AFSWP-778

UNCLASSIFIED

TECHNICAL LIBRARY
JUL 17 1956
of the
ARMED FORCES
SPECIAL WEAPONS PROJECT

AFSWP-778
Copy No. 173

PHYSICAL PROPERTIES AND BIOLOGICAL EFFECTIVENESS FOR BURN PRODUCTION OF FLAME SOURCES

Research and Development Technical Report USNRDL-TR-34
NM 006-015.02

21 December 1955

by

E. L. Alpen
C. P. Butler
S. B. Martin
A. K. Davis

DTL 005946

DNA1.940928.097

U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY

SAN FRANCISCO 24 · CALIFORNIA

HRE-0321

RECORD COPY

UNCLASSIFIED

U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY
SAN FRANCISCO 24, CALIFORNIA

3-700
ARB:mle
JUL 1 0 1956

From: Commanding Officer and Director
U. S. Naval Radiological Defense Laboratory
To: Department of Defense Agencies on Distribution List for Report

Subj: U. S. Naval Radiological Defense Laboratory Report USNRDL-TR-84; forwarding of

Encl: (1) U. S. Naval Radiological Defense Laboratory Report USNRDL-TR-84 entitled "Physical Properties and Biological Effectiveness of Flame Sources," Project NM 006 015.02, Phase 1

1. In the basic work described in the subject report, techniques previously developed for measurements of thermal radiation at nuclear detonations have been successfully applied to study the radiation characteristics of flaming fuel beds. By use of filter ratio techniques it has been possible to establish the color temperature of the source, its emittance, and its irradiance. This is the first time that the radiation parameters of flame sources have been quantitatively defined.

2. These physical parameters were then applied to measure the biological effectiveness of flame radiation and establish tolerance levels for human exposure to these sources.

3. From previously measured laboratory data and the results of this study a model system has been established from which "critical energy" for human burn production from any radiant energy source may be estimated.

4. In addition it has been shown that burning forest fuel beds are feasible radiation sources for both physical and biological measurements.

A. R. BEHNKE
By direction

UNCLAS

PHYSICAL

Researc

Reproduction of this document in any form by other than activities of the Department of Defense is not authorized unless specifically approved by the Secretary of the Navy or the Chief of Naval Operations as appropriate.

Health and Bi

Ca

Scientific Dir
P. C. Tompki

U. S. I

UNCLASSIFIED

PHYSICAL PROPERTIES AND BIOLOGICAL EFFECTIVENESS FOR BURN PRODUCTION OF FLAME SOURCES

Research and Development Technical Report USNRDL-TR-84
NM 006-015.02

21 December 1955

by

E. L. Alpen
C. P. Butler
S. B. Martin
A. K. Davis

Health and Biology

Technical Objective
AW-6

Thermal Injury Branch
E. L. Alpen, Head

Biological and Medical Sciences Division
Captain A. R. Behnke, Jr. (MC) USN, Acting Head

Thermal Radiation Branch
W. B. Plum, Head

Nucleonics Division
A. Guthrie, Head

Scientific Director
P. C. Tompkins

Commanding Officer and Director
Captain R. A. Hinners, USN

U.S. NAVAL RADIOLOGICAL DEFENSE LABORATORY
San Francisco 24, California

UNCLASSIFIED

ABSTRACT

Measurements of the physical characteristics of flame sources of radiant energy have been made, using radiometric equipment previously designed for use at nuclear weapon field tests. These measurements, made on an extended plane flame source approximately twenty by twenty feet, have shown the source to be equivalent to a black body source radiating at a temperature of approximately 1200°K and with an emissivity of about 0.3. The irradiance values for these sources is of the order of 0.7 cal/cm^2/sec at a distance of five feet from the flame front. Estimation of "color temperature" was made by a filter ratio method, using energy transmitted by silver chloride and two Corning vitreous filters (7-56 and 2-58).

Biological studies of the effectiveness of this radiation in producing cutaneous burns in man and the rat have shown that the radiation from this source has an effectiveness approximating the ideal maximum. This maximum is taken as the critical energy value for any thermal radiation on blackened skin. On rat skin 2.1 $\pm$ 0.2 cal/cm^2 was required in a 1 to 3 sec exposure to produce minimal perceptible coagulation. With increasing exposure time this value rose slightly to 2.6 $\pm$ 0.5 cal/cm^2 at 4 to 8 sec exposure times. For human skin 1.4 $\pm$ 0.13 cal/cm^2 was required for vesication at the shorter exposure times, $<$2.5 sec; for 5 to 10 sec exposures this value is 3.8 $\pm$ 0.29 cal/cm^2.

From this data and that previously reported on laboratory sources, critical energy for persistent erythema as a function of color temperature has been synthesized. It has been shown that for human skin the persistent erythema critical energy rises smoothly from 1.64 cal/cm^2 for a 1200°K source to 4.6 cal/cm^2 for a 6000°K source with no intermediate maxima in this range of temperatures. A general method has been stated for estimating critical energies for any spectral distribution of energy.

SUMMARY

The Problem

What are the radiation characteristics of flame sources and how effective is this radiation in cutaneous burn production?

Findings

Burning forest fuels radiate at a temperature of approximately 1200°K with an emissivity of 0.3. The radiation is very effective in burn production on rat and human skin. Approximately one-half as much total energy is required from this source as is required from a carbon-arc source for equivalent burns.

ADMINISTRATIVE INFORMATION

The work described in this report was done under special contract with the Armed Forces Special Weapons Project, approved in letter from Chief, AFSWP SWPSG/936-928 of 15 June 1955 to Chief, Bureau of Ships.

Approval of the Secretary of the Navy for human studies is contained in letter from Chief, Bureau of Medicine and Surgery BuMed-71-cm All/L5-2, 16 July 1951.

Acknowledgment

The authors wish to acknowledge the enthusiastic support and advice provided by the Fire Research Division of the U.S. Forest Service, and particularly the Chief of the Division, Mr. A.A. Brown, Washington, D.C. Without the continuing physical and moral support of the personnel of the California Range and Forest Experiment Station at Berkeley, particularly Messrs. W.L. Fons and A.R. Pirsko this project would not have been successful. In addition we would also like to acknowledge the able support of Mr. C.A. Abell, District Ranger at McCloud, California, not only for his tolerance during our stay in his district but also for the unlimited physical assistance provided.

1 INTRODUCTION

This Laboratory has for some time been interested in the nature of the response of human and animal skin to thermal radiation in various spectral regions. Studies with carbon arc sources have documented rather adequately the effects of visible and near infrared radiation on skin[1,2] but the limitations of this type of source prevent an extension into the infrared region.

The production and use of a constant source of low temperature thermal radiation was first suggested to this Laboratory by U.S. Forest Service personnel who had been using so-called crib fires[3] in their studies of the behavior of fire spread and its associated phenomena. Similar studies have also been done by the British for the purpose of evaluating the partition of energy in the combustion of wood.[4] In all these experiments, the purpose of building a given array of wood was to reproduce fires of the same characteristics. This source should be ideally adaptable as an infrared source for measurement of biologic effect at high irradiance levels in the spectral region beyond 2.0 μ. Simultaneously physical characteristics of flame sources could be studied with the aim of establishing the role of thermal radiation in production of burns in forest or urban conflagrations. With the risk of large urban conflagrations as a result of nuclear warfare it was felt that measurement of biological effectiveness and physical properties of flame sources was an extremely worthwhile objective.

2 PILGRIM CREEK EXPERIMENTAL STATION

A portion of the Shasta-Trinity National Forest, known as the Pilgrim Creek Experimental Station has been designated by the U.S. Forest Service as a site for work on fire research. This location was selected because the terrain is level, the tree growths range from open spaces of several acres to dense groves of trees (mostly Ponderosa pine), and

because the weather conditions are ideal for safe firing. Situated in a broad valley, the laboratory is located at a place where the diurnal flow of air changes direction twice a day, once in the morning and again in the evening. In the short interval between shifts in the wind direction, a nearly dead calm persists for an hour or more. It is during these times that it is relatively safe to ignite a large fire.

The laboratory facilities included one large building equipped with hot and cold running water, tables, chairs, and a wood stove for heat. The personnel housing equipment included tents and tent frames with cold water piped from a spring 5 miles away.

3 THE FUEL CRIB

The shape and size of the crib used in these fires was recommended by Mr. Wallace Fons of the U.S. Forest and Range Experiment Station, Berkeley, California, as the best for producing the maximum irradiance and the desired constancy.

For the types of fires required here, sound logs, with bark intact, about 4 in. in diameter and 10 ft long were required. Among the trees in the denser part of the woods there are many of 30 to 40 ft in height which are essentially dead, but which have not yet fallen and are still sound and free of dry rot. These trees were carefully selected, felled, limbed, cut to length, and hauled to the burning site.

It is obvious that in the selection of 100 logs, there will be variations in the diameters, so that in building a crib, large and small logs were distributed in such a manner that each row would have about an equal number of large and small logs. All cribs were identical in outside measurements and distribution of logs. Each log was weighed before being placed in the crib so that all contained essentially equal weights of fuel. Eight iron pipes were driven into the ground flush with the sides and wired together at the top to prevent the logs from falling away during the fire. Figures 1a and 1b are photos of a normal fuel crib before firing.

Ignition of the crib was started by two men with torches walking around the base and touching the scattered layers of pine needles which had been sprinkled among the logs near the bottom during the construction. The time lapse between the initial ignition and the blowup was about 1 minute.

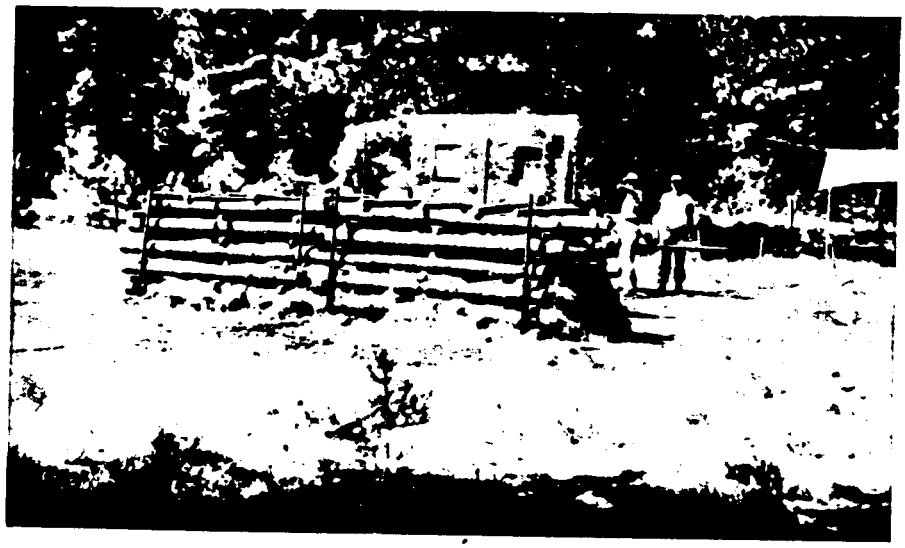

Fig. 1a, 1b Views of the Normal Fuel Crib Before Firing. In Fig. 1a the water-cooled radiometer is visible on the tripod at the right. Fig. 1b is a general view of the area showing exposure panels and instrument shelter.

TABLE 1

Fuel Crib Characteristics

Length	20 ft
Width at bottom	70 in.
Width at top	36 in.
Height	50 in.
Average log diameter	4 in.
Volume of fuel	88 ft^3
Volume of crib	368 ft^3
Surface area of fuel	1040 ft^2

Fire No.	Total Weight (lbs)	Density of Fuel (wet weight)
1	3620	0.57
2	3475	0.54
3	3620	0.57
4	3725	0.60
5	4090	0.64
6	3800	0.60

The data presented in Table 1 represent average values for the dimensions of the cribs. It should be pointed out that precise dimensions are not realistic in the building of such an array of fuel, but the lengths given were measured with a steel tape and are correct to approximately 1 in. It should be noted that the density of the wood as presented here is the wet weight density, or the actual density of the fuel as it was used. This is not the density often quoted by the USFS, in which the density of the dry fuel is implied.

4 FIRE BEHAVIOR AND GROSS APPEARANCES

During the time between ignition and the full development of the flames there was a sharp updraft carrying smoke and embers, probably mostly the pine needles and the bark. This phase of the fire has been called the "blowup" and during this period no measurements except radiant power as a function of time were made.

After about 2 to 3 minutes, the fire became much more stable and presented a more uniform appearance (Fig. 2). The flames were approximately 15 to 20 ft high and 15 to 20 ft wide. There were distinct and quite uniform contractions of the flame a few ft above the fuel bed. At eye level, it was estimated that the thickness of the flame looking along the length of the crib was not more than 18 inches. Likewise at either end the flames drew in from the maximum length of the crib.

While the photographs of the flames were alike in showing an opaque flame front, under certain observing conditions, it was apparent that the flames were not opaque. If one stood in a position opposite the exposure panels, most of the details of the shutters could be clearly seen through the flame. One of the reasons for this was the intense illumination of the panels from the visible radiation emitted by the flames. If one looked through the flames toward the dark background of the trees, they appeared opaque just as in the photographs, thus showing that the apparent optical density depends on the illumination of the background behind the flame front.

5 SPECTRAL DISTRIBUTION OF ENERGY AND FLAME TEMPERATURES

5.1 Technique

Since it was known from previous work on fires of the type used here that the irradiance would not be constant, it was thought impractical to scan the flame front with a calibrated spectrometer. It was therefore decided to measure the spectral distribution with filters isolating certain portions of the spectrum.

If the total radiation from a given source is measured with a detector sensitive to all wave lengths and simultaneously measurements are made with a nonselective receiver through a series of filters, a series of ratios will be obtained between each filter and the total radiation. These ratios can also be calculated on certain assumptions about the spectral distribution of energy at the source. The assumptions in the present case involve two paramèters of the flame front; first that it is a black or gray body, and second that it has a unique radiation temperature.

It should be emphasized that this entire procedure is based on the assumption that the source does in fact radiate as a black or gray

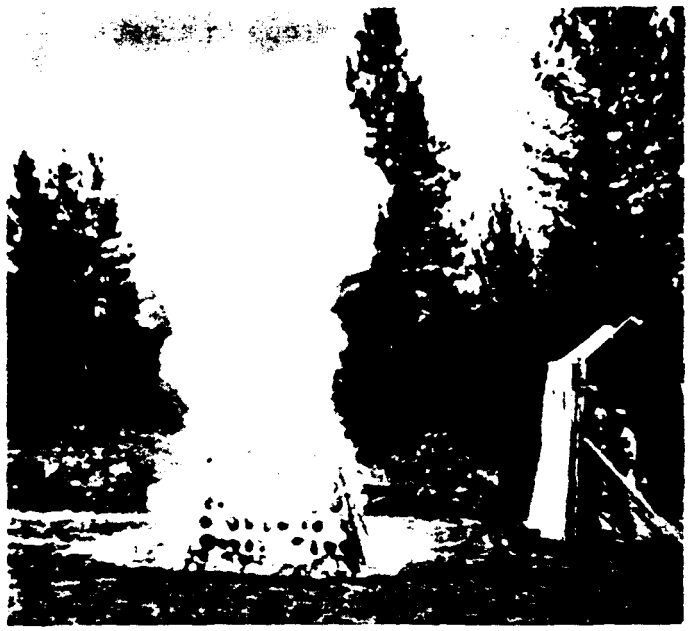

Fig. 2 Appearance of the Flaming Crib Approximately 2 Minutes After "Light-off." The stake at the right of the fire indicates the shield location at the time of exposures. During this blow-up period the shields were left at the position shown here.

body at the flame temperature. This is not completely unjustified for highly luminous flames[5]; Gaydon and Wolfhard[6] point out that the color temperature of the candle flame differs from its true temperature by only 100°C. They indicate further that as the thickness of a luminous flame is increased, its emission approaches that of a black body.

The sensitivity of this method depends among other things on the band width of the filters. In the present case, the band width is very wide in comparison with the interference filters commonly used in flame temperature determinations. This width was dictated by the sensitivity of the receivers and by the necessity of transmitting sufficient energy through each of the filters to produce a cutaneous burn in the animal. The sacrifice in sensitivity was compensated for by the ease of observing, and by the practical considerations of placing detectors in the radiation field of the flames at a distance of a few feet.

The method of determining the filter ratios theoretically starts with drawing energy distribution curves for a series of Planckian radiators at different temperatures. These curves are, of course, in terms of black body emitters and as such they describe the maximum possible intensity at each wave length.

After these series of curves have been drawn, the ordinates of each are multiplied by the spectral transmission of the filters and a second series of curves drawn under each of the Planckians. These curves are for each of the filters and there are sets of filter curves for each temperature. After these curves have been drawn, the areas under all curves are measured with a planimeter and ratios computed for each filter.

Expressed mathematically, the following operation was performed for each of several temperatures. The selection of the temperatures was made on a purely arbitrary basis with the hope that the experimental data would fall within the ranges chosen.

The ratios are

$$R = \frac{\int_{\lambda_1}^{\lambda_2} t(\lambda) J_T(\lambda) d\lambda}{\int_0^{\infty} J_T(\lambda) d\lambda}$$

Where R = Ratio

λ = Wave length

$t(\lambda)$ = Transmission of filter at λ

$J_T(\lambda)$ = Emittance of black body at temperature T.

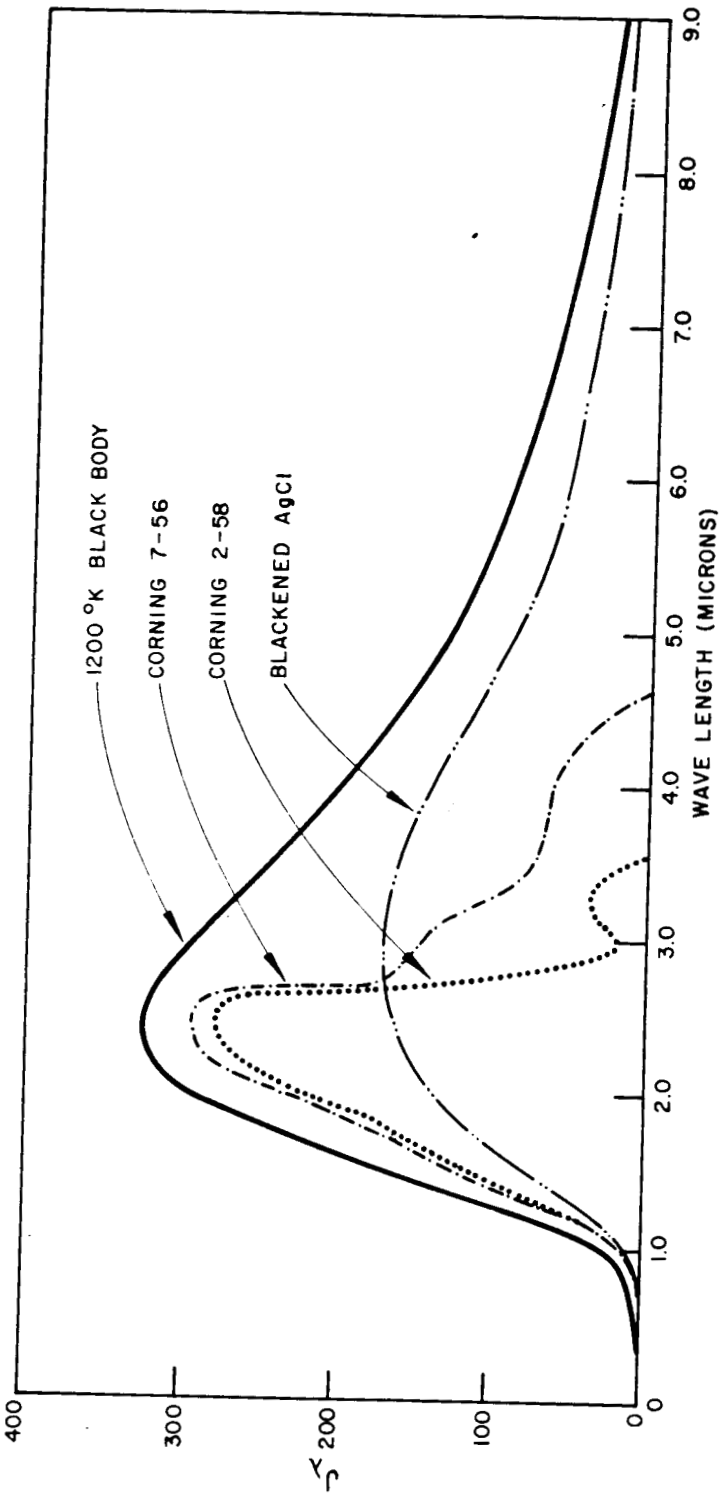

Fig. 3 Planckian Energy Distribution Curve and Filter Transmission Curves for a 1200°K Radiator.

Figure 3 shows one of the Planckian curves and the calculated energy transmission of each of the three filters. It should be clear from these curves, that if one observed the total radiation of a black body at the temperature indicated, one would see through each filter an irradiance corresponding to the ratio as expressed above.

In Fig. 4 are plotted the theoretical ratios, determined as shown, as a function of temperature. These are smooth curves, and it can be seen that the method is sensitive because of the nonuniformity of slope of the ratios between the glass filters and the silver chloride.

5.2 Instrumentation

The large exposure panel or shield is shown in Figs. 5 and 6, and the animal exposure panel is shown in Fig. 7. Below the animal rack can be seen the cases containing the calorimeter and radiometer used on each exposure.

In recording the irradiance level at any time in the burning period the following procedure was used:

1. An exposure panel with one calorimeter and one radiometer with filter attached was placed in the shield.

2. Electrical junctions were connected between the instruments and cables leading to the Heiland Recording Oscillographs located 60 feet behind the shields.

3. The recorders were started by the operator throwing a switch attached to the back of the shield. When they were in operation a red light blinked showing that the paper was running properly through the oscillographs.

4. After the recorders were started, a trip was pulled on the first shutter, thus opening the exposure panel to the radiation from the flames. At an appropriate time later, a second trip was pulled, dropping a second shutter thus closing the aperture.

5. After allowing the recorders to run for 10 seconds in order to get a good instrument thermal decay rate, the recorders were stopped.

After the operation was completed, electrical calibration deflections were placed on each oscillograph record for each instrument used. The reduction of the data followed the standard procedure used in reducing data from any thermal radiation pulse of energy.

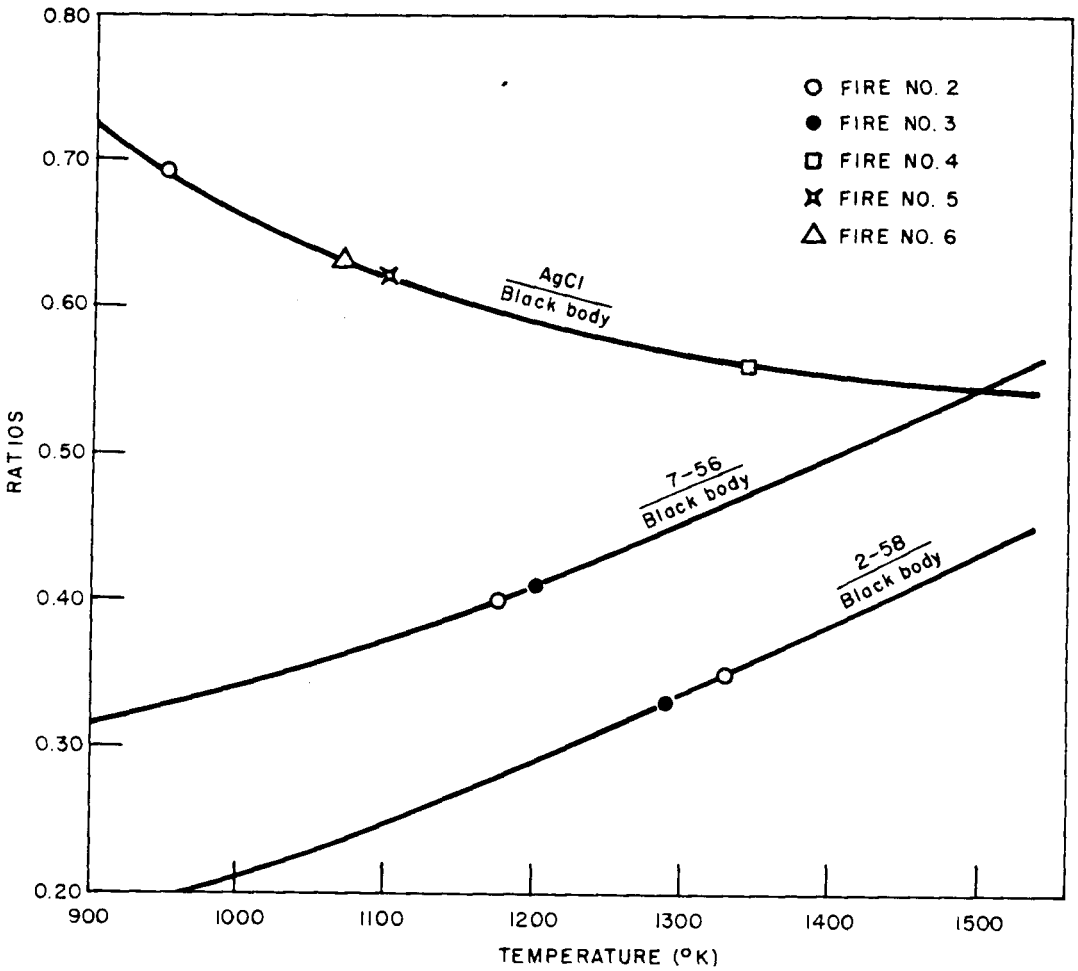

Fig. 4 Theoretical Curves for Filter/Black Body Transmission Ratios. Points are observed in the various fires.

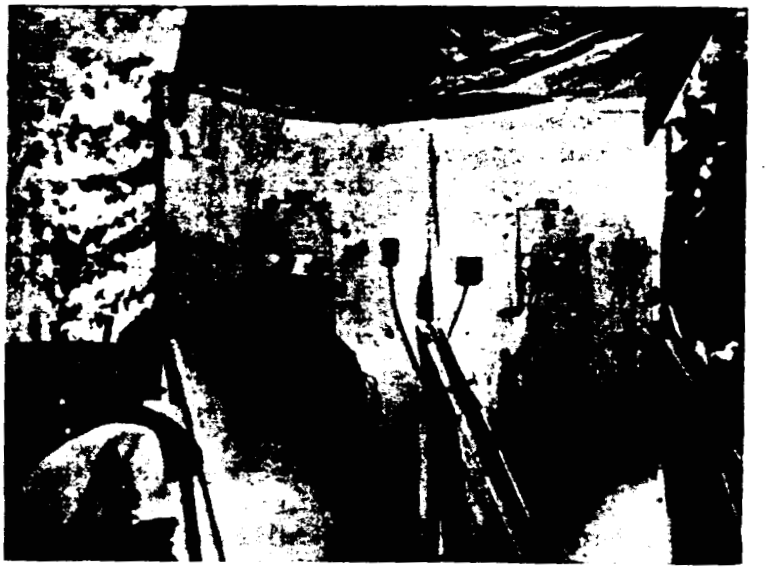

Fig. 5 Rear View of Shields Showing the Human Exposure Panel with Radiometers and Calorimeters in Place; Recorder Cables are Connected to the Appropriate Instrument.

Fig. 6 Front View of Shields with Aluminum Reflective Curtain in Position. The shutter on the left is closed. The right hand shutter is in the open position, exposing the filter array used in spectral studies.

The calibrations of all instruments were made in the laboratory using either the carbon arc or tungsten sources which in turn were calibrated by secondary standard calorimeters. All calorimeters used in the measurements had copper buttons 3/8 in. in diameter and 0.020 in. thick. The calibration constant for these instruments is in terms of $cal/cm^2/mv$. All radiometers used in the exposure panels were suitable for irradiances up to 10 $cal/cm^2/sec$. Radiometers of this type do not require a correction for the decay constant and by applying the calibration directly to the reading in millivolts, the irradiance may be calculated.

Actual exposure time could also be directly estimated from the radiometer deflection on the oscillograph trace.

For the measurement of the spectral distribution in the visible portion, small glass cells were blown which fitted into the calorimeter cases. These cells had front and back walls of the same glass used in the laboratory measurements and the solutions in each were identical to those described in these studies.[1]

Besides the irradiance measurements made of the flames at distances of a few ft, continuous measurements were also made of the flame irradiances at a distance of some 12 ft from the front of the crib. These were made with a water-cooled radiometer with a 2π field of view, of the type used in the laboratory for monitoring the 36-in. source. It has a sensitivity of approximately 1.0 $cal/cm^2/sec/mv$. Water was provided to the radiometer from a suspended 5-gal. can and rubber tubing running this water to the instrument. The rate of water flow was adjusted so there was just enough water to cool the instrument for the entire period of the burning, about 80 min. This measurement was made for the purpose of determining the total radiant output of the fire over the entire burning period.

6 PHYSICAL RESULTS

In order to assure the success of the physical measurements, one calorimeter and one radiometer were used in each of the exposures. This was done because these two instruments operate on different principles, and experience has shown that often information from one will be available when the other fails for any reason. Since the spectral region of interest in these fires extended well beyond the region of quartz transparency, the calorimeters were exposed with no filter of any kind. It was found that the variations in air currents altered the

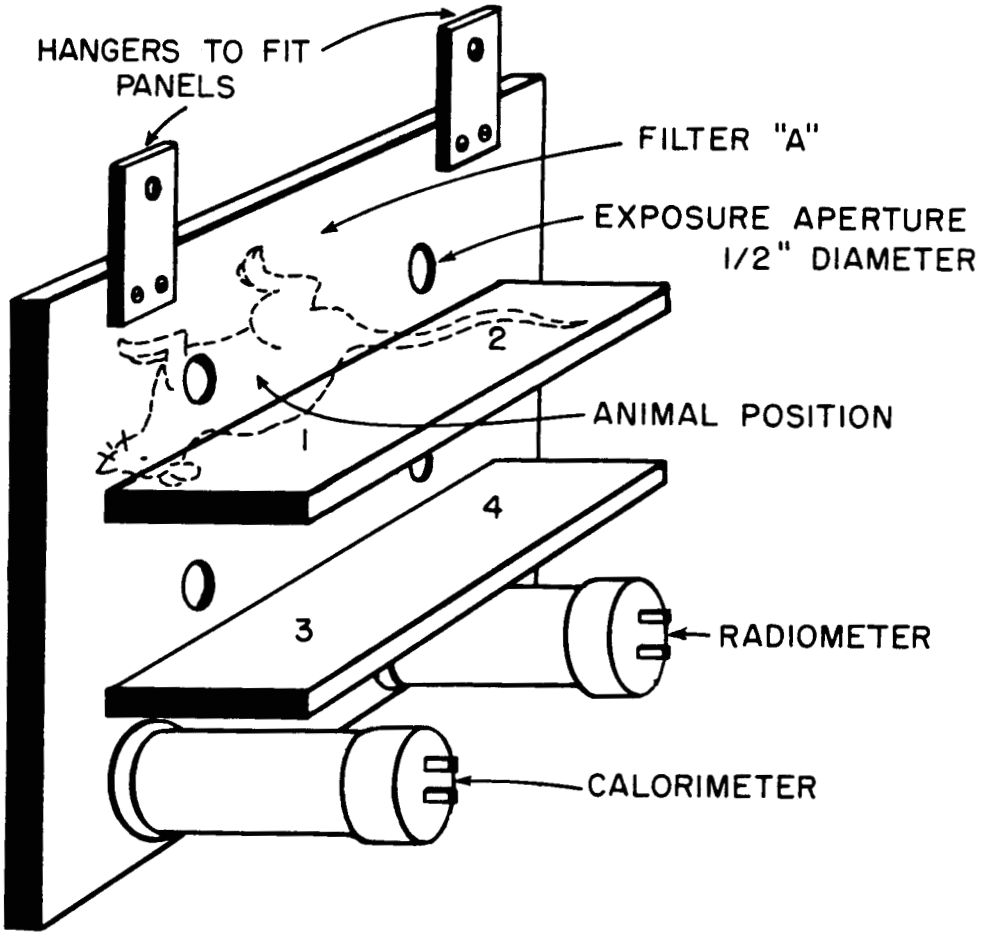

Fig. 7 Sketch of Rat Exposure Panel Showing Exposure Aperture and Calorimeter Radiometer Mounts.

temperature rise in the calorimeter buttons to such an extent that none of the measurements made with the bare calorimeters could be used. On return of these instruments to the laboratory, identical instruments were exposed to the sun with and without a filter, and it was found that there was an apparently greater irradiance in all cases with the quartz filter in place. Since the measured transmission of these filters for a 6000°K black body is 0.92, it was concluded that the button type calorimeters could not be used without a filter of some kind.

The radiometers on the other hand, because of their high inherent decay rates, are not appreciably affected by convective losses when no filter is used. Therefore they gave reliable estimates of irradiance even though they were not equipped with filters. For this reason, "no filter" irradiances were estimated from radiometer oscillograph traces, and calorimeter "no filter" measurements were rejected.

The irradiance of the fire for nearly the entire period of burning is shown in Fig. 8. The blowup at the beginning is clearly shown as a spike very soon after ignition. Then there is a period of time when the irradiance is more or less constant. The curve is a mean of Fires 4, 5, and 6.

In Fig. 9 are shown irradiance levels measured at the exposure shields at a distance of 8 ft from the flame front. It will be noticed that the time scale in this graph is considerably extended over that of the preceding figure. This fire was selected as showing the most uniform period for the longest time. Not all the fires showed such a uniform irradiance for the period shown here. These curves of irradiance vs time are very similar to those obtained for standard wood crib fires reported by the British.[8]

The three filters used and their respective irradiance levels are given in tabular form in Table 2. In the same table are shown the irradiance levels with no filter in place. The observed ratio of any filter is, then, its irradiance value divided by the corresponding "no filter" irradiance level.

The spectral results are shown in Fig. 4, where the observed ratios from the above table are plotted on their respective filter curves. It should be obvious that if no errors of observation had been made, and that if the fires radiate as a black or gray body, then all the ratios should have fallen on one temperature value. It is evident that all these ratios do not, in fact, fall at the same temperature. A mean of all values falls close to 1200°K. From these observations, then, the effective black body temperature of the flames may be taken as approximately 1200°K.

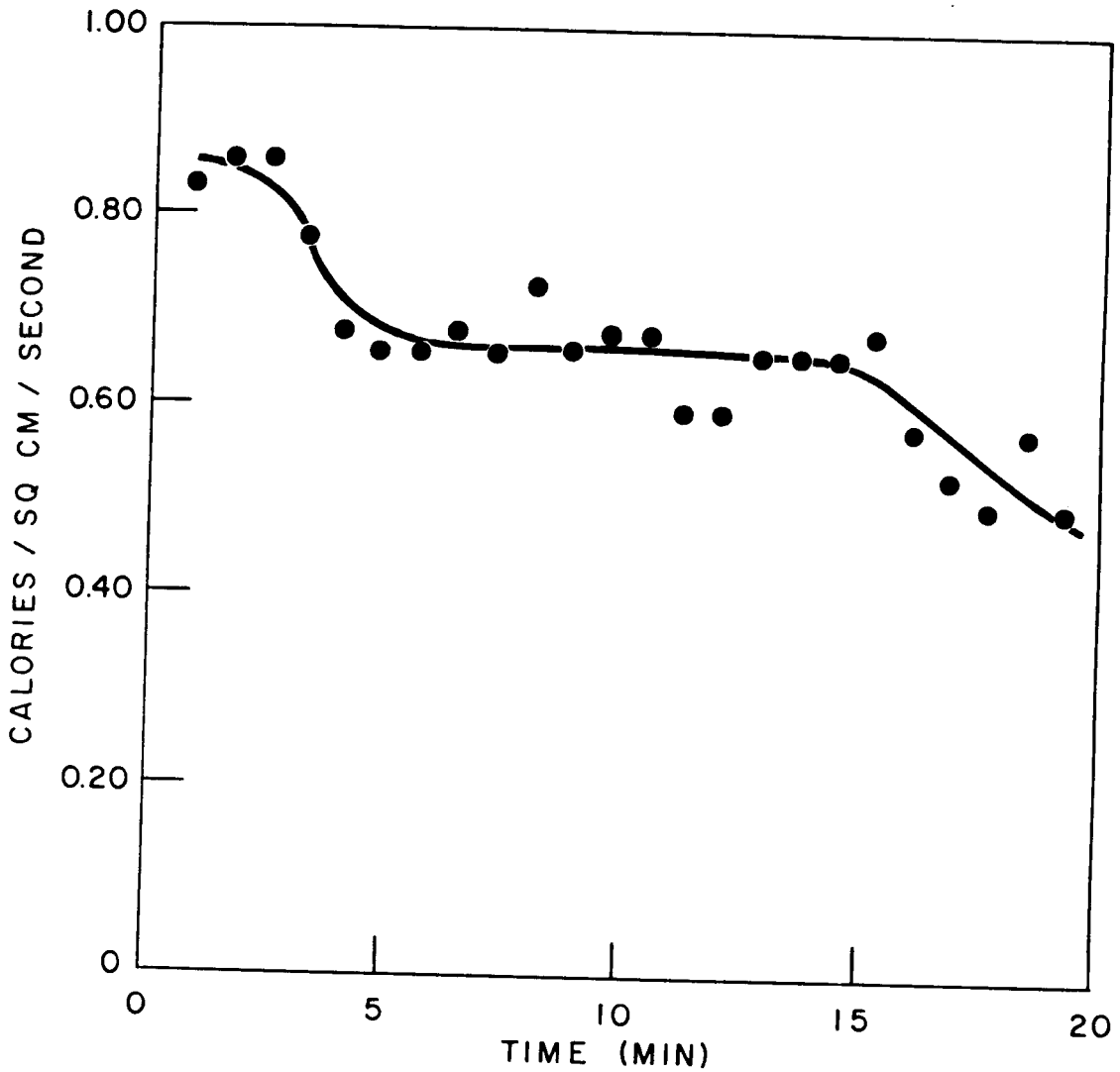

Fig. 8 Irradiance as a Function of Time for a Representative Fire. Points are observed irradiance for multiple exposures of calorimeters or radiometers in exposure shields.

TABLE 2

Summary of Spectral Irradiance Levels

(means of observed values during the period when biological exposures were made, cal/cm^2/sec)

Fire No.	Without Filter	Filter "A"	Filter "B"	Filter "C"
2	0.65	0.45	0.23	0.26
3	0.58	-	0.19	0.24
4	0.70	0.39	0.14	-
5	0.56	0.35	-	-
6	0.64	0.40	-	-

Filter "A": Silver chloride coated with a sulfide to reduce its transmission in the visible to a negligible value.

Filter "B": Corning glass filter known as 2-58.

Filter "C": Corning glass filter known as 7-56.

In order to examine the visible portion of the spectrum, a set of filters was prepared which would transmit only in the visible. The solutions used and the wave length limits of these filters have already been described.[1] Six calorimeters were mounted on a single panel so that all could be exposed simultaneously behind the appropriate filter. In none of the filters isolating the visible portion of the spectrum was there enough energy to produce a deflection of the traces, i.e., less than 0.03 cal/cm^2. It was concluded, therefore, that the amount of energy below about 1.0 micron was less than approximately 5 per cent of the total energy radiated by the fires.

7 EMISSIVITY OF THE FLAME FRONT

It can be shown that if a plane rectangular source of uniform emittance is measured by an instrument at a given distance from one corner of the plane, a view factor can be calculated.[7] In the present case, motion pictures of the flames showed that they were approximately 20 ft

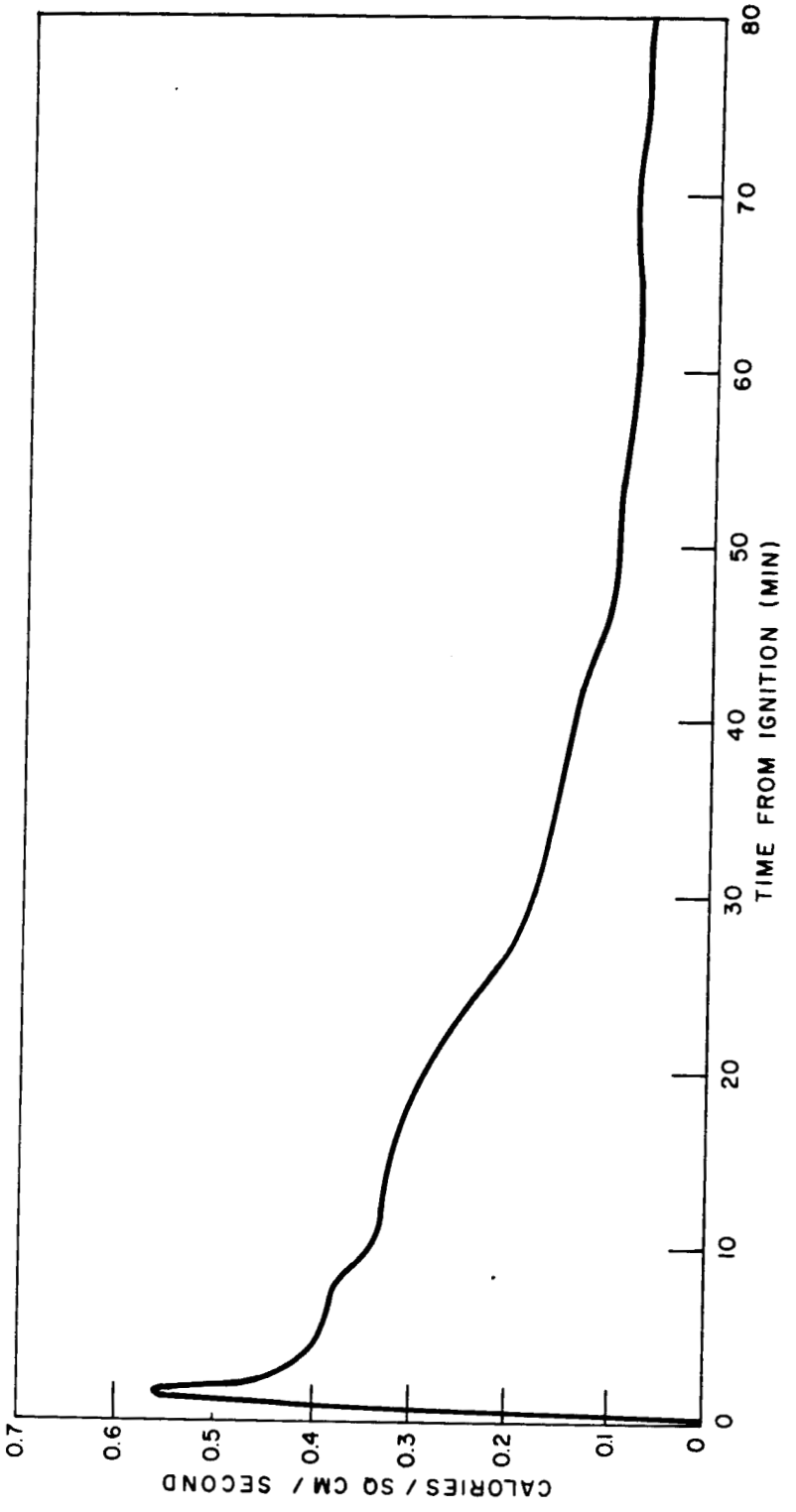

Fig. 9 Continuous Irradiance-time Measurement with a Water-cooled Radiometer at Eight Ft from the Flame Front.

ı set of
The
already
anel so
e filter.
um was
, less
int of
per cent

m emit-
ne corner
ase,
ely 20 ft

FIED

high and 20 ft wide during the steady state time of the burning. The water-cooled radiometer was placed at a distance of 10 ft from the front of the crib and was supported on a post 5 ft above the level of the ground. At this position the radiometer "saw" the whole flame front and no correction of view factor was necessary for radiometer field of view. Substituting these figures into the parameters given in the reference above, the view factor for the fires is 0.5.

The irradiance from a source such as was defined by these fires may be expressed by the following equation:

$$H = F\epsilon\sigma T^4$$

where

H = irradiance at the radiometer (cal/cm^2/sec)

F = view factor

ϵ = emissivity of the source

σ = Stefan-Boltzman constant

T = temperature of the source (^{o}K)

The measured quantities in the above equation on the assumptions noted are:

H = 0.41

F = 0.50

T = 1200°K.

Substituting these values in the equation and solving for the emissivity, a value of ϵ = 0.3 is obtained. The emissivity value is clearly dependent upon the thickness of the flame front and it is not to be assumed that this emissivity value can be assigned to flame sources in general.

8 BIOLOGICAL STUDIES

Methods

The exposure equipment described in the previous section was used in all biological exposures. Animal exposures were made in groups of four using the animal exposure port described in Fig. 7. Human exposures were made singly through the exposure ports shown in Fig. 5.

Preparation of skin of the rats was made by the method of Kuhl, et al.,[7] at least three days before exposure. The volar surface of the forearm of volunteer subjects was closely clipped and lightly cleansed with soap and water before exposure.

Animal burns were graded 5 min and 24 hr after exposure by the following scoring system:

Grade 0 – No response

Grade 1 – Barely perceptible coagulation

Grade 2 – Minimal white

Grade 3 – White

Grade 4 – White with minimal blanch

Grade 5 – White with full blanch.

This is a minor modification of a previously reported system.[1] Analysis of this data was by the method of regression of severity score on log dose as previously reported.[1]

Human burns were graded by the following scoring system:

Grade 0 – No response

Grade 1 – Transient erythema

Grade 2 – 24-hr persistent erythema

Grade 3 – Vesication

Grade 4 – Mild coagulation

No effort was made to fit the human data to a regression because of the relative paucity of data. It is not feasible to make as many exposures as are possible with the rat burns. For this reason, an average effective energy was calculated with its associated standard deviation.

9 RESULTS

9.1 Rat Skin

Eight rats were exposed in four different areas to radiation through each of four filter combinations, i.e., none, AgCl, Corning 2-58, Corning 7-56, at each of three fires. A total of 96 burns through each

of the four filters were then available for the regression analysis. The results of this analysis are given in Table 3.

Apparently the radiation reaching the animal's skin through all four filters approaches in effectiveness the value for radiation from a 6000°K source on blackened rat skin. The slight upward trend in critical energies seen in the various values for the four filters can be best explained in terms of failure of reciprocity as previously reported from this laboratory for a 6000°K source.[10]

TABLE 3

Burns on Rat Skin from a Flame Source

Exposure Time (sec)	Filter Used	Biological End Point: Minimal Perceptible Coagulation (cal/cm^2)	Biological End Point: Minimal White (cal/cm^2)
1-3	None (1200°K B.B.)	2.1 ± 0.2*	2.7 ± 0.4
2-5	AgCl	2.1 ± 0.3	3.0 ± 0.4
3-6	7-56	2.2 ± 0.4	3.0 ± 0.4
4-8	2-58	2.6 ± 0.5	3.5 ± 0.5
		Laboratory Findings	
2.0	None (6000°K B.B.)	4.5 ± 0.1**	6.5**
2.0	None (6000°K B.B.) Blackened skin	2.2***	

* Standard deviation
** From: Sheline, et al.[9]
*** From: Alpen, et al.[1]

9.2 Human Skin

Because of the obvious lack of critical energy dependence upon filter used that was observed in the rat data, studies with Corning 2-58 and 7-56 were excluded in this study. Exposures were made at two fires on eight subjects. Six burns were inflicted on each arm, three through each of the two filters. A total of 48 burns was observed.

Preliminary calculations of the "mean effective energy" for total radiation and radiation through silver chloride indicated that no significant differences existed between critical energies for the two filters. For this reason the data from the two were combined to arrive at a pooled estimate of the critical energy for the various end points. Table 4 contains the mean effective energies with their associated standard deviations.

TABLE 4

Human Burns from a Flame Source

End Point	Exposure Time (sec) 0 - 2.5 Av 1.7	2.6 - 3.5 Av 3.0	3.6 - 4.5 Av 4.0	4.6 - 5.5 Av 5.1	5.6 - 10.0 Av 8.0
No response (31)	0.9* ± 1.7 (6)**	1.5 ± 0.47 (3)	1.74 ± 0.34 (5)	1.78 ± 0.34 (9)	2.29 ± 0.56 (8)
Transient erythema (22)	1.7 (1)	1.95 ± 0.1 (3)	1.5 (1)	1.8 ± 0.65 (3)	2.5 ± 0.49 (14)
Persistent erythema (9)	1.38 ± 0.13 (2)	1.9 (1)	-	-	2.5 ± 0.39 (6)
Vesication (20)	-	2.1 ± 0.19 (3)	2.5 ± 0.52 (5)	2.9 ± 0.34 (5)	3.8 ± 0.29 (7)
White coagulation (9)	-	-	-	3.6 ± 0.26 (5)	4.9 ± 1.1 (4)

* Values listed in the table are critical energies in cal/cm^2.
** Numbers in parenthesis are the number of observations at each level.

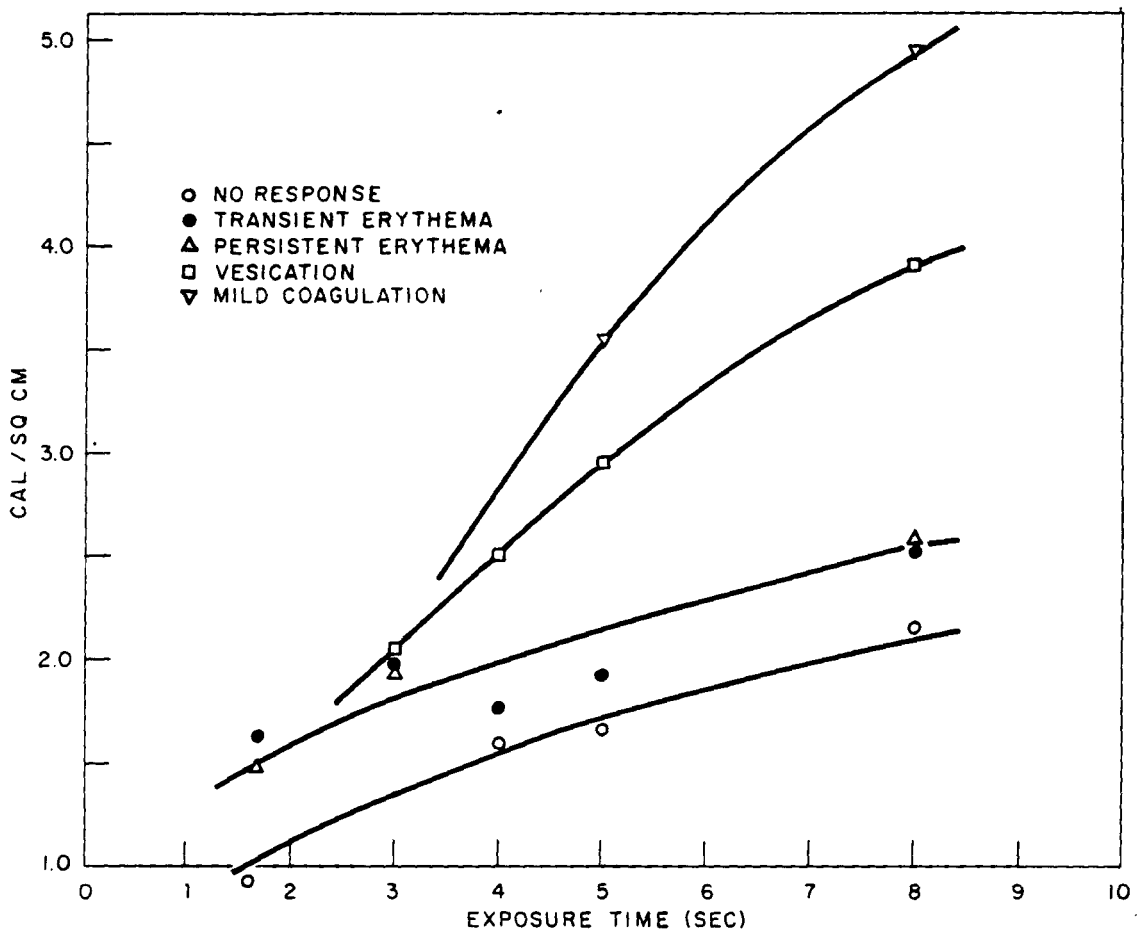

Fig. 10 Critical Energy for Various Degrees of Burn Severity on Human Skin as a Function of Exposure Time.

As in the laboratory studies on human skin, the energy increments required to produce increasing damage are relatively small, particularly for the shorter exposure times. At all exposure times the "effective energy" for transient and persistent erythema are not significantly different. However, at the longer exposure times significantly more energy is required for vesication and coagulation.

If this data is plotted as in Fig. 10, critical energy vs exposure time, it is apparent that approximately the same reciprocity relationships hold for human skin exposed to a 1200°K source as was found for rat skin exposed to a 6000°K source, (Sheline, et al.[9]).

10 DISCUSSION

The most significant finding in the data obtained from rat skin exposure is that this skin approximates a black body receiver for the wave length distribution found in flame sources. This is in accord with the findings of Hardy, et al.[11] that skin approximates a perfect radiator beyond about 2.5 to 3 μ. Conversely, it must also be a perfect absorber in the same region.

The lack of variability in response to radiation passing various filters arises from the fact previously mentioned in the section on physical characteristics that little or no energy is present in the visible region. With either 7-56 or 2-58, no energy appears below 1 μ and the peak of energy distribution of either filter is at approximately 2.4 μ. For this reason, critical energies determined with these filters are not comparable with critical energies obtained with the same filters and a 6000°K source. These findings again point up the fact that both filter and source characteristics are important parameters in determining energy distribution of transmitted radiation.

The pattern of response of human skin is quite similar to that of the rat at the wave lengths being investigated with this source. No difference is detected between radiation passing the silver chloride filter and the total radiation of the source.

From these data and that presented by Alpen, et al.[1] Table 5 (summary table) may be formulated. It can be seen that effectiveness is maximum for radiation beyond 2.5 μ, and it can be postulated that effectiveness of radiation in burn production will not appreciably exceed this value in any circumstances as the observed critical energy at $\lambda max = 2.4 \mu$ is approaching the limiting value obtained for radiation on blackened skin.

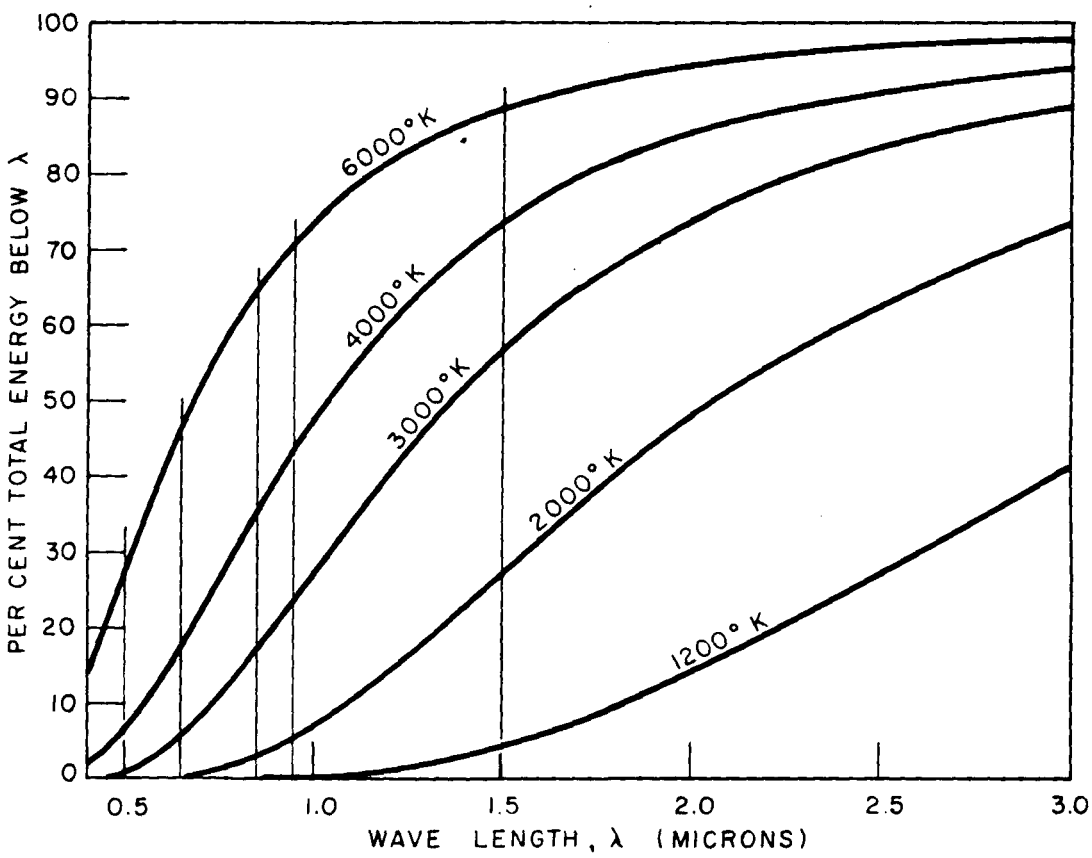

Fig. 11 Cumulative Energy Distribution Curves for Planckian Radiators at Various Temperatures. The vertical lines mark off the approximate spectral regions for which critical energies have been estimated.

TABLE 5

Summary of Spectral Dependence of Critical Energy for Human Burns

Spectral Region Maximum (μ)	Critical Energy for Persistent Erythema (2 sec exposure) (cal/cm^2)
0.4	2.20
0.55	3.25
0.65	9.9
0.85	14.0
1.7	2.5
2.4	1.6

It is possible with the data from this study, and that from spectral studies in the laboratory, to synthesize a critical energy value for any known spectral distribution of energy. After breaking down the energy distribution in question into spectral regions corresponding to those for which critical energies have been established, the weighted mean critical energy is estimated by a summation of critical energies multiplied by an appropriate weighting factor. The weighting factor is the proportion of the total energy available in the region considered. Figure 11 is a plot of cumulative energy as a function of wavelength for various black body sources at indicated color-temperatures. From these curves, or from the Planckian formulation, estimates of proportions of total energy in the various spectral regions can be made. These values are presented in Table 6. In Table 7, these proportions are multiplied by appropriate critical energy values and a summation of contributions is made to achieve the estimate of critical energy. It can be seen from Table 7 and Fig. 12 that there is an upward trend in critical energy with increasing color temperature with a plateauing of the value at about 4.5 cal/cm^2 for color temperatures over 4000°K.

The histology of graded severity burns on rat skin has been reported upon adequately in previous reports from this Laboratory.[9] However, a comment on the histopathology of human small-area burns is in order. Grossly, it has been observed by us that vesication can occur at two levels of severity of immediate damage; erythema or

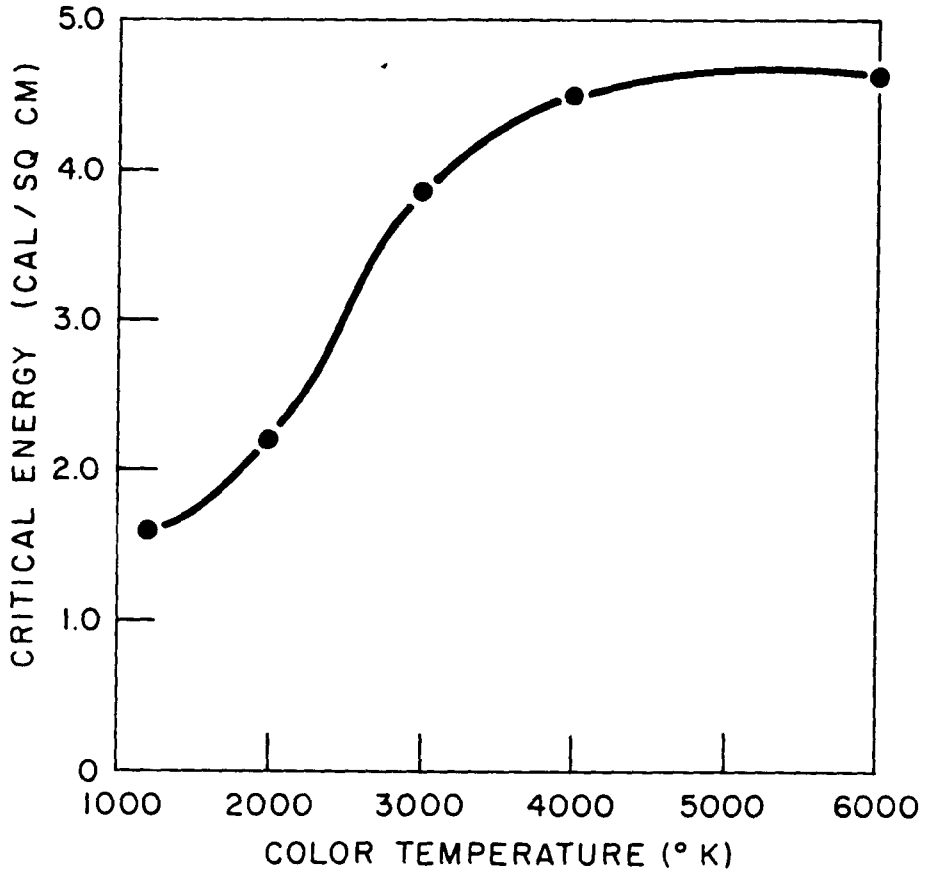

Fig. 12 Critical Energy for Persistent Erythema on Human Skin (2-sec exposure) as Calculated for the Indicated Color Temperatures from Table 7.

TABLE 6

Estimated Distribution of Energy in Black Body Sources at Various Temperatures

λ_{Max} (μ)	Black Body Temp. (°K)	Per Cent of Total B.B. Energy in Various Spectral Regions					
		0.5 μ	0.5-0.65 μ	0.65-0.85 μ	0.85-0.95 μ	0.95-1.5 μ	1.5 μ
2.4	1200	0	0	0	0	4	96
1.45	2000	0	0	2	2	24	72
.97	3000	1	5	7	11	33	43
.73	4000	6	12	18	8	29	27
.485	6000	24	21	19	7	18	11

TABLE 7

Estimated Critical Energy for Burn Production on Human Skin at Various Source Temperatures (Persistent Erythema, 2 sec exposure)

Temp. (°K)	Contribution to Critical Energy from Various Spectral Regions (cal/cm²)*						Predicted Critical Energy (cal/cm²)
	0.5 μ	0.5-0.65 μ	0.65-0.85 μ	0.85-0.95 μ	0.95-1.5 μ	1.5 μ	
	Total Critical Energy for Region						
	2.2	3.2	9.9	14.0	2.5	1.6	
1200	0	0	0	0	0.10	1.54	1.64
2000	0	0	0.20	0.28	0.60	1.15	2.23
3000	0.02	0.16	0.68	1.54	0.82	0.64	3.86
4000	0.13	0.38	1.74	1.12	0.72	0.40	4.49
6000	0.53	0.67	1.88	0.93	0.45	0.14	4.60

* Values in table are total critical energy for region multiplied by the estimated per cent of total B.B. energy in the region as listed in Table 6.

Fig. 13a Vesication Following White Coagulation after a Radiant Burn on Human Skin. H and E Stain (x 200)

Fig. 13b Persistent Erythema in Human Skin after Exposure to Thermal Radiation. H and E Stain (x 200)

moderate white coagulation. It is felt that vesication following erythema more nearly approximates the classical second degree burn and that the frequent vesication seen following a white coagulated burn does not correspond to a true second degree burn but is artifactual, arising from the smallness of the burn area.

In Figure 13a is a microphotograph of a human biopsy from a white coagulated lesion in which a blister formed. Biopsy was at 24-hr post burn and is from the marginal region of the burn including peripheral normal skin. The plane of cleavage of the blister cap is along the dermal epidermal interface. A collection of pink staining serous coagulum is seen beneath the nonviable epidermis. Moderate changes are present in the superficial portion of the dermis. These are pynknosis of nuclei, paleness of collagen staining and presence of edema. Hyperemia of deeper vessels is seen in the original section but is not clearly visible in the microphotograph. Viability of all epidermal tissue is unquestionably lost and it is felt that this lesion represents a mild third degree burn. Figure 13b is a biopsy from a persistent erythema lesion at 24-hr post burn. Normal epidermis is visible at the left edge of the section. This lesion is characterized by moderate paleness of staining in epidermal nuclei accompanied by nuclear halos. An intense hyperemia and edema is seen in the superficial dermis. Moderately severe epidermal damage approaching transepidermal necrosis is the best general expression of the nature of this lesion. It might be categorized as "threshold second degree".

One striking difference in the histopathology of burned human skin from that of the rat is the moderate nature of the leucocytic infiltration of the lesion compared to the massive response in the rat at comparable times.

Approved by:

A. R. BEHNKE, Jr.
Captain (MC) USN
Acting Head, Biological and
Medical Sciences Division

For the Scientific Director

U

RE

1.

2.

3.

4.

5.

6.

7.

8.

9.

REFERENCES

1. Alpen, E. L., Butler, C. P., Martin, S. B., and Davis, A. K., Effects of Spectral Distribution of Radiant Energy on Cutaneous Burn Production in Man and the Rat. U. S. Naval Radiological Defense Laboratory Technical Report USNRDL-TR-46, 25 April 1955. Also J. Appl. Phys. 8: 399 (1956).

2. Berkley, K. M., and Davis, T. P., Studies on Flash Burns: The Influence of Wave Length on the Production of Cutaneous Burns. University of Rochester Unclassified Report UR-283, 30 September 1953.

3. Fons, W. L., Analysis of Fire Spread in Light Forest Fuels. J. Agric. Res. 72: 93 (1946).

4. Scale Effects in the Burning of Timber. Ministry of Home Security (RCF 64) (1943).

5. Sobolev, N. N., and Shchetinin, T. I., An Optical Method for Measuring Temperatures in an Enclosed Flame. J. Exp. Theor. Phys. USSR 20: 356 (1950).

6. Gaydon, A. G., and Wolfhard, H. G., Flames, Their Structure, Radiation and Temperature. Chapman and Hall Ltd., London (1953).

7. McAdams, W. H., Heat Transmission. McGraw-Hill, New York (1954).

8. Kuhl, P. R., Sheline, G. E., and Alpen, E. L., Strontium Sulfide Depilation of Rat Skin and the Effect of Lanolin on Depilated Skin. U. S. Naval Radiological Defense Laboratory Report USNRDL-345, 17 March 1952. Also J. Lab. Clin. Med. 41: 913 (1953).

9. Sheline, G. E., Alpen, E. L., Kuhl, P. R., and Ahokas, A. J., Effects of High Intensity Radiant Energy on Skin. I. Type of Injury and its Relation to Energy Delivery Rate. U. S. Naval Radiological Defense Laboratory Report USNRDL-346, 17 March 1952. Also Arch. Path. 55: 265 (1953).

10. Alpen, E. L., Sheline, G. E., Kuhl, P. R., and Ahokas, A. J., Effects of High Intensity Radiant Energy on Skin. II. Quantitative Dependence of Tissue Injury on Duration of Exposure. U.S. Naval Radiological Defense Laboratory Report USNRDL-347, 17 March 1952. Also Arch. Path. 55: 280 (1953).

11. Hardy, J. D., The Influence of Thermal Radiation on Human Skin, A Summary Review. U.S. Naval Air Development Center, Aviation Medical Acceleration Laboratory Unclassified Report NADC-MA-5415, 10 November 1954.

, A. J.,
Quantitative
U.S. Naval
, 17 March

Human
nt Center,
l Report

DISTRIBUTION

COPIES

NAVY

1-6	Chief, Bureau of Ships (Code 348)
7	Chief, Bureau of Medicine and Surgery
8-9	Chief, Bureau of Aeronautics (Code AE40)
10	Chief, Bureau of Supplies and Accounts
11-12	Chief, Bureau of Yards and Docks (D-440)
13	Chief, Bureau of Ordnance
14	Chief of Naval Personnel (Pers C-115)
15	Office of Naval Research (Code 441)
16	Chief of Naval Research (Code 811)
17-18	CO, Office of Naval Research, New York
19-20	CO, Office of Naval Research Branch Office, SF
21-22	Chief of Naval Operations (Op-36)
23	Chief of Naval Operations (Op-03EG)
24	Commander, New York Naval Shipyard (Material Lab.)
25-27	Director, Naval Research Laboratory (Code 2021)
28	Director, Naval Research Laboratory (Code 2029)
29	Director, Naval Research Laboratory (Hulbert)
30	Naval Medical Research Institute
31	CO, Naval Medical Field Research Lab., Camp Lejeune
32	CO, Naval Unit, Army Chemical Center
33	CO, Naval Unit, CmlC Training Command
34	Commander, Naval Air Development Center, Johnsville
35	Commander, Naval Air Development Center (Hardy)
36	Commander, Naval Ordnance Lab., Silver Springs (R)
37	Commander, Naval Ordnance Lab., Silver Springs (EE)
38	CO, U.S. Naval Civil Engineering (Res. and Eval. Lab.)
39	U.S. Naval School (CEC Officers)
40	Commander, Naval Air Material Center, Philadelphia
41-42	CO, Naval Schools Command, Treasure Island
43	CO, Naval Damage Control Training Center, Philadelphia
44	U.S. Naval Postgraduate School, Monterey
45-46	CO, Fleet Training Center, Norfolk

47-48	CO, Fleet Training Center, San Diego	111
49-50	CO, Fleet Training Center, San Diego (SPWP School)	112
51	CO, Naval Electronics Lab., San Diego (Code 4223)	113
52	CO, Clothing Supply Office (Code 1D-O)	114
53	Commander, Naval Ordnance Test Station, Inyokern	115
54	CO, Air Development Squadron 5, Moffett Field	116
55	Commander Training Command, Pacific Fleet	117
56	Office of Patent Counsel, Mare Island	120
57	Commander Air Force, Atlantic Fleet (Code 16F)	121
58	President, Naval War College, Newport	122
59	CinC, U.S. Pacific Fleet	123
60	CinC, U.S. Atlantic Fleet	124
61-64	Commandant, U.S. Marine Corps (AO3H)	125
65	Commandant, Marine Corps Schools, Quantico (Library)	126
66	Commandant, Marine Corps Schools, Quantico (Development Center)	127

ARMY

67	Chief of Engineers (ENGEB, Dhein)	129
68-70	Chief of Engineers (ENGNB)	130
71	Assistant DCS for Military Operations (R&SW)	132
72	Chief of Research and Development (Atomics Div.)	133
73	Chief of Transportation	134
74	Chief of Ordnance (ORDTX-AR)	135
75-76	Chief Chemical Officer	137
77-78	CG, CmlC Res. and Eng. Command, ACmlC, Maryland	138
79-81	CO, CmlC Chemical and Radiological Laboratories (Library)	139
82	CO, Chemical Corps Materiel Command	140
83	CO, Chemical Corps Board	141
84	CO, Chemical Corps Medical Laboratories	142
85-86	CG, Aberdeen Proving Grounds (Ballistics Res. Lab.)	145
87	Ordnance Department, Aberdeen Proving Ground	146
88	Commandant, Chemical Corps Training Command (Library)	148
89-91	Chief Signal Officer (SIGOP)	149
92	CO, Army Medical Research Laboratory, Fort Knox	150
93-96	CG, Continental Army Command, Fort Monroe	151
97	President Board No. 1, Continental Army Command, Fort Sill	152
98	President Board No. 2, Continental Army Command, Fort Knox	155
99	President Board No. 4, Continental Army Command, Fort Bliss	156
100-101	Brooks Army Medical Center	157
102	Army Medical Service Graduate School (Dept. of Biophysics)	159
103-104	Walter Reed Army Medical Center	160
105	CG, Army Medical Service School, Fort Sam Houston	161
106	CG, Quartermaster Res. and Dev. Command (Library)	163
107-108	CG, Quartermaster Res. and Dev. Command (CBR Liaison Br.)	164
109	Office of Quartermaster General (R&D Div.)	165
110	Director, Operations Research Office (Librarian)	166

111	CO, Dugway Proving Ground
112	Surgeon General (Res. and Dev. Div.)
113	Surgeon General (MEDNE)
114	Director, Evans Signal Laboratory (Nucleonics Section)
115	Director, Evans Signal Laboratory (Technical Documents)
116	CO, Engineer Res. and Dev. Lab., Fort Belvoir
117-119	CG, The Engineer Center, Fort Belvoir
120	CO, Transportation Res. and Dev. Command, Fort Eustis
121	Tokyo Army Hospital
122	CO, Frankford Arsenal
123	CO, Picatinny Arsenal (ORDBB-TK)
124	Commandant, Command and General Staff College (ALLLS/AS)
125	Director, Special Weapons Development Office, Fort Bliss
126	Director, Waterways Experiment Station
127-128	CinC, Far East Command (J-3)

AIR FORCE

129	Director of Res. and Dev. (Combat Components Div.)
130-131	Directorate of Intelligence (AFOIN-1B2)
132	Director of Requirements (AFDRQ-SA/M)
133	Director of Plans (War Plans Div.)
134	Director of Operations (Operations Analysis)
135-136	Commander, Air Materiel Command
137	Commander, Air Materiel Command (MCMTM)
138	Commander, Wright Air Development Center (WCOSI)
139	Commander, Wright Air Development Center (WCRDO)
140	Commander, Wright Air Development Center (WCRTY)
141	Commander, USAF Institute of Technology
142-144	Commander, Air Res. and Dev. Command (RDTDA)
145	Commander, Air Res. and Dev. Command (RDTRH)
146-147	Commander, USAF School of Aviation Medicine
148	USAF, SAM, Randolph Field (Brooks)
149	CG, Strategic Air Command, Offutt Air Force Base (IGABD)
150	CG, Strategic Air Command (Operations Analysis)
151	CG, Strategic Air Command (Special Weapons Br.)
152-154	Commander, Kirtland Air Force Base
155	Office of the Surgeon General
156	Surgeon General (Biological Defense Br.)
157-158	Director, Air University Library, Maxwell Air Force Base
159	Commander, Air Defense Command, Ent Air Force Base
160	Commander, Tactical Air Command, Langley Air Force Base
161-162	Commander, Technical Training Wing, 3415th Technical Training Group
163	Commander, Technical Training Air Force, Gulfport
164	Commander, Crew Training Air Force, Randolph
165	CG, Air Proving Ground, Eglin Air Force Base (AF/TRB)
166	Commander, Air Training Command, Scott Air Force Base (DCS/O/GTP)

167-168	Commander, Flying Training Air Force, Waco
169	Commander, Cambridge Research Center (CRHTM)
170	Commander, Cambridge Research Center (CRQST-2)
171	AFOAT - Headquarters

OTHER DOD ACTIVITIES

172-186	Chief, Armed Forces Special Weapons Project
187	AFSWP, SWTG, Sandia Base (Library)
188-193	AFSWP, Hq., Field Command, Sandia Base
194	Assistant Secretary of Defense (Res. and Dev.)
195	Armed Forces Medical Library
196-200	Armed Services Technical Information Agency
201	Commandant, Armed Forces Staff College (Secretary)
202	National Military Representative, SHAPE
203	Director, Weapons Systems Evaluation Group

AEC ACTIVITIES AND OTHERS

204-206	Argonne Cancer Research Hospital
207-212	Argonne National Laboratory
213-215	Atomic Energy Commission, Washington
216-217	Atomics International
218-219	Battelle Memorial Institute
220-221	Bettis Plant
222	Boeing Airplane Company
223-226	Brookhaven National Laboratory
227	Brush Beryllium Company
228	California Forest Experimental Station (Fons)
229	Chicago Patent Group
230	Columbia University (Failla)
231	Columbia University (Hassialis)
232-233	Atomic Bomb Casualty Commission (APO-182)
234-235	Atomic Bomb Casualty Commission, Washington
236	Consolidated Vultee Aircraft Corporation
237	Department of Agriculture, Fire Research Division
238	Dow Chemical Company, Pittsburg
239	Dow Chemical Company, Rocky Flats
240-243	duPont Company, Aiken
244	duPont Company, Wilmington
245	Forest Products Laboratory (Bruce)
246-247	General Electric Company (ANPP)
248-253	General Electric Company, Richland
254	Goodyear Atomic Corporation
255	Hawaii Marine Laboratory
256	Iowa State College
257-259	Knolls Atomic Power Laboratory

260	Lockheed Aircraft Corp. (Cleveland)
261	Lockheed Aircraft Corp. (Marietta)
262-263	Los Alamos Scientific Laboratory
264	Los Alamos Scientific Laboratory (Graves)
265	Mallinckrodt Chemical Works
266	Massachusetts Institute of Technology (Hardy)
267	Massachusetts Institute of Technology (Hottel)
268	Massachusetts Institute of Technology (Williams)
269	Medical College of Virginia (Ham)
270	Mound Laboratory
271	National Bureau of Standards (Library)
272	National Bureau of Standards (Taylor)
273	National Lead Company of Ohio
274	New Brunswick Laboratory
275	New York Operations Office
276	Nuclear Development Corporation of America
277	Oak Ridge Institute of Nuclear Studies
278-283	Oak Ridge National Laboratory
284	Patent Branch, Washington
285-291	Phillips Petroleum Company
292	Pratt and Whitney Aircraft (FOX Project)
293	Princeton University (White)
294-295	Public Health Service, Washington
296	Radioisotopes Laboratory (Thoma)
297	RAND Corporation
298	Sandia Corporation (Library)
299	Sandia Corporation (Cox)
300	Technical Operations, Inc. (Henriques)
301	U.N. Scientific Committee (Randers)
302	Union Carbide Nuclear Company (C-31 Plant)
303-304	Union Carbide Nuclear Company (K-25 Plant)
305	United Aircraft Corporation
306	U.S. Geological Survey, Menlo Park
307	UCLA Medical Research Laboratory
308	University of California Medical Center
309-311	University of California Radiation Laboratory, Berkeley
312-313	University of California Radiation Laboratory, Livermore
314	University of Chicago Radiation Laboratory
315	University of Rochester (Technical Report Unit)
316	University of Rochester (Pearse)
317	University of Utah (Stoner)
318	University of Washington (Applied Fisheries Lab.)
319	Weil, Dr. George L.
320-323	Western Reserve University
324-348	Technical Information Extension, Oak Ridge
	USNRDL
349-390	USNRDL, Technical Information Division

DATE ISSUED: 28 June 1956

Naval Radiological Defense Laboratory
USNRDL-TR-84
PHYSICAL PROPERTIES AND BIOLOGICAL EFFECTIVENESS FOR BURN PRODUCTION OF FLAME SOURCES, by E. L. Alpen, C. P. Butler, and others. 21 Dec. 1955. 37 p. illus. tables, diagrs. (AFSWP-778) UNCLASSIFIED

Measurements of the physical characteristics of flame sources of radiant energy have been made, using radiometric equipment previously designed for use at nuclear weapon field tests. These measurements, made on an extended plane flame source approximately twenty by twenty

(over)

1. Thermal radiation - Sources
2. Burns - Production
I. Alpen, E. L.
II. Butler, C. P.
III. Armed Forces Special Weapons Project
IV. Title
V. NM 006-015.02

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84
PHYSICAL PROPERTIES AND BIOLOGICAL EFFECTIVENESS FOR BURN PRODUCTION OF FLAME SOURCES, by E. L. Alpen, C. P. Butler, and others. 21 Dec. 1955. 37 p. illus. tables, diagrs. (AFSWP-778) UNCLASSIFIED

Measurements of the physical characteristics of flame sources of radiant energy have been made, using radiometric equipment previously designed for use at nuclear weapon field tests. These measurements, made on an extended plane flame source approximately twenty by twenty

(over)

1. Thermal radiation - Sources
2. Burns - Production
I. Alpen, E. L.
II. Butler, C. P.
III. Armed Forces Special Weapons Project
IV. Title
V. NM 006-015.02

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84
PHYSICAL PROPERTIES AND BIOLOGICAL EFFECTIVENESS FOR BURN PRODUCTION OF FLAME SOURCES, by E. L. Alpen, C. P. Butler, and others. 21 Dec. 1955. 37 p. illus. tables, diagrs. (AFSWP-778) UNCLASSIFIED

Measurements of the physical characteristics of flame sources of radiant energy have been made, using radiometric equipment previously designed for use at nuclear weapon field tests. These measurements, made on an extended plane flame source approximately twenty by twenty

(over)

1. Thermal radiation - Sources
2. Burns - Production
I. Alpen, E. L.
II. Butler, C. P.
III. Armed Forces Special Weapons Project
IV. Title
V. NM 006-015.02

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84
PHYSICAL PROPERTIES AND BIOLOGICAL EFFECTIVENESS FOR BURN PRODUCTION OF FLAME SOURCES, by E. L. Alpen, C. P. Butler, and others. 21 Dec. 1955. 37 p. illus. tables, diagrs. (AFSWP-778) UNCLASSIFIED

Measurements of the physical characteristics of flame sources of radiant energy have been made, using radiometric equipment previously designed for use at nuclear weapon field tests. These measurements, made on an extended plane flame source approximately twenty by twenty

(over)

1. Thermal radiation - Sources
2. Burns - Production
I. Alpen, E. L.
II. Butler, C. P.
III. Armed Forces Special Weapons Project
IV. Title
V. NM 006-015.02

UNCLASSIFIED

feet, have shown the source to be equivalent to a black body source radiating at a temperature of approximately 1200°K and with an emissivity of about 0.3. The irradiance values for these sources is of the order of 0.7 cal/cm^2/sec at a distance of five feet from the flame front. Estimation of "color temperature" was made by a filter ratio method, using energy transmitted by silver chloride and two Corning vitreous filters (7-56 and 2-58).

Biological studies of the effectiveness of this radiation in producing cutaneous burns in man and the rat have shown that the radiation from this source has an effectiveness approximating the ideal maximum. This maximum is taken as the critical energy value for any thermal radiation on blackened skin. On rat skin 2.1 ± 0.2 cal/cm^2 was required in a 1 to 3 sec exposure to produce minimal perceptible coagulation. With increasing exposure time this value rose slightly to 2.6 ± 0.5 cal/cm^2 at 4 to 8 sec exposure times. For human skin 1.4 ± 0.13 cal/cm^2

(continued on next card)

UNCLASSIFIED

feet, have shown the source to be equivalent to a black body source radiating at a temperature of approximately 1200°K and with an emissivity of about 0.3. The irradiance values for these sources is of the order of 0.7 cal/cm^2/sec at a distance of five feet from the flame front. Estimation of "color temperature" was made by a filter ratio method, using energy transmitted by silver chloride and two Corning vitreous filters (7-56 and 2-58).

Biological studies of the effectiveness of this radiation in producing cutaneous burns in man and the rat have shown that the radiation from this source has an effectiveness approximating the ideal maximum. This maximum is taken as the critical energy value for any thermal radiation on blackened skin. On rat skin 2.1 ± 0.2 cal/cm^2 was required in a 1 to 3 sec exposure to produce minimal perceptible coagulation. With increasing exposure time this value rose slightly to 2.6 ± 0.5 cal/cm^2 at 4 to 8 sec exposure times. For human skin 1.4 ± 0.13 cal/cm^2

(continued on next card)

UNCLASSIFIED

feet, have shown the source to be equivalent to a black body source radiating at a temperature of approximately 1200°K and with an emissivity of about 0.3. The irradiance values for these sources is of the order of 0.7 cal/cm^2/sec at a distance of five feet from the flame front. Estimation of "color temperature" was made by a filter ratio method, using energy transmitted by silver chloride and two Corning vitreous filters (7-56 and 2-58).

Biological studies of the effectiveness of this radiation in producing cutaneous burns in man and the rat have shown that the radiation from this source has an effectiveness approximating the ideal maximum. This maximum is taken as the critical energy value for any thermal radiation on blackened skin. On rat skin 2.1 ± 0.2 cal/cm^2 was required in a 1 to 3 sec exposure to produce minimal perceptible coagulation. With increasing exposure time this value rose slightly to 2.6 ± 0.5 cal/cm^2 at 4 to 8 sec exposure times. For human skin 1.4 ± 0.13 cal/cm^2

(continued on next card)

UNCLASSIFIED

feet, have shown the source to be equivalent to a black body source radiating at a temperature of approximately 1200°K and with an emissivity of about 0.3. The irradiance values for these sources is of the order of 0.7 cal/cm^2/sec at a distance of five feet from the flame front. Estimation of "color temperature" was made by a filter ratio method, using energy transmitted by silver chloride and two Corning vitreous filters (7-56 and 2-58).

Biological studies of the effectiveness of this radiation in producing cutaneous burns in man and the rat have shown that the radiation from this source has an effectiveness approximating the ideal maximum. This maximum is taken as the critical energy value for any thermal radiation on blackened skin. On rat skin 2.1 ± 0.2 cal/cm^2 was required in a 1 to 3 sec exposure to produce minimal perceptible coagulation. With increasing exposure time this value rose slightly to 2.6 ± 0.5 cal/cm^2 at 4 to 8 sec exposure times. For human skin 1.4 ± 0.13 cal/cm^2

(continued on next card)

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84
PHYSICAL PROPERTIES AND BIOLOGICAL EFFECTIVENESS FOR BURN PRODUCTION OF FLAME SOURCES, by E.L. Alpen, C.P. Butler, and others. 21 Dec. 1955. 37 p. illus. tables, diagrs. (AFSWP-778) UNCLASSIFIED

Measurements of the physical characteristics of flame sources of radiant energy have been made, using radiometric equipment previously designed for use at nuclear weapon field tests. These measurements, made on an extended plane flame source approximately twenty by twenty

(over)

1. Thermal radiation - Sources
2. Burns - Production
I. Alpen, E.L.
II. Butler, C.P.
III. Armed Forces Special Weapons Project
IV. Title
V. NM 006-015.02

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84
PHYSICAL PROPERTIES AND BIOLOGICAL EFFECTIVENESS FOR BURN PRODUCTION OF FLAME SOURCES, by E.L. Alpen, C.P. Butler, and others. 21 Dec. 1955. 37 p. illus. tables, diagrs. (AFSWP-778) UNCLASSIFIED

Measurements of the physical characteristics of flame sources of radiant energy have been made, using radiometric equipment previously designed for use at nuclear weapon field tests. These measurements, made on an extended plane flame source approximately twenty by twenty

(over)

1. Thermal radiation - Sources
2. Burns - Production
I. Alpen, E.L.
II. Butler, C.P.
III. Armed Forces Special Weapons Project
IV. Title
V. NM 006-015.02

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84
PHYSICAL PROPERTIES AND BIOLOGICAL EFFECTIVENESS FOR BURN PRODUCTION OF FLAME SOURCES, by E.L. Alpen, C.P. Butler, and others. 21 Dec. 1955. 37 p. illus. tables, diagrs. (AFSWP-778) UNCLASSIFIED

Measurements of the physical characteristics of flame sources of radiant energy have been made, using radiometric equipment previously designed for use at nuclear weapon field tests. These measurements, made on an extended plane flame source approximately twenty by twenty

(over)

1. Thermal radiation - Sources
2. Burns - Production
I. Alpen, E.L.
II. Butler, C.P.
III. Armed Forces Special Weapons Project
IV. Title
V. NM 006-015.02

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84
PHYSICAL PROPERTIES AND BIOLOGICAL EFFECTIVENESS FOR BURN PRODUCTION OF FLAME SOURCES, by E.L. Alpen, C.P. Butler, and others. 21 Dec. 1955. 37 p. illus. tables, diagrs. (AFSWP-778) UNCLASSIFIED

Measurements of the physical characteristics of flame sources of radiant energy have been made, using radiometric equipment previously designed for use at nuclear weapon field tests. These measurements, made on an extended plane flame source approximately twenty by twenty

(over)

1. Thermal radiation - Sources
2. Burns - Production
I. Alpen, E.L.
II. Butler, C.P.
III. Armed Forces Special Weapons Project
IV. Title
V. NM 006-015.02

UNCLASSIFIED

feet, have shown the source to be equivalent to a black body source radiating at a temperature of approximately 1200°K and with an emissivity of about 0.3. The irradiance values for these sources is of the order of 0.7 cal/cm^2/sec at a distance of five feet from the flame front. Estimation of "color temperature" was made by a filter ratio method, using energy transmitted by silver chloride and two Corning vitreous filters (7-56 and 2-58).

Biological studies of the effectiveness of this radiation in producing cutaneous burns in man and the rat have shown that the radiation from this source has an effectiveness approximating the ideal maximum. This maximum is taken as the critical energy value for any thermal radiation on blackened skin. On rat skin 2.1 ± 0.2 cal/cm^2 was required in a 1 to 3 sec exposure to produce minimal perceptible coagulation. With increasing exposure time this value rose slightly to 2.6 ± 0.5 cal/cm^2 at 4 to 8 sec exposure times. For human skin 1.4 ± 0.13 cal/cm^2

(continued on next card)

UNCLASSIFIED

feet, have shown the source to be equivalent to a black body source radiating at a temperature of approximately 1200°K and with an emissivity of about 0.3. The irradiance values for these sources is of the order of 0.7 cal/cm^2/sec at a distance of five feet from the flame front. Estimation of "color temperature" was made by a filter ratio method, using energy transmitted by silver chloride and two Corning vitreous filters (7-56 and 2-58).

Biological studies of the effectiveness of this radiation in producing cutaneous burns in man and the rat have shown that the radiation from this source has an effectiveness approximating the ideal maximum. This maximum is taken as the critical energy value for any thermal radiation on blackened skin. On rat skin 2.1 ± 0.2 cal/cm^2 was required in a 1 to 3 sec exposure to produce minimal perceptible coagulation. With increasing exposure time this value rose slightly to 2.6 ± 0.5 cal/cm^2 at 4 to 8 sec exposure times. For human skin 1.4 ± 0.13 cal/cm^2

(continued on next card)

UNCLASSIFIED

feet, have shown the source to be equivalent to a black body source radiating at a temperature of approximately 1200°K and with an emissivity of about 0.3. The irradiance values for these sources is of the order of 0.7 cal/cm^2/sec at a distance of five feet from the flame front. Estimation of "color temperature" was made by a filter ratio method, using energy transmitted by silver chloride and two Corning vitreous filters (7-56 and 2-58).

Biological studies of the effectiveness of this radiation in producing cutaneous burns in man and the rat have shown that the radiation from this source has an effectiveness approximating the ideal maximum. This maximum is taken as the critical energy value for any thermal radiation on blackened skin. On rat skin 2.1 ± 0.2 cal/cm^2 was required in a 1 to 3 sec exposure to produce minimal perceptible coagulation. With increasing exposure time this value rose slightly to 2.6 ± 0.5 cal/cm^2 at 4 to 8 sec exposure times. For human skin 1.4 ± 0.13 cal/cm^2

(continued on next card)

UNCLASSIFIED

feet, have shown the source to be equivalent to a black body source radiating at a temperature of approximately 1200°K and with an emissivity of about 0.3. The irradiance values for these sources is of the order of 0.7 cal/cm^2/sec at a distance of five feet from the flame front. Estimation of "color temperature" was made by a filter ratio method, using energy transmitted by silver chloride and two Corning vitreous filters (7-56 and 2-58).

Biological studies of the effectiveness of this radiation in producing cutaneous burns in man and the rat have shown that the radiation from this source has an effectiveness approximating the ideal maximum. This maximum is taken as the critical energy value for any thermal radiation on blackened skin. On rat skin 2.1 ± 0.2 cal/cm^2 was required in a 1 to 3 sec exposure to produce minimal perceptible coagulation. With increasing exposure time this value rose slightly to 2.6 ± 0.5 cal/cm^2 at 4 to 8 sec exposure times. For human skin 1.4 ± 0.13 cal/cm^2

(continued on next card)

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84 (continued)

was required for vesication at the shorter exposure times, < 2.5 sec; for 5 to 10 sec exposures this value is 3.8 ± 0.29 cal/cm^2.

From this data and that previously reported on laboratory sources, critical energy for persistent erythema as a function of color temperature has been synthesized. It has been shown that for human skin the persistent erythema critical energy rises smoothly from 1.64 cal/cm^2 for a 1200°K source to 4.6 cal/cm^2 for a 6000°K source with no intermediate maxima in this range of temperatures. A general method has been stated for estimating critical energies for any spectral distribution of energy.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84 (continued)

was required for vesication at the shorter exposure times, < 2.5 sec; for 5 to 10 sec exposures this value is 3.8 ± 0.29 cal/cm^2.

From this data and that previously reported on laboratory sources, critical energy for persistent erythema as a function of color temperature has been synthesized. It has been shown that for human skin the persistent erythema critical energy rises smoothly from 1.64 cal/cm^2 for a 1200°K source to 4.6 cal/cm^2 for a 6000°K source with no intermediate maxima in this range of temperatures. A general method has been stated for estimating critical energies for any spectral distribution of energy.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84 (continued)

was required for vesication at the shorter exposure times, < 2.5 sec; for 5 to 10 sec exposures this value is 3.8 ± 0.29 cal/cm^2.

From this data and that previously reported on laboratory sources, critical energy for persistent erythema as a function of color temperature has been synthesized. It has been shown that for human skin the persistent erythema critical energy rises smoothly from 1.64 cal/cm^2 for a 1200°K source to 4.6 cal/cm^2 for a 6000°K source with no intermediate maxima in this range of temperatures. A general method has been stated for estimating critical energies for any spectral distribution of energy.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84 (continued)

was required for vesication at the shorter exposure times, < 2.5 sec; for 5 to 10 sec exposures this value is 3.8 ± 0.29 cal/cm^2.

From this data and that previously reported on laboratory sources, critical energy for persistent erythema as a function of color temperature has been synthesized. It has been shown that for human skin the persistent erythema critical energy rises smoothly from 1.64 cal/cm^2 for a 1200°K source to 4.6 cal/cm^2 for a 6000°K source with no intermediate maxima in this range of temperatures. A general method has been stated for estimating critical energies for any spectral distribution of energy.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84 (continued)

was required for vesication at the shorter exposure times, < 2.5 sec; for 5 to 10 sec exposures this value is 3.8 ± 0.29 cal/cm^2.

From this data and that previously reported on laboratory sources, critical energy for persistent erythema as a function of color temperature has been synthesized. It has been shown that for human skin the persistent erythema critical energy rises smoothly from 1.64 cal/cm^2 for a 1200°K source to 4.6 cal/cm^2 for a 6000°K source with no intermediate maxima in this range of temperatures. A general method has been stated for estimating critical energies for any spectral distribution of energy.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84 (continued)

was required for vesication at the shorter exposure times, < 2.5 sec; for 5 to 10 sec exposures this value is 3.8 ± 0.29 cal/cm^2.

From this data and that previously reported on laboratory sources, critical energy for persistent erythema as a function of color temperature has been synthesized. It has been shown that for human skin the persistent erythema critical energy rises smoothly from 1.64 cal/cm^2 for a 1200°K source to 4.6 cal/cm^2 for a 6000°K source with no intermediate maxima in this range of temperatures. A general method has been stated for estimating critical energies for any spectral distribution of energy.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84 (continued)

was required for vesication at the shorter exposure times, < 2.5 sec; for 5 to 10 sec exposures this value is 3.8 ± 0.29 cal/cm^2.

From this data and that previously reported on laboratory sources, critical energy for persistent erythema as a function of color temperature has been synthesized. It has been shown that for human skin the persistent erythema critical energy rises smoothly from 1.64 cal/cm^2 for a 1200°K source to 4.6 cal/cm^2 for a 6000°K source with no intermediate maxima in this range of temperatures. A general method has been stated for estimating critical energies for any spectral distribution of energy.

UNCLASSIFIED

Naval Radiological Defense Laboratory
USNRDL-TR-84 (continued)

was required for vesication at the shorter exposure times, < 2.5 sec; for 5 to 10 sec exposures this value is 3.8 ± 0.29 cal/cm^2.

From this data and that previously reported on laboratory sources, critical energy for persistent erythema as a function of color temperature has been synthesized. It has been shown that for human skin the persistent erythema critical energy rises smoothly from 1.64 cal/cm^2 for a 1200°K source to 4.6 cal/cm^2 for a 6000°K source with no intermediate maxima in this range of temperatures. A general method has been stated for estimating critical energies for any spectral distribution of energy.

UNCLASSIFIED