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EFFECTS OF SPECTRAL DISTRIBUTION OF RADIANT ENERGY ON CUTANEOUS BURN PRODUCTION IN MAN AND THE RAT

Research and Development Technical Report USNRDL-TR-46
NM 006-015

25 April 1955

by

E. L. Alpen
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S. B. Martin
A. K. Davis

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Encl: (1) U. S. Naval Radiological Defense Laboratory Report USNRDL-TR-46 entitled "Effect of Spectral Distribution of Radiant Energy on Cutaneous Burn Production in Man and the Rat," Project NM 006 015.02, Phase 1

1. In this report the radiant energy required for production of skin burns in human and in rat skin is shown to be dependent in a striking manner upon wave length. Corrected for spectral reflectance, the critical energy (Q) for burn production may vary as much as 4 fold in both rat and human skin depending upon the wave length of the penetrating thermal energy.

2. Additional noteworthy findings are:

a. Blackening of the rats' skin reduces the (Q) values to relatively constant values (about 50 per cent of the lowest unblackened skin values) independent of wave length of the thermal energy.

b. The severity of the burn is proportional (approx.) to the logarithm of the energy (Q) applied.

c. In human skin for any given wave length distribution there is a critical energy increment, amounting to a fraction of a calorie, required to raise the level of damage from persistent erythema to vesiculation.

3. Apart from these findings attention is invited to the instrumentation and procedures which make for the evaluation of standard burn lesions on a precise quantitative basis. These developments are the result of both the physicist and physiologist engaged in collaborative effort over a period of years.

A. R. BEHNKE
By direction

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Health and Biology

Technical Objective
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ABSTRACT

The radiant energy required for the production of cutaneous burns has been measured as a function of wave length for both rat skin and human skin. These studies have been accomplished using the carbon arc as a source of radiation and broad-band filters for isolation of regions of the spectrum. The reflectivities of skin for the same broad-band spectral regions have been measured. For the rat the reflectivities and critical energies for production of a standard burn are the following:

filter "B", $\lambda_{max} = 0.55\mu$, r = 36.5 ± 1.6 per cent, Q = 4.3 ± 0.2 cal/cm^2;

filter "C", $\lambda_{max} = 0.65\mu$, r = 50.5 ± 0.5 per cent, Q = 28 cal/cm^2 (approx.);

filter "E", $\lambda_{max} = 1.0\mu$, r = 24 ± 0.6 per cent, Q = 4.0 ± 0.2 cal/cm^2;

filter "F", $\lambda_{max} = 1.7\mu$, r = 13 ± 0 per cent, Q = 3.3 ± 0.2 cal/cm^2.

For human skin the following data were obtained:

filter "A", $\lambda_{max} = 0.42\mu$, r = 24.4 ± 3.5 per cent, Q = 3.20 ± 0.37 cal/cm^2;

filter "B", $\lambda_{max} = 0.55\mu$, r = 40.9 ± 3.8 per cent, Q = 3.25 ± 0.28 cal/cm^2;

filter "C", $\lambda_{max} = 0.65\mu$, r = 56.9 ± 2.5 per cent, Q = 9.9 ± 2.1 cal/cm^2;

filter "D", $\lambda_{max} = 0.85\mu$, r = 53.4 ± 2.2 per cent, Q = 14.0 ± 1.1 cal/cm^2;

filter "F", $\lambda_{max} = 1.7\mu$, r = 17 ± 0.60 per cent, Q = 2.50 cal/cm^2 (approx.).

The ranges shown are standard deviations.

The significance of the optical properties of skin has been discussed and the property of the high transmission of skin in the region 0.7 to 1.0 has been presented.

SUMMARY

The Problem

How does the critical energy for the production of standard burns in both rats and humans vary with the wavelength of radiant energy?

Findings

The critical radiant energy, corrected for spectral reflectance, required for production of standard burns in both rat and human skin varies as much as 4-fold depending on the wavelength.

ADMINISTRATIVE INFORMATION

The work for this report was done under Bureau of Medicine and Surgery Project NM 006-015.02, Phase 1, and was carried out under the financial sponsorship of the Armed Forces Special Weapons Project. The use of volunteers in this study was approved by Chief, BuMed ltr BUMED-71-cm A11/L5-2, 16 July 1951.

REPORT OF INVESTIGATION

INTRODUCTION

Several years ago, when the studies of the effects of thermal radiation on materials began, most of the workers in this field agreed that the high current carbon arc was the most suitable source of high intensity radiation. This selection was made largely on the basis that this source most nearly simulates the spectrum of a nuclear detonation and with suitable optics an irradiance level adequate for most investigations on the effects of thermal radiation on materials and biological systems could be achieved.

Since the original installation of a 36-in. Navy Searchlight source at this laboratory, two other sources have been installed, one a Mitchell Source and the other a 60-in Army Searchlight system for the production of large area burns. None of these sources employs an identical optical system, nor do they normally operate at the same current and carbon consumption rate. These differences in construction and operating characteristics give rise to spectral distributions of energy which are not the same for all sources. It was noted in this laboratory that the biological response of skin to two of these sources was appreciably different. This discrepancy stimulated the present study on spectral relationships in the production of skin burns.

METHODS

Physical Equipment

The source used for this work was a modified 36-in. Navy searchlight using front surface aluminized reflectors. No glass intervenes in the unfiltered beam from the source. The optical system and shutter system employed have been described elsewhere.[1] The only change made from the described equipment was the removal of the front window of the

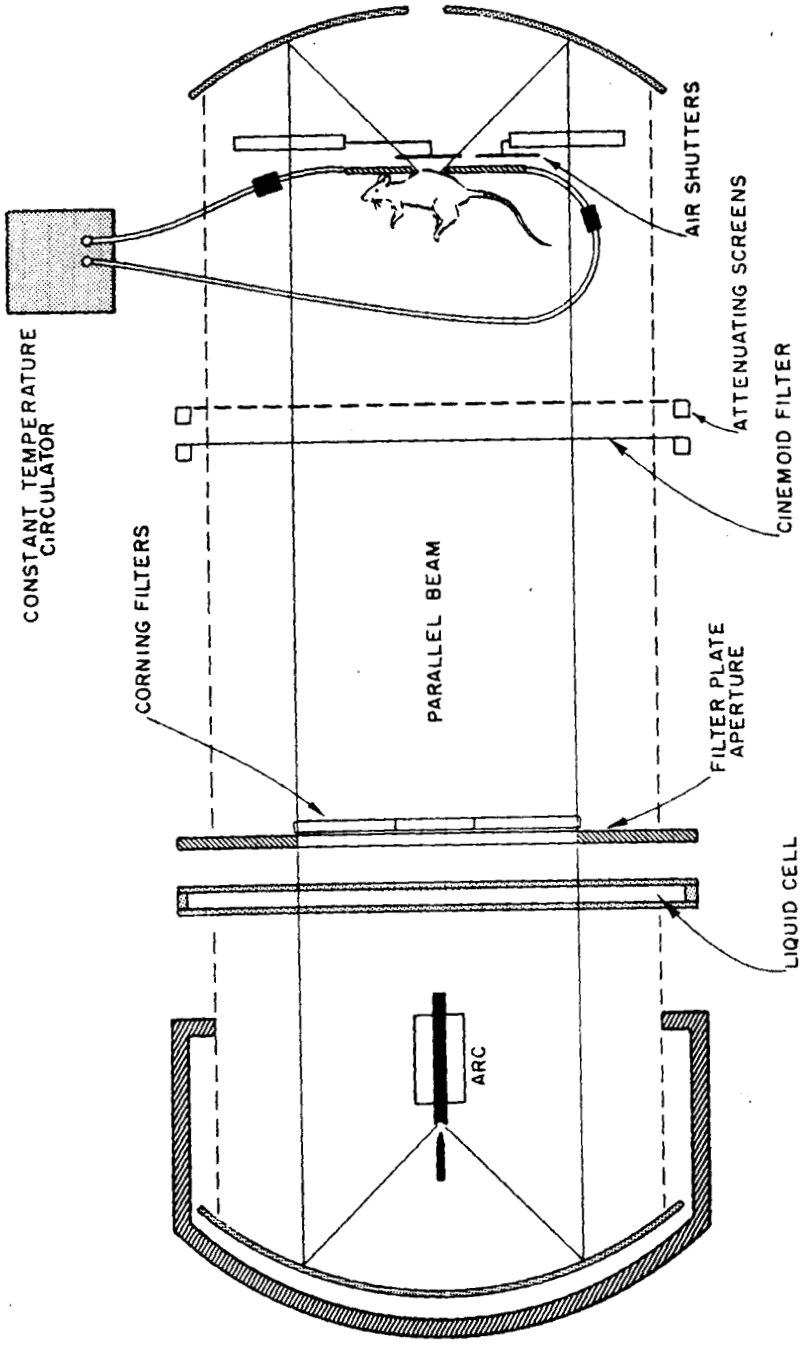

Fig. 1 Optical and Mechanical Diagram of the Source Showing the Location of Filters and Intensity Attenuators. In those cases where a liquid filter is not employed the glass water cells were removed.

searchlight and the plane reflecting monitor window.

Measurements of radiant energy flux were made with black body calorimeters and a recording potentiometer. The calorimeters were in turn calibrated against a primary standard water-flow calorimeter.[2]

Spectral Filters

Spectral studies with high flux radiant energy sources require the construction of a filter which can be placed in some position between the source and the focal plane and which will neither fracture nor melt during an exposure. In addition, the adjustment of the band width of the filter must be made so that sufficient energy is available in each region to produce the required energy level. All attempts at filtering of the condensed radiation in high flux sources failed because of damage to the filters. From this failure it was concluded that the only possible position for the filter was in some portion of the uncondensed beam where the irradiance level was low (Fig. 1). In the case of our 36-in. searchlight this requires a filter covering a reasonable proportion of the 800 sq in. of parallel radiation. Such large areas preclude the use of many available filters because of the attendant expense.

Combinations of water solutions of inorganic salts, Corning vitreous filters, and sheets of colored plastic ("Cinemoid," distributed in U.S.A. by Kliegl Bros.) were used to achieve the desired spectral bands. The combinations used in this study are listed in Table 1. The spectral curves for the individual filter combinations are given in Fig. 2. Because the distribution of energy as a function of wave length in the source is not uniform, a curve of energy distribution as a function of wave length for the various filters must be synthesized from the measured spectral emission curve of the arc and the transmission of the filter. These synthesized curves, which represent the true distribution of energy applied to the skin are represented in Fig. 3.

Skin Reflectance Measurements

Total diffuse reflectance of the skin was measured for each of the filter combinations used in burn production. These measurements are made by allowing collimated radiation after passing the filter and a 16 cycle chopper to enter an aperture in a 30-in. inside diameter sphere with a fumed MgO internal surface. The radiation was incident on the surface to be measured at the opposite point of the sphere on an equatorial plane. The thermocouple detector and amplifier from a Perkin-Elmer infrared spectrophotometer were used to measure the reflected radiation. The detector was placed normal to the entering beam of radiation. The measured deflection when a fresh surface of magnesium carbonate was used as the incident surface was taken as a 100 per cent reflectivity reference point.

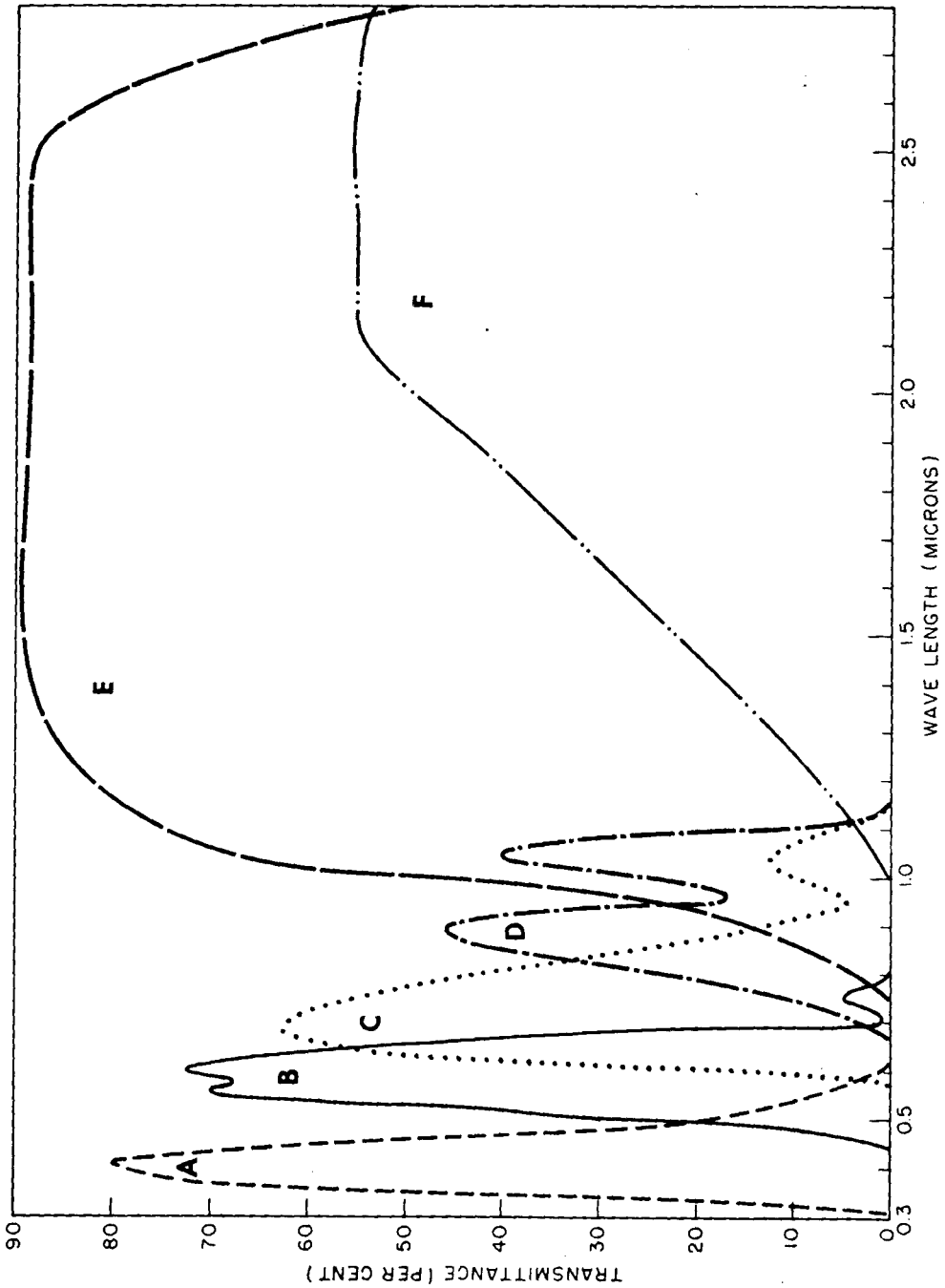

Fig. 2 Measured Transmittance of Filter Combinations Used. These measurements were made with a Perkin-Elmer Double Beam Recording Spectrometer.

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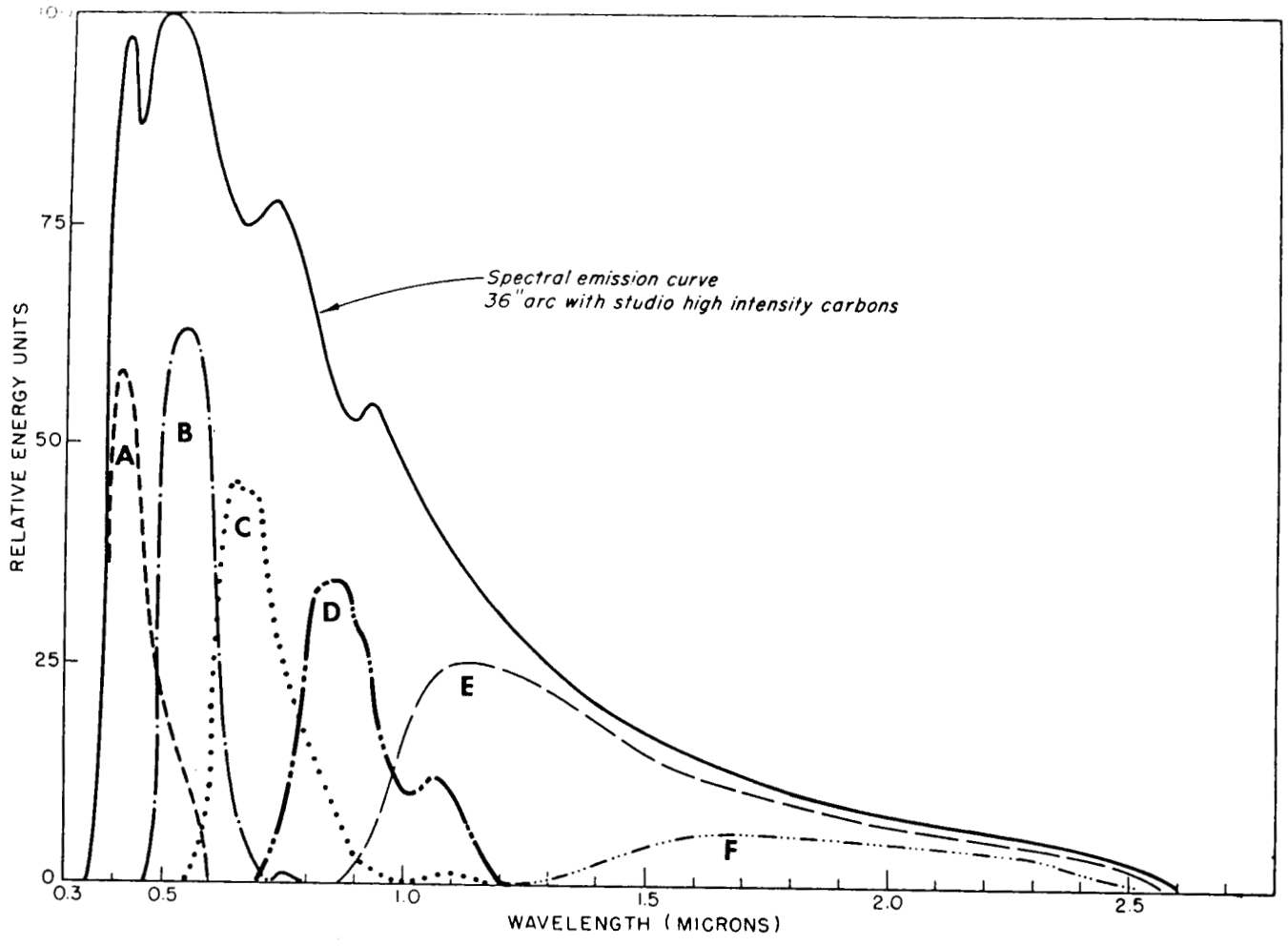

Fig. 3 Energy Distribution Curves for Filters Used. These are synthesized from the measured energy emission distribution of the arc and the transmission data of Fig. 2.

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TABLE 1

Filters Used for Burn Production

Filter Designation	Nominal λ_{max} (μ)	Filter Composition	Area (sq in.)	Irradiance ($cal/cm^2/sec$)
A	0.42	$CuSO_4$(sat'd sol'n) $CoCl_2$(10g/1)[a]	800	5.0
B	0.55	$CuSO_4$, (30g/1)[a] Cinemoid No. 1	800	5.3
C	0.65	$Fe(NH_4)_2(SO_4)_2$, (110g/1)[a] Cinemoid No. 6	800	8.3
C'	0.70	$Fe(NH_4)_2(SO_4)_2$(110g/1)[a] Corning 2-58	210	5.3
D	0.85	Water[a] Cinemoid No. 6, No. 1, No. 20	800	5.0
E	1.0	Corning 7-56	210	7.3
F	1.7	Corning 7-56 Corning 1-52	140	2.5

(a) The cell for all the liquid filters had a path length of 2.8 cm. The cell walls were 1/4" color-clear plate glass manufactured by Libby-Owens Ford.

Preparation of Skin Surfaces

Rats were depilated by the method of Kuhl, et al.[3] at least 3 days prior to burning. Blackening of the skin of the rat was accomplished by the application of black stencil ink to which had been added 5 per cent by weight of carbon black. The reflectivity of the surface thus prepared was 3 per cent or less over the spectral range of interest (0.35μ — 1.5μ).

Human skin was closely clipped with electric clippers on the volar surface of the forearm.

Design and Methods of Analysis

Every exposure of either rats or volunteers was so designed that each filter combination was evaluated an equal number of times on each individual.

On the rats the two sides of the animal were each divided into four areas to each of which was assigned a filter combination. The arrangement was such that each filter was assigned to each location an equal number of times. The four filters were tested twice on each animal giving a total of 8 burns per rat. Five minutes after grading the animals were graded according to a modification of a burning system previously described and used in this laboratory.[4] The system and the corresponding numerical scores are shown in Table 2. All burns, both rat and human, were made with a standard exposure time of 2.0 sec, unless otherwise noted. The exposure aperture was 3/8 in. in diameter for the human burns and 1/2 in. in diameter for the rat burns. The total radiant exposure was controlled by inserting attenuating screens into the path of the parallel beam. These screens do not have all the attenuating values which are desirable, but by varying the time around 2.00 sec by $\pm$ 0.20 sec, appropriate values were found to produce a given burn.

When the average severity scores for a group of exposures at constant total energy are plotted as a function of the logarithm of energy (Q) a good fit to a linear regression is obtained. From the calculated regression line the best estimate of the energy associated with a given response can be calculated along with its associated confidence limits. All confidence limits given herein are the standard deviation

For the studies on human skin a similar grading system as shown in Table 3 was employed. However, because of the non-homogeneity in response of human skin and because of the larger number of exposures that would be required, a precise analytic method such as used for the rat burns was not practicable. Instead, the simple mean of all energy values producing the same effect was employed as an index of effectiveness.

TABLE 2

Severity Scoring System for Rats

Description	Numerical Grade
No response	0
Transient Erythema	1
Perceptible Surface Coagulation (+)	2
Moderate Surface Coagulation (minimal white)	3
Full White	4

TABLE 3

Severity Score for Human Volunteer Burns

Description	Numerical Grade
No response	0
Transient Erythema	1
Persistent Erythema	2
Vesication	3
Immediate Mild Coagulation	4

RESULTS

Rat Skin

The energy for "minimal white" burn production in the rat was measured with filters B (λ_{max} = 0.55μ); C′(λ_{max} = 0.65μ); E (λ_{max} = 1.0μ) and F (λ_{max} = 1.7μ). The result for normal depilated rat skin is shown in Table 4.

For normal skin there is only a slight difference among filters B, E, and F. These values are 4.3 ± 0.2 cal/cm^2 for filter B; 4.0 ± 0.2 cal/cm^2 for filter E; and 3.3 ± 0.2 cal/cm^2 for filter F. However for filter C′the energy required is approximately 28 cal/cm^2. The maximum irradiance with this filter was 5.3 cal/cm^2/sec, therefore, it was necessary to increase the exposure time from the standard 2 sec exposure to over 5 sec for this wave length region. The results of Alpen, et al.[5] have shown previously, however, that for unfiltered carbon arc radiation there is a difference of only 8 per cent in the energy required for a minimal white burn at 2 sec and at 8 sec exposure time. It was not possible, within a reasonable range of exposure times, to get the range of response necessary to make a precise analysis for effective energy. Therefore, the figure 28 cal/cm^2 is an estimate only of the threshold for "minimal white" and confidence limits are not available. Certainly, however, burns at lower total energies will be infrequent.

When the skin of the rat is blackened,the effective energies are reduced to a relatively constant value independent of wave length. These are 2.3, 2.3, 2.4, and 2.2 cal/cm^2 for filters B, C′, E, and F respectively. No significant differences are present here and the pooled estimate for blackened skin is 2.3 ± 0.1 cal/cm^2 independent of spectral distribution of applied energy.

The reflectivity of rat skin was measured by means of the integrating sphere for the actual wave length distribution used in each filter by irradiating the intact skin with the energy of the carbon arc source passed by the filter and measuring total reflected energy with the thermocouple detector. The reflectivities relative to $MgCO_3$ are shown in Table 4.

The results for the human burns are presented in detail in Table 5. Certain aspects of these data are worth further comment. It is immediately evident that only a small variation in energy is required to span the range of effect from a mild transient erythema to a severe vesication equivalent to a second degree burn in the standard clinical classification. Indeed, in those two cases where a mild third degree burn was produced

TABLE 4

Critical Energy and Spectral Reflectivity of Rat Skin

Spectral Band	Reflectivity[a] (mean per cent ± s. d.)	Critical Energy for "Minimal White" (cal/cm^2 ± s. d.)
A	39 ± 1.0	-
B	36.5 ± 1.6	4.3 ± 0.2
C′	50.5 ± 0.5	28 ±
D	46 ± 0	-
E	24 ± 0.6	4.0 ± 0.2
F	13 ± 0	3.3 ± 0.2

(a) Relative to $MgCO_3$

TABLE 5

Energy Required for Burn Production on Human Skin in Various Spectral Regions

Filter	λ_{max} (μ)	Reflectivity[a] (per cent)	Average Effective Energy (Cal/cm^2)		
			Transient Erythema	Persistent Erythema	Vesicle Formation
A	0.42	24.5 ± 3.5	1.96 ± 0.32	2.20 ± 0.37	1.95 ± 0.68
B	0.55	40.9 ± 3.8	3.20 ± 0.48	3.25 ± 0.28	(2.96)[b]
C	0.65	56.9 ± 2.5	9.40 ± 3.3	9.9 ± 2.1	10.2 ± 0.6
D	0.85	53.4 ± 2.2	15.5 ± 2.0	14.0 ± 1.12	-
F	1.7	17.0 ± 0.6	1.87 ± 0.08	(2.50)[b]	2.56 ± 0.3

(a) Relative to $MgCO_3$.

(b) Single observations

(immediate mild coagulation, grade 4) the increase in energy required was small. These two burns were produced with 3.2 cal/cm^2 with filter E while 2.6 cal/cm^2 with the same filter produced erythema followed by vesication. The variability in energy required to produce a given effect is quite closely related to the variation in skin reflectivity for the region in question. In those regions where differences in skin reflectivity among subjects were smallest, i.e., filter E, the variability in energy requirement also became small. The coefficient of variation of energy requirement in every case closely approximates the coefficient of variation of the skin reflectivity. In contrast the rat skin reflectivities were remarkably constant and the effective energies reflect this lack of variability in reflectance.

DISCUSSION

In considering the mechanisms responsible for burn production it has been generally assumed that the process of heat coagulation of protein requires a time temperature history adequate for the denaturing process. This has been discussed at great length by Henriques and Moritz.[6] There is little likelihood that a specific photochemical reaction is responsible for the burning phenomenon when radiant energy at wave lengths beyond the sunburn erythema region are applied to skin but rather that it is dependent upon total energy absorption in the volume of tissue being heated. This process will be independent of spectral distribution of energy and would depend only on total energy transfer. If this is the case several of the optical properties of skin must be closely scrutinized. We might conveniently partition the energy applied to skin as the fraction reflected and the fraction absorbed. In this arbitrary classification we would include in the reflected fraction all that energy leaving the skin surface as a result of back scattering as well as the truly reflected energy. The skin, for purposes of transmission of energy, can be considered as a single boundary system in which a real concept of classical transmission properties are hard to define. It is an obvious statement that all energy not reflected is absorbed in the superficial portions of body tissue and it is only when we define a specific depth that transmission takes on significance.

Reflectivity can be rather simply measured and a real meaning attached to values of incident energy corrected for reflection losses. These measurements have been made and corrections applied. In Table 6 are shown the values for rat and human skin corrected for measured reflectivity. It is important to recollect in this regard that the reflectivity used to correct the basic values are measures of the exact loss of energy by

TABLE 6

Critical Energy for Burn Production Corrected for Spectral Reflectance

Filter	Rat Skin (Minimal White)			Human Skin (Persistent Erythema)		
	Reflectivity (per cent)	Q Uncorrected (cal/cm^2)	Q Corrected (cal/cm^2)	Reflectivity (per cent)	Q Uncorrected (cal/cm^2)	Q Corrected (cal/cm^2)
A	39.0	-	-	24.5	2.20	1.7
B	36.5	4.3	2.7	40.9	3.2	1.9
C	50.5	28	14.3	56.9	9.9	4.3
D	46.0	-	-	53.4	14.0	6.5
E	24.0	4.0	3.0	17.0	-	-
F	13.0	3.3	2.9	24.0	2.50	1.9

reflection for radiation incident on the skin with each filter. The measured reflectivity was with the same energy distribution as that used in burning.

It is apparent that skin reflectivity fails to account completely for variation in critical energy with wave length. Even for filters B, E, and F on rat skin the values 2.7, 3.0, and 2.9 cal/cm^2 respectively are significantly different at a probability level of less than .01 from the pooled estimate of 2.3 cal/cm^2 for blackened skin. This latter value represents the nearest possible approach to complete surface absorption of energy and the differential between this value and the corrected value most probably reflects transmission differences. It is also quite obvious on human skin that corrections of applied energy for reflection losses leaves a large variability in effective dose which must be accounted for on the basis of differences in transmissivity of skin in the various spectral regions.

ythema) Q Corrected (cal/cm^2)
1.7
1.9
4.3
6.5
-
1.9

When one considers the problem of transmissive properties of skin, however, it is not possible to make a clear-cut analytic correction for transmission losses. If the precise depth at which tissue damage takes place could be measured it would be possible to define a boundary condition with a concomitant transmission value or absorptivity which could be correlated with biological effectiveness. This end has not yet been achieved, however, and for this reason correlations of effectiveness of monochromatic light with biologic effectiveness in burn production must be on a qualified basis.

In general, it can be said that all observers have seen a region of higher transmission between 0.7 and 1.1 microns with a peak of transmission between 0.8 and 1 micron.[7,8,9] These values are corroborated by our findings of high critical burn energies at wave lengths between 0.6 and 1.0 microns for rat and human skin. Of critical importance to studies of skin transmission is the finding of Hardy[11] that skin does not obey Beer's law and that the absorption coefficient is not constant with skin depth. He has found that the absorption coefficients for the most superficial layers are greater than for deeper tissues. The work of Hansen[10] on the transmission of skin in the region 0.3 to 0.5μ has clearly shown an absorption band at 0.415μ which he related to the presence of myoglobin, hemoglobin and other porphyrin pigments. These compounds are known to have a peak absorption in this region. The high absorptivity in this region may account for the low value found for the critical energy with filter A (λ_{max} = 0.4μ) on human skin.

It has been reported by Berkeley and Davis[12,13] that in the pig the effective dose of infrared radiation is greater than that of unfiltered carbon arc radiation. They have also reported a qualitative difference between the erythema of ultraviolet radiation and the erythema of visible and infrared radiation in the pig. They have stated that the erythema associated with ultraviolet radiation is uniform and disappears, to be

followed by reappearance at 24 to 36 hr, while with visible and infrared radiation the erythema was mottled and grew in intensity over 24 to 30 hr. The latter erythema did not blanch with pressure while the former did.

Our experience in man and the rat has not substantiated these findings. However, with regard to the differences in spectral response, the reasons for discrepancy can be demonstrated. In their study a series of filters cutting off successively larger increments of visible radiation were used. The "infrared filter" passed radiation in the region of our filters C and D which we have shown to be ineffective.

However, appreciable amounts of energy at longer wave lengths were present. If their study had included a filter with a low end cut off at wave-length greater than 1.0μ they would most certainly have shown an increased effectiveness in this region.

The differences in erythema production observed by them were not seen in our study in either the rat or man. The erythema produced by radiation at any wave length uniformly developed rapidly during the first few minutes and blanched with pressure. In the rat the erythema was transient. In man it lasted several hours and could be characterized as classic "triple response." The susceptibility of individuals to wheal formation was remarkably variable, extending from a barely detectable raising to wheals 2 to 3 mm in height. The persistent erythema in man also blanched with pressure during the first 24 hr but the color became fixed with time.

Approved by:

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Captain (MC) USN
Acting Head, Biological and
Medical Sciences Division

For the Scientific Director

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34	Commander, Naval Air Material Center, Philadelphia
35	CO, Naval Air Development Center, Johnsville
36	Aviation Medical Acceleration Laboratory (Hardy)
37	Commander, Naval Ordnance Lab., Silver Springs (R)
38	Commander, Naval Ordnance Lab., Silver Springs (EE)
39-40	CO, Naval Schools Command, Treasure Island
41	CO, Naval Damage Control Training Center, Philadelphia
42	Superintendent, Naval Postgraduate School, Monterey
43-44	CO, Fleet Training Center, Norfolk

45-46	CO, Fleet Training Center, San Diego	107
47-48	CO, Fleet Training Center, San Diego (SPWP School)	108
49	CO, Naval Electronics Lab., San Diego (Code 4223)	109
50	CO, Naval Clothing Factory, Brooklyn	110
51	CO, Naval Ordnance Test Station, Inyokern	111
52	CO, Air Development Squadron 5, Moffett Field	112-113
53	Commander Training Command, Pacific Fleet	114
54	Office of Patent Counsel, Mare Island	115
55	Commander Air Force, Atlantic Fleet (Code 16F)	116
56	CinC, U.S. Atlantic Fleet	117
57	CinC, U.S. Pacific Fleet	118
58	President, Naval War College, Newport	119
59	Naval Attache, The Hague	120
60-63	Commandant, U.S. Marine Corps	121
64	Commandant, Marine Corps Schools, Quantico (Library)	122
65	Commandant, Marine Corps Schools, Quantico (Development Center)	123-124
	ARMY	
66	Chief of Engineers (ENGEB, Dhein)	125
67-69	Chief of Engineers (ENGNB)	126
70	Chief of Transportation	127-128
71	Chief of Ordnance (ORDTX-AR)	129
72-73	Chief Chemical Officer	130
74-75	CG, CmlC Res. and Eng. Command (RR and SW Mat'l)	131
76	CG, CmlC Res. and Eng. Command (Special Projects)	132-133
77-79	CO, CmlC Chemical and Radiological Lab. (Library)	134
80	CO, Chemical Corps Materiel Command	135
81	CO, Chemical Corps Medical Laboratories	136
82	CO, Chemical Corps Board	137
83-84	CG, Aberdeen Proving Grounds (Ballistics Research Lab.)	138
85	Commandant, Chemical Corps Training Command (Library)	139
86-88	Chief Signal Officer (SIGOP)	140-142
89-92	Chief, Army Field Forces, Fort Monroe	143
93	President, Army Field Forces Board No. 1, Fort Bragg	144-145
94	President, Army Field Forces Board No. 4, Fort Bliss	146
95	CO, Army Medical Research Laboratory, Fort Knox	147
96-97	Commandant, Army Medical Service Graduate School	148
98	Army Medical Service Graduate School (Dept Biophysics)	149-151
99	CG, Medical Field Service School, Fort Sam Houston	152
100	CG, Quartermaster Res. and Dev. Command (Library)	153
101	CG, Quartermaster Res. and Dev. Command (Davies)	154
102	Director, Operations Research Office	155-156
103	CO, Dugway Proving Ground	
104-106	CG, The Engineer Center, Fort Belvoir	157-158

107	CO, Engineer Res. and Dev. Lab., Fort Belvoir
108	Surgeon General (MEDDH-SP)
109	Surgeon General (Res. and Dev. Board)
110	Director, Evans Signal Laboratory (Nucleonics Section)
111	Director, Evans Signal Laboratory (Technical Documents)
112-113	CO, Transportation Res. and Dev. Command, Fort Eustis
114	Tokyo Army Hospital
115	CO, Frankford Arsenal
116	CO, Picatinny Arsenal (ORDBB-TK)
117	CO, Watertown Arsenal
118	Commandant, Command and General Staff College (ALLLS/AS)
119	Director, Special Weapons Development Office, Fort Bliss
120	Director, Waterways Experiment Station
121	Assistant Chief of Staff, G-3 (RR and SW)
122	Assistant Chief of Staff, G-4
123-124	CinC, Far East Command (J-3)

AIR FORCE

125	Directorate of Res. and Dev. (AFDRD-HF)
126	Directorate of Res. and Dev. (Armament Division)
127-128	Directorate of Intelligence (AFOIN-1B2)
129	Directorate of Requirements (AFDRQ-SA/M)
130	Director of Plans (War Plans Division)
131	Director of Operations (Operations Analysis)
132-133	Commander, Air Materiel Command (MCAIDS)
134	Commander, Wright Air Development Center (WCOES)
135	Commander, Wright Air Development Center (WCOESP)
136	Commander, Wright Air Development Center (WCRDO)
137	Commander, Wright Air Development Center (WCRTY)
138	USAF Institute of Technology, Wright-Patterson Air Force Base
139	Surgeon General (Biological Defense Branch)
140-142	Commander, Air Res. and Dev. Command (RDTDA)
143	Commander, Air Res. and Dev. Command (RDTDH)
144-145	Commandant, School of Aviation Medicine
146	USAF, SAM, Randolph Field (Brooks)
147	CG, Strategic Air Command, Offutt Air Force Base (IGABD)
148	CG, Strategic Air Command (Operations Analysis Office)
149-151	Commander, Special Weapons Center, Kirtland Air Force Base
152	Commander, Air Defense Command, Ent Air Force Base
153	CG, Tactical Air Command, Langley Air Force Base
154	Director, Air University Library, Maxwell Air Force Base (CR-4030)
155-156	Director, Air University Library, Maxwell Air Force Base (CR-5464)
157-158	Commander, Technical Training Wing, 3415th Technical Training Group

159	Commander, Hq., Technical Training Air Force, Gulfport
160	Commander, Crew Training Air Force, Randolph
161	CG, Air Proving Ground, Eglin Air Force Base (AF/TRB)
162	CG, Air Training Command, Scott Air Force Base (DCS/O, GTP)
163-164	Commander, Flying Training Air Force, Waco
165	Commander, Cambridge Research Center (CRHK)
166	Commander, Cambridge Research Center (CRQST-2)
167	AFOAT - Headquarters (Allen)

OTHER DOD ACTIVITIES

168-182	Chief, Armed Forces Special Weapons Project
183	AFSWP, SWTG, Sandia Base (Library)
184-189	AFSWP, Hq., Field Command, Sandia Base
190	Assistant Secretary of Defense (Res. and Dev.)
191	Commandant, Armed Forces Staff College (Secretary)
192	U.S. Military Representative, Hq., SHAPE
193	Director, Weapons Systems Evaluation Group
194	Armed Forces Medical Library
195-196	Armed Forces Institute of Pathology
197-201	Armed Services Technical Information Agency

AEC ACTIVITIES AND OTHERS

202-204	Argonne Cancer Research Hospital
205-210	Argonne National Laboratory
211-213	Atomic Energy Commission, Washington
214	Atomic Energy of Canada, Ltd.
215-216	Australian Atomic Energy Commission
217	Battelle Memorial Institute
218-220	Belgium, Union Miniere du Haut Katanga
221-224	Brookhaven National Laboratory
225	Brush Beryllium Company
226	California Forest Experimental Station (Fons)
227-229	Canadian Joint Staff
230	Carbide and Carbon Chemicals Company (C-31 Plant)
231-232	Carbide and Carbon Chemicals Company (K-25 Plant)
233-238	Carbide and Carbon Chemicals Company (ORNL)
239	Centre d'Etudes pour les Applications de l'Energie Nucleaire
240	Centro Informazioni Studi Esperienze
241-244	Chalk River Project, Canada
245	Columbia University (Failla)
246	Columbia University (Hassialis)
247-248	Committee on Atomic Casualties (APO-182)
249-252	Committee on Atomic Casualties, Washington
253	Commonwealth X-Ray and Radium Laboratory

254-255	Consolidated Vultee Aircraft Corporation
256	Department of Agriculture, Fire Research Division (Brown)
257	Division of Raw Materials, Denver
258-259	Dow Chemical Company, Midland
260	Dow Chemical Company, Rocky Flats
261-264	duPont Company, Augusta
265	duPont Company, Wilmington
266	Eldorado Mining and Refining, Ltd.
267	Forest Products Laboratory (Bruce)
268	General Electric Company (ANPP)
269-271	General Electric Company, Richland
272	Goodyear Atomic Corporation
273	Harshaw Chemical Corporation
274	Iowa State College
275-276	Isotopes Division, Oak Ridge
277-278	Knolls Atomic Power Laboratory
279	Lockheed Aircraft Corporation (Cleveland)
280	Lockheed Aircraft Corporation (Moore)
281-282	Los Alamos Scientific Laboratory (Library)
283	Los Alamos Scientific Laboratory (Graves)
284	Mallinckrodt Chemical Works
285	Massachusetts Institute of Technology (Hottel)
286	Massachusetts Institute of Technology (Williams)
287	Medical College of Virginia (Ham)
288	Mound Laboratory
289	National Bureau of Standards (Taylor)
290	National Lead Company of Ohio
291-293	National Research Council, Ottawa
294	New Brunswick Laboratory
295	Newport News Shipbuilding and Drydock Company
296	New York Operations Office
297-298	North American Aviation, Inc.
299	Nuclear Development Associates, Inc.
300	Oak Ridge Institute of Nuclear Studies
301	Patent Branch, Washington
302-307	Phillips Petroleum Company
308	Princeton University (White)
309-311	Public Health Service, Washington
312	RAND Corporation (Library)
313	Sandia Corporation (Library)
314	Sandia Corporation (Applied Physics Division)
315	Strong Memorial Hospital (Pearse)
316	Technical Operations, Inc. (Henriques)
317	Tokyo University
318	United Aircraft Corporation
319-333	United Kingdom Scientific Mission

334	U.S. Geological Survey, Denver (RCS-TEPCO)
335	UCLA Medical Research Laboratory
336	University of California (Engineering Research)
337	University of California Medical Center
338-340	University of California Radiation Laboratory, Berkeley
341-342	University of California Radiation Laboratory, Livermore
343	University of Chicago Radiation Laboratory
344-345	University of Michigan (Gomberg)
346-347	University of Rochester (Technical Report Unit)
348	University of Tennessee (Comar)
349-352	University of Utah (Bowers)
353	University of Washington, Applied Fisheries Lab.
354	Vitro Corporation of America
355	Weil, Dr. George L.
356-359	Western Reserve University
360-361	Westinghouse Electric Corporation
362-386	Technical Information Service, Oak Ridge

USNRDL

387-425	USNRDL, Technical Information Division

DATE ISSUED: 12 July 1955

Naval Radiological Defense Laboratory.
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filter C, λ(max) = 0.65μ, r = 50.5 $\pm$ 0.5 %, Q = 28 cal/cm^2(approx.);
filter E, λ(max) = 1.0μ, r = 24 $\pm$ 0.6 %, Q = 4.0 $\pm$ 0.2 cal/cm^2;
filter F, λ(max) = 1.7μ, r = 13 $\pm$ 0 %, Q = 3.3 $\pm$ 0.2 cal/cm^2.

For human skin the following data were obtained:

filter A, λ(max) = 0.42μ, r = 24.4 $\pm$ 3.5 %, Q = 3.20 $\pm$ 0.37 cal/cm^2;
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filter C, λ(max) = 0.65μ, r = 56.9 $\pm$ 2.5 %, Q = 9.9 $\pm$ 2.1 cal/cm^2;
filter D, λ(max) = 0.85μ, r = 53.4 $\pm$ 2.2 %, Q = 1.1 cal/cm^2;
filter F, λ(max) = 1.7μ, r = 17 $\pm$ 0.60 %, Q = 2.50 cal/cm^2 (approx.).

The ranges shown are standard deviations.

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The reflectivities of skin for the same broad-band spectral regions have been measured. For the rat the reflectivities and critical energies for production of a standard burn are the following:

filter B, λ(max) = 0.55μ, r = 36.5 $\pm$ 1.6 %, Q = 4.3 $\pm$ 0.2 cal/cm^2;
filter C$'$, λ(max) = 0.65μ, r = 50.5 $\pm$ 0.5 %, Q = 28 cal/cm^2 (approx.);
filter E, λ(max) = 1.0μ, r = 24 $\pm$ 0.6 %, Q = 4.0 $\pm$ 0.2 cal/cm^2;
filter F, λ(max) = 1.7μ, r = 13 $\pm$ 0 %, Q = 3.3 $\pm$ 0.2 cal/cm^2.

For human skin the following data were obtained:

filter A, λ(max) = 0.42μ, r = 24.4 $\pm$ 3.5 %, Q = 3.20 $\pm$ 0.37 cal/cm^2;
filter B, λ(max) = 0.55μ, r = 40.9 $\pm$ 3.8 %, Q = 3.25 $\pm$ 0.28 cal/cm^2;
filter C, λ(max) = 0.65μ, r = 56.9 $\pm$ 2.5 %, Q = 9.9 $\pm$ 2.1 cal/cm^2;
filter D, λ(max) = 0.85μ, r = 53.4 $\pm$ 2.2 %, Q = 14.0 $\pm$ 1.1 cal/cm^2;
filter F, λ(max) = 1.7μ, r = 17 $\pm$ 0.60 %, Q = 2.50 cal/cm^2 (approx.).

The ranges shown are standard deviations.

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The reflectivities of skin for the same broad-band spectral regions have been measured. For the rat the reflectivities and critical energies for production of a standard burn are the following:

filter B, λ(max) = 0.55μ, r = 36.5 $\pm$ 1.6 %, Q = 4.3 $\pm$ 0.2 cal/cm^2;
filter C, λ(max) = 0.65μ, r = 50.5 $\pm$ 0.5 %, Q = 28 cal/cm^2 (approx.);
filter E, λ(max) = 1.0μ, r = 24 $\pm$ 0.6 %, Q = 4.0 $\pm$ 0.2 cal/cm^2;
filter F, λ(max) = 1.7μ, r = 13 $\pm$ 0 %, Q = 3.3 $\pm$ 0.2 cal/cm^2.

For human skin the following data were obtained:

filter A, λ(max) = 0.42μ, r = 24.4 $\pm$ 3.5 %, Q = 3.20 $\pm$ 0.37 cal/cm^2;
filter B, λ(max) = 0.55μ, r = 40.9 $\pm$ 3.8 %, Q = 3.25 $\pm$ 0.28 cal/cm^2;
filter C, λ(max) = 0.65μ, r = 56.9 $\pm$ 2.5 %, Q = 9.9 $\pm$ 2.1 cal/cm^2;
filter D, λ(max) = 0.85μ, r = 53.4 $\pm$ 2.2 %, Q = 14.0 $\pm$ 1.1 cal/cm^2;
filter F, λ(max) = 1.7μ, r = 17 $\pm$ 0.60 %, Q = 2.50 cal/cm^2 (approx.).

The ranges shown are standard deviations.

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filter D, λ(max) = 0.85μ, r = 53.4 ± 2.2 %, Q = 14.0 ± 1.1 cal/cm^2;
filter F, λ(max) = 1.7μ, r = 17 ± 0.60 %, Q = 2.50 cal/cm^2(approx.).

The ranges shown are standard deviations.

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filter C, λ(max) = 0.65μ, r = 56.9 ± 2.5 %, Q = 9.9 ± 2.1 cal/cm^2;
filter D, λ(max) = 0.85μ, r = 53.4 ± 2.2 %, Q = 14.0 ± 1.1 cal/cm^2;
filter F, λ(max) = 1.7μ, r = 17 ± 0.60 %, Q = 2.50 cal/cm^2(approx.).

The ranges shown are standard deviations.

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The significance of the optical properties of skin have been discussed and the property of the high transmission of skin in the region 0.7 to 1.0μ has been presented.

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filter C, λ(max) = 0.65μ, r = 56.9 $\pm$ 2.5 %, Q = [illegible]
filter D, λ(max) = 0.85μ, r = 53.4 $\pm$ 2.2 %, Q = 14.0 $\pm$ 1.1 cal/cm^2;
filter F, λ(max) = 1.7μ, r = 17 $\pm$ 0.60 %, Q = 2.50 cal/cm^2 (approx.).
The ranges shown are standard deviations.
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