beneath fabric had been produced with the carbon arc with irradiances comparable to that in the field, except that a small area source and small exposure area were used in the laboratory. Work conducted by the University of Rochester has since demonstrated that the edematous type of burns can be produced in the laboratory by using a large exposure area and a magnesium flash source.

Although not directly related to the specific objective of this test it is interesting to note that the effect of spacing cotton fabrics away from the backing was again clearly demonstrated. As may be seen from Fig. 6.2 a temperature differential of from 0 to 90°C in favor of the spaced fabrics was observed. The complicating factor of induced and sustained glow phenomenon was eliminated from this test by virtue of the fact that all fabrics except the top layer had been treated with diammonium phosphate. This was somewhat fortuitous for although it was known that diammonium phosphate was a good glow retardant it had been applied primarily to lower the scorching temperatures of the backing fabrics.

## 6.4 CONCLUSIONS

For protective layers of fabric there is a definite minimum exposure area below which lateral heat losses become significantly greater with decreasing area size. A quantitative order of magnitude for lateral heat loss has not been established. However, this factor should be kept in mind when one is dealing with exposure areas less than 2 in. in diameter.

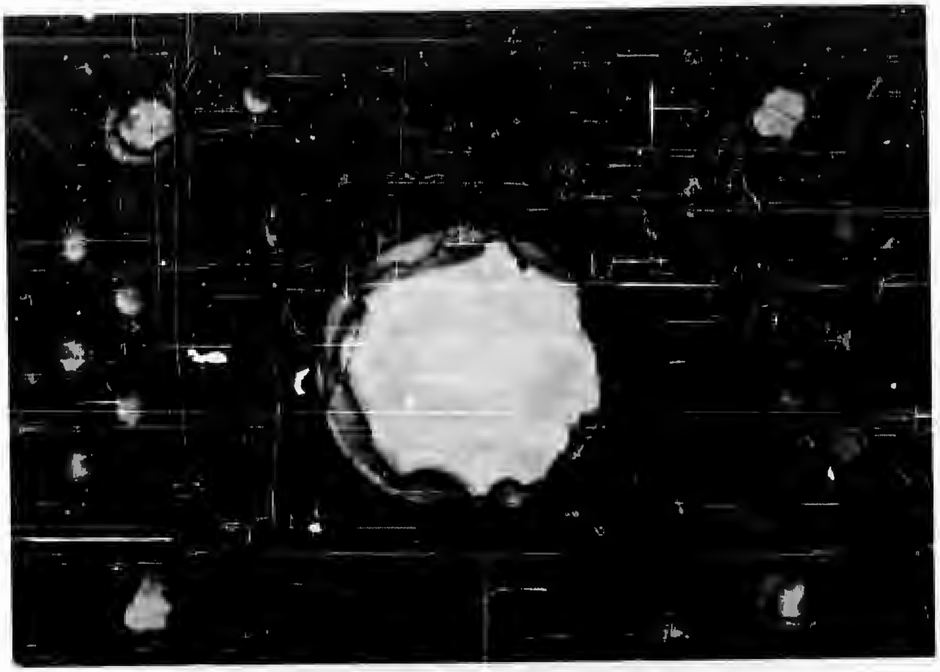

Fig. 6.3 First Layer of an Area Study Panel
(Exposed to 75.0 cal/cm$^2$)

Fig. 6.4 Second Layer of an Area Study Panel
(Exposed to 75.0 cal/cm$^2$)

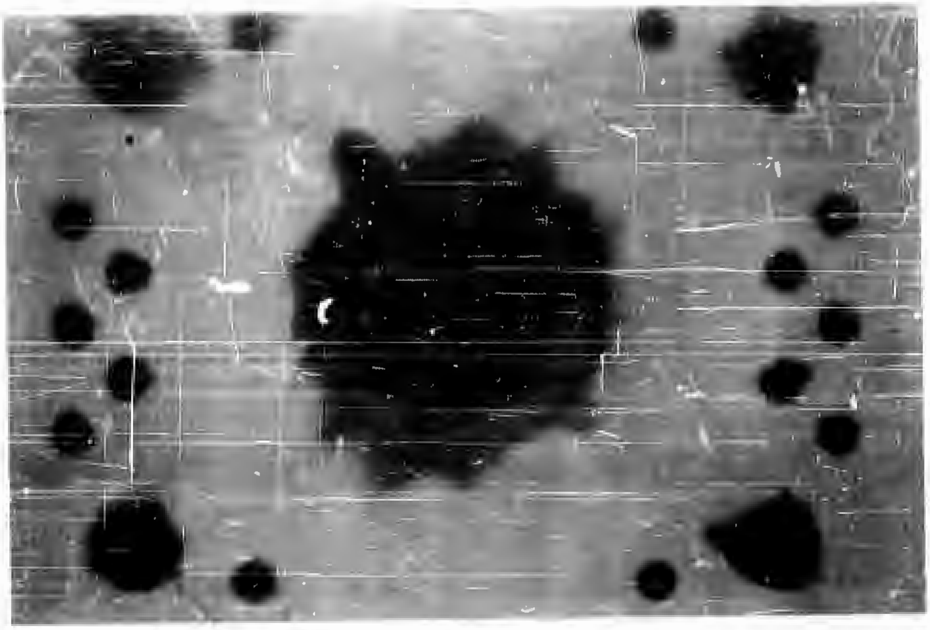

Fig. 6.5 Third Layer of an Area Study Panel (Exposed to 75.0 cal/cm$^2$)

Fig. 6.6 Fourth Layer of an Area Study Panel (Exposed to 75.0 cal/cm$^2$)

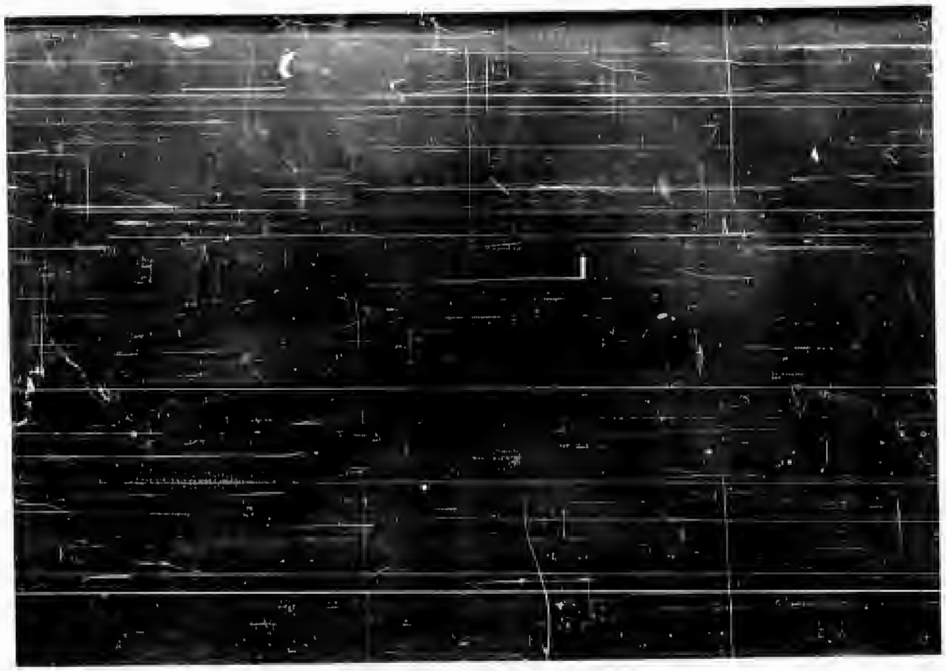

Fig. 6.7 Fifth Layer of an Area Study Panel
(Exposed to 75.0 cal/cm$^2$)

CHAPTER 7

EFFECT OF THERMAL RADIATION ON
CERTAIN MISCELLANEOUS ITEMS OF MILITARY INTEREST

## 7.1 OBJECTIVE

The objective was to obtain limited data on the performance characteristics of a few miscellaneous materials including some items of Chemical Corps issue which were also of interest to the Quartermaster Corps.

## 7.2 CHEMICAL CORPS ITEMS

### 7.2.1 Experiment Design

The Chemical Corps has joint responsibility with the Quartermaster Corps, or may have sole responsibility, for certain items of Protective Clothing. A few such items used, or intended for use, for gas warfare protection were to be field tested at UPSHOT-KNOTHOLE. Included in the test were a plastic protective cover, impregnated clothing fabrics, and gas mask components.

#### 7.2.1.1 Materials

Table 7.1 lists the materials and combinations tested and the radiant energy to which they were exposed.

The mylar film is a plastic under consideration as a material for protective capes. It was exposed over four fabric layers which simulated the double-layer field jacket, wool shirt, and underwear of the temperate uniform. (Chap. 2)

The impregnated materials exposed were supplied by the Chemical Corps and were impregnated with $XXCC_3$

The gas mask material was a special fabric composed of random fiber batt impregnated with an absorbent material.

The gas mask face pieces were from two types of civilian masks. They were made of rubber with plastic eye pieces.

TABLE 7.1 - Chemical Corps Items Exposed

| Item | Radiant Energy (cal/cm$^2$) | | | | |
|---|---|---|---|---|---|
| | 60.0 | 40.5 | 33.5 | 21.5 | 12.5 |
| Mylar film over temperate uniform assembly | x | | | | |
| 9 oz sateen, impregnated, over 10 oz cotton underwear fabric, impregnated | | x | x | | x |
| 9 oz sateen, impregnated, over 10 oz cotton underwear fabric, unimpregnated | | x | x | | x |
| Gas mask material | | | x | x | |
| Gas mask face pieces | | | | x | x |

7.2.1.2 Methods of Exposure

All the materials listed in Table 7.1 (except the face pieces) were exposed on panels with paper temperature indicators beneath, as described in par. 1.4.

Two replicate panels of Mylar film were exposed on Shot 10 at 60.0 cal/cm$^2$.

The impregnated sateens, as shown in Table 7.1 were exposed on Shot 10 at three intensities over both impregnated and unimpregnated heavy cotton underwear fabrics. One panel of each was exposed to 40.5 cal/cm$^2$ and two replicate panels of each to 33.5 and 12.5 cal/cm$^2$.

The configuration of the gas mask face pieces did not permit them to be mounted as the other materials with temperature indicators beneath. Hence, they were attached to plywood boards and exposed normal to the burst. Visual evidence of damage was the only criterion for their evaluation. The masks were exposed on Shot 9 to 12.5 and 21.5 cal/cm$^2$.

7.2.2 Results and Discussions

7.2.2.1 Mylar Film

Owing to the unexpected and severe blast damage at the 60.0 cal/cm$^2$ station, only one of the Mylar film panels were recovered intact. The outer layers of this combination, consisting of the film, sateen, and oxford, were thermally destroyed, the middle layer (shirting) was heavily scorched, and the underwear fabric was discolored. The temperature indicating papers showed that the temperature under the fabric system was less than 54°C.

Comparison with previous results (Shot 9) on the same fabric assembly with no film at a comparable energy level (75 cal/cm$^2$) indicated that the Mylar film might have had a detrimental effect on the thermal resistance of the fabrics, although the temperatures under the panels with and without the film were similar. In the previous exposure only the outer sateen layer was destroyed, the oxford was scorched or lightly charred in spots, the wool shirting was singed, and the underwear fabric slightly discolored. These findings cannot be considered conclusive, however, since only one panel with the Mylar film was recovered.

### 7.2.2.2 Impregnated Fabrics

Table 7.2 lists the visual evidences of damage noted on the impregnated fabrics at the three stations and the temperatures recorded beneath each assembly. At all stations except the 12.5 cal/cm$^2$ the impregnated sateen was destroyed, the impregnated underwear was intact but badly discolored, and the unimpregnated underwear was discolored and scorched. The much darker color on the impregnated underwear, which was also evident on the wood backing of these fabrics, was probably the result of decomposition of the impregnating compound.

At the 12.5 cal/cm$^2$ station the critical energy of the impregnated sateens was not reached, and so the fabric remained intact although it was almost completely charred. Both the impregnated and unimpregnated underwear fabrics were browned and scorched. In the absence of a completely unimpregnated assembly for a control, the results of the 12.5 cal/cm$^2$ exposures can only be compared with the same untreated fabric assemblies which were exposed to identical energies on Shot 9. In this case the sateen was destroyed and the underwear layer lightly scorched. The temperature under the unimpregnated assembly was the same (205°C). It may be that the Impregnite caused a rise in the critical energy level so that the treated sateen on Shot 10 was spared and the untreated on Shot 9 destroyed. Absence of the brown color on the unimpregnated underwear fabric made it appear less damaged than the impregnated.

The temperatures under the fabric assemblies with the impregnated underwear were difficult to read accurately because the temperature indicators were stained with the same brown deposit that covered the underwear fabrics and wood backings. However, it appears that at all stations except that farthest from the blast, the unimpregnated underwear was more effective than the impregnated in thermal protection. This advantage was not noted at 12.5 cal/cm$^2$ where the highest temperatures of all were recorded. The higher temperatures at the more distant stations are not inconsistent with other data on thermal effects observed during these tests. (See Chapter 2)

In the case of the more distant station the outer fabric layer remained intact thus acting as a heat reservoir whereas at the closer stations complete thermal destruction of the outer layer removed the heat reservoir. This is reasonable and has been observed in laboratory work [4] where certain levels of thermal energy resulted in less severe burns on pigs, protected by fabric layers, than were observed for lower energy levels. This suggests the distinct possibility that two or more layers of light weight fabrics should afford greater protection against the primary thermal effects of a nuclear detonation than one heavy layer. This should be especially true at thermal irradiances below the critical energy of a heavy fabric but above the critical energy for one or more layers of light weight fabric.

TABLE 7.2 - Damage Sustained by Impregnated Fabric Assemblies

| $cal/cm^2$ | Outer Layer Impregnated Sateen | 2nd Layer Impregnated Underwear | 2nd Layer Unimpregnated Underwear | Beneath Fabric Temperature |
|---|---|---|---|---|
| 40.5 | Destroyed | Intact, very heavy brown color through the fabric to the wood backing. | | 142-163°C |
| | Destroyed | | Brown color and scorching. | 94°C |
| 33.5 | Destroyed | Intact, very heavy brown color, greasy to the touch. Color and greasy material penetrated to wood backing. | | 205°C |
| | Destroyed | | Brown color and scorching. | 77°C |
| | Destroyed | Intact, very heavy brown color, greasy to the touch. Color and greasy material penetrated to wood backing. | | 172-205°C |
| | Destroyed | | Brown color and scorching. | 94°C |
| 12.5 | Heavy Char | Brown color with scorching. | | 205°C |
| | Heavy Char | | Brown color with scorching. | 205°C |
| | Heavy Char | Brown color with scorching. | | 205°C |
| | Heavy Char | | Brown color with scorching. | 205°C |

#### 7.2.2.3 Mask Material

The mask material showed good resistance to thermal transfer as evidenced by the failure of any of the temperature indicators beneath them to turn black (i.e., the temperatures were less than 54°C). At both 33.5 cal/cm$^2$ on Shot 10 and 21.5 cal/cm$^2$ on Shot 9 the two outer layers of fabric were destroyed and the third layer partially destroyed and charred. It was difficult to distinguish the char on the inner layers because of the black color of the filler used in each layer of the material. Further damage was caused by glow at the 21.5 cal/cm$^2$ station. Some portions, edges and corners in particular, were destroyed down to the wood backing which was charred. Since these charred areas were not over the temperature indicators the change in temperature due to glow could not be observed, but it must have been considerably greater than that under other areas of the mask material that did not glow. Other panels which exhibited glow over the temperature indicators had temperatures over 305°C.

#### 7.2.2.4 Gas Mask Face Pieces

The rubber portions of the face pieces appeared to have sustained no damage, but the plastic eye pieces had blackened areas at both stations (12.5 and 21.5 cal/cm$^2$). Some areas of the eye pieces appeared to have been softened by the thermal pulse and to have remained plastic when the blast wave arrived. Dirt and small particles were then driven into the softened portions especially at the 21.5 cal/cm$^2$ station. After 24 hours a green bloom appeared on the rubber portions of the masks from the 21.5 cal/cm$^2$ station, and a few hours later a similar bloom, but lighter in color, also appeared on the face pieces exposed to 12.5 cal/cm$^2$. The significance of this bloom is not known at present. The wood backing under the transparent eye pieces at both stations was scorched and charred.

## 7.3 PACKAGED QM ITEMS

### 7.3.1 Experiment Design

Four each of standard packs of QMC 5/1 rations, bale packs of clothing, and fiberboard boxes of clothing were exposed to 94.0, 40.5, 12.5, and 6.9 cal/cm$^2$ on Shot 10. At the closest station two each of the three types of containers were staked and anchored to the ground. This was done in order to compare the blast effects upon anchored and free containers. At the farther stations the blast effect was not expected to be significant on these items.

The 5/1 ration containers consisted of a waterproofed fiberboard box in a waterproofed fiberboard sleeve. The clothing boxes were of the double wall corrugated fiberboard type. The clothing bale was of the standard type. A core of compressed clothing with baling boards on top and bottom was wrapped in a waterproof Kraft paper and an outer layer of burlap.

7.3.2 Results and Discussion

Information obtained from a previous test at Bikini which involved some packaged materials showed considerable variation in results which could not be interpreted due to lack of specific information concerning the exposure. Since containers of food and bales of clothing do not lend themselves to laboratory studies of this nature, field studies had to be conducted in order to evaluate the effects of an atomic explosion and obtain guidance as to future work on these items.

At the closest station all containers were destroyed, and the contents which escaped destruction were strewn over a large area. Some of the ruptured food cans from the ration boxes were found as far back as the 40.5 cal/cm$^2$ station. These cans have the appearance of having been in a fire and exploding. In addition, items of clothing from the bales were scattered over distances ranging up to 1000 ft. One unit of clothing was recovered without its protective coverings and, on examination, was found to have had dust driven into it to depth of 4 to 5 in.

There was a progressive decrease in the amount of displacement of the packaged items as the distance from ground zero became greater. This was as expected. The clothing bales and boxes were displaced approximately 30 ft. at the 40.5 cal/cm$^2$ station and just rolled over on their side at the 12.5 cal/cm$^2$ station.

The thermal damage, however, was not consistent. As in the blast damage the most severe effects appeared to be at the closest station, particularly as the food containers were concerned. The only other station where severe damage was sustained was at the 12.5 cal/cm$^2$ station where a bale of clothing was completely consumed by fire leaving only the metal portions of the clothing and bale (Fig. 7.1). At the 40.5 cal/cm$^2$ station the bales were stripped of their burlap covering. The 5/1 ration boxes at this location were scorched. Inasmuch as the blast arrival time was such as to limit burning of the fabric to those areas incident to the thermal radiant energy it appears likely that the unburnt portions were stripped off by the blast wave, blown away and possibly consumed by fire which continued after the blast effect. The ration boxes had the asphalt waterproof layer softened to the point where it bled through the outer paper layer. Dust was found on the inside of all boxes, although part of this may have resulted from dust storms during the time the items were on location prior to the actual detonation of the bomb.

At the 12.5 cal/cm$^2$ station the boxes were scorched and the outer layers of paper destroyed (Fig. 7.2).

The packaged materials seemed to be scorched the heaviest wherever there was black printing exposed to the blast.

At the farthest station there was little or damage to the boxes or bales other than a very slight scorching on some of the items and a slight delamination of the paper from the asphalt layer on some of the boxes.

Evaluation of the contents revealed that the food and clothing from all the stations except the closest were in a usable condition.

Fig. 7.1 Remains, Bale of Clothing Consumed by Fire

Fig. 7.2 Ration Boxes after Exposure

TABLE A.1 - Temperatures Attained under Uniform Fabric Assemblies

| Energy (cal/cm²) | Assembly | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | HW | | HWFR | | HW 50/50 | | HWFR 50/50 | | T | |
| | Contact | Spaced | Contact | Spaced | Contact | Spaced | Contact | Spaced | Contact | Spaced |
| 9.5 | 254 | 205 | 205 | 121 | 142 | 77 | | | | |
| | 205 | 205 | 205 | 121 | 163 | 77 | | | | |
| | 205 | — | 205 | 121 | 163 | 77 | | | | |
| 12.5 | 205 | 205 | 205 | 121 | 101 | 77 | | | | |
| | 205 | 107 | 205 | 94 | 101 | 77 | | | | |
| | 205 | 77 | 205 | 94 | 101 | 77 | | | | |
| 12.5 | 205 | 77 | 205 | 127 | | | 127 | 77 | 54 | 54 |
| (Shot 10) | 205 | 77 | | | | | 121 | 77 | | |
| 16.0 | 205 | 101 | 205 | 121 | 121 | 77 | | | | |
| | 205 | 94 | 205 | 77 | 101 | 77 | | | | |
| | 205 | 94 | 205 | 77 | 101 | 77 | | | | |
| 17.0 | 172 | 127 | 254 | 121 | 101 | 94 | 127 | 77 | 54 | 54 |
| | 172 | 163 | 254 | 121 | 121 | 85 | 127 | 77 | 54 | 54 |
| 21.5 | 205 | 94 | 205 | 121 | 142 | 77 | | | | |
| | 205 | 142 | 205 | 121 | 142 | 77 | | | | |
| | 205 | 121 | 205 | 107 | 142 | 77 | | | | |
| 26.0 | 254 | 205 | 254 | 127 | 142 | 107 | 121 | 77 | 54 | 54 |
| | 254 | 254 | | | 142 | 121 | 101 | 77 | 54 | 54 |
| 29.5 | | | | | | | | | 62 | — |
| | | | | | | | | | 62 | — |
| | | | | | 142 | 107 | | | 54 | 54 |
| | | | | | 142 | 107 | | | 54 | 54 |
| | | | | | | | | | 54 | 54 |
| 33.5 | | | | | 142 | 127 | 142 | 77 | | |
| | | | | | 142 | 142 | 127 | 77 | | |
| 40.5 | | | | | [illegible] | 163 | 101 | 85 | | |
| | | | | | [illegible] | 142 | | | | |
| 41.0 | | | | | | | | | 54 | 54 |
| | | | | | | | | | 54 | 54 |
| | | | | | | | | | 54 | 54 |
| | | | | | | | | | 54 | 54 |
| | | | | | | | | | 54 | 54 |
| 50.0 | | | | | | | | | 54 | 54 |
| | | | | | | | | | 54 | 54 |
| | | | | | | | | | 54 | 54 |
| | | | | | | | | | 62 | 54 |
| 60.0 | Not recovered | | | | | | | | | |
| 75.0 | | | | | | | | | 54 | 54 |
| | | | | | | | | | 54 | 54 |
| | | | | | | | | | 2 not recovered | |

TABLE A.2 - Maximum Temperatures (°C) under Wool/Synthetic Blended Serge Combinations

| % Synthetic in Blend | Dynel 17.0 cal/cm² | Dynel 33.5 cal/cm² | Dynel 40.5 cal/cm² | Orlon 17.0 cal/cm² | Orlon 33.5 cal/cm² | Orlon 40.5 cal/cm² | Acrilan 17.0 cal/cm² | Acrilan 33.5 cal/cm² | Acrilan 40.5 cal/cm² |
|---|---|---|---|---|---|---|---|---|---|
| 0* Spaced | 54 | 54 | 54 | | | | | | |
| Contact | 62 | 62 | 62 | | | | | | |
| 15 Spaced | 54 | 54 | 54 | 62 | 62 | 54 | 62 | 54 | 54 |
| Contact | 62 | 54 | 54 | 62 | 62 | 62 | 54 | 62 | 62 |
| 30 Spaced | 75 | 54 | 69 | 54 | 54 | 54 | 77 | 127 | 127 |
| Contact | 62 | 54 | 62 | 54 | 62 | 77 | 62 | 77 | 62 |
| 50 Spaced | 94 | 54 | 107 | 77 | 85 | 107 | 94 | 142 | 172 |
| Contact | 54 | 54 | 62 | 62 | 77 | 115 | 77 | 115 | 142 |
| 100 Spaced | 94 | 94 | 121 | 85 | 94 | 107 | 115 | 205 | 205 |

**Wool/Nylon Series**

| | 15% Nylon/85% Wool Serge 17.0 | 15% Nylon/85% Wool Serge 33.5 | 15% Nylon/85% Wool Serge 40.5 | 15% Nylon/85% Wool Shirting 26* | 15% Nylon/85% Wool Shirting 33.5 | 15% Nylon/85% Wool Shirting 40.5 | 100% Wool Shirting 26* | 100% Wool Shirting 33.5 |
|---|---|---|---|---|---|---|---|---|
| Contact | 62 | 62 | 62 | 107 | 62 | 62 | 94 | 62 |
| Spaced | 54 | 54 | 54 | 107 | 54 | 54 | 85 | 62 |

* At this station the Wool Nylon and Wool Shirting was exposed as a single layer (without the underwear as the second layer).

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1 Asst. Chief of Staff, G-3, D/A, Washington 25, D.C. ATTN: Dep. CofS, G-3 (RR&SW)
2 Chief of Research and Development, D/A, Washington 25, D.C. ATTN: Special Weapons and Air Defense Division
3 Chief of Ordnance, D/A, Washington 25, D.C. ATTN: ORDTX-AR
4- 6 Chief Signal Officer, D/A, P&O Division, Washington 25, D.C. ATTN: SIGOP
7 The Surgeon General, D/A, Washington 25, D.C. ATTN: Chief, R&D Division
8- 9 Chief Chemical Officer, D/A, Washington 25, D.C.
10 The Quartermaster General, D/A, Washington 25, D. C. ATTN: Research and Development Div.
11- 15 Chief of Engineers, D/A, Washington 25, D.C. ATTN: ENGNB
16 Chief of Transportation, Military Planning and Intelligence Div., Washington 25, D.C.
17- 19 Commanding General, Continental Army Command, Ft. Monroe, Va.
20 President, Board #1, Headquarters, Continental Army Command, Ft. Bragg, N.C.
21 President, Board #2, Headquarters, Continental Army Command, Ft. Knox, Ky.
22 President, Board #3, Headquarters, Continental Army Command, Ft. Benning, Ga.
23 President, Board #4, Headquarters, Continental Army Command, Ft. Bliss, Tex.
24 Commanding General, U.S. Army Caribbean, Ft. Amador, C.Z. ATTN: Cml. Off.
25 Commander-in-Chief, European Command, APO 128, c/o PM, New York, N.Y.
26- 27 Commander-in-Chief, Far East Command. APO 500, c/o PM, San Francisco, Calif. ATTN: ACofS, J-3
28- 29 Commanding General, U.S. Army Europe, APO 403, c/o PM, New York, N.Y. ATTN: OPOT Div., Combat Dev. Br.
30- 31 Commanding General, U.S. Army Pacific, APO 958, c/o PM, San Francisco, Calif. ATTN: Cml. Off.
32- 33 Commandant, Command and General Staff College, Ft. Leavenworth, Kan. ATTN: ALLLS(AS)
34 Commandant, The Artillery and Guided Missile School, Ft. Sill, Okla.
35 Secretary, The Antiaircraft Artillery and Guided Missile School, Ft. Bliss, Texas. ATTN: Maj. George L. Alexander, Dept. of Tactics and Combined Arms
36 Commanding General, Medical Field Service School, Brooke Army Medical Center, Ft. Sam Houston, Tex.
37 Director, Special Weapons Development Office, Headquarters, CONARC, Ft. Bliss, Tex. ATTN: Lt. Arthur Jaskierny
38 Commandant, Army Medical Service Graduate School, Walter Reed Army Medical Center, Washington 25, D.C.
39 Superintendent, U.S. Military Academy, West Point, N.Y. ATTN: Prof. of Ordnance
40 Commandant, Chemical Corps School, Chemical Corps Training Command, Ft. McClellan, Ala.
41- 42 Commanding General, Research and Engineering Command, Army Chemical Center, Md. ATTN: Deputy for RW and Non-Toxic Material
43- 44 Commanding General, Aberdeen Proving Grounds, Md. (inner envelope) ATTN: RD Control Officer (for Director, Ballistics Research Laboratory)
45- 47 Commanding General, The Engineer Center, Ft. Belvoir, Va. ATTN: Asst. Commandant, Engineer School
48 Commanding Officer, Engineer Research and Development Laboratory, Ft. Belvoir, Va. ATTN: Chief, Technical Intelligence Branch
49 Commanding Officer, Picatinny Arsenal, Dover, N.J. ATTN: ORDBE-TK
50 Commanding Officer, Frankford Arsenal, Philadelphia 37, Pa. ATTN: Col. Tewes Kundel
51 Commanding Officer, Army Medical Research Laboratory, Ft. Knox, Ky.
52- 53 Commanding Officer, Chemical Corps Chemical and Radiological Laboratory, Army Chemical Center, Md. ATTN: Tech. Library
54 Commanding Officer, Transportation R&D Station, Ft. Eustis, Va.
55 Director, Technical Documents Center, Evans Signal Laboratory, Belmar, N.J.
56 Director, Waterways Experiment Station, PO Box 631, Vicksburg, Miss. ATTN: Library
57 Director, Armed Forces Institute of Pathology, 7th and Independence Avenue, S.W., Washington 25, D.C.
58 Director, Operations Research Office, Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase, Md. Washington 15, D.C.
59- 61 Commanding General, Quartermaster Research and Development Command, Quartermaster Research and Development Center, Natick, Mass. ATTN: CBR Liaison Officer
62- 68 Technical Information Service, Oak Ridge, Tenn. (Surplus)

NAVY ACTIVITIES

69- 70 Chief of Naval Operations, D/N, Washington 25, D.C. ATTN: OP-36
71 Chief of Naval Operations, D/N, Washington 25, D.C. ATTN: OP-03EG
72 Director of Naval Intelligence, D/N, Washington 25, D.C. ATTN: OP-922V
73 Chief, Bureau of Medicine and Surgery, D/N, Washington 25, D.C. ATTN: Special Weapons Defense Div.
74 Chief, Bureau of Ordnance, D/N, Washington 25, D.C.
75- 76 Chief, Bureau of Ships, D/N, Washington 25, D.C. ATTN: Code 348
77 Chief, Bureau of Yards and Docks, D/N, Washington 25, D.C. ATTN: D-440
78 Chief, Bureau of Supplies and Accounts, D/N, Washington 25, D.C.
79- 80 Chief, Bureau of Aeronautics, D/N, Washington 25, D.C.
81 Chief of Naval Research, Department of the Navy Washington 25, D.C. ATTN: Code 811
82 Commander-in-Chief, U.S. Pacific Fleet, Fleet Post Office, San Francisco, Calif.
83 Commander-in-Chief, U.S. Atlantic Fleet, U.S. Naval Base, Norfolk 11, Va.
84- 87 Commandant, U.S. Marine Corps, Washington 25, D.C. ATTN: Code A03H
88 President, U.S. Naval War College, Newport, R.I.
89 Superintendent, U.S. Naval Postgraduate School, Monterey, Calif.
90 Commanding Officer, U.S. Naval Schools Command, U.S. Naval Station, Treasure Island, San Francisco, Calif.
91 Commanding Officer, U.S. Fleet Training Center, Naval Base, Norfolk 11, Va. ATTN: Special Weapons School
92- 93 Commanding Officer, U.S. Fleet Training Center, Naval Station, San Diego 36, Calif. ATTN: (SPWP School)
94 Commanding Officer, Air Development Squadron 5, VX-5, U.S. Naval Air Station, Moffett Field, Calif.
95 Commanding Officer, U.S. Naval Damage Control Training Center, Naval Base, Philadelphia 12, Pa. ATTN: ABC Defense Course

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96 Commanding Officer, U.S. Naval Unit, Chemical Corps School, Army Chemical Training Center, Ft. McClellan, Ala.
97 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: EE
98 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: EH
99 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: R
100 Commander, U.S. Naval Ordnance Test Station, Inyokern, China Lake, Calif.
101 Officer-in-Charge, U.S. Naval Civil Engineering Res. and Evaluation Lab., U.S. Naval Construction Battalion Center, Port Hueneme, Calif. ATTN: Code 753
102 Commanding Officer, U.S. Naval Medical Research Inst., National Naval Medical Center, Bethesda [illegible] Md.
103 Director, Naval Air Experimental Station, Air Material Center, U.S. Naval Base, Philadelphia, Penn.
104 Director, U.S. Naval Research Laboratory, Washington 25, D.C. ATTN: Code 2029
105 Director, The Material Laboratory, New York Naval Shipyard, Brooklyn, N.Y. Norfolk, Va.
106 Commanding Officer and Director, U.S. Navy Electronics Laboratory, San Diego 52, Calif. ATTN: Code 4223
107-110 Commanding Officer, U.S. Naval Radiological Defense Laboratory, San Francisco 24, Calif. ATTN: Technical Information Division
111 Commanding Officer and Director, David W Taylor Model Basin, Washington 7, D.C. ATTN: Library
112 Commander, U.S. Naval Air Development Center, Johnsville, Pa.
113 Director, Office of Naval Research Branch Office, 1000 Geary St., San Francisco, Calif.
114 Commanding Officer, Clothing Supply Office, Code 1D-0, 3rd Avenue and 29th St., Brooklyn, N.Y.
115-121 Technical Information Service, Oak Ridge, Tenn. (Surplus)

AIR FORCE ACTIVITIES

122 Asst. for Atomic Energy, Headquarters, USAF, Washington 25, D.C. ATTN: DCS/O
123 Director of Operations, Headquarters, USAF, Washington 25, D.C. ATTN: Operations Analysis
124 Director of Plans, Headquarters, USAF, Washington 25, D.C. ATTN: War Plans Div.
125 Director of Research and Development, Headquarters, USAF, Washington 25, D.C. ATTN: Combat Components Div.
126-127 Director of Intelligence, Headquarters, USAF, Washington 25, D.C. ATTN: AFOIN-IB2
128 The Surgeon General, Headquarters, USAF, Washington 25, D.C. ATTN: Bio. Def. Br., Pre. Med. Div.
129 Deputy Chief of Staff, Intelligence, Headquarters, U.S. Air Forces Europe, APO 633, c/o PM, New York, N.Y. ATTN: Directorate of Air Targets
130 Commander, 497th Reconnaissance Technical Squadron (Augmented), APO 633, c/o PM, New York, N.Y.
131 Commander, Far East Air Forces, APO 925, c/o PM, San Francisco, Calif.
132 Commander-in-Chief, Strategic Air Command, Offutt Air Force Base, Omaha, Nebraska. ATTN: Special Weapons Branch, Inspector Div., Inspector General
133 Commander, Tactical Air Command, Langley AFB, Va. ATTN: Documents Security Branch
134 Commander, Air Defense Command, Ent AFB, Colo.
135-136 Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, O. ATTN: WCRRN, Blast Effects Research
137 Commander, Air Training Command, Scott AFB, Belleville, Ill. ATTN: DCS/O GTP
138 Assistant Chief of Staff, Installations, Headquarters, USAF, Washington 25, D.C. ATTN: AFCIE-E
139 Commander, Air Research and Development Command, PO Box 1395, Baltimore, Md. ATTN: RDDN
140 Commander, Air Proving Ground Command, Eglin AFB, Fla. ATTN: AG/TRB
141-142 Director, Air University Library Maxwell AFB, Ala.
143-150 Commander, Flying Training Air Force, Waco, Tex. ATTN: Director of Observer Training
151 Commander, Crew Training Air Force, Randolph Field, Tex. ATTN: 2GTS, DCS/O
152 Commander, Headquarters, Technical Training Air Force, Gulfport, Miss. ATTN: TA&D
153-154 Commandant, Air Force School of Aviation Medicine, Randolph AFB, Tex.
155-160 Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, O. ATTN: WCOSI
161-162 Commander, Air Force Cambridge Research Center, LG Hanscom Field, Bedford, Mass. ATTN: CRQST-2
163-165 Commander, Air Force Special Weapons Center, Kirtland AFB, N. Mex. ATTN: Library
166 Commandant, USAF Institute of Technology, Wright-Patterson AFB, Dayton, O. ATTN: Resident College
167 Commander, Lowry AFB, Denver, Colo. ATTN: Department of Armament Training
168 Commander, 1009th Special Weapons Squadron, Headquarters, USAF, Washington 25, D.C.
169-170 The RAND Corporation, 1700 Main Street, Santa Monica, Calif. ATTN: Nuclear Energy Division
171 Commander, Second Air Force, Barksdale AFB, Louisiana. ATTN: Operations Analysis Office
172 Commander, Eighth Air Force, Westover AFB, Mass. ATTN: Operations Analysis Office
173 Commander, Fifteenth Air Force, March AFB, Calif. ATTN: Operations Analysis Office
174-180 Technical Information Service, Oak Ridge, Tenn. (Surplus)

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

181 Asst. Secretary of Defense, Research and Development, D/D, Washington 25, D.C. ATTN: Tech. Library
182 U.S. Documents Officer, Office of the U.S. National Military Representative, SHAPE, APO 55, New York, N.Y.
183 Director, Weapons Systems Evaluation Group, OSD, Rm 2E1006, Pentagon, Washington 25, D.C.
184 Armed Services Explosives Safety Board, D/D, Building T-7, Gravelly Point, Washington 25, D.C.
185 Commandant, Armed Forces Staff College, Norfolk 11, Va. ATTN: Secretary
186-191 Commanding General, Field Command, Armed Forces Special Weapons Project, PO Box 5100, Albuquerque, N. Mex.
192-193 Commanding General, Field Command, Armed Forces, Special Weapons Project, PO Box 5100, Albuquerque, N. Mex. ATTN: Technical Training Group
194-202 Chief, Armed Forces Special Weapons Project, Washington 25, D.C. ATTN: Documents Library Branch
203 Office of the Technical Director, Directorate of Effects Tests, Field Command, AFSWP, PO Box 577, Menlo Park, Calif. ATTN: Dr E. B. Doll
204-210 Technical Information Service Oak Ridge, Tenn. (Surplus)

ATOMIC ENERGY COMMISSION ACTIVITIES

211-213 U.S. Atomic Energy Commission, Classified Technical Library, 1901 Constitution Ave., Washington 25, D.C. ATTN: Mrs. J. M. O'Leary (For DMA)
214-215 Los Alamos Scientific Laboratory, Report Library, PO Box 1663, Los Alamos N. Mex. ATTN: Helen Redman
216-220 Sandia Corporation, Classified Document Division, Sandia Base, Albuquerque, N. Mex. ATTN: Martin Lucero
221-223 University of California Radiation Laboratory, PO Box 808, Livermore, Calif. ATTN: Margaret Edlund
224 Weapon Data Section, Technical Information Service, Oak Ridge, Tenn.
225-285 Technical Information Service, Oak Ridge, Tenn. (Surplus)



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