TECHNICAL REPORT

MATERIAL LABORATORY

NEW YORK NAVAL SHIPYARD
BROOKLYN 1, NEW YORK

DISCLAIMER

DASA-1148

THE BURNS UNDER A "HOT-WET" UNIFORM SPACED FROM SKIN FOR NUCLEAR WEAPON PULSES OF THERMAL RADIATION (U)

Lab. Project 5046-16, Pt. 7, Final Report

Technical Objective AW - 7

DASA-1148

12 May 1959

Guy P. de Lhery
Willard L. Derksen
Edmund A. Garde
Thomas I. Monahan
George Mixter, Jr. M.D.

Optics and Nucleonics Branch
J.M. McGreevy, Head

Technical Director
GEO. J. DASHEFSKY

The Director
CAPTAIN C. H. GERLACH, USN

NAVAL MATERIAL LABORATORY
New York Naval Shipyard
Brooklyn 1, New York

Lab. Project 5046-16, Pt. 7
Final Report

SUMMARY

In the studies on the protection by clothing against the thermal radiation associated with nuclear detonations, the Naval Material Laboratory has investigated the situation in which the Hot-Wet Uniform assembly is separated from the rat skin a fixed distance of 5mm. The fabric assembly was irradiated by the radiant flux from a carbon-arc pulsed to simulate the thermal radiation associated with nuclear detonations.

The radiant exposures to cause burns resulting in eschar on skin of anesthetized rats were 14.7, 16.2, 16.3, and 19.7 cal/cm^2 for the thermal radiation flux corresponding to 250, 1000, 2900, and 10,000 kiloton detonations, respectively. The critical radiant exposure for a 10 megaton thermal pulse is 34 percent greater than that for a 250 kiloton pulse.

The critical radiant exposures to produce eschar are slightly less than those required for ignition of the fabric system. The threshold burns are caused by the volatile products transferred from the heated cloth to the skin. Lesions resulting in eschar are produced by volatile products when the skin temperature is held between 43 and 45°C for at least 5 seconds.

The data from this experiment can be used to predict the effects of thermal radiation on other cotton uniforms under similar conditions.

TABLE OF CONTENTS

INTRODUCTION

The Naval Material Laboratory is studying the influence of factors relevant to protection by uniforms against burns caused by the thermal radiation associated with nuclear detonations. The purpose of this investigation was to study the influence of weapon yield on the critical (or minimal) radiant exposures which would cause burns to skin when behind and separated from the uniform. The skin of anesthetized white rats was employed as the sensing element; the fabric system investigated was the so-called "Hot-Wet" uniform. The heat transfer mechanism, temperatures, and other physical phenomena associated with such burns also were studied as part of this investigation.

The uniform-rat system was exposed to a modified carbon arc whose irradiance was caused to vary so as to represent the thermal flux emitted by nuclear detonations with yields ranging from 250 to 10,000 kilotons. The exposure level of immediate interest was that which would result in minimal white burns and eschar. During the exposures the rats' skin surface temperatures were recorded. The NML skin simulants were exposed behind the fabrics to the same radiant exposures as the rats. Temperatures were recorded on the surface and at a 0.05 cm depth in the skin simulants.

The complete evaluation of the protection of a fabric or uniform system involves the consideration of several important exposure parameters. The fabrics may be either in contact or spaced from the body, the layers may be doubled as in reinforced areas, or the inner layers may not be present, as for legs and arms. The situation in which the layers of the uniform are in contact has been investigated and reported(1). The next important situation requiring study is the normal uniform assembly when spaced, this geometry also representing important areas of the uniform. The study of two other important situations, multiple layers and single layers, has been deferred, although some information can be inferred from the simple contact and spacing studies. At present data on burns under fabrics separated from the skin which result from the absorption of the thermal radiation of nuclear detonations are drawn principally from laboratory exposures to constant-irradiance pulses or from field exposures to a very limited range of weapon yields. While good inferences may be drawn from such data for use in predicting results in actual situations the uncertainties in such predictions may be considerable.

BACKGROUND

During 1953-1954 NML investigated the temperature rise of a polyethylene skin simulant behind fabrics when exposed to constant-irradiance thermal exposures of the carbon arc(2). These studies show that spacing a uniform in front of the subject necessitates higher radiant exposures to produce the same effects as in the uncovered and uniform-in-contact situations. The University of Rochester reported that spacing a cloth 5 mm from pigs offered increased protection to carbon arc constant-irradiance exposures(3). In May 1956 NML reported that the critical radiant exposures for ignition of single fabrics were a function of weapon yield(4). While these results indicate the importance of studying the phenomenology of the spacing burn, they do not give the critical exposures for burns from nuclear-weapon thermal pulses; they do not yield information on the basic heat transfer phenomena.

In the field, studies have been made of the validity of laboratory methods employed in the investigation of the protection given by uniforms. Exposures of skin simulants spaced from uniform assemblies as well as other fabric-backing situations were made at Operations Plumbbob(5) and Hardtack(6). It was determined that the exposure area of 17 mm diameter approximated by the source employed in this study is adequate. The variation of flux with time of the laboratory source was found to be satisfactory, but careful accounting must be made for the final phases of the pulse, which are not simulated in the laboratory. Spectral differences between the laboratory source and the field source under some conditions gave significantly different results for the spectrally selective "Hot-Wet" uniform. The blast wave markedly altered the burn phenomenology under spaced fabrics in those cases in which ignition is involved, tending to increase the amount of protection for the lower range of weapon yields.

For a particular cotton fabric assembly there are at least two important variables which can affect the production of burns in the spaced situation. One is the moisture content of the cloth and the other the air supply to or flow of air over the irradiated area(7). During the exposures the "Hot-Wet" uniform was subjected to an air stream of 1 ft/sec maintained at 65 percent relative humidity. This particular spacing geometry was selected since it was easiest to control experimentally. Earlier experiments indicate that an approximate air flow of 1 ft/sec enhanced cloth combustion at the lowest possible radiant exposure. Lower rates of flow would cause suffocation of any flames which may develop, while faster flow rates would inhibit ignition. The maintenance of air flow across the uniform also excludes possible variables resulting from free convection.

Cloth samples for testing are normally stored at 65 percent relative humidity. Therefore the air stream in this experiment was conditioned to maintain this relative humidity.

Temperature histories at the surface of rat skin and at the surface of and at a depth of 0.05 cm in the skin simulant were recorded. Pre-exposure monitoring of the rat's surface temperature is essential for control of the rat skin's burn response. Despite such efforts for controlled experiments there are some variables affecting results which are not easily controlled. These variables include variations in arc irradiance and pulsing mechanism, variable rat skin response and sub-epidermal temperatures.

Earlier data on rat burns and skin simulant temperatures have indicated that a temperature rise maximum of 25°C at a depth of 0.05 in. in the simulant, corresponded, with minor qualifications, to minimal white burns in rats. This criterion was derived from exposures of rat and skin simulant, uncovered and in contact with the cloth, for pulses equivalent to weapon yields ranging from 40 kt to 10 Mt.

Although investigations at NML have shown that the kρc's of rats and humans differ by a ratio of 1.4 to 1, it may be assumed that, at radiant exposure levels causing burns associated with cloth combustion, burns would result in both subjects. Only in those areas where boundary effects occur, such as burns resulting from volatile products, would the minimal critical radiant exposure for human skin be less than that of rat skin. Assuming that burn severity is directly related to the skin's temperature rise and that the radiant exposure to cause the temperature rise is in turn indirectly proportional to the square root of the kρc product 40 percent less radiant exposure would be required to produce the same damage to human skin as to the skin of anesthetized rats.

EXPERIMENTAL APPARATUS AND PROCEDURE

In this series of experiments, the rats and skin simulants were exposed 4 and 6 mm, respectively, behind a "Hot-Wet" uniform suspended vertically in the exposure plane of a high-intensity carbon arc whose radiant flux was varied with time to simulate thermal pulses produced by nuclear weapons and whose time to second maximum ranged from 0.5

to 3.2 seconds. The apparatus and procedure were the same as those employed in the cloth-contact study except for the addition of the spacer and the air flow apparatus. The apparatus is shown in section in Figure 1.

The thermal source was a modified 24-inch Naval carbon-arc searchlight utilizing an ellipsoidal first-surface aluminum mirror with foci at 11 and 52 inches. The lamp was water cooled to allow the employment of high current densities with the 11 mm Ultrex positive carbons and Orotip negative carbons. The negative carbons were stripped of their copper jackets to prevent splattering of molten copper on the mirror. No door glass was employed. The spectrum of this source has not been measured but is probably very similar to that of the NML source previously measured(10). The irradiance distribution in the exposure plane was essentially gaussian with the irradiance ninety percent of the maximum value at a radial distance of 0.6 cm. The radial vane shutter of the searchlight was driven by a cam to produce pulses equivalent to the generalized field pulse(11).

A radiometer, with a fast response recorder, measured the variation of irradiance during the pulse. The time to second maximum, t_m, for the equivalent nuclear weapon pulse curve was determined by matching the irradiance history to the generalized field pulse in the vicinity of maximum irradiance. A copper button calorimeter measured the radiant exposure (laboratory), Q_l, and maximum irradiance, H_m, incident at the exposure plane. For the generalized pulse the field radiant exposure, Q_f, is related to the maximum irradiance, H_m, and time to second maximum, t_m:

$$Q_f = 2.57 H_m t_m .$$

Since $Q_l = k H_m t_m$, where Q_l is the laboratory radiant exposure and k is a constant of proportionality, $Q_f = 2.57 Q_l/k$.

The ratio, 2.57/k, describes the compensation necessary to compare the energy produced in the laboratory with that produced in the field since the pulse in the laboratory is arbitrarily stopped at a time equal to approximately 10 t_m. k has a magnitude of about 2.0, and varies slightly as the shutter mechanism wears.

During the exposures, the "Hot-Wet" uniform was subjected to an air stream of 1 ft/sec conditioned at 65% R.H. resulting in an environmental stability in the air surrounding the uniform. Since cloth samples for test are stored at 65% R.H. the air stream was conditioned to maintain this standard.

Temperature histories during the thermal insult were recorded at the surface of the rat skin and in the skin simulant on the surface and at 0.05 cm depth. The air flow was adjusted by passing it through a manometer. Moisture was added to the air by passing it through spun glass saturated with water. The moisture content of the air was stabilized by passing it through a chamber containing a saturated solution of ammonium nitrate. Linear flow was achieved, through use of a long tube with a cross section 1 x 2 inches which terminated coincidently with the uniform's edge. The air flow was controlled by a stop-cock valve.

At the time of irradiation the rat was placed on a platform behind a copper plate 0.05 cm thick. A 12 mm aperture was cut in the plate to expose the rat. The rat was gently pressed against the aperture and held in place with foam rubber pads backed by an aluminum plate. The outer edges of the copper plate were double walled to allow passage of thermostatically controlled water which maintained the rat skin's surface temperature between 31° and 32°C. A 0.006 cm diameter thermocouple was suspended vertically behind the copper plate and in the center of the aperture in 0.5 gm tension. The thermocouple was connected in series with an ice bath and a recording potentiometer. The "Hot-Wet" uniform was suspended vertically at the secondary focus under firm tension. In irradiating the simulant the skin simulant thermocouples on the surface and at 0.05 cm depth were connected directly to the recorder. No attempt was made to control the initial temperature of the simulant.

The "Hot-Wet" uniform was stored in bell jars maintained at 65% R.H. for at least four hours prior to the experiment. The moisture of the cloth during exposure was kept at 65% R.H. by the air flow.

Sprague-Dawley Albino rats were employed in this experiment. Females, 60-70 days old and averaging 150 grams, were clipped and the hair was removed with "Nair" depilatory 24 hours prior to exposure. The cream was left on the animals for 8 to 10 minutes. In earlier experiments this method resulted in the most complete hair removal with least irritation. Anesthesia was essential for this operation.

Twenty minutes before an exposure series the rat was anesthetized with a 1:11 solution of veterinary Nembutal in saline, injected intraperitoneally, in a dose of 40 mg per kilogram of body weight.

Immediately after exposure the burns were assessed by visual estimate as "no burn", "minimal", "moderate", or "severe" red, "minimal", "moderate" or "severe" white. Thirty minutes later they were re-examined and again assessed, using the same criteria. Eighteen to twenty-four hours later they were examined for the occurrence of scabs.

In March 1958, skin simulants were exposed 5 mm behind the "Hot-Wet" uniform to pulses of equivalent yields ranging from 250 to 10,000 kt. The radiant exposures which would cause a temperature rise of 25°C were measured. Assuming that these radiant exposures were critical in the production of minimal white burns, rats were exposed under the same conditions at these radiant exposure levels. Exposures were increased or decreased in 10 percent increments, depending upon the production or non-production of minimal white burns. Using the March 1958 data as a guide the rats and skin simulants were exposed to a second series during September and October of the same year.

RESULTS

The frequency of cloth ignition, burns and eschar as a function of equivalent field radiant exposure, Q_f, and time to second maximum, is given in Table I. For t_m of 1.0 and 3.2 seconds the number of exposures reported under "Immediate Assessment" is greater than that reported for the "24 Hour Assessment." Animal mortality explains this anomaly.

In March 1958, 21 percent of the total exposures were conducted. During this period white burns and scabs not associated with ignition of the fabrics were found, especially for a t_m of 1.7 seconds. To investigate this phenomenon and to obtain sufficient data for a probit analysis additional experiments were conducted in the period, September to December 1958.

Pulse times less than that corresponding to a weapon yield of 0.25 Mt were not investigated because the source could not deliver sufficient radiant exposure to effect ignition of the "Hot-Wet" uniform.

Table 2 presents the fifty percent effective radiant exposures, RE_{50}, and the ninety-five percent confidence limits for cloth ignition, for white burns, and for scabs. The modified probit method of Litchfield and Wilcoxon(12) was used in this analysis.

There is a 40 percent increase in RE_{50} for a change of pulse length from a t_m of 0.5 second to 3.2 seconds. This pulse range represents nuclear detonations in the lower atmosphere of weapon yields ranging from 250 kt to 10 Mt. During the experimentation it was noted that white burns occurred in situations which did not result in ignition of the cloth. On the other hand, some red burns, according to immediate assessment, eventually developed into lesions with scabs. Analysis of the data indicates a 4 to 7 percent lower RE_{50} for white burns than for cloth ignition, and a 2 to 9 percent lower RE_{50} for scab burns than for white burns. The occurrence of burns in non-ignition situations was unexpected. The lower energy requirement for scabs had been noted previously(1). Table 3 presents the healing time in hours for all scab burns, including those which did not result from ignition of the fabric system.

Twenty-four hours after exposure each animal was examined for lesions. If scabs were present their development was followed until their disappearance. Since scabs were observed only at 24-hour intervals, the reported duration times are given in multiples of 12 hours.

Sub-ignition scabs were deep pink or light tan at the initial 24-hour assessment. These turned brown subsequently. The ignition scabs, however, were deep brown at the 24-hour assessment. Ignition scabs lifted like those for the bare rat and for the rat in contact with the "Hot-Wet" Uniform(9). The non-ignition scabs, however, faded away.

The average duration of eschar is presented in Table 4 for the various equivalent weapon yields investigated. The heading, "Total Scabs", includes all scabs, ignition and non-ignition. It is to be noted that scabs not associated with ignition heal faster than those associated with ignition of the fabric.

At t_m's of 0.5 and 1.0 seconds the average duration of all "Hot-Wet" spaced scabs was longer than that for the contact and bare situations, whereas the bare and contact scabs remained longer for pulses with a t_m of 3.2 seconds.

Figure 2 presents the maximum temperature rise at the surface of rat skin as a function of the equivalent field radiant exposure, solid points indicating temperature rises which are associated with subsequent scab burns. It is to be noted that the maximum temperature rises associated with cloth-ignition situations were always higher than 20°C and resulted in scabs. The scab burns associated with situations in which the cloth did not ignite represent 29, 23, 52 and 42 percent of the total scabs for t_m's of 0.5, 1.0, 1.7 and 32 seconds respectively. The points in Figure 3 represent all the exposures for which temperatures were measured. However, temperatures were not recorded during all exposures due to the breaking of thermocouples during the experiment. Temperature maxima less than 44°C, at which Hardy et al report irreversible tissue damage(13), seldom resulted in burns except for an equivalent t_m of 3.2 seconds, for which some burns occurred at slightly lower temperatures.

The temperature rise maximum associated with threshold scabs spaced behind the Hot-Wet Uniform is about 13°C. For the "Hot-Wet" contact situation the maximum temperature rise is about 21 to 24°C., and maximum temperature rises on bare rat skin range from 45 to 27°C for pulses with t_m ranging from 0.5 to 3.2 seconds. Analysis of the temperature histories indicates that the temperature rises behind spaced clothing are maintained the longest while those of bare rat skin usually tend to follow the shape of the irradiating pulse, with temperature rises for the contact situation lagging the pulse somewhat with respect to the time interval for which the temperature is maintained.

Figures 3 and 4 present typical temperature histories associated with scabs. In each case, the curve with the higher maximum temperature and slower cooling is associated with an ignition situation. The lower curves are associated with non-ignition scab situations. All temperature histories for radiant exposures less than those required to cause cloth ignition have the same time dependence as the non-ignition scab curves but with less amplitude. As indicated by the maximum temperatures of Figure 3, temperature histories with magnitudes between those given for each exposure in Figures 4 and 5 rarely occurred.

Temperature histories at the surface of the skin simulant were similar to those of rat skin for similar situations. Contrary to the prediction of theory, the maximum temperatures of the skin simulants were lower than those of the rat skin. This discrepancy was a result of different spacing distances for rat and skin simulant; because of difficulty in controlling the bulge of the rat through the 12 mm aperture the spacing varied from 3.4 to 5.4 mm, while the spacing for the simulant was 6 mm (See Figure 1).

Skin simulant maximum temperatures at the surface and at a depth of 0.05 cm indicated an average temperature gradient of 10 to 15 percent for non-ignition and ignition situations.

Analysis of skin simulant temperature histories reveal that after 20 to 30 seconds the temperatures in depth were equal to surface temperatures for situations associated with charring and flaming. For situations which caused glow the temperature gradiant was maintained longer. Depth temperatures sometimes were higher than surface temperatures in the later phases of the pulse, indicating appreciable heat loss at the surface.

In ignition of the "Hot-Wet" uniform in the spaced situation, temperature rises of 15°C or higher were maintained after the maximum temperature had been attained, for seven times as long as typical "Hot-Wet" contact scab-associated temperature histories, for t_m's of 0.5, and twice as long for t_m's of 1.0 and 3.2 seconds.

In non-ignition situations the temperature rise was due primarily to heated air, steam and volatile products. There was no visual evidence of condensation of moisture or tar products from the cloth. The first maximum in the temperature-time curves for equivalent t_m of 0.5, 1.0 and 1.7 is due to the rapid production of volatile products for the most intense period of the thermal pulse. The temperature of the surface of the rat's skin does not reach a maximum until the irradiance has reached its maximum. Heat is not transferred until after the radiant energy has transferred enough heat to the cloth to boil the absorbed moisture and sublimate the volatile materials. As mentioned above, the energy pulse is terminated at 10 times t_m; in non-ignition situations, if the entire pulse were delivered, the additional volatile products which would be released could conceivably lower the threshold radiant energy for producing scab burns.

Since the temperature rise maximum occurs at 10 to 30 seconds after zero time, possible voluntary or involuntary evasive action could occur during a nuclear attack, thereby avoiding the serious burns caused by ignited cloth.

Typical exposed cloths, representing non-ignition and ignition situations are presented in Figure 5, for several equivalent weapon yields and radiant exposure levels. It is to be noted that the data presented are for the situations in which actual experimentation was carried out and that the observed effects might have been obtained at other radiant exposure levels. For 0.5 second t_m when flaming occurred the outer garment was flashed off leaving the underwear charred. At 1.7 seconds t_m however both garments were consumed. Glow at all times resulted in relatively equal cloth destruction. Upon termination of the pulse, the cloth was allowed to burn or glow and the rat was held in position until total skin temperature dropped to 40°C.

Figure 6 presents the distance, in feet, at which RE_{50} occurs for eschar, as a function of weapon yield. The relationships employed are for detonations in the lower atmosphere and for atmospheric transmissivity of 0.9 per land mile. The relationships between t_m, weapon yield radiant exposure, and distance from ground zero, are:

$$W = t_m^2, \text{ and,} \qquad (1)$$

$$Q = \frac{1000 \, WT^D}{D^2}, \qquad (2)$$

where W is the weapon yield in megatons

t_m is the time to second maximum (sec)

D is the distance from burst in miles (5280 ft/mile)

T equals atmospheric transmissivity per land mile

and Q equals radiant exposure (cal/cm^2)

Equations (1) and (2) hold only for detonations in the lower atmosphere.

An empirical equation has been fitted to the RE_{50} scab data for the "Hot-Wet" uniform separated from the backing:

$$D = AW^b,$$

where D equals the equivalent distance for scab RE_{50} in land miles,

W equals weapon yield megatons,

A equals a constant (5.6 from 0.02 to 2.0 Mt and 6.3 from 2 Mt to 10 Mt), and

b equals a constant (0.44 from 0.02 Mt to 2 Mt and 0.27 from 2 Mt to 10 Mt)

DISCUSSION

Although 100 percent scab production was expected at cloth-ignition radiant-exposure levels, the production of scabs at sub-ignition levels and those involving volatile products was considered rather unlikely. As the pulse time is increased the production of sub-ignition burns increases. In the development of protective fabrics this phenomenon necessitates, not only the development of fabrics with efficient flame retardant components, but also additives which do not volitalize readily and fabrics whose absorption of moisture is minimum.

The difference between the RE_{50} level for white burns and that for scabs is not considered significant. Since the burn assessment is made immediately after exposure, threshold type white burns are not immediately discernible. However, some sub-white immediate assessments have developed, on second examination, into white burns and subsequently into scabs. The second assessments were made fifteen minutes after exposure. The difference between the RE_{50} level for white burns and that for scabs is, therefore, insignificant. It should be pointed out that with the probit method employed(12) the RE_{50} and 95 percent confidence levels are dependent to some extent on the manner in which the best curve fit is estimated.

The increased protection afforded by the "Hot-Wet" system spaced from the backing, relative to that of the "bare" and "contact" situations is more pronounced at the lower weapon yields than at the higher yields.

Analysis of the scab data indicates that burns caused by volatile product are not as severe as those resulting from cloth ignition. The observed maximum temperature associated with non-ignition burns verify that they are threshold lesions. The scabs associated with volatile products are less severe than those produced in the contact and bare situations, whereas the scabs due to ignition are more severe than those produced in the bare and contact situations. Elimination of flaming by non-volatile flame retardents or evasive action would increase the RE_{50} for the spaced "Hot-Wet" Uniform.

At radiant exposures below the RE_{50} for cloth ignition, heat is transferred by the impinging of volatile products on the skin surface. Since the temperature rise is not appreciable until after the irradiance reaches its maximum value, the temperature rise due to direct radiant energy is negligible. At low radiant exposures the moisture entrapped by the fibers is evaporated, causing an increase in temperature at the uniform backing. As the radiant exposure is increased, the volatile products in the cloth fibers are vaporized, resulting in scorching and charring. Some steam and volatile products escape at the irradiated uniform surface while the rest transfers heat to the skin. At radiant exposures causing severe cloth char the volatile products are ignited and then flame during the irradiation period. At the termination of the pulse, flaming may cease but ignition continues as cloth glow. Heat transfer from the glowing fabric is by radiation, convection and conduction, and is a function of the ignited cloth area, the distance of the cloth from the skin, and the transmittance of the volatile products. The volatile products and steam are the agents for convection. Conduction results from the condensation of steam and volatile products at the skin surface. For the "Hot-Wet" spaced situation heat transfer is due mainly to convection and conduction.

The maximum temperature rises of the rat skin at radiant exposures less than those required to cause ignition range from 10 to 15°C, the higher temperature rises causing irreversible tissue damage as evidenced by scab burns. The temperatures, when ignition occurs, are much higher than those at non-ignition levels and range from 20 to 40°C.

The influence of parameters, such as wind speed, moisture content of the uniform, and initial rat skin temperature, was not determined in this experiment. These variables would influence the amount of heat transferred by volatile products, the energy required for ignition, and the energy transferred to the skin by the flaming cloth. For the contact situation, where the heat transfer is due mainly to conduction, these factors would have little or no influence.

Lower ambient temperatures would lower the temperatures of the cloth, but, unless the change was extreme, the heat transfer would be affected little since the degradation temperatures for cotton are relatively high. The influence of a change in moisture content would depend on the duration of the irradiation pulse. For short pulses an increase in the moisture content of the cloth might decrease the radiant exposures to cause burns, since there is an increase of the amount of steam produced .

Air flow below 1 ft/sec would allow the accumulation of volatile products at the irradiated surface of the cloth, which would then absorb some of the radiant flux. At higher wind speeds the volatile products are partially removed, thereby lessening the severity of the burns due to these products. Still higher wind speeds also inhibit ignition and would extinguish the flame. The radiant exposures to cause burns behind a cloth separated from the backing, therefore, increase with wind speeds in excess of 1 ft/sec. The wind speed employed in this experiment approximates that for which the radiant exposures for burns behind spaced fabrics is a minimum.

Data derived from this investigation can be employed to derive the effects on other uniforms of cotton fibers in similar situations. Fabrics made of synthetics or of wool would experience different effects in the spaced situation, for the absorption of heat by such fabrics usually results in melting.

CONCLUSIONS

The distance from the point of a nuclear detonation, at which 50 percent of the rat population would receive scab burns may be related to the weapon yield in megatons by the expression;

$$D = AW^b$$

Data from which the constants for this equation was derived are 3.5, 5.7, 8.5 and 11.9 land miles for nuclear weapon yields of 0.25, 1.0, 2.9 and 10 megatons.

Threshold burns may be effected at radiant exposures which do not cause ignition.

Assuming healing time for scabs as a good criterion for burn severity, a uniform of fibers with high ignition points would reduce the number of burns for a given situation.

For sub-ignition burns, heat transfer is mainly due to volatile products. Ignition-type burns are caused by radiation, convection and conduction of heat.

Maximum temperature rises associated with sub-ignition burns range from 10 to 15°C. Maximum temperature rises causing ignition burns range from 25 to 40°C.

Wind speed, cloth moisture content and initial skin temperature influence the radiant exposures to cause burns under spaced clothing.

Data published in this report can be employed to predict effects on other cotton uniforms under similar conditions.

Approved: R P Hall

R. P. HALL, LCDR, USN
Acting Assistant Director

eew

REFERENCES

1. Derksen, W.L., de Lhery, G.P., Monahan, T.I., Mixter, G. Jr. M.D., Protection by a "Hot-Wet" Uniform in Contact with Skin for Nuclear Weapon Pulses of Thermal Radiation. Naval Material Laboratory, Lab. Project 5046-16, Pt. 3, April 1958.

2. Derksen, W.L., Bates, W.J., Monahan, T.I., Use of Polyethylene as a Physical Measuring System for Evaluating Physiological Burns Behind Fabrics, Naval Material Laboratory, Lab. Project 5046-3, Pt. 42, (Nov. 1954).

3. Berkely, K.M., Studies on Small Area Sub-Fabric Flash Burns, University of Rochester Report, UR-493, (Oct. 1957).

4. Bates, J.J., Monahan, T.I., Derksen, W.L., Thermal Damage to Cloth as a Function of Time of Exposure, Nuclear Weapon Pulses, Naval Material Laboratory, Lab. Project 5046-3, Pt. 75, (May 1956).

5. Evaluation of Laboratory Methods for Studying the Effects of Thermal Radiation on Biological Systems, Naval Material Laboratory, Operation Plumbbob Preliminary Report, ITR-1445, Project 8.2.

6. Effects on Materials of Thermal Radiation from Nuclear Detonations, Hardtack Preliminary Report Naval Material Laboratory, ITR-1647, Project 8.1.

7. Derksen, W.L., Bates, J.J., The Influence of Air Supply and Air Flow on Burns Behind Irradiated Fabrics, Naval Material Laboratory, Lab. Project 5046-3 Pt. 100, (June 1956).

8. The Thermal Conductivity and Diathermancy of Albino Rat Skin, Naval Material Laboratory, Lab. Project 5046-16, Pt. 4, (April 1959).

9. The Healing History of Intense Thermal Radiation Burns to White Rat Skin, Naval Material Laboratory, Lab. Project 5046-16, Pt. 6, (To be Published).

10. de Lhery, G.P., Derksen, W.L., The Relative Spectral Energy Distribution of The Naval Material Laboratory Carbon-arc Source of Intense Thermal Radiation, Naval Material Laboratory, Lab. Project 5046-3, Part 103 (July 1956)

REFERENCES (CONT'D)

11. Streets, L.B., The Basic Characteristics of Thermal Radiation of An Atomic Detonation, AFSWP 503 (Nov 1953).

12. Litchfield, J.T., Jr. and Wilcoxon, F., "A Simplified Method of Evaluating Dose-Effect Experiments; J. Pharm and Thera., 96:99 (1949).

13. Stoll, Alice M., Greene, Leon C.; The Relationship between Pain and Tissue Damage due to Thermal Radiation; Aviation Medical Acceleration Laboratory, Report No. 15, June 1958.

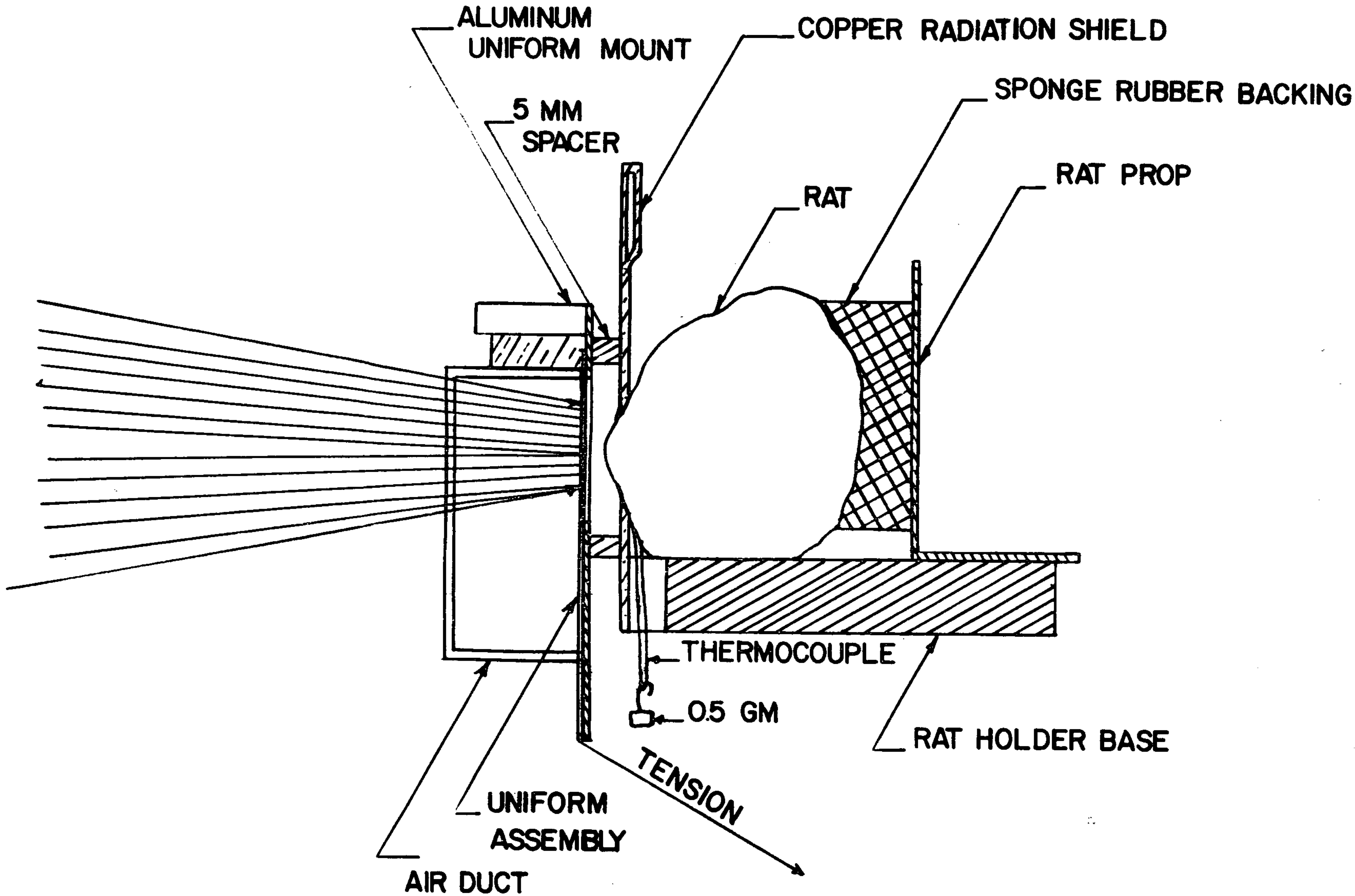

Figure 1 - Side Section View of the Rat - Uniform Exposure Mount

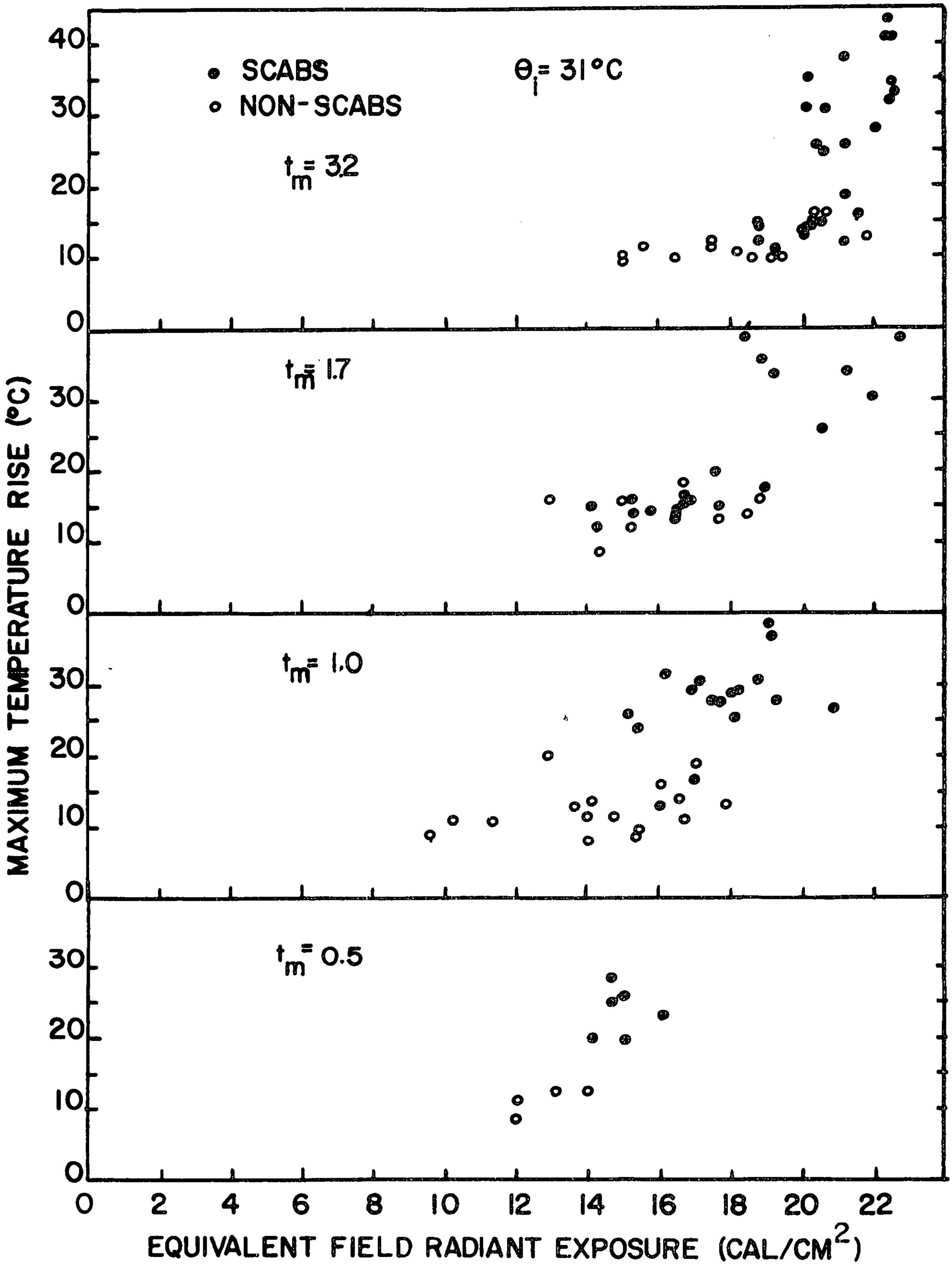

Figure 2 - The Maximum Temperature Rise at the Surface of Rat Skin, Spaced from the "Hot-Wet" Uniform

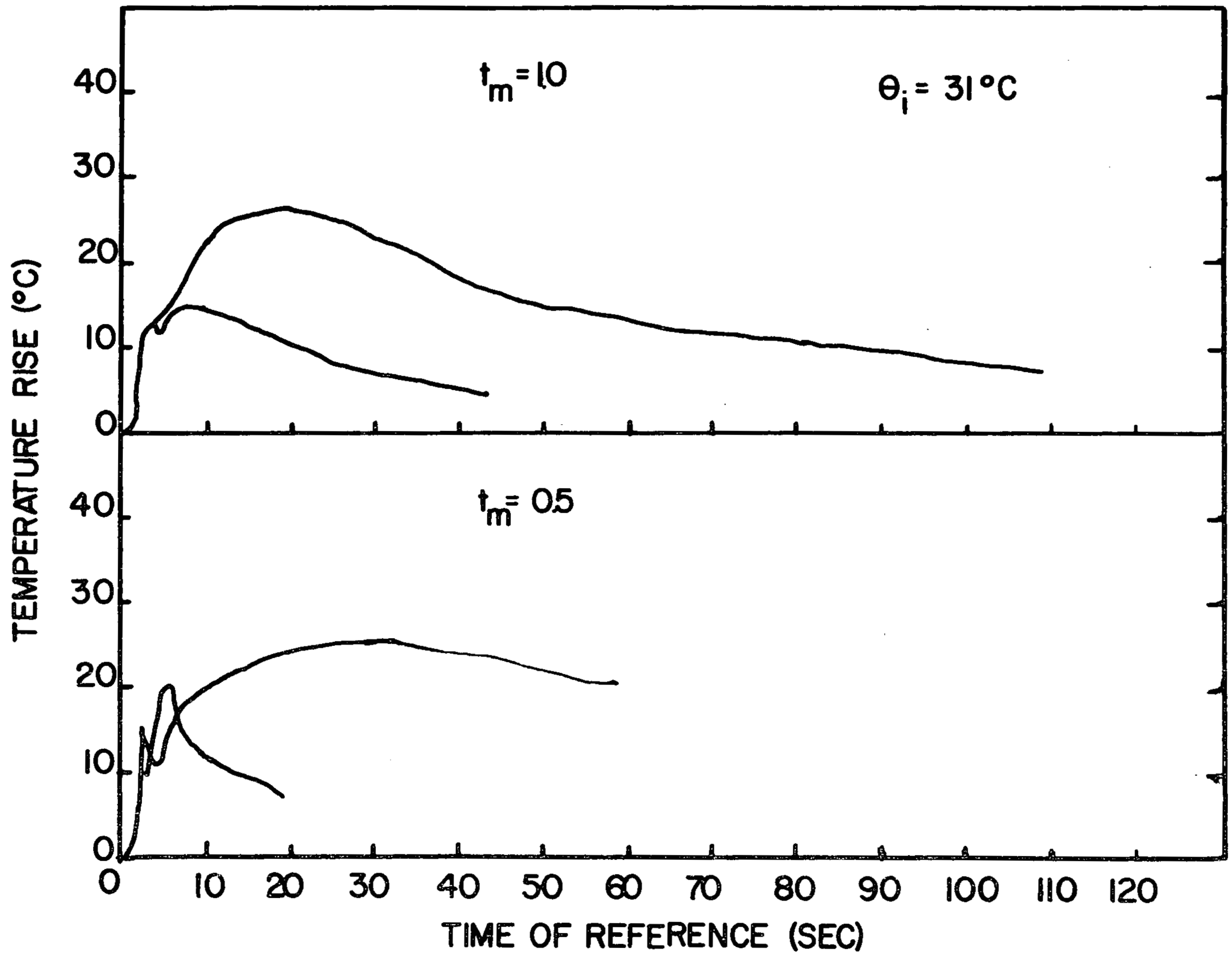

Figure 3 - Typical Temperature Histories of Rat Skin, Spaced from The "Hot-Wet" Uniform, for Non-Ignition and Ignition - Type Scab Burns

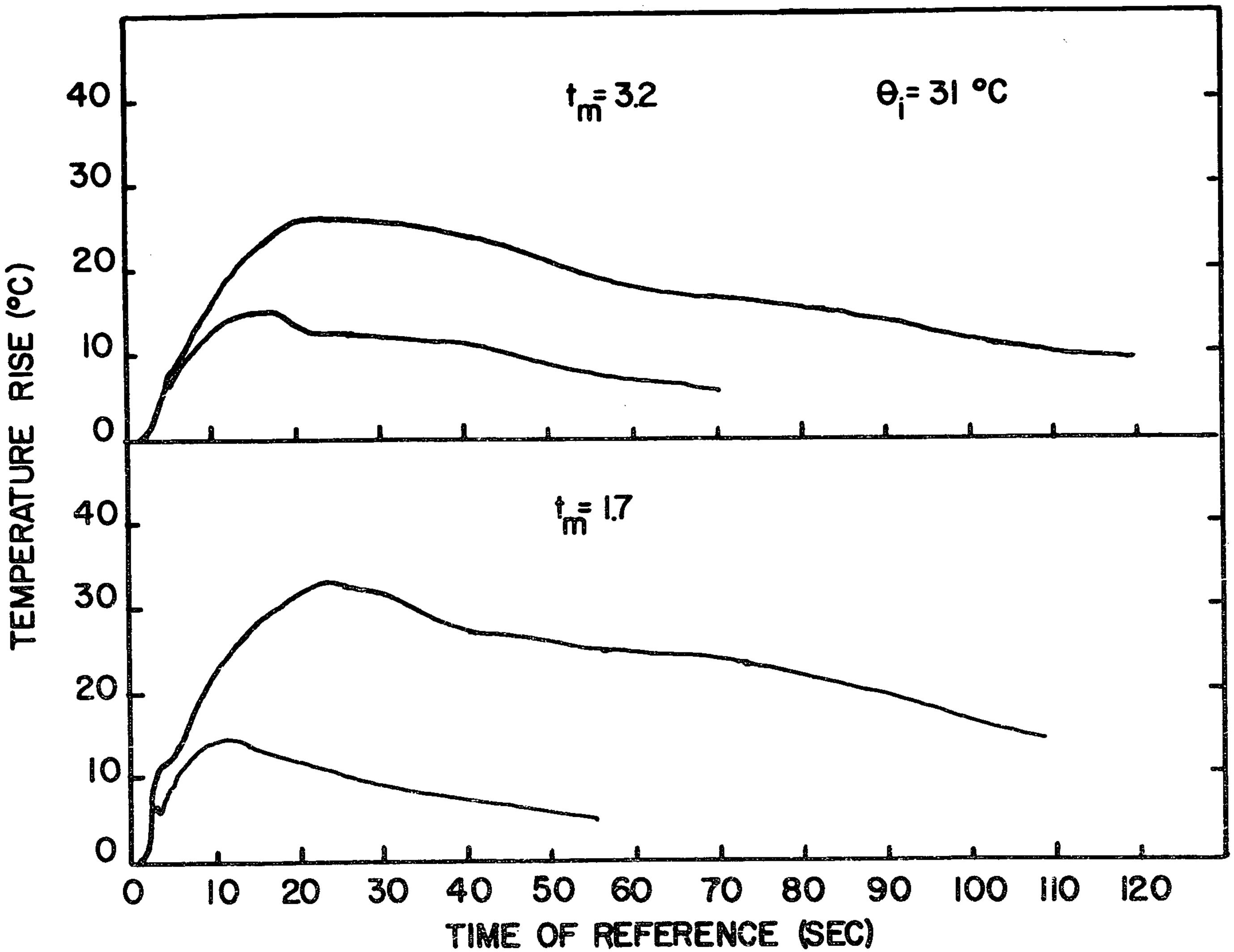

Figure 4 - Typical Temperature Histories of Rat Skin, Spaced from the "Hot-Wet" Uniform, for Non-Ignition and Ignition - Type Scab Burns

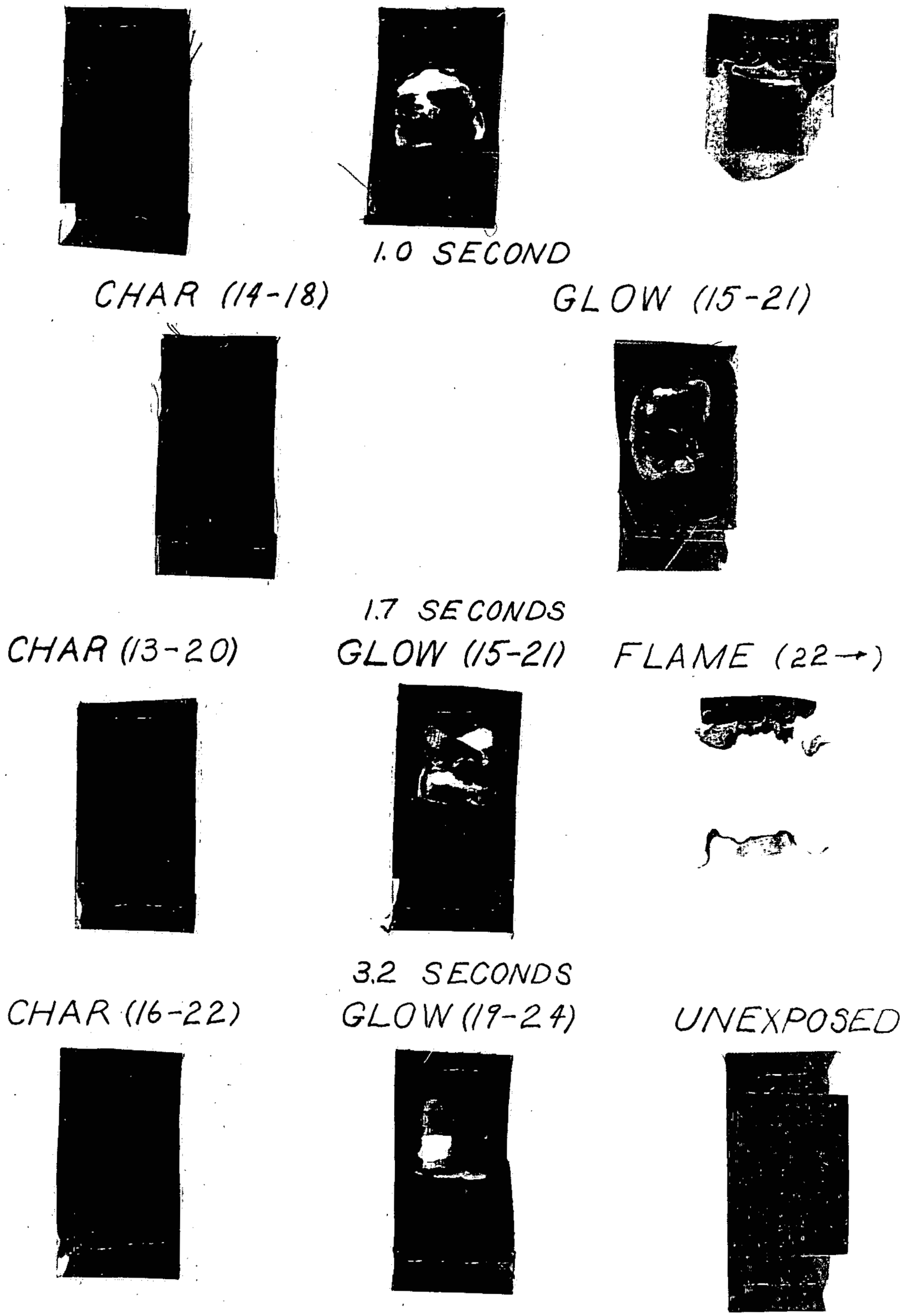

Figure 5 - Typical Damage to the "Hot-Wet" Uniform Spaced from Rat Skin for Several Nuclear Weapons Pulses and Radiant Exposures

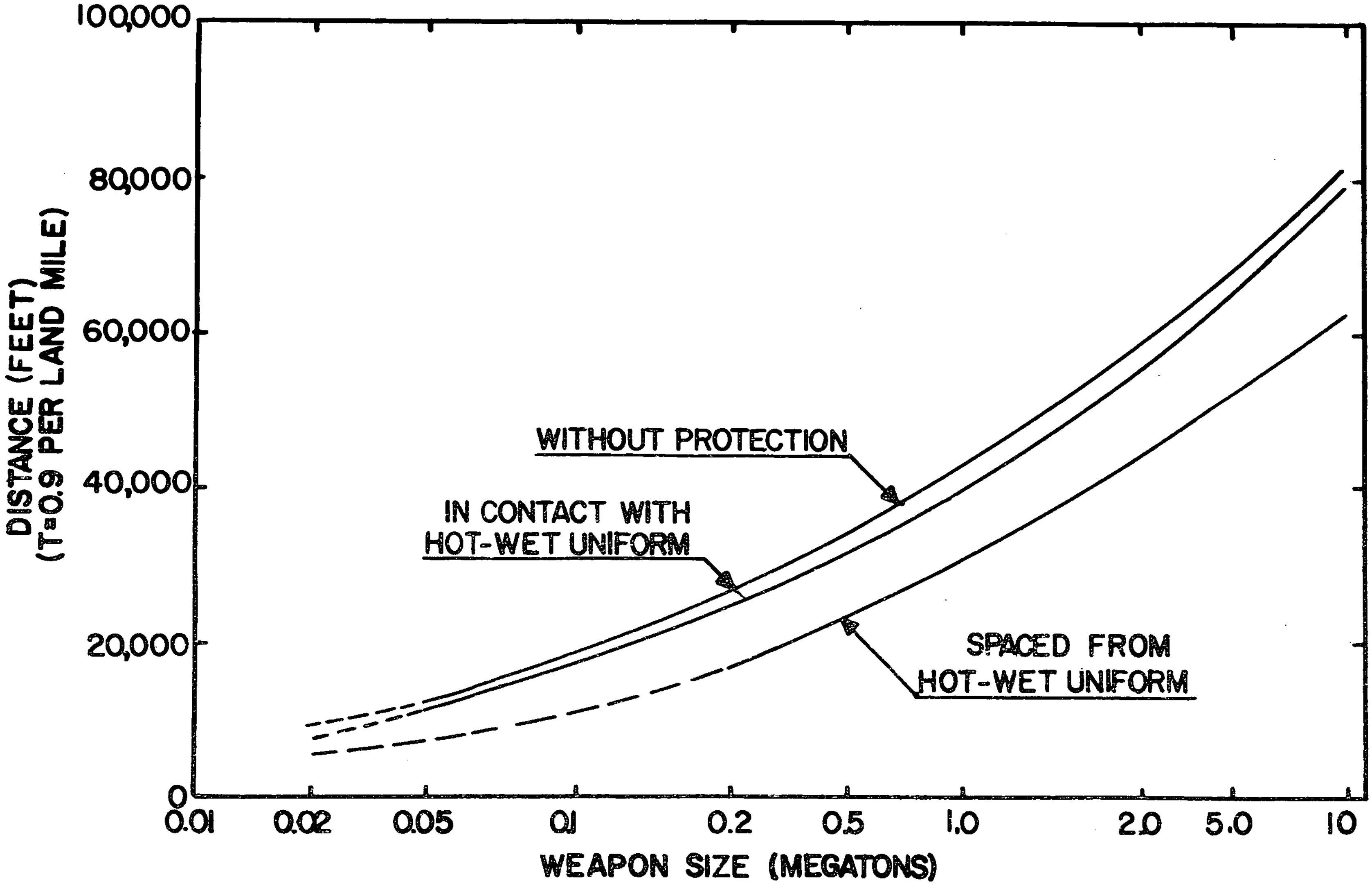

Figure 6 - Critical Distances for Scab Occurence in Rat Skin

TABLE I

Frequency of Burns, Scabs and Cloth Effect as a
Function of Equivalent Field Radiant Exposure

t_m (sec)	Radiant Exposure (cal/cm²)	Cloth Damage		Immediate Assessment					24 Hour Assessment			
		Char	Ignition	No Burn	Red Burns	White Burns	Number of Exposures	Percent White Burns	No Visual Effect	Scab	Number of Exposures	Percent Scab
0.5	12.5	3	-	1	2	-	3	0	3	-	3	0
	13.5	4	-	2	2	-	4	0	4	-	4	0
	14.5	4	2	2	2	2	6	33	3	3	6	50
	15.5	1	1	-	-	2	2	100	-	2	2	100
	16.5	-	2	-	-	2	2	100	-	2	2	100
1.0	13.5	2	-	1	1	-	2	0	2	-	2	0
	14.5	5	-	1	4	-	5	0	5	-	5	0
	15.5	4	1	4	0	1	5	20	2	2	4	50
	16.5	6	2	1	5	2	8	25	3	2	5	40
	17.5	4	4	2	1	5	8	62	1	4	5	80
	18.5	-	3	-	-	3	3	100	-	3	3	100
	19.5	-	3	-	-	3	3	100	-	2	2	100
	20.5	-	1	-	-	1	1	100	-			
1.7	13.5	2	-	2	-	-	2	0	2	-	2	0
	14.5	6	-	4	1	1	6	17	4	2	6	33
	15.5	7	-	5	-	2	7	29	4	3	7	43
	16.5	8	-	3	3	2	8	25	4	4	8	50
	17.5	3	-	1	1	1	3	33	1	2	3	67
	18.5	5	3	1	2	5	8	63	3	5	8	63
	19.5	1	2	-	-	3	3	100	-	3	3	100
	20.5	-	2	-	-	2	2	100	-	2	2	100
	21.5	-	5	-	-	5	5	100	-	5	5	100
3.2	16.5	1	-	-	1	-	1	0	1	-	1	0
	17.5	2	-	1	1	-	2	0	2	-	2	0
	18.5	8	-	4	3	1	8	13	6	2	8	25
	19.5	5	1	1	3	2	6	33	3	3	6	50
	20.5	9	4	-	4	9	13	69	5	7	12	58
	21.5	4	3	-	-	7	7	100	1	6	7	86
	22.5	-	6	-	-	6	6	100	-	5	5	100
	23.5	-	1	-	-	1	1	100	-	1	1	100

TABLE 2

The Fifty Percent Effective Radiant Exposures
Causing Cloth Ignition, White Burns And Scabs

Time to Second Maximum (sec)	Cloth Ignition	White Burns	Scabs	
0.5	15.0 ± 1.3	15.0 ± 1.3	14.7 ± 1.1	
1.0	17.5 ± 1.0	16.8 ± 0.7	16.2 ± 1.1	
1.7	18.9 ± 1.1	17.7 ± 1.2	16.3 ± 1.7	
3.2	21.9 ± 1.1	19.8 ± 0.8	19.7 ± 0.7	

TABLE 3

The Healing Time of Scabs

t_m	Q_ε	Average Duration of Scabs (Hours)														
sec.	cal/cm²	84	108	132	156	180	204	228	252	276	300	324	348	372	396	420
0.5	14.5					(1)*		1		1						
	15.5					(1)	1									
	16.5									1	1					
1.0	15.5	(1)							1							
	16.5											1				1
	17.5			(1)		(1)				1				1		
	18.5								1	1		1				
	19.5								1			1				
	20.5															
1.7	14.5		(2)													
	15.5		(2)					(1)								
	16.5	(1)	(1)	(2)		(1)										
	17.5	(1)			(1)											
	18.5			(1)			1		1						1	1
	19.5						(1)						1			1
	20.5							1								1
	21.5						2			1			1			2
3.2	18.5	(1)	(1)													
	19.5	(1)														
	20.5		(2)					2	1							
	21.5	(2)	(1)					1	1			1				
	22.5							2	1				1			1
	23.5												1			

* Numbers in paranthesis indicate scabs not associated with ignition.

TABLE 4

Duration of Scabs Behind the "Hot-Wet" Uniform
for Various Weapon Yields

Equivalent Weapon Yield (Mt)	Average Duration (Hours)		
	Total Scabs	Volatile Products Scabs	Ignition Scabs
0.25	237	180	257
1.0	271	132	312
2.9	285	132	373
10.0	193	79	278
Average of all Yields	230	118	307

DISTRIBUTION LIST NO.100 REVISED: 13 Aug 1959
Thermal Radiation Reports
(Research)

ADDRESSEE	ARMY	No. of copies
Deputy Chief of Staff for Military Operations Department of the Army Washington 25, D. C.	ATTN: Director of SW&R	1
Chief of Research & Development Department of the Army Washington 25, D. C.	ATTN: Atomics Division	1
Chief of Ordnance Department of the Army Washington 25, D. C.	ATTN: ORDTN	1
Chief Signal Officer Department of the Army Combat Dev & Ops Div Washington 25, D. C.	ATTN: SIGCO-4	1
The Surgeon General Department of the Army Washington 25, D. C.	ATTN: MEDNE	1
Chief Chemical Officer Department of the Army Washington 25, D. C.		2
Chief of Engineers Department of the Army Washington 25, D. C.	ATTN: ENGNB	3
The Quartermaster General Department of the Army Washington 25, D. C.	ATTN: R&D Division	1
Chief of Transportation Department of the Army Washington 25, D. C.	ATTN: Military Planning & Intelligence Division	1
Commanding General U. S. Continental Army Command Ft. Monroe, Va.		4
President U. S. Army Artillery Board Ft. Sill, Oklahoma		1
President U. S. Army Infantry Board Ft. Benning, Georgia		1
President U. S. Army Air Defense Board Ft. Bliss, Texas		1

Dist List No.100 (Cont'd)

ADDRESSEE	ARMY (Cont'd)	No. of copies
Commandant Command & General Staff College Ft. Leavenworth, Kansas	ATTN: Archives	1
Commanding General Army Medical Service School Brooke Army Medical Center Ft. Sam Houston, Texas		1
Director Special Weapons Development Hq CONARC Ft. Bliss, Texas	ATTN: Capt Chester I. Peterson	1
Commandant Walter Reed Army Institute of Research Walter Reed Army Medical Center Washington 25, D. C.	ATTN: Dept of Biophysics	1
Commandant Chemical Corps School Chemical Corps Training Command Ft. McClellan, Alabama		1
Commanding General U. S. Army Chemical Corps Research & Development Command Washington 25, D. C.		2
Commanding General The Engineer Center Ft. Belvoir, Virginia	ATTN: Ass't Commandant, Engineer School	3
Commanding General Aberdeen Proving Ground Aberdeen Proving Ground, Md.	ATTN: Director, Ballistics Research Laboratory	2
Commanding Officer Engineer Research & Development Laboratory Ft. Belvoir, Va.	ATTN: Chief, Tech Support Branch	1
Commanding Officer Picatinny Arsenal Dover, N.J.	ATTN: ORDBB-TK	1
Commanding Officer Frankford Arsenal Bridge & Tacony St. Philadelphia, Pa.		1
Commanding Officer Army Medical Research Laboratory Ft. Knox, Ky.		1

ADDRESSEE	ARMY (Cont'd)	No. of copies
Commanding Officer Chemical Warfare Lab Army Chemical Center, Md.	ATTN : Tech Library	2
Commanding Officer Transportation R&E Command Ft. Eustis, Va.	ATTN: Special Projects Division	1
Commanding Officer U. S. Army Signal R&D Lab Ft. Monmouth, N. J.	ATTN: Technical Documents, Evans Area	1
Director Waterways Experiment Station P. O. Box 631 Vicksburg, Miss.	ATTN: Library	1
Director Operations Research Office The Johns Hopkins University 6935 Arlington Rd. Bethesda 14, Maryland		1
Commanding General Quartermaster R&D Command Quartermaster R&D Center Natick, Mass.	ATTN: CBR Liaison Officer	2
	NAVY	
Chief of Naval Operations Department of the Navy Washington 25, D. C.	ATTN: OP-75	2
Chief of Naval Operations Department of the Navy Washington 25, D. C.	ATTN: OP-03EG	1
Chief Bureau of Medicine & Surgery Department of the Navy Washington 25, D. C.	ATTN: Special Weapons Defense Div.	1
Chief Bureau of Ordnance Department of the Navy Washington 25, D. C.		1
Chief Bureau of Ships Department of the Navy Washington 25, D. C.	ATTN: Code 423 Code 335	2 4

ADDRESSEE	NAVY (Cont'd)	No. of copies
Chief Bureau of Supplies & Accounts Department of the Navy Washington 25, D. C.		1
Chief Bureau of Yards & Docks Department of the Navy Washington 25, D. C.	ATTN: D-400	1
Chief Bureau of Aeronautics Department of the Navy Washington 25, D. C.		2
Chief of Naval Research Department of the Navy Washington 25, D. C.	ATTN: Code 811	1
Commander-in-Chief U. S. Pacific Fleet, FPO San Francisco, Calif.		1
Commander-in-Chief U. S. Atlantic Fleet U. S. Naval Base Norfolk 11, Va.		1
Commandant of the Marine Corps Department of the Navy Washington 25, D. C.	ATTN: Code AO3H	4
President U. S. Naval War College Newport, R.I.		1
Superintendent U. S. Naval Postgraduate School Monterey, California		1
Commanding Officer U. S. Naval Schools Command U. S. Naval Station Treasure Island San Francisco, Calif.		2
Commanding Officer Nuclear Weapons Training Center Atlantic Naval Base Norfolk 11, Va.	ATTN: Nuclear Warfare Dept.	2

ADDRESSEE	NAVY (Cont'd)	No. of copies
Commanding Officer Nuclear Weapons Tng Center, Pacific Naval Station North Island San Diego 35, Calif.		2
Commanding Officer Air Development Squadron 5, VX-5 China Lake, Calif.		1
Commanding Officer U. S. Naval Damage Control Training Center Naval Base Philadelphia 12, Pa.	ATTN: ABC Defense Course	1
Commander U. S. Naval Ordnance Laboratory White Oak, Silver Spring, Md.	ATTN: EE Division	1
	R Division	1
Commander U. S. Naval Ordnance Test Station China Lake, Calif.		1
Commanding Officer U. S. Naval Medical Research Institute National Naval Medical Center Bethesda 14, Md.		1
Commanding Officer U. S. Naval Air Development Center Johnsville, Pa.	ATTN: Dr. J.D. Hardy, Aviation Acceleration Lab.	1
Director U. S. Naval Research Laboratory Washington 25, D. C.	ATTN: Code 2029	1
Commander New York Naval Shipyard Brooklyn 1, New York	ATTN: Director, The Material Laboratory	1
Commanding Officer & Director U. S. Naval Electronics Lab. San Diego, Cal.		1
Commanding Officer & Director U. S. Naval Radiological Defense Lab. San Francisco, 24, Calif.	ATTN: Tech Info Div	3
Commanding Officer U. S. Naval Development Cntr. Johnsville, Pa.		1

ADDRESSEE	NAVY (Cont'd)	No. of copies
Officer-in-Charge U. S. Naval Supply Research & Development Facility Naval Supply Depot Bayonne, N. J.		1
Commanding Officer Naval Medical Fld Research Lab Camp Lejune, N. C.		1
Commander-in-Chief Pacific %Fleet Post Office San Francisco, Calif.		1
	AIR FORCE	
Assistant for Atomic Energy Hq, USAF Washington 25, D. C.		1
Deputy Chief of Staff Operations, Hq, USAF Washington 25, D. C.	ATTN: Operations Analysis	1
Deputy Chief of Staff Plans & Programs, Hq, USAF Washington 25, D. C.	ATTN: War Plans Division	1
Director of Research & Development DCS/D, HQ, USAF Washington 25, D. C.	ATTN: Guidance & Weapons Division	1
Asst Chief of Staff Intelligence, Hq USAF Washington 25, D. C.	ATTN: AFCIN-3B	2
The Surgeon General Hq USAF Washington 25, D. C.	ATTN: Bio Defense Branch, Prev. Med Division	1
Commander-in-Chief Strategic Air Command Offutt AFB, Nebr.	ATTN: OAWS	1
Commander Tactical Air Command Langley AFB, Va.	ATTN: Doc Sec Branch	1
Commander Air Defense Command Ent AFB, Colorado	ATTN: Atomic Div, ADLAN-A	1
Commander Air Material Command Wright-Patterson AFB, Ohio		2

ADDRESSEE	AIR FORCE (Cont'd)	No. of copies
Commander Air Research & Development Command Andrews AFB Washington 25, D. C.	ATTN: RDRWA	3
Commander Air Proving Ground Command Eglin AFB, Fla.	ATTN: PGTRIL	1
Director Air University Library Maxwell AFB, Alabama		2
Commander USAF School of Aviation Medicine Randolph AFB, Texas		2
Commander Wright Air Development Center Wright-Patterson AFB, Ohio	ATTN: WCOSI	1
Commander AF Cambridge Research Center L. G. Hanscom Fld, Bedford, Mass.	ATTN: CRQST-2	1
Commander AF Special Weapons Center Kirtland AFB, N. M.	ATTN: Tech Info Office	3
Commander 3415th Tech Training Wing Lowry AFB, Colorado	ATTN: Dept of Weapons Training	1
	OTHER DOD ACTIVITIES	
Director Weapons Systems Evaluation Group, OSD Room 1E880 The Pentagon Washington 25, D. C.		1
U. S. Documents Officer Office of the United States National Military Representative SHAPE, APO 55, New York, N. Y.		1
Director of Defense Research & Engineering Washington 25, D. C.	ATTN: Tech Library	1
Commandant Armed Forces Staff College Norfolk 11, Va.	ATTN: Secretary	1

ADDRESSEE	OTHER DOD ACTIVITIES (Cont'd)	No. of copies
Commander Field Command, DASA Sandia Base Albuquerque, N. M.		21
Chief Defense Atomic Support Agency Washington 25, D.C.		5
Commander ASTIA Arlington Hall Station Arlington 12, Va.	ATTN: TIPDR	15

OTHERS

Dr. Hermann E. Pearse University of Rochester Atomic Energy Project P.O. Box 287, Station 3 Rochester 20, New York	ATTN: Tech Report Control Unit	1
Sandia Corporation Sandia Base Albuquerque, New Mexico	ATTN: Classified Document Division	1
Los Alamos Scientific Lab P. O. Box 1663 Los Alamos, N. M.	ATTN: Report Librarian	1
Medical College of Virginia 12th & Broad Sts Box 222 Richmond 19, Va.	ATTN: Security Officer (For Dr. William T. Ham)	1
Director Lincoln Lab Massachusetts Institute of Technology P. O. Box 73 Lexington 73, Mass.	ATTN: Publications (For Prof. G. C. Williams)	1
Los Alamos Scientific Lab P. O. Box 1663 Los Alamos, N. M.	ATTN: Report Librarian (For Dr. Alvin C. Graves)	1
Prof. Hoyt C. Hottel Lincoln Lab Massachusetts Institute of Technology P. O. Box 73 Lexington 73, Mass.		1

3ND-P&PO-6592

Naval Material Laboratory. New York Naval Shipyard. Project 5046-16, Part 7.
BURNS UNDER A "HOT-WET" UNIFORM SPACED FROM SKIN FOR NUCLEAR PULSES OF THERMAL RADIATION, by G.P. de Lhery and others. Final Report. 12 May. 1959. 19 p. tables. (DASA-1148). UNCLASSIFIED

The burns to the skin of anesthetized rat skin were determined for the thermal radiation pulses of a carbon arc on a Hot-Wet uniform when spaced 5 mm from the skin. The radiant exposures to cause burns resulting in eschar were 14.7, 16.2, 16.3 and 19.7 cal/cm^2 for the thermal radiation pulses corresponding to 250, 1000, 2900, and 10,000 kiloton detonations, respectively. The threshold lesions were caused by volatile products not associated with ignition. The associated temperatures were recorded.

1. Thermal Radiation - Physiological Effects
2. Skin - Effects of radiation
I. de Lhery, G.P. and others
II. DASA-1148
III. S-F011-0513 (Formerly NS 081-00)

UNCLASSIFIED

Naval Material Laboratory. New York Naval Shipyard. Project 5046-16, Part 7.
BURNS UNDER A "HOT-WET" UNIFORM SPACED FROM SKIN FOR NUCLEAR PULSES OF THERMAL RADIATION, by G.P. de Lhery and others. Final Report. 12 May. 1959. 19 p. tables. (DASA-1148). UNCLASSIFIED

The burns to the skin of anesthetized rat skin were determined for the thermal radiation pulses of a carbon arc on a Hot-Wet uniform when spaced 5 mm from the skin. The radiant exposures to cause burns resulting in eschar were 14.7, 16.2, 16.3 and 19.7 cal/cm^2 for the thermal radiation pulses corresponding to 250, 1000, 2900, and 10,000 kiloton detonations, respectively. The threshold lesions were caused by volatile products not associated with ignition. The associated temperatures were recorded.

1. Thermal Radiation - Physiological Effects
2. Skin - Effects of radiation
I. de Lhery, G.P. and others
II. DASA-1148
III. S-F011-0513 (Formerly NS 081-00)

UNCLASSIFIED

Naval Material Laboratory. New York Naval Shipyard. Project 5046-16, Part 7.
BURNS UNDER A "HOT-WET" UNIFORM SPACED FROM SKIN FOR NUCLEAR PULSES OF THERMAL RADIATION, by G.P. de Lhery and others. Final Report. 12 May. 1959. 19 p. tables. (DASA-1148). UNCLASSIFIED

The burns to the skin of anesthetized rat skin were determined for the thermal radiation pulses of a carbon arc on a Hot-Wet uniform when spaced 5 mm from the skin. The radiant exposures to cause burns resulting in eschar were 14.7, 16.2, 16.3 and 19.7 cal/cm^2 for the thermal radiation pulses corresponding to 250, 1000, 2900, and 10,000 kiloton detonations, respectively. The threshold lesions were caused by volatile products not associated with ignition. The associated temperatures were recorded.

1. Thermal Radiation - Physiological Effects
2. Skin - Effects of radiation
I. de Lhery, G.P. and others
II. DASA-1148
III. S-F011-0513 (Formerly NS 081-00)

UNCLASSIFIED

Naval Material Laboratory. New York Naval Shipyard. Project 5046-16, Part 7.
BURNS UNDER A "HOT-WET" UNIFORM SPACED FROM SKIN FOR NUCLEAR PULSES OF THERMAL RADIATION, by G.P. de Lhery and others. Final Report. 12 May. 1959. 19 p. tables. (DASA-1148). UNCLASSIFIED

The burns to the skin of anesthetized rat skin were determined for the thermal radiation pulses of a carbon arc on a Hot-Wet uniform when spaced 5 mm from the skin. The radiant exposures to cause burns resulting in eschar were 14.7, 16.2, 16.3 and 19.7 cal/cm^2 for the thermal radiation pulses corresponding to 250, 1000, 2900, and 10,000 kiloton detonations, respectively. The threshold lesions were caused by volatile products not associated with ignition. The associated temperatures were recorded.

1. Thermal Radiation - Physiological Effects
2. Skin - Effects of radiation
I. de Lhery, G.P. and others
II. DASA-1148
III. S-F011-0513 (Formerly NS 081-00)

UNCLASSIFIED

REPORT ABSTRACT FORM
3ND-NYNS-900-95

Leave at least one space free in front of these four lines.