UNCLASSIFIED

| | |
|---|---|
| AD NUMBER: | AD0076914 |

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 22 Jul 1955. Other requests shall be referred to Defense Atomic Support Agency, Washington, DC 20301

AUTHORITY

USNML/NYNS ltr dtd 15 Aug 1966

THIS PAGE IS UNCLASSIFIED

# AD 76914

# UNCLASSIFIED

ND-PSPO-2481

UNCLASSIFIED

FC

# TECHNICAL REPORT

## MATERIAL LABORATORY

NEW YORK NAVAL SHIPYARD
BROOKLYN 1, NEW YORK

DEPARTMENT OF THE NAVY
BUREAU OF SHIPS

3ND-NYNS-900-P-1A

UNCLASSIFIED

# RESEARCH REPORT
# ON
# A REVIEW OF THE DEVELOPMENT OF A PLASTIC PHYSICAL SKIN SIMULANT FOR EVALUATING SUB-FABRIC FLASH BURNS

Lab. Project 5046-3, Part 84
Final Report
NS 081-001

22 July 1955

T.I.Monahan W.L.Derksen

Technical Objective AW-7
AFSWP-850

Optics and Nucleonics Branch
J.M. McGreevy, Head

Superintending Engineer
GEO. J. DASHEFSKY

The Director
CAPTAIN A. B. JONES, Jr., USN

MATERIAL LABORATORY
New York Naval Shipyard
Brooklyn 1, New York

UNCLASSIFIED

Lab. Project 5046-3, Part 84
Final Report

## SUMMARY

The Naval Material Laboratory has been engaged in the development of a physical skin simulant for evaluating flash burns behind fabric systems. Progress in this development as of 15 May 1955 is summarized in this report.

Prosecution of this project has included study in the following areas:

a. Measurement of some thermal and optical constants of skin, and computation of the skin temperatures associated with burns;

b. development of a thin-film coating to use with the black polyethylene or other skin simulant to approximate the constants of skin;

c. use of the coated polyethylene skin simulant to predict burn severities as compared to porcine skin when covered with various fabric systems;

d. development of the so-called ideal skin simulant having the thermal and optical characteristics of human skin;

e. feasibility of using passive indicators with a physical skin simulant.

## TABLE OF CONTENTS

FIGURES

TABLE OF CONTENTS (CONT'D)

TABLES

Lab. Project 5046-3, Part 84
Final Report

## ADMINISTRATIVE INFORMATION

1. The research reported herein was conducted as part of the program originally proposed by COMNAVSHIPYDNYK conf ltr S99/L5, Ser 960-92, of 15 March 1950 and formally approved by Bureau of Ships Restricted Speedletter S99-(0)(348), Ser 348-75, of 6 April 1950. The General Thermal Radiation program at the Naval Material Laboratory is sponsored by the Armed Forces Special Weapons Project.

2. This report covers essentially the material presented by the Naval Material Laboratory on 19 May 1955 at the 14th meeting of the Armed Forces Special Weapons Project Panel on Thermal Radiation and has been prepared in response to several requests for copies of the presentation. For detailed information, reference should be made to the more complete Laboratory project reports.

3. The research reported herein represents the combined efforts of several personnel, including R. Maggio, T. D. Murtha, A. Hirschman, T. B. Gilhooley, and L. Banet, whose services are gratefully acknowledged.

## INTRODUCTION

4. The purpose of developing a skin simulant is the study of flash burns behind fabrics in a physical laboratory and use in large-scale field tests where the use of animals might be undesirable from either an operational or statistical viewpoint. The basic requirements for a physical substitute for skin in studying sub-fabric burns are that its thermal and optical properties be comparable to those of average human skin and also that it be durable and easily manipulated. The question naturally arises as to how closely the properties of skin should be matched, since, obviously, a perfect match to all the properties of skin is impossible, and probably not necessary. Since tissue damage is related to the rise in temperature of the skin, it may be said that the physical properties of the skin simulant should approximate those of skin sufficiently so that the heat transfer mechanism and the influence of the backing on the cloth's reaction to radiation, including steaming, charring, ignition and formation of volatile products, be the same for the skin substitute as for skin.

## NML SKIN SIMULANT PROGRAM

5. The work carried on during the past year in the NML skin simulant studies may be grouped into five areas. First, the develop-

ment of a coating to use with the polyethylene for a better approximation to the optical constants of skin, and the use of this modified polyethylene skin simulant to predict burns in the pig for comparable exposures. Second, determination of the thermal and optical constants of skin and polyethylene under conditions encountered in the sub-fabric burns, and, using these values, computation of the skin temperatures associated with burns. Third, use of the polyethylene skin simulant in studies of the protection afforded by special fabrics. Fourth, feasibility studies of the use of passive indicators with plastic skin simulants. Fifth, the development of a plastic skin simulant with the thermal and optical constants of skin.

## POLYETHYLENE SKIN SIMULANT

6. In the early phases of the skin simulant development, little was known as to the exact values of skin's thermal constants (k c was quoted from 5 to $35 \times 10^{-4}$ c.g.s. units). The heat transfer mechanism, temperatures and radiant exposures involved in sub-fabric flash burns were not understood. Polyethylene had the highest k c of those substances which could be readily adapted to use as a skin simulant. Polyethylene was chosen for study of the quantitative nature of the factors involved in the sub-fabric burn, having in mind that when the skin constants became more definitely known or when some factor would arise indicating that polyethylene is inadequate to predict burns, a better substance would be employed.

7. The polyethylene skin simulant was employed for the study of the phenomenology associated with burns. At that time (June 1952) arrangements were made with the University of Rochester to obtain pig burn data under standardized conditions. The first factor studied was the thermocouple placement, the only requirement at that time was that its temperature rise be the same under identical exposure conditions. A #30 iron-constantan thermocouple was embedded in the surface. The temperature indicated, however, is not that of the surface, but that of the polyethylene at a depth of 0.023 cm. At this point the control necessary on degree of contact pressure and on spacing tolerance between cloth and backing was determined. The effects of pressure and spacing were studied as well as exposure area, rate of energy delivery and fabric moisture content. From the pig burn data a family of polyethylene temperature histories associated with the various burn levels was determined. These studies allowed the selection of representative and reproducible flash burn situations from the pig burn data that was soon available. This family is described

and discussed in the NML report on the polyethylene skin simulant. As shown in Fig. 1, the temperature histories associated with a 2+ burn range from a sharp temperature rise as high as 100°C of relatively short duration to 50°C or lower, maintained for several seconds. Figure 1 refers to the bare pig, uncovered polethylene situation, whereas Figures 2, 3, 4 depict the clothed-pig, covered-polyethylene situation. These figures demonstrate the similarity of the several temperature histories for diverse exposure situations.

## THEORETICAL CONSIDERATIONS

8. Figures 5 through 8 depict several mathematical analogs of interest in the skin simulant study. Figure 5 represents the opaque semi-infinite solid which is applicable to a blackened substance; Fig. 6 represents the opaque finite medium which approximates the situation of an irradiated cloth. Figures 7 and 8 represent, respectively, the diathermous semi-infinite medium and an opaque medium over an opaque semi-infinite medium. The equations given in these figures must be used with care in computing the temperatures associated with burns since many of the important constants are inadequately known for the flash-burn situation. It is also to be noted that all substances are diathermous to a degree and that the opaque-solid solution is always an approximation.

9. Firm thermal contact between an irradiated fabric assembly and a backing is not always easy to achieve experimentally. The University of Rochester "contact" or "zero separation" situation used in sub-fabric burn studies has been shown to produce temperatures 25 per cent lower than those obtained for firm contact achieved by applying tension to the cloth. The effect of pig stubble on the "contact" situation temperatures is difficult to compute.

10. The usefulness of theory is unquestioned in obtaining constants from experimental results and in determining approximate temperature values and the relative effect of the various parameters.

## COATED POLYETHYLENE SKIN SIMULANT

11. A coating was developed to compensate for the differences in absorptance and in diathermancy between skin and black polyethylene.[2] The coating is a white Saran paint with titanium oxide pigment. It is sufficiently thin (0.005 cm) to be thermally insignificant when used in sub-fabric burn studies. As shown in Figure 9, the spectral reflectance of the coating is similar to

that of skin so that the modified polyethylene could be used, if desired, to evaluate burns for most of the sources employed in these studies.

## PREDICTION OF SKIN BURNS

12. The method employed to interpret the temperature histories of the polyethylene skin simulant in terms of the corresponding burns to pigs has been empirical; namely, exposing the skin simulant to situations known to result in a particular burn severity to pig skin, and using the resulting temperature history as a criterion. This method is elaborated in the NML polyethylene report;[1] typical critical temperature histories are given in Figures 2, 3 and 4. The usefulness of the method was demonstrated at NML in a study of the so-called Gray series. Burns behind a set of gray cotton sateens with different absorptances had been evaluated at Rochester. The same cloths were exposed at NML without reference to the Rochester results. The temperature histories of the polyethylene skin simulant were determined for various irradiances and times of exposure. From the temperature histories obtained and from the corresponding "critical" temperature histories known from the previous studies to result in pig burns, it was possible to determine which temperature histories would result in pig burns. It was then possible to assign a critical radiant exposure for each time of exposure. These data are shown in Table 1. Data are included for both zero and 5 mm spacing, for low and high irradiances, for opaque and transmitting cloths. The agreement between the two sets of data is very good for the 5-mm spacing situation. The data for zero separation do not correlate as well, probably due to the difficulties encountered in obtaining a contact burn in the pig because of his stubble. In this experiment it was noted that differences in air supply and in depth of aperture may cause differences in temperature histories as large as 100 per cent. This experiment parallels that at Rochester,[3] except for the significant facts that the absorptance of the skin simulant was modified and that burns are predicted on the basis of temperature history rather than temperature maximum. The transmission of the fabrics varies from 15 per cent for the white to zero for the darker shades; the use of the Saran paint film over the black polyethylene resulted in differences in predicting the radiant exposure for 2+ burns as large as 30 per cent for the situation in which the cloth is in contact with the backing and as large 100 per cent for the situation in which the cloth and backing are separated by air.

## OPTICAL CONSTANTS OF SKIN

13. The spectral reflectance of human skin was determined for four subjects with the NML Recording Reflectometer.[4,5] The spectral absorptance, which is defined as "one minus the reflectance", is shown in Figure 10, together with the spectra of three sources which are of interest in the skin simulant studies. The curve is the average for four areas (forearm, back of arm, palm, and forehead) of four individuals, a fair Caucasian, a ruddy Caucasian, and two medium Negroes. The average total absorptance for carbon-arc radiation, for all four areas for all four individuals is 0.72, within ± 5 per cent. There was no appreciable difference in this value for 3000°K and 6000°K Planckian radiation.

## THERMAL CONSTANTS OF SKIN, SKIN TEMPERATURES

14. The surface temperatures of several individuals were measured upon exposure to intense thermal radiation at levels equal to or below that corresponding to pain in the subject.[6] From the measurements on blackened skin, k c was determined to be $8.6x10^{-4}$, which value holds for exposures from 20 seconds down to 0.2 second. This value corresponds closely to that [7] of Hardy, $9x10^{-4}$, which was obtained for longer exposures than those used in the NML studies. The primary objective of this experiment, the validity of this method for determining the k c of skin simulant plastics, was considered to have been established.

15. The temperatures of unmodified human skin for carbon-arc irradiation are shown in Figure 11. It is to be noted that for exposures longer than 1 second the surface temperatures may be approximated by opaque-solid theory and an artificial absorptance of 0.5, and more realistically from a physical viewpoint by diathermous-solid theory, using the spectrophotometrically determined absorptance of 0.72 and a of 30 per cm. The best fit over the entire range of times investigated is given by assuming that the incident carbon-arc radiation has two components, one with an extinction coefficient of 5 per cm over the spectral region from 0.55 to 1.35 microns in which 28 per cent of the total incident radiation is absorbed, and the other, opaque ( $=\infty$ ) for ultraviolet and visible radiation below 0.55 micron and for infrared radiation beyond 1.35 microns, in which regions 44 per cent of the total incident energy is absorbed.

16. In order to check and extend the temperature criteria which have been determined empirically and in order to evaluate other criteria for predicting burn severities, the temperatures of skin for situations resulting in burns have been computed, using the thermal and optical constants as determined at NML. First, using opaque solid theory and the artificial absorptance, the maximum temperature rise was determined as a function of exposure time for several depths up to 2 mm, and for exposures which will cause a 2+ burn in pig skin. The data are presented in two forms in Figures 12 and 13. The general pattern one would expect is shown here, where for short times, contrasted to the longer exposure times, 2+ mild burns involve high temperature rises at the surface and low temperature rises at the greater depths. The temperature-depth profile in Figure 13 shows the approximate depth of heat penetration for various exposures and a depth (0.05 cm) at which the maximum temperature rise, on the basis of these assumptions, is independent of the time of exposure.

17. The more realistic, but more complex, computation involves the use of an absorptance which varies with the exposure time to compensate for the diathermancy value which must be used in order to explain the temperatures of the surface as measured. Using opaque solid theory, the temperature-depth-time profiles have been determined, as shown in Figures 14 and 15. For the shorter exposures the temperatures are higher, and at a depth of approximately 0.04 cm the temperature rise is the same for all exposure times. Computations, using diathermous-solid theory, are incomplete, but they should give a more realistic picture.

## SELF-RECORDING SKIN SIMULANT

18. Because field use of a self-recording skin simulant would eliminate complex and costly instrumentation, some attention has been given to studying the feasibility of such a system. The best system to date employs temperature-sensitive papers. The papers are set into the skin simulant perpendicularly to the surface. The papers do not alter the heat flow in the skin simulant, since most of the heat flow is parallel to the plane of the paper. Several papers of different temperature sensitivities are employed and a temperature maximum versus depth profile is the measured quantity. The wax on the paper will melt at the surface of the polyethylene and at all depths for which the temperature exceeds the critical value of the paper. Rectangular pulses known to result in various burn severities were applied to a dark gray cotton sateen behind which the self-recording polyethylene skin simulant was mounted with zero separation behind the cloth. The expo-

sure conditions employed in this series were obtained by consideration of the University of Rochester data on pig burns behind cloth. With minor modifications, they represent ED$_{50}$ dosages for the 1+ severe and 2+ severe burn levels, respectively, for various exposure times on pigs clothed in the identical manner. In Figures 16, 17, and 18, the temperature indicated by specific papers is plotted as a function of the depth beneath the surface for which the temperature exceeded the critical value. Figures 16, 17, and 18 represent exposures of less than 1 second, approximately 5 seconds, and approximately 10 seconds, respectively. The critical temperatures for the papers are those assigned for them by the Quartermaster Corps and by the University of Dayton, and are believed to be reasonably accurate. Examination of the data given in these three figures indicates that a 2+ severe burn can be distinguished readily from a 1+ severe burn, and that the method has value. Considerable additional work must be done in this field; NML proposes to continue this work and would welcome any suggestions which would aid in the further development of a self-recording skin simulant.

## IDEAL SKIN SIMULANT

19. It was feasible to proceed with a skin simulant matching the thermal and optical constants of skin with the publication[7] of Hardy's data for $k\rho c$ and with the development of a valid method of determining thermal constants of plastics from surface temperatures. The criterion for the ideal skin simulant is that its constants should match the thermal characteristics of skin, i.e., $k\rho c = 9 \times 10^{-4}$ and $\rho c = 0.8$. Emphasis is placed on its use as a sub-fabric burn indicator, for which both $k\rho c$ and $k/\rho c$ are important, but consideration would also be given to the bare or uncovered situation. For this reason, the optical match to skin is considered to be of secondary importance. A synthetic optical match is readily possible, as demonstrated in the case of polyethylene. A full optical match is also possible.

20. The general program involves the selection of a plastic having approximately the proper thermal constants and mixing into it various amounts of an inorganic powder such as copper or quartz, until a match of the thermal constants of skin is achieved. Several base plastics have been investigated so that the one with the best physical properties could be chosen. The variation of $k\rho c$ with composition for a given molding cycle for 20 gram specimens cast in $1\frac{1}{2}$-inch diameter discs is shown in Fig. 19. The $k\rho c$ product was determined by surface temperature

measurements with the fine-wire thermocouple. One might conclude that the desired $k\rho c$ is readily achieved, provided the correct ratio of filler powder to resin is employed. These data are based on measurements on the first samples, which were made with a single pressure and temperature molding cycle on a press which had limited application. A new molding press was received in February which allowed a variety of sample sizes and a variable molding cycle which would give better control over air pockets and other molding faults. On the other hand, it was discovered recently that the particular molding cycle may change the $k\rho c$ product for some of the skin simulants and most likely, the simulant's thermal diffusivity ($k/\rho c$). The various mixes which give a $k\rho c$ of approximately $8.6\times10^{-4}$ are tabulated in Table 2, together with the densities which were determined experimentally, the specific heats which were calculated by the method of mixtures from handbook data, and the resulting computed $\rho c$'s and $k/\rho c$'s. Again, it should be noted that these data hold for a given molding cycle for 20 - gram specimens cast in 1½-inch diameter discs. It may also be noted that the use of copper powder results in an essentially opaque substance, whereas the use of quartz powder results in an essentially diathermous substance. For this reason, NML at the present time prefers the Beetle-quartz combination.

21. As projected by AFSWP, NML is to prepare a series of skin simulants for distribution to the various laboratories engaged in this field for their evaluation and study. Inasmuch as the handbook values for the constants are not necessarily appropriate when the material is in powder form, and since these constants are affected by the particular molding cycle, NML believes that distribution of the skin simulants should be postponed until reproducible homogeneous units can be prepared, having thermal and optical constants documented by direct experimentation. Calorimetric equipment for measuring specific heats is on order and should be delivered in one or two weeks. Earlier distribution of the skin is possible, but, because of nonuniformity of the material, may lead only to eventual confusion as to the actual merits of the skin simulant.

## FUTURE PLANS

22. The immediate task with highest priority at NML is the processing and distribution of the skin simulants. In addition to documenting the thermal constants of the units, NML will perform the following test of adequacy, as agreed at the December meeting at Technical Operations. The skin simulant and human skin will

be subjected to identical thermal pulses, when covered with an opaque clothing assembly. Surface temperatures will be measured. If the surface temperature histories for the skin and skin simulant are the same for this and for cloth conditions involving other modes of heat transfer, then the skin simulant is probably adequate. The subsequent phases, in which the other laboratories will cooperate, involve measurements at a depth specified by the skin simulant's constants; if the temperatures are the same for the skin simulant and for porcine and rat skin, then it is safe to conclude that the skin simulant is valid for studying sub-fabric burns.

23. When the validity of the ideal skin simulant is established, a series of temperature histories of the skin simulant will have been obtained for specific exposure situations which result in burns to skin. It will then be necessary to develop a general burn criterion. For this purpose, the reaction rate integral proposed by Henriques may be a suitable empirical tool. Secondly, experiment may bear out the calculations which indicate that at a certain depth the temperature will rise to a maximum value which is the same for all times of exposure. The work at NML in this direction will be pursued, applying diathermous-solid theory to the problem at hand. Thirdly, the characteristics of the temperature histories may be such that a general relationship may be drawn, correlating the temperature histories in the immediate vicinity of the temperature maximum. This possibility will be examined.

24. When these phases of the skin simulant program are completed, NML will then turn its attention to the basic studies of the sub-fabric flash burn. In the interim, in its Laboratory Services Testing Program, NML will employ the polyethylene skin simulant as required to determine the heat transfer characteristics of fabric systems.

Approved:

W. E. Jeremiah
for A. B. JONES, JR., CAPTAIN, USN
The Director

ml

## BIBLIOGRAPHY

1. Naval Material Laboratory, New York Naval Shipyard. Use of Polyethylene as a Physical Measuring System for Evaluating Physiological Burns Behind Fabrics. Laboratory Project 5046-3, Part 42 (December, 1954). Unclassified

2. Naval Material Laboratory, New York Naval Shipyard. A Method to Improve the Optical Characteristics of the Black Polyethylene Skin Simulant. Laboratory Project 5046-3, Part 78. (March, 1955). Unclassified

3. Atomic Energy Project, University of Rochester. An Evaluation of Black Polyethylene as a Skin Simulant Under Fabrics Exposed to Thermal Radiant Energy. Report UR-353(September, 1954). Unclassified.

4. Naval Material Laboratory, New York Naval Shipyard. Reflectance and Absorptance of Human Skin. Laboratory Project 5046-3, Part 54 (March, 1955). Unclassifed.

5. Naval Material Laboratory, New York Naval Shipyard. Automatic Recording Reflectometer for Measuring Diffuse Reflectance in the Visible and Infrared Regions. Laboratory Project 5466 (March, 1955). Unclassified.

6. Naval Material Laboratory, New York Naval Shipyard. The Thermal Conductivity and Diathermancy of Human Skin. Laboratory Project 5046-3, Part 81 (June, 1955). Unclassified.

7. Aviation Medical Acceleration Laboratory, Naval Air Development Center. Measurement of Some Thermal Properties of Human Tissues. Report No. NADC-MA-5405 (April, 1954) Unclassified.

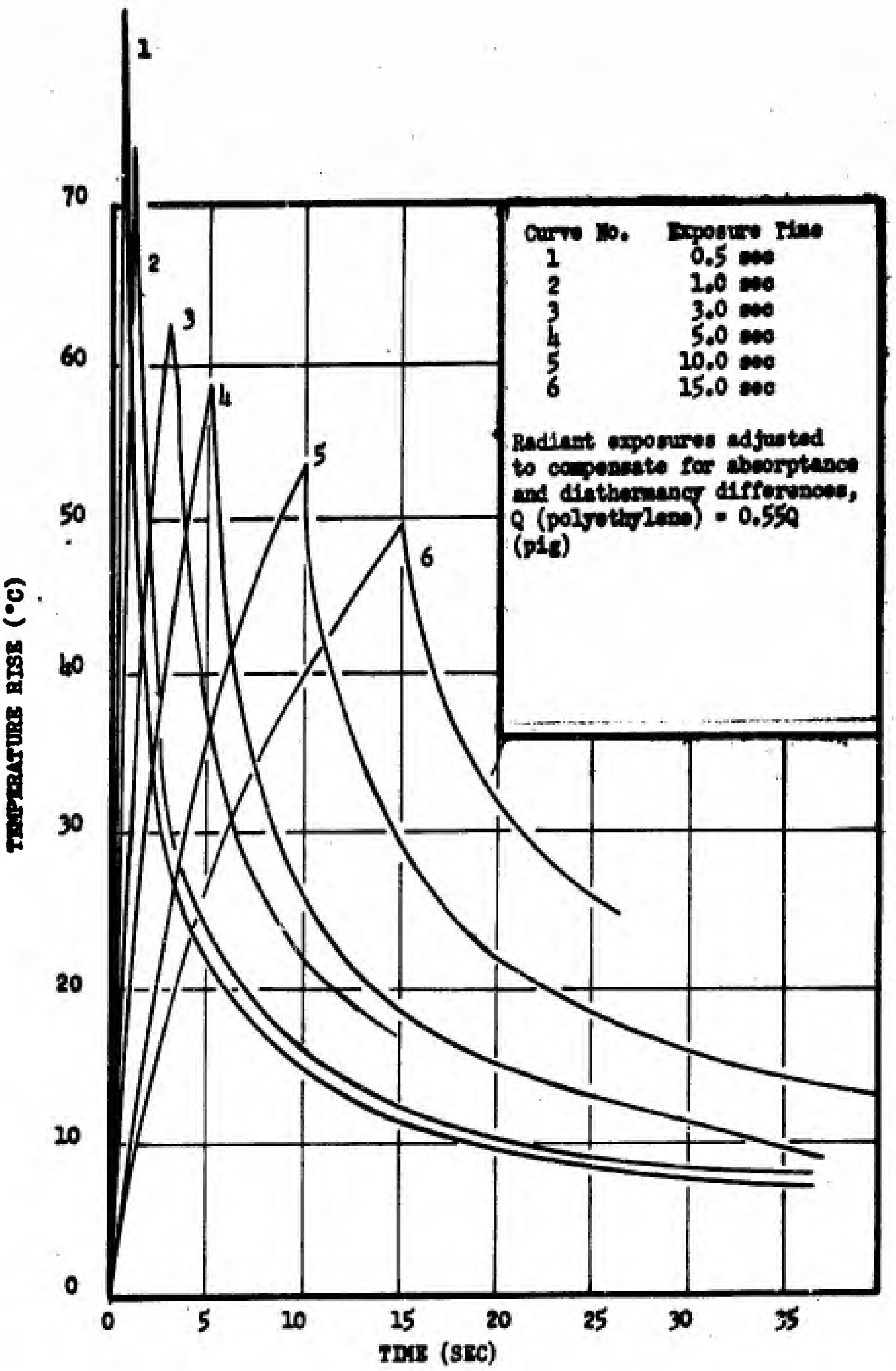
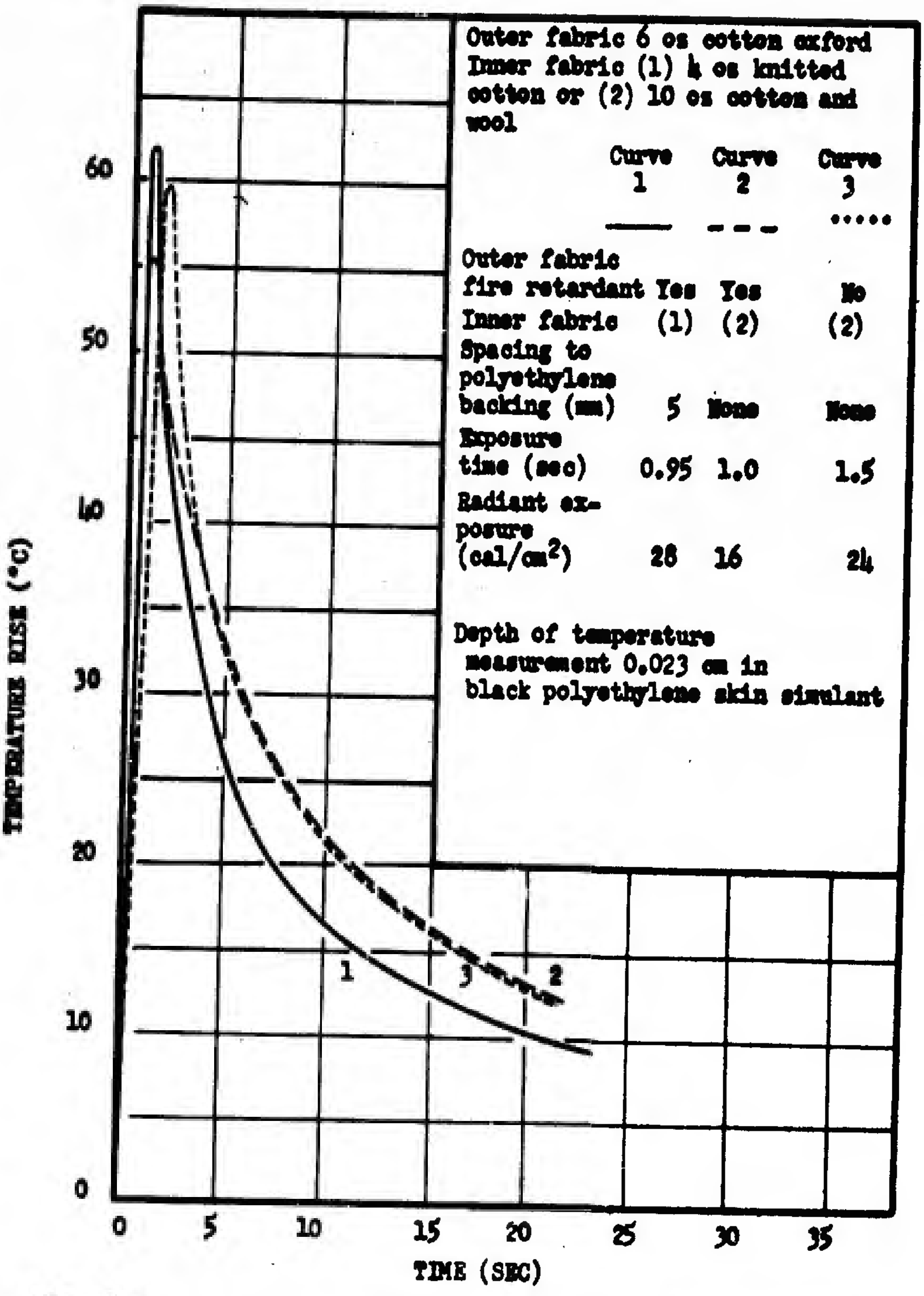


Fig. 1 - Temperature Histories of the Uncovered Black Polyethylene Skin Simulant, Corresponding to a 2+ Mild Burn in Pig Skin, for Several Exposure Times



Outer fabric 6 oz cotton oxford
Inner fabric (1) 4 oz knitted cotton or (2) 10 oz cotton and wool

| | Curve 1<br>——— | Curve 2<br>- - - | Curve 3<br>••••• |
|---|---|---|---|
| Outer fabric fire retardant | Yes | Yes | No |
| Inner fabric | (1) | (2) | (2) |
| Spacing to polyethylene backing (mm) | 5 | None | None |
| Exposure time (sec) | 0.95 | 1.0 | 1.5 |
| Radiant exposure (cal/cm²) | 28 | 16 | 24 |

Depth of temperature measurement 0.023 cm in black polyethylene skin simulant

**Fig. 2 -** Temperature Histories of Covered Polyethylene Corresponding to a 2+ Mild Burn in Pig Skin; Typical Clothing Assemblies

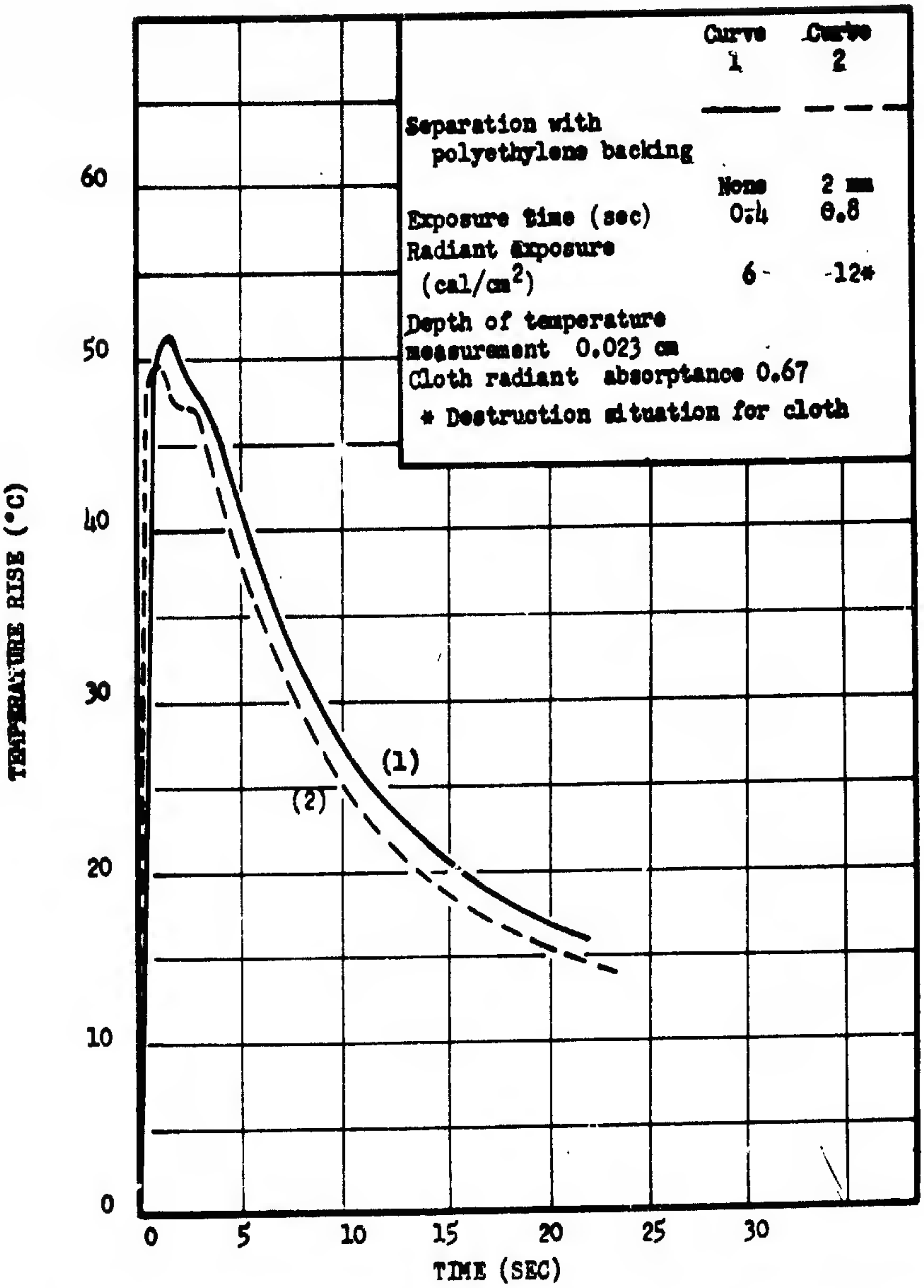


Fig. 3 - Temperature Histories of Covered Polyethylene Corresponding to a 2+ Mild Burn in Pig Skin; Single Layer of OG Cotton Sateen

Exposure time, 6.4 sec
Radiant exposure, 9.5 cal/cm$^2$
No separation with polyethylene
or between cloths
Depth of temperature measurement, 0.023 cm
Cloth radiant absorptance, 0.67

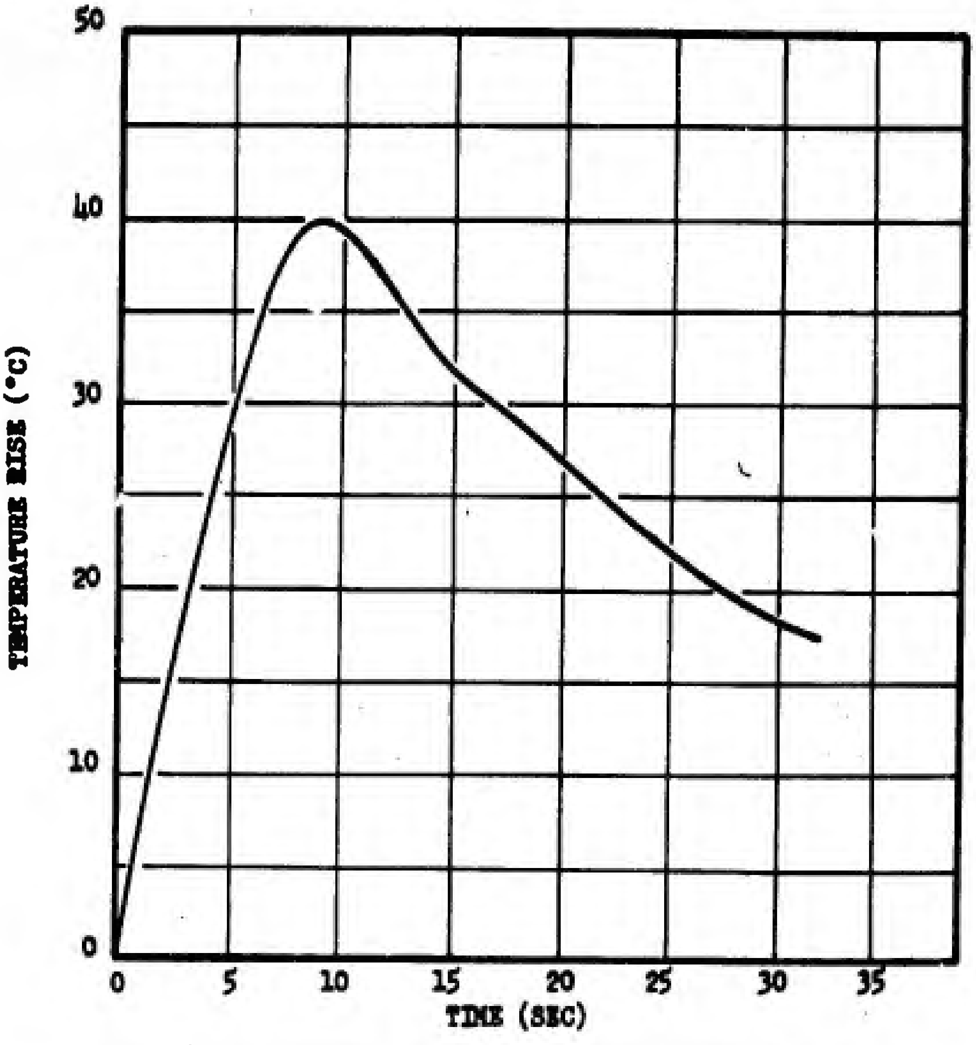
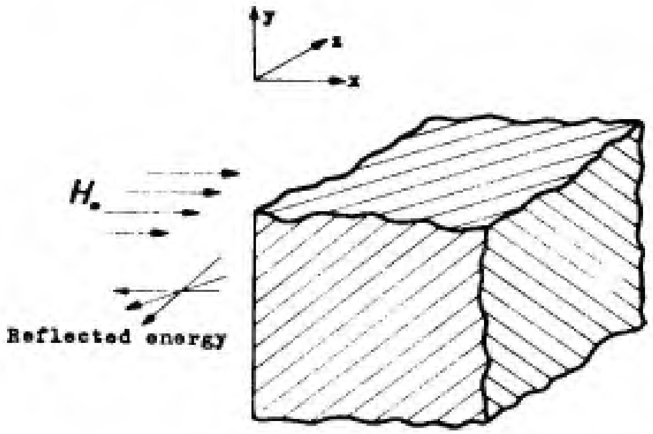


Fig. 4 - Temperature History of Covered Polyethylene Corresponding to a 2+ Mild Burn in Pig Skin; Two Layers of OG Cotton Sateen

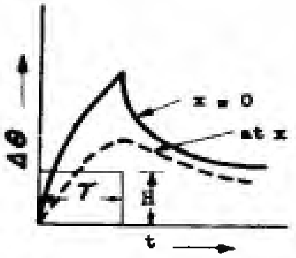


At the surface (x = 0)

$$\Delta\theta = \frac{2AHt^{1/2}}{\sqrt{\pi K \rho c}}, \text{ and}$$

$$\Delta\theta_{max} = \frac{2AH\tau^{1/2}}{\sqrt{\pi K \rho c}}, \text{ or}$$

$$\Delta\theta_{max} = \frac{2AQ}{\sqrt{\pi K \rho c \tau}}$$



At depth X

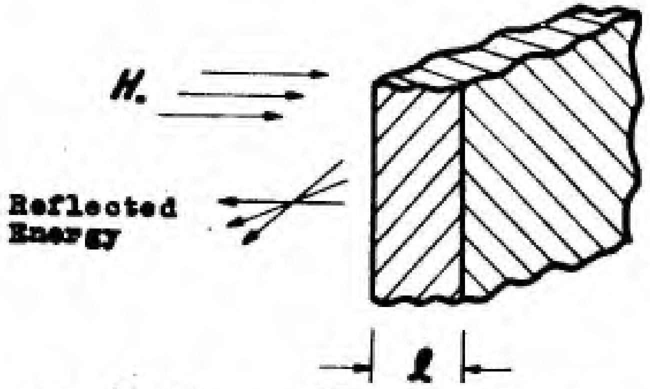
$$\Delta\theta = \frac{2AHt^{1/2}}{\sqrt{\pi K \rho c}}\left[e^{-x^2/4ht} - \frac{\sqrt{\pi}\,x}{2\sqrt{ht}}\,\mathrm{erfc}\left(x/\sqrt{4ht}\right)\right]$$

| | | | |
|---|---|---|---|
| $\theta$ | Temperature rise (°C) | K | Conductivity (cal/sec cm °C) |
| A | Radiant Absorptance | $\rho$ | Density (gms/cm$^3$) |
| H | Irradiance (cal/cm$^2$sec) | c | Specific heat (cal/gm °C) |
| t | Time of reference (sec) | h | Thermal diffusivity $K/\rho c$ |
| $\tau$ | Time of exposure (sec) | Q | Radiant Exposure (cal/cm$^2$) |

$$\mathrm{erfc}\left(x/\sqrt{4ht}\right) = 1 - \frac{2}{\sqrt{\pi}}\int_0^{x/\sqrt{4ht}} e^{-v^2}\,dv$$

Reradiation and convection losses not included in derivation

Fig. 5 - Semi-Infinite Opaque Solid Representing An Opaque Skin Or Skin Simulant



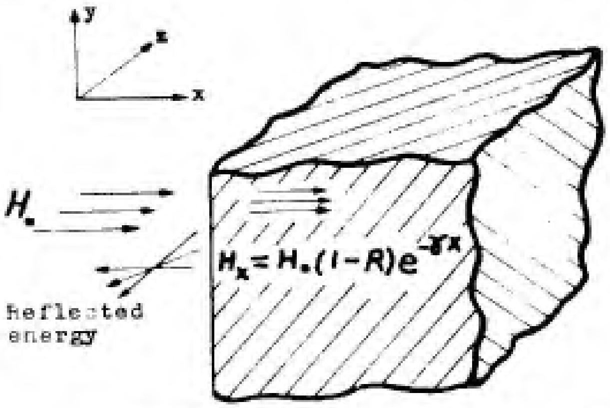
$$\Delta\theta = \frac{2AHt^{1/2}}{\sqrt{\pi K\rho c}}\left[1 + 2\sum_{n=0}^{\infty} e^{-(2nz)^2} - 2\sqrt{\pi}\, nz \operatorname{erfc}(2nz)\right]$$

| | | | |
|---|---|---|---|
| $\theta$ | Temperature rise (°C) | K | Conductivity (cal/sec cm °C) |
| A | Radiant Absorptance | $\rho$ | Density ($gms/cm^3$) |
| H | Irradiance ($cal/cm^2 sec$) | c | Specific heat (cal/gm °C) |
| t | Time of reference (sec) | h | Thermal diffusivity $K/\rho c$ |
| $\ell$ | Thickness (cm) | | |

Reradiation and convection losses not included in derivation

Useful for short exposure times and low conductivities as in the case of fabrics

Fig. 6 - Temperature Rise Of The Irradiated Face Of A Finite Opaque Solid



Temperature rise of diathermous semi-infinite solid

$$\Delta\theta = \frac{(1-R)H}{K}\left\{2\left(\frac{ht}{\pi}\right)^{1/2} e^{-x^2/4ht} - x\,\mathrm{erfc}\left(\frac{x}{\sqrt{4ht}}\right) + \frac{e^{\gamma^2 ht}}{2\gamma}\left[e^{-\gamma x}\,\mathrm{erfc}\left(\gamma\sqrt{ht} - \frac{x}{\sqrt{4ht}}\right) + e^{\gamma x}\,\mathrm{erfc}\left(\gamma\sqrt{ht} + \frac{x}{\sqrt{4ht}}\right)\right] - \frac{e^{-\gamma x}}{\gamma}\right\},$$

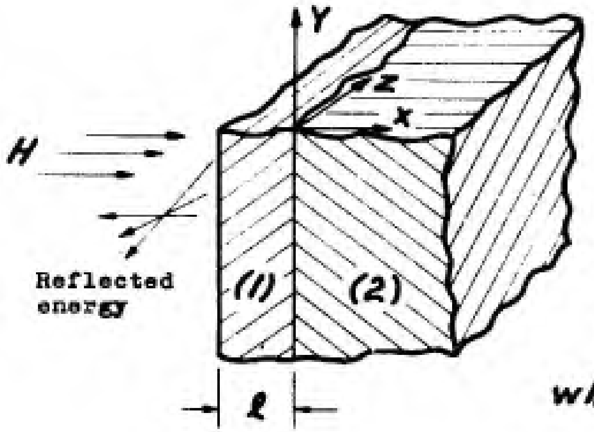
Temperature rise at the surface of a diathermous semi-infinite solid

$$\Delta\theta = \frac{(1-R)H}{K}\left\{2\left(\frac{ht}{\pi}\right)^{1/2} + \frac{e^{\gamma^2 ht}}{\gamma}\,\mathrm{erfc}\ \gamma\sqrt{ht} - \frac{1}{\gamma}\right\}$$

| | | | |
|---|---|---|---|
| $\theta$ | Temperature rise (°C) | K | Conductivity (cal/sec cm °C) |
| R | Radiant Reflectance | $\rho$ | Density (gms/cm$^3$) |
| H | Irradiance (cal/cm$^2$sec) | c | Specific heat (cal/gm °C) |
| t | Time of reference (sec) | $\gamma$ | Extinction Coefficient (cm$^{-1}$) |
| $h$ | Time of exposure (sec) | | |

Reradiation and convection losses not included in derivation

Fig. 7 - Semi-Infinite Diathermous Solid Representing Skin Or Skin Simulant Which Absorbs Radiant Energy In Depth



$$\Delta\theta = \frac{2AHt}{\sqrt{\pi K_1 \rho_1 C_1}} \left(\frac{1}{1+\sigma}\right) \sum_{n=0}^{\infty} a^n \left[ e^{-z^2} - \sqrt{\pi}\, z \operatorname{erfc} z \right],$$ where

$$\sigma = \sqrt{\frac{K_2 \rho_2 C_2}{K_1 \rho_1 C_1}}, \quad a = \frac{1-\sigma}{1+\sigma} \quad \text{and} \quad Z = \frac{(2n+1)\ell}{2\sqrt{h t}}$$

$$\text{where } X = 0; \text{ or } Z = \frac{(2n+1)\ell + x\sqrt{h_1/h_2}}{2\sqrt{h_1 t}}, \text{ at depth } X$$

| | | | |
|---|---|---|---|
| $\theta$ | Temperature rise (°C) | K | Conductivity (cal/sec cm °C) |
| A | Radiant Absorptance | $\rho$ | Density (gms/cm$^3$) |
| H | Irradiance (cal/cm$^2$ sec) | c | Specific heat (cal/gm °C) |
| t | Time of reference (sec) | $\ell$ | Cloth thickness (cm) |
| $h$ | Time of exposure (sec) | | |

$$\operatorname{erfc} z = 1 - \frac{2}{\sqrt{\pi}} \int_0^z e^{-v^2}\, dv$$

Reradiation and convection losses not included in derivation

Fig. 8 - Finite Opaque Medium In Perfect Thermal Contact With A Semi-Infinite Medium, Representing A Cloth-Covered Skin Or Skin Simulant

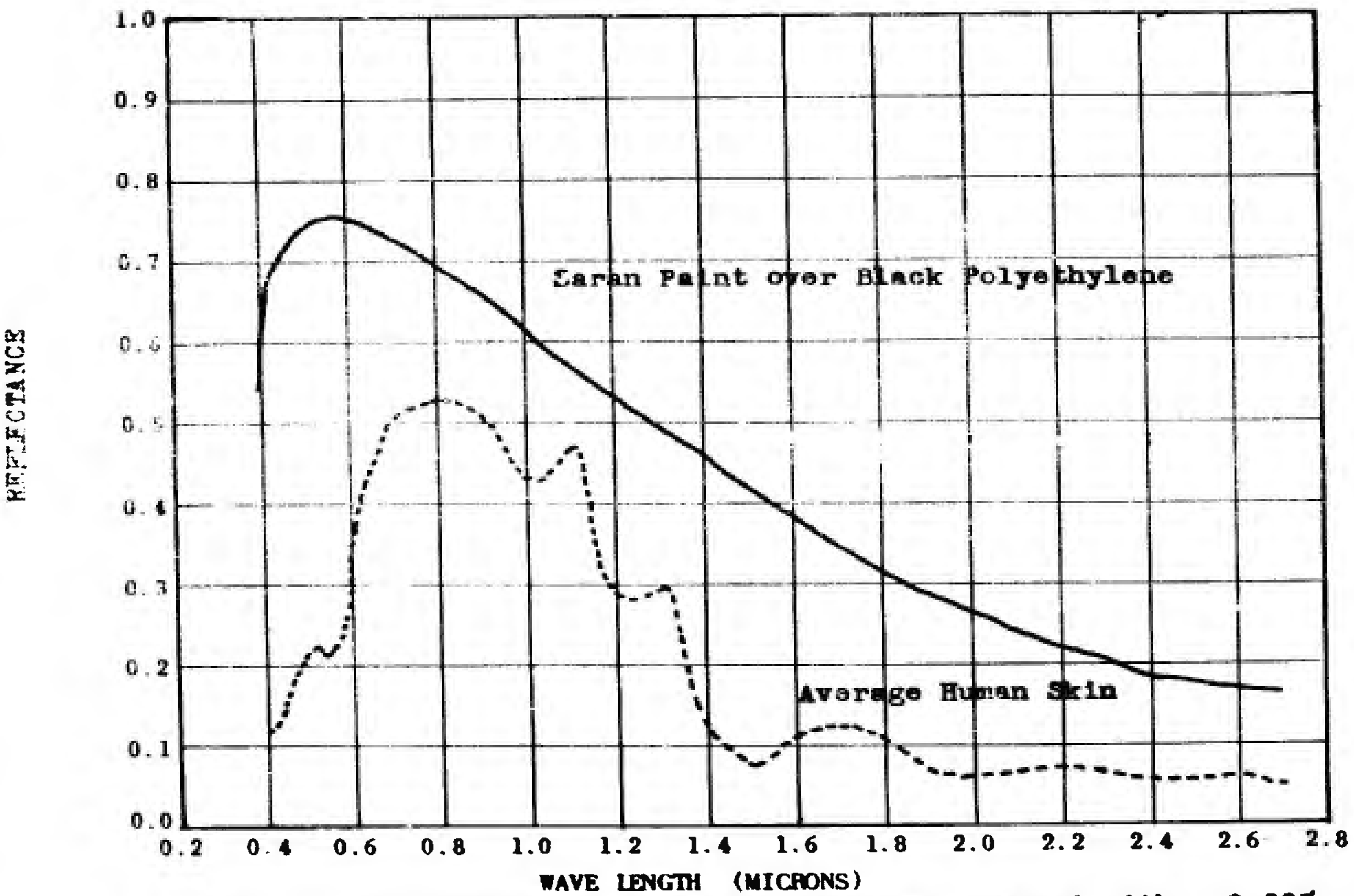


Fig. 9. Reflectance of Black Polyethylene Covered with a 0.005 cm Film of Saran Paint and the Average Reflectance of Human Skin

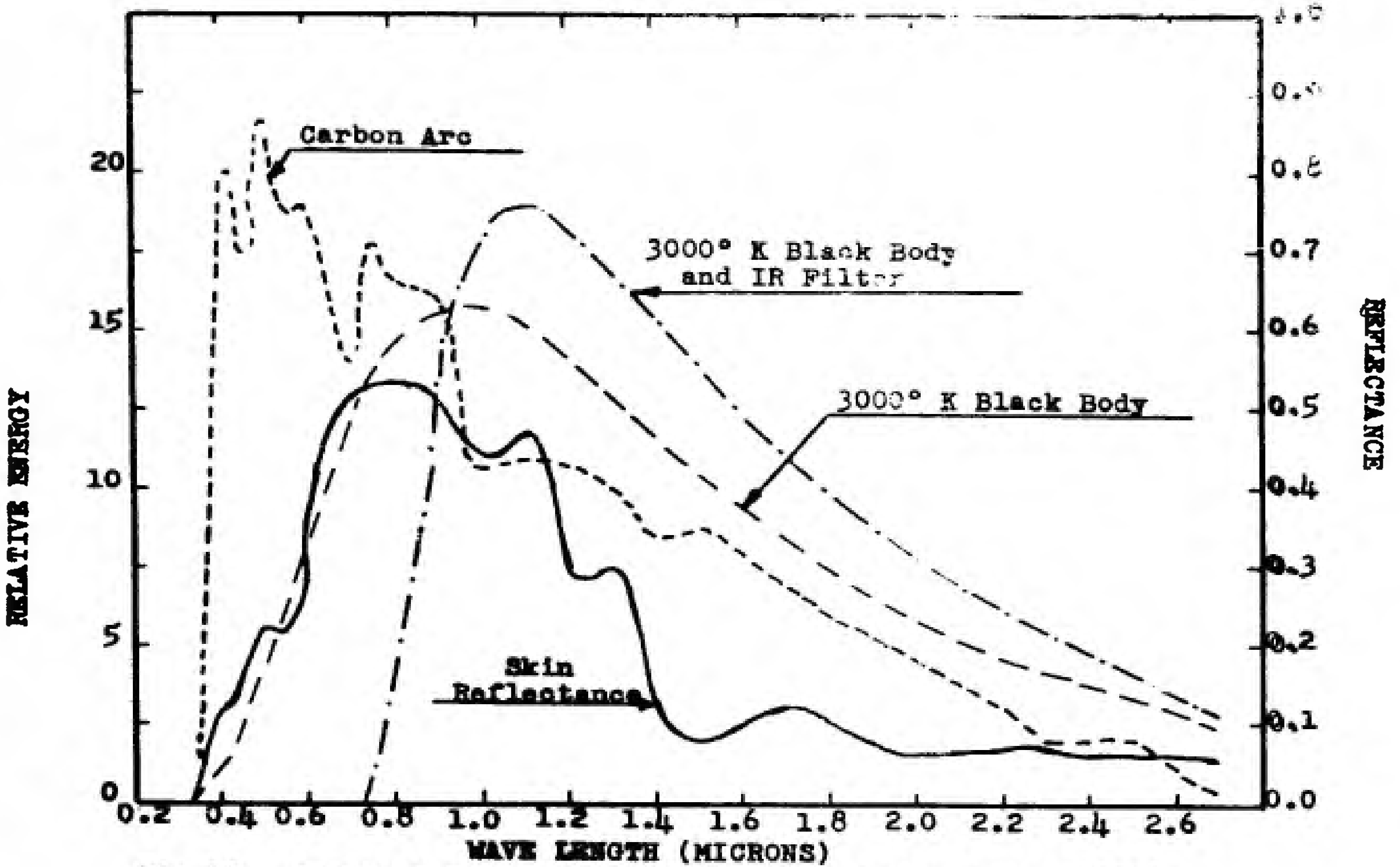


Fig.10 - Spectral Energy Distribution of Carbon -arc, 3000°K Planckian Radiation (Unfiltered and Filtered to Pass Only Infrared Radiation), and the Average Reflectance of Human Skin

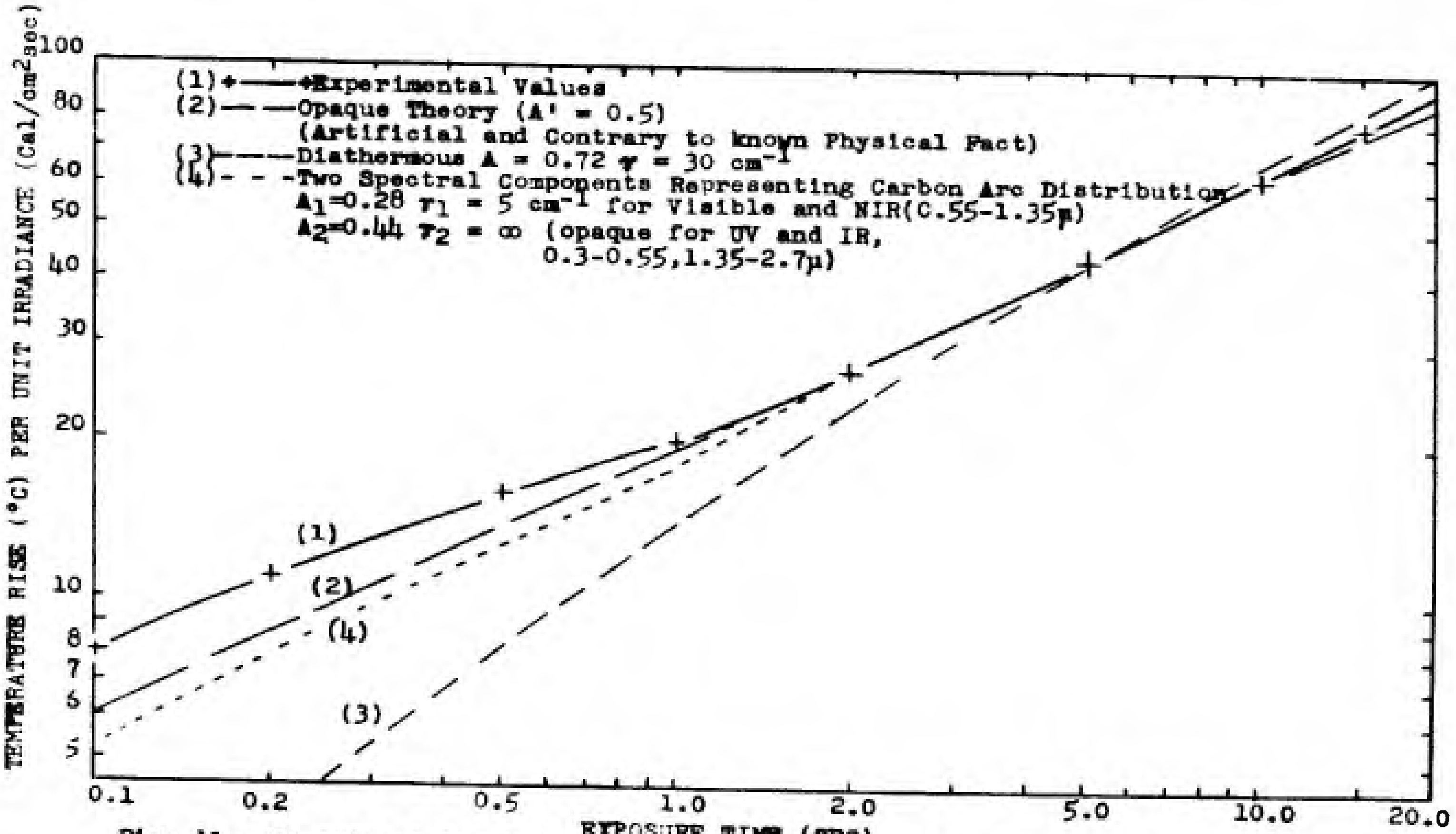


Fig. 11 - Experimental and Calculated Human Skin Surface Temperature Rises for Carbon-arc Radiation

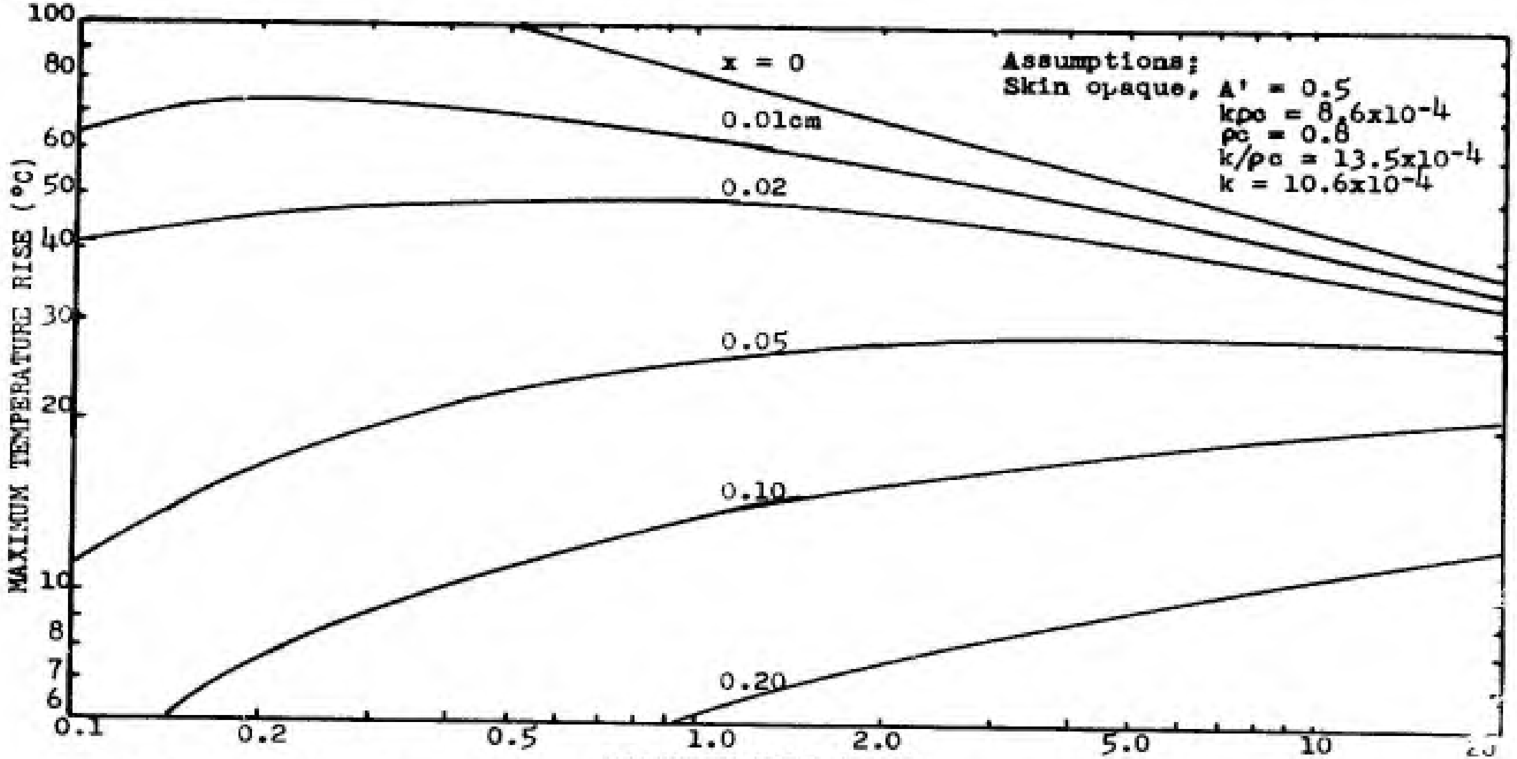


Fig.12 - Maximum Temperature Rise Computed for Human Skin for Radiant Exposures Resulting in 2 + Mild Burns in Pig Skin

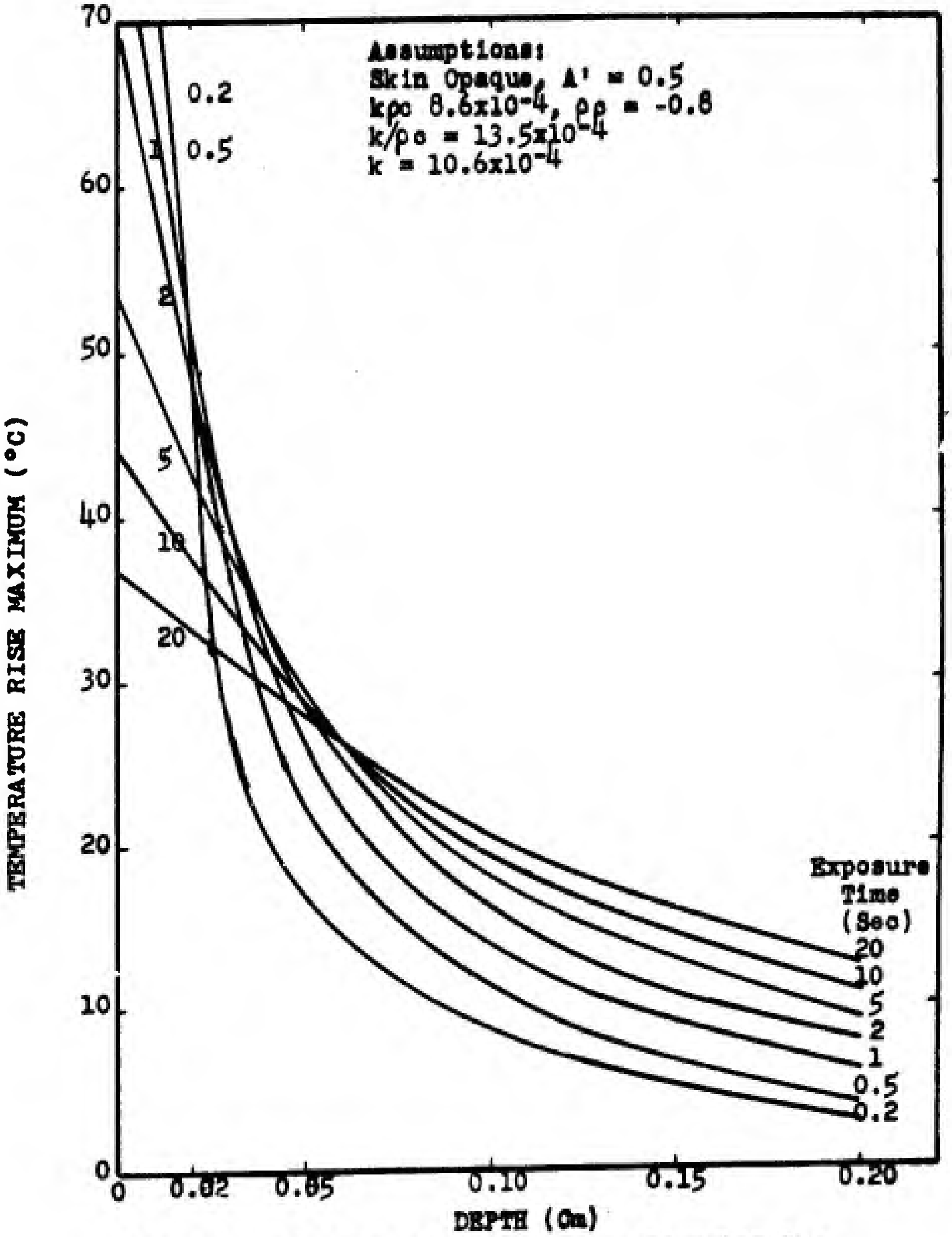
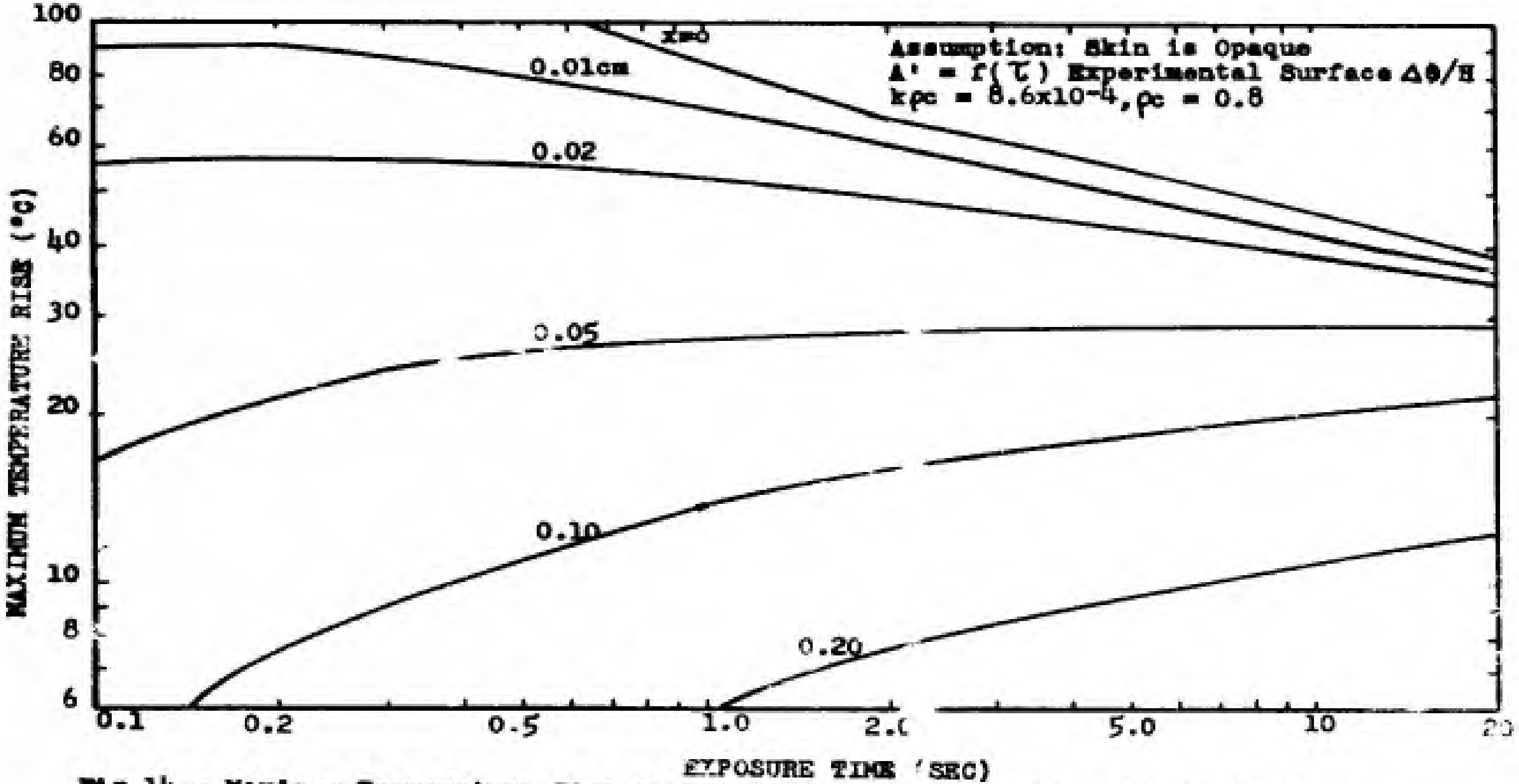


Fig. 13 - Maximum Temperature Rise Computed for Human Skin for Radiant Exposures for 2 + Mild Burn in Pig Skin



Assumption: Skin is Opaque
A' = f($\tau$) Experimental Surface $\Delta\theta/H$
$k\rho c = 8.6 \times 10^{-4}, \rho c = 0.8$

Fig.14 - Maximum Temperature Rise Computed for Human Skin for Radiant Exposures Resulting in 2 + Mild Burns in Pig Skin

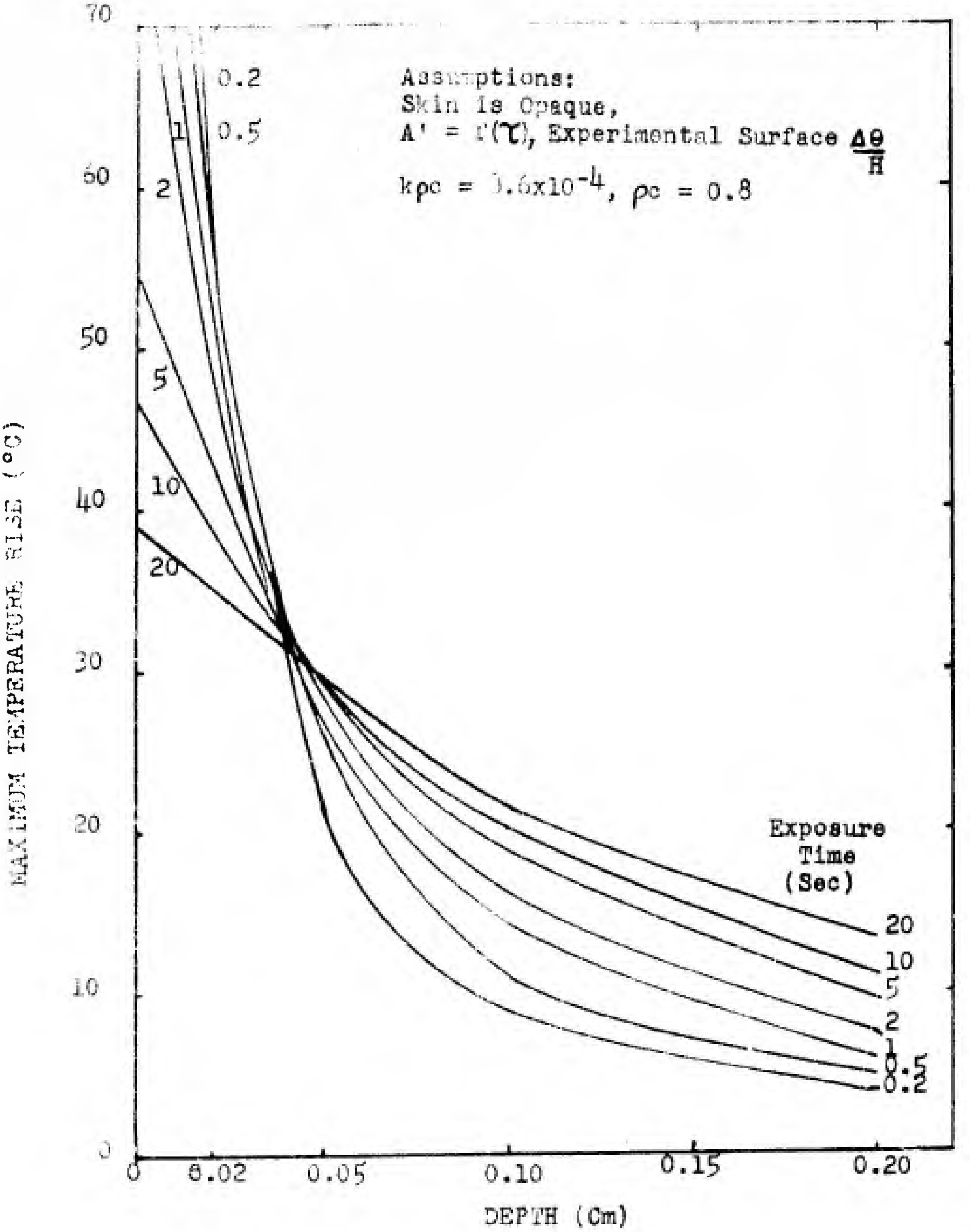


Fig.15 - Maximum Temperature Rise Computed for Human Skin for Radiant Exposures Resulting in 2 + Mild Burns in Pig Skin

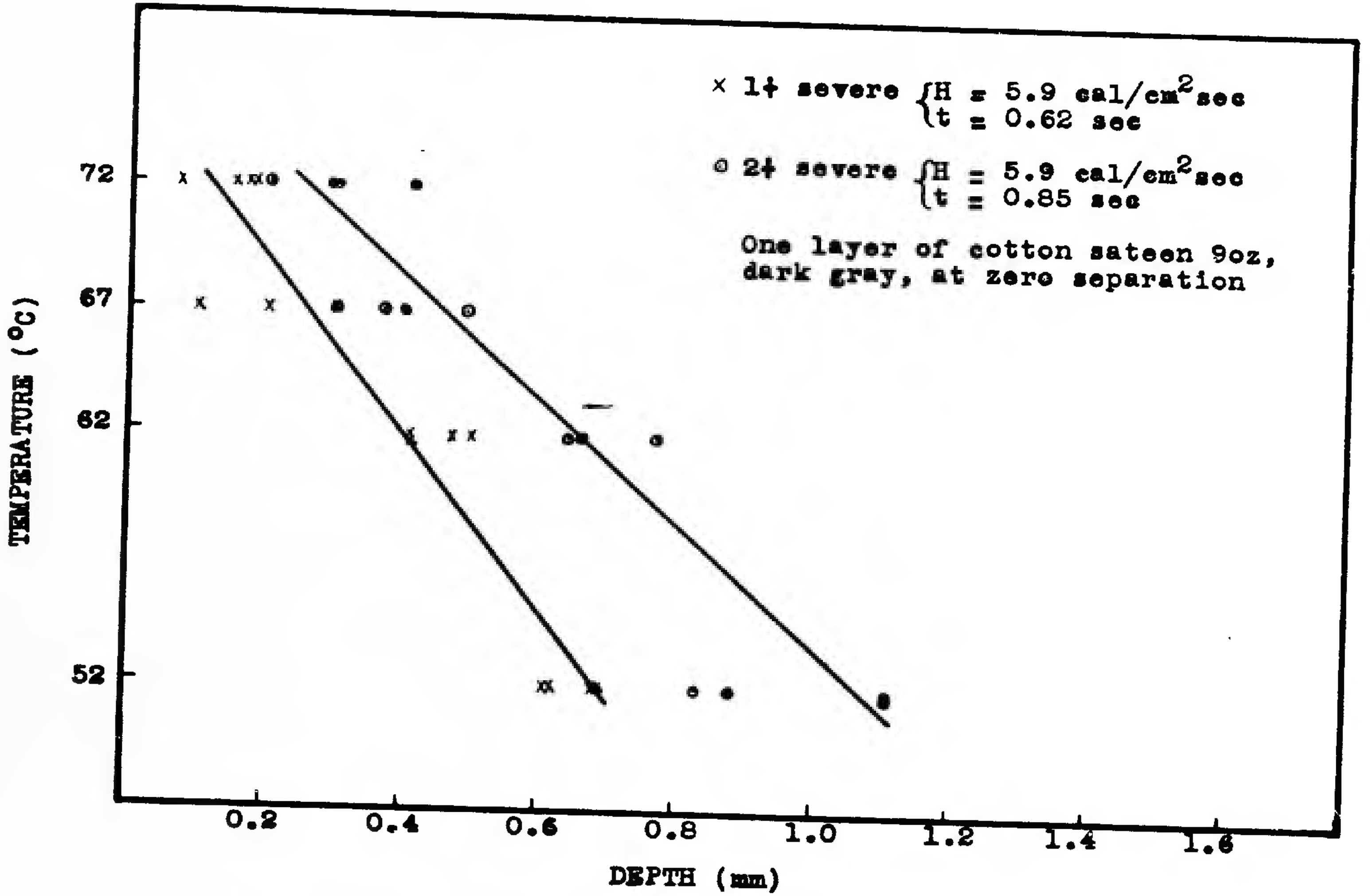
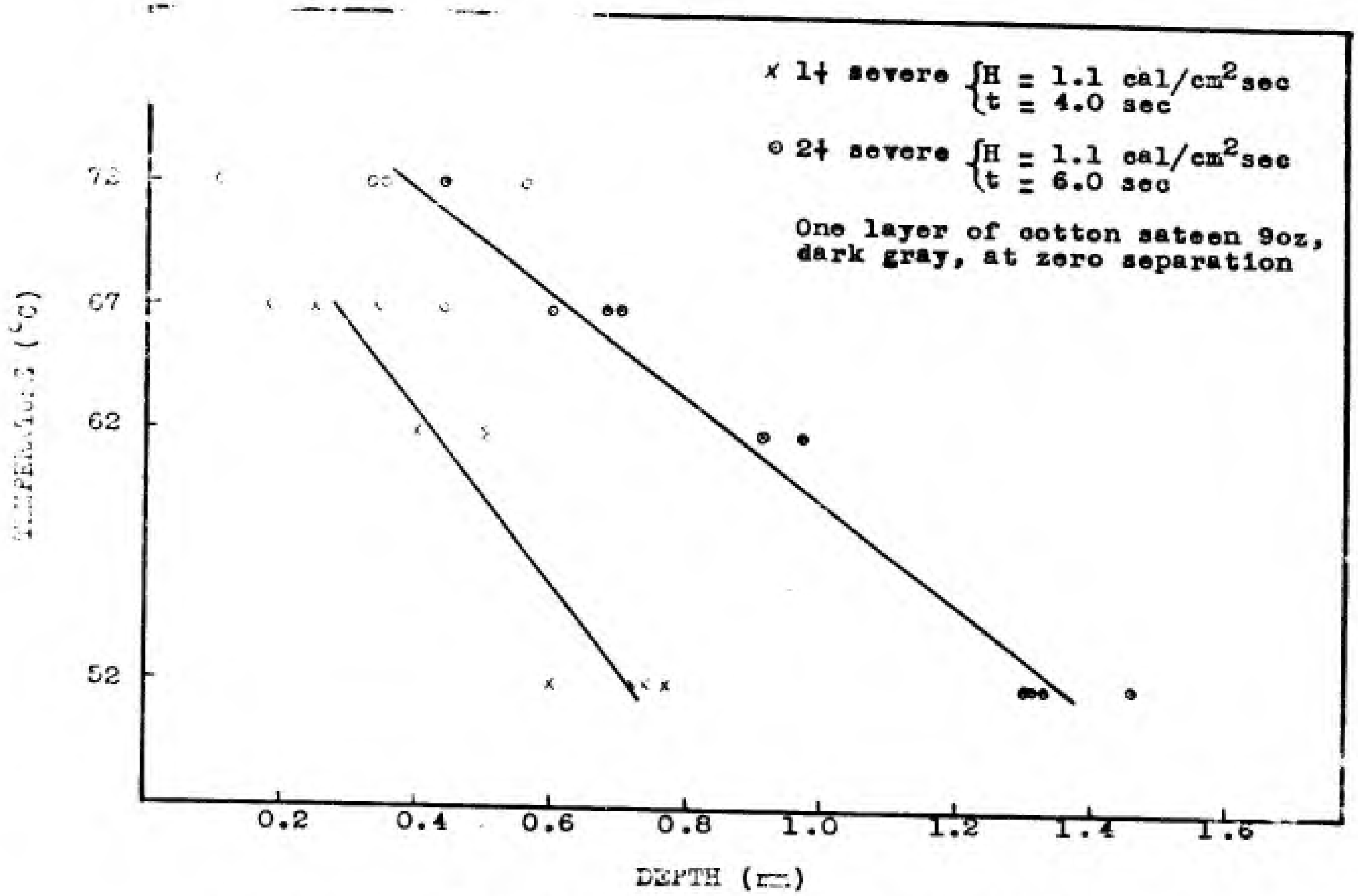


Fig. 16 - Maximum Temperature as a Function of Depth in Polyethylene as Determined by Four Temperature Sensitive Papers



[illegible] Temperature as a Function of Depth in [illegible] as Determined by Four Temperature [illegible]sitive Papers

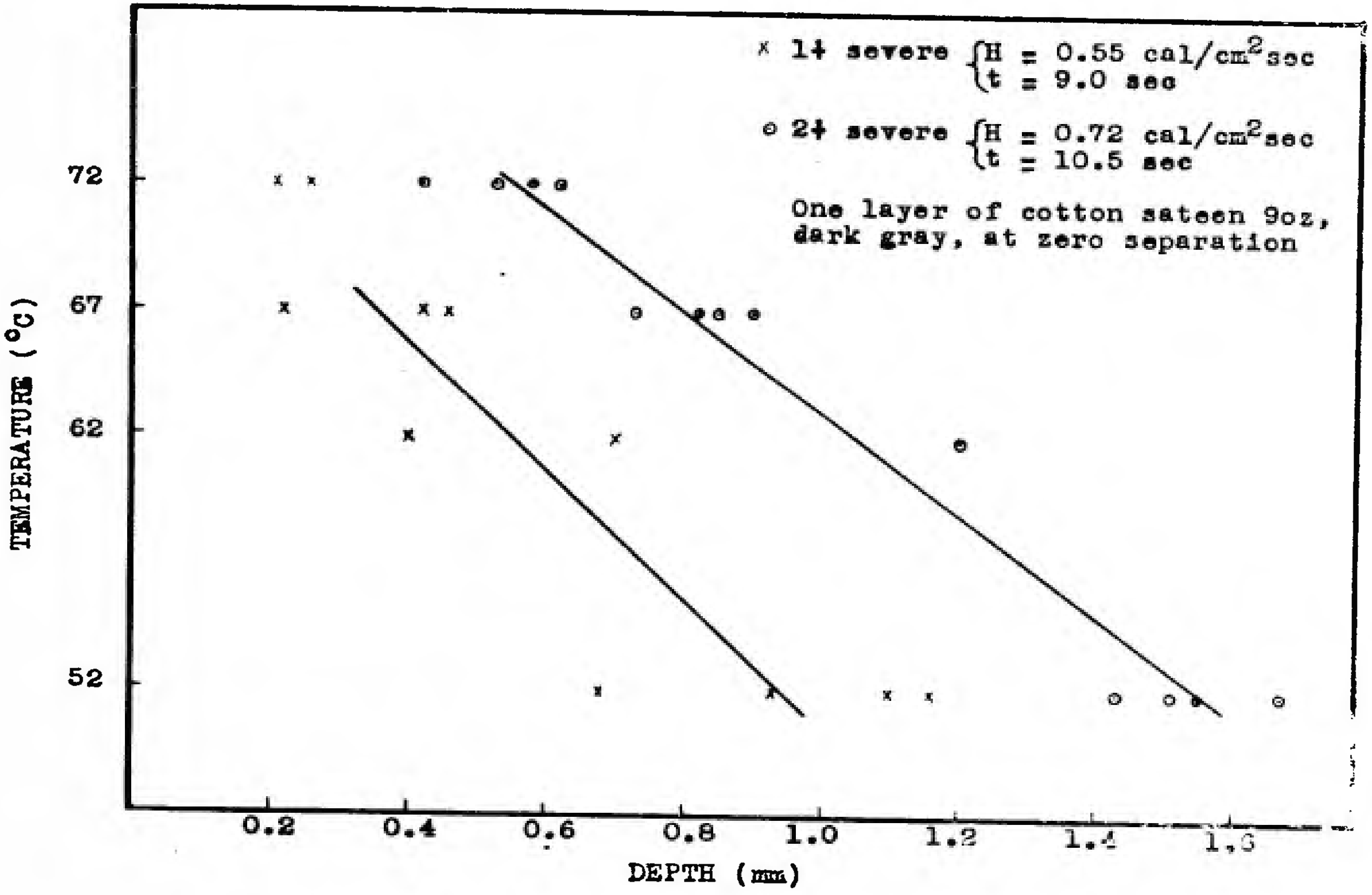


Fig. 18 - Maximum Temperature as a Function of Depth in Polyethylene as Determined by Four Temperature Sensitive Papers

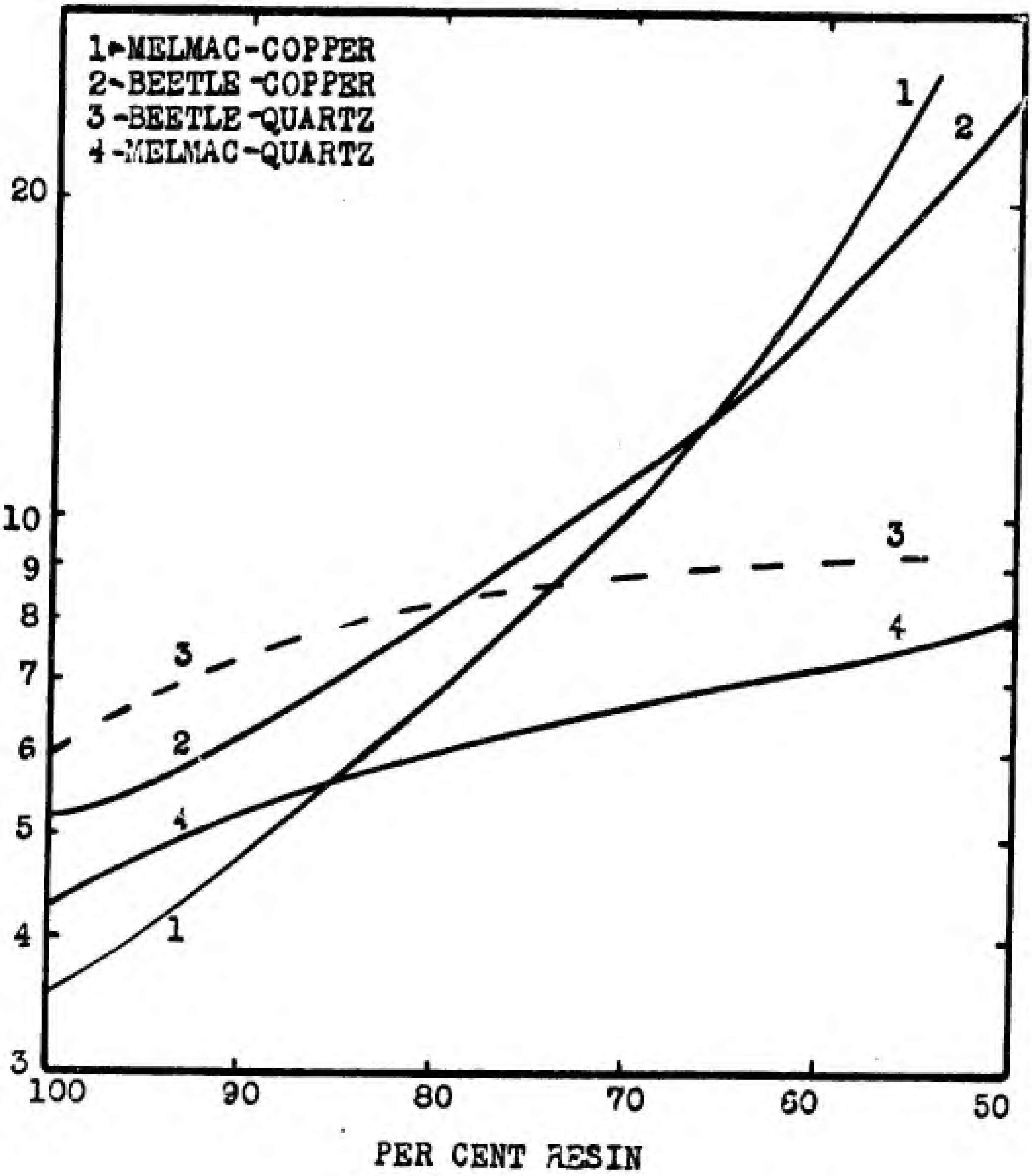


Fig. 19 - Ideal Skin Simulant kpc of Resin-Metal and Resin-Quartz Mixes

### TABLE 1

### FLASH BURNS TO CLOTH-COVERED PORCINE SKIN-CORRELATION OF RADIANT EXPOSURES DETERMINED EXPERIMENTALLY WITH THOSE PREDICTED BY THE TEMPERATURE RISE OF THE COATED POLYETHYLENE SKIN SIMULANT

| Shade of 9 oz. Cotton Sateen | Cloth-Backing Separation (mm) | Irradiance ($cal/cm^2sec$) | Critical Radiant Exposure ($cal/cm^2$) | |  Difference(%) |
|---|---|---|---|---|---|
| | | | NML | UR | |
| Dark Gray | 0 | 11.5 | 5.0 | 3.8 | +32 |
| Dark Gray | 5 | 11.5 | 15.3 | 15.0 | + 2 |
| Dark Gray | 0 | 0.9 | 5.5 | 5.5 | 0 |
| Dark Gray | 5 | 0.9 | 14.2 | 12.4 | +15 |
| Medium Gray | 0 | 11.5 | 6.3 | 5.6 | +12 |
| Medium Gray | 5 | 11.5 | 17.9 | 17.0 | + 5 |
| Medium Gray | 0 | 0.9 | 7.5 | 6.4 | +17 |
| Medium Gray | 5 | 0.9 | 17.0 | 16.3 | + 4 |
| Light Gray | 0 | 11.5 | 9.1 | 7.3 | +25 |
| Light Gray | 5 | 11.5 | 18.0 | 19.0 | - 5 |
| Light Gray | 0 | 0.9 | 9.3 | 9.2 | - 1 |
| White | 0 | 11.5 | 12.2 | 14.5 | -16 |
| White | 5 | 11.5 | 41.0 | 34 | +20 |

Notes:
1. NML values based on methods outlined in NML Report 5046-3, Part 42
2. UR values based on values given in private correspondence

### TABLE 2
### COMPOSITION AND PROPERTIES OF MOLDED FILLED PLASTICS HAVING A k c OF 8-9x10$^{-4}$

| BASE MOLDING MATERIAL | | FILLER | | DENSITY | SPECIFIC | k/ c | |
|---|---|---|---|---|---|---|---|
| MATERIAL | % | MATERIAL | % | g/cm$^3$ | HEAT | x10$^{-4}$ | c |
| Beetle | 75 | Copper Dust | 25 | 1.96 | 0.32 | 22.8 | 0.63 |
| Melmac (404) | 75 | Copper Dust | 25 | 1.92 | 0.32 | 22.0 | 0.62 |
| Beetle | 75 | Quartz Dust | 25 | 1.60 | 0.36 | 25.3 | 0.58 |
| Melmac (404) | 50 | Quartz Dust | 50 | 1.84 | 0.32 | 23.4 | 0.59 |
| Bakelite | 100 | (Note 1) | - | 1.93 | 0.39 | 16.2 | 0.75 |

Notes:

1. Special molding cycle
2. Density was determined by actual measurement
3. Specific heat computed, using theory of ideal mixtures
4. Calculated from k c/( c)$^2$
5. "Beetle" is the trade name for American Cyanimid's alpha cellulose-filled urea formaldehyde (C-509,tan)
6. "Melmac" is the trade name for American Cyanimid's melamine formaldehyde

## DISTRIBUTION LIST
## No. 100
## Thermal Radiation Reports
## (Research)

5 October 1954

ARMY

| ADDRESSEE | NO. OF COPIES |
|---|---|
| Assistant Chief of Staff, G-3, Department of the Army<br>Washington 25, D.C. ATTN: DCS/G-3 (RR & SW) | 1 |
| Assistant Chief of Staff, G-4, Department of the Army,<br>Washington 25, D.C. | 1 |
| Chief of Ordnance, Department of the Army, Washington 25, D.C.<br>ATTN: ORDTX-AR | 1 |
| Chief Signal Officer, Department of the Army, P & O Division,<br>Washington 25, D.C. ATTN: SIGOP | 3 |
| The Surgeon General, Department of the Army, Washington 25, D.C.<br>ATTN: Chief, Research & Development Division | 1 |
| Chief Chemical Officer, Department of the Army, Washington 25, D.C. | 2 |
| Chief of Engineers, Department of the Army, Washington 25, D.C.<br>ATTN: ENGNB | 3 |
| The Quartermaster General, Chemical, Biological and Radiological<br>Warfare Liaison Office, Research & Development Division,<br>Department of the Army, Washington 25, D.C. | 2 |
| Chief of Transportation, Military Planning & Intelligence Division,<br>Washington 25, D.C. | 1 |
| Chief, Army Field Forces, Fort Monroe, Virginia | 4 |
| President, Board #1, Office, Chief of Army Field Forces,<br>Fort Bragg, North Carolina | 1 |
| President, Board #2, Office, Chief of Army Field Forces,<br>Fort Knox, Kentucky | 1 |
| President, Board #4, Office, Chief of Army Field Forces,<br>Fort Bliss, Texas | 1 |
| Commander-in-Chief, Far East Command, APO 500, c/o PM,<br>San Francisco, California, ATTN: ACOFS J-3 | 2 |
| Commandant, Command & General Staff College, Fort Leavenworth,<br>Kansas, ATTN: ALLIS(AS) | 1 |

DIST. LIST NO. 100 (Cont'd)

**ARMY** (Cont'd)

| **ADDRESSEE** | **NO. OF COPIES** |
|---|---|
| Commanding General, Medical Field Service School, Brooke Army Medical Center, Fort Sam Houston, Texas | 1 |
| Director, Special Weapons Development Office, Office, Chief of Army Field Forces, Fort Bliss, Texas | 1 |
| Commandant, Army Medical Service Graduate School, Walter Reed Army Medical Center, Washington 25, D.C. ATTN: Department of Biophysics | 1 |
| Commandant, Chemical Corps School, Chemical Corps Training Command, Fort McClellan, Alabama | 1 |
| Commanding General, Research & Engineering Command, Army Chemical Center, Maryland ATTN: Special Projects Officer | 2 |
| Commanding General, Aberdeen Proving Grounds, Maryland ATTN: Director, Ballistics Research Laboratory | 2 |
| Commanding General, The Engineer Center, Fort Belvoir, Virginia ATTN: Assistant Commandant, Engineer School | 3 |
| Commanding Officer, Engineer Research & Development Laboratory, Fort Belvoir, Virginia ATTN: Chief, Technical Intelligence Branch | 1 |
| Commanding Officer, Picatinny Arsenal, Dover, New Jersey ATTN: ORDBB-TK | 1 |
| Commanding Officer, Frankford Arsenal, Philadelphia 37, Pa. ATTN: Mr. C. C. Fawcett | 1 |
| Commanding Officer, Army Medical Research Laboratory, Fort Knox, Kentucky | 1 |
| Commanding Officer, Chemical Corps. Chemical & Radiological Lab., Army Chemical Center, Md. ATTN: Technical Library | 2 |
| Commanding Officer, Transportation Research & Development Division Station, Fort Eustis, Virginia | 1 |
| Director, Technical Documents Center, Evans Signal Laboratory, Belmar, New Jersey | 1 |
| Director, Waterways Experiment Station, PO Box 631, Vicksburg, Miss. ATTN: Library | 1 |
| Director, Operations Research Office, Johns Hopkins University, 7100 Connecticut Ave., Chevy Chase, Md., Washington 15, D.C. ATTN: Library | 1 |

DIST. LIST NO. 100 (Cont'd)

| ADDRESSEE | NO. OF COPIES |
|---|---|
| ARMY | |
| ~~Chief, Quartermaster, Research & Development Division., Philadelphia Quartermaster Depot, 2800 S. 20th St., Philadelphia 45, Pennsylvania ATTN: Mr. John Davies~~ | ~~1~~ |
| NAVY | |
| Chief of Naval Operations, Department of the Navy, Washington 25, D.C. ATTN: OP-36 | 2 |
| Chief of Naval Operations, Department of the Navy, Washington 25, D.C. ATTN: OP-374(OEG) | 1 |
| Chief, Bureau of Medicine and Surgery, Department of the Navy, Washington 25, D.C., ATTN: Special Weapons Defense Division | 1 |
| Chief, Bureau of Ordnance, Department of the Navy, Washington 25, D.C. | 1 |
| Chief of Naval Personnel, Department of the Navy, Washington 25, D.C. ATTN: Pers C | 1 |
| Chief, Bureau of Ships, Department of the Navy, Washington 25, D.C. ATTN: Code 348 | 2 |
| 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: P-440 | 1 |
| Chief, Bureau of Aeronautics, Department of the Navy, Washington 25, D.C. | 2 |
| Chief of Naval Research, Washington 25, D.C. ATTN: LTJG F. McKee, USN | 1 |
| Commander-in-Chief, U.S. Pacific Fleet, Fleet Post Office, San Francisco, California | 1 |
| Commander-in-Chief, U.S. Atlantic Fleet, U.S. Naval Base, Norfolk 11, Virginia | 1 |
| Commandant, United States Marine Corps. Washington 25, D.C. ATTN: Code A03H | 4 |
| President, U.S. Naval War College, Newport, Rhode Island | 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, California | 2 |
| **Commanding General<br>Headquarters Quartermaster Research and Development Command,<br>Quartermaster Research and Development Command,<br>Natick, Massachusetts,<br>ATTN: CBR Liaison Branch** | 4 |

**NAVY**

| **ADDRESSEE** | **NO. OF COPIES** |
|---|---|
| Commanding Officer, U.S. Fleet Training Center, Naval Base, Norfolk 11, Virginia ATTN: Special Weapons School | 2 |
| Commanding Officer, U.S. Fleet Training Center, Naval Station, San Diego 36, California ATTN: (SPWP School) | 2 |
| Commanding Officer, Air Development Squadron 5, VX-5, U.S. Naval Air Station, Moffett Field, California | 1 |
| Commanding Officer, U. S. Naval Damage Control Training Center, Naval Base, Philadelphia 12, Pennsylvania ATTN: ABC Defense Course | 1 |
| Commanding Officer, U. S. Naval Unit, Chemical Corps School, Army Chemical Training Center, Fort McClellan, Alabama | 1 |
| Commander, U.S. Naval Ordnance Laboratory, White Oak, Silver Spring 19, Maryland ATTN: EE | 1 |
| R | 1 |
| Commander, U.S. Naval Ordnance Test Station, Inyokern, China Lake, California | 1 |
| Commanding Officer, U.S. Naval Medical Research Institute, National Naval Medical Center, Bethesda 14, Maryland | 1 |
| Director, U.S. Naval Research Laboratory, Washington 25, D.C. ATTN: Code 2029 | 1 |
| Commander, New York Naval Shipyard, Brooklyn, New York ATTN: Director, The Material Laboratory | 1 |
| Commanding Officer & Director, U.S. Naval Electronics Laboratory, San Diego, California ATTN: Code 4223 | 1 |
| Commanding Officer, U.S. Naval Radiological Defense Laboratory, San Francisco 24, California ATTN: Tech Info Div | 3 |
| Commander, U.S. Naval Air Development Center, Johnsville, Pa. | 1 |
| Director, Office of Naval Research Branch Office, 1000 Geary Street, San Francisco, California | 1 |
| Officer-in-Charge, U. S. Naval Clothing Factory, U. S. Naval Supply Activities New York, 3rd Avenue & 29th Street, Brooklyn 32, N.Y. ATTN: Research & Development Division | 1 |
| Commanding Officer, Naval Medical Field Research Laboratory, Camp Lejeune, North Carolina | 1 |

DIST. LIST NO. 100 (Cont'd)

## AIR FORCE

| ADDRESSEE | NO. OF COPIES |
|---|---|
| Assistant for Atomic Energy, Headquarters United States Air Force, Washington 25, D. C. ATTN: Deputy Chief of Staff, Operations | 1 |
| Director of Operations, Headquarters, United States Air Force, Washington 25, D. C. ATTN: Operations Analysis | 1 |
| Director of Plans, Headquarters, United States Air Force, Washington 25, D. C. ATTN: War Plans Division | 1 |
| Directorate of Requirements, Headquarters United States Air Force, Washington 25, D. C. ATTN: AFDRQ-SA/M | 1 |
| Directorate of Research & Development, Armament Division, DCS/D, Headquarters United States Air Force, Washington 25, D. C. ATTN: Combat Components Division | 1 |
| Directorate of Intelligence, Headquarters, United States Air Force, Washington 25, D. C. ATTN: AFOIN-1B2 | 2 |
| The Surgeon General, Headquarters, United States Air Force, Washington 25, D. C. ATTN: Bio. Defense Br., Prev. Med. Division | 1 |
| Commander, Strategic Air Command, Offutt Air Force Base, Omaha, Nebraska, ATTN: Chief, Operations Analysis | 1 |
| Commander, Tactical Air Command, Langley Air Force Base, Virginia, ATTN: Document Security Branch | 1 |
| Commander, Air Defense Command, Ent Air Force Base, Colorado | 1 |
| Commander, Air Materiel Command, Wright-Patterson Air Force Base, Dayton, Ohio ATTN: MCAIDS | 2 |
| Commander, Air Training Command, Scott Air Force Base, Belleville, Illinois ATTN: Deputy Chief of Staff, Operations GTP | 1 |
| Commander, Air Research & Development Command, PO Box 1395, Baltimore, Maryland ATTN: RDDN | 3 |
| Commander, Air Proving Ground Command, Eglin Air Force Base, Florida ATTN: AG/TRB | 1 |
| Director, Air University Library, Maxwell Air Force Base, Alabama ATTN: CR-5454 | 2 |
| Commander, Flying Training Air Force, Waco, Texas, ATTN: Director of Observer Training | 2 |

DIST. LIST NO. 100 (Cont'd)

AIR FORCE (Cont'd

| ADDRESSEE | NO. OF COPIES |
|---|---|
| Commander, Crew Training Air Force, Randolph Air Force Base, Randolph Field, Texas ATTN: RCTS, Deputy Chief of Staff, Operations | 1 |
| Commander, Headquarters Technical Training Air Force, Gulfport, Mississippi ATTN: TA & D | 1 |
| Commander, Air Force School of Aviation Medicine, Randolph Air Force Base, Texas | 2 |
| Commander, Wright Air Development Center, Wright-Patterson Air Force Base, Dayton, Ohio ATTN: WCOESP<br>WCRTY-2 | 1<br>1 |
| Commander, AF Cambridge Research Center, 230 Albany Street, Cambridge 39, Massachusetts ATTN: CRW, Atomic Warfare Directorage<br>~~CRQST-2~~ | 1<br>~~1~~ |
| Commander, AF Special Weapons Center, Kirtland Air Force Base, New Mexico, ATTN: Library | 3 |
| Commander, United States Air Force Institute of Technology, Wright-Patterson Air Force Base, Dayton, Ohio ATTN: Resident College | 1 |
| Commander, Lowry Air Force Base, Denver, Colorado ATTN: Department of Armament Training | 1 |

## OTHER DOD ACTIVITIES

| | |
|---|---|
| Director, Weapons Systems Evaluation Group, OSD, Rm 2E1006, Pentagon, Washington 25, D. C. | 1 |
| United States National Military Representative Headquarters, SHAPE, APO 55, c/o PM, New York, N.Y. ATTN: Col. J. P. Healy | 1 |
| Assistant Secretary of Defense for Research and Development, Department of Defense, Washington 25, D.C. ATTN: Technical Library | 1 |
| Commandant, Armed Forces Staff College, Norfolk 11, Virginia, ATTN: Secretary | 1 |
| Commanding General, Field Command, Armed Forces Special Weapons Project, P.O. Box 5100, Albuquerque, New Mexico | 6 |
| Commanding General, Field Command, Armed Forces Special Weapons Project, PO Box 5100, Albuquerque, New Mexico, ATTN: Technical Training Group | 2 |
| Commander<br>AF Cambridge Research Center<br>L. G. Hanscom Field<br>Bedford, Mass[illegible]<br>ATTN: [illegible] | 1 |

DIST. LIST NO. 100 (Cont'd)

| ADDRESSEE | NO. OF COPIES |
|---|---|
| **OTHER DOD ACTIVITIES (Cont'd)** | |
| Chief, Armed Forces Special Weapons Project, Washington 25, D. C. | 15 |
| **PANEL ON THERMAS RADIATION** | |
| Professor H. C. Hottel, Massachusetts Institute of Technology, Cambridge, Massachusetts | 1 |
| Dr. E. O. Hulburt, Naval Research Laboratory, Washington 25, D. C. | 1 |
| Dr. H. E. Pearse, Strong Memorial Hospital, 260 Crittenden Blvd., University of Rochester, Rochester 7, New York | 1 |
| Dr. J. D. Hardy, Aviation Medical Acceleration Laboratory, Naval Air Development Center, Johnsville, Pennsylvania | 1 |
| **OTHERS** | |
| Dr. E. F. Cox, Applied Physics Division, Sandia Corp., Albuquerque, New Mexico | 1 |
| Dr. Alvin C. Graves, Los Alamos Scientific Lab., Box 1663, Los Alamos, New Mexico | 1 |
| Director, Los Alamos Scientific Lab., PO Box 1663, Los Alamos, New Mexico, ATTN: Reports Library | 1 |
| Director, Engineering Research, University of California, PO Box 4063, Westwood Village Station, Los Angeles 24, California | 1 |
| Dr. William T. Ham, Medical College of Virginia, Richmond, Virginia | 1 |
| California Forest and Range Experimental Station, U. S. Forest Service, PO Box 245, Berkeley, California ATTN: W. L. Fons, Division Forest Fire Research | 1 |
| Professor G. C. Williams, Dept. of Cml Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts | 1 |
| Mr. H. D. Bruce, Forest Products Lab., North Walnut St., Madison 5, Wisconsin | 1 |
| Mr. A. A. Brown, Chief, Fire Research Division, Forest Service, USDA, Washington 25, D.C. | 1 |
| Technical Operations Inc., 6 Schouler Court, Arlington 74, Massachusetts ATTN: Dr. Frederick C. Henriques | 1 |

Naval Material Laboratory  New York Naval
Shipyard  5046 3  Part 84

A REVIEW OF THE DEVELOPMENT OF A PLASTIC PHYSICAL SKIN SIMULANT FOR EVALUATING SUB FABRIC FLASH BURNS by T I Monahan and W L Derksen. Final Report 22 July 1955. 14 p Figs tables (AFSWP 850)

UNCLASSIFIED

Progress in the development of a physical skin simulant to evaluate sub fabric burns is reviewed including measurement of the optical and thermal constants of skin in order to compute the skin temperatures associated with burns and to direct the development of the ideal plastic skin simulant development of a coating to use with black poly ethylene to approximate the constants of skin and use of this simulant to predict burns in porcine skin study of the feasibility of using passive indicators with physical skin simulants

1 Flash burns Physiological effects
2 Skin Effects of radiation
3 Skin Simulation
I Monahan T I
II Derksen, W L.
III NS 081 001
IV AFSWP 850

UNCLASSIFIED

Naval Material Laboratory  New York Naval
Shipyard  5046 3, Part 84

A REVIEW OF THE DEVELOPMENT OF A PLASTIC PHYSICAL SKIN SIMULANT FOR EVALUATING SUB FABRIC FLASH BURNS by T I Monahan and W L Derksen  Final Report 22 July 1955  14 p  Figs  tables (AFSWP 850)

UNCLASSIFIED

Progress in the development of a physical skin simulant to evaluate sub fabric burns is reviewed including measurement of the optical and thermal constants of skin in order to compute the skin temperatures associated with burns and to direct the development of the ideal plastic skin simulant development of a coating to use with black poly ethylene to approximate the constants of skin and use of this simulant to predict burns in porcine skin study of the feasibility of using passive indicators with physical skin simulants

1 Flash burns Physiological effects
2 Skin Effects of radiation
3 Skin Simulation
I Monahan, T I.
II. Derksen. W L.
III. NS 081 001
IV. AFSWP 850

UNCLASSIFIED

Naval Material Laboratory  New York Naval
Shipyard.  5046 3  Part 84

A REVIEW OF THE DEVELOPMENT OF A PLASTIC PHYSICAL SKIN SIMULANT FOR EVALUATING SUB FABRIC FLASH BURNS by T.I Monahan and W.L Derksen. Final Report 22 July 1955  14 p. Figs  tables (AFSWP 850)

UNCLASSIFIED

Progress in the development of a physical skin simulant to evaluate sub fabric burns is reviewed including measurement of the optical and thermal constants of skin in order to compute the skin temperatures associated with burns and to direct the development of the ideal plastic skin simulant development of a coating to use with black polyethylene to approximate the constants of skin and use of this simulant to predict burns in porcine skin study of the feasibility of using passive indicators with physical skin simulants.

1 Flash burns Physiological effects
2 Skin · Effects of radiation
3 Skin Simulation
I. Monahan T I.
II Derksen W.L
III NS 081 001
IV AFSWP 850

UNCLASSIFIED

Naval Material Laboratory  New York Naval
Shipyard  5046 3  Part 84

A REVIEW OF THE DEVELOPMENT OF A PLASTIC PHYSICAL SKIN SIMULANT FOR EVALUATING SUB FABRIC FLASH BURNS by T.I  Monahan and W L  Derksen  Final Report 22 July 1955  14 p  Figs  tables ([illegible] 850)

UNCLASSIFIED

Progress in the development of a physical skin simulant to evaluate sub fabric burns is reviewed including measurement of the optical and thermal constants of skin in order to compute the skin temperatures associated with burns and to direct the development of the ideal plastic skin simulant; development of a coating to use with black poly ethylene to approximate the constants of skin and use of this simulant to predict burns in porcine skin. study of the feasibility of using passive indicators with physical skin simulants.

1. Flash burns Physiological effects
2 Skin Effects of radiation
3 Skin Simulation
I Monahan T I
II. Derksen W L.
III. NS 081 001
IV. AFSWP 850

UNCLASSIFIED

Naval Material Laboratory  New York Naval
Shipyard  5046 3  Part 84

A REVIEW OF THE DEVELOPMENT OF A PLASTIC PHYSICAL SKIN SIMULANT FOR EVALUATING SUB FABRIC FLASH BURNS by T I  Monahan and W L  Derksen.  Final Report 22 July 1955.  14 p  Figs  tables (AFSWP 850)

UNCLASSIFIED

Progress in the development of a physical skin simulant to evaluate sub fabric burns is reviewed including measurement of the optical and thermal constants of skin in order to compute the skin temperatures associated with burns and to direct the development of the ideal plastic skin simulant development of a coating to use with black poly ethylene to approximate the constants of skin and use of this simulant to predict burns in porcine skin  study of the feasibility of using passive indicators with physical skin simulants

1 Flash burns  Physiological effects
2 Skin  Effects of radiation
3 Skin  Simulation
I Monahan  T I
II Derksen, W L
III NS 081 001
IV AFSWP 850

UNCLASSIFIED

---

Naval Material Laboratory  New York Naval
Shipyard  5046 3  Part 84

A REVIEW OF THE DEVELOPMENT OF A PLASTIC PHYSICAL SKIN SIMULANT FOR EVALUATING SUB FABRIC FLASH BURNS by T I  Monahan and W L  Derksen  Final Report 22 July 1955  14 p  Figs  tables (AFSWP 850)

UNCLASSIFIED

Progress in the development of a physical skin simulant to evaluate sub fabric burns is reviewed including measurement of the optical and thermal constants of skin in order to compute the skin temperatures associated with burns and to direct the development of the ideal plastic skin simulant development of a coating to use with black poly ethylene to approximate the constants of skin and use of this simulant to predict burns in porcine skin  study of the feasibility of using passive indicators with physical skin simulants

1 Flash burns  Physiological effects
2 Skin  Effects of radiation
3 Skin  Simulation
I Monahan, T I
II. Derksen, W L
III. NS 081 001
IV AFSWP 850

UNCLASSIFIED

---

Naval Material Laboratory  New York Naval
Shipyard  5046 3  Part 84

A REVIEW OF THE DEVELOPMENT OF A PLASTIC PHYSICAL SKIN SIMULANT FOR EVALUATING SUB FABRIC FLASH BURNS by T I  Monahan and W L  Derksen  Final Report 22 July 1955  14 p  Figs  tables (AFSWP 850)

UNCLASSIFIED

Progress in the development of a physical skin simulant to evaluate sub fabric burns is reviewed including measurement of the optical and thermal constants of skin in order to compute the skin temperatures associated with burns and to direct the development of the ideal plastic skin simulant development of a coating to use with black poly-ethylene to approximate the constants of skin and use of this simulant to predict burns in porcine skin  study of the feasibility of using passive indicators with physical skin simulants.

1 Flash burns  Physiological effects
2 Skin  Effects of radiation
3 Skin  Simulation
I. Monahan  T I
II Derksen  W L
III NS 081 001
IV AFSWP 850

UNCLASSIFIED

---

Naval Material Laboratory  New York Naval
Shipyard  5046 3  Part 84

A REVIEW OF THE DEVELOPMENT OF A PLASTIC PHYSICAL SKIN SIMULANT FOR EVALUATING SUB FABRIC FLASH BURNS by T I  Monahan and W L  Derksen  Final Report 22 July 1955  14 p  Figs  tables (AFSWP 850)

UNCLASSIFIED

Progress in the development of a physical skin simulant to evaluate sub fabric burns is reviewed including measurement of the optical and thermal constants of skin in order to compute the skin temperatures associated with burns and to direct the development of the ideal plastic skin simulant, development of a coating to use with black poly ethylene to approximate the constants of skin and use of this simulant to predict burns in porcine skin, study of the feasibility of using passive indicators with physical skin simulants

1. Flash burns  Physiological effects
2 Skin  Effects of radiation
3 Skin  Simulation
I Monahan  T I
II Derksen  W L
III NS 081 001
IV AFSWP 850

UNCLASSIFIED