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Progress Report 7
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MATERIAL LABORATORY

NEW YORK NAVAL SHIPYARD
BROOKLYN 1, N. Y.

TECHNICAL REPORT

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SECURITY INFORMATION

THERMAL RADIATION STUDIES

REPORT OF PROGRESS, JULY - SEPTEMBER, 1952

Lab. Projects 5046-2, 5046-3
Progress Report 7
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SECURITY INFORMATION

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CONFIDENTIAL

Lab. Projects 5046-2, 5046-3
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Encl: (1) List of Materials for Critical Thermal Energy Evaluations
(2) Absorptances of Materials for Thermal Radiation

INTRODUCTION

Reported herein is the progress of the Naval Material Laboratory in its Thermal Radiation Studies sponsored by the Armed Forces Special Weapons Project. This report covers the Naval Material Laboratory's participation in the field tests, inasmuch as it concerns the progress of the Laboratory studies.

GENERAL PROGRESS

During the current Quarter, the Naval Material Laboratory's studies on the Effects of ABD Thermal Radiation on Materials were directed along three principal lines: first, the completion of the TUMBLER-SNAPPER operation reports; second, the development of a suitable skin simulant for use in the studies of the heat transfer through clothing; and, third, preparations for participation in Operation UPSHOT-KNOTHOLE.

All experimental work in connection with participation in past field tests has been completed. In addition, first drafts of the TUMBLER-SNAPPER reports have been submitted to the Armed Forces Special Weapons Project, and the final project report for Operation BUSTER has been published by them. The publication of the Naval Material Laboratory's report covering participation in Operation GREENHOUSE has been delayed. The depth-of-char studies on the woods exposed at BUSTER have been completed and a report is being prepared. The planning of the NML studies at Operation UPSHOT-KNOTHOLE has progressed satisfactorily and the necessary pre-shot experimentation is underway.

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The development of wide-area laboratory sources of thermal radiation has continued. The graphite-resistor furnace is ready for studies requiring exposures to such a unit. The aluminum-sun furnace developed a leak in its cover when fired for the first time. An improved cover has been designed and is being fabricated. The Services Testing program is continuing with the publication of reports as data become available. In the Protective Measures program, emphasis has now shifted from the evaluation of commercial fire-retarding processes to the study of the significant factors in such treatments which may be applied to protection against flash fires. In the Source and Material Parameters program, the development of a skin simulant has been stressed. The behavior of polyethylene behind a cloth barrier under irradiation is being studied, with emphasis to date on the fabrication of thermocouples and proper placement of the couple in order to determine the temperature rise of the plastic's surface. In general, the response of the polyethylene is similar to that of the beefsteak used in the Orlon investigation and that determined by theoretical considerations.

The detailed reports of progress covering the problems under investigation by the Naval Material Laboratory follow. Progress during the current quarter is emphasized. For additional information refer to the quarterly progress reports of September 1951, December 1951, March 1952, and June 1952.

REPORTS OF TECHNICAL PROGRESS - PARTICIPATION IN FIELD TESTS

1. CORRELATION OF LABORATORY AND FIELD DAMAGE (Operation GREENHOUSE).

The Naval Material Laboratory report covering its participation in Operation GREENHOUSE has been completed, except for processing. The delay in publication of this report has been due to the necessity for meeting the report requirements for the other field tests. A summary of the significant findings of the NML GREENHOUSE studies was included in the June Quarterly Progress Report.

2. EFFECTS OF THERMAL RADIATION ON MATERIALS (Operation BUSTER).

Inasmuch as the final project report has been published by the Armed Forces Special Weapons Project, this investigation is considered closed.

3. ATMOSPHERIC TRANSMISSION AND WEATHER MEASUREMENTS (Operation TUMBLER-SNAPPER).

During the current quarter the first draft of the NML Project 8.4 report was prepared and forwarded to the Armed Forces Special Weapons Project. The findings of this experiment are summarized in the June Progress Report.

4. MEASUREMENTS OF THERMAL RADIATION, USING PASSIVE INDICATORS (Operation TUMBLER-SNAPPER)

During the current quarter the first draft of the NML Project 8.3a report was prepared and has been forwarded to the Armed Forces Special Weapons Project. The significant findings are summarized in the June Progress Report. The diffuse reflection of the sand accounts for the anomaly in response of the vertical and horizontal roundels. This characteristic of the Nevada sand is discussed under Problem 15.

5. EFFECTS OF THERMAL RADIATION ON MATERIALS (Operation UPSHOT-KNOTHOLE).

The scope of the NML studies at Operation UPSHOT-KNOTHOLE has been determined from a review of the knowledge gained during previous field tests and in current laboratory studies. The formal proposal for studying the effects of thermal radiation on materials includes the following subjects:

a. Source spectrum,
b. Damage-time characteristic of materials,
c. Transfer of heat through clothing,
d. Protective value of materials,
e. Distribution of energy in foxholes.

It is considered desirable to instrument five stations, corresponding to 3, 6, 12, 18, and 24 cal/cm^2, which cover the range of thermal radiation energies of principal interest in ABD studies.

The principal effort on this problem during the current quarter involved the development of a suitable skin simulant, the development and evaluation of heat-sensitive media for use in the Source Spectrum and Cloth Experiments, and analysis of filter requirements for the spectral studies. In this way, it was possible to translate general planning data into a definite program which would lead to the procurement of materials and equipment and fabrication of instrumentation required for the actual field experiments.

In the search for a suitable skin simulant, it has been found that plastics have thermal properties approximating those of human skin. Polyethylene was selected as the best available simulant, since its diffusivity is similar to that of human skin and in addition, its

temperature-time characteristic upon irradiation by the carbon-arc source of thermal radiation is similar to that of beefsteak and checks closely with the anslytical expression developed mathematically from the constants for skin. Furthermore, its properties are constant over prolonged time periods. Its principal disadvantage lies in the fact that its surface does not lend itself readily to the application of paints and other heat-sensitive media.

Several heat-sensitive media are being investigated. These are primarily of the paint and wax types, which indicate not the radiant energy received, but the maximum temperatures attained. Additional research will have to be done on correlating this maximum temperature with the temperature-time characteristic of the backing and, in turn, with the burn severity on animals.

A review of the previous field Source Spectrum studies has been made. It was considered desirable to obtain filters with cutoffs which were sharper than those of the Corning filters which have been employed. Jena filters RG10A and GG-13 have optimum characteristics but are not readily available. It has been decided, therefore, that the Corning filters 2550 and 3060 will be employed.

REPORTS OF TECHNICAL PROGRESS - LABORATORY STUDIES

6. DEVELOPMENT OF GRAPHITE FURNACE

a. Objective: To provide a high-irradiance, large-area thermal radiation source for edge-effect and source-geometry studies.

b. General Summary of Project Progress: A 150-kw graphite-lined, graphite-resistor furnace was built for the Material Laboratory by the Kuhlman Electric Company of Bay City, Michigan. The chamber has a 1-ft-square aperture and is 7 in. deep. The irradiance at the center of the aperture for each furnace temperature has been found to equal roughly

black-body emittance at the same temperature; for the practical maximum of 2400°C, the irradiance at the center of the aperture is 70 cal/cm^2 sec. The irradiance at 2 in. transversely from the center drops to about 96 per cent of this value, and at 4 in. to about 65 per cent.

A simple inert-gas system was installed to reduce combustion of the graphite parts.

A 10-in. circular-aperture shutter was built for use with this source. The shutter was designed to be fast-acting, despite its large aperture diameter and radiation resistance, because of the importance of this characteristic in edge-effect studies. Exposure times of 0.1 to 10 sec are possible. The original shutter did not operate at the higher irradiances available because of warping due to the high temperature gradients which are maintained by the incident radiation. It has been modified to overcome this shortcoming.

c. Work During Current Quarter: The shutter has been operated at several furnace temperatures, and irradiance distributions in the plane of the shutter aperture were taken. It was found that in some cases the irradiance was considerably less than was expected from the furnace temperature reading; this can be explained by the fact that the furnace is not always in equilibrium, so that the history of the power input affects the temperature distribution of the interior.

The furnace was used in evaluating modifications to the NML cosine indicators

d. Contemplated Work During Next Three Months: The time characteristics of the shutter will be measured, as will the variation of irradiance with time during an exposure. The furnace will be used in cases where a high-irradiance large-area source is required.

7. DEVELOPMENT OF ALUMINUM-SUN FURNACE

a. Objective: To provide a low-cost, large-area thermal radiation source for use in medical and other studies.

b. General Summary of Project Progress: The furnace was developed from its original form as a ceramic sphere in which aluminum was burned, by the Research Institute of Temple University under the technical direction of NML. The present model consists of a water-cooled, 14-in.-square steel box, 7 in. high. Within this box is welded a vertical, steel cylindrical container, 10 in. in diameter, lined with 1/4 in. of alumina. The lid of the box contains a 6-in. circular window. The window is closed between exposures by a water-cooled metal slab, which is replaced rapidly by a quartz plate for exposures. In order to maintain the irradiance constant with time, a technique has been developed wherein about 2000 g of aluminum is fed rapidly into the furnace. As the deep pool of molten aluminum burns, the aluminum oxide produced occupies approximately the same volume as the aluminum consumed, and the level of the emitting surface remains constant for at least 15 minutes. The irradiance can be kept constant for a further period by suitably altering the oxygen feed rate. Irradiances of over 20 cal/cm^2 sec have been measured.

Rough spectral irradiance measurements were made with portable equipment at the Research Institute, and were reported in the September 1951 Quarterly Progress Report. The temperature of the emitting surface is about 3000°C. At the termination of the Research Institute's contract at the end of May 1952, a furnace unit was delivered to NML.

c. Work During Current Quarter: The furnace has been installed at NML, where a short run was made; the run was terminated by water leaking into the chamber. A new, improved cover for the furnace is being fabricated at the Laboratory. A 6-in.-aperture shutter has been constructed and installed. Copies of the Research Institute's final report on this furnace have been distributed to the AFSWP Thermal Radiation Distribution List.

d. Contemplated Work During Next Three Months: The irradiance as a function of time, position, and wave length will be measured. The time characteristics of the shutter will be measured.

8. MEASUREMENT OF CRITICAL ENERGY VALUES OF ARMED FORCES SERVICE MATERIALS

a. Objective: The purpose of this investigation is to evaluate the thermal radiation characteristics of the materials which are of special interest to the Armed Forces. The critical energy values of the various materials are being determined experimentally and reported as the data become available. In addition, changes of critical energy values under the influence of individual parameters of the materials are evaluated and the effect on material assemblies is being determined.

b. Summary of Project Progress: Enclosure (1) shows the number of materials proposed by the Armed Forces for evaluation of thermal radiation characteristics, the number of materials received, and the number of materials exposed to the carbon-arc source of thermal radiation. The evaluation of these materials is being carried out continuously and the reports on this phase of the study of thermal radiation effects are being distributed as significant data become available.

c. Work During Current Quarter: Seven additional paint systems and six doped fabrics submitted by the Bureau of Aeronautics were evaluated. It was found that the doped fabrics suffer initial discoloration at radiant exposures ranging from 0.43 to 1.4 cal/cm^2 and they have developed flames at exposures ranging from 0.81 to 6.3 cal/cm^2. Destruction of the fabrics was observed at exposures ranging from 6.5 to 40 cal/cm^2. It was noted that the thermal radiation resistance of the white paints investigated was greater than the resistance of the colored paints, particularly at the incipient stages of destruction. Initial effects on the paints, such as dulling, occurred at radiant exposures ranging from 0.88 to 2.4 cal/cm^2 on the colored paints, and at radiant exposures ranging from 38 to 43 cal/cm^2 on the white paints. Ignition of colored paints was noted at radiant exposures between 2.1 and 14 cal/cm^2, and of white paints at radiant exposures between 55 and 76 cal/cm^2. Complete carbonization occurred on the colored paints at radiant exposures between 120 and 150 cal/cm^2, and on the white paint specimens at 170 to 180 cal/cm^2. Softening of the base metal occurred at 180 to 270 cal/cm^2 on the colored paints and at 270 to 280 cal/cm^2 on the white paints.

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The plastic materials proposed for test by the Bureau of Ships were evaluated. It was found that the 1/8-in.-thick specimens suffered initial destructive effects at radiant exposures ranging from 0.45 to 67 cal/cm^2, depending on the material used. Formation of non-propagating flames was observed on some specimens at radiant exposures ranging from 13 to 63 cal/cm^2, but polyethylene continued to burn after an exposure of 160 cal/cm^2. Extreme damage occurred at exposures ranging from 13 to 170 cal/cm^2, depending upon the specific plastic material exposed.

Several materials submitted by the Forest Products Laboratory, U. S. Forest Service, were evaluated in connection with the Laboratory's study of the initiation of fires resulting from nuclear detonations. The materials included fabrics used for typical household furnishings. Upon exposure to the carbon-arc source, it was found that the fabrics suffered initial thermal damage at radiant exposures ranging from 1.7 to 14 cal/cm^2; the fabrics developed flames and were destroyed at radiant exposures ranging from 18 to 37 cal/cm^2. The rug and carpet materials developed non-propagating flames at 8.8 and at 27 cal/cm^2, respectively, but were not completely destroyed, even at the maximum radiant exposure, 107 cal/cm^2.

Wood and fiberboard packaging materials under the cognizance of the Bureau of Supplies and Accounts were evaluated. Initial effects occurred on wood at radiant exposures ranging from 3.6 to 8.8 cal/cm^2, on fiberboards at exposures ranging from 5.1 to 6.2 cal/cm^2; temporary flaming was noted on wood at exposures ranging from 6.5 to 13 cal/cm^2 and on fiberboard at exposures ranging from 6.8 to 13 cal/cm^2. Propagating flames were not observed on the materials for exposures up to 107 cal/cm^2. It was noted that the laminated boards offer higher resistance to thermal radiation than the corrugated boards.

d. Contemplated Work During Next Three Months: The evaluation of service materials will continue and the results will be reported as significant findings become available.

9. DEVELOPMENT OF PROTECTIVE MEASURES

a. Objective: The objective of this program is to evaluate the resistance to thermal radiation of various types of building and textile materials that have been coated or impregnated with the most effective commercial fire-retardants. An attempt will be made to correlate the results of field and laboratory exposures so that further evaluations of protective measures can be accomplished by a means of a laboratory source. The results of these studies will indicate the direction of further developmental work on the commercial products to obtain the maximum thermal protection of materials.

b. General Summary of Project Progress: A survey of the investigations of civilian and government agencies in the field of flame-retarding has been completed and the report distributed. This survey included a classification of the mechanisms by which fire-retardants function, application techniques, and evaluation methods for determining the effectiveness of protective coatings. Painted wood specimens were exposed at the BUSTER tests and calibrated with the Material Laboratory carbon-arc thermal source. The paints employed were Albi Temp Kote 99, Vita Var Exterior 20, Glyptol 2527 and TT-E-489. In addition, three types of cotton twill febrics, commercially treated, were exposed in the BUSTER tests. Rezgard A, Pyroset and Erifon were the impregnants. These impregnated specimens were cut and mounted with M6 liquid-vesicant heat-sensitive paper backing, leaving a 1/16-inch air gap between the cloth and paper. The laboratory evaluations of the treated cloths and coated woods have been completed and the data reported.

c. Work During Current Quarter: Depth-of-char studies on the coated woods exposed at BUSTER have been completed and will be reported shortly. The significant findings are summarized herein under problem 18. A re-survey of the field of fire-retardants and procurement of about forty products from twenty different manufacturers have been completed. Approximately half of these products are chemical impregnants for cloth, consisting chiefly of the temporary or water-soluble-inorganic-salt type. The remaining products consist in large part of coatings for various kinds of building materials together with a few manufacturers' specially prepared specimens. The Laboratory now has on hand for evaluation and study, samples of products representing almost all of the types of flame retarding compounds now being manufactured in this country. Special methods and techniques have been developed for the systematic evaluation and classification of all of these compounds as to their relative effectiveness for imparting or enhancing thermal radiation resistance of certain types of base materials.

d. Contemplated Work for Next Quarter: Using No. 29 Whatman Black Filter Paper Strips as base material, critical energy values for each of the samples of flame retarding impregnating compounds will be determined for five different add-ons ranging from 5 to 25 per cent. The compounds will be classified into chemical types and rated in accordance with their relative standing as effective agents for increasing the resistance of cellulose-like materials to high intensity thermal radiation.

Thermal radiation exposures and depth-of-char measurements will be initiated on wood specimens coated with two, three and four layers of each of the commercial samples of surface coatings. The compounds will then be classified as to their principal chemical constituents and rated in accordance withtheir relative standing as effective agents for protecting wood-like surfaces against high-intensity thermal radiation damage.

Chemicals and necessary facilities will be obtained for the laboratory-scale preparation of fire-retarding compounds.

10. EFFECTS OF SOURCE SPECTRUM ON THERMAL DAMAGE TO MATERIALS

This problem has been inactive for some time due to the higher priority of other problems. It is expected that the study will be resumed in the near future. During the next quarter a summary of the findings to date will be prepared.

11. RECIPROCITY STUDIES

a. Objective: The purpose of the reciprocity studies is to determine the effect of the rate of application of energy (irradiance) on the degree of damage to materials. In addition to the investigation of the range of irradiance where reciprocity holds, it is also of considerable importance to determine the irradiance-damage relationship for the range of irradiance wherein reciprocity does not hold. The study of reciprocity is essential in order to extrapolate critical energy data obtained at one rate of application of energy to other rates, such as those occurring in the field.

b. General Summary of Project Progress: The methods and equipment employed were described in the September 1951 Quarterly Progress Report. The experimental results on maple wood, tropical-weight wool and clear Bakelite are described and discussed in the December 1951 Quarterly Progress Report. The contribution of the "tail" of the thermal radiation pulse of a bomb detonation in furthering damage on maple wood, tropical-weight wool and yellow bond paper was investigated and the results were given in the June 1952 Quarterly Progress Report. It was found that the irradiance after a 0.5-second pulse must be at least 20 to 30 per cent of the original pulse to increase threshold damage and 10 to 30 per cent to further increase damage to the sample. The damage to a material is a function of temperature and, therefore, if the energy in the latter part of the pulse is insufficient to maintain or raise the temperature of the sample, further damage will not occur.

c. Work During Current Quarter: The contribution of the "tail" in extending damage on carbon and matte paper was investigated. It was found that a "tail" of at least 30 per cent is necessary to further both threshold and advanced damage. Due to the difficulty in obtaining an irradiance that will just begin to destroy the sample during the initial 0.5-second pulse, the results on the effect of the "tail" at the point of destruction of the papers are not complete.

d. Contemplated Work for Next Quarter: A continuation of the studies with a 0.5-second pulse and a 0.5-second "tail" will be made on passive indicators, wool serge, cotton sateen and other materials of interest to the Thermal Radiation program. Use will also be made of shorter pulses commensurate with recent data obtained on the field pulse shape. A mechanism will be designed to approximate the field pulse in the Laboratory.

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12. REFLECTOMETRY

a. Objective: The purpose of this inveetigation is to study the reflectance and tranamittance of materials, including dependence on wave length and angle of incidence of the radiation, and on previously sustained damage.

b. General Summary of Project Progress: The spectral reflectance and transmittance of a number of materials of interest in the investigation of damage by thermal radiation were measured. The radiant abeorptances of these materials were calculated for sources of interest. These results have been published in various reports covering the complete inveetigations of the thermal properties of the materiale and also in previous Quarterly Progress Reports. The instruments and techniques employed in the investigation of the reflectance and transmittance have been continuously improved to make possible more accurate measurements on the different typee of samples involved.

c. Work During Current Quarter: The reflectance and transmittance of 28 samplee of cloth were determined as a function of wave length. The radiant absorptance was calculated for these cloths for 10,000°K black-body radiation after passage through 2,000 yards of atmosphere with a visual transmissivity of 50 per cent per mile and for the laboratory carbon-arc source. These results are listed in Enclosure (2). A report is being prepared to present all the important results on reflectometry to date.

The infrared reflectometer is being remodeled for semiautomatic curve-drawing operation. The usefulness of this instrument will thereby be increased and the time required per sample will be considerably reduced.

The 12-in. sphere reflectometer was operated using a lead sulphide cell receiver and a tungsten lamp with a 2-cm water cell. Fifty-six per cent of the radiant energy was in the visible region and 44 per cent in the infrared region as determined by selective filters. Values of radiant absorptance as determined for 20 materials were compared with the radiant absorptance as calculated from the spectrophotometric data and the carbon-arc source. The absorptance values as measured by the sphere were within 6 per cent of the calculated value.

d. Contemplated Work During Next Three Months: The remodeling of the infrared reflectometer will be completed and the reflectance measurements continued. The report covering all the reflectance and transmittance work to date will be completed.

13. THERMAL AND OPTICAL CHARACTERISTICS OF NAVADA SAND

Inasmuch as the report on the thermal and optical characteristics of Nevada Sand has been completed and distributed to the AFSWP Thermal Radiation Distribution List this problem is considered closed.

14. THERMAL AND OPTICAL CHARACTERISTICS OF ENIWETOK SAND

a. Objective: To study the "explosion" of the ground sand noted at field tests, and to measure the pertinent characteristics of the sand.

b. General Summary of Project Progress: The explosion characteristics and chemical properties of the Nevada sands and two common sands, and the thermal and optical properties of the Nevada sands have been measured and reported. A sample of Eniwetok sand was subsequently received and measured.

c. Work During Current Quarter: The thermal and optical properties of the Eniwetok sand were measured and found to be very close to those of the Nevada sands. The chemical composition, however, was much different; the Eniwetok sand is composed essentially of calcium carbonate, while the Nevada sands are mainly silicon dioxide. The Eniwetok sand required 31 cal/cm^2 sec, applied for 0.5-second, to explode; the Nevada sands required only 11 cal/cm^2 sec, and exploded more violently.

d. Contemplated Work During Next Three Months: The final report will be completed and distributed.

15. EFFECT OF REFLECTION FROM SAND ON RADIANT EXPOSURES

a. Objective: To calculate theoretically the effect on exposed materials, of reflection of thermal radiation by the ground in ABD field tests.

b. General Summary of Project Progress: The effect of ground reflection is a potential factor in the evaluation of the results of field tests. In the case of the cosine attenuators exposed by NML at TUMBLER-SNAPPER, determination of this effect was necessary for a complete explanation of the results. For this reason, a theoretical calculation of the magnitude of the effect was made.

c. Work During Current Quarter: The irradiance on an arbitrarily oriented surface was found to be approximately

$$J = \frac{r\,I\,H}{2\,R^3}\, e^{-\alpha R}\, (1 + \cos V),$$

where J = irradiance in cal/cm^2 sec,
r = reflectance of ground,
I = intensity of ball of fire in cal/sec steradian
H = height of ball of fire in cm,
R = slant distance of receiver in cm,
α = attenuation coefficient of atmosphere in per cm, and
V = angle between inward normal to receiver surface and an upward vertical line.

The assumptions made in the calculation, which were all valid as approximations for the conditions obtaining in NML field tests, were:

1. The ball of fire is a point source.
2. The ball of fire is much higher than the receiver.
3. The ground is a diffuse reflector.
4. The attenuation of the atmosphere is not very great.
5. V is not small.

According to this formula, the highest ratio of reflected to direct radiation for a plane sample aimed at the ball of fire is 3 per cent. For a sample not aimed at the source, the reflected radiation may be important. For the cosine attenuators exposed by NML, for instance, an otherwise anomalous effect was adequately explained by the above formula.

d. Contemplated Work During Next Three Months: A final report covering the derivation of the above formula and its application to the cosine attenuators will be completed and distributed.

16. THERMAL CHARACTERISTICS OF HEAT TREATED ORLON

The report, "Relative Protection against Radiation Burns by Heat-treated Orlon", has been distributed to the AFSWP Thermal Radiation Distribution List. This problem, therefore, is considered closed.

17. THERMAL CHARACTERISTICS OF UNIFORM CLOTHING

a. Objective: To determine the heat transfer through one or more layers of uniform clothing under exposure to thermal radiation; to determine the effects of physical parameters, including weight, weave, color, lamination, etc., on the transfer of heat through clothing.

b. General Summary of Project Progress: The thermal characteristics of clothing, particularly the radiant exposures required to produce certain destructive effects on material, have been studied as part of the Services Testing Program. The purpose of this investigation, however, is to determine the physical parameters of clothing influencing the burns produced by thermal radiation to personnel. The first phase of this study is the development of a good substitute for skin to allow physical measurement, either by active or passive indicators, of the heat transfer through clothing materials. The second phase is the correlation of the physical data with those of the actual burns produced on pig skin for identical exposure conditions. During the special investigation of heat-treated Orlon, the usefulness of measuring the temperature rise at the interface between cloth and backing was demonstrated. These results were presented in Material Laboratory Report 5046-3, Part 20. A meat backing was employed for the Orlon studies.

c. Work During Current quarter: Arrangements for cooperative experiments have been made with the University of Rochester Medical School. Rochester will expose pigs to carbon-arc radiation to produce the various types of burns and measure the temperature-time characteristic of the pig's skin during exposure. The Material Laboratory will develop the skin simulant and use similar exposures with this skin simulant instead of the live animal. The results of the experiments of the two activities will then be compared and the temperature-time characteristics of the skin simulant correlated with the temperature-time and burn characteristics of the pig skin.

Polyethylene has been chosen as a skin simulant to be used in laboratory and field studies of thermal radiation burns. Theoretical calculations and experimental work have shown that the temperature-time relationship of polyethylene for a 0.5-second thermal pulse is almost identical with that of the meat used in the study of Orlon characteristics. Preliminary studies have been made on the effect on the temperature-time curves of area of exposure, contact pressure of the cloth, placement of thermocouples and thickness of the backing material.

d. Contemplated Work During Next Three Months: The experimental and theoretical work on the proper contact pressure, exposure area, thickness of backing and other conditions governing proper exposure will be continued. Radiant exposures will be made using the carbon-arc sources at various irradiances and various layers of a standard cloth using polythylene and meat as skin simulants. The temperature of the surface of the skin simulant will be determined as a function of time by employing a fine wire thermocouple and a recorder.

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18. DEPTH OF CHAR MEASUREMENTS ON EXPOSED WOOD

a. Objective: To determine whether depth-of-char may be employed as an index of the thermal damage to wood exposures; to develop a quantitative method of determining the efficiency of coating materials in reducing the amount of thermal damage to wood surfaces.

b. General Summary of Project Progress: The depth-of-char studies of control samples exposed to the laboratory carbon-arc source were outlined in the June, 1952 Quarterly Progress Report. The characteristics of unprotected wood indicate that initial charring begins at a threshold radiant exposure. The actual charred depth increases for greater radiant exposures reaching an asymptotic value as the radiant exposure is increased further. The effect of painted surfaces is to change the shape of this characteristic curve.

c. Work During Current Quarter: The damage to the woods exposed at Operation BUSTER has been analyzed and the problem report is being prepared. It should be published during the next three months.

19. CALORIMETRY

a. Objective: To develop the high-irradiance radiometers required by NML in its thermal radiation program, and to calibrate these and radiometers submitted by other agencies.

b. General Summary of Project Progress: Several types of radiometers have been developed at NML to meet special needs. Recently, radiometers have been received from several agencies for calibration.

c. Work During Current Quarter: A radiometer consisting of a single, directly exposed, thin-wire thermocouple was calibrated for the University of Rhode Island on a contract from the Air Force Cambridge Research Laboratories. The response was linear up to an irradiance of 18.5 cal/cm^2 sec, the highest measured. The sensitivity was 1.5 cal/cm^2 sec per millivolt. The time constant was 0.12 sec. The radiometer is extremely sensitive to air currents; it must be covered for accurate use.

d. Contemplated Work During Next Three Months: Two radiant calorimeters which have been submitted by the Army Chemical Center will be calibrated. They consist of a copper cylinder, 2.5 in. in diameter; one is 2 in. long, the other 1 in. long with a 1-in. projection. Each is enclosed in a box which exposes the flat end through a 2-in. aperture. It will be necessary to use a large area source to calibrate these.

REPORTS SUBMITTED

The progress of the Naval Material Laboratory in its Thermal Radiation studies is summarized in reports which are prepared and distributed as significant findings warrant. To date, the following reports have been issued. Copies are available to the various activities on the Armed Forces Special Weapons Project Thermal Radiation Distribution List upon request. The reports released during the current quarter are indicated by an asterisk (*).

a. Sources of Thermal Radiation and Methods of Exposure

Report of Investigation of Gas-fired Radiant Panel Manufactured by Selas Corporation of America as a Source of Radiant Energy (Naval Material Laboratory Project 5046-2, Part 1, Unclassified) (March, 1951).

Report of Investigation of Analytical and Graphical Determinations of Cam Shapes for Imparting Specified Motions by Means of a Cord over a Fixed Pulley (NML Project 5046, Part 6, Unclassified) (January, 1950).

Determination of the Energy of High-Intensity Radiation at the Focus of a Parabolic Reflector, Using (A) a Black-body Receiving Cell; (B) Metal Foil Receiving Strips (NML Project 5046, Part 4 Unclassified) (July, 1949).

Determination of Intensity Distribution at the Focus of a Parabolic Mirror and the Energy Density on a Moving Surface Using a Tungsten Lamp Source (NML Project 5046, Part 5, Unclassified) (July, 1949).

Theoretical Requirements for a Laboratory Source of Thermal Radiation (NML Project 5046-3, Part 17, Restricted) (April, 1952).

b. Calorimetry

A Method of Measuring High Intensities at the Focus of a Parabolic Reflector with Large Relative Aperture (NML Project 5046, Part 3, Unclassified) (November, 1948)

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Approved:

B H Andrews

B. H. ANDREWS, COMMANDER, USN
For the Director

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LIST OF MATERIALS FOR CRITICAL THERMAL ENERGY EVALUATIONS

Service	Bureau or Agency Concerned	Type of Material	Number of Materials		
			Proposed Originally	Received at NML	Exposed Lab. Source
Navy	Bureau of Supplies and Accounts				
	(1) Naval Clothing Depot	Clothing	25	20	20
	(2) Marine Corps	Clothing	14	14	14
	Bureau of Supplies and Accounts	Packing Materials	3	17	-
	Bureau of Yards and Docks	Construction Materials	13	-	-
	Bureau of Ordnance	Optical Glass	3	13	-
	Bureau of Ships	Plastics	6	12	12
	Bureau of Ships	Decking	8	-	-
	Bureau of Ships	Special Fabrics	3	6	6
	Bureau of Ships	Paint Systems	4	4	4
	Bureau of Ships	Rubber	9	13	-
	Bureau of Ships	Ceramics	2	2	-
	Bureau of Aeronautics	Coatings	4	6	6
	Bureau of Ships	Plastics, Treated Fabrics	3	23	13
Air Force	Air Material Command	Clothing	12	12	12
		Plastics, Metals	14	35	14
Army	Quartermaster Corps	Clothing	20	20	20
	Surgeon General's Office	Clothing, (Assemblies)	9	9	9
Forest Products Laboratory		Draperies	8	8	8

ABSORPTANCE OF MATERIALS FOR THERMAL RADIATION

Material	Radiant Absorptance	
	Black Body Source *	Carbon-arc Source
Nylon faced, wool backed, Spec. No. 16207, U. S. Air Force No. 4, o.d.	0.78	0.57
Nylon ribbon, type 5, Spec. No. 16213, U. S. Air Force No. 5, white	0.40	0.39
Nylon, type II-for flying clothes, Spec. No. 16169, U. S. Air Force No. 6, o.d. class "A"	0.69	0.44
Wool, gabardine, type II, Spec. MIL-C-6403, U. S. Air Force No. 7, gray 167	0.53	0.42
Nylon satin, Spec. No. 16211, U. S. Air Force No. 8, o.d.	0.77	0.55
Wool, gaberdine, type I, Spec. MIL-C-6403, U. S. Air Force No. 9, blue 84	0.84	0.64
Cotton sateen, 3-ply warp type II, water and mildew resistant, Spec. No. 16159, U. S. Air Force No. 10, o.d.	0.81	0.60
Nylon, type II, class "A" for flying clothes, Spec. No. 16169, U. S. Air Force No. 11, blue	0.80	0.52
Cotton twill, U. S. N. No. 1, white	0.26	0.25
Cotton twill, U. S. N. No. 2, khaki	0.64	0.42
Cotton herringbone twill, U. S. N. No. 3, green	0.87	0.68
Cotton, denim, U. S. N. No. 4, blue	0.85	0.64
Cotton, chambray, U. S. N. No. 5, blue	0.68	0.48
Cotton, knitted undershirt, U. S. N. No. 6, white	0.30	0.25
Cotton, jungle winter clothing, U. S. N. No. 7, green	0.91	0.86

* 10,000 K

Material	Radiant Absorptance	
	Black Body Source *	Carbon-arc Source
Cotton twill, impregnated for protective clothing, U. S. N. No. 8, white	0.34	0.29
Rayon, acetate, neckerchief, U. S. N. No. 9, black	0.94	0.93
Wool, melton, U. S. N. No. 15, 16 oz., blue	0.90	0.71
Wool, kersey, U. S. N. No. 16, 30 oz., blue	0.90	0.73
Wool, flannel, U. S. N. No. 17, 11 oz., blue	0.90	0.71
Wool, serge, U. S. N. No. 18, 14 oz., blue	0.91	0.75
Wool, trop. worsted, officer's uniform, U. S. N. No. 19, khaki	0.69	0.52
Cloth, combined butyl rubber, rain clothing -N-2, U. S. N. No. 20	0.82	0.65
Cloth, coated alkyd resin, foul weather clothing, U. S. N. No. 21, gray	0.91	0.91
Cloth, combined vinyl resin, U. S. N. No. 22	0.97	0.92

* 10,000 K

3 September 1952

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