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WT-1440

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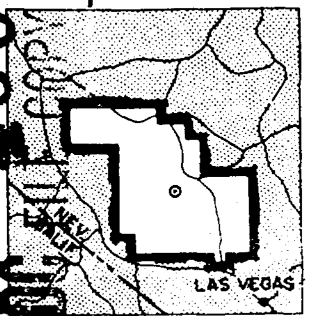
OPERATION PLUMBBOB



NEVADA TEST SITE
MAY-OCTOBER 1957

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Project 8.1

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THERMAL PROTECTION of the INDIVIDUAL SOLDIER

Issuance Date: June 10, 1959

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21 Report on OPERATION PLUMBBOB—PROJECT 8.1

6 THERMAL PROTECTION of the INDIVIDUAL SOLDIER.

10 Frank H. Babers
Allan J. McQuade

5 [redacted] Army Quartermaster
Research and Engineering Command,
Natick, Mass[redacted]

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FOREWORD

This report presents the final results of one of the 43 projects comprising the Military Effects Program of Operation Plumbbob, which included 28 test detonations at the Nevada Test Site in 1957.

For overall Plumbbob military-effects information, the reader is referred to the "Summary Report of the Director, DOD Test Group (Programs 1 – 9)," WT–1445, which includes: (1) a description of each detonation, including yield, zero-point location and environment, type of device, ambient atmospheric conditions, etc.; (2) a discussion of project results; (3) a summary of the objectives and results of each project; and (4) a listing of project reports for the Military Effects Program.

ABSTRACT

The objectives were to evaluate in the field, under the conditions of an actual nuclear detonation, the performance of clothing and other items developed for the protection of the individual soldier and to provide assistance to the personnel of Project 8.2 in an investigation of the feasibility of using a skin simulant as a substitute for animate skin in studying weapon effects.

The items developed to provide thermal protection for the soldier included two experimental hot-weather uniform ensembles, three shielding materials, a protective cream, and a three-layer flashoff-reflector-insulating system. These were exposed during Shot Priscilla to anticipated thermal energies varying from 10 to 25 cal/cm^2, together with appropriate controls, while using white-skinned pigs as test subjects.

Both experimentally designed uniform ensembles provided considerably greater protection than did the control. These experimental uniforms were similar with respect to their outer layer, fire-resistant-treated cotton poplin, and a cotton tee-shirt underlayer. They differed with respect to their middle layer, one using a light-weight 50-50 wool-cotton fabric and the other a fabric designed to separate the inner and outer layers. Of these, the uniform containing the spacing fabric was considered the most effective in preventing burns, for eight of the twelve animals exposed at the three stations were judged to have received essentially no burns, and large-area burns were no more than 1+. However, all uniform assemblies were so damaged at all exposure levels as to be judged functionally unsuitable.

The three shielding materials tested were: (1) a light-weight cotton poplin, 5 oz/yd^2, fire-retardant treated; (2) an 8.5 oz/yd^2 sateen; and (3) neoprene-coated Fortisan poncho material. The shields were positioned 6 inches in front of clothed animals with bare skin areas and subjected to radiant exposures of 14.5 and 24 cal/cm^2. The poncho material and the fire-resistant poplin prevented damage to the uniform ensemble and reduced the bare-skin burns from 5+ on unshielded animals to spotty 1+ and 2+ burns. At 24 cal/cm^2 of exposure, the sateen shield offered little or no protection to the animal or uniform, but gave some protection at the 14.5-cal/cm^2 station. All shielding materials were destroyed, but the efficiency of the shielding principle was demonstrated.

An experimental thermal protective cream, QMC 305-X and a three-layer flashoff-reflector-insulator system showed excellent protective qualities when subjected to radiant exposures of 14.5 and 24 cal/cm^2.

The Naval Material Laboratory conducted a skin-simulant study in conjunction with the QMC project and provided the project with data as to the calorie levels produced at each station. The results of this test will be given in the final report of Project 8.2 (Naval Material Laboratory).

It is considered that the overall objectives of the test were met successfully.

PREFACE

The authors wish to thank the many of their coworkers at the Quartermaster Research and Engineering Command, Natick, Massachusetts, who contributed to this report and participated in the activities at the test site. Their services were ably supplemented by three medical specialists from the Atomic Energy Project at the University of Rochester, Rochester, New York. In addition, the invaluable aid provided by the seven veterinary specialists from the Walter Reed Army Institute of Research, Washington, D. C., is acknowledged.

To all these and to those unnamed who provided aid both on and off the test site, the authors offer sincere thanks for helping in successfully completing this project.

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Chapter 1
INTRODUCTION

1.1 OBJECTIVES

The objectives of Project 8.1 on Operation Plumbbob were to evaluate in the field, under the conditions of an actual nuclear detonation, the performance of clothing and other items developed for the protection of the individual soldier and to provide assistance to the Naval Material Laboratory (NML) in an investigation of the feasibility of using a skin simulant as a substitute for animate skin in studying weapon effects.

1.2 BACKGROUND AND THEORY

With the introduction of nuclear weapons into warfare, the soldier became subject to two new battlefield hazards, thermal and ionizing radiation. Although flame-type weapons have long been used in warfare, thermal radiation from them had no mass-casualty-producing potential. Nuclear weapons have drastically changed that picture and thermal radiation is now a serious hazard. According to Tsuzuki (Reference 26), 90 percent of the Japanese who sought aid the first week after the atomic bombing did so because of thermal burns. Burns can be expected when unprotected skin is exposed to about 3 cal/cm^2 of thermal energy delivered in 1 second or less. When the skin is covered with untreated summer-weight clothing, the hazard of burns becomes further pronounced, due to the ignition of such clothing. As the weapon yield increases, the danger area for incapacitating burns also increases. Further, it should be remembered that thermal damage combined with radiation exposure is more serious than either hazard alone (Reference 6).

The Quartermaster Corps (QMC) is presently engaged in a long-range program whose objective is to provide thermal protection for the individual soldier and his clothing. This program was initiated in 1943 as a result of casualties suffered by members of tank crews during the African Campaign in World War II. A contract titled, "The Flameproofing of Army Clothing" under Project NRC QMC-27 was negotiated in October 1943 with Columbia University. QMC TC No. 5 dated 24 March 1948 established Project 7-92-06-001, "Flame and Thermal Protective Clothing." In 1950, The Quartermaster General requested Continental Army Command (CONARC), then Army Field Forces, to determine requirements for flame-resistant clothing and, as a result, military characteristics were prepared. These military characteristics were the first to require protection against napalm, phosphorus, and fuels and gases.

As a result of QMC TC No. 17, 27 December 1951, Project 7-12-01-001, "Implications of Atomic Warfare on QM Items" was established. At QMC TC Meeting No. 3 on 20 June 1956, the objectives of Projects 7-92-06-001 and 7-12-01-001 were re-examined and, as a result, the Project 7-12-01-002, "Thermal Protection of the Individual Soldier" was established.

Quartermaster personnel participated in Operations Ranger (Reference 7), Buster (Reference 9), Desert Rock IV, Tumbler-Snapper (Reference 8), Upshot-Knothole (References 11 and 20) and Desert Rock VI, Teapot (Reference 2). Some QM materials were exposed on pigs by the

University of Rochester Project during Greenhouse (Reference 22). Chester White pigs were used during Upshot-Knothole to determine the protection afforded by various uniform assemblies. In the other tests, the primary objective was to determine the properties of the fabrics that contributed to its ability to withstand high thermal irradiances. Some indication of the protection that might be afforded was gained by the use of passive temperature indicators placed behind the assemblies.

The University of Rochester has conducted research in this field since 1947 under contract to the Atomic Energy Commission. The work has been directed toward understanding the characteristics of flash burns. In connection with this research, Chester White pigs have been used as experimental animals, since their skin closely resembles that of humans in response to thermal damage (Reference 18).

A biomedical technique has been developed for grading the animal burns in which the severity is given a numerical designation (References 19, 23, and 24). Erythema of the skin signifies a 1+ burn, while carbonization of the skin signifies a 5+ burn. There are corresponding intermediate numerical designations in the system. It has been reported that 1+ and 2+ burns on pigs correspond to first- and second-degree burns in humans while 3+, 4+, and 5+ relate to third-degree burns of varying severity (Reference 23).

Using this burn-grading system, the University of Rochester workers have reported that the susceptibility of unprotected pig skin to radiant thermal energy as applied in the laboratory varies with the irradiance and time of application. They have attempted to define the relationship in mathematical terms (References 16 and 23). Behind fabrics the pig burns do not follow this same mathematical relationship, because other factors, such as spacing, flaming when it occurs, and the heat reservoir function of a fabric, are important in influencing the occurrence or inhibition of burns (Reference 17).

In a search for a laboratory thermal source, many types of equipment have been evaluated, and a modified carbon-arc searchlight (Reference 10) and a magnesium flash (Reference 13) have been established as fairly satisfactory laboratory tools. The carbon arc has the disadvantage as a laboratory tool of providing high-intensity radiation over only a small area and has limited use in the study of materials spaced away from the focal point. To overcome some of these difficulties, a solar furnace has been constructed at the QM Research and Engineering Command. The solar furnace has a greatly increased output intensity, as well as larger effective area.

The magnesium flash distributes its energy over a large area, but it is difficult to prevent flame and molten metal from coming in contact with the test material. It is also difficult to closely predict the thermal yield. The thermal spectrum of the arc closely resembles that from a nuclear detonation, but that from the magnesium flash differs widely.

During Operation Upshot-Knothole (Reference 20) it was shown that test animals wearing simulated cold-wet clothing, with or without the frieze liner, were (according to the military characteristics of that time, 1953) adequately protected against "disabling" burns when exposed to thermal energies as high as 30 cal/cm^2. An elaborate system involving body area and degree of burn was worked out to determine the protection provided.

The animals were divided into five groups:

Group 0. No evidence of burn.

Group 1. The 1+ burn covering less than 10 percent of body area, or 2+ burn totaling 1 to 3 percent of body area.

Group 2. The 1+ burn covering 10 to 30 percent of body area, or 2+ burn covering 3 to 10 percent of body area.

Group 3. The 1+ burn covering 30 percent or more of body area, or 2+ burns covering 10 to 30 percent of body area.

Group 4. The 2+ burn covering over 30 percent of body area.

Unless "disabling burns" were suffered, protection was considered adequate. However, while fulfilling the 1953 requirements, only the six-layer cold-wet uniform ensemble on animals recovered alive fulfilled the present requirement that no burns should occur beneath the uniform. In general, fabrics when spaced away from the skin gave better protection than those in direct contact. It was established that in order to prevent flaming, fire-retardant-treated cotton fabrics were of benefit. The most-critical problem yet to be resolved is the thermal protection of the individual soldier when wearing clothing suitable for warm-weather conditions and, particularly, the protection of the hands, face, and eyes, which are normally uncovered in such climates. However, in view of the changed military requirements, the temperate-climate uniform also requires improvement in thermal protective qualities.

For the critical body areas, particularly the face, development work has been concerned with creams, for the most part. In 1943, a thermal protective cream was developed by the Department of the Navy to protect the face of crews in gun turrets against the flash-type fires encountered during naval engagements. The cream was later adopted by the Armored Corps for use by tank crews and is still in the Army supply system. Naval combat reports indicated the cream provided adequate thermal protection for a short time but soon dried, cracked, and lost its effectiveness, and the Navy discontinued its use. This cream was not intended for use against the high thermal energies expected from nuclear detonations. When used in $\frac{1}{16}$-inch layers according to directions, Payne and Hinshaw (Reference 21) found the cream provided excellent protection against greater than 33 cal/cm^2 of radiant thermal energy. Bales, et al, (Reference 3) had previously reported that the cream, when used in very thin "realistic" layers (not according to the directions, which specified a $\frac{1}{16}$-inch layer), was a hazard. In tests in the QM laboratories (unpublished results), a $\frac{1}{16}$-inch layer of the issue cream provided thermal protection to approximately 9 cal/cm^2, but ignited and burned above that level. The skin beneath the burning cream was protected, but burns occurred in adjacent uncovered areas.

The field study by QMC during Operation Plumbbob was conducted to evaluate the most-promising experimental materials developed to date in the form of summer-weight clothing systems, shielding devices, and a flashburn cream for protection of the hands and face. These materials were previously critically evaluated in the laboratory using the carbon arc or magnesium flash, and suitable thermal protection was indicated. There were four areas of primary concern to QMC:

1.2.1 Measurement of the Protective Value of Hot-Weather Clothing of Improved Design and Material. Two hot-weather clothing ensembles of improved design and material were compared with a control hot-weather uniform:

The control uniform, designated HW-C, was the uniform previously tested during Upshot-Knothole (Reference 20) and is the uniform recommended by CONARC for standardization (Reference 1) as the hot-weather uniform. This ensemble consisted of an outer layer of cloth (cotton, poplin, 5 oz/yd^2, shade 116), not fire-retardant treated, and an inner layer of tee-shirt material (cotton, tubular knit, 3.2 oz/yd^2).

One experimental assembly, designated HW-U, was a three-layer system incorporating an outer layer of cloth (cotton, poplin, 5 oz/yd^2, before treatment, shade 116, fire-retardant treated with tetrakishydroxymethyl phosphonium chloride, THPC), Lynrus finishing (Reference 25), an intermediate layer of cloth (tubular knit, 50 percent cotton, 50 percent wool, 4.5 oz/yd^2) and an inner layer of cloth (cotton, tubular knit, 3.2 oz/yd^2, tee-shirt).

The second experimental ensemble, designated HW-S, included the same outer and inner layers as the HW-U ensemble, but the inner layer was separated from the outer layer by an experimental spacer material. The spacer was made from cloth, heat-set polyethylene, Leno weave ("Trilok") and provided approximately $\frac{1}{4}$ inch of spacing.

The animal uniforms were made according to the patterns developed for use during Operation Upshot-Knothole. They were based on the body measurements of a number of pigs made by the Department of Agriculture at the Agriculture Research Center, Beltsville, Maryland. A full length zipper, about 3 inches beyond the back seam and so located as to not be exposed to the radiant energy, facilitated putting on and taking off the uniform. Seams, zippers, and draw strings were constructed in accordance with specifications for the jacket, shell, field, M-1951. Because of the small size of the uniforms, all seams were made similar to the seam joining the arm to the body in the M-1951 jacket.

1.2.2 Measurement of the Protection Afforded by Thermal Shields. Three materials readily available to the soldier were tested as thermal shields to determine the protection provided to bare skin and to the uniform when placed 6 inches in front of the animal: (1) cloth, cotton, poplin, 5 oz/yd^2, shade 116, fire-retardant treated with THPC, designated as SF; (2) cloth, cotton, sateen, 8.5 oz/yd^2, OG 107, designated SS; and (3) experimental poncho material (neoprene-coated Fortisan) designated SP.

The feasibility of using shielding materials for protection against thermal radiation from shots fired by friendly forces was demonstrated by the use of personnel dummies during Operation Teapot. However, the data obtained on inanimate receivers was not considered conclusive.

In the laboratory, the carbon arc is not suitable for testing shields placed several inches away from the target area; for the testing of such materials, the magnesium flash is generally used. The thermal spectrum obtainable by this procedure does not duplicate that of a nuclear weapon, and in addition, it is almost impossible to prevent spattering of the material with molten magnesium.

The sateen material, SS, is that used in the gas cape. As tested in the field, it was not impregnated with the chemicals that would normally be used if attack by chemical agents was considered imminent. It is normally stocked untreated.

The neoprene-coated Fortisan material, SP, is designed to be used in a new poncho, which will replace the present vinyl-coated nylon standard item. In laboratory tests at the University of Rochester using the magnesium flash, the vinyl-coated nylon poncho became a flaming torch, and burns behind the material were more serious than those suffered by unshielded animals (Reference 5). At Desert Rock VI, dummies behind the nylon shield were spattered with molten nylon globules, but the outer clothing layers were not penetrated (Reference 2).

1.2.3 Measurement of the Protection Available for the Hands and Face in Hot or Temperate Climates. To provide thermal protection in such climates, creams and shields seem the most feasible approach. The experimental cream tested (QMC 305X) is a water-in-oil type emulsion; from laboratory tests, it was the best of many such formulations previously tested. The formulation of Cream 305X is:

Ingredients	Parts by Weight
	grams
Methyl Cellulose	1.6
Chlorinated Paraffin	36.4
Titanium Dioxide	8.7
Magnesium Carbonate	3.8
Ferric Oxide	0.1
Water	25.9
Stearic Acid	4.2
Calcium Stearate	8.6
Hydroabietyl Alcohol	10.7

The density of the cream was 1.2, the optical reflectance measured on a photoelectric reflection meter with a tri-green filter was 60 to 65 percent, and the transmittance of a $\frac{1}{16}$-inch layer was zero. Using the carbon arc, a $\frac{1}{16}$-inch layer permitted no burns on experimental animals at exposures of 30 cal/cm^2, the maximum thermal energy obtainable with the available equipment. While excellent thermal protection was provided, the cosmetic qualities of the cream still require improvement. In the tables, the abbreviation "FC" applies to face creams.

A flashoff-reflector-insulator system suitable for the fabrication of hand or face shields was tested. The outer layer of vicara (a synthetic proteinogenous fabric) was to cover the reflective aluminized layer. This outer layer on exposure to thermal radiation was expected to burn or flash off, exposing the reflector intermediate layer of aluminized scrim, which in turn should give protection to the inner insulating layer of ⅛-inch ensolite. In the laboratory, protection against more than 30 cal/cm^2 was indicated by the system.

1.2.4 Correlation of Results with Animals and Inanimate Receivers. In cooperation with NML, pigs in uniforms were exposed at the same energy levels at which NML exposed inanimate receivers (referred to as skin simulants) protected by the same uniform ensemble. The objective was to learn from those experiments whether or not the results obtained in the field using the inanimate receivers could be correlated with those obtained using animals. Quartermaster participation was limited to furnishing NML with animals, technical assistance, and equipment.

Chapter 2
PROCEDURE

2.1 OPERATIONS

The tests were so scheduled that all could be included in each of two shots, with the second shot to be used in the event that duplication was necessary. The shot for primary participation was Priscilla, with Hood the alternate. However, because of the successful nature of Shot Priscilla, participation in the alternate was not required. The overall layout of the test is shown in Table 2.1.

2.1.1 Hot-Weather Uniform Ensembles. The two experimental ensembles, HW-U and HW-S, were compared with the HW-C standard at radiant energy levels of 10, 14.5, and 21 cal/cm^2. The test was run in quadruplicate. Thirty-six anesthetized pigs in the uniform assemblies were placed on animal-holding racks and exposed at the desired energy levels.

2.1.2 Shielding. In the test of the three shielding materials, SS, SP, and SF, 24 pigs were used as animate receivers. Each material was exposed in quadruplicate at expected energy levels of 15 and 25 cal/cm^2.

The experimental design was such that each animal was clothed in a modified control uniform, HW-C. As used in the shield experiment, the uniform contained a square opening approximately 4 by 4 inches to provide a bare skin area behind the shield in the direction of ground zero. In each instance, a shield of the desired material was interposed between the ensemble-bare skin situation and ground zero. The distance between the animal and thermal shield was 6 inches. At the bottom of each shield was an 8-inch apron of heavy aluminized fabric, whose purpose was to assure that no thermal radiation reflected from the ground would hit the unshielded animal.

2.1.3 Thermal Protective Cream and Protective Material for Hands and Face. One flash-burn cream for the hands and face, water-in-oil (QMC 305X) was evaluated in quadruplicate on anesthetized pigs at a thickness of $\frac{1}{16}$ inch at two radiant-exposure levels, 14.5 and 24 cal/cm^2. Because Cream 305X does not develop a surface film and, hence, lacks abrasive resistant properties, after application to the animal the surface of the cream was sprayed lightly with an aerosol formulation of Kel-F 800 resin in methyl ethyl ketone. For protection against the lower night temperatures, the animals were clothed in a uniform which had an outer layer of aluminized fabric to prevent its destruction at the expected energy level. The uniform had two openings on the side facing ground zero, each opening about 6 by 6 inches. On one area, the cream was applied. The other served as bare-skin control. On a portion of the same uniform was an insert of material suitable for hand and face shielding (ensolite-aluminum-vicara) which had proven effective in excess of 30 cal/cm^2 in laboratory tests. Eight pigs were required for this part of the project.

2.1.4 Study on the Use of NML Skin Simulants. Pigs under anesthesia and clothed with the desired special uniforms were exposed to 6.5 and 14.5 cal/cm^2. At the same site, Project 8.2 exposed a skin simulant under similar conditions and determined the temperature rise on the simulant according to NML's standard procedure. Six pigs were required for this part of the test.

The pigs, pig holders, and uniforms were furnished to Project 8.2 by QMC, and the burns were assessed by the QMC surgical team. However, preparation, placement and recovery of animals was done by NML personnel, and the results will be given in the Project 8.2 report.

2.1.5 Experimental Boots. Without dilution to the main effort and with no cost to the project, two experimental boots were exposed to 10, 14.5, and 21 cal/cm^2 to learn the relative thermal resistance of the various types of boot construction. This work is reported in Appendix C.

2.1.6 Quartermaster Inanimate Receivers. Without dilution to the main effort and with no cost to the project, inanimate thermal receivers similar to those normally used at the Quartermaster Research and Engineering Command were exposed at the 6.5- and 14.5-cal/cm^2 levels. These receivers were connected to spare channels of the same Heiland recorders used by NML

TABLE 2.1 ANIMAL EMPLACEMENT CHART FOR QUARTERMASTER CORPS PARTICIPATION DURING SHOT PRISCILLA

Official Station Designation	F8.1-9044.01	F8.1-9044.02	F8.1-9044.03	F8.1-9044.04	F8.1-9044.05
Nominal Station Designation	58	64	75	90	120
Anticipated Energy Level, cal/cm^2	25	20	15	10	5
Hot Weather (H-W) Uniform Assemblies:					
Standard H-W Uniform HW-C	—	4	4	4	—
H-W with 50-50 Underwear HW-U	—	4	4	4	—
H-W with Spacer HW-S	—	4	4	4	—
Shielding Materials:					
Fire-Retardant Poplin (SF)	4	—	4	—	—
Sateen Gas Cape Material (SS)	4	—	4	—	—
Neoprene-Coated Fortisan Poncho Material (SP)	1	—	4	—	—
Face Cream and Flashoff Material (FC)	4	—	4	—	—
NML Skin Simulant (NML)	—	—	3	—	3
Bare Skin Only (BS)	—	2	—	2	—
Number of Pigs	16	14	31	14	3

to record data on its skin simulant. The objective was to obtain field data for correlation with that from the laboratory carbon arc. The test is further described and the data reported in Appendix D.

2.1.7 Bare-Skin Areas. To serve as a basis of comparison, unprotected bare-skin areas were exposed at each of the stations. At those stations at which the face creams were exposed, openings in the environmental protective uniform were used. At the 10- and 20-cal/cm^2 stations, where only the hot-weather assemblies were placed, two animals were used at each station solely for bare-skin controls.

2.1.8 Emplacement Area. At distances from ground zero at which the desired thermal intensity was expected to occur, the surface soil was previously leveled and stabilized by Atomic Energy Commission (AEC) contractors. The purpose was to reduce danger of injury to the animals by flying debris and to provide a smooth level surface for emplacing the animal racks, required instrumentation, and moving-picture cameras. The areas were of such size as to extend 100 feet in front of the line of animal frames, 50 feet to the rear, and 10 feet on each end.

The animal racks were similar to those used during Operation Upshot-Knothole. They were emplaced on the stabilized areas on a line normal to ground zero so that the left side of the animal was also normal to ground zero. Each frame was securely staked to the ground to prevent movement due to the blast or shock from the explosion.

2.2 INSTRUMENTATION

The instrumentation necessary to measure the various levels of thermal energy for this project was accomplished by Project 8.2, NML. At two stations, 6.5 and 14.5 cal/cm^2, the Naval Radiological Defense Laboratory (NRDL) field-type recording calorimeters and radiometers were mounted normal to the radiation. At all five stations, NML exposure meters were used as passive receivers. The meters were selected to bracket the expected energy levels and were used in duplicate.

Young (25-to-35-pound) crossbred Chester White-Yorkshire pigs were used as animate receivers for measuring the thermal protection provided by the various standard and developmental items. The hair on the left side of the animals, the side toward ground zero, was removed with electric clippers about 18 hours prior to the scheduled time of the shot. No food was given for 24 hours and no water for 12 hours prior to shot time. About 6 hours prior to shot time, the animals were anesthetized intraperitoneally with Dial in urea-urethane (Ciba) 55-to-60 mg/kg (Reference 13), clothed in the desired ensemble, and placed in the animal racks previously located on the stabilized areas.

The animals were recovered, starting at approximately an hour after exposure to the thermal radiation from Shot Priscilla. At the time of recovery, due to the distances of the exposure areas from ground zero, the intensity of nuclear radiation was less than 10 mr/hr. Evaluation of damage to the materials and items was accomplished by visual inspection and by analysis of motion pictures and still photographs. Skin damage was assessed visually as soon after recovery as possible and 24 hours later by the biomedical technique developed at the University of Rochester and employed at that institution and at the Quartermaster Research and Engineering Command (References 19, 23, and 24).

Following the 24-hour evaluation, numerous biopsy samples were taken for preparation at the University of Rochester for histological examination. Sixteen animals from the 24-calorie station were evaluated, including the securing of biopsy samples, at 24-hour intervals for 14 days in a study on wound healing by University of Rochester personnel. Their results will be published later as a University of Rochester report.

Because of the large number of animals involved, it was not considered feasible to cover all animals by moving pictures during the detonation. Hence, only representative animals at each station were so photographed. The cameras, using 16-mm film and operating at 64 frames/sec, were started electrically a few seconds before the detonation and continued in operation until after the arrival of the blast wave (Reference 12).

In addition to the primary efforts of Project 8.1, and without cost to the project or interference with its principal objectives, paper-type calorimeters used by the Quartermaster Research and Engineering Command and a self-contained passive-type calorimeter developed at the University of Rochester were exposed at each station. The experiments are described in Appendixes A and B.

Chapter 3
RESULTS

The data obtained show the thermal-energy levels at the several stations and the effects of that energy on the materials and animals and, thereby, indicate the amount of thermal protection that may be expected from the materials tested. Thus, the objectives of the test were met successfully.

3.1 RADIANT EXPOSURES

The radiant energy at the several stations immediately following the detonation closely approached the calculated anticipated values. The data obtained by Project 8.2 from recording calorimeters at two stations and from copper-plate and foil meters at all stations as well as the estimated best value is shown in Table 3.1. This data is more completely described in the reports from Project 8.2 (NML).

The thermal energies indicated by QMC paper calorimeters and the University of Rochester instruments agreed closely with those reported by Project 8.2. The data is given in Appendixes A and B.

3.2 BURNS ON BARE SKIN

Table 3.2 shows the burns that resulted when the skin of unprotected pigs was exposed to the thermal pulse. The curvature of the pig's flank, as well as variations over the 36-in^2 exposed area made it difficult for the medical technicians to evaluate the burned bare-skin area in the terms of a single value. This may readily be accomplished in the laboratory when the 1-in^2 area from the carbon arc is evaluated. Thus, in some instances of Table 3.2, a range in values has been indicated. In general, there is a decrease in burn severity as the radiant exposure decreased.

3.3 HOT-WEATHER UNIFORMS

The results of the biomedical evaluation of the burns on the clothed pigs 24 hours after the detonation and the visual determination of the damage to the uniform assemblies are given in Tables 3.3, 3.4, and 3.5. Table 3.6 shows the location of the burns by body areas, whereas Table 3.7 lists the burns by severity. Table 3.8 groups the animals according to the system used during Operation Upshot-Knothole, in which area and degree of burn are integrated to groups.

Motion-picture films taken just prior to, during, and just after the detonation show that the outer layer of the control uniform was essentially destroyed during the thermal pulse. However, smoking and smoldering continued until after the arrival of the shock wave and, in several cases, continued until the arrival of the animal recovery party at about H + 1 hour. There was much convulsive movement of the animals following the arrival of the thermal pulse. Flaming was indicated as the method of uniform decomposition. The results as indicated in the films are given in detail in Appendix E (Table E.1).

The films showed that the physical structure of the outer layer of the HW-U and HW-S assemblies remained intact in four out of the eleven animals covered by motion-picture

TABLE 3.1 THERMAL RADIATION, SHOT PRISCILLA, PROJECT 8.1*

Official Station Designation	Nominal Station Designation	Expected	Thermal Radiation Measurements: Recording Meter	Copper Plate Meter	Foil Meter	Estimated Best Value †
		cal/cm²	cal/cm²	cal/cm²	cal/cm²	cal/cm²
F8.1-9044.01	58	25	—	24	23 16‡	24
F8.1-9044.02	64	20	—	21	21 9‡	21
F8.1-9044.03	75	15	15.0 13.9	15	19 10‡	14.5
F8.1-9044.04	90	10	—	10	8	10
F8.1-9044.05	120	5	6.7 6.3	5	5	6.5

* Data furnished by Project 8.2.
† Personal communication from W. L. Derksen, Project 8.2.
‡ Subject to screen transmission error.

TABLE 3.2 DAMAGE TO BARE PIG SKIN FOLLOWING EXPOSURE TO VARIOUS LEVELS OF THERMAL RADIATION

Station Location and Ensemble Containing Bare Skin Area	Pig No.	Radiant Exposure	Assessment of Burns 24 Hours After Exposure
		cal/cm²	
58-FC-1	109	24	5+
58-FC-2	53	24	4+ to 5+
58-FC-3	168	24	3+ to 4+
58-FC-4	94	24	4+ to 5+
64-BS-1	36	21	2+ to 5+
64-BS-2	87	21	3+ to 5+
75-FC-1	90	14.5	3+ to 4+
75-FC-2	52	14.5	3+ to 4+
75-FC-3	64	14.5	3+ to 4+
75-FC-4	123	14.5	3+ to 4+
90-BS-1	71	10	1+ to 5+
90-BS-2	104	10	2+ to 3+
120-NML-1	10	6.5	1+
120-NML-2	15	6.5	No burn
120-NML-3	106	6.5	1+

TABLE 3.3 DAMAGE TO SKIN AND ENSEMBLE OF PIGS CLOTHED IN THE HOT-WEATHER CONTROL UNIFORM (NON-FIRE-RETARDANT TREATED POPLIN AND TEE-SHIRT MATERIAL) AFTER EXPOSURE TO VARIOUS LEVELS OF THERMAL RADIATION

Station Location and Ensemble	Pig No.	Radiant Exposure	Burn Damage to Skin Indicated at Examination 24 Hours After Exposure	Damage to Uniform Ensemble
		cal/cm^2		
64-HWC-1	91	21	Background of 2+ with areas of 3+; large 5+ from flaming.	Cotton poplin destroyed, tee-shirt charred with glow spots.
64-HWC-2	63	21	4+ and 5+; much of skin tanned; animal moribund. Severe burns on right (unexposed) side.	Both layers of entire ensemble almost totally destroyed, evidence of flame and glow.
64-HWC-3	156	21	4+ and 5+ with areas of 2+ and 3+ charring due to flame.	Cotton poplin destroyed, tee-shirt charred with glow spots.
64-HWC-4	98	21	4+ burn at neck drawstring; 2+ with 4+ and 3+ areas.	Cotton poplin destroyed, tee-shirt charred with large portions, evidence of glow.
75-HWC-1	40	14.5	Numerous 5+ and 4+ areas; general 2+ mild shading to 3+ at edges.	Both layers of ensemble destroyed, evidently by flame.
75-HWC-2	114	14.5	Died during night following exposure apparently due to severe burns.	Uniform almost totally destroyed, remaining portions charred.
75-HWC-3	184	14.5	5+ all over.	Uniform almost totally destroyed.
75-HWC-4	45	14.5	5+ areas; scattered 4+ with some 3+.	Cotton poplin destroyed, large sections of tee-shirt destroyed with glow spots on remainder.
90-HWC-1	78	10	2+ shading to 3+; bad flame burn.	Cotton poplin destroyed, tee-shirt charred.
90-HWC-2	166	10	Bad flame burns.	Cotton poplin destroyed, tee-shirt charred.
90-HWC-3	208	10	Severe flame burns; 4+ to 5+.	Cotton poplin destroyed, tee-shirt charred.
90-HWC-4	113	10	Bad flame burns; 5+.	Cotton poplin destroyed, tee-shirt charred with small area of destruction.

TABLE 3.4 DAMAGE TO SKIN AND ENSEMBLE OF PIGS CLOTHED IN THE EXPERIMENTAL HOT–WEATHER UNIFORM ENSEMBLE (FIRE–RETARDANT TREATED POPLIN OUTER LAYER, 50–50 WOOL–COTTON INTERMEDIATE LAYER AND TEE–SHIRT INNER LAYER) AFTER EXPOSURE TO VARIOUS LEVELS OF THERMAL RADIATION

Station Location and Ensemble	Pig No.	Radiant Exposure	Burn Damage to Skin Indicated at Examination 24 Hours After Exposure	Damage to Uniform Ensemble
		cal/cm^2		
64-HWU-1	117	21	No burn.	Cotton poplin destroyed, 50-50 charred but intact, tee-shirt scorched.
64-HWU-2	222	21	No burn over most of area; 2+ burn on belly.	Cotton poplin destroyed, 50-50 partially destroyed, tee-shirt charred in spots, otherwise scorched.
64-HWU-3	127	21	No burn.	Cotton poplin destroyed, 50-50 charred but intact, tee-shirt scorched.
64-HWU-4	82	21	Scattered 2+ areas on 1+ background.	Cotton poplin destroyed, 50-50 charred but intact, tee-shirt scorched.
75-HWU-1	209	14.5	Areas of 3+ on 2+ background on shoulder; 2+ on flank.	Cotton poplin destroyed, 50-50 charred but intact, tee-shirt scorched.
75-HWU-2	93	14.5	1+ to 2+ on shoulder; band of 4+ with 3+ on hip.	Cotton poplin destroyed, 50-50 charred but intact, tee-shirt scorched.
75-HWU-3	140	14.5	Band of 3+.	Cotton poplin destroyed, 50-50 charred, tee-shirt scorched.
75-HWU-4	159	14.5	Scattered 2+ with occasional 1+ areas.	Cotton poplin destroyed, 50-50 charred, tee-shirt scorched.
90-HWU-1	130	10	Small char area on shoulder; 2+ areas on rear leg and side.	Cotton poplin destroyed, 50-50 charred, tee-shirt stained.
90-HWU-2	35	10	Areas of 2+.	Cotton poplin destroyed, 50-50 charred, tee-shirt stained.
90-HWU-3	54	10	No burn.	Cotton poplin 90% destroyed, 50-50 charred, tee-shirt stained.
90-HWU-4	61	10	Two small areas of 2+ and one of 3+ near belly.	Cotton poplin destroyed, 50-50 charred, tee-shirt stained.

TABLE 3.5 DAMAGE TO SKIN AND ENSEMBLE OF PIGS CLOTHED IN EXPERIMENTAL HOT-WEATHER UNIFORM ENSEMBLE (FIRE-RETARDANT TREATED POPLIN OUTER LAYER, SPACER MATERIAL INTERMEDIATE LAYER, AND TEE-SHIRT INNER LAYER) AFTER EXPOSURE TO VARIOUS LEVELS OF THERMAL RADIATION

Station Location and Ensemble	Pig No.	Radiant Exposure	Burn Damage to Skin Indicated at Examination 24 Hours After Exposure	Damage to Uniform Ensemble
		cal/cm^2		
64-HWS-1	81	21	No burn.	Cotton poplin destroyed, spacer destroyed with melted edges, tee-shirt intact but scorched.
64-HWS-2	69	21	No burn.	Cotton poplin destroyed, spacer melted, tee-shirt intact but scorched.
64-HWS-3	158	21	No burn.	Cotton poplin destroyed, spacer destroyed with melted edges, tee-shirt scorched with spotty char.
64-HWS-4	50	21	Two 4+ areas, one 3+, and one 2+. All small on left rear ham.	Cotton poplin destroyed, spacer destroyed with melted edges, tee-shirt charred.
75-HWS-1	134	14.5	No burn.	Cotton poplin destroyed, spacer destroyed, tee-shirt intact but scorched.
75-HWS-2	96	14.5	1+ patchy on side; area of 3+ and 2+ on leg.	Cotton poplin destroyed, spacer destroyed, tee-shirt intact but scorched.
75-HWS-3	150	14.5	No burn.	Cotton poplin destroyed, spacer destroyed, tee-shirt intact but scorched.
75-HWS-4	151	14.5	No burn.	Cotton poplin destroyed, spacer destroyed, tee-shirt charred.
90-HWS-1	58	10	No burn.	Cotton poplin destroyed, spacer intact, tee-shirt stained.
90-HWS-2	105	10	Diffuse 1+ with occasional 2+ areas; large areas of no burn.	Cotton poplin destroyed, spacer essentially destroyed, tee-shirt stained.
90-HWS-3	62	10	No burn.	Cotton poplin destroyed, spacer partially destroyed, tee-shirt stained.
90-HWS-4	119	10	Background 1+ with three 2+ areas.	Cotton poplin destroyed, spacer partially destroyed, tee-shirt stained.

TABLE 3.6 NUMBER AND LOCATION OF BURNED AREAS ON PIGS CLOTHED IN THE EXPERIMENTAL UNIFORM ENSEMBLES

Location of Burned Area	Ensemble HWC	HWU	HWS
Dorsal area	7	2	1
Ventral	7	2	3
Neck	8	3	2
Rib cage	12	1	2
Left fore quarter	5	1	0
Left rear ham			
Anterior	7	3	3
Posterior	4	0	0
Drawstring	12	4	5
Total	62	16	16

TABLE 3.7 TABULATION OF BURN SEVERITY FOR ALL IRRADIANCES TESTED

	Uniform Assembly HWC	HWU	HWS
Total No. Burned Areas	62	16	16
No. of 1+ burns	1	3	6
No. of 2+ burns	12	9	7
No. of 3+ burns	8	2	1
No. of 4+ burns	13	2	2
No. of 5+ burns	28	0	0

TABLE 3.8 CLASSIFICATION OF ANIMALS INTO BURN GROUPS ACCORDING TO UPSHOT–KNOTHOLE SYSTEM

Operation	Uniform	Number Test Subjects	Burn Group Number 0	1	2	3	4
Upshot-Knothole	Temperate*	5	1	4	0	0	0
Upshot-Knothole	HW 50-50†	10	1	9	0	0	0
Upshot-Knothole	HW 50-50 FR‡	8	4	2	2	0	0
Upshot-Knothole	HWC	15	0	0	9	6	0
Plumbbob	HWC	12	0	0	0	12	0
Plumbbob	HWU	12	3	7	2	0	0
Plumbbob	HWS	12	8	2	2	0	0

* The "temperate" uniform is a four-layer ensemble identical to Army cold-wet uniform without the frieze liner. The outer layer is of 9 oz sateen, water-repellent treated; the second layer is 5.5 oz water-repellent cotton oxford; the third layer is 16 oz cloth, 85 pct wool, 15 pct nylon; and the fourth layer is 50-50 wool cotton, 10.5 oz.

† The HW 50-50 uniform consists of an outer layer of 5.2 oz cotton oxford and an inner layer of 10.5 oz 50-50 wool cotton knit winter underwear material.

‡ The HW 50-50 FR is similar to the HW 50-50 except that the outer layer is fire-retardant treated with brominated triallyl phosphate polymer.

photography. Smoking and charring occurred in all cases during the thermal pulse and until the arrival of the blast wave, when the charred outer layer disintegrated. Flaming was indicated at the 21-cal/cm^2 station, but thermal decomposition apparently ceased upon arrival of the blast wave. Detailed results as shown by the films are given in Appendix E (Tables E.2 and E.3).

3.4 SHIELDING MATERIALS

The principle that certain light-weight articles that are readily available to the individual soldier will shield against thermal radiation was confirmed. The conditions of the test included an air space of 6 inches between the uniformed test subject and the vertically positioned

TABLE 3.9 DAMAGE TO SKIN AND ENSEMBLE OF PIGS CLOTHED IN THE HOT-WEATHER CONTROL UNIFORM PROTECTED BY THREE TYPES OF SHIELDING MATERIALS AFTER EXPOSURE TO VARIOUS LEVELS OF THERMAL RADIATION

Shielding Material	Radiant Exposure	No. of Replicates	Burn Damage to Skin and Ensembles Indicated at Examination 24 Hours After Exposure
	cal/cm^2		
Cloth, cotton, poplin, 5 oz, OG-116, fire-resistant	24	4	Bare skin area sustained large area 2+ burn, which was spotted with more severe burns of 3+ and 4+. Shields destroyed. Uniforms undamaged.
Cloth, cotton, poplin, 5 oz, OG-116, fire-resistant	14.5	4	Three pigs had no burns, and the fourth showed a small area of 1+ burn. Shields destroyed. Uniforms undamaged.
Cloth, cotton, sateen, 8.5 oz, OG-107	24	4	Bare skin area sustained large area burns of 2+ to 3+. These were spotted with small areas of 3+ and 4+. On two pigs, 5+ burns were noted beneath the uniform This was accompanied by evidence of burning. Shields destroyed. Two uniforms totally and one partially destroyed. One undamaged.
Cloth, cotton, sateen, 8.5 ox, OG-107	14.5	4	One animal showed no burns. Three showed large area burns of 2+ severity. Shields destroyed. Uniforms intact.
Neoprene-coated Fortisan rayon (Poncho fabric)	.24	4	Results varied from no burn on one animal to 2+ on two others. The fourth animal sustained a large area 1+. Shields destroyed. Uniforms undamaged.
Neoprene-coated Fortisan rayon (Poncho fabric)	14.5	4	Three animals had no burns on bare skin area, and the fourth showed general 1+. Some small area burns of 2+ were noted. Shields destroyed. Uniforms undamaged.

test material. In every instance, the material tested was destroyed. However, the protective properties provided by the shield made from fire-retardant-treated cotton poplin (SF) and the neoprene-coated Fortisan poncho fabric (SP) were significant.

The burns suffered by the animals behind the shields and the effect of the thermal pulse on the assemblies are shown in Table 3.9. In this table, the "bare-skin areas" were those not covered by the uniform but were behind the shield.

The motion-picture films showed that at both stations the sateen (SS) and fire-retardant-poplin (SF) shields were destroyed during the thermal pulse. In contrast, the poncho material (SP) smoked and was obviously decomposed, but the shield remained in position until the arrival of the blast wave. Some smoking, apparently of the poncho, continued after the thermal pulse. This smoke seemed to be due to the decomposing inner coating (the side nearest the animal) on the shield. More detailed information obtained from the examination of the films is given in Appendix E.

3.5 PROTECTION FOR HANDS AND FACE

Little pertinent information relating to the behavior of the face cream or flashoff-reflector-insulator system was obtained from the moving pictures. No evidence of flaming or smoking was noted. The pictures did show extensive convulsive movement of the animals starting immediately upon arrival of the thermal pulse. On recovery from the test area of the animals, numerous small pebbles and grains of sand were imbedded in the creams, but there was no evidence of damage to bare-skin areas by these missiles. No burns were suffered by the animals protected by the flashoff-reflector-insulator system. The vicara flashoff material performed as expected and was totally destroyed.

Excellent protection was provided by the cream. Three minor burns, each approximately ½ inch in diameter, were distributed among the eight animals, apparently due to poor application of the cream.

3.6 RADIATION EFFECTS

As indicated under "Procedure," all sixteen animals from Station 58, the station nearest ground zero, were retained for observation by the University of Rochester group in a study of the rate of burn healing. Pig 53 died on 1 July 1957, seven days after the detonation, and autopsy indicated that radiation damage was the primary cause of death. Pig 205 showed typical symptoms of radiation sickness on the same day. The condition of the animal progressively worsened, and it was destroyed on 5 July 1957. The initial diagnosis was confirmed by autopsy. Pig 189 died suddenly on 7 July 1957 without previous symptoms, but autopsy again indicated that radiation was the cause of death. Thus, of the sixteen animals nearest ground zero, three (19 percent) had died from effects of radiation 13 days following exposure, and no other animals indicated illness. Burn healing was normal and practically complete so observations were discontinued, and the thirteen surviving animals were destroyed.

Chapter 4
DISCUSSION

4.1 HOT-WEATHER UNIFORMS

Severe damage was sustained by all uniforms as indicated in Tables 3.3, 3.4, and 3.5. The damage noted for the three uniforms at 10 cal/cm^2, the smallest amount of energy to which they were exposed, was such that the environmental protective aspects of the uniform were destroyed. Thus, in future development work, emphasis should be on materials resistant to thermal destruction.

The control uniforms fabricated from cloth not treated for fire resistance experienced considerable damage as a result of the thermal pulse. The films taken during exposure show that holes developed rapidly in both the outer and the inner layers at thermal exposures of 20 and 15 cal/cm^2. In addition, their manner of decomposition suggested that flaming occurred. However, flames, per se, could not be directly observed. After exposure to 15 cal/cm^2 at Station 64, on recovery of the animals after exposure to the detonation, approximately 70 percent of the skin area on the exposed side of the test animal was uncovered, due to destruction of the inner layer of material. However, the films show that upon completion of the thermal pulse, only the outer layer was destroyed and only small holes were present in the under layer. This difference, together with the smoking noted at the time of blast wave arrival, suggests that flame or glow occurred and may have continued following the blast wave. Some instances of uniforms still smouldering were noted by recovery team personnel at H + 1 hour following the event.

At the 10-cal/cm^2 station (Station 90) there was no evidence of flaming. In this case, the films indicated that the damage should be limited to the outer layer of cotton poplin, and examination of the uniforms following exposure confirmed this. The underwear material, although intact, was scorched and charred.

All test animals wearing the HW-C uniform ensemble were severely burned, and all had sustained burns rated as 4+ or 5+. Further, as shown by the data in Table 3.6, the burns were likely to occur at any location over the exposed side of the test animal. Thus, no design feature of this uniform provided substantial protection.

The moving-picture films, as shown by the data in Tables E.1 and E.2, indicated two differences in the manner of decomposition of the HW-U and HW-C assemblies: (1) The outer layer usually decomposed rapidly, accompanied by dense smoking which blanketed the exposed side of the animal. (2) The outer layer decomposed to a black, charred surface, which remained intact until the arrival of the blast wave unless broken previously by animal movements.

The burn data in Tables 3.7 and 3.8 indicate a marked decrease in burn severity, as well as in the incidence burns among animals clothed in the HW-U or HW-S assembly compared with those in the control uniform.

There are four protective mechanisms that seem likely to be responsible for the protection afforded by the uniforms with the 50-50 underwear. At the same time, two actions which could detract from its effectiveness are introduced by the thermal pulse of the bomb. These are given below:

Increased Effectiveness. (1) Added mass and thickness are provided by the introduction of 4.5 oz/yd^2 knitted underwear fabric. (2) Flaming and glowing are decreased by the use of fire-resistant treated outer layer. (3) A protective layer of char is formed as the outer layer which shields or shadows the under layers and pig skin. (4) Dense smoke is produced for possible attenuation of energy.

D e c r e a s e d E f f e c t i v e n e s s . (1) Charred outer layer permits absorption of greater amounts of thermal energy in latter stages of thermal pulse. (2) Products of decomposition (tars or similar materials) from flame-resistant outer layer may aid in increasing energy transferred to pig skin.

The films show that, with the exception of decreased effectiveness due to products of decomposition, all of the above conditions are present to some degree. This conclusion is supported by available literature and observations made by biomedical personnel of the many tar-like stains on the under fabric layers and on unburned pig skin.

The analysis of the films indicates that smoking was not a major factor in effecting protection, for the earliest observed smoking occurred well after maximum thermal energy was delivered in the second peak. At this time 40 to 50 percent of the total thermal energy had been delivered.

Whether the added mass or the use of a flame-retardant outer layer with its subsequent formation of a charred surface is primarily responsible for the protective qualities of this uniform cannot be determined solely by viewing the films. A report by Waldron (Reference 26) bears directly upon this problem. Waldron shows that the prevalence of either protective quality in a typical HW-U assembly is a function of irradiance, and it is to be expected that fire resistance would have more effect at the higher irradiances, where flaming may be expected, while mass is of more importance in the lower irradiances.

Taking into consideration the flaming suggested by the film at thermal exposures of 15 cal/cm^2 or above, as well as the report mentioned above, it is apparent that a combination of mechanisms is responsible for the attenuating characteristics of the HW-U uniform ensemble.

The experimental hot-weather uniforms containing the spacing fabric behaved similarly to those containing the 50-50 underwear. It follows, therefore, that the protective mechanisms are probably about the same as that suggested above for the HW-U uniform ensemble.

The films do not provide any firm information as to whether the added mass of the spacer fabric or the flame-resistant finish on the outer layer is responsible for the degree of protection afforded by the spacer uniform as contrasted to the two-layer control uniform (HW-C). However, Laible (Reference 14) showed that the mass of a polyethylene spacing fabric does not provide any attenuation of energy until its decomposition is effected. Even then its ability to attenuate energy is limited and may be related to the low specific heat of polyethylene. The attenuating capacity of polyethylene in this system is in the order of 5 percent of the incident energy applied. Further, the work has shown that when ignition of the outer layer in a spaced fabric system is effected, considerable energy may be transmitted through the spacer fabric assembly and is capable of effecting skin burns.

In the case of the spacer fabric assembly, one of the major contributions for protection may be attributed to the properties imparted to the outer layer by the flame-retardant finish, and the films show that the system performed under actual conditions in a manner predictable from laboratory studies. However, as is shown in Table 3.8, the spacer uniform provided markedly greater protection than did the underwear uniform. On the basis of present laboratory data, no explanation for the phenomena is available.

Both new experimental uniforms reduced the incidence of burns by 75 percent from that sustained under the control uniform. The severity of burns beneath the protective uniforms was also markedly reduced for with the HWC assembly, approximately 70 percent of the burns were in the range of 3+, 4+, and 5+, while only 20 percent were sustained to that degree beneath the protective types of uniform assembly.

Where area of burn is considered along with burn severity, both experimental assemblies (HWU and HWS) provided excellent thermal protection. As was also observed during Operation Upshot-Knothole, the incidence of burn at or adjacent to the drawstrings was considerable and would be an area of future study, except that drawstring type of closure is not expected to be used in future hot-weather clothing.

Both the HWU and HWS uniform assemblies of Operation Plumbbob provided protection equivalent to the HW 50-50 uniform assemblies of Operation Upshot-Knothole. Further, the classification in Group 2 of four out of the 24 animals clothed in HWU and HWS assemblies was required because of burns sustained at or near the drawstring. This is further evidence to confirm the decision already made that correction should be made in future designs. The data of Table 3.8 provides the first real distinction between the protective qualities of the HWS and HWU assemblies. The occurrence of eight out of twelve animals in burn Group 0 indicates a definite superiority of the HWS assembly containing the polyethylene spacer fabric over the HWU, which has the 4.5-oz cotton-wool (50-50) knitted underwear fabric as an intermediate layer.

The results from Operation Plumbbob yield another interesting relationship with respect to the effect of thermal exposure. Review of the data to determine the location and incidence of burns showed that the incidence of burns under the HWS and HWU uniform assemblies was less at a thermal exposure of 21 cal/cm^2 than at the lower thermal exposures of 14.5 and 10 cal/cm^2. While the immediate data does not permit a definitive answer to these phenomena, this data, coupled with prior knowledge of fabric behavior, does offer an explanation.

It has been shown (References 17 and 28) that a fabric system's response to thermal radiation and protectivity will vary with the irradiance or rate of applied energy and that the quantity of heat penetrating the ensemble is not a simple function of the irradiance but rather is a complex function of the response of the specific ensemble at a given irradiance.

It has been similarly demonstrated (Reference 27) that a two-layer fabric system, equivalent in bulk and outer layer properties to the experimental ensembles used here, offered greater resistance to heat penetration at the higher thermal exposure than at the lower. These laboratory observations strengthen the belief that for a given ensemble, the degree of protection it can afford is controlled to a large extent by the rate at which it reacts to a particular irradiance, i.e., if the irradiance is such that total destruction of the ensemble occurs very rapidly, no hot material remains behind to transfer heat to the animal or body. Conversely, if destruction proceeds at a slower rate, the physical properties of the heat-transfer system, ensemble plus animal, dictates that a greater proportion of the heat must seep through the ensemble during the destruction process.

These tests showed that while complete protection against the desired levels of thermal radiation was not attained, it is possible of attainment as exemplified by the performance of the HWS uniform. However, unless entirely new materials and concepts are developed, it appears that complete resupply of uniforms probably will be required immediately after exposure.

All of the fabrics used in this test were new, and none had been laundered prior to the test.

4.2 SHIELDING MATERIALS

The importance of modifying the normal combustion process of cotton, as was accomplished by this test, is also seen from a comparison of the behavior of the fire-retardant 5-oz poplin (SF) and the untreated 8½-oz sateen (SS) shields. On the basis of mass and tightness of weave, it would be expected that the sateen shield would show superior performance. A comparison of the effects at the 24-cal/cm^2 station shows that mass, per se, was not the controlling factor. At this station, the bare-skin controls showed radiation burns in the range of 4+ to 5+. The 8½-oz/yd^2 sateen shield did not protect the uniform or animal, and 5+ burns were observed. In contrast, the light-weight fire-retardant-treated poplin shield completely protected the uniform and reduced large-area burns to a 2+ level. If burns produced behind the 8½-oz/yd^2 shield resulted solely from radiation, one would not expect them to exceed in severity the burns produced behind the 5-oz fabric, and certainly not to equal the burns produced on bare skin unprotected in any way.

As shown in the motion picture, the sateen shields burned rapidly and were totally consumed, the bare skin areas on the animals being clearly visible prior to the completion of the thermal pulse. The decomposition was marked by dense smoke during the thermal pulse of the detonation. Between the end of the thermal pulse and the arrival of the blast wave, there was little smoking—the sateen shields had already been almost completely destroyed. Such smoking as did occur originated either on fragments at points where there had been a double thickness of cloth, or the shield had fallen in such a manner as to form multiple layers of cloth.

The cotton sateen used in this experiment represents the base fabric used in the gas cape. The sateen was not treated with any chemical agents. Present military plans require the fabricated gas capes to be stored in untreated condition with impregnations of chemical to be made in the field as required. It would be expected that the addition of a fire-retardant agent or other chemical that would act to inhibit flaming would markedly increase the protective effect of this material. Conversely, a flammable additive would probably decrease usefulness of the material as a thermal shield still less than that of the untreated fabric.

The shields fabricated from fire-resistant-treated poplin fabric did not decompose as quickly or as completely as the sateen shields. Approximately 50 percent of the shielding surface had been destroyed prior to the arrival of the blast wave. The residue was then quickly blown away as would be expected, for the residual charred material has little or no strength. The smoke produced during the thermal pulse was very dense and completely covered the entire frontal surface. The residual material smoked considerably following the thermal pulse before the arrival of the blast wave, but its coverage over the shielding surface was not as extensive as noted in the prior stage.

Following destruction of the shield, the bare-skin areas of animals 58-SF-2 and 58-SF-3 were completely uncovered by the thermal effect and that for 75-SF-2 was partially uncovered. It could not be noted whether this effect occurred more rapidly for any one shield. Thus, beyond the difference in calorie level, there is little to suggest why 75-SF-2 suffered no burns and 58-SF-2 and 58-SF-3 sustained severe burns.

The films show that the shields fabricated from the newly developed poncho fabric resisted destruction the best of the three materials tested. Although charred, the shields all remained in place until arrival of the blast wave and apparently, except for the development of a small hole in 75-SP-2, retained a solid plane surface or barrier. There was no evidence that the bare-skin areas became exposed prior to arrival of the blast wave. As might be expected, although the poncho material retained sufficient strength to remain vertically positioned through the thermal effect of the detonation, its residual strength was not great enough to withstand the blast wave.

The smoking that resulted from decomposition of the poncho shield was considerable. The smoke covered the frontal surface of the shield during the thermal pulse. Upon completion of the thermal pulse and prior to the arrival of the blast wave, smoking continued. However, this smoke did not originate to a significant extent from the frontal surface, but seemed to stem either from the pig uniform or the neoprene coating on the back side of the shielding poncho fabric. In view of the data contained in Table 3.9, which shows that the uniforms behind the poncho shields were undamaged, it is logical to attribute the smoking and the debris noted for three test animals to the neoprene backing of the poncho fabric.

The relatedness of the above observations was considered both as a group and as equally exposed pairs. However, there is nothing to suggest why burns occurred. As a result, it can be recommended that in a forthcoming field exposure, an attempt be made to photograph the poncho with the camera focused on the air space interval between the shield and the test animal in order to seek information as to how energy is being transferred from the shield to the test animal.

4.3 FACE CREAMS

The films show that the animals used to test the thermal protective creams struggled convulsively after the arrival of the thermal wave. Although under anesthesia, the reflex reaction might be due to the severe insult to the bare-skin control area. During the struggles in the early part of the thermal pulse, some of the cream could easily have been removed, causing thin spots or even small bare areas. Such thin areas could account for the few scattered burns under the creams, since it is well established that a $\frac{1}{16}$-inch layer is required for protection.

It was impossible to tell whether or not the cream ignited during the exposure by viewing the motion pictures. The pictures (taken in black and white) showed some smoke rising from the uniform area, but no flames were visible. By analyzing the uniforms worn for environmental protection, it is seen that the uniforms ignited in the foreleg, hindleg, and the abdominal areas where the uniform was not protected with the aluminum scrim.

The cream protected at all energy levels up to 24 cal/cm^2, although three burns over small areas (ranging from 0.38 to 0.69 in^2) were found under the cream. When the burns are interpreted in terms of percentage of area protected, the cream, QMC 305 X, gave complete protection to approximately 96 percent of the exposed area at the 24-cal/cm^2 station and 99 percent at the 15-cal/cm^2 station.

4.4 ANIMAL MOVEMENT

It was mentioned by many viewers of the films, as well as those present when burn evaluations were conducted in the field, that some of the burns may have been induced by movement of the test animal in the holder. Examination of the films and the data obtained shows considerable variation, preventing the drawing of firm conclusions.

There was no marked movement of the test animals prior to the thermal pulse, but there was considerable activity thereafter. The stimulus of the thermal injury was apparently sufficient to temporarily partially overcome effects of the anesthesia. Movement was noted for twelve of the fifteen animals that could be viewed in the films.

With respect to the burns sustained by the moving animals, the only relationship noted concerned neck burns. The four burns that occurred in the neck area were found to have been sustained by animals that had moved vigorously during the thermal pulse. Whether the burns resulted from contact with hot metal of the animal holder or as a result of burns sustained on parts of the body other than the neck is not known. Indeed, because of the nature of the injury, it is not certain whether the burns were caused by rubbing against the frame holding the head of the animal, rather than by flame or flash.

Chapter 5
CONCLUSION and RECOMMENDATIONS

5.1 CONCLUSIONS

At radiant energies of 10 cal/cm^2 or above, severe burns up to 5+ over much of the body can be expected on troops clothed in the control (HWC) uniform unless further protection is provided. Complete replacement of all uniforms can be expected even if the troops survive their burns which is problematical. Flaming occurred in the non-fire-retardant-treated outer layers at 14.5 and 21 cal/cm^2.

The experimental hot-weather uniform (fire-retardant treated) with spacer fabric (HWS) will, in some instances, provide complete protection against the thermal effects of a nuclear detonation at a radiant energy level of 21 cal/cm^2 and, in the remaining instances, limit injury to spotty 1+ and 2+ burns. At energies of 10 and 15 cal/cm^2, this ensemble will limit injuries to 1+ with spotty 2+ burns, as compared with the 5+ burns received with the control ensemble. Replacement of all uniforms at exposures of 10 cal/cm^2 or greater will be required.

The experimental hot-weather uniform (HWU) with intermediate layer of 4.5-oz/yd^2 50-50 wool-cotton underwear will, in some instances, provide complete protection against thermal effects at an energy level of 21 cal/cm^2 and, in the remaining instances, limit burn injury to 1+ to spotty 2+. At energies of 10 and 15 cal/cm^2, this ensemble will, in general, limit the occurrence of burns to an occasional 1+ and 2+ as compared with the 5+ burns received with the control ensemble. Complete uniform replacement will be required at 10 cal/cm^2 or greater.

The thermal shield made from neoprene-coated Fortisan will completely protect the non-fire-retardant-treated uniform against the thermal effects at all radiant energies up to 24 cal/cm^2. It will similarly reduce injury to bare skin from 4+ or 5+ to 2+ or 3+ and, in limited instances, will provide complete protection against 24 cal/cm^2 incident energy. At an incident energy of 15 cal/cm^2, it will, in some instances, provide complete protection and, in the remaining instances, reduce bare skin injury to 1+ with spotty 2+.

The thermal shield made of 5-oz/yd^2 fire-retardant cotton poplin will completely protect the non-fire-retardant uniform against the effects of nuclear detonations at all energies up to 24 cal/cm^2. It will similarly reduce injury to unclothed portions of the body from 4+ or 5+ to 2+ or 3+ at an incident energy of 24 cal/cm^2. At an incident energy of 15 cal/cm^2, it will, in the majority of instances, provide complete protection and otherwise limit injury to a 1+ burn.

The thermal shield made of 8.5-oz/yd^2 cotton sateen (not chemically treated) will provide no significant protection when spaced 6 inches from the skin and exposed at an energy of 24 cal/cm^2. It will limit injury, in the majority of instances, to 1+ burns with spotty 2+ burns when exposed to 14.5 cal/cm^2 incident energy. After exposure to 24 cal/cm^2, uniform replacement would be required but not at 14.5 cal/cm^2.

The thermal protective cream may completely protect at all energies up to 24 cal/cm^2. In the remaining instances at 24 cal/cm^2, incident energy injury will be in the range of 2+ to 3+ over small areas corresponding to imperfect areas of cream application as compared to the large area of 4+ to 5+ burns observed with the bare-skin control. At 15 cal/cm^2 of incident energy, the cream will, in the majority of cases, provide complete protection. In limited instances, small area 2+ injuries may be observed possibly due to improper application of ruboff, as compared to the 4+ to 5+ injuries observed with the bare-skin control.

The flash-off-reflector-insulator system provided protection at all energies up to 24 cal/cm^2.

5.2 RECOMMENDATIONS

The spacer ensemble remains a promising approach to increasing protection in the hot-weather uniforms. Continued research and development efforts should be made to produce more-stable materials for utilization in both the spacer layer and the outermost layer.

The use of fire-retardant-treated fabrics in the outer layer of a uniform layer containing a spacing fabric is indicated to prevent flame-type burns.

Appendix A
TEST of PAPER CALORIMETERS

As a supplement to the main part of the test described in the body of the report and without additional cost to the project or dilution of the main effort, a series of calibrated passive-receiver-type calorimeters were placed at each station.

The objective of this test was to determine the irradiance at each station using this type instrumentation and to compare the results obtained with those from other methods whose reliability is considered standard.

The calorimeters consisted of a $^1/_{16}$- or $^1/_8$-inch-thick aluminum plate; the face of the plate was blackened with stove polish, and a series of paper thermometers was attached to the back with adhesive. The plates were mounted on channel iron 5 feet above the ground.

The paper thermometers consisted of a series of pure, finely powdered chemical compounds having varying melting points. The compounds were printed onto black absorbent paper from a water dispersion using methyl cellulose as a binder. When the proper temperature was reached, the compound melted and was absorbed by the paper and recrystallization effectively prevented.

The calorimeters were calibrated in the laboratory using the carbon-arc source, by comparison with a QM button calorimeter. A more-complete description of these calorimeters is made in the report by Levine (Reference 17).

TABLE A.1 THERMAL MEASUREMENTS, PAPER CALORIMETERS, SHOT PRISCILLA

Station	Expected Radiant Exposure	Official Observed Data*	Observed QM Passive Receivers
	cal/cm^2	cal/cm^2	cal/cm^2
F8.1-9044.01	25	24	25.3
F8.1-9044.02	20	21	18.5
F8.1-9044.03	15	14.5	14.1
F8.1-9044.04	10	10	9.4
F8.1-9044.05	5	6.5	4.8

* Data furnished by Naval Material Laboratory, Project 8.2

The results are shown in Table A.1. The results indicate that the use of paper thermometers is feasible for the determination of radiant energy obtained from a nuclear detonation. They are particularly indicated where it is not possible or practical to use more refined conventional devices.

For calibration in the laboratory, pulses of 1 second in duration were used, and the field results indicate that for this effect such a pulse closely approximates the field pulse. Nuclear detonations of different yields may require standardization under different conditions. Clarification is expected when the QM solar furnace is available for use.

Appendix B
TEST of SELF-CONTAINED FIELD CALORIMETERS

As a supplement to the main part of the test described in the body of the report and without additional cost to the project or dilution of the main effort, a self-contained field-type calorimeter developed at the University of Rochester was placed at each station in order to obtain readings of the thermal intensity of the radiation received at that station.

The objective of this test was to determine the radiant exposure at each station by the use of this new type of instrumentation and to compare the results obtained with those from other methods whose reliabilities are accepted.

The calorimeter consisted of two helically wound cones of bimetallic strips mounted in a brass cylinder. The forward end of the cylinder was closed with a ⅛-inch quartz disk, and the rear end with lucite for viewing purposes. The instrument was dustproof and waterproof. One instrument was mounted at each station of Project 8.1.

The bimetallic cones were mounted at the apex to a single shaft, one cone facing forward as a receiver cone and the other rearward as a compensator. The base of each cone was fastened to the calorimeter body. On the shaft at the rear of the calorimeter was mounted a small drum blackened by holding it in a sooty flame. The point of a phonograph needle rode on this drum. When the receiver cone was exposed to thermal energy, the cone would expand, causing the shaft to rotate an amount proportional to the energy received, and the rotation was indicated by a line on the drum. By measuring the length of the line on a calibrated instrument, the amount of thermal energy received could be calculated. This calorimeter will be further described in a report by the Atomic Energy Project of the University of Rochester. The results obtained are shown in Tables B.1 and B.2.

TABLE B.1 THERMAL MEASUREMENTS, ROCHESTER CALORIMETERS, SHOT PRISCILLA

Station	Expected Radiant Exposure	Official Observed Data*	Observed Radiant Exposure
	cal/cm²	cal/cm²	cal/cm²
F8.1-9044.01	25	24.0	23
F8.1-9044.02	20	21.0	18
F8.1-9044.03	15	14.5	14
F8.1-9044.04	10	10.0	10
F8.1-9044.05	5	6.5	5.2

* Data furnished by Naval Material Laboratory, Project 8.2

The University of Rochester calorimeters were set out to record thermal yield during Shot Hood. They were placed alongside of the NML calorimeters at a distance of 3 to 4 feet east of the NML rack and at the same location.

Angular elevation was made nearly identical to that of the NML calorimeters. Upon recovery, it was found that three of the calorimeters had been thrown off their initial setting by the shock wave. Only in Calorimeter 2 did this lead to unreadability of the recorded trace.

TABLE B.2 THERMAL MEASUREMENTS, ROCHESTER CALORIMETERS, SHOT HOOD

Official Observed Data furnished Naval Material Laboratory, Project 8.2, was 15 cal/cm^2.

Placement Calorimeter No.	Expected Radiant Exposure	Observed Radiant Exposure	Placement at Priscilla
	cal/cm^2	cal/cm^2	
1	15	16	Observer area
2	15	Not Readable	F8.1-9044.02
3	15	14	F8.1-9044.01
4	15	13	F8.1-9044.03
5	15	15	F8.1-9044.04
6	15	15	F8.1-9044.05

Appendix C
COMPARISON of TWO EXPERIMENTAL TROPICAL BOOTS

As a supplement to the main part of the test described in the body of the report and without additional cost to the project or dilution of the main effort, two experimental tropical boots were placed at stations for 10, 14.5 and 21 cal/cm^2 in order to compare resistance to thermal radiation.

The objective of the test was to differentiate between the thermal resistance of a nylon and acetylated cotton upper and also to determine whether the flesh side or the hide was more resistant to thermal radiation.

Two replicates of each of two types of tropical boots were exposed at each of three stations, i.e., at 10, 14.5, and 21 cal/cm^2 incident energy. The nomenclature assigned to each type boot is as follows:

Type A - Boot, Leather, Flesh-Out, Acetylated-Cotton Uppers, Rawhide Laces

Type B - Boot, Leather, Hide-Out, Nylon Uppers, Nylon Laces.

Each boot was mounted in its entirety on a pine plank facing ground zero. The method of mounting was such that a full half of the boot faced outward with the several boots being spaced approximately a foot apart.

The results observed in this experiment are shown in Table C.1.

TABLE C.1 RESPONSE OF TROPICAL BOOTS TO ATOMIC THERMAL RADIATION

Exposure	Type A Flesh-Out Leather, Acetylated-Cotton Upper, Rawhide Laces				Type B Hide-Out Leather, Nylon Upper, Nylon Laces			
	Condition of Leather	Condition of Cotton Upper	Condition of Laces	Condition of Sole Rubber	Condition of Leather	Condition of Nylon Upper	Condition of Laces	Condition of Sole Rubber
cal/cm^2								
10	Surface slightly charred	Surface undamaged	Laces undamaged	Edge of sole undamaged	Leather surface charred	Surface of nylon upper fused but intact	Surface of laces fused but intact	Edge of sole undamaged
14.5	Surface slightly charred	Surface scorched but intact	Laces scorched but intact	Edge of sole scorched	Leather surface charred	Nylon upper destroyed	Laces fused on surface	Edge of sole charred
21	Surface charred; no evidence of flaming	Surface charred but intact; no evidence of flaming	Laces charred in spots, but intact	Edge of sole charred	Leather heavily charred	Nylon upper destroyed with gravel adhering to undestroyed portions	Laces partially destroyed	Edge of sole charred

The observations of damage made upon recovery indicate that at each energy level, Boot, Type A, showed superior resistance to thermal degradation. In each instance, at equivalent exposures, the flesh-out leather, leather laces, and acetylated-cotton uppers suffered less damage than did their counterparts in Boot, Type B.

In particular, the marked superiority of the acetylated-cotton upper as compared to the nylon upper was demonstrated. Whereas in each instance at 14.5 and 21 cal/cm^2 the destruction incurred by the nylon upper would necessitate re-supply, this problem would not occur with the components of Boot, Type A.

Appendix D
QUARTERMASTER CORPS INANIMATE THERMAL RECEIVERS

As a supplement to the main part of the test described in the body of the report and without additional cost to the project or dilution of the main effort, inanimate thermal receivers similar to those normally used at the Quartermaster Research and Engineering Command were exposed to 6.5 and 14.5 cal/cm^2 during Shot Priscilla in order to obtain field data for comparison with that obtained in the laboratory from the carbon arc at the same exposure levels.

The inanimate receivers used are transite blocks about 4 inches square and 1 inch thick. A fine constantan wire plated with copper to form a thermocouple was mounted in a groove at the center of the face of the block such that the thermocouple was approximately 0.08 cm below the surface. The leads to the thermocouple were then connected to spare channels of the Heiland recorder used by Project 8.2.

At Stations F8.1-9044.03 and F8.1-9044.05, two transite-block receivers were covered by a combination of non-fire-retardant-treated 5-ounce poplin over tee-shirt material. On one block they were in close contact with the surface of the backing. On the other block, the fabrics were placed so that the rear surface was spaced 0.3 cm from the front surface of the transite receiver. A record was obtained of the temperature rise behind the ensembles following the detonation. The results are shown in Table D.1.

The data obtained in the field were compared to laboratory data by the use of a square pulse and the same total exposure. The shapes of the curves of ΔT versus time are similar, except for the spaced fabric at Station F8.1-9044.05 and for the occurrence of large-area flaming in some of the field exposures.

At Station F8.1-9044.03, flaming was evident and the fabrics were completely destroyed. Both spaced and contact field exposures reached ΔT_{max} at about the same time. The interval from time zero was about 3.5 times as long as the duration of the square pulse used in laboratory comparisons. Both field pulses show higher initial rates of temperature increase due to the early maximum of irradiance for a shaped pulse.

At Station F8.1-9044.05, the curves for contact conditions were similar to those observed in the laboratory; however, the curve for spaced conditions deviates considerably from the laboratory curve with increasing time. The time for ΔT_{max} in the field was again about 3.5 times the duration of the laboratory square-wave pulse. The value for ΔT_{max} was reached at about the same time as for the contact field exposures.

If it had been possible to use more samples in the field test, correlation with laboratory results could have been made over a range of square-wave-pulse durations, and temperature values would be more reliable. However, space was so limited that an extensive program of this type was impossible. Factors that could have affected the results, such as tar or char formation, the rate of reaction, and the mechanical effects of the blast wave, should be included in a complete comparison of laboratory and field exposures to thermal radiation.

TABLE D.1 TEMPERATURE RISE RECORDED AT THE SURFACE OF TRANSITE RECEIVERS

Maximum temperature rise, ΔT_{max} in degrees centigrade.

Material	Station F8.1-9044.03 Observed Radiant Exposure 14.5 cal/cm^2		Station F8.1-9044.05 Observed Radiant Exposure 6.5 cal/cm^2	
	No. 1	No. 2	No. 1	No. 2
Poplin plus tee-shirt in contact	40	58	25	25
Poplin plus tee-shirt spaced	46	—	22	—

Appendix E

RESULTS from EXAMINATION of MOTION PICTURE FILMS

It was stated in Chapter 2 of the main report that representative animals at each station were covered by motion-picture photography. Exposures were made on black-and-white, 16-mm film at a rate of 64 frames/sec.

After review of the films, the course of events at each station could be reconstructed with a fair degree of accuracy. Repeated viewing of the films yielded the information contained in Tables E.1 through E.6.

TABLE E.1 EVENTS INDICATED BY MOTION PICTURES TAKEN OF PIGS CLOTHED IN THE HOT-WEATHER CONTROL UNIFORM

Observations	Code:	64-HWC-3	64-HWC-4	75-HWC-4	90-HWC-3	90-HWC-4
	Radiant Exposure cal/cm^2:	21	21	14.5	10	10
	Pig Number:	156	98	45	208	113
Did outer layer remain intact through thermal pulse?		No	No	No	No	No
If destroyed, extent of destruction during thermal pulse.		Complete	Complete	Complete	Partial	Charred
If destroyed, extent of destruction during blast wave.		—	—	—	Complete	Complete
Can under layer be observed during thermal pulse?		Yes	Yes	Yes	Yes	No
Can bare skin be observed following blast wave?		Yes	Yes	Yes	Yes	No
How extensive were holes that developed in the under layer?		Large	Large	Small	Small	Undeterminable
Did smoking occur during thermal pulse?		Yes	Yes	Yes	Yes	Yes
If so, indicate density and coverage.		Moderate-Upper half	Dense-Complete	Moderate-Upper half	Moderate-Complete	Moderate-Complete
Did smoking occur following thermal pulse prior to blast wave arrival?		Yes	Yes	Yes	Yes	Yes
If so, indicate density and coverage.		Slight - Not enough to obscure any area.	Slight - Not enough to obscure any area.	Very slight - Not enough to obscure any area.	Very slight - Lower half	Very slight - Lower half
Did pig jump extensively?		Yes	Yes	Yes	Yes	Yes
Was flaming observed or suggested by mode of decomposition?		Suggested	Suggested	Suggested	No	No
If so, what fabric involved?		Under layer	Under layer	Under layer	Outer layer	Outer layer
Degree of burn inflicted on test animal:						
Rib area		2+ - 3+	2+ - 3+	3+	2+	2+
Neck		None	4+	4+ - 5+	4+ - 5+	None
Drawstring area		4+ - 5+	4+	5+	5+	5+
Belly		4+ - 5+	4+	4+ - 5+	4+ - 5+	4+

TABLE E.2 EVENTS INDICATED BY MOTION PICTURES TAKEN OF PIGS CLOTHED IN THE EXPERIMENTAL HOT–WEATHER UNIFORM ENSEMBLE (FIRE–RETARDANT TREATED POPLIN OUTER LAYER, 50 – 50 WOOL–COTTON INTERMEDIATE LAYER AND TEE–SHIRT INNER LAYER)

Observations	Code:	64-HWU-2	64-HWU-3	75-HWU-4	75-HWU-3	90-HWU-2	90-HWU-3
	Radiant Exposure cal/cm^2:	21	21	14.5	14.5	10	10
	Pig Number:	222	127	159	140	35	54
Did outer layer remain intact through the thermal pulse?		No	No	Yes	No	Yes	Yes
If destroyed, extent of destruction during thermal pulse.		Partial	Partial	Charred	Charred-Broke	Charred	Charred
If destroyed, extent of destruction by blast wave.		Complete	Complete	Complete	Complete	Complete	Complete
Can under layer (50-50) be observed during thermal pulse?		Yes	Yes	No	Yes	No	No
Can bare skin be observed following blast wave?		No	No	No	No	No	No
How extensive were the holes that developed in the outer layer?		Very large	Large holes (3)	None	Small hole (1)	None	None
Did smoking occur during thermal pulse?		Yes	Yes	Yes	Yes	Yes	Yes
If so, indicate density and coverage.		Very dense-Complete	Very dense-Complete	Very dense-Complete	Very dense-Complete	Very dense-Complete	Very dense-Complete
Did smoking occur following thermal pulse prior to blast wave arrival?		Yes	Yes	Yes	Yes	Yes	Yes
If so, indicate density and coverage.		Dense-Upper half	Moderate-Complete	Moderate-Complete	Moderate-Complete	Moderate-Complete	Moderate-Complete
Did pig jump extensively?		Undeterminable	Yes	Yes	Yes	No	Slightly
Was flaming observed or suggested by mode of decomposition?		Suggested	No	No	No	No	No
If so, what fabric involved?		50-50 under layer	Outer layer and 50-50	Outer layer	Outer layer	Outer layer	Outer layer
Degree of burn inflicted on test animal:							
Rib area		None	None	Scattered 2+	None	2+	None
Neck		None	None	None	None	None	None
Drawstring area		None	None	None	3+	2+	None
Belly		2+	None	1+	None	None	None

TABLE E.3 COURSE OF EVENTS INDICATED BY MOTION PICTURES TAKEN OF PIGS CLOTHED IN THE EXPERIMENTAL HOT–WEATHER ENSEMBLE (FIRE–RETARDANT TREATED POPLIN OUTER LAYER, SPACER MATERIAL INTERMEDIATE LAYER, AND TEE–SHIRT INNER LAYER)

Observations	Code:	64-HWS-2	64-HWS-3	75-HWS-4	90-HWS-2	90-HWS-3
	Radiant Exposure cal/cm^2:	21	21	14.5	10	10
	Pig Number:	69	158	151	105	62
Did outer layer remain intact through the thermal pulse?		No	No	No	Yes	No
If destroyed, extent of destruction during the thermal pulse.		Char-Broke	Char-Broke	Char-Broke	Char	Char-Broke
If destroyed, extent of destruction by blast wave.		Complete	Complete	Complete	Partial	Partial
Can under layer be observed during thermal pulse?		Yes	Yes	Yes	No	Yes
Can bare skin be observed following blast wave?		No	No	No	No	No
How extensive were holes that developed in outer layer?		Charred surface broke, but holes did not develop.			None Determined	—
Did smoking occur during thermal pulse?		Yes	Yes	Yes	Yes	Yes
If so, indicate density and coverage.		Very dense-Complete	Very dense-Complete	Dense-Complete	Dense-Complete	Dense-Complete
Did smoking occur following thermal pulse prior to blast wave arrival?		Yes	Yes	Yes	Yes	Yes
If so, indicate density and coverage.		Moderate-Upper half	Moderate-Above pig	Moderate-Above pig	Moderate-Upper half	Dense-Complete
Did pig jump extensively?		Yes	Yes	Yes	No	Yes
Was flaming observed or suggested by mode of decomposition?		Yes	Yes	None	None	None
If so, what fabric involved?		Under layers Darker	Under layers Darker	Poplin and Under layers	Poplin	Poplin
Degree of burn inflicted on test animal:						
Rib area		None	None	None	None	None
Neck		None	None	None	None	4+
Drawstring area		None	2+	None	1+ - 2+	None
Belly		None	None	None	None	None

TABLE E.4 COURSE OF EVENTS INDICATED BY MOTION PICTURES TAKEN OF PIGS CLOTHED IN HOT-WEATHER CONTROL UNIFORM PROTECTED BY SHIELD FABRICATED FROM POPLIN, FIRE-RETARDANT TREATED

Observations	Code:	58-SF-2	58-SF-3	75-SF-2
	Radiant Exposure cal/cm^2:	24	24	14.5
	Pig Number:	67	31	172
Did loss of shielding fabric occur during the thermal pulse?		Yes	Yes	Yes
Did loss of shielding fabric occur during blast wave?		Yes	Yes	Yes
Did holes develop in shield during thermal pulse?		Partial - 60 pct	Partial - 50 pct	Partial - 40 pct
Could bare skin be observed?		Yes	Yes	Yes
Complete or partial?		Complete	Complete	Partial
Did animal move?		No	Yes; at blast arrival	Yes
Did shield smoke during thermal pulse?		Yes	Yes	Yes
If so, estimate density.		Very dense	Very dense	Very dense
Did smoke cover frontal surface of shield?		Yes	Yes	Yes
If so, how extensive was its coverage?		Complete	Complete	Complete
Was smoking of shield observed following thermal pulse?		Yes	Yes	Yes
If so, estimate density.		Slight	Very dense	Slight
Where did smoke originate?		Partially decomposed shield and covered upper half of shield		
Could smoking of uniform be observed following thermal pulse?		Undeterminable	Undeterminable	Undeterminable
Degree of burn inflicted on bare skin area.		2+	2+ (with scattered fine 4+)	None
Degree of burn inflicted outside bare skin area.		None	None	None

TABLE E.5 COURSE OF EVENTS INDICATED BY MOTION PICTURES TAKEN OF PIGS CLOTHED IN HOT-WEATHER CONTROL UNIFORM PROTECTED BY SATEEN SHIELD (GAS CAPE MATERIAL)

Observations	Code:	58-SS-2	58-SS-3	75-SS-3
	Radiant Exposure cal/cm^2:	24	24	14.5
	Pig Number:	65	77	194
Did loss of shielding fabric occur during thermal pulse?		Yes	Yes	Yes
If so, how extensive?		Approximately 90 pct	Approximately 90 pct	Approximately 90 pct
Did loss of shielding fabric occur during blast wave?		Displaced or consumed prior to blast arrival.		
Did holes develop in shield during thermal pulse?		Yes	Yes	Yes
Could bare skin area be observed?		Yes	Yes	Yes
Did animal move?		Yes - once	No	Yes - Slightly
Could smoking of shields be observed at time of thermal pulse?		Yes	Yes	Yes
If so, estimate density.		Very dense	Very dense	Very dense
Did the smoke cover the frontal surface of shield?		Yes	Yes	Yes
Could smoking of shield be observed following thermal pulse?		No (Smoke present from displaced shielding fabric)	No	Yes- Very slight
Origin of smoke.		—	—	Narrow hem at top of shield.
Could smoking of uniform be observed following thermal pulse?		Undeterminable	Yes - slightly	Undeterminable
Degree of burn inflicted on bare skin area.		2+ - 4+	4+ - 5+	None
Degree of burn inflicted outside bare skin area.		3+	4+ - 5+	None
Location of such burns.		Small area on left front flank	Large area on left rear ham	—

TABLE E.6 COURSE OF EVENTS INDICATED BY MOTION PICTURES TAKEN OF PIGS CLOTHED IN HOT–WEATHER CONTROL UNIFORM PROTECTED BY SHIELD FABRICATED FROM NEOPRENE–COATED FORTISAN (PONCHO MATERIAL)

Observance of animal movement impossible due to obstruction by the poncho shield.

Observations					
	Code:	58-SP-2	58-SP-3	75-SP-2	75-SP-3
	Radiant Exposure cal/cm^2:	24	24	14.5	14.5
	Pig Number:	2	189	14	74
Did loss of shielding fabric occur during thermal pulse?		No	No	No	No
Did loss of shielding fabric occur during blast wave?		Yes	Yes	Yes	Yes
Did any holes develop in shield during thermal pulse?		No	No	Yes– Small hole	No
Did shield smoke during thermal pulse?		Yes	Yes	Yes	Yes
If so, estimate density.		Very dense	Very dense	Very dense	Very dense
Did smoke cover frontal surface of shield?		Yes	Yes	Yes	Yes
If so, how extensive was the coverage?		Complete	Complete	Complete	Complete
Was smoking observed following the thermal pulse?		Yes	Yes	Yes	Yes
If so, estimate density.		Moderate	Moderate	Moderate	Dense
Where did majority of smoke originate?		Back of shield	Back of shield	Back of shield	Back of shield
Degree of burn inflicted on bare skin area.		2+ - 3+	None	None	None
Degree of burn inflicted outside bare skin area.		None	1+ - 3+	None	2+ on 1+ area
Location of such burns.		--	Belly	—	High on rear left flank

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