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Project 8.5

THERMAL RADIATION PROTECTION AFFORDED TEST ANIMALS BY FABRIC ASSEMBLIES

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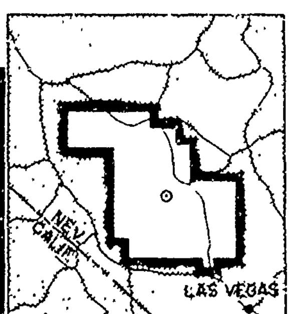

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OPERATION UPSHOT-KNOTHOLE

Project 8.5

THERMAL RADIATION PROTECTION AFFORDED TEST ANIMALS BY FABRIC ASSEMBLIES

REPORT TO THE TEST DIRECTOR

by

J. Fred Oesterling and Staff

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Quartermaster Research and Development Laboratories
Army Medical Service Graduate School
Walter Reed Army Medical Center
University of Rochester Atomic Energy Project

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ABSTRACT

Field tests at UPSHOT-KNOTHOLE, Shots 9 and 10, were conducted in which Chester White Pigs, clothed in Armed Services fabric assemblies or placed behind a series of open or fabric-covered portholes, were exposed to the effects of atomic explosions. These tests were carried out (1) to determine the protective value of a limited number of clothing combinations, (2) to obtain field information that could be related to laboratory data on fabric protective characteristics, (3) to investigate the value of a fire resistant treatment in reducing thermal injuries, and (4) to study the effect of various details of clothing design on thermal protection.

Three different fabric assemblies were tested, each with and without a fire resistant treatment on the outer layer. These assemblies were: (1) A four-layer Temperate ensemble (corresponding to the cold-wet uniform with the frieze liner removed) which provided excellent protection at all incident energies up to 40 cal/cm^2 with no reason to doubt its efficacy up to 75 cal/cm^2; (2) Hot-Wet 50/50 ensemble (5.2 oz oxford over 10.5 oz 50/50 wool/cotton knit underwear fabric), which provided good protection up to the highest energy levels for which data were obtained, 41.0 cal/cm^2 for the untreated ensemble and 33.5 cal/cm^2 for the treated; and (3) Hot-Wet ensemble (5.2 oz oxford over, 3.2 oz knit cotton underwear fabric), which was inadequate at energy levels from 9.0 to 50.0 cal/cm^2, whether or not it was treated for fire resistance.

Flaming was noted in some uniforms not treated for fire resistance. The treated assemblies gave better protection than their untreated counterparts, especially at the more distant stations, 5800, 6800, and 7800 ft from ground zero. Burns beneath the fabric assemblies at the higher levels of thermal energy were consistently less serious than anticipated from prior laboratory experience. Smoke developed during the early stages of the thermal pulse may have reduced the damaging effects by obscuring the clothed animals from some of the radiation. Where the fabrics were spaced away from the skin, the burns in general were less serious than where the fabrics were in close skin contact.

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.

PREFACE

Since the development of the atomic bomb, the Armed Services have been engaged in a coordinated program of research and experimentation, a vital part of which is concerned with the protection of the soldier from the thermal effects of this weapon. The evidence from Hiroshima and Nagasaki is that clothing can play a vital role in sparing those not in the immediate vicinity of the explosion from severe burns. Just how effective is it? Up to what distance from ground zero does it protect? Is a fire resistant treatment necessary for the fabric? How many fabric layers are needed? What elements of clothing design should be considered?

To help find an answer to these and many kindred questions, the field tests described in this report were carried out as a result of the cooperative efforts of three agencies: Quartermaster Research and Development Laboratories, United States Army; Army Medical Service Graduate School, Walter Reed Army Medical Center; and University of Rochester Atomic Energy Project. The work of the University of Rochester was sponsored in part by a transfer of funds from the Quartermaster Corps.

The complete list of names of those who participated in some phase of this program is too lengthy to set down here. The following is an accounting of those who have taken an active part in the planning, preparation and conduct of the tests, in the assessment of the results and in the preparation of this report:

Col. Wm. S. Stone, Commandant, Army Medical Service Graduate School, Walter Reed AMC; Dr. Ralph G. H. Siu, Technical Director, Res. and Dev. Div., Office of the Quartermaster General; Dr. S. J. Kennedy, Research Director, Textiles, Clothing, and Footwear Br., Res. and Dev. Div., OQMG; Col. Roy D. Maxwell, Lt. Col. James T. Brennan, and Capt. Thomas G. Murnane, AMSGS, Walter Reed AMC: Drs. Herman E. Pearse, H. D. Kingsley, and George Mixter, University of Rochester (Medical School) Atomic Energy Project; Lt. Col. Therman Bouse, QMC; Dr. J. Fred Oesterling; Dr. Allen C. Werner, Mssrs. A. J. McQuade, William A. Caskie, R. W. Persico, John Davies, and David Feldman, QM Res. and Dev. Labs.

The authors gratefully acknowledge the assistance of Lt. Commander Roger G. Preston, Director, Program 8 and that of the staff of the Directorate of Weapons Effects Test, Field Command, AFSWP, without whose help this work would not have been possible.

The work of Mr. Norman E. Roberts, QM Res. and Dev. Labs., in editing this report is acknowledged.

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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 overall 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 on thermal radiation protection afforded test animals by fabric assemblies were designed and carried out at Shots 2, 9, and 10, to provide the following:

(1) Immediate information on the protective value of a limited number of Armed Forces standard and experimental clothing assemblies which could be used as a basis for prompt action should the need for protective uniforms arise in the near future. Laboratory methods have not yet advanced far enough to provide such information.

(2) Data on fabric protective characteristics as obtained in the field on test animals with a view to correlating these data with the results of laboratory tests, in which animals may or may not be used, with the ultimate objective of developing standard laboratory methods using purely physical techniques, thus dispensing with the use of animals both in the field and laboratory, except as a check method.

(3) Data on the effect of fire resistant treatment on the thermal protective characteristics of fabrics.

(4) Data on the effect of various details of clothing design and construction on thermal protection.

The long range program involves the establishment of factual information for the selection of that combination of fabrics and design of clothing which will afford the maximum thermal protection consistent with other requirements. To test adequately the large number of possible materials and assemblies it will be necessary to develop laboratory methods which can be reliably correlated with field results.

1.2 BACKGROUND

Fabric test panels and a limited number of clothing items exposed at Operations BUSTER and RANGER indicated that reflectance, fabric thickness, 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. (1, 2)

Early work in this field was directed toward 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 burning or scorching was not necessarily a good index of the heat transmitted from the outer surface to the inner surface of a fabric system. These criteria of whether fabric did or did not burn gave no conclusive indication of what would happen to skin behind the fabric.

The Naval Material Laboratory, Brooklyn, New York, has been conducting investigations on fabric destruction and the transfer of thermal energy to backing material. More recently its efforts have been concentrated on the development of an inanimate backing material that will simulate the time-temperature behavior of human skin when subjected to thermal stress. Field tests utilizing a backing made of black polyethylene were carried out by Project 8.9 at UPSHOT-KNOTHOLE, Shots 9 and 10.

Considerable work has been carried out by numerous investigators on assessment of the local burn in animals (principally in pigs, rats, and dogs) when exposed to varying degrees of thermal energy as produced in the laboratory. (3,4,5) Most of this work has been done on unprotected skin. Only recently has attention been focused on burns which result from thermal energy impinging upon a layer or layers of fabric placed against or in close proximity to the skin of test animals. (6,7)

Laboratory studies conducted by the University of Rochester, with a carbon arc as the energy source, during the past year have demonstrated that pig burns behind fabrics do not follow the same time-thermal intensity relationship as found for unprotected skin. These studies have indicated that spacing, flaming (when it occurs), and the so-called "heat reservoir" function of heavier fabrics are important factors. The term heat reservoir function refers to the storing of thermal energy by the fabric with subsequent release to the skin. At high levels of radiant energy the fabric may be completely destroyed and the heat reservoir disappear. Hence, there exists the apparent anomaly whereby a larger thermal dose will, under certain conditions, produce a less severe burn. This function has been related to various times and rates of delivery and to the "critical energy" of a fabric, i.e., the minimum thermal energy by which the fabric is completely destroyed. (8, 9)

An extensive field investigation of burns on the bare skin of pigs behind small portholes was carried out under the direction of the University of Rochester at GREENHOUSE in 1951 (10) and at TUMBLER-SNAPPER in 1952. (11) The purpose of these exposures was to determine the relative effectiveness of various portions of the thermal pulse and also to ascertain the degree of burn at various calorie levels.

The University of Virginia also conducted a limited number of tests using dogs behind portholes at BUSTER. (4) In the dog experiment fabrics were used over the portholes but no burns were observed because of the low intensity of thermal radiation to which the test animals were exposed.

1.3 EXPERIMENT DESIGN

1.3.1 General

The field tests at Shots 2, 9, and 10, conducted cooperatively by the Quartermaster Research and Development Laboratories, Walter Reed Army Medical Center, and University of Rochester Atomic Energy Project, envisioned the use of animals fully clothed with fabric assemblies comparable to actual military ensembles and subjected to thermal exposures ranging from approximately 9.0 to 75 cal/cm^2. In addition, a number of unclothed animals were exposed in aluminum cylinders, each having eight 1-5/8 in. portholes on the side toward the burst. These tests were included in order that burns under fabrics could be observed in the field under controlled conditions of contact and separation, thus simulating the laboratory studies with the arc.

Chester White pigs were selected as the experimental animals because the skin on the side of this animal has a close structural similarity to that of man and gives a comparable response to quantitatively similar thermal stimuli. (12) Its reflectance of radiant energy appears to be similar to that of a fair-skinned human.

1.3.2 Preliminary Tests at Shot 2

A trial run or test in miniature (8 pigs) carried out at Shot 2, 24 March 1953, demonstrated that the equipment, test technique, and operational procedure as planned for the main tests scheduled for May, 1953 were, with minor modifications, quite satisfactory. (See Appendix A.)

1.3.3 Uniform Assemblies

Three principal uniform assemblies were tested; these are identified as Hot-Wet, Hot-Wet 50/50, and Temperate.

The Hot-Wet is a two-layer, lightweight combination intended for hot rainy climates, consisting of an outer layer of cloth, cotton, permeable, oxford, 5.2 oz., Shade 116 (dark green), and an underlayer of cloth, cotton, knit, 3.5 oz.

The Hot-Wet 50/50 consists of the same outer fabric as the Hot-Wet, with Cloth, 50 per cent Wool/50 per cent Cotton, Knit, 10.5 oz., as the under layer in place of the 3.5 oz. cotton. The uniform identified as Temperate is a four-layer ensemble, identical with the Army Cold-Wet uniform without the frieze liner. The outer layer is cloth, cotton, wind resistant, sateen, 9 oz., water repellent, O.G. 107, and the second layer, cloth, cotton, wind resistant, oxford, water repellent, 5.5 oz. O.G. 107. (These two layers are the fabrics used in the jacket, field, M-1951.) The ensemble is completed with cloth, 85 per cent wool/15 per cent nylon, shirting, 16 oz., O.G. 108, as the third layer, and cloth, 50 per cent wool/50 per cent cotton, knit, 10.5 oz., as the undergarment.

Duplicates of these three uniforms with the outer fabric fire-resistant treated with brominated triallyl phosphate polymer were included in the test. Throughout this report these uniforms will be referred to as HW (Hot-Wet); HWFR (Hot-Wet Fire Resistant); HW 50/50 (Hot-Wet 50/50); HWFR 50/50 (Hot-Wet Fire Resistant 50/50); T (Temperate); and TFR (Temperate Fire Resistant). No uniform assemblies heavier than the Temperate were tested in Shots 9 and 10 since preliminary experience in Shot 2 indicated that this ensemble should provide excellent protection up to and including regions where effects other than thermal would be critical factors.

The animal uniforms were constructed from patterns based on body measurements of several pigs at the Department of Agriculture in Beltsville, Md. On the basis of these measurements, uniforms were made up in two sizes and fitted to the individual pigs on the basis of weight. Drawstrings were provided at the waist, the neck, and at the ends of the legs of the uniforms. A full-length zipper, about three inches beyond the back seam and not exposed to the radiant energy, facilitated putting on and taking off the uniform. Seams, zippers, and drawstrings were constructed in accordance with the specifications for the jacket, shell, field, M-1951. Because of the small size of the uniforms, all seams were made like the seam joining the arm to the body in the jacket. In Shot 9 the channel for the drawstring of the HW, HWFR, HW 50/50, and HWFR 50/50 uniforms was made by joining the two layers of fabric with two parallel seams at the waist. In Shot 10 the channel was formed by stitching a one-inch strip of oxford to the underside of the top layer in a construction like that used in the Army Hot-Wet uniform. This provided an extra layer of fabric at the waist for these Shot 10 uniforms. In all the uniforms the ratio of the outer layer size to the second layer size was identical with that specified for the jacket, field, M-1951.

A photograph of an unexposed uniform is shown in Fig. 1.1.

1.3.4 Animal Holders

Photographs of the animal holders are shown in Figs. 1.2 and 1.3. The pig rested on a welded iron rod frame and was supported and securely held in place by a 2-1/4 in. web strap which passed under the pig inside the uniform. Parts of the pig's body not covered by the uniform were protected by heavy gage aluminum sheets which surrounded the animal's head and the side of its legs towards the flash. The pig's fore and hind legs rested in two aluminum wells which were open to the rear and which were fitted with metal rods to which the legs were fastened with thongs. The animal rested against an aluminum backing sheet which gave support against the pressure of the blast wave. The entire assembly was held in place by guy wires and stakes as shown in Fig. 1.2. The cylinder holders for the porthole exposures have been described previously.[11]

1.3.5 Exposure Program

On Shot 9 a total of 55 Chester White pigs weighing from 26 to 43 lbs. were anesthetized in the field with dial-urethane[13] and placed in the field exposure holders immediately after the anesthesia became effective. Forty-four were clothed with appropriate fabric ensembles and exposed at eight stations. The remaining 11 animals were placed in cylindrical aluminum containers at three stations. Small areas of the latter animals were exposed through portholes which held combinations of fabrics under controlled conditions of contact and spacing.

Fifty-six anesthetized Chester White pigs weighing 25 to 53 lbs. were exposed on Shot 10. Forty-two were clothed with appropriate fabric ensembles and exposed at eight stations; 2 were partially protected by Quartermaster protective cream (a high reflectance cream designed to provide protection of the face and hands against thermal radiation);* 11 of the heavier animals were placed in the standard porthole cylinders; and one was placed in an improvised porthole cylinder with thermocouples placed in contact with the pig's skin behind two of the ports which held 9 oz. sateen fabric.

The exposure conditions for each individual uniformed pig (along with the results obtained) are shown in Appendix Tables B.1 to B.6. The overall exposure plans are summarized here, for the uniformed pigs in Table 1.1 and for the cylinder pigs in Table 1.2.

1.3.6 Photography

The photographic work was carried out under Program 9 by Edgerton, Germeshausen, and Grier, Inc. Details may be obtained from their reports.(14) Motion pictures (64 frames/sec) of 18 of the animals in the holders were taken. In both Shots 9 and 10 color motion pictures were taken at the 4500 ft. and 5800 ft. stations, and black and white motion pictures at the 3200 ft. station. At these stations cameras were mounted on 11 ft. towers located in the front and to the side of the animals photographed. The motion photography for the 4500 ft. station was obtained by moving a total of six test animals, three on Shot 9, and three on Shot 10, from the test line (21° S of W from ground zero) to a line 57° S of W where photographic facilities had been installed on a stabilized area for Project 3.27.

As soon as the test area could be safely entered, the animals were removed from the holders and transported back to the base where photographs, black and white and in color, were taken of each animal, clothed and unclothed. Color photographs of the unclothed animals were also taken 72 hr after exposure.

1.3.7 Burn Evaluation

Burns were evaluated as soon as possible after exposure (approximately 3-4 hrs), and also 24 and 72 hr after exposure. In addition biopsies were made at 72 hrs of all burns of interest. Skin sections were made and autopsies performed on all the animals that died. The biopsies were fixed and preserved at the base. They will be made the subject of a supplemental report as soon as microscopic sections have been made and evaluations completed.

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*Unfortunately, neither of these pigs was recovered alive, and hence no valid results were obtained on this cream.

Fig. 1.1 Animal Uniform - Unexposed

Fig. 1.2 Animal Holders

Fig. 1.3 Animal in Position in Holder

[redacted]

TABLE 1.1 Overall Plan for Exposure of Pigs

Shot	Thermal Energy (cal/cm²)		Number of Pigs Exposed at Various Stations								
			Uniformed Pigs						Face Cream	Cylinder Pigs	Total
	Planned	Observed	TFR	T	HWFR 50/50	HW 50/50	HWFR	HW			
9	75.0	75.0	2	2							4
	48.0	50.0					2	2		4	8
	36.0	41.0			2	2					4
	24.0	33.5			1	1		1			3
	24.0	29.5			1	1					2
	18.0	21.5				3	3	3		4	13
	14.0	16.0				3	3	3			9
	10.5	12.5				3	3	3		3	12
10	75.0	60.0			2	2					4
	48.0	40.5			1	1				1	3
	36.0	33.5			2	2				2	6
	24.0	26.0		2	2	2	2	2	1	2	13
	15.0	17.5		1			1	1			3
	15.0	17.0		1	2		1	1	1	2	8
	10.5	12.5		2	2		2	2		3	11
	7.8	9.0			2		2	2		2	8
Total			2	8	17	20	19	20	2	23	111

[redacted]

TABLE 1.2 Plan for Exposure of Cylinder Pigs

Shot	Thermal Energy (cal/cm²)		Number of Ports with Each Fabric Combination												Open Ports
			HWFR 50/50		HW 50/50		HWFR		HW		9 oz Sateen Fire Res.		9 oz Sateen Untreated		
	Planned	Observed	Contact	Spaced	Contact	Spaced	Contact	Spaced	Contact	Spaced	Contact	Spaced	Contact	Spaced	
9	48.0	50.0		2		2	4	4	4	4		2		2	8
	18.0	21.5		2		2	4	4	4	4		2		2	8
	10.5	12.5		1		1	3	3	3	3		2		2	6
10	48.0	40.5	2	2	1	2									1
	36.0	33.5	4	4	3	3									2
	24.0	26.0	4		4			3		3					2
	15.0	17.0	3		3			4		4					2
	10.5	12.5					5	4	5	4			4		2
	7.8	9.0					4	4	3	3					2
	Total		13	11	11	10	20	26	19	25	0	6	4	6	33

[redacted]

CHAPTER 2

DESCRIPTION AND CLASSIFICATION OF PIG BURNS

2.1 GENERAL

No valid quantitative assessment could be made of burns on pigs that were not alive at the time of recovery. The reasons for this are as follows:

(1) Certain physiological reactions such as production of edema and erythema could not occur in the case of a dead animal.

(2) The body temperature of a dead animal is lower than that of a live animal. Consequently, part of the thermal energy available for producing a burn is used to heat the skin to body temperature.

Hence, only burns on animals which were alive at the time of recovery were used in the assessments as tabulated in this report.

The burns were examined immediately after exposure and 24 and 72 hr later. Because progressive changes occur in the condition of burned skin, the 24 hr assessments are more reliable than those made immediately after exposure. Waiting for a longer period than 24 hr is not advisable since milder burns are often completely healed in 48 hr. Hence, in evaluating the overall degree of burn, the 24 hr assessments were used.

2.2 OVERALL BURN GROUPS FOR EVALUATION OF UNIFORM PROTECTION

For the quantitative assessment of various areas of burn on each animal, the system used was that developed and used for several years in laboratory studies by the University of Rochester. This system, which has been described elsewhere in detail, [15] consists briefly of the division of burns into the following five grades:

1+ erythema (persistent reddening)
2+ patchy coagulation (spotty whiteness)
3+ uniform coagulation (entirely white)
4+ steam blebs
5+ carbonization

The 1+ burn is similar to a 1st-degree human burn, the 2+ to a 2nd-degree human burn, and the 3+, 4+, and 5+ to 3rd-degree human burns of increasing severity.

In the assessment of the degree of individual burns, accompanying effects such as edema and various types of stains discussed below were not included. Edema was not included because previous laboratory

[redacted]

experience gave no indication of the extent and importance of this effect and no information on the clinical course of this lesion was available. Stains were omitted because laboratory experience indicated that they did not affect the severity of a burn. They were included in the data since they might yield information on the mechanism of heat transfer through the fabric.

Using this classification of local burns, the recovered living animals were divided into five groups as follows:

<u>Group 0-</u> No evidence of burn.

<u>Group 1-</u> 1+ burn covering less than 10 per cent of body area; or 2+ burn totaling 1 to 3 per cent of the body area in spots.

<u>Group 2-</u> 1+ burn covering 10 to 30 per cent of body area; or 2+ burn covering 3 to 10 per cent of body area, with or without small 3+ to 5+ burns.

<u>Group 3-</u> 1+ burn covering 30 per cent or more of body area, with or without 3 to 5 per cent of 3+ to 5+ burns; or 2+ burns covering 10 to 30 per cent of body area.

<u>Group 4-</u> 2+ burn covering over 30 per cent of body area.

In defining these groups no attempt was made to relate the extent of thermal injury to the probable degree of resulting disability, since:

(1) There is marked disagreement among medical authorities as to the extent of burn which can be considered disabling.

(2) The extent of disability produced by a specified area of burn is a function of the location of the burn. Burns on the hands, for example, will be much more serious from the standpoint of disability than burns of the same area and degree on the back.

(3) The extent of disability produced by a specified burn will vary widely among different personnel. It will depend on such factors as physical condition, desire to return to combat, etc.

(4) This classification does not distinguish between immediate and long-term effects. First- and second-degree burns are much more painful immediately after exposure than third-degree burns. Hence a man suffering extensive first- and second-degree burns will not be able to perform as efficiently immediately after the burst as a man suffering third-degree burns in small areas although the latter burns will require longer to heal.

(5) Considerable variation is possible within each group.

Burns produced beneath various fabric combinations in the laboratory present certain differences in appearance from those produced on bare skin. The erythema which occurs in the sub-fabric burn is often of a deep purplish (cyanotic) or brownish hue, and usually fails to blanch on pressure. Its distribution may be spotty, central or peripheral, depending on the circumstances, but almost never presents the uniform light pink color of a true flash burn. In addition, microscopic examination reveals that, in general, burns incurred beneath fabric are deeper for a given surface appearance than true flash burns. In this respect they are more similar to contact burns pro-

[redacted]

duced at relatively low temperature, and to burns produced by infrared energy delivered over longer periods. Vascular, particularly venous, stasis is very prominent.

2.3 PERSISTENT FLAME TYPE BURNS

Included in the overall burn assessment was a highly characteristic lesion (previously observed by the University of Rochester in their laboratory work (19) which is sustained by pigs when the fabric covering them catches fire under radiant exposure and continues to burn for 6 sec. or more. This lesion typically has a shriveled, granular, firm center, which is basically white with an overlying brown stain. Surrounding this center is a raised, edematous border which in turn shades off through a zone of purplish erythema to normal skin. Such burns have such a characteristic appearance and genesis in the laboratory that they have been called "persistent flame type," although it is possible that they may be produced by some other mechanism not encountered in the laboratory. A good example of a typical persistent flame type burn is shown in Fig. 2.1.

In deciding whether or not a particular animal showed evidence of having been burned by flaming or glowing of the uniform fabric, the following four criteria were used:

(1) The presence of a burn of the "persistent flame type," described above.

(2) The presence of a severe burn in a shadowed area. Some such were burns found on a number of pigs on the side away from the blast or on the lower legs.

(3) The presence of burns which were more severe than would have been sustained by an unclothed animal for the irradiance received at the station in question.

(4) The coincidence of areas of apparent flame or glow damage on the uniforms with burns which were probably, but not certainly, caused by flaming fabric.

It was considered evidence that flaming or afterglow had occurred if any one of these four criteria was met.

2.4 EDEMA

Two distinct types of edematous burns have been observed in the experimental animals. The first type is characterized as a subcutaneous edema with a puffy appearance. In small-area lesions it subsides quite rapidly and often disappears in 24 hr. Recent work in the laboratory has shown that this type of edematous burn can be easily produced beneath fabrics.

In the second type of edema, which was first observed in Shots 9 and 10, the tar-stained epithelium was lifted up in a pebbly or wrinkled fashion by superficially trapped fluid so as to form tiny fluid-filled blebs or blisters which persisted for at least 24 hr. Often the surface became abraded and exuded a clear serous fluid. This lesion was carefully distinguished from the first and more common type in which the full thickness of skin is involved in a firm, elevated, rather browny edema. This pebbly or wrinkled burn has been produced only recently in the laboratory. Preliminary laboratory results indicate that these edemas are probably related to the condensation of tarry or gaseous decomposition products. Whether this lesion is produced by chemical irritation caused by these by-products or is related to the method of heat transfer is unresolved at present.

2.5 STAINING OF THE SKIN

The one feature common to all sub-fabric burns produced in the laboratory is the presence of a tacky, persistent deposit on the skin surface. This appears to consist largely of tar; the color is basically yellow to yellow-brown, and may be greenish or orange under certain conditions. This tarry layer tends to obscure the characteristic delicate pearliness of a minimal 2/ lesion, and generally complicates the surface appearance of any degree of burn. It can be removed by gently sponging with alcohol.

Fig. 2.1 Example of Persistent Flame Burn

[redacted]

CHAPTER 3

RESULTS AND OBSERVATIONS

3.1 ANIMALS RECOVERED ALIVE

Out of a total of 111 Test animals placed on exposure (55 on Shot 9 and 56 on Shot 10), 39 were recovered alive from Shot 9 (71 per cent) and 29 from Shot 10 (52 per cent). One animal died on the trip back to the pens and no assessment was made of its burns. Of the 67 animals that survived long enough for burn assessment, 51 were clothed in uniforms and 16 were exposed in cylinders. These survival rates are far less satisfactory than those reported for the studies at GREENHOUSE [10] and TUMBLER-SNAPPER.[11] The probable causes for this will be discussed below.

3.2 ANIMALS RECOVERED DEAD

Immediate mortality from the primary effects of the weapons was not extensive. None died of burns alone; four animals at the closest station on Shot 10 were blown apart; and two animals on Shot 2 were moribund on recovery, presumably as a result of large doses of ionizing radiation.

The high mortality on Shot 9 is attributed to anesthetic over-dosage. Through an error, a number of the animals received 100 mg/Kg of dial urethane, instead of the correct dosage of 70 mg/Kg. Although many of these survived, all the immediate casualties were in this group of animals that had received the overdose of anesthetic.

On Shot 10, all animals received the correct dosage, yet only about half survived. The predominant cause of this high mortality is felt to be the cold weather. Barbiturates, including dial-urethane, render the animal sensitive to extremes of temperature. In the laboratory this is not a serious problem, and at GREENHOUSE and TUMBLER-SNAPPER careful precautions were taken to avoid such extremes. The night previous to Shot 10 was not only very cold, but was windy and dusty. It was not possible to protect the animals, either those in uniforms or those in cylinders, as had been done in previous tests.

Two additional factors should be mentioned as being possible contributors, particularly since many of the animals on Shot 10 succumbed before being exposed to the inclement weather for any length of time:

(1) Deterioration of the anesthetic solution. Dial-urethane must be freshly prepared, continuously refrigerated, and

[redacted]

protected from light; otherwise it rapidly becomes extremely toxic. Hence deterioration of the anesthetic might have caused some fatalities, although the solutions used on Shots 9 and 10 were fresh, and were carefully guarded from heat and light.

(2) Pre-existing illness in the experimental animals. This is known to cause increased mortality, particularly when it is a diarrheal. A slight outbreak of diarrhea was present in the pens before Shot 10, and in addition some of the animals had been coughing. The latter was attributed at the time to the dust and dryness, as its significance is not known, although immediate non-survivors had post-mortem evidence of early pneumonia.

It will be noted from examination of Appendix Tables B.1 to B.6 that fewer animals were recovered alive from the closer stations than from the more distant stations. On Shot 9, those pigs given an overdose of anesthetic were the ones at the closest stations that were placed in the holders first. On Shot 10, ten additional live pigs were available to replace those that died during placement and the substitutions were made at the farthest stations which were nearest the field operations base.

3.3 EVALUATION OF SKIN BURNS UNDER UNIFORM ASSEMBLIES

3.3.1 Overall Evaluation of Protection Afforded by Various Assemblies

A detailed listing of the overall protection afforded the test animals is presented in Appendix Tables B.1 to B.6. Each table presents data for one type of uniform listed in order of decreasing thermal exposure. The appendix tables are summarized in Table 3.1.

TABLE 3.1 Severity of Burns in Uniformed Pigs

Uniform	No. Recovered Alive	Burn Group			
		0	1	2	3
T	5	1	4	0	0
TFR	0	0	0	0	0
HW 50/50	10	1	9	0	0
HWFR 50/50	8	4	2	2	0
HW	15	0	0	9	6
HWFR	13	1	3	5	4
Total	51	7	18	16	10

The Temperate uniform ensemble provided almost complete protection, none of its wearers being classified in a burn group higher

[redacted]

than one. Of the five animals recovered alive that were clothed in this ensemble, two showed mild 1+ burns over significant areas. The remainder of the burns were small 1+ to 3+ burns undoubtedly arising from a persistent exothermic reaction (either flame or glow) in these regions. Although burns of this degree and extent would generally be painful, require medical treatment and be slow-healing, they would not be disabling.

Three animals, one on Shot 2 and two on Shot 9, provided with Temperate Fire Resistant uniforms were exposed. All three animals were dead on recovery. However, the skin of these animals underneath the uniform showed no evidence of having been subjected to sufficient thermal energy to cause burn injury. This also applied to five additional animals recovered dead which were clothed in untreated Temperate uniforms. One animal clothed in a Temperate ensemble, exposed to a calculated 48 cal/cm^2 on Shot 2 was recovered alive. This animal showed no sign of any thermal injury.

Although no animals clothed in the Temperate ensemble were recovered alive at the maximum calorie level (75 cal/cm^2) to which they were exposed, the data is such that it may be concluded this uniform afforded excellent protection at all levels up to 40 cal/cm^2. Furthermore there is no evidence to indicate that the thermal protection will not extend to 75 cal/cm^2 for weapons in the nominal bomb range. This conclusion is based on the following observations:

(1) The absence of burns on three animals, two clothed in six and one in four layer uniforms on Shot 2, in which the exposures were at a calculated 75 cal/cm^2 and 48 cal/cm^2 respectively.

(2) In both Shots 2 and 9 (no Temperate clothed animals were exposed on Shot 10 at calorie levels above 26.0), at the highest levels of exposure 75 cal/cm^2 thermal destruction and damage was limited to the two outer cotton layers, with the two heavy under layers (16 oz all wool shirting and 10.5 oz wool-cotton underwear) remaining undamaged. (If there had been any question, in the minds of the medics and textile personnel who participated in Shots 2 and 9, as to the protective value of the Temperate uniform at 75 cal/cm^2 additional exposures would have been made on Shot 10).

(3) The complete lack of any qualitative evidence of thermal injury to the fabric-protected skin of animals dead on recovery at the 75 cal/cm^2 station.

(4) As reported in Project 8.6 the maximum backing temperature (as measured by passive indicators) on panel exposures (Project 8.6) of the Temperate assembly did not exceed 62°C, and averaged 54°C or less. Where fabric panels were exposed side-by-side with the test animals no clinically significant skin burns were observed in any case where the maximum panel backing temperatures recorded for a given fabric assembly were below 100°C.

HW 50/50 and HWFR 50/50 uniform ensembles also provided excellent protection. Eighteen animals were recovered alive from exposures up to 41.0 cal/cm^2, 10 wearing the untreated ensemble, and 8 wearing the fire-resistant ensemble. Of these 18, 5 were not burned at all, 2 were classified mild Group 2 on the basis of area of 1+ burn, and the remainder suffered very small non-disabling burns. Most of the burns in the latter group were 1+ to 3+ burns on either side of, and close to, the waist drawstring.

As expected, the least amount of protection was afforded by the HW and HWFR assemblies, although it is significant that pigs wearing these uniforms were recovered alive as near to ground zero as the 50.0 cal/cm^2 station. All those recovered from exposures of 26.0 to 50.0 cal/cm^2 were burned severely enough to be classified in Group 3. However, the protective value of even these two layers of thin fabric will be appreciated when the results on the cylinder pigs are considered (Section 3.4). There it will be seen that up to 3+ burns were sustained by the unprotected skin (that is, in the areas under the open ports) at energies as low as 9 cal/cm^2.

The most severe burns on animals clothed in HW and HWFR ensembles occurred at radiant energy levels higher and lower than 16.0 cal/cm^2, and minimum burns were sustained at this intermediate level. This minimum is more evident for the HWFR ensembles where the added complication of persistent flame or glow would not be encountered. In fact, one animal clothed in the HWFR uniform and exposed at the 16.0 cal/cm^2 level showed no evidence of burn at all. These overall results are in good agreement with previous laboratory work. The results of the panel exposures of these uniform assemblies also parallel the findings of the pig experiment.

In general, the HWFR uniform provided somewhat better protection than did the HW uniform. However, while the burns were less extensive, they were accompanied by an unusual type of edema not previously observed in laboratory studies. This is described above in Section 2.4. The increased protection is particularly marked at the more distant stations where persistent afterflaming or afterglow is more likely to occur. The most severely burned animal in the entire test was exposed to 12.5 cal/cm^2 in Shot 9. This animal was clothed with an HW uniform assembly.

3.3.2 Edema

As pointed out above (Chapter 2), there were two distinct types of edematous burns. The occurrence of these is listed separately in the Appendix in Tables B.1 to B.6, and summarized here in Table 3.2. In addition, the presence of edemas of either type which persisted for 24 hr is tabulated. It will be noted that the pebbly, blistered weeping edema occurred only under the HWFR uniform, and that every case of edema which persisted for 24 hr was associated with fire resistant uniforms. Furthermore, the puffy subcutaneous edema appeared with much greater frequency under the HWFR uniform than under any other. There is a relationship between the fire resistant uniform and the occurrence of edematous burns. Current investigations at the University of Rochester are being directed toward a better understanding of the mechanisms involved in producing such burns.

3.3.3 Persistent Flame Type Burns

This lesion, described in Chapter 2 above, was commonly seen in the field tests. Whether or not such a burn occurred is specified for each animal in Appendix Tables B.1 to B.6. These burns were usually small in extent and were generally grouped around the drawstring or in other areas (such as the dorsum and legs) where the uniform was partially protected from the radiant energy of the burst and from the blast wave. Of the surviving animals, as shown in Table 3.2, 3 out of 5 wearing Temperate uniforms, 4 out of 10 wearing HW 50/50 uniforms, and 13 out of 15 wearing HW uniforms showed burns of this type. This lesion was never observed on any animal clothed in a fire resistant uniform.

The most severe persistent flame type burns were observed at the most distant stations. Burns of this type were observed only on the side away from the blast on two of the four animals at the closest stations. Persistent flame type burns in areas directly exposed to the energy source occurred only around the drawstring, and these, as the tables in Appendix B show, were not noted at the closer stations where the short blast arrival time appeared to be a critical factor in preventing this type of burn.

On the basis of the characteristic appearance and extent of the burns, a separate survey of results was made in an attempt to determine whether or not there was evidence that an exothermic reaction (flame or glow) persisted in the fabric after the advent of the blast wave. Motion pictures of this phase of the test were completely obscured by dust. There were 17 animals, however, in which the burns were of a type and severity which had never been produced in the laboratory except by fabric flaming for a longer period than the blast arrival time.

3.3.4 Burns in Areas Adjacent to Drawstring

On 29 of the 51 pigs recovered alive, there were burns of varying degrees of severity concentrated in areas adjacent to that covered by the drawstring. An example of such a burn is shown in Fig. 3.1. Seventeen pigs which were burned did not exhibit this local increased severity. The remaining six surviving pigs showed no burn and hence no distinction could be made.

The occurrence of drawstring burns under the various uniform ensembles are summarized in Fig, 3.2. The number of burns of this type was significantly lower on Shot 10, where the drawstring section was modified using an extra layer of fabric, than on Shot 9. Considering the HW, HWFR, HW 50/50, and HWFR 50/50 uniforms 23 out of 29 pigs sustaining any burns in Shot 9 exhibited this type of burn, whereas only 4 out of 12 burned pigs in Shot 10 were burned in this way. This indicates that the addition of as little as one layer of lightweight fabric will give added protection in areas of garments under belts or drawstrings.

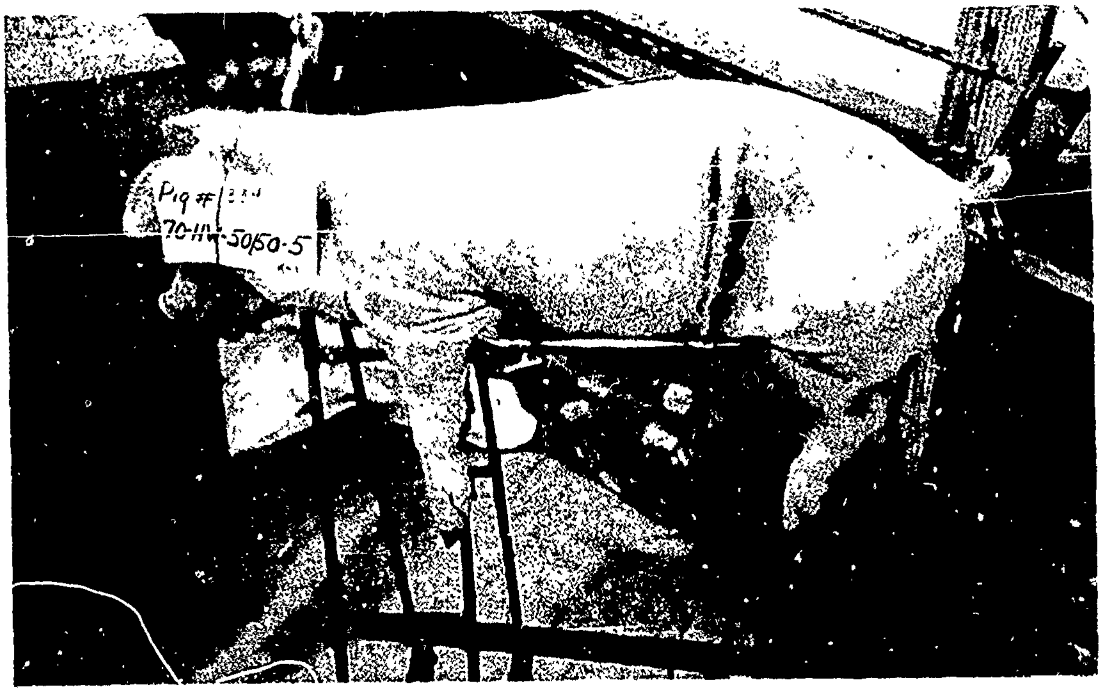

Fig. 3.1 Example of Burn in Area Adjacent to Drawstring

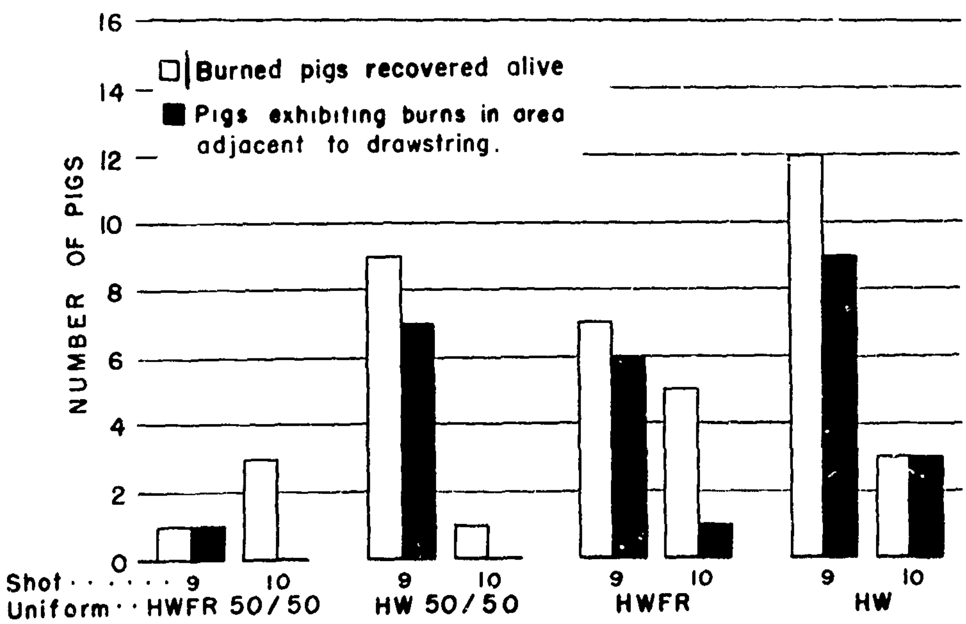

Fig. 3.2 Burns Sustained in Area Adjacent to Drawstring

[redacted]

TABLE 3.2 Occurrence of Edemas and Persistent Flame Type Burns in Uniformed Pigs

Uniform	No. Recovered Alive	Edema				Persistent Flame Type Burns
		No Edema	Common Type	Weeping Type	Persistent Both Types	
TFR	0	0	0	0	0	0
T	5	3	2	0	0	3
HWFR 50/50	8	7	1	0	1	0
HW 50/50	10	8	2	0	0	4
HWFR	13	1	9	7	12	0
HW	15	9	6	0	0	13

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3.3.5 Stains

Three types of skin stains were observed: a yellowish-brown or orange tarry stain, a green stain, and a dusty black, sooty stain.

The orange or brown tarry stain was quite generally observed under all types of uniforms regardless of the severity of burn. It was noted as well where no burn was observed. This tarry type stain was much more pronounced under fire resistant treated uniforms than under untreated uniforms.

The green stain was much less common. It was associated primarily with the HW uniform, occurring on 30 per cent of the animals clothed in the HW uniform and on 7 per cent of all other animals. There appeared to be no correlation between this stain and the severity of burn.

The dusty black, sooty stain is of unknown origin and was generally associated with areas of slight burn. This type of stain occurred more frequently at the closer stations as shown in Table 3.3.

TABLE 3.3 Occurrence of Dusty Black Stain at Various Thermal Energies

Thermal Energy (cal/cm^2)	No. Pigs Surviving	Pigs with Dusty Black Stain	
		No.	Per Cent
9.0 - 12.5	12	1	8
16.0 - 21.5	24	3	13
26.0 - 33.5	11	6	55
41.0 - 50.0	4	3	75

3.3.6 Sparing Mechanisms

All the pigs were spared from burns beneath the dorsal seam and under the midsection drawstring. This sparing refers to a section directly under the drawstring and not to the areas adjacent to it. An example of this sparing is shown in Fig. 3.3.

Sparing due to skin folds occurred definitely in 5 animals and probably in 7 more. In 19 animals there was no evidence of sparing by this mechanism.

Sparing in areas where the underwear was raised away from the skin, as evidenced by matching photographs of clothed and unclothed pigs, occurred in 22 animals and probably in 4 more.

3.3.7 Hair Singeing

Eighteen of the 20 clothed pigs recovered alive from Shot 10 exhibited a singeing of the hair beyond the limits of the uniform.

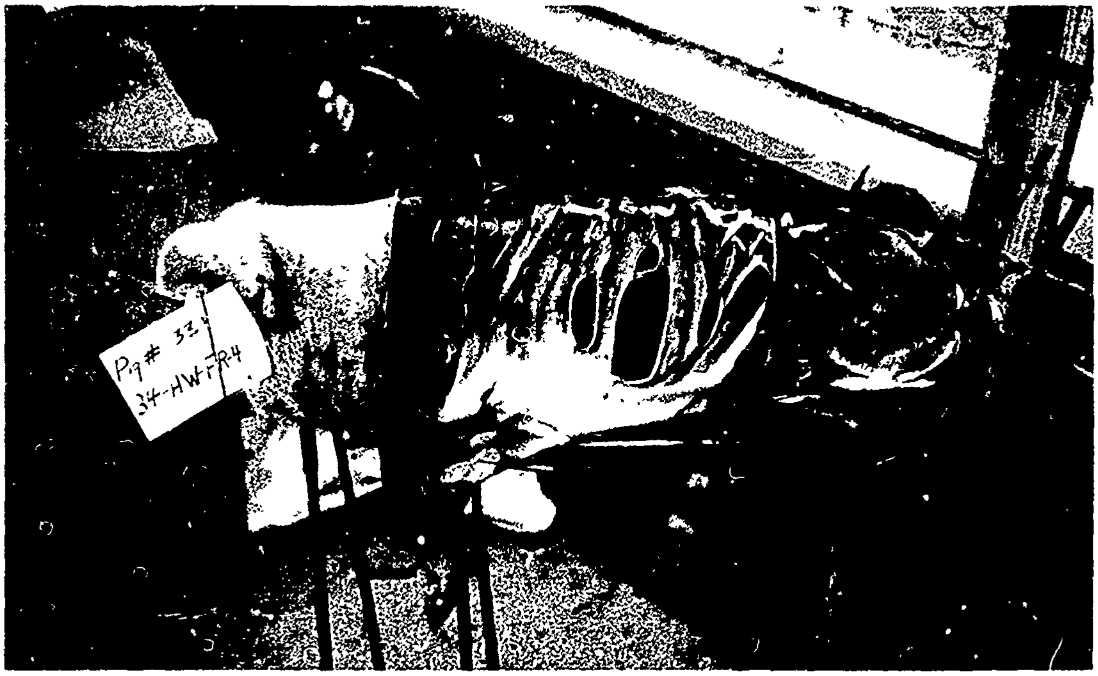
[redacted]

TABLE 3.4 Average Burn Scores on Cylinder Pigs

Shot	Distance to GZ (ft)	Thermal Energy (cal/cm²)	Average Burn Score*												
				Contact					Spaced						
			Open Port	HW	HWFR	HW 50/50	HWFR 50/50	Sateen Untr.	HW	HWFR	HW 50/50	HWFR 50/50	Sateen Untr.	Sateen Fire Res.
9	3160	50.0	12.0	9.0	7.5	-	-	-	10.0	7.8	9.0	8.0	8.5	6.0
10	3270	33.5	12.0	-	-	1.2	1.1	-	-	-	0.7	0.0	-	-
10	3870	26.0	9.0	-	-	0.5	1.0	-	0.0	1.5	-	-	-	-
9	5720	21.5	10.1	2.3	6.3	-	-	-	1.3	3.3	0.0	1.0	3.5	4.5
10	4870	17.0	7.5	-	-	1.3	2.0	-	2.8	4.5	-	-	-	-
9	7700	12.5	7.0	6.7	2.7	-	-	-	3.0	2.0	0.0	0.0	2.3	2.0
10	5870	12.5	7.0	4.5	4.3	-	-	4.8	4.0	3.8	-	-	-	-
10	6870	9.0	5.0	7.0	3.5	-	-	-	1.0	3.5	-	-	-	-

*Method of scoring burns:

Burn	Score	Burn	Score	Burn	Score	Burn	Score
0	0	2+ mild	3	3+ mild	6	4+ mild	9
1+ mild	1	2+ moderate	4	3+ moderate	7	4+ moderate	10
1+ severe	2	2+ severe	5	3+ severe	8	4+ severe	11
						5+	12



A - Before Removal of Uniform from Exposed Pig

B - After Removal of Uniform from Exposed Pig

Fig. 3.3 Example of Sparing of Animal under Drawstring

These areas were shielded from direct radiation during the shot by aluminum plates. Although burns in these areas were sometimes observed, they were infrequent and showed no correlation with the singeing. The singeing phenomenon was not observed in Shot 9 although there were five cases of skin burns involving the shielded areas. The mechanism of the singeing is unknown.

3.4 RESULTS ON CYLINDER PIGS

Tabular summaries of the burn assessments on cylinder pigs are given in Tables 3.4 and 3.5; these include only results on surviving animals.

In order to present a summary of the situation at each station, the burn degree was reduced to a numerical value on an arbitrary scale, and an average made of this numerical score for each combination at each station. The results are presented in Table 3.4. While these numbers have no real arithmetic significance, they do give an approximate idea of the degree of protection afforded, and are most useful for purposes of comparison.

The most striking feature of the combined data when presented in this fashion is the unmistakable superiority of 50/50 wool/cotton underwear over light cotton. At no thermal level from 33.5 cal/cm^2 down to 12.5 cal/cm^2 was the average burn beneath any such two-layer system more serious than 1+ severe. This observation tallies well with the results seen in the uniformed animals.

The effectiveness of a single layer of 9 oz sateen when separated from the skin is also evident, though in the one instance where it was held in contact (12.5 cal/cm^2 Shot 10), the average burn was more severe than under any observed two-layer system at the same distance from ground zero.

In the porthole exposures the fire resistant fabric systems failed to give better protection than the untreated systems. In fact at the intermediate 17.0, 21.5, and 26.0 caloric locations, burns beneath fire resistant fabric were consistently worse than those under the untreated cloth. At the closer and at the more distant stations, fire resistant outer layers usually gave better protection. However, since the geometry of the exposure ports made sustained flaming unlikely after the arrival of the blast wave, the degree of protection seen was far less evident in the cylinder animals than it was in the uniformed animals.

As was postulated on the basis of laboratory studies, there was in many instances a clear-cut improvement in protection afforded by any two-layer system when it was elevated from the skin rather than held in contact. This difference was not as marked in the field as in the laboratory. Despite every effort to obtain laboratory accuracy in the apposition of the pig to the aluminum porthole plates, there were many failures. In some instances the skin had obviously bulged into the 1-5/8 in. opening, reducing the 5 mm spacing. In others, the animals on recovery were found to have poor contact with certain ports, thereby increasing the amount of spacing. Much of this difficulty was due to involuntary shivering or struggling movements

[redacted]

during the long period (5 to 7 hr) within the cylinders. In two cases the animals had shifted position during the thermal energy pulse, which resulted in overlapping areas of severe (4+ to 5+) flash burns behind the open ports.

Edema burns of both types (Section 2.4) were also produced under fabrics exposed in portholes. Table 3.5 presents a summary of the observations on surviving animals at 24 hr.

As in the uniformed animals, edema was predominantly seen beneath fire resistant treated fabrics and every case of weeping edema occurred under the HWFR combination.

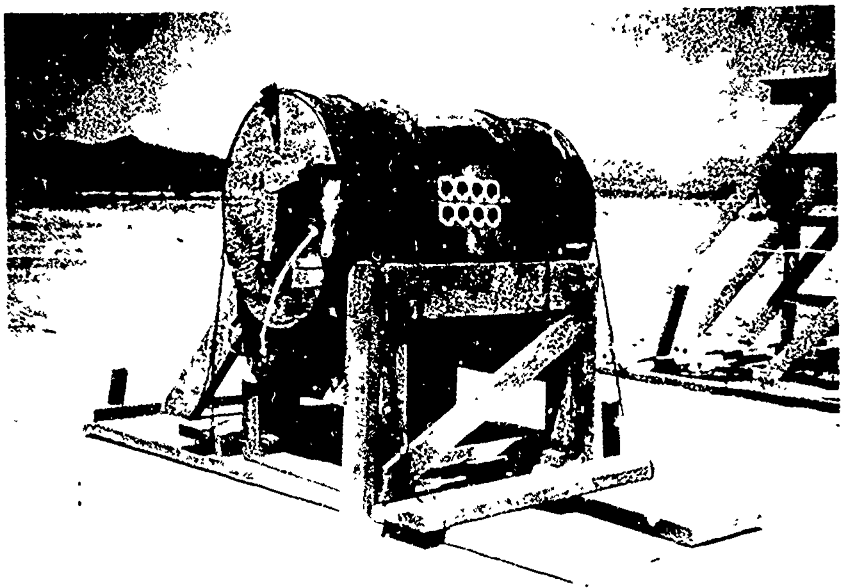
Insufficient data are available to make an extensive comparison between porthole burns in this field test with cylinder pigs and burns produced in the laboratory with the carbon arc. However, some analogies can be drawn. In the Hot-Wet fabric combination, for example, complete protection was noted at 26.0 cal/cm^2 when the fabrics were separated from the skin; this minimal response appears to correspond with that observed in the laboratory at 15 to 16 cal/cm^2. The combinations with the 50/50 wool/cotton underwear cannot be compared because of insufficient laboratory data. In the case of the untreated sateen in contact with the skin, the critical level for 2+ burns was apparently 9 cal/cm^2 in the porthole test while it was 6 cal/cm^2 in the laboratory. Spaced away from the skin the critical levels for untreated sateen in the field (porthole) and laboratory were 17.0+ and 12 cal/cm^2 respectively. When the sateen was fire resistant treated and spaced away from the skin the critical level in the porthole test was also 17.0+ cal/cm^2 and in the laboratory was 17 cal/cm^2. The data indicate that in sub-fabric as well as bare-skin burns, the sharply peaked bomb pulse of thermal energy appears to be less efficacious, calorie for calorie, than the trapezoidal pulses of lower irradiance delivered by the carbon arc.

Although a complete comparison for the various fabric combinations is not possible between porthole experiments in the field and laboratory tests, the cylinder exposures have provided a limited means of relating controlled laboratory experience to the interpretation of large-area burns sustained by uniformed animals exposed in the field.

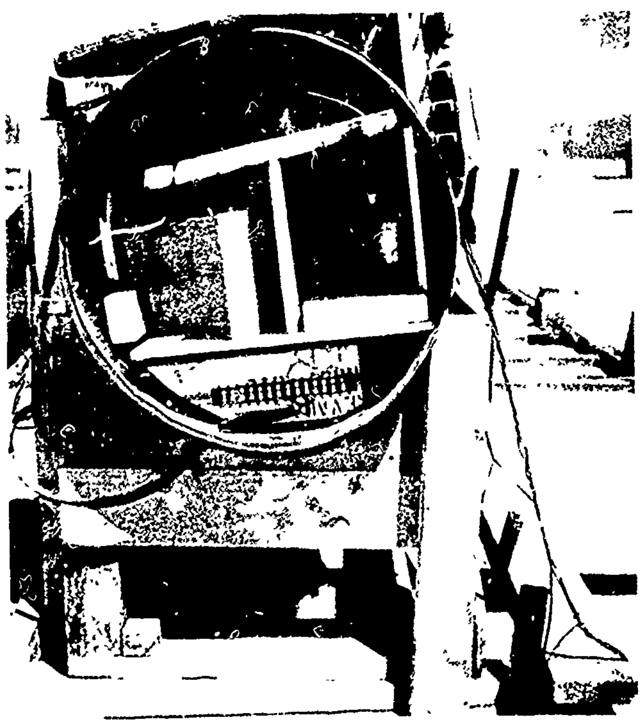
3.5 THERMOCOUPLE EXPERIMENT

Shortly before Shot 10 there were made available to Project 8.5 two thermocouple recording channels, through the cooperation of Project 8.9. It was considered desirable to compare the surface time-temperature responses of polythene simulant (Project 8.9) with pig's skin under identical cloth samples at the same station.

An improvised exposure cylinder was constructed from a 55 gal drum as shown in Fig. 3.4. Two of the ports were supplied with iron-constantan couples about 0.008 in. in diameter. An anesthetized animal was placed in this cylinder prior to shot time, and the thermocouples placed in careful apposition with the skin; a single layer of 9 oz sateen was fixed over this, in contact.



A - Outside View



B - Inside View Showing Arrangement of Thermocouples

Fig. 3.4 Improvised Cylinder Used for Thermocouple Experiment

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Recordings were obtained from both thermocouples. One of them was still unbroken and in good skin contact at the time of recovery, 6 hr after placement. The thermal records from this couple indicated that the fabric was not in good contact with the skin, and a maximum temperature rise of 20°C was observed prior to the arrival of the shock wave. In the other case, the thermocouple was evidently in good contact with the fabric, but not with the pig; the temperature curve attained a maximum rise of 287°C. The clinical burn observed in both instances (the fabric failing to maintain contact with skin) was 2+ mild to moderate. Such records, while occasionally seen in the laboratory, are not considered to be technically satisfactory because of the failure to maintain proper contact.

3.6 ASSESSMENT OF UNIFORM DAMAGE

In evaluating the extent of fabric destruction, the uniforms from both dead and surviving animals were examined since the physiological response was not of consequence. The only uniforms omitted from the evaluation were those from the animals at the closest station on Shot 10, which were so badly damaged mechanically that no assessment of thermal damage was possible.

All estimates of the amount of fabric destruction were made visually and hence, in comparing fabrics, not too much significance should be attached to small differences.

3.6.1 Gross Damage to Exposed Portions of Uniform

Gross overall damage to the portion of the uniform exposed to radiant thermal energy from the burst is tabulated in Appendix Tables B.7 and B.8 and are shown graphically in Fig. 3.5.

These data may be summarized as follows:

(1) Maximum damage was sustained by the Hot-Wet uniform. At all stations there was almost complete destruction of the outer layer and there were no instances in which the underlayer completely escaped damage.

(2) The layers under fire resistant fabrics, especially for the HW uniform, were afforded more protection than those under untreated outer fabrics. In addition, damage to the fire resistant outer fabrics themselves was less than to the untreated fabrics.

(3) Damage to the heavier fabrics was less than to the lighter fabrics as was expected.

(4) Protection afforded the second layer by heavier outer fabrics was greater than that afforded by lighter outer fabrics. The 9 oz sateen of the Temperate uniform provided complete protection from the primary thermal effects of the blast except at the closest station 75.0 cal/cm^2) on Shot 9. The second layer was only very slightly scorched. The 1 to 3 per cent damage to the second layers of the Temperate uniforms were all strongly indicated to have been caused by persistent afterglow or afterflame.

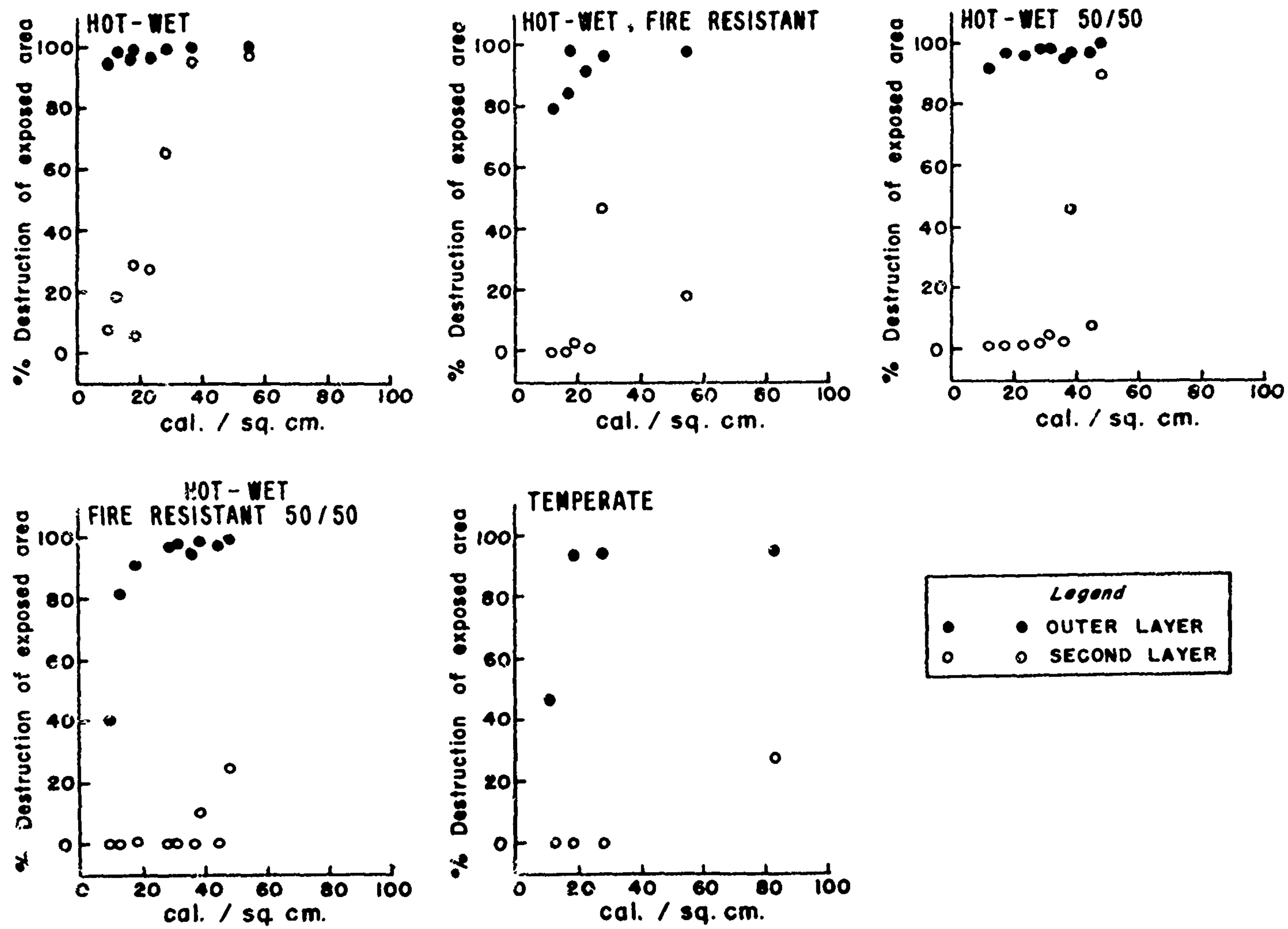


Fig. 3.5 Destruction of Outer and Second Layers of Pigs' Uniforms (Shots 9 and 10)

3.6.2 Damage to Unexposed Portions and Boundaries of Uniform

In many cases the uniforms were damaged in areas not exposed to the thermal pulse. Such areas are in the front near the neck which was protected by the animal holder; beyond the dorsal seam to the zipper which is in a shadowed area; and in the legs which were protected by aluminum shields.

In 8 out of 20 HW uniforms, and 3 out of 18 HW 50/50 uniforms destruction of the outer layer extended to the front seam at the neck drawstring. None of the fire resistant uniforms were destroyed all the way to the seam. Since this portion of the uniform was not exposed to radiant energy directly, destruction must have been due to a sustained exothermic reaction. It is significant that none of these 11 uniforms were fire resistant treated.

Many of the untreated assemblies showed damage far beyond the dorsal seam to an area shadowed from direct radiation. No damage in this portion was shown by the fire resistant uniforms.

Damage extended down the fore legs all the way to the edge of the uniform in 11 out of 20 HW uniforms and in 5 out of 19 HWFR uniforms. The predominance of damage in this area to the untreated uniforms again seems significant. That these protected parts were damaged at all in the fire resistant uniforms may be due to some fortuitous exposure.

3.6.3 Persistent Exothermic Reaction

Assessment of burns gave strong evidence that some persistent exothermic reaction had taken place. (See Section 3.3.3.) Examination of the uniforms revealed the following characteristics which are considered as evidence of either sustained flame or glow:

(1) Presence of a characteristic smooth edge of the fabric rather than a torn edge. This is generally indicative of afterglow.

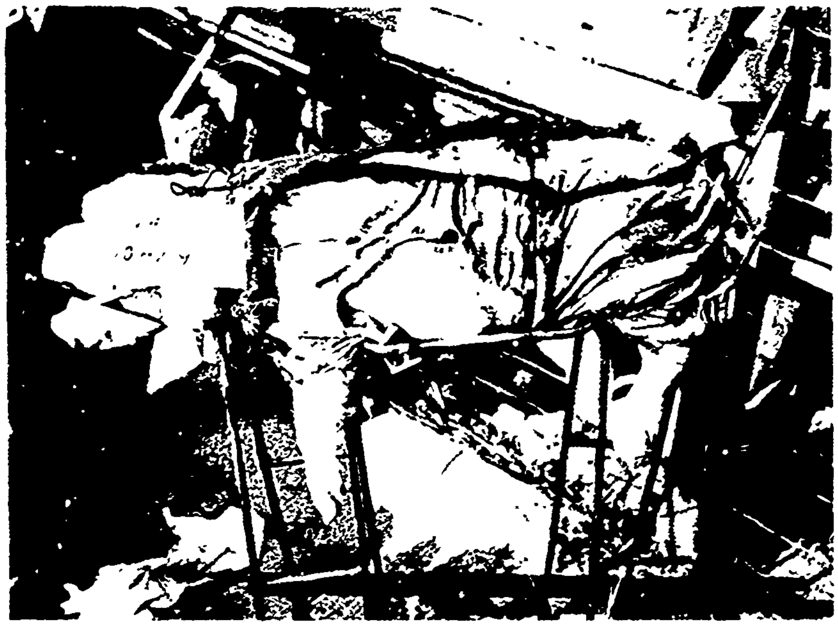
(2) Penetration of damage to an unusual depth, e.g., small area destruction extending to the 3rd and 4th layers of the Temperate uniform.

(3) Damage to untreated fabrics in unexposed regions such as the area far beyond the dorsal seam to the zipper, and also in the neck and leg regions.

None of the fire resistant uniforms, compared with 28 of the 46 untreated uniforms, gave evidence of persistent exothermic reaction (either afterflame or afterglow). In 15 of these 28 cases, there were pig burns of the persistent flame type under the portions of the uniform where this evidence was found. In 8 additional cases, the pig was recovered dead and no such comparison could be made. In only 5 cases was there no typical persistent flame type burn on the animals corresponding to such an area in the uniform.

3.6.4 Correspondence of Areas of Maximum Fabric Damage with Areas of Animal Burn

In general gross areas of maximum damage to the uniform corresponded to areas of most severe pig burn. This correspondence



A - Before Removal of Uniform from Exposed Pig

B - After Removal of Uniform from Exposed Pig

Fig. 3.6 Example of Sparing under Completely Destroyed Area of Uniform can be clearly seen in the photographs of Pig 331, clothed and unclothed (Fig. 3.3), which was shown earlier to demonstrate sparing under the drawstring. That most of the severe burns occurred under badly damaged areas of the uniforms is indicated by the summary in Table 3.6.

TABLE 3.5 Occurrence of Edema in Cylinder Pigs
(24-Hour Assessment)

Fabric Combination	Edema			
	Common Type		Weeping Type	
	Contact	Spaced	Contact	Spaced
HW	1	3	0	0
HWFR	3	3	1	5
HW 50/50	0	0	0	0
HWFR 50/50	1	1	0	0
9 oz Sateen, Untr.	0	1	0	0
9 oz Sateen, Fire Res.	-	0	-	0

TABLE 3.6 Coincidence of Severe Burns
and Badly Damaged Portions of Uniforms

Uniform	Severe Burns Under Badly Damaged Uniform Area	Severe Burns Not Under Badly Damaged Uniform Area
HW	11	1
HWFR	12	1
HW 50/50	7	4
HWFR 50/50	1	3

An example in which portions of both layers of the uniform were destroyed over a fairly large area and yet in which there was complete sparing of the animal under this area is shown in Fig. 3.6. In this case the two layers of fabric were probably in good contact with one another and spaced away from the animal.

It had been noted that where there was a difference, burns posterior to the midsection drawstring often seemed to be more severe than those anterior to the drawstring. Hence it became of interest to compare the damage to the uniforms in these two areas. The data are summarized in Table 3.7. The significance of this trend is not yet clear.

3.6.5 Fabric Folds

In all but 15 cases (all Temperate uniforms, both fire resistant and untreated, and 5 other uniforms) the presence of folds had a marked local effect on the uniform damage. A typical example is shown in Fig. 3.7.

Fig. 3.7 Example of Uniform Damage at Fabric Folds

3.7 MOTION PICTURES

Examination of the motion pictures yielded the following important information:

(1) Flaming of the uniforms not treated for fire resistance could be observed in numerous instances. This flaming occurred

TABLE 3.7 Comparative Severity of Uniform Damage Anterior and Posterior to the Drawstring

Shot	More Damage Posterior	Less Damage Posterior	No Difference
9	22	6	16
10	11	1	26

most prominently at the periphery of the exposed areas and in the area past the dorsal seam.

(2) At the 3160 ft station, where black and white motion pictures were taken, smoke started to emanate from the uniforms from 60 to 125 ms after the detonation of the bomb. Heavy smoking continued for more than 500 ms. Since virtually the entire effective thermal pulse occurs between 100 and 500 ms (16, 17) it seems likely that a significant fraction of the available radiation was absorbed or scattered by the smoke during the thermal pulse. The fire resistant uniforms gave off much more smoke than the untreated. There is no available information on the fraction of the radiant energy absorbed, or scattered, by this smoke.

(3) The outer layer of the untreated uniforms was burned completely through, exposing the underlayer in most cases before the arrival of the shock wave whereas with the fire resistant uniforms a char always remained until the arrival of the shock wave.

CHAPTER 4

DISCUSSION

4.1 ANTICIPATED AND OBSERVED RESULTS

4.1.1 Protection Afforded by the Various Uniform Assemblies

Perhaps the most outstanding result of these tests was the degree of thermal protection afforded the test animals by the various uniform assemblies. At the higher levels of radiant energy, where laboratory tests (with the carbon arc) indicated that the animals should have sustained at least 2+ burns,[7] an unexpected degree of protection was found in the field. In the laboratory, thermal energies as low as 44 cal/cm^2 (delivered in 2 sec.) were sufficient to produce burns in pigs' skin under the four layers of the Temperate ensemble. In the field the maximum level at which any animals, clothed in the Temperate uniform, were recovered alive on Shots 9 and 10 was 26.0 cal/cm^2 and one at 48 cal/cm^2 (calc.) on Shot 2. Although no animals were recovered alive at the maximum exposure level of 75 cal/cm^2, there was a complete lack of any evidence to indicate that the animals would have suffered burns from the primary effects of the thermal radiation. Some of the animals wearing the Temperate uniform not treated for fire resistance sustained minor skin burns, but these resulted from exothermic reactions (flame or glow) and occurred only at the more distant stations. Damage to the fabric itself from direct thermal radiation was also less serious than expected, being limited to the two outer layers, whereas in the laboratory three of the layers were damaged and the underwear layer discolored at 40 to 60 cal/cm^2.

The two-layer HW 50/50 and HWFR 50/50 assemblies had not been tested in the laboratory with the carbon arc, although tests in connection with napalm studies had indicated that the wool/cotton underwear of this combination might be quite effective. The outstanding results obtained in the field with these fabric assemblies, however, exceeded the most optimistic anticipations. Exceptionally good thermal protection was observed up to the closest stations from which data were obtained: 41.0 cal/cm^2 for HW 50/50 and 33.5 cal/cm^2 for HWFR 50/50.

Severe burns were sustained by the majority of the pigs wearing the two-layer HW and HWFR assemblies. However, even these thin cotton fabrics were of considerable protective value as can be seen by comparing these results with the bare-skin exposures of the porthole pigs (Section 3.4). The degree and extent of burns noted beneath these assemblies were less than would have been expected on the basis of previous laboratory experience, especially at the higher calorie levels.

4.1.2 Factors Contributing to the Greater Degree of Thermal Protection in the Field.

There are several conditions encountered in the field, especially at the higher energy levels, but not duplicated in the laboratory (at least not up to the present time) that may account for the fact that like amounts of thermal energy did not produce comparable results in the laboratory and in the field. First, the thermal energy is delivered much more rapidly with the explosion of an atomic bomb than it is in the laboratory. Second, due to smoke obscuration the animals in the field actually received a smaller percentage of the total energy delivered than they did in the laboratory. Third, the blast wave following the explosion tended to extinguish flames and remove char, whereas no such wave was present in the laboratory tests. Fourth, where the heat reached the fabric layer next to the skin, uniform drape (or spacing) provided additional protection in the field.

(1) In comparing field with laboratory results, consideration must be given to irradiance, which expresses the time-intensity of the thermal pulse ($cal/cm^2/sec$). At the highest calorie levels laboratory irradiances were much lower than field irradiances. The reason for this is that an atomic explosion delivers a high quantity of thermal energy per unit area in a much shorter time than the same quantity can be delivered over a practical exposure area (1.7 cm diam) with existing laboratory equipment. For example, approximately 2 sec are required to deliver 75 cal/cm^2 in the laboratory with the carbon arc operating at peak capacity, an irradiance of 37.5 $cal/cm^2/sec$. In the field this much energy was delivered at the forward stations in both Shots 9 and 10 in approximately 0.5 sec, an irradiance of 150 $cal/cm^2/sec$.

Irradiances have been varied within the limits possible in the laboratory, and it has been found that certain levels of thermal energy will produce a more serious lesion if applied slowly than if applied rapidly.(18) Beneath the HW assembly spaced 5 mm from the skin, for example, a 2+ burn was produced when a thermal energy of 17 cal/cm^2 was applied in 2 sec (8.5 $cal/cm^2/sec$) but no burn, or at the most a mild 1+ burn, resulted when the same energy was applied in 0.5 sec (34 $cal/cm^2/sec$). With lower irradiances the fabric may be scorched or charred but remain intact and thus act as a heat reservoir from which heat can subsequently be transmitted to the skin. With higher irradiances, laboratory results indicate that all or part of the thermal input may be dissipated by an endothermic decomposition of the fabric. In the field, especially at the closer stations where irradiances exceeded 35 $cal/cm^2/sec$, conditions were favorable for such dissipation of energy.

(2) Motion pictures of clothed animals, exposed to 50.0 and 33.5 cal/cm^2 on Shots 9 and 10 respectively, showed heavy clouds

[redacted]

of black smoke enveloping the animals within 120 ms of the explosion. There is reason to believe that, in view of the short time within which most of the radiant energy from the explosion was delivered, much of this energy was prevented from reaching the animals by this smoke. In the laboratory tests, because the exposure area was so much smaller and the time of energy application at the high calorie levels so much longer, smoke obscuration appears to be of little or no significance.

(3) The blast wave following the explosion, which has not been duplicated in laboratory applications of thermal energy, has two possible protective effects. First, it can be expected to extinguish flames induced by the radiation in assemblies not treated for fire resistance, thus removing a source of high heat. Although the blast wave may not actually extinguish the flame in all cases,* it can be expected in general to have this effect. Second, the blast wave would tend to remove any char which, if allowed to remain, would act as a heat reservoir and increase the likelihood of a severe burn.

(4) The drape of the uniform may have contributed to a reduction of thermal injury in the field, in the case of the two-layer Hot-Wet assemblies. Laboratory tests upon which estimates of protection in the field were based consisted of the application of energy to fabrics in tight contact with the animal's skin. Other tests on cotton fabrics have indicated that spacing the fabric away from the skin would increase the protection afforded. In the uniforms, although some fabric areas were in close skin contact, many were spaced away in normal drape. This fact undoubtedly gave the uniforms an additional protective value as compared to laboratory tests where fabrics were held in close skin contact.

4.2 THE ROLE OF THE FLAMEPROOFING TREATMENT

One of the major problems designated for study at UPSHOT-KNOTHOLE was to determine whether materials actually did flame under the conditions of the test and, if so, how much protection could be afforded by fire resistant treating the outer layer. The results of the test show conclusively that flaming and probably glow did occur in many instances. The principal value of the fire retardant used in these tests, brominated triallyl phosphate, lay in its prevention of these exothermic reactions. In some cases it also seemed to give additional protection against the primary thermal effects of the explosion, although in other cases the untreated fabrics gave better protection than the treated. The peculiar pebbly, blistered, weeping edema noted in these tests occurred only in pigs wearing the fire resistant uniforms.

*The occurrence of persistent flame type burns that require longer to produce (according to laboratory tests) than the blast arrival time may indicate that the blast wave does not always extinguish the flame. On the other hand such burns may have been induced by glow.

4.2.1 Prevention of Exothermic Reactions

Secondary thermal effects from persistant exothermic reactions (flame, glow or both) significantly increased the severity of the burns sustained by the pigs. The most severely burned animal observed in the entire test was clothed in an untreated uniform and located at the most distant station (12.5 cal/cm^2) in Shot 9. In this case the seriousness of the burn was due in large part to the occurrence of a persistent exothermic reaction. Although numerous other pigs received severe local burns as a result of flame or glow, none of these were wearing fire resistant uniforms.

4.2.2 Protection from Primary Thermal Effects

Apart from its prevention of exothermic reactions, the fire resistant treatment has an influence on the protection afforded by the fabric against primary thermal effects. This influence is favorable in most cases but not all. The burns under the HWFR fabric combinations were less serious than those under the HW combinations expecially at the more distant stations. At the close stations the burns under both the treated and untreated Hot-Wet uniforms were so extensive that it was difficult to make a distinction. At the intermediate stations some of the results seemed to favor the untreated fabrics.

There are two phenomena, both of which have already been noted, that would point to better protection by the fire resistant fabrics. One of these is that the smoke from the fire resistant fabrics, which tends to obscure the animals from the radiation, was shown by the motion pictures to be much denser than the smoke from the untreated fabrics. The other is that the large amount of fabric spaced away from the skin in normal uniform drape would favor the fire resistant fabrics. Laboratory tests with the carbon arc have shown that while fire resistant and untreated fabrics are about equal in protective value when in tight skin contact, the treated fabrics afford much more protection than the untreated if spaced away from the skin. The University of Rochester [19] has found that flaming of non-fire resistant fabrics is more prevalent among those spaced away from the skin. This phenomenon may be a contributing factor to the better performance of fire-resistant fabrics.

4.2.3 Edema

In this test edematous burns (see Section 3.3.2) beneath the fire resistant assemblies appeared to persist longer than those beneath untreated assemblies. Furthermore, weeping, brown edema, noted for the first time in these tests, occurred only under the HWFR assemblies.

The mechanism, causative agent, and significance of the edemas produced, particularly this weeping, brown edema are not clearly understood. As was pointed out in describing the edemas, this type had not been observed either in the laboratory or in the field before UPSHOT-

[redacted]

KNOTHOLE. Hence not much is known about it at present. It has been produced in the laboratory by irradiating a circular area about 2-1/2 in. in diameter behind an HWFR ensemble with energy from burning magnesium. This has been accomplished only recently and there has been no opportunity for detailed study. Previous attempts with an energy application over a smaller area (1.7 cm diam) resulted in an edema resembling the weeping, brown edema, but of a transient nature. The following observations are based on these earlier attempts. The indications are of a preliminary nature and the present conclusions may be altered as more data are available.

(1) Edemas of the common, subcutaneous type can be produced in the laboratory a number of ways, but they disappear rapidly. One method is to isolate the tar from the decomposition of fabric treated with brominated triallyl phosphate, paint it on the skin, and then burn the skin. Field tests indicated that a tarry-like condensate from the fire resistant fabrics was deposited onto the skin. Evidence of this had not been seen in previous laboratory tests, suggesting that the tar as observed in the field may have been a contributing factor to the formation of the weeping brown edema.

(2) Although the weeping, brown edema never occurred in the field under untreated fabrics, it was simulated in the laboratory beneath fabric saturated with tar. Since this tar could be from either untreated or treated fabric, the same experiment was tried using mineral oil instead of tar, and the same type of edema was again produced. That such a bland substance as mineral oil could be used suggests that the production of this type of edema might be physical (that is, related in some way to the transfer of energy by vapor condensation) rather than chemical.

(3) No persistent edema ever occurs unless at least a 2+ burn is produced, and the burn probably must not exceed a mild 3+.

No information is available on the edema-producing effect of fire resistant fabrics on human skin. Although pig skin and human skin are similar in reflectance and in response to thermal stimuli, they are quite different in the ease with which edema is produced.

4.3 FACTORS CONTRIBUTING TO EXOTHERMIC REACTIONS.

In untreated fabrics, which these tests have shown to be susceptible to exothermic reactions (flame, glow, or both) as a result of an atomic explosion, there are two circumstances that tend to increase or decrease the extent of such reactions. One of these might be called the geometry of exposure, which includes such considerations as the angle at which the energy strikes and the geometric shape assumed by the uniform on the animals' body at the time of the explosion. The other is the distance of the subject from ground zero.

4.3.1 Geometry of Exposure

Exposures of uniform fabrics in the form of flat panels at Shots 9 and 10 (Project 8.6), and also at other tests, showed no definite evidence of sustained flaming. In the pig experiment, however, uniform burn patterns and motion pictures proved conclusively that the untreated assemblies did flame in many instances. From this evidence it is reasonable to believe that irregular surface contours, folds, and free fabric edges increase the likelihood of ignition. In this connection folded fabrics exposed at BUSTER (1) with the folded edges normal to the burst were destroyed by sustained glowing of the fabric. Because of these geometric characteristics, the angle of incidence is not uniform over the entire exposed fabric surface, thus favoring the attainment at some points of just the amount of energy required for ignition.

4.3.2 Distance from Ground Zero

There were indications that the effects of sustained exothermic reactions were most serious at the stations farthest from ground zero. This might be explained on the basis that the flame persisted only until the arrival of the shock wave. Thus the flame would last longer in those uniforms located farthest from ground zero. However, pathological evidence (See Section 3.3.3) indicated that in some instances at least, an exothermic reaction persisted after the arrival of the blast wave. No information concerning the persistence of flaming after the arrival of the blast wave could be obtained from the motion pictures since the accompanying dust completely obscured the animal holders for some time.

4.4 EFFECT OF UNIFORM DESIGN ON PROTECTION

From examination of the uniforms worn by the animals in this test it is possible to suggest some design features that may have contributed to, or detracted from, the protection afforded.

The added protection at the dorsal seam is obviously simply a function of extra fabric, since the seam construction provided at least six layers of cloth in this area of each uniform.

The severe burns noted in the area adjacent to the drawstring can be partially explained on the basis that in this area the fabric is drawn in close skin contact. Both laboratory and field tests have demonstrated the decreased protective value of a fabric in contact with the skin as compared to that of a fabric spaced away from the skin. The persistent flame type burns noted in the drawstring area under untreated fabrics may be explained by the fabric bunching that occurs here when the drawstring is tightened, thus presenting folds and curved surfaces which favor flaming. The fact that the burns in this area were significantly reduced in Shot 10 where an extra layer of fabric was used in forming the drawstring channel suggests the advantage of designing protective garments with additional layers of fabric in areas of constriction or tight fit.

It has already been pointed out that where there was a difference in uniform damage posterior and anterior to the drawstring, the posterior damage was more severe. There was also a corresponding tendency toward more severe animal burns in the posterior region. Why this part of the uniform provided more protection is not known, although it may be due to the drape of the uniform or to the angle of incidence of the thermal radiation.

4.5 SIGNIFICANCE OF RESULTS IN TERMS OF PROTECTION OF HUMANS FROM ATOMIC EXPLOSIONS

In translating these results on animals to possible results on humans, it can be stated that the protection afforded would be dependent to a large degree on the number of fabric layers in the clothing ensemble and on whether or not the outer layer is treated for fire resistance. If the fabric is untreated there is a distinct possibility that the burns incurred may be more serious than otherwise, due to flaming or glowing of the fabric. The tests have also indicated that even as little as two layers of thin fabric have a significant thermal protective value. The seriousness of bare-skin burns in the cylinder exposures points to a difficult problem with respect to protection of the hands and face or any uncovered parts of the body. Areas of tight fit for the Temperate uniform were of no special significance on the clothed pigs, since there were sufficient layers of insulation to protect the animal whether the fabric was spaced or in contact. In case of the two layer uniforms, HW50/50 and HW (fire or non-fire resistant) spacing due to drape contributed much to the protection afforded. In the case of humans principle areas of tight fit would be across the chest, across the shoulders, at the waist, at the buttocks, and to a lesser extent the elbows and knees depending upon the position of the man. If a man were wearing a jacket the matter of a tight fit at the waist or belt should not be serious, since the belt area would be protected by the lower portion of the jacket which is loose fitting in that area. However, if he were wearing light weight clothing, without a jacket, it could be anticipated that the most severe burns (exclusive of the unprotected hands and face) would be sustained in those areas of tight fit enumerated above.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

1. The four-layer Temperate ensemble (corresponding to the Cold-Wet uniform without the frieze liner) will provide excellent protection against the thermal effects of atomic explosions at all incident energies up to 40 cal/cm^2, with no reason to doubt its efficacy up to 75 cal/cm^2.
2. The two-layer Hot-Wet 50/50 ensemble (5.2 oz dark green oxford over 10.5 oz 50/50 wool/cotton knit underwear fabric) provided good protection up to the highest levels of thermal energy for which data were obtained: 41.0 cal/cm^2 for the untreated ensemble and 33.5 cal/cm^2 for the ensemble with the outer layer treated for fire resistance.
3. The Hot-Wet ensemble (5.2 oz dark green oxford over 3.2 oz knit cotton underwear fabric) provided inadequate protection at energy levels from 9.0 to 50.0 cal/cm^2.
4. Flaming occurred in some of the uniform ensembles in which the outer layer was not treated for fire resistance.
5. Especially at the lower energy levels, the protection afforded by the fire resistant ensembles against the primary and secondary thermal effects of the atomic bursts was better than that of the untreated assemblies.
6. The occurrence of edema, particularly the persistent type, was more common under the fire resistant assemblies.
7. Summation of the advantages and disadvantages of fire resistant fabrics from the standpoint of overall thermal protection definitely indicates the need for a fire resistant treatment for the outer fabric.
8. Burns incurred beneath the uniforms, especially at the higher levels of thermal energy, were consistently less serious than anticipated on the basis of previous laboratory experience.
9. In general, burns were less severe when the uniform was spaced away from the skin than where it was in close skin contact.

5.2 RECOMMENDATIONS

The results of these tests indicate that in future laboratory studies, consideration should be given to:

[redacted]

1. Garment design to eliminate or compensate for areas of tight fit and to take advantage of the added protection provided by fabric spacing.

2. The part fire resistant treatments play in increasing the protective value of fabrics against thermal radiation.

3. The effect of the time-intensity relationship of thermal irradiation, the effect of smoke obscuration due to apparent endothermic decomposition of fabric, and the effect of blast arrival time and size of exposure area.

4. Development of ways and means of protecting the hands and face against thermal radiation.

5. The protective characteristics of clothing fabrics when exposed to low irradiance-long pulse thermal energy.

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APPENDIX A

Trial Run (Shot 2)

A trial run or test in miniature was carried out at UPSHOT-KNOTHOLE Shot 2, 24 March 1953 to check the functioning of the equipment, test techniques, and operational procedures that were to be used in the main tests scheduled for May, 1953.

Eight Chester White pigs anesthetized and clothed in various uniform assemblies were exposed (on holders as described in Section 1.3.4) to a tower shot. The trial run was conducted in the Yucca Flat test area on unstabilized ground. Details as to distances from ground zero, calculated overpressures and thermal energies, and uniform worn by each animal are given in Table A.1.

TABLE A.1 Trial-Run Exposures (Shot 2)

Distance from Ground Zero (ft)	Overpressure (psi, calc)	Thermal Energy (cal/cm^2, calc)	Uniform Assembly*	Status of Animal on Recovery
2900	12-14	75+	CW	Alive
2900	12-14	75+	CWFR	Alive
3100	10-12	48+	T	Alive
3100	10-12	48+	TFR	Dead
3400	9-10	36+	T	Dead
3700	8	24+	HWFR	Alive
4300	6	18+	HW	Alive
5600	4	12+	HW	Alive

*CW (Cold-Wet assembly) consisted of 9 oz sateen and 5.5 oz oxford as in the Field Jacket M-1951, a liner of 16 oz frieze and 1.8 oz rip-stop Fortisan, a 16 oz 85% wool/15% nylon shirting fabric and a 10.5 oz 50% wool/50% cotton underwear fabric. The CWFR was the same as the CW except that the entire garment was given a nondurable fire resistant treatment with borax-boric acid. The other uniform assemblies were the same as described in Section 1.3.3. In the TFR and HWFR assemblies, the outer layer only was treated for fire resistance with brominated triallyl phosphate.

Selection of the exposure distances from ground zero was made principally on the basis of estimated overpressures. The thermal energies which were probably higher than shown in Table A.1, were given secondary consideration, since the main purpose of this trial was to check on the mechanical functioning of the equipment under blast conditions.

The results demonstrated that the exposure equipment was quite satisfactory and that it should perform well under the more favorable conditions of the tests (Shots 9 and 10) scheduled for Frenchmens' Flat.

The animals located at 2900 ft, 3100 ft, and 3700 ft from ground zero suffered some bruises and lacerations from flying debris. The uniforms on the pigs at the 2900 ft location were badly torn and abraded by the sand, sticks, and stones accompanying the blast wave. Although two of the pigs were dead on recovery, it was determined on autopsy that these were anesthesia deaths and while the effect of blast may have been a contributing factor it was not the primary cause.

The animals clothed in the CW, CWFR, T, and TFR assemblies showed no evidence of burns beneath the uniforms. The animal clothed in the HWFR uniform at 3700 ft from ground zero received severe and extensive burns on the left or exposed side. The severity of burns decreased for the two pigs clothed in the HW uniforms at 4300 ft and 5600 ft with the one at 5600 ft suffering only limited 2+ to 3+ burns under the uniform fabric next to the waist drawstring.

Because of the high degree of thermal protection afforded by the Cold-Wet (six-layer) and Temperate (four-layer) uniforms it was decided to eliminate the Cold-Wet ensemble from the main tests. This trial run or test in miniature served as an excellent guide and contributed much to the success of the large-scale tests carried out in Shots 9 and 10.

APPENDIX B

TABLES

TABLE B.1 Burn Assessment Under Temperate Fire Resistant Uniforms

Pig			Exposure Conditions				Over-all Burn Group	Edema			Per-sis-tent Flame Type Burns	Stains		
No.	Weight (lb)	Uni-form Size	Shot	Dis-tance to GZ (ft)	Thermal Energy (cal/cm2)	Blast Arri-val (sec)		Com-mon Type	Weep-ing Type	Persis-tent (Either Type)		Dusty Black	Orange Brown	Green
374	25.0	M	9	2110	75.0	1.58	Dead	–	–	–	–	–	–	–
384	23.0	M					Dead	–	–	–	–	–	–	–

TABLE B.2 Burn Assessment Under Temperate Uniforms

Pig			Exposure Conditions				Over-all Burn Group	Edema			Per-sis-tent Flame Type Burns	Stains		
No.	Weight (lb)	Uni-form Size	Shot	Dis-tance to GZ (ft)	Thermal Energy (cal/cm2)	Blast Arri-val (sec)		Com-mon Type	Weep-ing Type	Persis-tent (Either Type)		Dusty Black	Orange Brown	Green
379	26.0	M	9	2110	75.0	1.58	Dead	–	–	–	–	–	–	–
391	25.0	M					Dead	–	–	–	–	–	–	–
202	27.5	M	10	3870	26.0	2.10	Dead	–	–	–	–	–	–	–
254	31.0	M					0(1)	+	0	0	0	0	0	0
264	37.5	M	10	4870	17.5	2.88	1(0)	+	0	0	0	0	0	0
247	25.5	M	10	4900	17.0	2.91	1	0	0	0	++	0	0	0
225	35.5	M	10	5890	12.5	3.72	1	0	0	0	+	0	+	0
248	33.0	M					1	0	0	0	+	+	0	0

TABLE B.3 Burn Assessment Under HWFR 50/50 Uniforms

Pig			Exposure Conditions				Over-all Burn Group	Edema			Per-sis-tent Flame Type Burns	Stains		
No.	Weight (lb)	Uni-form Size	Shot	Dis-tance to GZ (ft)	Thermal Energy (cal/cm²)	Blast Arri-val (sec)		Com-mon Type	Weep-ing Type	Persis-tent (Either Type)		Dusty Black	Orange Brown	Green
203	30.5	M	10	2170	60.0	0.75	Dead	-	-	-	-	-	-	-
233	29.5	M					Dead	-	-	-	-	-	-	-
235	32.0	M	10	2850	40.5	1.28	Dead	-	-	-	-	-	-	-
335	33.5	L	9	3750	41.0	2.58	Dead	-	-	-	-	-	-	-
365	33.0	L					Dead	-	-	-	-	-	-	-
222	34.5	M	10	3270	33.5	1.63	Dead	-	-	-	-	-	-	-
269	29.0	M					Dead	-	-	-	-	-	-	-
388	30.0	L	9	4310	33.5	2.98	0	0	0	0	0	0	0	0
351	35.5	L	9	4730	29.5	3.28	1	0	0	0	0	+	+	0
230	28.0	M	10	3870	26.0	2.10	1	0	0	0	0	0	+	0
242	30.0	M					0	0	0	0	0	0	0	+
243	28.0	M	10	4870	17.0	2.91	0	0	0	0	0	0	+	0
266	35.5	M					2	+	0	+	0	0	0	0
221	33.0	M	10	5870	12.5	3.72	2	0	0	0	0	0	+	0
239	27.0	M					Dead	-	-	-	-	-	-	-
252	35.0	L	10	6870	9.0	4.55	Dead	-	-	-	-	-	-	-
255	24.5	M					0	0	0	0	0	0	+	0

TABLE B.4 Burn Assessment Under HW 50/50 Uniforms

Pig			Exposure Conditions				Over-all Burn Group	Edema			Per-sis-tent Flame Type Burns	Stains		
No.	Weight (lb)	Uni-form Size	Shot	Dis-tance to GZ (ft)	Thermal Energy (cal/cm2)	Blast Arri-val (sec)		Com-mon Type	Weep-ing Type	Persis-tent (Either Type)		Dusty Black	Orange Brown	Green
208	28.0	M	10	2170	60.0	0.75	Dead	-	-	-	-	-	-	-
253	36.0	M					Dead	-	-	-	-	-	-	-
256	33.5	M	10	2850	40.5	1.28	Dead	-	-	-	-	-	-	-
380	25.5	M	9	3750	41.0	2.58	0	0	0	0	0	+	0	0
383	24.5	M					Dead	-	-	-	-	-	-	-
210	36.0	M	10	3270	33.5	1.63	Dead	-	-	-	-	-	-	-
213	31.0	M					Dead	-	-	-	-	-	-	-
381	24.0	M	9	4310	33.5	2.98	1	+	0	0	+	0	0	0
386	30.0	M	9	4730	29.5	3.28	1	0	0	0	0	+	+	0
224	33.0	M	10	3870	26.0	2.10	1(0)	+	0	0	+	+	0	0
238	32.0	M					Dead	-	-	-	-	-	-	-
348	35.5	M	9	5720	21.5	4.04	1	0	0	0	0	0	+	0
373	32.0	M					1(0)	0	0	0	0	0	+	0
382	34.5	M					1	0	0	0	0	0	+	0
534	37.5	L	9	6710	16.0	4.86	1	0	0	0	+	0	+	0
347	38.0	M					1	0	0	0	+	0	+	0
352	35.5	L					1	0	0	0	0	0	+	0
336	42.0	L	9	7700	12.5	5.64	Dead	-	-	-	-	-	-	-
364	32.5	L					Dead	-	-	-	-	-	-	-
368	39.0	L					Dead	-	-	-	-	-	-	-

[redacted]

TABLE B.5 Burn Assessment Under HWFR Uniforms

Pig			Exposure Conditions				Over-all Burn Group	Edema			Per-sis-tent Flame Type Burns	Stains		
No.	Weight (lb)	Uni-form Size	Shot	Dis-tance to GZ (ft)	Thermal Energy (cal/cm^2)	Blast Arri-val (sec)		Com-mon Type	Weep-ing Type	Persis-tent (Either Type)		Dusty Black	Orange Brown	Green
331	32.0	M	9	3160	50.0	2.19	3	+	0	+	0	+		0
340	34.0	M					Dead	-	-	-	-	-	-	-
257	34.0	M	10	3870	26.0	2.10	Dead	-	-	-	-	-	-	-
263	34.0	M					3	+	0	+	0	+	+	0
346	34.0	M	9	5720	21.5	4.04	2	+	+	+	0	0	+	0
378	27.0	M					2	0	+	+	0	0	+	0
387	28.0	M					2	0	+	+	0	0		0
240	30.0	M	10	4840	17.5	2.88	3	+	+	+	0	0	+	0
268	31.5	M	10	4870	17.0	2.91	3(2)	+	0	+	0	+	+	0
332	41.5	L	9	6710	16	4.86	1	0	+	+	0	0	+	0
343	38.0	M					Dead	-	-	-	-	-	-	-
366	36.5	L					0	0	0	0	0	0	0	0
341	39.0	L	9	7700	12.5	5.64	1	+	0	+	0	0	+	0
375	23.0	L					Dead	-	-	-	-	-	-	-
392	29.0	L					2	+	+	+	0	0	+	0
249	33.0	M	10	5870	12.5	3.72	1(2)	+	+	+	0	0	+	0
250	28.5	M					2	+	0	+	0	0	+	0
216	27.5	M	10	6870	9	4.55	Dead	-	-	-	-	-	-	-
245	37.5	M					Dead	-	-	-	-	-	-	-

TABLE B.6 Burn Assessment Under HW Uniforms

Pig			Exposure Conditions				Over-all Burn Group	Edema			Per-sis-tent Flame Type Burns	Stains		
No.	Weight (lb)	Uni-form Size	Shot	Dis-tance to GZ (ft)	Thermal Energy (cal/cm2)	Blast Arri-val (sec)		Com-mon Type	Weep-ing Type	Persis-tent (Either Type)		Dusty Black	Orange Brown	Green
354	36.5	M	9	3160	50.0	2.19	3	+	0	0	0	0	0	0
385	28.0	M					3	0	0	0	+	+	0	+
360	39.0	L	9	4310	33.5	2.98	3	+	0	0	+	+	0	+
260	32.5	M	10	3870	26.0	2.10	Dead	-	-	-	-	-	-	-
262	37.0	M					3	0	0	0	+	+	+	0
342	32.0	M	9	5720	21.5	4.04	2	0	0	0	+	0	+	0
350	27.0	M					2	+	0	0	+	0	+	+
357	35.0	M					3	0	0	0	0	+	+	0
234	35.5	M	10	4840	17.5	2.88	Dead	-	-	-	-	-	-	-
205	40.0	M	10	4870	17.0	2.91	2	+	0	0	+	0	+	0
333	39.0	L	9	6710	16.0	4.86	2(1)	0	0	0	+	0	+	0
367	43.0	L					2	0	0	0	+	0	+	0
377	38.0	M					2	0	0	0	+	+	+	0
344	38.5	L	9	7700	12.5	5.64	2	0	0	0	+	0	+	0
372	35.5	L					2	+	0	0	+	0	+	0
390	34.0	L					3(4)	+	0	0	+	0	+	0
212	24.0	M	10	5870	12.5	3.72	Dead	-	-	-	-	-	-	-
258	28.5	M					Dead	-	-	-				
237	40.5	M	10	6870	9	4.55	2	0	0	0	+	0	+	0
251	35.0	M					Dead	-	-	-				

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TABLE B.7 Percentage Destruction of Exposed Fabric Layers of Various Uniforms

Thermal Energy (cal/cm2)	HW		HWFR		HW 50/50		HWFR 50/50		T		TFR	
	Outer Layer	Second Layer	Outer Layer	Second Layer	Outer Layer	Second Layer	Outer Layer	Second Layer	Outer Layer	Second Layer	Outer Layer	Second Layer
					Shot 9							
75.0									95	30	95	0
									95	25	95	0
50.0	100	98	95	20								
	100	95	98	15								
41.0					98	15	98	0				
					98	2	95	0				
33.5	100	95			95	2	95	0				
29.5					90*	5	98	0				
21.5	98	30	90	2	98	0						
	98	10	90	0	95	0						
	95	40	95	0	95	0						
16.0	95	30	90	0	98							
	98	25	80	0	95							
	98	30	75	0	98							
12.5	98	15	75	0	85	1						
	95	10	70	0	95	0						
	100	60	70	0	98	1						
					Shot 10							
40.5					100	90	100	25				
33.5					98	60	98	5				
					98	30	98	15				
26.0	98	50	98	75	98	0	98	0	98	0		
	100	80	95	15	98	3	95	0	90	1		
17.5	98	5	95	5					98	0		
17.0	100	5	95	0					90	3		

*This animal had shifted in the holder.

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