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CLOTHING TEST METHODS

Edited by

L. H. NEWBURGH (*Physiological Tests*)
and
MILTON HARRIS (*Physical Tests*)

of Subcommittee on Clothing
of the
National Research Council (U.S.A.)

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FOREWORD

The following articles have been prepared by both military and civilian investigators. The points of view and the methods set forth by these men are the ones upon which they rely for obtaining information about military clothing. The articles are gathered into two groups: I. Those that examine the functional capacity of the clothing to meet the physiological requirement. II. Those designed to obtain information about the physical properties of textiles.

The writers were selected by the Subcommittee on Clothing of the National Research Council (U.S.A.) because it was thought that they were well fitted for the task assigned to them. No doubt, equally capable individuals have been overlooked. Nevertheless, the authors are, in every case, leading investigators in laboratories that have made important contributions to the war effort.

None of the articles are official and none commit the officers in charge of the laboratories. All are open to criticism and none is final.

They are published for the consideration of and use by our colleagues who are endeavoring through improvement in military clothing to make their small contribution towards winning the war.

L. H. N.

February 1945

Ann Arbor, Michigan

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PART I

Physiological Tests

MEASUREMENT OF SKIN AND CLOTHING TEMPERATURES

L. P. Herrington

Among the methods now in use by various workers are:

a. resistance thermometers,
b. thermocouples attached to the skin or clothing with adhesive tape or sewn onto the clothes, and
c. thermocouples soldered on thin copper discs and held in place by means of harnesses.

With proper precautions, all these methods are satisfactory for measuring relative changes of surface temperatures on exposure to heat or cold. Junction wires should be as fine as is consistent with mechanical strength, but no heavier than #30 gauge. Capillary circulation must not be disturbed by pressure of junctions against the skin. It is desirable to check all methods against readings of a radiation thermopile under conditions that are suitable to thermopile use.

[1]Thermopiles should be provided with a thermocouple for measuring the temperature of its cold junctions. Good results may be obtained by the use of a long thermocouple junction, made of 40 gauge copper-advance wire and cemented onto the thermopile junctions, after coating with duco or some other insulating material.

For high temperature work at least 10 surface-temperature measurements are necessary to obtain a fair average skin temperature for the whole body. On exposure to cold more readings are necessary because of the steep temperature gradients over the body's surface.

Instructions for construction, calibration and correct use of thermocouples and radiation thermopiles will be found in "Temperature: Its Measurement and Control in Science and Industry," Reinhold Publishing Corporation, 330 West 42nd St., New York, 1941.

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1. We have found that cheap and convenient cencopile is subject, at low temperatures, to calibration changes of considerable order. For this reason we use a double "reference bath" and calibrate for a 10°F. difference between baths on every measurement. We believe the effect is probably due to moisture changes in the internal parts of pile which probably are less important in a precision constructed instrument.

CALCULATION OF THE HEAT DEBT

A. C. Burton

1. Introduction

In the "Clo determination" of the insulating value of clothing it is necessary to know the heat that passes through the clothing by radiation plus convection. This quantity divided into the temperature gradient across the clothing gives the insulation. A direct calorimeter measures the total heat loss, and from this the heat loss by evaporation, E Cals/Sq.M./Hr., obtained from the weight loss of subject plus clothing, may be subtracted to give the quantity desired. However, where such a calorimeter is not available, recourse is had to indirect calorimetry. The total heat loss must be equal to the heat produced, M Calories/Sq.M./Hr., plus any heat given up by the body tissues in falling to a lower average temperature, D Cals/Sq.M./Hr. This is by agreement known as the "Heat Debt" acquired by the body, since it must be made good to restore the body to normal temperature. The quantity used in the Clo determination is then $(M + D - E)$ Cals/Sq.M./Hr.

2. Calculation of D

The heat debt D is equal to the thermal capacity of the body times the fall of average body temperature T_A.

$$\text{i.e.,} \quad D = W.S. \quad T_A \qquad (1)$$

where W is the weight, and S the average specific heat of the body tissues. As a first approximation T_A was taken to be the same as the drop of deep body temperature (say deep rectal temperature) T_R. However, it was recognized that this might lead to very serious errors since a large proportion of the body is at a much lower temperature than the deep tissues, and skin temperature changes were often not at all correlated with changes in rectal temperature. The first intensive attempt to obtain a better approximation by using also the change of skin temperature was in 1935. (1) For complete explanation and details the reader is referred to that paper. It was there shown that the average temperature of the tissues could be expressed by the equation:

$$T_A = A_1T_1 + A_2T_2 + A_3T_3 + ---- \qquad (2)$$

where T_1, T_2, T_3, etc., were temperatures measured at various points in the body, and A_1, A_2, A_3 were coefficients derived by physical considerations of shape and size of the appropriate body parts, and of the nature of the gradients of temperature within the tissues.

The method of calculating these coefficient for any desired temperature points is given in the paper referred to. Some of the results are given in the table below:

Table 1

Value of Coefficients in Formula for Average Body Temperature

Position where temp. was measured	Coeff.	Position where temp. was measured	Coeff.
Rectum	0.59	Skin of trunk	0.09
Mouth	0.05	Skin of head	0.02
Skin of lower leg	0.07	Skin of upper arm	0.03
Skin of thigh	0.12	Skin of lower arm	0.03

If fewer temperature points are desired, the temperature of any point omitted is assumed to be midway between that of the points proximal and distal to that point, and the coefficient appropriate to the omitted point is divided equally between these two points and added to their coefficients.

3. Average Surface Temperature

Merely for convenience in calculation, formula (1) can be re-cast into the form:

$$T_A = A_1T_R + A_sT_s \qquad (3)$$

where T_s is an "average surface temperature" calculated from the original formula as

$$T_s = B_2T_2 + B_3T_3 + ---- \qquad (4)$$

(The new coefficients B_2, B_3, etc., are, of course, merely the old coefficients A_2, A_3, etc., divided by A_s). In this way it was predicted that in this form the best partition of coefficients would be likely to be:

$$T_A = 0.64\ T_R + 0.36\ T_s \qquad (5)$$

It was then shown by analysis of 40 one-hour periods where both indirect and direct calorimetry was made, that for these periods the statistically best partition was:

$$T_A = 0.7\ T_R + 0.3\ T_s \qquad (6)$$

However, any value between 0.6 and 0.75 for the first coefficient gave satisfactory results. The improvement over the use of the rectal temperature above in calculating the heat debt was very marked.

Subsequently, Hardy and DuBois found that a partition of 0.8 T_R + 0.2 T_s gave the best results for their data.(2) The Pierce Laboratory adopted a coefficient very similar to that given here.(3) It was pointed out that necessarily the best partition would be different for different individuals, whether obese or slim and might also vary with the state of vasodilation and constriction. The best "mixing coefficient" must either be chosen by valid statistical methods on a number of results for simultaneous direct and indirect calorimetry, or a "universal" value be adopted as the best available approximation for all cases.

It is recommended that the coefficients

$$T_A = \frac{2}{3}\ T_R + \frac{1}{3}\ T_s \ ------ \qquad (7)$$

be adopted for such "universal" use, the average surface temperature T_s to be calculated from the skin temperature points measured according to the method outlined in the paper referred to. (The values used in the work at the Cold Chamber, No. 1 Clinical Investigation Unit, R.C.A.F., Toronto, are:

$$T_s = \frac{1}{3}\left(T_{trunk} + T_{thigh}\right) + 0.18\,T_{leg} + 0.15\,T_{upper\ arm}$$

Average Surface Temperature

It must be emphasized that the average surface temperature T is calculated according to the *weight* of tissue represented by any temperature point, not according to the *surface area* it represents. The coefficients (B in Eq. 4) are quite different from those pertaining to a "surface area average" of skin temperature. In the Clo determination the gradient across the clothing and the surrounding air is taken as (average skin temperature - air temperature). The average skin temperature in this part of the calculation should, to be precise, be separately calculated on an area rather than a weight basis. However, the average surface temperature rarely changes by more than 4 or 5 degrees C. in even an extreme experiment while the total gradient will be 50°C. or more in experiments at 0°F. (-18°C.). Thus the difference in the final result if the average "weight" skin temperature is used, in this part of the calculation, instead of the average "surface" skin temperature, is likely to be insignificant.

On the other hand, to use a "surface" rather than a "weight" average skin temperature in the calculation of heat debt may introduce very serious errors. For example, each hand represents only 1.8% by weight of the whole body, but 2.5% by surface area.(4) Since the temperature of the hands may change a very great deal compared to the change of other parts, use of the wrong formula may greatly overemphasize the contribution of the hands to the total heat debt, and destroy the usefulness of the inclusion of skin temperature in the calculation of heat debt.

Value of Specific Heat

In the calculations an average specific heat of 0.83 was assumed, based on values of Pembrey (5). It was shown for the data used in the original calculations that any value between 0.70 and 0.90 gave almost as good results, but 0.83 actually gave the best results. This is the only direct determination, to our knowledge, of the average specific heat of the whole body.

It is recommended that the value of 0.83 be used for the specific heat of the body, until a further experimental determination on the whole human body suggests another value.

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(4) E. R. DuBois, Arch. Int. Med. 17, 863, 1916.
(5) Pembrey, Animal Heat, Schäfer's Textbook of Physiology, Vol. 1, p. 838, 1898.

EVALUATION OF THERMAL INSULATION PROVIDED BY CLOTHING

H. S. Belding, R. C. Darling, D. R. Griffin,
S. Robinson and E. S. Turrell

The part played by clothing as a barrier to body heat loss in cold environments has been assessed quantitatively at the Fatigue Laboratory and elsewhere using an approach first described by Burton.[1] The methods described here have been found useful in evaluating the relative warmth of different clothing assemblies as affected by styling and materials during actual use. They have been used extensively at the Fatigue Laboratory to determine the comfort-temperature range of sleeping bags and Arctic uniforms for the Army Quartermaster and of electrically heated and other clothing for the Army Air Forces.

These methods have been used on human subjects, thereby permitting an integration of objective data with the subjective reports of comfort, and they have also been used on a thermostatically controlled, electrically heated copper "man."

For human subjects the heat loss through a clothing assembly (H_{cl}) must be equivalent to the sum of the metabolic heat production of the body (M) and whatever heat is lost through cooling of the body tissues (D) after subtraction of heat loss via avenues other than through the clothing. These other avenues include heat loss via the lungs in vaporization of moisture (E_l) and warming the inspired air (A), and heat loss through vaporization of the insensible perspiration at the skin (E_s). This relationship may be expressed as follows:

$$M + D - (E_l + E_s + A) = H_{cl}.$$

All values are calculated in Calories per square meter of body surface per hour to facilitate comparison of results obtained on different subjects. D, the symbol for heat debt, is used in the positive sense to indicate a loss of stored heat from the body mass.

The procedures for obtaining the data necessary for solving this equation are outlined below. Experience has shown that a cold room exposure of three hours is desirable, the first hour serving for equilibration and the last two for collection of the data from which the calculations of H_{cl} are made.

Determination of M, heat production of the body

Metabolic heat production is usually determined indirectly with a closed-circuit respiration apparatus. The subject is connected to the apparatus continuously during the second and third hours of each experiment.[2]

Flutter valves, spirometer, and soda lime canister are all located outside the cold room and assembled as shown in Fig. 1. Flexible rubber tubing of 1"

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[1] "An Analysis of the Problem of Protection of the Aviator Against Cold and the Testing of the Insulating Power of Flying Clothing," by A. C. Burton, a "restricted" report submitted to the Canadian National Research Council, August 11, 1941.

[2] In prolonged respiration experiments everything feasible should be done for the comfort of the subject. For most subjects the rubber mouthpiece can be trimmed from the size ordinarily used in basal metabolism determinations without danger of leakage. The nose clip should have sponge rubber pads and be adjusted so that pressure is just sufficient to prevent leakage of air when the subject blows gently with mouth closed. If the temperature is below +25°F., the tip of the nose must be covered to prevent freezing. Below +10°F. cheeks, chin and forehead should also be covered.

internal diameter is used for connections. The tubing that goes into the cold room is detachable so that it may be taken out of the cold room, drained and dried between experiments. The whole system is tested for leaks before each use by placing a weight on the spirometer bell and a rubber stopper in the mouthpiece. A graphic record of each breath and of total oxygen consumption is made on a kymograph. If desired a gas flowmeter may be installed to measure the volume of air respired. A nomogram is used for reduction of observed wet gas volumes to STP dry volumes (Fig. 4).

Good results may also be obtained with an open-circuit system if a larger Tissot gasometer or a carefully calibrated gas flowmeter is used; the R.Q. is known as a result of the gas analyses made when using this system.

Heat production (M) is calculated from oxygen consumption. Calculations are based on an assumed value of 4.9 Calories per liter of oxygen (assumed R.Q. = 0.88) when the closed circuit system is used.

Determination of D, Heat Gained or Lost by the Body Mass

Burton has shown that the mean temperature of the body mass (T_b) is best represented by a formula involving skin (T_s) and internal (T_i) temperatures as follows:

$$0.33\ T_s + 0.67\ T_i = T_b.^{3}$$

T_s may be determined by taking the weighted mean of readings on eleven copper-constantan or chromel-alumel thermocouples as follows:

Location of Thermocouple	Factors Used in Determining Mean Skin Temperature
Front of chest	.083
Lateral aspect of one thigh	.125
Over kidney on back	.083
Lateral aspect of upper arm	.070
Medial aspect of first phalanx of great toe	.050
Medial aspect of thigh	.125
Medial aspect of lower arm	.070
Over shoulder blade	.083
Over gastrocnemius muscle	.150
Edge of hand at base of first finger	.060
Forehead	.101
	1.000

Assigned weighings roughly correspond to the percentage of the total surface represented by each couple, and are derived from the general assumption that the total surface of the adult body is divided approximately into 40% legs, 25% trunk, 14% arms, 10% head, 6% hands and 5% feet. In practice the forehead thermocouple is omitted when head covering is held constant, and the weighting of all couples is then increased proportionately. Actually, a straight average of ten couples gives satisfactory results unless the hands and feet become excessively cold. A fair approximation of T_s may be obtained from a straight average of the first five thermocouples listed. Couples at the tips of fingers and toes and on the knee and elbow are useful in providing special information but usually are not considered in the calculation of stored heat because they are not representative

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[3] A.C. Burton. J. Nutrition, 9:261-280, 1935.

Calculation of Clo Value

Once H_{cl} is known it is possible to calculate the resistance to heat flow provided by a clothing assembly. In this connection it has proven convenient to utilize the Clo, a unit of clothing insulation suggested by Gagge, Burton, and Bazett.[4] One Clo has been defined as the insulation necessary to maintain in comfort a sitting, resting subject in a normally ventilated room (air movement 20 feet per minute) at a temperature of 70°F. and a humidity of the air less than 50 percent; in metric units

$$\text{one Clo} = 0.18^{\circ}\text{C.}/\text{Cal}/\text{m}^2/\text{hr.}$$

The fundamental equation used in calculating insulation is

$$\text{Insulation} = \frac{\Delta T}{H}$$

where ΔT is the difference of temperature between any two surfaces in the thermal pathway and H is the heat flow between them.

When insulation provided by a clothing assembly is to be expressed in Clo units, I_{clo}, and available temperature data are given in degrees Fahrenheit, the fundamental formula for insulation is adapted as follows:

$$\frac{3.09\ (T_s - T_a)}{H_{cl}} - I_a = I_{clo}$$

where T_s = average skin temperature of subject
T_a = ambient temperature
[5]I_a = the insulation of the air in Clos at the wind velocity present during the test

Sample Work Sheet

Table I is presented as a sample work sheet to show treatment of the data for determination of Clo values.

Usefulness of Clo Value Determinations on Man; Variability of Results

Experience indicates that the procedures described here are principally useful for determining the thermal protection of whole garment assemblies which provide reasonably well-balanced protection to all parts of the body. However, it is readily admitted that results obtained with the method have not been as precise as might be desired. An elementary analysis of the average spread in duplicate I_{clo} values obtained when using the same clothing assembly gives some idea of the limitations of accuracy of the method (Table II). This analysis is based on unselected data. 91% of duplicate results obtained on the same man and 86% of results on different men had a spread of less than 25%. It is obvious that single experiments cannot be relied upon to establish the I_{clo} at all accurately.

In practice it has been found that variability of results can be substantially reduced by giving attention to certain details listed below.

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[4] Science, Vol. 94, page 428.

[5] I_a varies with wind velocity and altitude. At ground level I_a, with no air movement, is about 0.8 Clos; with wind at 1 m.p.h. it is about 0.6 Clos; at 2 m.p.h. it is about 0.4 Clos; at 5 m.p.h. it is about 0.3 Clos; at 10 m.p.h. and above it is about 0.2 Clos. At a given wind velocity I_a increases with altitude, is about twice as great at 40,000 feet as at ground level. For details see Burton's analysis, loc. cit. Incidentally, Clo values determined at different wind velocities will check only if the outer layer of clothing is a good windbreak.

Table 1

SAMPLE WORK SHEET USED IN CALCULATION OF CLOTHING INSULATION

Simplified by Inclusion of data for only one hour (60' - 120')

OUTFIT: Sleeping bag "XX" with standard sleeping clothing
SUBJECT : JE
WEIGHT: 69.3K.
DATE: 4/28/43
S.A.: 1.77 Sq. M.
AMBIENT T.: -10°F. - 23°C.
WIND: 5 m.p.h. turbulent
I_a (air insulation): 0.3 Clos

Calculation of D

$\Delta T_1 = 0.1°F.$ $\quad \Delta T_s = 2.52°F.$

$\Delta T_b = 0.33\ \Delta T_s + 0.67\ \Delta T_1 = 0.90°F$

$$D = \frac{\Delta T_b \times 0.83 \times W}{1.8 \times S.\ A.} = 16.2$$

Calculation of M

O_2 (liters/hr/STP) = 20.88

Cals./hr. (O_2 x 4.9) = 102.3

$$M = \frac{\text{Cals./hr}}{S.\ A.} = 57.8$$

Ventilation (liters/hr/STP dry) = 625

Calculation of A

ΔT insp. and exp. air°C. = 56

$$A = \frac{\text{Vent.} \times 0.00031 \times \Delta T \text{ insp.\& exp.}}{S.\ A.} = 6.1$$

Calculation of $E_1 + E_s$ (Method I)

ΔW before and after = 151 g.

Time between weighings (hrs.) = 3.25

ΔW/hr. = 46.5

$$E = \frac{[\Delta W/\text{hr.} - (0.30 \times O^2/\text{hr.})] \times 0.58}{S.\ A.} = 13.2$$

Calculation of $E_1 + E_s$ (Method II)

(1) Vapr. lungs = $\frac{0.242 \times \text{Vent.}}{S.A.} = 8.6$

(2) Insensible Persp. (assume 6.3) = 6.3

$E_1 + E_s = 14.9$

Calculation of $H_{cl} = M + D - [(E_1 + E_s) + A]$

$H_{cl} = 57.8 + 16.2 - (13.2 + 6.1) = 54.7$ (Method I)

$H_{cl} = 57.8 + 16.2 - (14.9 + 6.1) = 53.0$ (Method II)

Calculation of $I_{clo} = \frac{3.09\ (T_s - T_a)}{H_{cl}} = I_a$

T_s at mid-time = 90.2°F.

$I_{clo} = \frac{3.09\ (90.2 - -10)}{54.7} - 0.3 = 5.4$ (Method I)

$I_{clo} = \frac{3.09\ (90.2 - -10)}{53.0} - 0.3 = 5.5$ (Method II)

Table II

	Quartermaster's Arctic Assembly		Assorted Sleeping Bags	
	Number of pairs of experiments	Mean % diff. between duplicate results	Number of pairs of experiments.	Mean % diff. between duplicate results
On the same man and at the same ambient temperature.	21	9%	10	13%
On the same man, at two different ambient temperatures.	15	17%	14	12%
On two different men run at the same ambient temperature.	115	15%	94	13%
On two different men run two different ambient temperatures.	89	14%	29	14%

(a) Insofar as possible use the same subjects throughout a series of experiments when outfits are being compared; it is known that Clo values obtained on some subjects are consistently higher than on others, the spread between highest and lowest being as great as 25%; this may be attributed to differences in shape and size of different individuals and resulting differences in fit of the clothing and differences in "effective" surface area for heat loss. Regarding the latter, it is obvious that any apposition of body surfaces results in a corresponding reduction of the "effective" surface for heat loss; thus, the regions between the thighs and under the arms are usually not effective for heat loss. It is possible that use of the total surface presented by the clothing as worn rather than the body surface area would give greater uniformity of Clo values between subjects, but this method has not seemed practical for large numbers of determinations.

(b) Select temperature conditions where subjects will be cool but not cold. Probably the least reliable figures in Clo value calculations are those used in determining the stored heat loss. Consequently it is desirable to keep stored heat loss at a minimum.

(c) Where body clothing is the variable take precautions to assure uniform head and face covering for all experiments.

(d) Insofar as possible use experienced subjects.

When these precautions have been taken, and where experiments have been run in duplicate on each of several garment assemblies we have been reasonably certain that average apparent differences of 15% or more in I_{clo} of any two assemblies are significant. Under some circumstances differences as small as 10% have been considered probably significant.

It should be noted that calculations of Clo value by this method assume a fairly uniform heat flow over the entire garment assembly, and results are therefore distorted if one part of the assembly provides critically poor protection.

Likewise the limitations of the method for detecting small differences between garments used to cover a small area of the body should be realized. For example, let us assume that two jackets are to be tested with an insulation difference of 10% and that their actual insulation values are 1.0 Clo and 0.9 Clo respectively. If the woolen shirt and undershirt worn in the experiments contribute 1.0 Clo of insulation then the total insulation over the trunk and arms wearing one jacket is 2.0 Clo, wearing the other is 1.9 Clo. But this 5% difference will not appear as a 5% difference in Clo value for the entire assembly because the clothing of hands, feet, legs, and head representing some 65% of the surface of the body will remain constant. The two jackets, then, account for a difference in overall insulation of less than 2%. It is readily seen that it would be practically impossible to determine the difference between these jackets by present Clo methods using human subjects.

It should be noted that up to the present time these methods have not been applied for assessment of insulation when men are engaged in activitites that involve sweating.

Method for Determining Insulation Value of Clothing on Thermostatically Controlled, Electrically Heated Dummies

It has been pointed out that the usefulness of the methods described above for determining the insulation of clothing assemblies on man is practically limited to whole assemblies differing by 15% or more in I_{clo}. Electrically heated, thermostatically controlled copper dummies have been fabricated in an effort to estimate smaller differences in insulation of clothing assemblies and to provide information on the relative insulation provided by different foot and handwear combinations. Three items of this type are now in use at the Fatigue Laboratory, a "man," a "hand," and a "foot."[6] All three of these items are designed to maintain a constant internal temperature regardless of the clothing worn.

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[6] The dummies are made up of sheet copper, 0.625 inches in thickness, and are blackened inside and out. They are heated internally by resistance wire or light bulbs connected in series with a sensitive thermostat and a watthourmeter. In the case of the dummy "man" a motor blower is mounted in the trunk. It constantly draws air through rubber tubes from the extremities, returning the air through the open cavity into the extremities again. A coil of heating wire is mounted along the center of each limb and two coils are mounted vertically in the trunk cavity. The motor blows constantly and the thermostat acts to turn heating coils on and off as required to keep the internal temperature constant. Nine "skin" thermocouples and one internal thermocouple are used to follow temperatures. It so happens in this dummy that with the internal temperature held at 98°F. the "skin" temperatures are about those of a man dressed in the same garments. The "foot" has a very small fan mounted inside it for circulation of air, and is heated by a small coil of resistance wire. Thermocouples indicate internal temperature and skin temperature at four points.

The "hand" is in the extended position, with straightened fingers, and is heated by a small bulb mounted in the middle. When the fingers are uppermost convection is sufficient to maintain suitable finger "skin" temperatures. Here again thermocouples indicate internal temperature and "skin" temperature at four points.

None of the dummies is considered ideal for the purpose in its present form. Actually the arms and head were removed from the "man" to simplify mechanical servicing and eliminate difficulties in putting on jackets. The "foot" is modeled in the position of standing on the toes to facilitate putting on footwear; this means that it is better adapted for study of socks than for shoes. The thumb of the "hand" is immovable, making it somewhat difficult to put gloves on it. An attempt should be made to provide articulation of certain joints in future dummies made for this purpose.

"Skin" temperatures are measured by thermocouples. Clo value is calculated by the usual formula

$$I_{clo} = \frac{3.09\ (T_s - T_a)}{H_{cl}} - I_a$$

H_{cl} is derived by converting the watts of energy input registered on a sensitive watthourmeter to Calories per square meter of dummy surface per hour. Calculation of stored heat loss is not necessary because the determinations are made while the internal temperature is maintained at a constant value.

When this method is used 5% differences in insulation values are considered significant. One disadvantage of our dummies is that they do not sensibly or insensibly perspire and consequently they are useless to pick up differences in insulation value that may be occasioned by differences in vapor permeability of the insulating materials.

Interpretation of the Adequacy of Protection from a Knowledge of Clo Value

It has been established in our long series of experiments, that subjects do not complain of being cold if their trunk skin temperatures lie from 92° to 94°F., arm and leg temperatures from 86° to 90°F., and foot and hand temperatures from 75° to 90°F. A T_s of 90°F. may, then, be considered satisfactory and even generous for complete comfort in the cold. If the heat cost of an activity is known (M), then evaporation losses ($E_l + E_s$) and losses due to warming the inspired air (A) can be accurately estimated. If in addition it be assumed that there is no loss of stored heat (D = 0) then it is possible to calculate the Clo value necessary for comfort at various temperatures by substituting in the following formula:

$$I_{clo} \text{ required for complete comfort} = \frac{3.09\ (T_s\ -\ T_a)}{M + D - [(E_l + E_s) + A]} - I_a$$

For example, if the temperature is -10°F. and the wind velocity is 2 m.p.h. what protection is required by a man driving a truck, assuming a caloric expenditure of 80 Cals/m²/hr., $E_l + E_s = 16$, and A = 5.

$$I_{clo} \text{ required for complete comfort} = \frac{3.09\ (90\bar{n}\ -\ 10)}{80\ +\ 0\ -\ (16\ +\ 5)} - 0.4 = 4.8$$

Another example, at the same temperature and wind velocity, what protection is required by a sleeping man, assuming an expenditure of 40 Cals/m²/hr.?

$$I_{clo} \text{ for comfort} = \frac{3.09\ (90\ -\ -10)}{40\ +\ 0\ -\ (11\ +\ 3)} - 0.4 = 11.5$$

These are the Clo values required to maintain a man in comfort indefinitely at these activities. In practice, the truck driver can get out of his cab and run around to warm up and the sleeper will tolerate considerable loss of stored heat if inured to the cold.

In recalculating to determine the minimum protection that would be satisfactory for the truck driver for three hours, let us assume that his activity was sufficient so that he was comfortably warm when he climbed into the cab; i.e., T_1 = 99.2°F. and T_s = 93°F. A rectal fall of 0.5°F. per hour and a T_s fall of 3°F. per hour could then reasonably be tolerated for three hours. Then D, calculated by the usual methods, is + 22 Cals/m²/hr. and the minimum acceptable Clo value becomes:

$$\text{Minimum acceptable } I_{clo} = \frac{3.09\ (88\ -\ -10)}{80\ +\ 22\ -\ (16\ +\ 5)} - 0.4 = 3.3$$

We may conclude that a truck driver would tolerate for three hours a 31% reduction in protection from the "complete comfort" value of 4.8 Clos.

If the assumption is made that before entering the sleeping bag $T_1 = 99.2^{\circ}F.$ and $T_s = 93^{\circ}F.$, then a T_1 fall of $0.2^{\circ}F.$ per hour and a T_s fall of $0.5^{\circ}F.$ per hour will be tolerated without interrupting sleep. Actually an overnight T_1 fall of this magnitude often occurs while a man is sleeping comfortably in bed. Under these conditions D becomes + 5 Cals/m^2/hr. and

$$\text{Minimum acceptable } I_{clo} = \frac{3.09\ (90 - -10)}{40 + 5 - (11 + 3)} - 0.4 = 9.6$$

Thus the sleeper would tolerate for eight hours a 16% reduction in protection from the "complete comfort" value of 11.5 Clos.

The calculated protection required for complete comfort during various activities which do not involve sweating is indicated in Fig. 2. The records of comfort taken in experiments in this laboratory indicate that these curves are essentially correct.

However, these comfort records also suggest that there are marked differences in sensibility to cold among different subjects. To take a typical case, an arctic uniform that is inadequate by 25% according to our "complete comfort" standards will be regarded as about adequate by subject #1 and as quite inadequate by subject #2 in four hour tests. No clue to explain the difference in sensation is to be found in the Clo value because it is the same on both men and was the basis for the judgment that the suit was inadequate. However, when the data is examined it becomes obvious that the physiological response of the two men has been quite different. Subject #1 lost a considerable amount of stored heat judging by the marked fall in his rectal temperature, but his skin temperature was not low even in the extremities and his metabolism was only slightly elevated. On the other hand subject #2 exhibited an early and marked fall in skin temperatures, but lost very little stored heat because muscle tone was increased and there was light intermittent shivering.[7] The high loss of stored heat (D) by subject #1 was balanced by a lower O_2 consumption (M), so that the Clo value was the same as for subject #2 who had a low D but a higher M due to the increased muscle tone and slight shivering.

Since differences of this sort between subjects are common, it is clear that dependence should not be placed on subjective reactions nor a single objective criterion such as skin temperature or O_2 consumption, unless a statistical approach using several subjects is used. The advantage of the Clo methods described here is that relatively small differences in clothing insulation can be found with a limited number of experiments of relatively short duration and that variations in D and M are automatically taken into account. Any individual man may require slightly more or less than the theoretical minimum Clo value for comfort but the comparative insulation of different outfits can be determined with considerable accuracy.

As was indicated earlier, the Clo value method is applicable only for well-balanced outfits. For outfits that are unbalanced and for comparison of items of hand and footwear we regard skin temperature measurements and subjective data as more useful criteria.

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[7] These phenomena seem to indicate that the central mechanisms for heat regulation are more sensitive in some men than in others, and furthermore that a person's sensibility to cold is closely related to the sensitivity of his mechanisms of physiological protection to body cooling.

Closed Circuit Respiration Apparatus Adapted for Use in the Cold Room

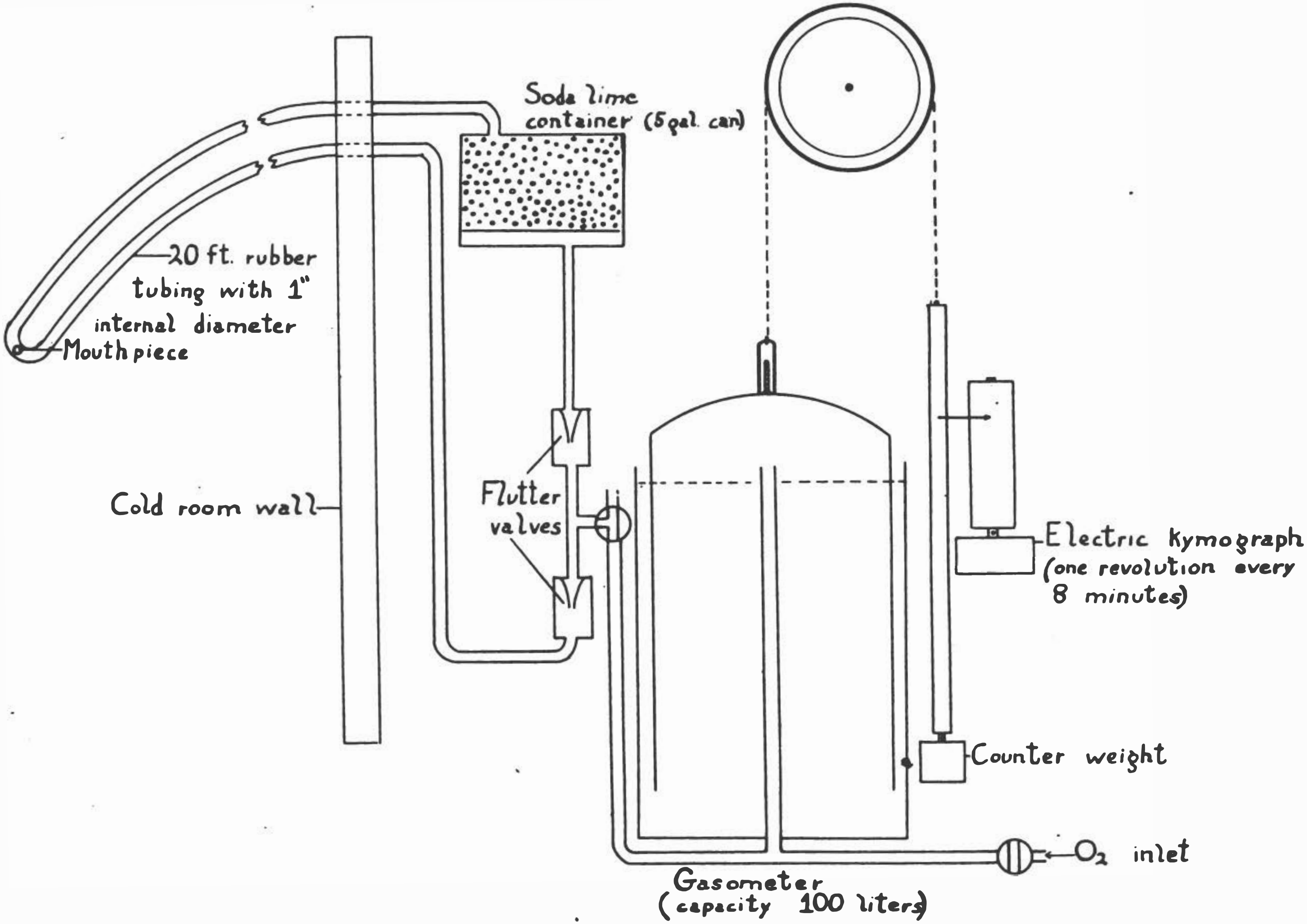
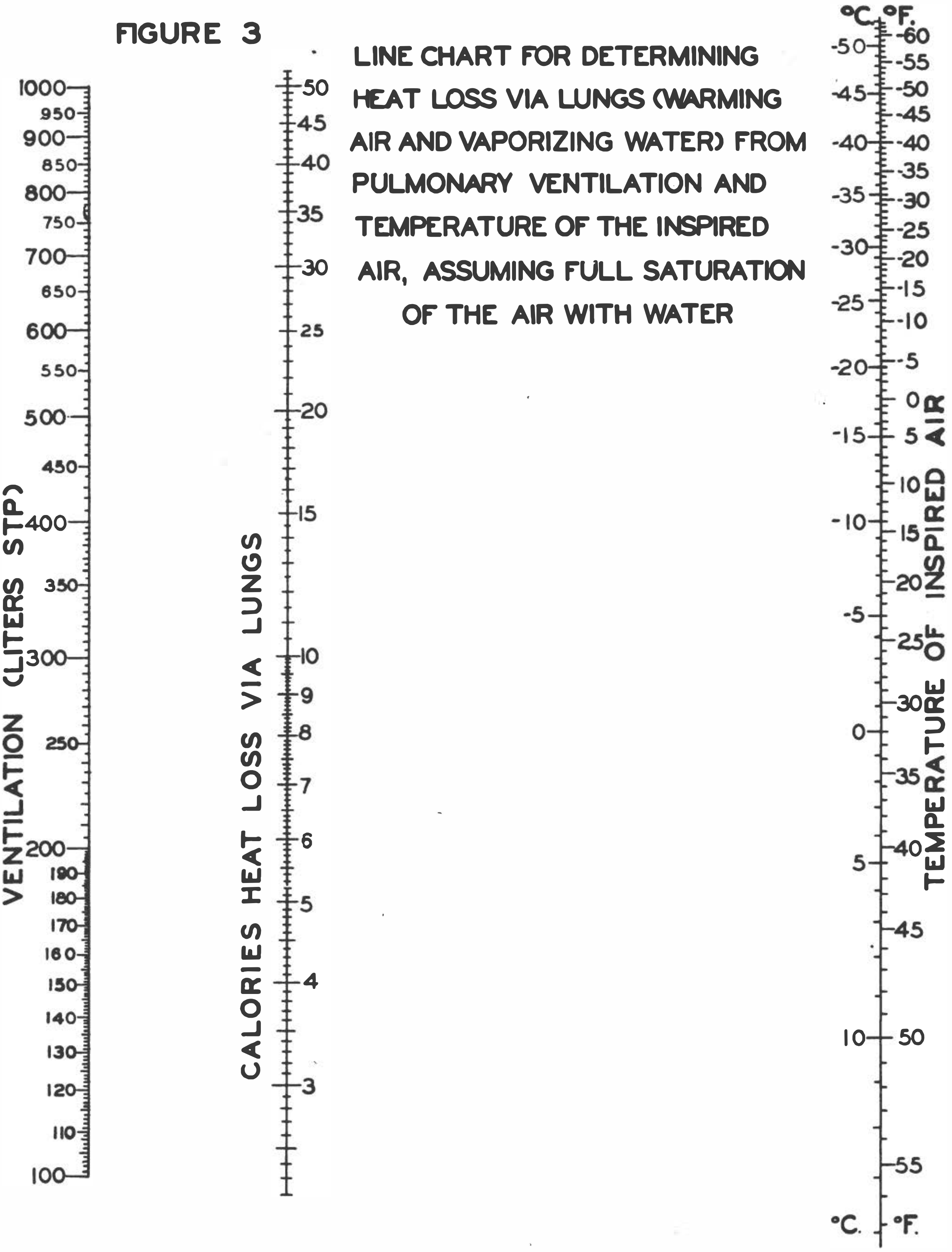


FIGURE 3



LINE CHART FOR DETERMINING HEAT LOSS VIA LUNGS (WARMING AIR AND VAPORIZING WATER) FROM PULMONARY VENTILATION AND TEMPERATURE OF THE INSPIRED AIR, ASSUMING FULL SATURATION OF THE AIR WITH WATER

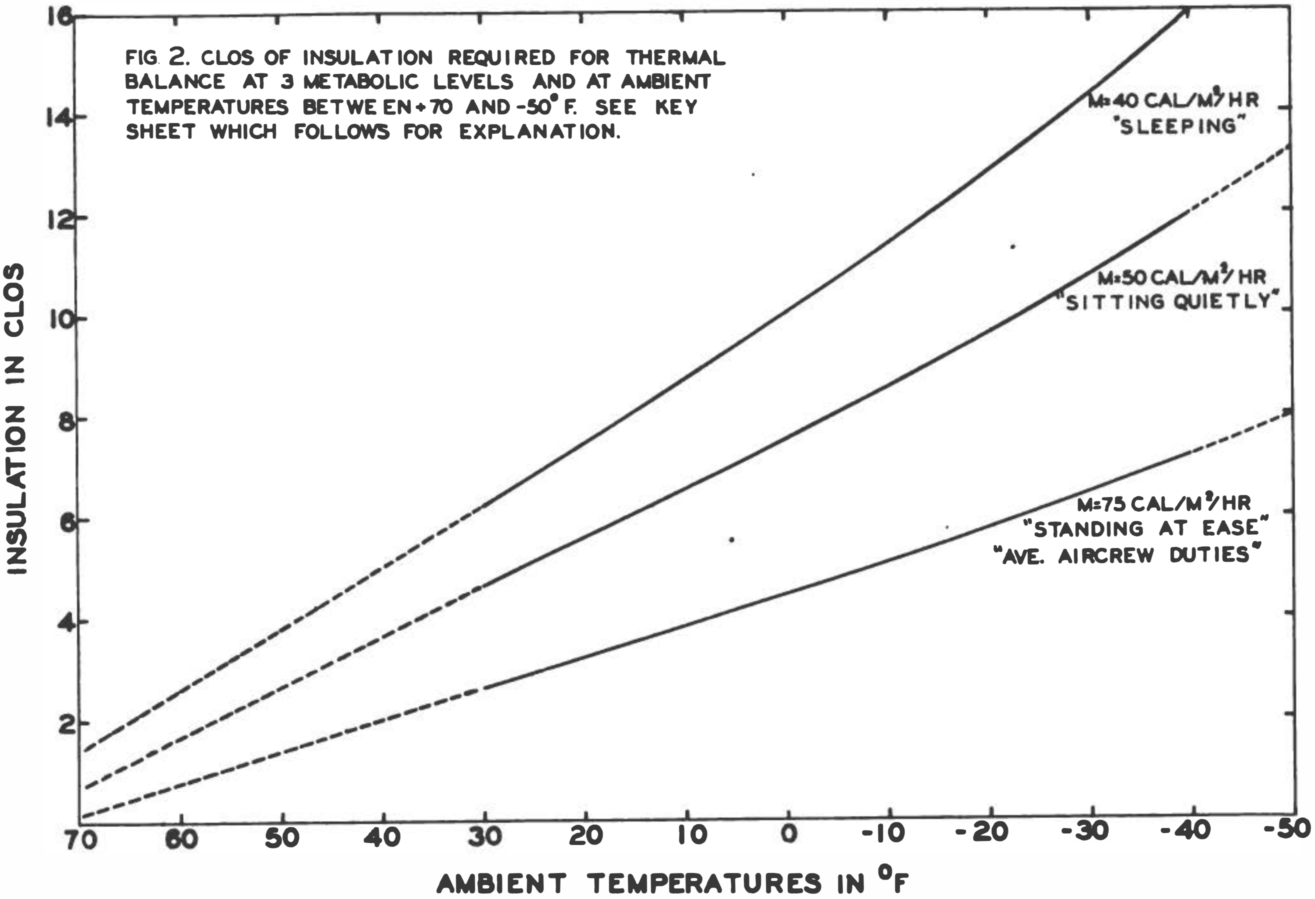


FIG. 2. CLOS OF INSULATION REQUIRED FOR THERMAL BALANCE AT 3 METABOLIC LEVELS AND AT AMBIENT TEMPERATURES BETWEEN +70 AND -50° F. SEE KEY SHEET WHICH FOLLOWS FOR EXPLANATION.

Fig. 2

Clos of Insulation Required for Complete Comfort at 3 Metabolic Levels and at Ambient Temperatures between +70 and -50°F.

The solid portions of the curves have been substantiated by our experimental work. Curves are probably accurate within 5%. The following assumptions were made in constructing the curves:

1. Wind velocity = 0 m.p.h.; I_a is 0.8 Clos under these conditions. To correct curves for other velocities add to required Clo value as indicated on curve as follows: 1 m.p.h. = 0.2 Clos; 2 m.p.h. = 0.4 Clos; 5 m.p.h. = 0.5 Clos; 10 m.p.h. or above = 0.6 Clos. These values apply for ground level; corrections are less at altitude.

2. Fundamental equation for the curves is:

$$I_{clo} \text{ required for complete comfort} = \frac{3.09\ (T_s - T_a)}{M + D - (E_1 + E_s + A)} - I_a$$

3. $T_s = 90°F$.

4. T_a is in °F.

5. M = 40, 50, or 75 Cals./m^2/hr., as indicated.

6. D = 0

7. E is divided into two fractions: (a) 6.3 Cals./m^2/hr. is assumed value for insensible cutaneous perspiration. To this is added (b) heat of vaporization of inspired air assuming inspired air half-saturated at existing ambient temperature (Smithsonian tables) and expired air saturated at + 33°C. This is the reason why the lines in the Figure are slightly curved.

8. A = Cals./m^2/hr. dissipated in raising temperature of inspired air to 33°C.

9. Surface area = 1.8 m^2.

10. Ventilation rates are assumed to be 400 liters per hour at a metabolic rate of 40 Cals./m^2/hr., 50(liters at 50 Cals./m^2/hr. and 750 liters at 75 Cals./m^2/hr.

MOISTURE LOSS AND MOISTURE EVAPORATED

L. P. Herrington

These are estimated from successive weighings of subjects, a) clothed, b) naked and c) naked and dried with a towel, when there is visible perspiration on the skin. The following quantities may be computed from these readings:

Moisture secreted = weight loss of naked subject after drying + weight of CO_2 produced - weight of O_2 consumed.

Moisture loss = weight loss of naked subject without drying, + CO_2 - O_2.

Moisture evaporated = weight loss of clothed subjects + CO_2 - O_2.

Under ordinary conditions with subjects at rest, the correction CO_2 - O_2 amounts to less than 5 grams per hour, but it may become significant during muscular work.

Moisture in Clothing

Clothing absorbs not only liquid sweat, but also moisture evaporated from the skin, increasing in weight without containing any liquid water. It is desirable to standardize the initial moisture content, and measure the change during the experiment. The initial water content can be standardized for a given series of experiments by exposing the clothing for at least 8 hours to moving air of known relative humidity and temperature. The equilibrium moisture content is more sensitive to changes in relative humidity than to changes in temperature. The following measurements are needed:

Conditioned weight = weight after exposure to the reference atmosphere of moving air for at least 8 hours. The clothing should be well opened. Heavy clothing may require longer exposure. The conditioned weight will be somewhat greater if the clothing dries from a previously wetter state than if it absorbs moisture during the conditioning. Any relative humidity below 80% can be used as a reference standard. Standard conditions for textile testing are 65% ± 2% relative humidity, 70°F ± 10°F.

Water uptake = weight at end of experimental period - conditioned weight. This will check with the difference between moisture evaporated and moisture loss, except for drying during the period of weighing. Such drying can be reduced by enclosing the clothing in tarred metal boxes or other air-tight containers while weighing.

Dry weight = constant weight reached after drying in a ventilated oven at 105°C. If it is not convenient to dry the whole mass of the clothing, samples of the fabrics, taken in the proportion which they constitute of the total weight, can be conditioned in the reference atmosphere along with the clothing, and dried separately.

$$\text{Regain} = \frac{\text{weight of absorbed water}}{\text{dry weight of cloth}} \text{ as } \%.$$

Knowing the dry weight and the regain corresponding to the reference condition, the water uptake during the experiment can be roughly divided between absorbed water and liquid water, if the clothing is made of one kind of fiber. The maximum regains of the various fibers are rather approximate, however, since the transition between absorbed and liquid water at 100% relative humidity is continuous. Approximate values for regain at 100% RH are: cotton, 20-24%, mercerized cotton or viscose rayon 40-45%, wool 30-36%. Curves of regain against relative humidity are given in Valko, Kolloid Chemische Grundlagen der Textilveredlung, and in International Critical Tables. For particular fibers, see: cellulose fibers, Ott, Cellulose and Cellulose Derivatives; cotton, Urquhart and Williams, J. Textile Institute 15. T 559 (1924); for wool, Speakman and Cooper, J. Textile Institute 27, T 183 (1936); for rayons, Urquhart and Eckersall, J. Textile Inst. 23, T 163 (1932); for nylon, Physical and Chemical Properties of Nylon and the Processing of Nylon Textiles, Nylon Sales Division, E. I. du Pont de Nemours and Co.

Body heat, lost by evaporation. Under ordinary room conditions when there is no visible sweating, evaporation takes place on the surfaces of the skin and lungs and it is assumed that the body itself furnishes all the latent heat necessary to evaporate the water.

Body heat lost by evaporation = moisture evaporated x L.H.E. The L.H.E. varies with the temperature of the water film at which evaporation takes place. The following linear relationship applies to temperatures between 25 and 100°C.

$$\text{L.H.E.} = 538.9 + 0.599\ (100 - t^{o}),\ \text{cal./Kg. } H_2O.$$

Usually L.H.E. is taken as 580 cal./Kg. H_2O which is close enough for most practical purposes.

When liquid sweat is absorbed by the clothing on exposure to heat or during muscular work, this sweat will evaporate at some distance from the skin drawing its heat of vaporization from the clothing and surrounding air. The body does not derive the full benefit of this evaporative cooling but only that part which results from increased temperature gradients between the skin and clothing surfaces on which evaporation takes place. Sweat that drips off the body is totally wasted.

Body heat loss by evaporation is also considerably reduced by condensation and freezing of perspiration in the clothes on exposure to subfreezing temperatures. The heat of vaporization which is released by condensation and the heat of fusion is absorbed by the clothes and surrounding air. Part of this heat is lost from the outer clothing surfaces, and the remaining part is returned to the body through decreased temperature gradients. Diffusion of water vapor through clothing is greatly reduced by freezing, and the frost may accumulate over a period of hours apparently without doing any harm until it begins to thaw.

There is no way of estimating accurately body heat loss by evaporation on exposure to intense heat or cold, or during muscular exertion. The weight loss from the clothed human body (corrected for the unequality of CO_2 eliminated and O_2 consumed) always overestimates the effective evaporation loss under such conditions. Clothing ventilation by bellows action, or otherwise, increases the effective evaporation, and is an advantage on exposure to heat but a distinct disadvantage in the cold.

Other observations that are worthwhile recording in tests of this sort are skin area exposed and total skin area, weight and thickness of fabrics, outer circumference of clothing at the chest, waist, around the sleeve and the leg, and a description of tightness of closure at the neck, coat front, waist, wrist and and ankle.

SOLAR HEAT LOAD[1]

Harold F. Blum

INTRODUCTION

This report attempts to answer the specific question whether experiments to determine the effectiveness of field uniform fabrics in combating the solar heat load can be carried out in the laboratory or must be made in the field.

Under field conditions, sunlight, both direct and reflected, forms a certain portion of the total heat load. This will be referred to herein as the solar heat load. If the influence of clothing on the total heat load is to be analyzed, this factor is best treated as separate from the heat load contributed indirectly by the sun through its influence on the temperature of the ambient air, and the terrain.

The evaluation of the effect of clothing on the solar heat load by direct experimental methods presents many difficulties. Sunlight cannot be closely simulated in the laboratory, and on the other hand, testing under outdoor conditions presents difficulties because numerous factors cannot be accurately evaluated and controlled.

THE SOLAR SPECTRUM

In order to view the problem properly, reference must be had to the spectrum of sunlight. Curve 0 in Fig. 1 represents the spectral distribution of sunlight outside the earth's atmosphere. The spectral distribution is altered in passage through the atmosphere due to the fact that all wave lengths are not absorbed equally. The atmospheric constituents chiefly responsible for this alteration of the spectrum are ozone, which absorbs the short wave length ultraviolet end of the spectrum, and water vapor which absorbs the long infrared wave lengths. The latter is of particular importance with regard to the present problem. The quantities of both ozone and water vapor in the atmosphere at different times and places vary, and the spectral distribution of sunlight is altered accordingly. The other gases in the atmosphere absorb very little within the spectral range of sunlight. The spectral distribution is also altered by scattering by gas molecules and by dust particles. Curves 1 and 2 in Fig. 1 represent sunlight at the earth's surface when certain quantities of ozone (2.8 mm.), water vapor (20 mm.), and dust (300 particles/cm^3) are present in the atmosphere. Curve 1 represents the spectrum when these atmospheric conditions pertain and when the sun is directly overhead, while curve 2 represents the spectrum under the same conditions when the sun is 60° from zenith, at which time the rays pass through twice as thick a layer of atmosphere.

Considering all these factors it is obvious that accurate predictions cannot be made about sunlight without direct measurements, or without knowledge of the atmospheric conditions and proper consideration of latitude, season and time of day, all of which determine the angle of the sun with respect to the zenith.

Fig. 1 shows that the maximum of the solar spectrum occurs at about 0.48 μ. Thermal emission having its maximum at this wave length would be given off by a black body at 6,000°K. Such a temperature is not attainable in the laboratory

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[1] The substance of this article has appeared as a report from the Naval Medical Research Institute.

π μμ

for a mass great enough to supply quantities of radiant energy comparable to sunlight. This presents an apparently insurmountable barrier to the simulation of sunlight in the laboratory.

The curves R and C in Fig. 1 indicate the spectral sensitivity of, respectively, scotopic vision (rods) and photopic vision (cones). The latter covers the approximate range 0.4µ to 0.7µ. This is generally referred to as the visible spectrum, shorter wave lengths being denoted ultraviolet, and longer wave lengths infrared. Measurements in which the human eye is used as the photosensitive instrument (this includes all "Photometric" measurements) give inaccurate information as to the intensity of the ultraviolet or infrared radiation or of total sunlight.

In the present problem we are concerned with the heat load contributed by sunlight, which is made up of wave lengths ranging from approximately 0.29µ to 2.2µ. A certain portion of the radiation falling upon the body is absorbed, and the remainder reflected. If the body were covered with a surface which reflected a large proportion of all these wave lengths, as for example, with aluminum paint, the solar heat load would be reduced to a negligible quantity. Even white clothing would reduce the load, but camouflage requirements limit the amount of sunlight that can be reflected in certain regions of the spectrum, for a part of the visible spectrum must be absorbed in order that a man may appear to blend into the terrain. Thus, any attempt to improve the reflecting power of clothing must be limited by the requirements of camouflage so far as visible wave lengths (0.4µ to 0.7µ) are concerned. Since photographic reconnaisance using infrared sensitive photographic emulsions must also be considered, similar restrictions are placed on the amount of reflection allowable in the near infrared, to which these emulsions are sensitive. If the more common infrared sensitive emulsions are used, the long wave length limit is about 0.9µ; if it is possible to use the most sensitive emulsions, this must be extended to 1.2µ. In Table 1 the amounts of solar radiant energy falling on a horizontal surface are shown for various spectral regions for different conditions.

RELFECTION OF SUNLIGHT FROM FABRICS

Aldrich has recently measured the reflection of sunlight by a number of military fabrics. His measurements, quoted by Wulsin (2), are reproduced in Table II, together with a few older measurements (3). Earlier measurements by Coblenz (4) are in general agreement with these, but refer to only limited portions of the spectrum. Aldrich's data include measurements of transmission of sunlight by the fabrics, which in no instance is high. It may be assumed that most of the transmitted radiation is eventually absorbed either at the skin surface or by the fabric, so it has been included in the percentage contributing to the heat load in the first column of Table II.

There is considerable difference in reflection by the different fabrics. As would be expected, white fabrics reflect more than colored fabrics, but the total reflection need not parallel too closely the apparent darkness to the eye. Aldrich has estimated the per cent of radiation reflected in the "visible" (.3µ to .7µ) and in the "infrared" (.7µ to 2.5µ), for the items described in Table II, and these data are reproduced in Table III. In general these fabrics reflect infrared radiation to a greater extent than visible. This is contrary to a widespread, erroneous belief that all substances absorb infrared radiation almost completely.

Improvement of the reflecting power of clothing within the limits imposed by military field requirements would depend chiefly upon finding dyes which, while presenting appropriate colors to the eye (or contrasts to the photographic emulsion) compatible with camouflage requirements, permit greatest reflection of the total radiation. This would entail mainly the reflection of infrared radiation. Texture of the fabrics is also of importance, since some will be better diffuse reflectors than others. These will probably be minor factors, however, and the absorption spectra of the dyes can be regarded as placing the limits of attainable reflection. The absorption spectra of dyes, and hence their reflecting properties, depend upon their chemical constitution. As a rule they do not give sharp spectral cut offs. It would probably be difficult to predict the appropriateness of particular dyes without laborious study of their absorption spectra, including ranges outside the scope of the usual spectrographic equipment. Thus, the selection of dyes to improve the reflecting powers of military fabrics would be a difficult task, and the degree of success to be expected is not great.

Under the field conditions clothing becomes soiled and this may alter both the total reflection and the reflection in different spectral regions.

REFLECTION BY HUMAN SKIN

The reflection of sunlight by human skin provides a basis of comparison with the reflection by fabrics. Martin (3) found 43 per cent reflection of total sunlight from average blond human skin. Brunet skin showed 35 per cent reflection, and negro skin 16 per cent. The values for white skin are in general agreement with those of Adolph (5) for reflection of total sunlight, and compatible with those of others who have measured the reflection of visible, ultraviolet, and infrared wave lengths (6,7,8).

THE SOLAR HEAT LOAD AND ITS RELATIVE IMPORTANCE

The total solar heat load, L, impinging upon a man exposed directly to the sun may be divided into three portions, D, the direct radiation which strikes the profile exposed, H, the reflected radiation from the sky, and T, the radiation reflected from the terrain. Thus,

$$L = D + H + T \qquad (1)$$

While a great many data have been collected on the direct and "sky" radiation falling upon a horizontal surface, there is little information available as regards the sunlight reflected from the earth, or the total energy from these three sources which falls upon a solid object such as the human body. The relative importance of the three factors, direct, sky, and earth radiation, varies with the position of the man exposed to them. Hence, integrated measurements of the energy from the three sources by means of a physical instrument such as the Vernon sphere are not directly interpretable in terms of the solar heat load received by a man exposed to the same conditions. The following estimates in which the human body is treated as though made up of simple geometrical surfaces give an idea of the variations of the solar heat load with various conditions, and provide approximate values for comparison with the metabolic heat load.

<u>The direct radiation</u>.--Let us designate as S, the total energy of all wave lengths contained in sunlight (approximately 0.29μ to 2.2μ) falling on unit area of a surface normal to the sun's rays in unit time. Let F represent the fraction of sunlight diffusely reflected by a fabric or by human skin; the portion

of the incident energy absorbed by the clothing or body is then $(1-F)$[2].

The direct component of the solar heat load, D, is then

$$D = S(1-F)P \qquad (2)$$

Where P is the profile exposed, i.e., the projection of the body shadow in a plane normal to the sun's rays. With the sun directly overhead and the man standing erect, P is equal to about 7 per cent of the body surface or about 0.12 m^2 for a man of average body surface, 1.7 m^2. For a man lying prone, P is equal to about 30 per cent of the body surface or for an average man, 0.51 m^2. As the sun moves away from the zenith, P approaches 0.51 m^2 for a man facing the sun, approximately as the sine of the zenith angle. At 15° from zenith (one hour) the profile presented should be about 0.13 m^2, i.e., about the same as when the sun is at zenith. At 60° from zenith (four hours), however, the profile should be about $.51 \times \sin 60^\circ = 0.42\ m^2$.

For a man lying prone P decreases as the cosine of the zenith angle, so that when the sun is at 60° the profile presented is only one-half as great as when the sun is at zenith, i.e., 0.255 m^2. Direct solar heat loads have been calculated on the above basis for 0° and 60° zenith angle, and these appear in Table IV. In all calculations in Table IV the values of solar radiation for 20 mm. water vapor, which appear in Table I have been used; and the reflection factor F taken as 0.43, the value found by Martin for blond human skin.

Rough as these estimates are, they show clearly that the direct solar heat load must vary considerably with the position of the man and the time of day; and that the maximum direct load may be received in one position at one time of day, and in another position at another time.

The "sky" radiation.--Direct measurements show that about 15 per cent of the radiation falling on a horizontal surface when the zenith angle is between 0° and 60° is reflected radiation from the sky (see 9, p. 60). The proportion of sky radiation increases rapidly for zenith angles greater than 60°, but between 0° and 60° the sky radiation falling on a horizontal surface of unit area should be equal to approximately $\left(\frac{.15}{1.00-.15}\right) S \cos z$, where z is the zenith angle. The sky radiation falling on a vertical surface will be only one-half that striking a horizontal surface since the former presents itself to only one-half the heavens. This makes it difficult to estimate the amount of sky radiation striking an irregular body such as a man. In calculating the heat load we have used one-half the total body surface for both the erect and prone positions, on the assumption that about half the body is presented horizontally to the sky when prone and that the greater part of the body surface is presented vertically to the sky when erect. Estimates based on these assumptions are presented in Table IV.

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[2]

$$S = \int_{\lambda .29\,\mu}^{\lambda 2.2\,\mu} S_\lambda \, d_\lambda, \text{ and } F = \frac{\int_{\lambda .29\,\mu}^{\lambda 2.2\,\mu} F_\lambda S_\lambda \, d_\lambda}{S}$$

when S_λ and F_λ are, respectively the solar energy, and the reflection for wave length λ. Since S_λ and F_λ vary independently with λ the numerical value of D in equation (1) depends upon a given set of conditions throughout which the sunlight spectrum and the reflection spectrum remain unchanged. Since the solar spectrum varies and the reflection spectrum is different for each fabric, such estimates are only approximate; but the error is certainly not greater than errors introduced by other assumptions that must be made in such an analysis.

The terrain reflection.--Estimation of the heat load reflected from the terrain is yet another problem. It is necessary, first, to know the albedo, A, or fraction of the solar radiation that is diffusely reflected by the terrain.[3] A good many determinations of the albedoes of terrains have been made by visual photometry, and hence can only be accepted as approximate values for total sunlight. For our estimates in Table IV, 25 per cent diffuse reflection has been assumed. This value was obtained for a desert sand by Mr. Irving F. Hand (personal communication). Hulburt (10) obtained somewhat higher values for beach sands. Coblenz found 30 per cent diffuse reflection from the leaves of the tulip tree, but lower values for other foliage. Some high albedos have been obtained for snow, in the ultraviolet and visible, but the infrared is largely absorbed (see 10).

For approximate estimates it may be assumed that the terrain is a surface of infinite area, which reflects 25 per cent of the solar radiation falling on it. A horizontal plane facing this surface will receive per unit area that quantity of radiant energy reflected from a similar area of the reflecting surface; whereas a horizontal plane facing upwards will receive none of the reflected radiation. A vertical plane will receive one-half the radiation received by a horizontal plane facing the reflecting terrain.

If we assume that in the erect position most of the body surface is exposed vertically, we may write

$$T = \frac{M(1-F)\ A\ \left(S \cos z + \frac{.15}{1.00-.15} S \cos z\right)}{2} \qquad (3)$$

where M is the portion of the body surface exposed to the diffusely reflected radiation from the terrain. Assuming that all the surface is exposed vertically the value 1.7 m^2 may be assigned to M. Since any part of the body exposed horizontally facing the earth's surface will receive twice this much reflected radiation from the terrain whereas those that face upward will receive none at all, this assumption seems not too unreasonable.

In the prone position, the surface presented to the terrain is relatively small. Assuming that a profile 0.5 m^2 is in contact with the ground and another equal profile is presented to the sky, 1.0 m^2 of the body surface will receive no appreciable amount of reflected radiation from the terrain. The remainder of the body surface, 0.7 m^2 may be regarded as presenting a vertical surface, and hence may be substituted for M in equation (3).

In Table IV estimates of the direct, sky, terrain, and total heat loads for the erect and prone positions and for 0° and 60° zenith angle, are presented. Reference to this table indicates that, even though considerable errors may have been introduced in estimating the heat loads from the sky and from the terrain, these factors cannot be neglected in the estimation of the total solar heat load. They also show that these factors may be expected to have very different relative importance under different conditions. This alone throws doubt on the possibility of obtaining satisfactory estimates of the solar heat load by means of experiments in which men are exposed to sunlight out of doors.

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[3]

$$A = \frac{\int_{\lambda .29\mu}^{\lambda 2.2\mu} A_\lambda\ S_\lambda\ d_\lambda}{S}$$

hence the same qualifications apply as for S and F, see footnote (1).

THE RELATIVE IMPORTANCE OF THE SOLAR HEAT LOAD

The relative importance of the solar heat load may best be evaluated by comparing it with the heat load of human metabolism. The metabolism of a man of average height and weight is about 96 kilocalories per hour when seated and about 265 kilocalories per hour, when marching at 3 miles per hour. For comparative purposes the average of all the values for the total solar heat load presented in Table IV may be used. This is roughly 4 kilocalories per minute or 240 kilocalories per hour. This is 2 to 3 times the resting metabolism, and about equal to the marching metabolism. It would be necessary to evaporate approximately 420 gms. of water per hour to take care of the solar heat load of 240 kilocalories. This is about one-half the water requirement of a man marching in the desert in the middle of the day under average summer conditions (see 5, 11).

To what extent may this heat load be decreased by choosing clothing with the best reflection characteristics? The values for the heat load calculated in Table IV are based on reflection of 43 per cent. If the reflection were 71 per cent, as measured by Martin for white cloth, the solar heat load would be about one-half or 120 kilocalories per hour. This would seem to be about the best achievable condition, but would not be compatable with military field requirements. On the other hand, if the reflection were 12 per cent, as found for dark flannel suiting, the solar heat load would be increased to about 370 kilocalories per hour. In terms of evaporation of water, this means a difference of about 420 gms. per hour as the range between the best and the worst conditions. Considering the limits entailed by the requirements of camouflage, and the nature of fabrics and dyestuffs, the difference between field uniform fabrics in terms of the saving of water by reflection of the solar heat load would probably be much less than this.[4] Reference to Table I will show that if, because of camouflage requirements, the saving must be made principally from the longer wave length infrared, it could not be very great in any case.

EXPERIMENTAL DETERMINATION OF THE EFFECTS OF CLOTHING ON THE SOLAR HEAT LOAD

Physiological measurements. It is generally assumed that when the air is relatively dry and the ambient temperature is near that of the body's surface, the amount of water evaporated, as measured by the decrease of body weight, provides a measure of the amount of heat which the body has dissipated within a given time. This is true only when surrounding surfaces and objects are also at the temperature of the body's surface; it does not imply that it is possible accurately to estimate the solar heat load by comparing evaporative losses for men in the sun and in the shade, as has been attempted. In the first place, the establishment of adequate shade for such an experiment is difficult, since reflection of sunlight from the sky and from the terrain, which remain when the direct sunlight is eliminated, are difficult to evaluate. Furthermore, the use of any object for shading the body introduces another factor, the radiation reëmitted by by that object, and there are still other factors which need to be taken into consideration.

Under conditions in which the ambient air temperature is below body temperature, heat is lost by convection and conduction, which thus interfere with estimates of the solar heat load. Convection, provided by wind or simply by body movement, may be a factor even when the ambient temperature is above that of the

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[4] The solar heat load may be easily estimated for the types of military clothing described in Table II. The values of L presented in Table IV need only be multiplied by percentage reflection 143.

body since it may affect the rate of evaporation on the body surface in the case of porous clothing. The estimation of these factors is beyond the scope of this paper, but they should be considered in any calculation of the total heat load.

Another factor seldom taken into account is the exchange of radiation of longer wave lengths than those found in sunlight, between the body and its surroundings, i.e., the terrain and the atmosphere. To appreciate this phase of the problem let us first consider the exchange between the body and the terrain. For the purpose, the terrain may be assumed to be a diffusely radiating surface of infinite extent, in which case the same geometry applies as for the reflection of sunlight from the terrain (see p. 8). On the basis of the assumptions made above, a man standing erect would present his body surface vertically and would receive one-half the radiation from the terrain. We may thus treat the problem as the exchange of radiation between two surfaces of area equal to one-half the body surface or 0.85 m^2. If the air were absolutely dry, these two surfaces might be treated as black body radiators, and the Stefan-Boltzmann law applied. This law states that the exchange of radiation between two such bodies is proportional to the fourth power of the difference between their absolute temperatures. The magnitude and direction of this heat exchange would depend, upon the temperature of the body surface and that of the terrain. By way of example, if the body surface were at 37°C. and the terrain at 60°C. the body of a man standing erect should gain 128 calories per hour from the terrain, a sizeable addition to the total heat load. If the terrain were cooler than the body, the latter would lose heat.

When water vapor is present a certain fraction of this radiation will be absorbed by the atmosphere lying between the body and the terrain. Black bodies at the temperatures of the human body and the terrain, emit radiation over a broad range with a maximum at about 10 μ. Water vapor is transparent to a wide spectral band at about this wave length, but strongly absorbs wave lengths on both sides including a large fraction of that radiated by such bodies (<u>12</u>, <u>13</u>). The other gases of the atmosphere do not absorb in the spectral region to which water vapor is transparent, with the exception of ozone which is only present in important concentration in the upper layers of the atmosphere. Because of this specific absorption of certain wave lengths the Stefan-Boltzmann law is not directly applicable when water vapor is present in the atmosphere, and the estimation of the heat load emitted by the terrain thus involves considerable uncertainty under these conditions. However, since most of the radiation from the terrain which strikes the body comes from relatively near regions, the effect of absorption by water vapor may not be great.

It is improbable that the heat load received by such radiation from the terrain can be reduced appreciably by choice of fabrics. Aldrich has made measurements of the reflection by those military fabrics listed Table II and III of radiation from a body at 60°C.; these are presented in Table V. Very little of such radiation is reflected by any of the fabrics.

Radiation exchange exclusive of sunlight, between the body and the atmosphere involves the same factors, but is even more complex. The transparency of water vapor permits some of the radiation from the body to pass to higher layers of the atmosphere which are cooler than the ambient layers. This is a channel of heat loss usually disregarded. Accurate estimate of this radiant energy loss is difficult, but an idea of its relative magnitude may be gained from an analysis made by Simpson (<u>14</u>, <u>15</u>) for an entirely different purpose. In considering the heat loss from the earth, this investigator (<u>15</u>) estimates maximum and minimum values for atmospheric transmission taking differences in amount of water vapor into account, and arrives at mean and limiting values for the long wavelength radiant energy lost to the heavens by a horizontal surface at a given temperature (figure 2). This is generally known as the "nocturnal" radiation because it is usually measured at night. The out going radiation measured independently of solar radiation during the day is comparable, and is dependent chiefly on the temperature and humidity (16). Measurements by different methods (17, 18) give values falling withing Simpson's estimates.

Extrapolating Simpson's mean curve (figure 2) we see that a surface at 37°C may be expected to lose about 2.5 Kilocalories per m^2 per minute by this channel. Using the same treatment as for solar radiation reflected from the sky (p.7) a man standing erect would present 1.7 m^2 vertically to the heavens and should lose about 128 Kilocalories per hour as long wavelength radiation. This might be considerably higher or lower depending upon the amount of water vapor in the atmosphere.

For purely illustrative purposes, a thermodynamic balance sheet has been attempted in Table VI, for a hypothetical set of conditions, namely; sun at zenith, temperature of the terrain 60°C, ambient air relatively dry and at a temperature somewhat above that of the body, the man erect marching at 3 miles per hour. The evaporation factor is based on the loss of 882 gms. of water per hour, an average figure obtained by Adolph et. al. (11) for men walking in the desert. Convection and conduction losses are assumed to be small because the temperature of the ambient air is near that of the body, but represent an unknown value. The radiation values are those calculated in this paper.

The close over all balance obtained is fortuitous, as is the exact balance between radiation from the terrain and to the heavens. Had the ground temperature been taken as 10° lower or the assumption made that the sun had warmed the clothing to a temperature 10° higher than the chosen, the balance would be considerably upset. It should be pointed out that for a man at rest, the long wavelength radiation exchange would be more important relative to the metabolism, and it might be interesting to explore other possibilities. However, Table VI shows clearly that a balance is possible with values of these magnitudes, but that none of the various items estimated therein can be neglected in drawing up a balance sheet.

The evaporation factor tends to adjust itself due to sweating so that the body temperature does not rise excessively. Thus this factor may be expected to vary to compensate when the other factors shift with various conditions. When the magnitude and variability of the other factors are considered, it does not seem surprising that Adolph and his coworkers (5, 11), should have obtained different values for evaporative heat loss under the various conditions they explored, nor on the other hand that these values display the general consistency they do.

The whole problem of radiant exchange with outdoor surroundings is, thus, quite complex, and cannot be accurately simulated in an enclosed room. Moreover, all these factors render physiological measurements out of doors subject to considerable variability, not only insofar as the solar heat load is concerned, but with regard to the heat load as a whole.

CONCLUSIONS

Since the amount of saving of solar heat load to be anticipated by improvement of the reflecting properties of military uniform fabrics is not great, it would seem wise to concentrate effort on the evaluation of properties of fabrics that can be studied in the laboratory, and which are of importance under all conditions of hot environment, namely, their effect on cooling by conduction, convection, and radiation at ordinary temperatures.

Where reflecting properties of clothing are to be considered, they should be determined by direct physical measurement.

Necessary data are lacking for evaluation of the thermal relationships of man with an outdoor environment, some of which lie in a domain that is generally left to the physicist, the meteorologist, or the astronomer. It would seem important to obtain some of these data with the express problems of the environmental physiologist in mind, if human climatology is to be properly understood, in relation either to military or civilian problems.

ACKNOWLEDGEMENTS

Most of the values for reflection of sunlight by military fabrics used in this report were obtained by Dr. L. B. Aldrich of the Smithsonian Institution of Washington at the request of Dr. F. B. Wulsin of the Military Planning Division, Office of the Quartermaster General. Albedo measurements of terrain made by Mr. Irving F. Hand of the U. S. Weather Bureau have also been employed. It is a pleasure to acknowledge the cooperation of these men in placing their material at my disposal.

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Table I

ENERGY OF SUNLIGHT[1]

Zenith angle	Energy of sunlight Kilocalories per m^2 per minute			
	All wave lengths	Exclusive of visible (all except 0.4μ to 0.7μ)	0.7μ to 0.9μ	0.9μ to 1.2μ
$^{2}0^{\circ}$	14.7	8.7	5.0	2.7
$^{3}0^{\circ}$	13.2	7.3	3.9	1.9
$^{3}60^{\circ}$	10.6	5.9	3.3	1.5

---

1. Estimated from the data of Moon (1)
2. Dry air, 2.8 mm. ozone, 300 dust particles/cm^3.
3. 20 mm. H_20, 28 mm. ozone, 300 dust particles/cm^3.

Table II

REFLECTION OF TOTAL SUNLIGHT BY VARIOUS FABRICS

Item		Per cent contributing to the heat load[1]	Per cent reflected	Per cent transmitted
	Data of Aldrich			
1.	Shirt, Mock Leno, slightly permeable	55.9	44.1	5.1
2.	Cotton, khaki-8.2 oz.	43.7	56.3	0.0
3.	Cotton, percale, white	33.2	66.8	0.5
4.	Cotton, percale, O.D.	51.5	48.5	2.5
5.	Cotton, tubular balbriggan	37.6	62.4	3.2
6.	Cotton, twill, khaki	48.3	51.7	0.2
7.	Cotton, shirting worsted, O. D.	61.1	38.9	0.1
8.	Cotton denim, blue	67.4	32.6	0.0
9.	Cotton, herringbone twill	73.7	26.3	0.1
10.	Cotton, duck #746	92.8	07.2	0.0
	Data of Martin (3)			
11.	Cotton shirt, white unstarched, 2 thicknesses	29.0	71.0	
12.	Cotton shirt, khaki	57.0	43.0	
13.	Flannel suiting, dark gray	88.0	12.0	
14.	Dress suit	95.0	5.0	

---

[1] The transmitted radiation is considered to be absorbed by the skin (see text).

Table III

REFLECTION OF VISIBLE AND INFRARED PORTIONS OF SUNLIGHT BY FABRICS

Data of Aldrich

Item	Per cent reflection of sunlight "Visible" 0.3μ to 0.7μ	Per cent reflection of sunlight "Infrared" .7μ to 2.5μ
1.	24.1	53.7
2.	27.8	64.5
3.	69.3	60.2
4.	28.8	55.0
5.	62.7	58.3
6.	25.8	58.9
7.	72.1	49.0
8.	12.1	49.0
9.	13.3	30.2
10.	6.6	7.5

Table IV

ESTIMATED SOLAR HEAT LOAD UNDER VARIOUS CONDITIONS

Position of man	Zenith angle	Solar Heat Load[1] Kilocalories per min. Direct (D)	Sky (H)	Terrain[2] (T)	Total (L)
Erect	0°	0.90	1.13	1.88	3.91
	60°	2.67	0.45	0.75	3.87
Prone	0°	3.84	1.13	0.78	5.75
	60°	1.54	0.45	0.31	2.30

---

1. Under the following atmospheric conditions, 20 mm. H_2O, 2.8 mm. ozone, 300 dust particles per cm^3, and assuming that 43 per cent of the total solar radiation is reflected by the body.
2. Albedo of terrain assumed to be 0.25.

Table V

REFLECTION BY MILITARY FABRICS OF RADIATION FROM A BLACK BODY AT 60°C.

Data of Aldrich

Item	Per cent contributing to the heat load[1]	Per cent transmitted	Per cent reflected
1.	87.0	4.6	13.0
2.	90.0	0.6	10.0
3.	74.8	0.6	25.2
4.	75.0	2.4	25.0
5.	90.5	1.5	9.5
6.	88.5	0.0	11.5
7.	90.4	0.0	9.6
8.	90.0	0.0	10.0
9.	81.0	0.0	19.0
10.	90.9	0.0	9.1

---

1. The transmitted radiation is considered to be absorbed since it will be largely absorbed by the skin.

Table VI

Attempted thermodynamic balance sheet for a man marching at 3 miles per hour; ambient dry air with temperature about 37°C, terrain at 60°C, and body surface at 37°C. Sun at zenith.

	Kilocalories per hour
Metabolism	+ 265
Total Solar heat load	+ 234
Long Wavelength radiation exchange with terrain	+ 128
Long Wavelength radiation exchange with heavens	- 128
Evaporation	- 506[1]
Convection and Conduction	± ?
Total	- 7 ± ? (this close apparent balance is fortuitous)

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[1] Based on average value from Adolph et.al. (11), 882 gms. of water loss per hour.

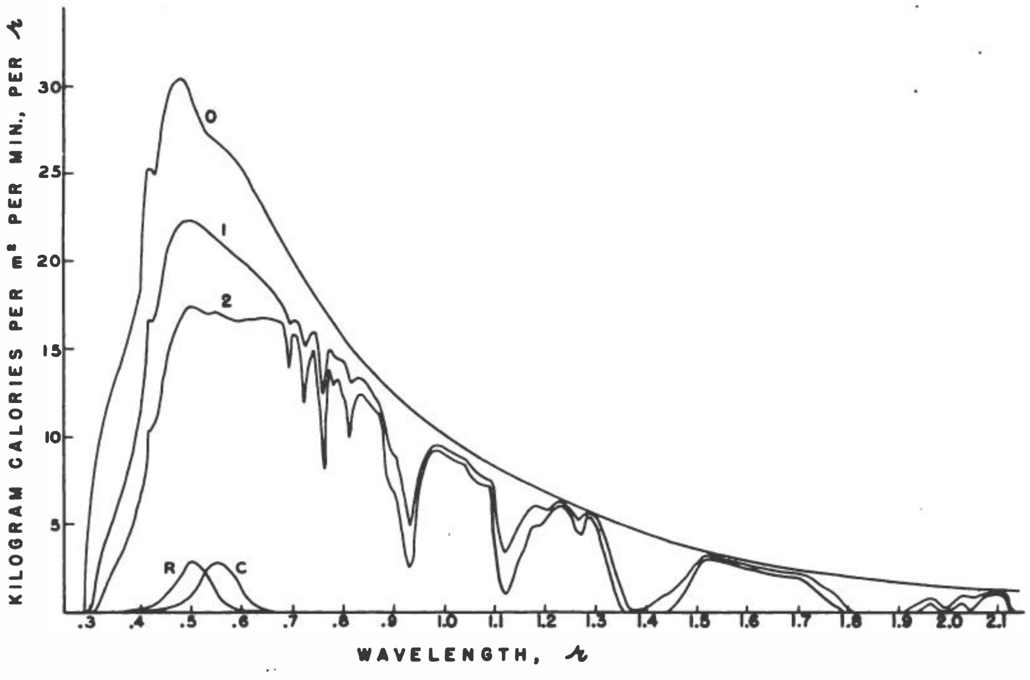

Fig. 1

Spectral distribution of sunlight: 0, outside the atmosphere; 1, with the sun at zenith; 2, with the sun at 60° from zenith. Curves 1 and 2 are for 20 mm. H_2O, 2.8 mm. ozone, and 300 dust particles per cm³. From the data of Moon (1).

Curves R and C indicate, respectively, the spectral sensibility of the human rods, and cones; the ordinate units are arbitrary.

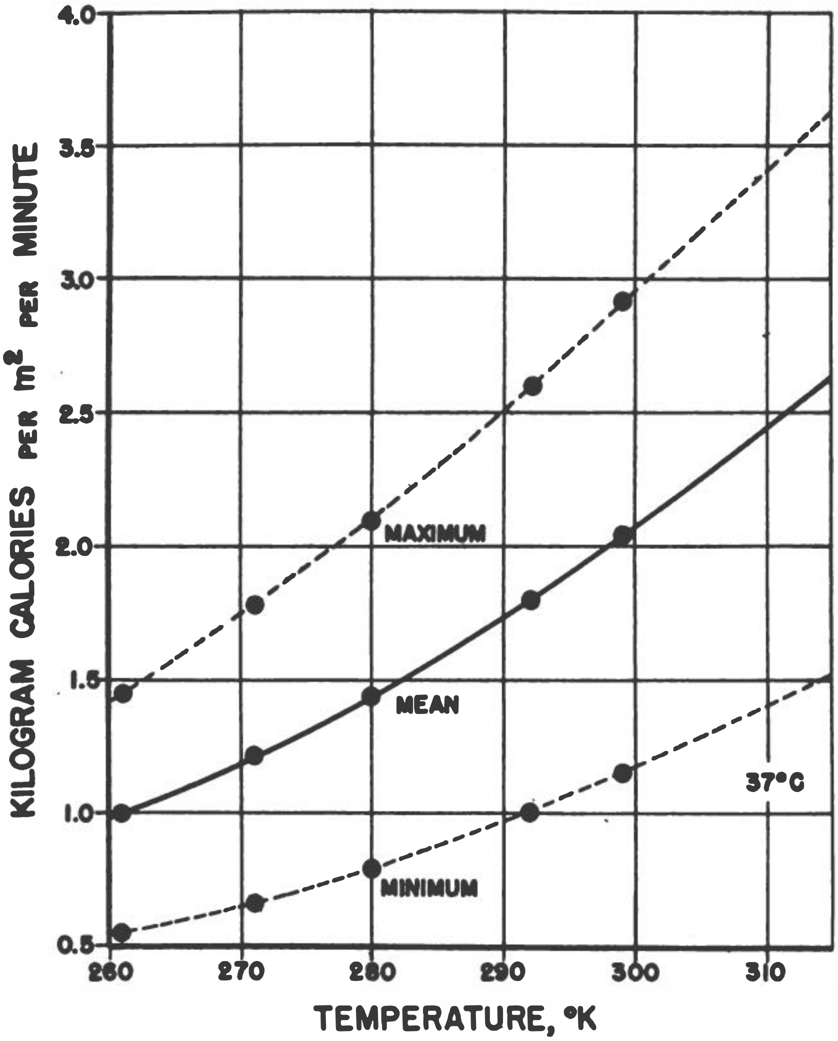

Fig. 2

Estimated radiation loss from a horizontal surface to the atmosphere. From the data of Simpson (15).

TRANSFER OF HEAT TO THE AMBIENT AIR, AND THE THERMAL INSULATION OF THE AMBIENT AIR

A. C. Burton

Heat is transferred from a warmer surface to the cooler surrounding air by two routes.

(a) By Radiation, which, by incontrovertible laws of thermodynamics, is proportional to the difference of the fourth powers of the temperature of the surface and that of the air.

(b) By Convection, including a small contribution by conduction. This is known to be proportional, to a close approximation for small differences of temperature, to the difference of the first powers of the two temperatures. The effect of wind, or air movement, on the transfer of heat convection is known. The magnitude of the effect depends on the size and shape of the surface, but the dependent on wind velocity is the same in each case.

In human calorimetry, as in the "Clo determination" we are, however, more concerned with the total heat loss, which is the sum of the losses by (a) and (b) above, rather than on the partition. Long experience in the laboratory of physicists, engineers and physiologists has shown that the total heat loss is, to the first approximation, proportional to the difference of temperature between surface and ambient air.

Two theoretical difficulties arise from this statement. (1) How can the linear proportionality hold for the total heat loss when a considerable portion of the heat loss, namely, that by radiation, follows not a linear but a fourth power law?

The answer lies in the fact that the differences of temperature concerned in work on the clothed or naked human body are small compared to the absolute temperatures of either clothing or body surface and of the ambient air. For example, this difference of temperature will rarely exceed 10°C., for if it did the heat loss would so greatly exceed possible heat production, that life could not be maintained. Even at -40°F. (-40°C.), the absolute temperature is 233°K. and a difference of 10°C. is small compared to this. In this case the differential calculus applies, and:

$$(T_1^4 - T_2^4) = 4\,T^3 \qquad (T_1 - T_2) \qquad (1)$$

The linear proportionality is quite closely approximated. In cases where equilibrium is very far from being reached, the difference of temperature between clothing surface and air may be so great that this approximation no longer holds, but such cases are outside the field of practical interest.

(2) Evan though this difficulty is resolved, another arises. Will not the constant of proportionality in the above equation for radiation exchange (i.e., $4\,T^3$) be very different at low temperatures from what it is at ordinary room temperatures? How then can a standard coefficient for the total heat loss (for, say, a 5°C. difference of temperature) be used in experiments at widely different temperatures? For example, if the clothing surface temperature be 25°C. (298°K.) in an ambient temperature of 20°C. (293°K.), the difference of the fourth powers of absolute temperature is 516 x 10^6, whereas if the clothing surface were at -35°C. (238°K.) at an ambient of -40°C. (233°K.) the difference of fourth powers would be only 262 x 10^6. The loss of heat by radiation for the

same 5°C. difference of temperature would then be reduced to about half at the lower temperatures.

The answer to this objection is that the heat loss by convection also changes with the ambient temperature but in the opposite sense, and the resultant total heat loss in ordinary cases, where emissivity of surfaces is high, is practically unchanged at low temperatures.

Heat loss by convection, for a given velocity of air movement, increases as the density of the air increases with lowered temperature.

Total Heat Loss, Insulation of the Air

In human calorimetry, the values advocated (Burton and Macdougall, "Analysis of the Problem of Protection of the Aviator Against Cold and the Testing of the Insulating Power of Flying Clothing," August 11, 1941, A.C.A.M.R. Report No. C 2035 (N.R.C. Canada) are based upon the work of the Pierce Laboratory on the heat losses of the naked and the clothed human body with various air movements (Winslow, Gagge and Herrington, Am. J. Physiol. 127, 505, 1939). The data are described by an equation, which converted to Clo units, is:

$$I_A = \frac{1}{0.61 + 0.19\ V}\ \text{Clo} \qquad (2)$$

where V is the velocity of air movement in cms./sec. In this equation the term 0.19 V represents the loss by convection, the other term 0.61, which is not dependent on air movement, the loss by radiation. The data were obtained at ordinary room temperatures (25°C.). The equation can be modified for low temperatures in accordance with the foregoing discussion to take account of the changed radiation factor and the changed density of the air. It becomes:

$$I_A = \frac{1}{0.61 \times \left(\frac{T}{298}\right)^3 + 0.19\ V \times \frac{298}{T}} \cdot \qquad (3)$$

where T is the ambient temperature.
For example, for -40°F., T = 233°K. and the equation becomes:

$$I_A = \frac{1}{0.29 + 0.21\ V} \cdot \qquad (4)$$

From equations (2) and (4) a table of values of the insulation of the air may be constructed, for ordinary room temperatures and for low temperatures (-40°F.) respectively.

From the relation of the two terms in the denominator in equation (4) the percentages of the total heat loss by radiation and by convection (for clothing of high emissivity) may be estimated. These are also given in Table 1.

It will be seen that in relatively still air, the insulation increases at low temperatures, while in high air movements it decreases at low temperatures. However, over the working range of laboratory and field experiments, from 30 cm./sec. up, the values differ by less than 0.1 Clo unit. The similarity of the two curves is shown in Fig. 1.

Standard Values Recommended

Since the accuracy of Clo determinations cannot be expected to be better than to 0.1 Clo units or more, due to the variables introduced by tightness of fit of clothing (an air space of $\frac{1}{40}$ gives an extra 0.1 Clo), it is recommended that the effect of low ambient temperatures on the insulation of the air may be

Table 1

Air Movement		Room Temp. 25°C.			-40°C.		
cm./sec.	ft./min.	% Rad'n.	% Convection	Insulation Clo	% Rad'n.	% Convection	Insulation Clo
9	18	52	48	0.85	32	68	1.08
25	49	39	61	0.64	22	78	0.75
36	71	35	65	0.57	19	81	0.64
49	96	31	69	0.52	16	84	0.57
81	159	26	74	0.43	13	87	0.46
121	238	23	77	0.37	11	89	0.39
225	443	18	82	0.29	8	92	0.29
400	790	14	86	0.23	6	94	0.22
625	1,230	11	89	0.19	5	95	0.18
1,024	2,010	9	91	0.15	4	96	0.14
2,500	4,920	6	94	0.10	3	97	0.09

neglected in practice. A mean curve may be drawn falling between the two curves of Fig. 1, and from it a table of standard values made. These will be accurate to within about 0.05 Clo over the working range.

Table 2

Standard Values of I_A to be Used at all Temperatures

Insulation Clo Units	0.1	0.15	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.85
Air Movement Ft./Min.	4,500	2,000	1,050	425	210	120	75	50	35	30
Cm./Sec.	2,280	1,015	534	216	107	61	28	25	18	15

Measurement of Air Movement

It must be emphasized that the velocity of random air movement is required rather than "drift velocity" of wind. The ordinary type of anenometer with rotating cups or vanes is not really a suitable instrument for the purpose. The best method is to use a Katathermometer, which measures directly the cooling power of the air movement, rather than the velocity of this which is deduced from it.

A method making use of an ordinary field thermometer, instead of the Katathermometer, has just been devised and will be reported separately. This has a sounder basis for application to the problem here discussed than has the Katathermometer, which, to our knowledge, was never calibrated for low temperatures.

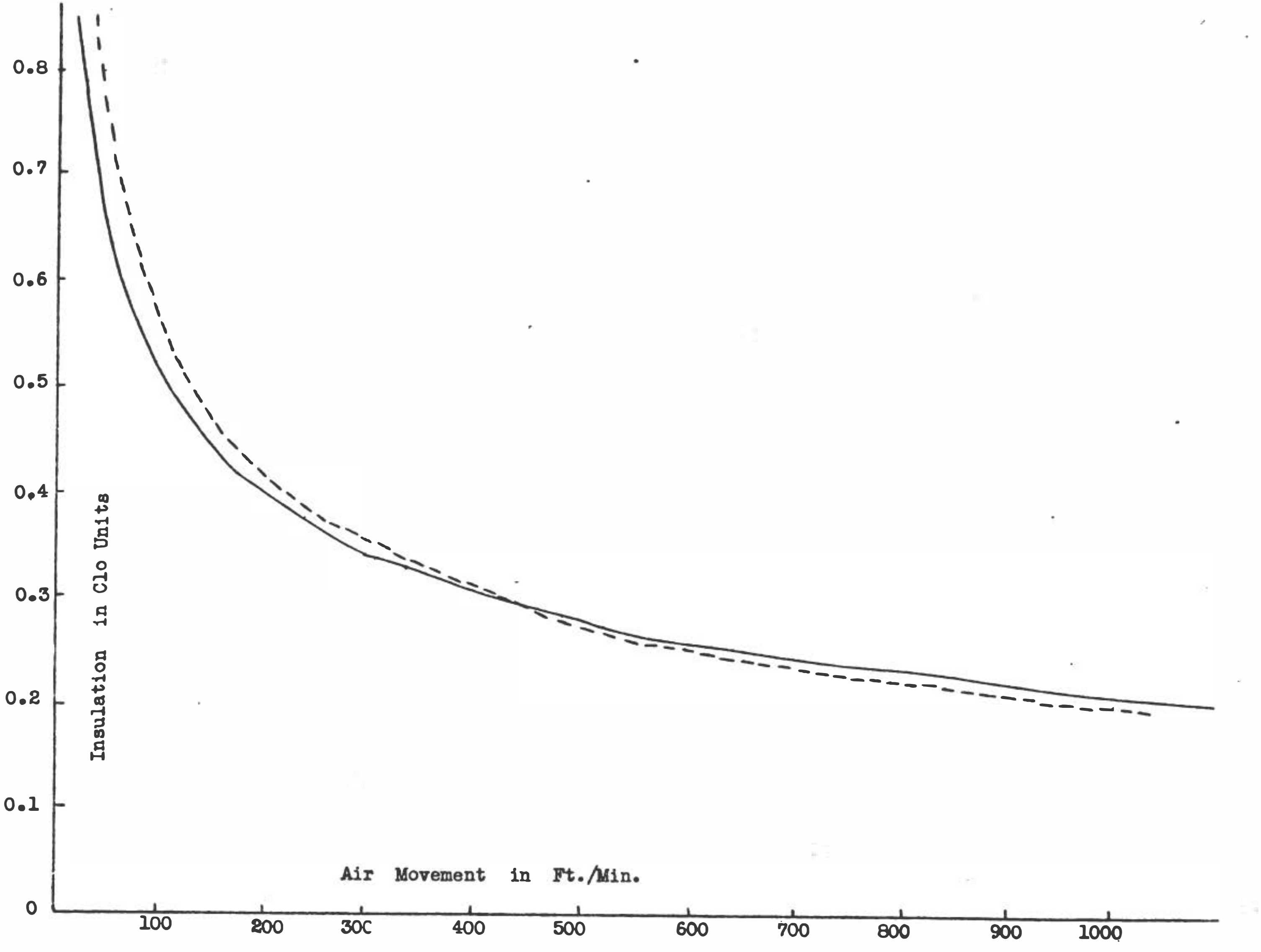

Fig. 1

Insulation of the Ambient Air

——— 25° C - - - - 40° C

STANDARDIZATION OF SUBJECTS

John H. Talbott

Proper standardization of subjects is of great importance when one is testing tolerance time, dexterity, functional utility, morale and similar factors. When determination of insulation units (clo) is planned, standardization is less important.

The number of subjects should be adequate for proper statistical analysis. Their previous exposure history should be stated. If only one or two subjects are used daily for an extensive series of experiments, this should be noted. The other extreme is the employment of twenty or thirty enlisted men for a prolonged experiment (two or three months) following which they are returned to their organization for a new or previous assignment and are not employed as experimental subjects again. A satisfactory system that is in vogue at the Climatic Research Laboratory is a group of six or eight subjects participating daily for eight or ten weeks in the testing and then relieved by assignment to a non-testing job for a month, following which they are reassigned for cold-room testing.

Selection

An attempt should be made to select experimental subjects who are not older than thirty years of age. In the medical history there should be no record of having been intolerant to either heat or cold, nor having had any previous untoward results following exposure to climatic extremes. Mild frostbite is not a contraindication to a person being a suitable candidate for cold-room studies. On the other hand, cold allergy is a contraindication. Extensive frostbite may render a previously resistant subject intolerant to the cold and any person with such a history should be selected only after careful consideration. In the high temperature range, sunstroke (heat hyperpyrexia) is a contraindication. Heat prostration and heat cramps are temporary exaggerated physiological responses to the heat and should not exclude a subject from selection.

The region of the United States in which subjects are born and raised should not bias a physiological reaction to either climatic extreme. Cold-resistant subjects are as likely to have been domiciled in the southern part of this country as elsewhere. The reverse is probably also valid.

Training

Trained subjects are to be preferred in all laboratory testing. The period of training may vary considerably depending upon the intelligence, cooperation and background of the subjects as well as upon the nature of the experiment. An identical or similar experiment should be experienced by each subject before acceptable data are collected.

Acclimation

Only acclimated subjects should be used for testing. Acclimation to the cold should involve at least ten days exposure, a minimum of four hours each day, before reportable results are to be collected. This length of time is usually needed for the first stage of acclimation to become effective. Beyond this time repeated exposure may increase acclimation but these changes are slight and more difficult to evaluate and so may be disregarded. It is believed by some explorers that full and complete acclimation requires as long as six or nine months. In experimental subjects, retrogression or even intolerance to the cold may develop after several months of repeated daily exposure. Whether this is a pure effect of exposure to the cold or intolerance to being an experimental subject, the phenomenon should be recognized when it occurs.

Once a subject is acclimated he will maintain effective acclimation with no more than two or three exposures per week, three or four hours each.

Quartering and Messing

Subjects should be housed and messed together in barracks and mess hall adjoining the laboratory if possible, Unless dietary studies are a primary object of the test, a constant dietary intake need not be provided. The twenty-four hours prior to an experiment are important, especially with regard to alcoholic consumption and adequate rest.

Pretesting Conditioning

Uncontrolled vasodilation and sweating or vasoconstriction and chilling should be avoided during the sixty-minute period prior to each experiment. The preferred dressing-room temperature for cold-room work is 60°F.

A controlled degree of asodilation is permissable, such as may be produced by a fixed amount of work or by diathermy. It should be remembered, however, that the effects of a single exposure to severe heat may last several days and partial acclimation to heat may complicate cold-room experiments.

At one laboratory in this country studies on acclimation to the cold are conducted only in the summer and acclimation to the heat only in the winter. This is desirable but it should not preclude cold-room testing in the winter or hot-room testing in the summer.

Time of Day

Data on a comparative study of similar items should be collected at the same time of each experimental day. The tolerance times tend to be larger and the skin temperatures higher in the afternoon than in the morning. If a series of experiments are planned, the morning series should be considered independently of the afternoon series. Furthermore, there is some evidence from the Climatic Research Laboratory studies which indicates that evening conditions are yet different from afternoon and morning.

Regular meals should be provided when daytime gear is tested during morning and afternoon exposures. If sleeping gear is tested during the day there should be no intake of food during the exposure in order to more closely simulate conditions in the field.

Stabilization Period

Some laboratories provide a stabilization period for subjects in the cold room before the collection of data. At the Fatigue Laboratory, this consists of a short walk at a standard rate in order to produce vasodilation. Other laboratories do not precede their experiments by such a procedure. If a stabilization period provides sufficiently strenuous exercise to produce sweating this should be taken into account, since profuse sweating into thick garments may reduce tolerance times appreciably. Until it has been demonstrated that a stabilization period is necessary, it should be optional with each laboratory.

Reaction to Cold

This should be determined for each subject, since the variation from subject to subject in an acclimated group of individuals is considerable. At the Climatic Research Laboratory the subjects are classified as Resistant, Average, and Susceptible to the cold. The reaction of each subject may usually be determined within a few days after acclimation has been effective.

A resistant or susceptible reaction to the cold may apply only to a particular portion of the body. Thus an average reactor in sleeping gear may be susceptible when footgear is tested. The classes of items that may be differentiated in regard to reaction produced are footgear, handgear, clothing and sleeping gear. At the Climatic Research Laboratory it has not been observed that a resistant subject in one gear is a susceptible subject for another type of gear. The only variation that has been observed is up or down one grade and not two grades, such as resistant to average or average to susceptible. Furthermore, in any type of gear a subject may change from being an average subject one month to a susceptible subject the next month. Most subjects, however, maintain the grade of reaction for the eight or ten weeks period of experimental exposure. It is recommended that the experimental data be surveyed periodically and the subjects placed in their proper category.

Clothing Worn

A subject should be very well clothed, even overdressed, in all parts of the body that are not being tested. Since no clothing combination provides complete protection at rest for indefinite periods of the time below zero without supplementary heat, it is impossible to overdress a subject with functionally useful gear at these temperatures. In order that adequacy may be approached as nearly as possible, it may be desirable to provide for such items as a face mask in a footgear study at subzero temperatures.

In testing handgear and footgear it is important that the clothed body be exposed to the same ambient temperature, in order to produce generalized vasoconstriction similar to that encountered under actual conditions in the field. If only a hand or foot is exposed to the cold, the remainder of the body meanwhile being in a warm environment, the absence of generalized vasoconstriction and the failure to lose stored body heat, will alter the final result materially.

Activity

The amount and duration of activity during exposure should be stated. If possible, exercise should be graded and carried out on a treadmill with recording of oxygen consumption in a few instances to verify the level of activity. If a treadmill is available, walking with a pack should be at the rate of 3.5 miles per hour, walking fifty minutes and resting ten minutes out of the hour. If a pack is carried, it should be standardized at 40 pounds and the rate should be 3.0 miles per hour.

Since reproducible data are obtained best in the resting state, this will probably be preferred for most cold-room studies. Rest should be as absolute as possible since any movement of the body or movement locally of fingers and toes will influence tolerance time.

Fit of the Gear

Unless specifically requested to the contrary, gear should be selected for each subject that would provide a suitable fit in the field. In the testing of handgear and footgear it is especially important that constriction be avoided since this will shorten tolerance time markedly. Conversely, if an unnecessarily loose-fitting gear is worn, it should be so stated, since such gear would not usually be issued in the field.

Adequacy

The term adequacy, when used in the description of gear, should be clearly defined. It should be defined as to whether it is adequate functionally and useful for the mission for which it was devised. Secondly, the amount of activity should be clearly stated. Finally, tolerance time with the degree of exercise permitted should be noted.

ADDENDA

This was submitted to Captain Steven M. Horvath, Armored Medical Research Laboratory, who differed in two paragraphs as follows:

Acclimation

There is no real evidence that the phenomena of acclimatization (in terms of the acclimatization observed for hot environments) exists for cold environments. If such a phenomenon exists, its magnitude must be very minute since no definite physiological effects have so far been accurately delineated. Many people believe that what has been glibly called acclimatization is really nothing more than becoming used to handling oneself and ones clothing and equipment efficiently in the cold. Regardless of whether or not there is acclimatization, subjects for cold-weather testing must have had recent experience with cold.

Activity

If a treadmill is available, walking with a pack (20 pounds for Armored personnel and 40 pounds for others) should be at the accepted Army rate of 2.5 miles per hour, walking fifty minutes and resting ten minutes out of the hour. If a pack is not carried, it should be standardized at 3.0 miles per hour and a five per cent grade.

STANDARDIZATION OF CLOTHES AND GEAR

John H. Talbott

It is believed unnecessary by some laboratories to condition items before use. Other laboratories believe it is desirable.

If clothes are conditioned before use it would be desirable to have them kept overnight in an atmosphere of 50 per cent relative humidity at approximately room temperature. If items are worn daily in the cold room and stowed away in a locker with little or no ventilation at night, essentially the same effect will result as if they were left in a conditioned room at the above humidity and temperature. When garments are used for the first time, either new or unused for some weeks, the tolerance time may be longer until such time as the garments take up considerable moisture from the body.

The precooling of garments for the cold room is not recommended since it will shorten the tolerance time considerably.

There is little need to precool sleeping bags before use. Except in a grossly inadequate sleeping bag, most of the body heat that is expended in warming up the bag immediately after entering it, is not lost. It would have been dissipated eventually in a 6-hour exposure period without reducing significantly the tolerance time.

TOLERANCE TIME

John H. Talbott

Tolerance time is a very useful unit of measure in the studies pursued in the cold room. It may be applied to any item of clothing, handgear, footgear or sleeping gear. It is the capacity of an item to perform its function expressed in units of time. The term is comparable to the capacity of a gasoline stove to provide heat. When the gasoline in a stove has been expended, the utility of the stove for the immediate purpose of supplying heat has passed temporarily and the tolerance time has been reached. The stove is still a useful item in that it has not been broken or damaged but some change in its state must be provided (supplying additional fuel) to restore its usefulness.

In an item of clothing or other gear that provides thermal insulation, tolerance times have been used as the limit of usefulness under specified conditions. Woolen mittens with a windproof shell may be taken as an example. If a subject were to dress in a complete Arctic outfit with face mask and the best mukluks or felt shoes available and sit at rest without moving the hands at an exposure temperature of minus 40°F., in order to simulate duty on a look-out post, the hands would become uncomfortably cold within 30 or 45 minutes. After 60 minutes had passed the hands would become painful and by the end of 90 minutes some change in state must be provided otherwise the fingers will become frostbitten. It can be assumed that the tolerance time has been reached for the pair of mittens at the exposure temperature specified under the conditions of activity provided, which in this instance is rest.

For the sake of emphasis it should be restated that the above-specified tolerance time of 90 minutes applies only to a subject at rest, wearing clothes as enumerated and at an exposure temperature of minus 40°F. If any one of these conditions is modified, tolerance time is altered. If the subject is simulating sentry duty and is slowly walking about, the breakdown point of the mitten becomes longer than 90 minutes, possibly 120 minutes. If the subject is engaged in physical activity, sufficiently strenuous to simulate a soldier in an engineer battalion building a bridge or a soldier pulling a sledge in the snow, the mitten may provide sufficient protection for several hours and the tolerance time will be increased to 4 or 6 hours.

A second factor which increases tolerance time for a particular item is the insulation provided for the remainder of the body. The human body should be considered as a stove capable of generating considerable heat but the arms, legs and head are conducting the heat away faster than it can be produced. If the loss of heat through the feet can be reduced, the covering over the remainder of the body including the hands remaining the same, the tolerance time for the mittens will be increased. The reverse is also true. It was stated that the subject in the cold room would wear the full Arctic assembly, a face mask and mukluks or felt boots. Instead of this footgear, let it be assumed that less adequate covering were provided for the feet and that the subject wore service shoes and a pair of cloth overshoes. If this one item only, footgear, were altered other conditions being kept constant, the breakdown point in the hands would come in a shorter time than 90 minutes, possibly 70 minutes.

Finally, the third controllable variable is exposure temperature. If the mitten combination provides protection for 90 minutes at rest with the clothing specified at minus 40°F., the breakdown point will come in a shorter time at colder temperatures, 80 minutes probably at minus 50°F., and at a longer interval, 100 minutes, at minus 30°F.

There are other factors which influence tolerance time in addition to the degree of exercise, clothing worn over the remainder of the body and exposure temperature. These factors are more difficult to recognize and evaluate and for practical purposes may be neglected.

In this discussion it has been tacitly assumed that at subzero temperatures, tolerance times must be taken into account since no clothing or other gear is adequate for indefinite periods of time under all conditions. Throughout the exposure, from the beginning of the experiment until the breakdown point, the body is slowly losing heat and the margin of reserve becomes smaller and smaller. Even though it may appear that the mittens break down at 90 minutes when the hand becomes unbearably cold, this statement does not do justice to the facts. The mitten is providing only relative protection throughout the exposure period. Changes may be introduced to lengthen or shorten the tolerance time but unless something is done to prevent inevitable loss of body heat, there comes a time when intolerance appears. Exercise and additional clothing may be but temporary expedients and do not necessarily prevent further heat loss or restore the heat already dissipated.

It is reasonable to inquire how reproducible are tolerance times. In trained subjects, accustomed to the cold room, the results from subject to subject and from day to day are consistent and satisfactory. Some subjects have consistently longer tolerance times and appear to be more resistant to the cold than the average. Other subjects have shorter tolerance times and appear more susceptible to the cold. The majority of subjects tested show neither a resistant nor a susceptible reaction to the cold and fall in the average group.

Because tolerance times for a given item of clothing under controlled conditions give reproducible results, the data obtained may be transposed into performance in the field, either maneuvers or combat. If it can be stated to the Commanding General that this mitten combination keeps a soldier from being frostbitten for a 90-minute period at rest at minus 40°F., it is a tangible statement. It is based solely upon subjective evidence but the expression is in everyday understandable units. If tolerance times for all items of clothing are known it is of great help in planning the total clothing for a soldier and in approximating the possibilities and limitations of performance in the field.

GRADING OF SENSATION

John H. Talbott

It is highly desirable that a schema for grading sensations be established. Sufficient work has now been done in the various laboratories in this country and in Canada to establish such a schema. Once it is agreed upon by interested parties it is hoped that it will be adopted widely.

The proposed differentiation may be applied generally and should not be restricted to any one field of testing, such as cold-room or hot-room testing. It may be applied in fields already explored, such as cold, heat, fire, poisonous and obnoxious gases, decompression sickness, diminished oxygen pressure, mechanical trauma, fatigue, dietary deficiency, exposure and immersion, among others. The proposed system is sufficiently elastic that it may be applied in realms of testing not yet explored.

The schema is based upon function and should find its greatest application in the interpretation of laboratory testing and transposition of laboratory and controlled field testing into field operations. The grade assigned comprises the specific level of usefulness and function under the various conditions imposed upon the item.

The grades are as follows:

Grade 0

This includes the comfort range but does not exclude awareness of the stimulus.

Examples. High Temperature. The subject is aware that the ambient temperature is above the optimal comfort range, but discomfort has not developed.

Obnoxious Gases. The subject smells the gas or otherwise is aware of its presence but suffers in no way from it.

Mechanical Trauma. The subject is aware that a suit of underwear is rubbing the skin but no irritation or damage to the skin has appeared.

Grade I

The sensation of the stimulus has progressed to severe discomfort or mild pain but the ability to carry out the mission or the function for which the item was devised is not impaired.

Examples. Low Temperature. The fingers of a subject are uncomfortably cold but they may be partially warmed by exercise and the firing of a rifle is not appreciably affected.

Decompression Sickness. Onset of mild pain. Subject can move about and perform functions necessary for protection in a bomber as before the onset of pain.

Exposure. The victim on the life raft has a moderate sunburn. This is uncomfortable, but the mission can still be carried out. Signalling devices can be used, rowing can be done effectively and fresh water can be prepared, since the mission on a life raft is to stay alive and to be rescued.

Grade II

The symptoms of distress, discomfort, or pain have intensified and the mission is interfered with.

Examples. Fatigue. The subject is too fatigued to carry on combat or return promptly from a difficult patrol.

Low Temperature. A sleeping bag would be in this grade if it failed to provide six hours sleep at night, since the mission of a sleeping bag is to provide sleep for at least this long a period at night.

Irritant Gas. Subjects are not severely afflicted but the irritation prevents effective combat.

Grade III

Severe pain or disability has developed and attempts at pursuing the mission must be abandoned and unless steps are taken to improve the situation, injury will ensue.

Examples. High Temperature. Heat prostration is impending and the soldier in the desert can no longer carry on combat.

Low Temperature. The feet of a soldier in a particular boot have become numb and further exposure may result in frostbite or more serious sequellae.

Low Oxygen Pressure. The pilot of a plane in combat has been partially deprived of his oxygen supply. If the situation is not corrected at once, the consequences may be fatal.

Grade IV

Development of pathology, temporary or permanent.

Examples. Poisonous Gas. Mustard gas has just been sprayed from a plane on inadequately alerted troops. Many burns will result but permanent damage will be minimal if proper anti-gas measures are instituted at once.

Immersion. The feet of a victim have been exposed a sufficiently long time to develop immersion foot with permanent damage and need for amputation of toes eventually.

Dietary Deficiency. Scurvy, pellagra, or beriberi has developed but under proper care the disease may be cured.

METABOLIC RATES FOR MILITARY ACTIVITIES

Frederick R. Wulsin

Section I

Techniques for measuring metabolic rates in laboratories are highly developed. It is not the purpose of this paper to discuss them, but rather to give the laboratory worker factual information about the kinds of work and stress involved in military service, so that realistic metabolic rates may be used in experiments and calculations related to military equipment.

Army activities can be divided into two broad classes: those which involve a fairly steady work rate, and those in which the work rate is highly irregular. In the first class are a number of occupations which resemble those of civilian life--stevedoring, cooking, truck driving, repairing and servicing vehicles, road building, ditch digging, construction work, office work and so on. Marching at a steady pace, with or without a pack, involves a very uniform output of energy except in so far as terrain may vary. Any particular activity in this group is usually carried on for several hours at a stretch, and as a rule the total output of energy per day will not exceed that for similar civilian occupations. When this is the case, it should not prove difficult to select appropriate metabolic rates for representing these activities in the laboratory, or to determine them afresh where necessary.

In emergencies, however, men may be obliged to carry on these tasks day and night, to the limits of human endurance, sometimes with insufficient food and sometimes under fire. It would be surprising if such conditions of stress did not alter the metabolic rates of men engaged in any particular activity, in addition to imposing burdens upon the nervous system. It remains to be determined whether the effects of such stresses can be reproduced and measured in the laboratory.

Other army activities, including combat, make highly irregular metabolic demands. The most intense physical work, as in moving over rough ground at a run with heavy equipment, alternates with periods of stationary waiting, firing, or slow careful movement. During the working phase, metabolic rates may rise far above possible oxygen supply, but these bursts of activity will be short: a man carrying a 50-lb. trench mortar part, or a case of ammunition, in addition to 40 lbs. of basic clothing and equipment, may have to dash forward uphill for 20 to 50 yards at top speed, but he must then lie still behind cover until a fresh opportunity to advance presents itself. There are also longer alternations, as when a man digs a trench and then lies still in it, or carries heavy burdens of supplies and ammunition over rough ground in the dark, perhaps for several hours, and then returns to watching and waiting.

The rate of muscular work involved in these activities will range from the maximum performance of an athlete to almost complete rest. It is likely that maximum hourly totals will not exceed those reached in a hard college football game, and many hours may be passed in comparatively light muscular activity. It is probable, also, that the total amount of muscular work done per 24 hours in battle, if averaged for a large number of soldiers, would be found to lie within reasonable limits. To the extent that these assumptions are true, metabolic rates, which approximate the purely physical exertions involved in combat, can be selected for use in the laboratory.

The battle situation is complicated, however, by factors which may render experiments based on these assumptions quite unrealistic. In the first place, however closely we may estimate average loads, there is no telling what extremes of exertion may be demanded of some individuals. Second, little adjustment for temperature is possible. The soldier usually has to go through the fight with what he has on when it starts, and he is sure to be too hot or too cold a large part of the time; thus a thermal stress is added to the stress of exertion. Third, the soldier may remain in combat for days or weeks, working and fighting with little or no unbroken rest, often with scanty food at irregular hours, perhaps at times with insufficient water. Finally, his activities are carried on to an accompaniment of loud noises and concussions, he is surrounded by gruesome sights, and he is continually under the nervous and emotional strain of imminent danger.

The first three of these combat conditions can perhaps be approximated in the laboratory. The last can hardly be duplicated away from the actual battlefield, yet battles are won or lost by the endurance of troops, as much as by any other factor. It is therefore desirable to examine the nature and magnitude of the stresses peculiar to combat, and to determine if possible their bearing on the selection of army clothing, rations and equipment. The possibility of reproducing them in the laboratory can then be considered.

Section II

It is clear, from the preceding section, that the total stress on the soldier can be considered most conveniently under two headings: first, work load, in the sense of muscular exertion, whether steady or fluctuating; and second, extra stress due to long hours of work, insufficient sleep, sometimes insufficient food or water, and danger. Work load will be discussed in this section, and extra stress in section III.

Numerous determinations of the metabolic rates connected with various civilian occupations are available. These can frequently be applied to army problems. In addition, the Harvard Fatigue Laboratory has made direct measurements of the caloric expenditure of soldiers during various military activities.[1] The results are given in Table I. In interpreting them, the following points should be borne in mind: (1) The determinations were made in June, 1943, at Camp Lee, Virginia. The weather was hot. (2) The figures have been reduced to values for a 150-lb. man. (3) The weight of clothing worn was about 7-1/2 lbs. (4) Full equipment, when specified in the table, weighed a total of 18 lbs. 10 oz. This weight was made up as follows:

Belt, Cartridge, Cal. .30, Dismounted, M-1923	1 lb.	10 oz.
Ammunition, Cal. .30, Rifle, 80 Rounds	5	0
Canteen, Filled with Water, with Cup and Cover	3	10
Packet, First Aid, with Pouch		6
Helmet, Steel, with Liner	3	0
Gas Mask, Service, Complete	5	0
	18 lbs.	10 oz.

The Bayonet with Scabbard (1 lb. 8-1/2 oz.) and the Intrenching Shovel with its Carrier, (2 lbs. 3-1/2 oz.) were carried on the pack and are therefore included in its weight. The Rifle, M-1, weighs 9 pounds.

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[1] Report to the Surgeon General's Office, July 12, 1943, entitled "Comparison between estimates of caloric expenditure of soldiers as obtained by calculations involving standard values and as obtained by direct measurement in the field," by R. E. Johnson, G. C. Pitts, and Major H. Pollach, M. C., with the technical assistance of Pfc. J. Stachelek; from the Harvard Fatigue Laboratory, Harvard University, and the Quartermaster Board, Camp Lee, Virginia. The writer is indebted to Dr. Johnson for permission to reproduce the figures given in tables I and II and for much other assistance.

Table I

CALORIC EXPENDITURE OF A 150-POUND SOLDIER DURING VARIOUS TYPES OF ACTIVITY

Energy expenditure measured by Harvard Fatigue Laboratory

Description of Activity	Cals/hr.
1. Marching on level with 30-lb. pack, rifle and full equipment; 50 mins. of marching and 10 mins. rest, covering 3 miles	410
2. Similar marching and equipment, but with 50-lb. pack	457
3. Field rushes with full equipment (repetition of 5 secs. running, 10 secs. lying prone). One hour consists of 10 mins. march to area, 40 mins. rushing in which 15 mins. is spent rushing and 25' spent lying prone. 10 mins. rest at end	415
4. Creeping and crawling with full equipment. One hour consists of 20 mins. marching, 10 mins. resting, 7-1/2 mins. creeping, 7-1/2 mins. crawling both high and low, with 15' of prone resting	405
5. Obstacle course with light pack and rifle. Course lasts about 5 minutes and consists of pit jump, hurdles, log crossing, ditch jump, maze run, log step climb, ditch climb up and down, 12-foot landing net climb, high tunnel run, log ladder up and down, broken field run, low tunnel crawl, rope swing, high fence climb, one log sitting bridge, walking log bridge, and parapet ditch jump. One hour consists of 20 mins. marching, 2 circuits of course and 20 mins. rest	380
6. Digging fox holes. Two hours consists of 20 mins. march, eighty minutes of digging (half the time spent resting) followed by 20-min break	240
7. Field fortification, - continuous digging	325
8. Calisthenics: 1/2 hour consists of 15 mins. standing about and 15 mins. activity including 1 min. running in place, 50 side straddle hops, 48 squat hops, 15 pushups, 50 knee-bends, 10 mins. of light arm exercise	300
9. Close order drill--presumably rifle only	200
10. Rifle exercises, 1/2 hour consists of 15 minutes of standing about, and 15 mins. of exercises including 32 squat hops with rifle above head, 36 side lunges with rifle and other exercises as in 8, but with rifle	450

In the course of the same study, the total energy expenditure per day of a 150-lb. soldier in the training regiment at Camp Lee was established by the Harvard Fatigue Laboratory for 2 sample days, using the measured metabolic rates given above, supplemented where necessary by rates from other sources. The results are given in Table II.

Dr. Johnson, who conducted the tests at Camp Lee, points out that the soldiers attended to all their personal errands, chores, and diversions in the periods marked "rest" and "off duty," and that the metabolic rates for those periods as given in the Table, and consequently the totals, are somewhat too low.

It should be noted also that the total caloric expenditure for the second sample day is greater than the amount of energy contained in the B ration, a point of considerable importance in experiments which bear on the adequacy of army rations.

A confirmation of the metabolic rates for marching with a load which are given in Table I is found in the work of Brezina and Kolmer, which was published in 1912. Brezina's metabolic rate was determined while he walked with different loads at different speeds. The results have been plotted in Fig. 1, in such a way as to show energy expenditure per hour marched and also per mile, at different speeds and with different loads. Brezina weighed 155 lbs., the loads given are exclusive of clothing worn, and the values are for a whole hour of marching, not for 50 minutes of marching and 10 minutes of rest, as in the case of the figures in Table 1. When allowanace is made for these factors, the graph shows good agreement with the measurements made by the Harvard Fatigue Laboratory at Camp Lee.

The figures in Tables I and II are for a 150-lb. man, and the values in Fig. 1 are for a 155-lb. man. It is appropriate to ask whether the results would be different for men who are heavier or lighter. Does the metabolic rate at work depend primarily on the task, the surface area of the subject, or the weight of the subject? Here experimental evidence is available, which shows that one must distinguish between activities in which a man moves his whole body, such as marching, digging, etc., and those in which the body weight is supported and only a few groups of muscles are used, such as riding a stationary bicycle. Winslow and Gagge[2] have shown that the increase in metabolic rate during work on a stationary bicycle is not related to body weight, but only to work output on the ergometer. Most military activities, however, and especially the activities of combat, involve moving the whole body. Robinson has shown that in this case metabolism is proportional to body weight.[3] He measured the metabolism of two excellent athletes who walked and ran at the same speed under conditions of severe heat stress. One of the men weighed 61 kilograms and the other 99 kilograms. The results are given in Table III. It is obvious from these data that the men's metabolic rates at a given rate of walking were proportional to body weight.

The purpose of Robinson's experiment was to determine the influence of body size upon a man's ability to dissipate heat. Heat production, when walking or running, proved to be a function of body weight, whereas heat dissipation is a function of surface area. Therefore, the heavier man with 44 kilograms of body weight per M^2 of skin surface was unable to maintain thermal balance in the more severe experiments, whereas the lighter man, who had only 36 kilograms of body weight per M^2 of skin surface, was able to remain in thermal balance throughout.

Thus total mebabolism varies directly with body weight, for activities which involve moving the whole body. When a man carries a pack of moderate weight, up to about 20 kilograms, his total metabolism goes up by the same amount as if his body weight had been increased to equal his actual weight plus the weight of the pack. In other words, it does not matter whether the load is tissue or baggage; the metabolic cost of carrying it is the same[4]. When heavier weights are carried the expenditure of energy per kilogram is increased; the same is true when the maximum economic velocity of walking, which is about 3 miles per hour, is exceeded. These relationships are apparent in the curves of Fig. 1.

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[2] Am. J. Physiol. 134: 664, 1941.

[3] Robinson, S. "The effect of body size upon energy exchange in work" Am. J. Physiol. 136: 363, 1942.

[4] Lusk "Science of Nutrition," 4th Edition, 1928, p. 431, quoting Brezina and Rechel, Bio-chem. Z., 1914, 63, 170.

Table II

CALORIC EXPENDITURE DURING TWO SAMPLE DAYS (150-POUND SOLDIER)

Time	Activity	Value calculated from generally accepted figures in literature (Calories)	Value, measured or customarily used by Harvard Fatigue Laboratory (Calories)
	1st Sample Day		
5 AM	1st call		
5:10	Reveille	22	25
5:15-5:45	Calisthenics	250	150
5:45-6:00	Rest and fatigue duties	33	25
6:00-6:30	Breakfast	54	55
6:30-7:30	Calisthenics with rifle	418	450
7:30-8:30	Creeping and Crawling	318	305
8:30-9:30	Field march without eqpt. or gear	319	310
9:30-10:30	Obstacle course	374	380
10:30-11:30	Field march, without eqpt. or gear	319	310
11:30-12:0 PM	Rest and fatigue duties	65	50
12:00-12:45	Dinner	56	85
12:45-2:45	Rest and fatigue duties	130	200
2:45-3:45	Light activities	120	120
3:45-4:45	Boxing and Wrestling	375	350
4:45-5:15	Light activities	60	60
5:15-5:30	Rest and fatigue duties	33	25
5:30-6:15	Supper	56	85
6:15-7:15	Close order drill	200	280
7:15-8:15	Calisthenics with rifle	417	450
8:15-9:30	Fatigue duties	163	190
9:30-5:0 AM	Bed	502	525
	Totals	4284	4430
	2nd Sample Day		
5 AM	1st call		
5:10	Reveille	22	25
5:15-5:45	Calisthenics	250	150
5:45-6:00	Rest and fatigue duties	33	25
6:00-6:20	Breakfast	25	35
6:20-6:45	Fatigue duties	54	50
6:45-11:45	Road march	1960	2050
11:45-12:0 PM	Fatigue duties	33	30
12:00-12:20	Dinner	25	35
12:20-1:15	Rest and fatigue duties	119	110
1:15-4:15	Road march	1176	1230
4:15-5:30	Fatigue duties	166	150
5:30-5:50	Supper	25	35
5:50-9:30	Off duty in area	478	365
9:30-5:00 AM	Bed	502	525
	Totals	4868	4815

Table III

		Temperature		Weight of subject		Metabolic rate	
Activity	Subject	Dry bulb	Wet bulb	Initial weight-Kg.	Weight loss during work-Grams/Kg. body wt./hr.	Total per hr.	Per Kg. body wt. per hr.
1. Walking on treadmill, 5.6 Km./hr., 8.6% grade	E.U.	31.7	27.4	99	25.4	792	8.0
	M.T.	32.2	27.4	61	20.1	488	8.0
2. Walking on treadmill, 6.7 Km./hr., 8.6% grade	E.U.	31.7	27.8	99	25.2	980	9.9
	M.T.	32.2	27.3	61	62.2	585	9.6
3. Running on treadmill, 10.5 Km./hr., level	E.U.	31.1	26.7	99	-	1287	13.0[1]
	M.T.	31.6	27.0	61	-	713	11.7
4. Walking on treadmill, 6.7 Km./hr., 8.6% grade, with artificial wind	E.U.	34.8	24.9	99	20.1	940	9.5
	M.T.	35.2	25.2	61	20.2	592	9.7

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[1] E. U. was forced to stop after 30 minutes, with a rectal temperature of 40.5°C. and a heart rate of 182. M. T. continued for 40 minutes and remained in heat balance.

Robinson has measured the effect of weight of footgear on metabolic rate in marching. He found that the energy requirement for carrying 1 kilogram of weight added to a man's shoes is as great as for carrying 4 kilograms added to his pack.[5] In this connection, the effect on the energy cost of marching,of different kinds of terrain, and of different types of pack, also deserve study.

In selecting tasks to represent the activities of the soldier, one must remember that the amount of marching and the weight carried vary from one theatre of operations to another, and change also within any given theatre, with the tactical situation and the amount of transport available. In the campaigns of the British 8th Army in North Africa, men were carried long distances in trucks and marched relatively little, except in the immediate vicinity of the battlefield. In combat they usually carried only weapons, rations, and an absolute minimum of personal gear, making a total load of 30 to 40 lbs.[6] In the New Guinea campaign, the Australian soldiers who crossed the Owen-Stanley Range carried 51 lbs. 10 oz. of clothing, equipment, rations, ammunition and personal armament, plus a share of extra ammunition and heavy weapons, averaging 20 to 30 lbs. per man. Even so, the amount of clothing and food that they carried was the bare minimum for existence. The trails were bad, with a constant succession of steep hills and gullies, and the footing was deep mud mixed with roots. The going was so arduous when climbing steep grades that men usually moved forward for 20 minutes and then rested for 10. Such work is far more exhausting than ordinary marching.

In assessing the burdens imposed upon the soldier in this sort of campaign, and the metabolic rates to represent them, the elements of cumulative fatigue and malnutrition must be considered. The Australians in the Owen-Stanley Mountains received a daily ration containing about 1900 calories, with irregular supplementary issues which brought the total up to about 2500 calories, and were in constant touch with the enemy. As a result of their hardships, these men lost 20 to 30 lbs. in 8 to 10 weeks. A discussion of the effect of such extra stresses on metabolic rates is found in the next section.

Section III

The extra stresses which fall on the soldier in the field can be given tentative classification under the following headings: (1) Exposure to heat and cold; (2) long hours of work; (3) insufficient sleep; (4) insufficient food or water; (5) danger.

Thanks largely to the work on arctic and tropical clothing, on diet for soldiers, and on related problems, which has been done under the direction of the Committee on Medical Research, a great deal is known about the effects of heat and cold on the body. Dehydration also has been studied by various agencies.[7] As a result, no discussion of these topics in this paper seems necessary. Much less is known about the effects of the other stresses which have been mentioned. In some cases it seems possible that useful quantitative information about them could be gained by laboratory experimentation. It is one of the purposes of this paper to call attention to these opportunities.

In examining the effects of extra stress on the soldier, metabolic rate is only one of the quantities in which we are interested. Cumulative fatigue, as measured by decrease in capacity for performance, is fully as important. Some standard task must be chosen, which a man will perform less well or less willingly

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[5] See Interim Report No. 3 to OSRD, from the Department of Physiology, Indiana University.

[6] These figures and those for New Guinea were given to the writer by Major L. E. Dawson, D.S.O., of the Australian Imperial Forces, who participated in both campaigns.

[7] Adolph, Armored Medical Research Laboratory, and others.

when he is tired than when he is fresh, and which is so arranged that improvement due to practice can be eliminated as a source of error. Since it is well known that there is great individual variation in resistance to fatigue, a man's performance under one condition should usually be compared with his own performance under another, or the results for large groups should be averaged.

Long Hours of Work--Long hours of work and insufficient sleep will be discussed together, because they are usually associated in practice.

When hours of work are increased, the total metabolism per 24 hours is increased also, if the metabolic rate during work is higher than the metabolic rate during relaxation. Thus the soldier who marches 10 hours expending 400 kg. cal. per hour, will use up more calories and need more food than if he marches 6 hours at this rate, and loafs or strolls for 4 hours at 100 kg. cal. per hour. The effect on food requirements of this increased caloric expenditure is easily calculated. It would be interesting to know whether the amount of sleep which is needed to maintain perfect health is increased also, and whether a quantitative relationship between total caloric output per 24 hours and hours of sleep required can be established. The matter could be tested by observing the amount of sleep taken voluntarily by healthy subjects at moderate and again at severe work levels.

Long hours of work do not always involve increased total caloric expenditure. For example, the office worker who stays at his post for 12 hours may have a lower total metabolism for the day than if he stayed at his post for 8 hours and then went for a walk or played baseball. Nevertheless he will probably be far more tired, at the end of a month of working 12 hours a day, than if he had worked less, exercised more, and had a higher total daily metabolism. Here the relation between hours of work and cumulative fatigue is what we are trying to determine. A measurement of the accuracy and speed with which familiar but skilled operations can be performed would appear to provide a useful test for this purpose.

When working hours are abnormally long the total time available for sleep, relaxation and necessary personal chores is reduced. The net effect is usually a reduction in sleep, for some chores cannot be postponed, and men are often more reluctant to give up diversion than to shorten their hours of rest. It is possible that from the point of view of cumulative fatigue the choice is a wise one; this point also should be investigated.

It would be advantageous to know how work and rest should be divided, for minimum fatigue, with a given total number of hours work. For example, if men must march 12 hours a day for 4 days, it would be advantageous to know whether it is better to march 4 hours and rest 4, throughout the day and night, or to march 12 hours with 2 one-hour halts for meals, and then rest 10, or to adopt some different system. Should meals be small and frequent, or larger and further apart, for such an effort? Is it better to march fast and gain longer rest periods, or the reverse? These questions can be approached in two ways: we can either have the subjects perform a standard task--say a 40 mile forced march in 24 hours--using two different systems of resting or of feeding, and then perform tests on them to measure how tired they are; or we can see how far or how fast they can march, with a given incentive, when each of two systems is used. For example, let the task be a 7-day march and let two teams participate, each team using a particular system of rest or feeding. Every man on the team that marches furthest in 7 days gets a 3-day pass, and the distance marched is the average for the best three-quarters of the team. In a repetition of the experiment the teams interchange their systems of resting and feeding, but the same incentive is held out. A few such tests would show which system is best.

Insufficient food--The effect of total starvation has been studied by a number of workers. The effect of insufficient feeding, that is of caloric intake less than caloric output, has received less attention. Yet soldiers in active combat rarely get adequate meals, and sometimes cannot or will not eat all the emergency rations they carry. Thus underfeeding in the army may arise from one of two causes: sheer breakdown of supply, so that soldiers do not receive enough food to eat; and failure to eat the food which they do receive, because it has become monotonous or distasteful.

Insufficient rations may be issued for fairly long periods, through military necessity. The situation may nevertheless demand that the soldier perform full military duty, and he will do so as long as he is physically able to, meanwhile using up his reserves. It might prove useful to know how long a rate of activity in excess of caloric intake can be maintained, and how long it takes a man, who is well fed after a period of overwork and partial starvation, to come back to his normal weight and strength. Throughout such an investigation two criteria would appear to be useful; body weight, and performance in response to a fixed incentive.

Malnutrition which is due to the fact that rations, though supplied, are not eaten, has been discussed by the Harvard Fatigue Laboratory, the Armored Medical Research Laboratory, and others. Here the problem is getting the men to eat the food which has been provided, in spite of the fact that they do not like it, or do not like some components. It would appear to be desirable to examine the practical usefulness of additions which might improve appetite, or in other ways make the food more acceptable. The use of carminatives, relishes, seasonings and alcohol, in forms which could be transported and issued in the field, may be considered. Gain or loss of body weight, when men are doing a fairly large but fixed amount of work on a monotonous and unpalatable diet, will give a simple and direct means of measuring the value of the additions suggested. The experiment should continue long enough to have the diet of the control group become deadly monotonous and almost uneatable. Additions to it, for the experimental group, should be very limited in quantity, but should be made with skill and imagination.

Danger--Earlier paragraphs have dealt with the physical hardships of campaigning. Here we are concerned with the effects which exposure to danger, as distinguished from physical hardship, may have on a man's metabolism, his need for food and sleep, and his ability to undergo fatigue. A number of psychological stresses, which increase in intensity with approach to the battlefield, are involved. Our problem is, if possible, to find means of measuring the effects of such stresses on the body. For the purposes of this paper, this immensely complex subject can be considered under two headings: the effects of strong emotion in general, and the effect of the conflict, which all or nearly all men feel, between fear and duty.

Strong emotion often enables a man to outdo his ordinary physical performance. Bock and Dill have discussed this effect in the case of athletes.[8] The added performance involves an increase in cardiac accelerator tone, in blood flow, pulmonary ventilation and metabolism; this last involves an increase in heat production and food requirements. While momentary maxima in metabolism may be of no particular importance, as far as overall requirements for food and clothing are concerned, it is quite possible that the metabolic rate is increased significantly over the whole period during which a man remains exposed to danger, even though activity be light; for danger is a stimulus which keeps him intensely alert, and this presumably involves increased muscle tone and blood flow.

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8. Bainbridge, Physiology of Muscular Exercise, 3rd Edition, Rewritten by A. V. Bock and D. B. Dill, 1931.

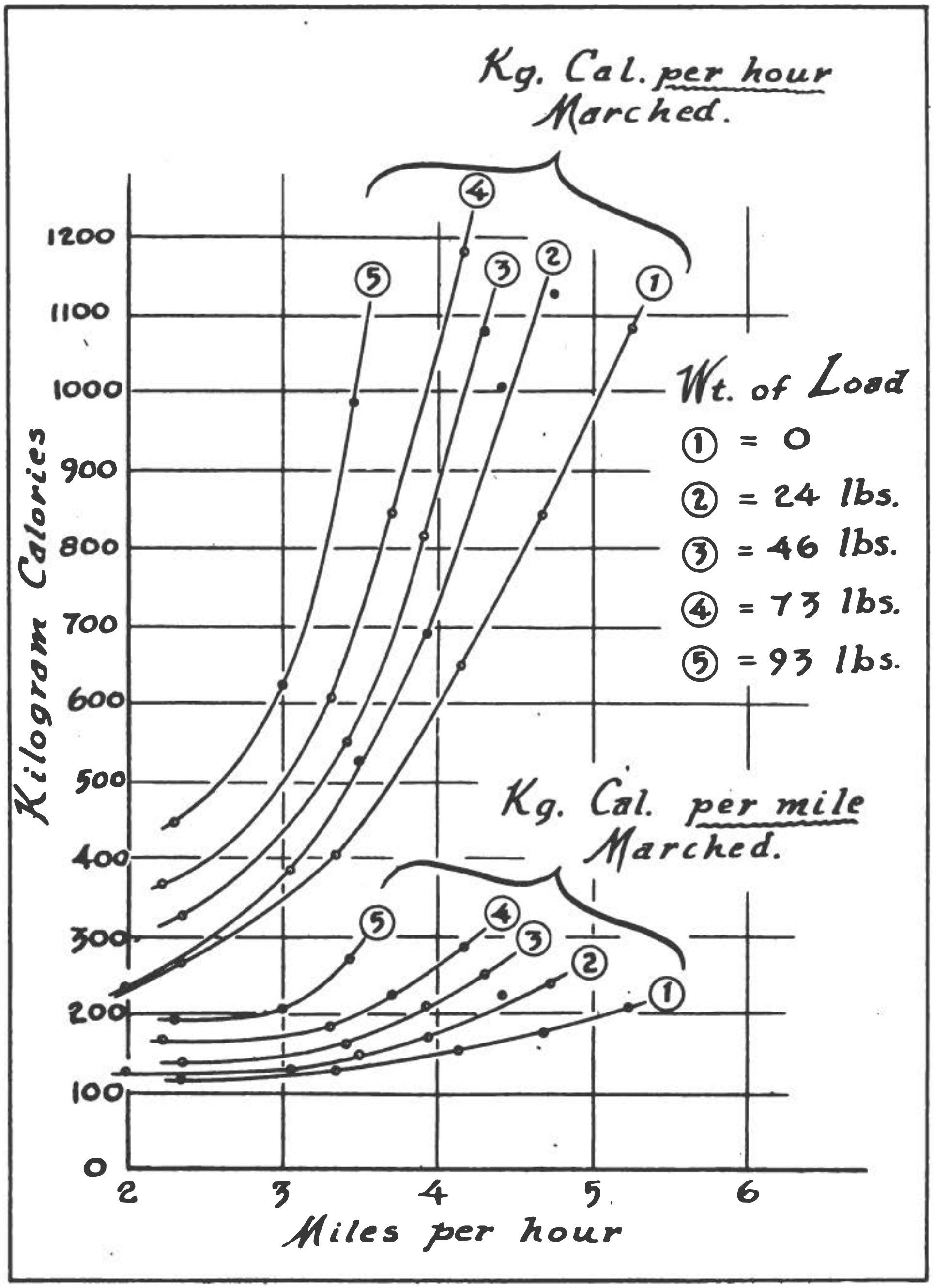
To test this hypothesis by measuring metabolic rates on the battlefield seems to be out of the question. To obtain a measure of the metabolic cost of constant strain on the attention, combined with a trace of fear, should not, however, prove too difficult. Let a man ride a bicycle on a broad and safe treadmill, and again on a narrow, elevated treadmill, where he must be constantly alert to avoid falling off and receiving bruises; let the amount of mechanical work required be the same in both cases, and let metabolism and other relevant quantities be measured. Such an experiment should tell us whether the nervous strain of riding in a slightly dangerous situation increases the metabolic rate, and how much, and thus give some indication of changes in nutritional requirements which may be brought about by combat. It might give other information also; for instance, one might be able to determine the degree of fatigue brought on by each type of riding, by following the experiment with some test of performance in which fatigue would figure.

The measurement of the physical effects of a mental conflict, such as that between fear and duty, is fraught with great difficulties. We do not know what physical effects to look for, and the type of conflict we are concerned with cannot be produced in men in a simulated situation. This suggests the use of laboratory animals, which have been conditioned to mutually exclusive courses of action in response to distinct stimuli. Such animals can be exposed to both stimuli at once, and the relative intensity of the stimuli can be varied, thus producing any desired degree of conflict. Once that situation has been produced, however, one is still faced with the problem of knowing what quantities to measure. Capacity for work suggests itself; but it is already well known, from ordinary human experience, that mental conflict can be exhausting, and to simply confirm this observation by experiments on animals seems hardly worth while. What is desired is information as to the chemical or physiological mechanism involved in producting the exhaustion which is known to occur, when conflict is intense, because mutually exclusive courses of action are desired ardently at the same time. We also want to know what occurs when the stimuli are not evenly balanced, so that one course of action is followed and the desire for the other remains unsatisfied. One approach to these questions is suggested below.

The psychological mechanism of conflict seems to be, that imagination embraces first one alternative and then theother; but before either one can be followed out, it is inhibited, so that there is a great deal of psychological starting and stopping. May not these mental preparations, always thwarted, involve chemical changes which could be detected by sufficiently refined methods?

It is hoped that other and perhaps more valid lines of approach to these problems will suggest themselves to those who may undertake their study.

ENERGY EXPENDITURE BY
155 lb. MAN CARRYING A PACK



plotted from figures determined by Brezina and Kolmer, 1912, as quoted by Benedict and Murchhauser, 1915

Fig. 1

STATISTICAL CONSIDERATION OF DATA

Miss Agnes Galligan
Dr. Richard L. Day

The selection of the group of subjects to be used in a test procedure is important. If conclusions pertinent to a large population of individuals are to be drawn from a small group of test subjects, it is vital that a representative sample be available. If the test subjects are not representative, results are not indicative.

In any experiment, a good approach is to divide first the questions to be answered and the criteria for measurements. The next step is to determine the known extraneous factors which may influence the results and to set up the experiments in such a manner that the effect of all complicating variables on the results can be accounted for. "The essence of the (statistical) method lies in the determination that you are really comparing like with like and that you have not overlooked a relevant fact"(1) (one that is capable of producing bias in the results)."

The various statistical techniques that are available for the treatment of data can then be applied. It must be remembered that no statistical technique can uphold inadequate data. By proper statistical analysis it is possible to determine whether results obtained are within a normal range of variation or if the chance of obtaining such results is so small that it can be assumed to be a result of the factor that is being measured.

TABLES

"After a series of observations have been obtained, the first object is to express them in a simple form which will permit directly or by means of further calculations, conclusions to be drawn. The worker must first consider the questions which he believes the material is capable of answering and then determine the form of presentation which brings out the true answers most clearly." (1) Pearl suggests that in the construction of tables, the following questions be considered.

"What is the purpose of the table? What is it supposed to accomplish in the mind of the reader? Wherein does its failure or attainment fall?" (2)

GRAPHS

"Graphs should always be regarded as subsidiary aids to the intelligence and not as the evidence of association and trends. That evidence must be largely drawn from the statistical tables themselves or in other words, graphs should not be substituted for statistical tables."

REFERENCES

(1) A. Bradford Hill. Principles of Medical Statistics. London, Lancet, Ltd. 2nd Ed. 1939.

(2) Raymond Pearl. Medical Biometry and Statistics, Philadelphia and London. W. B. Sanders, Co. Ltd. 2nd Ed. 1930.

DEFINITION OF ADEQUACY OF CLOTHING IN COLD CLIMATES

Paul Siple

1. Adequacy for General Activity at Dry Ambient Air Temperatures Below That of the Body

A standard definition of adequacy is difficult to posit, because it involves a corrleation of activity, time, and severity of exposure. Each of these elements is composed of many variables. After careful examination of clothing which in the past has been considered adequate, the following definition is hereby proposed:

> Adequate clothing for temperatures between 86°F. and 14°F. shall provide a comfortable equilibrium at the temperature of the environment for men who are standing in the shade with wind at approximately 5 miles per hour.[1]

Normally, men who have this protection will be obliged to ventilate their clothing or to remove surplus items when they exercise at higher rates of activity. If they sit idly or try to lie down without other protection, their clothing will not be adequate indefinitely but only for a certain period of time; although, some additional protection will be furnished them if the wind is reduced to a minimum.[2] The necessary clo values for comfort at any activity and temperature are indicated in Graph No. 1, with the activity of standing marked by the heavy line.

To determine whether clothing is adequate for any part of the world for a given period, it is proposed to take the monthly average of the daily mean temperature of the environment. Actual day and night temperatures will vary around this within a certain range. Men may find it necessary to exercise more at the minimum nighttime temperatures and may be overdressed during the heat of the day, particularly if they are exposed to direct solar radiation. While the monthly average of the daily mean is not most representative temperature over a period of 24 hours, the adequacy of clothing may be more precisely determined than is possible for military purposes by taking the average maximum daytime temperature for use in day and average minimum nighttime temperature for night use.

Climatic zone maps have been developed, showing the range of temperature for any part of the world for each month of the year. The mean temperature of each zone has a range of 18°F. from the warmest to the coolest part of the zone. For clothing purposes, the temperature range of one clo may be said to approximate the temperature range of one climatic zone, for activities which include those of truck driving, standing still, and standing still but with occasional movements as in guard duty. However, since the deficit of ½ clo may cause considerable loss of equilibrium, these zones should be subdivided to give the half clo range. The correlation of climate zone clo values and activities are shown more precisely in Table No. 1 and Graph No. 4. From the graph, it will be obvious that at the higher ambient temperatures the men may have a lower activity while still remaining in

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[1] Since at present no suit which provides sufficient mobility is adequate indefinitely for temperatures below 14°F., either the activity must be increased or the duration of exposure shortened.

[2] For laboratory correlation, it may be noted that protection for three hours tolerance time for men sitting absolutely still at a work rate of 50 Kg. Cals/M²hr. is approximately equivalent to indefinite protection for men standing at 75 Kg. Cals/M²/hr. at the same temperature.

equilibrium. It should be remembered, however, that although the number of clo required increases more rapidly with progressively lower temperatures; nevertheless, a far greater amount of energy must be supplied to make up a small clothing deficit when the temperatures are near those of the body. The two dotted lines on Graph No. 4 represent the amount of additional energy needed to keep in equilibrium if the clothing is deficient by ½ clo and 1 clo respectively. At low temperatures, to cite an extreme example, a deficiency of ½ clo may mean that a man need raise his activity by only 10 Kg. Cals/M^2/hr. (an amount which is easily achieved by muscular exercise or slight heightening of activity). If he is ½ clo deficient at high temperatures, he may need to increase his activity by as much as 40 Kg. Cals/M^2/hr. This apparently anomalous occurrence is due to percentage difference in insulation and holds true for small deficiencies of clothing and low activities only. This does not mean that it is safe to issue inadequate clothing, but it does mean that adequate clothing will be safe when the temperature falls a certain amount below average.

For temperatures below 14°F., either the time of exposure must be stated or the standard activity of the body must be increased. Graph No. 4 shows the amount of increase necessary with the 4 clo uniform. Graph No. 2 shows the relationship between severity of exposure and time limitations for various clo values. It is assumed that the body may lose only 80 Kg. Cals/M^2 before reaching a state of unbearable cold. This figure is somewhat arbitrary but is chosen to represent a suitable average since in combinations of clothing which are poorly balanced, the breakdown may occur sooner due to local cooling; while in those which give equal distribution throughout, the length of time during which he can withstand the cold may be extended for a considerable period beyond that indicated.

2. Adequate Protection for Sleeping Men

The following definition of adequate protection for sleeping men is proposed:

> Sleeping gear should be considered adequate if it provides eight hours comfortable sleep at the average minimum temperature of the environment.

This is on the assumption that heat production will be 40 Kg. Cals/M^2/Hr. and that total heat debt will not exceed 40 Kg. Cals/M^2. The debt value of 40 Kilogram Calories has been recommended by the Harvard Fatigue Laboratory in Report No. 19 and substantiated from records of comfort and discomfort made by the Climatic Research Laboratory at Lawrence, Massachusetts. It is estimated to be the amount which can be lost before a sleeping man will become restless in an effort to build up a higher metabolic rate. The conditions for applying this standard of adequacy are the same as for general activities. The sleeping gear would be more than adequate on the warmest nights; it would, however, provide a shorter, but still reasonable, night's rest when the temperature dropped considerably below the average minimum.

Inefficient cold spots or drafts due to badly designed sleeping gear may substantially decrease the adequacy of the bag even though the insulation as determined by clo values would indicate comfort for most of the body.

Graph No. 3 shows the relationship of clo values, temperature, and time for the protection of a sleeping man.

3. The Effect of Moisture on Clothing Protection

The definitions of adequacy as given are theoretically applicable irrespective of the dryness or dampness of the material. That is, if the man is able to remain in equilibrium indefinitely while standing or if he is able to sleep comfortably for eight hours, the clothing and equipment should be adequate under any normal conditions. This is not true, however, of any given item or combinations of items which has as yet been constructed. The charts and subsequent discussion of clo values apply to dry clothing only. At the present time, no standard of the decrease in adequate protection afforded by damp clothing can be analyzed. Preliminary tests show that sleeping bags preconditioned at a high relative humidity afforded rest for only half the time which was provided by sleeping bags preconditioned at a low relative humidity. Furthermore, the addition of a minimum amount of sweat to an arctic uniform over a ten day period appears to reduce the value of the equipment by about one clo.

It is obvious that evaporative heat loss substantially decreases the value of the insulation. These are, however, only initial studies in a wide field. The humid and wet climatic zones have been mapped, but more research is necessary before the corresponding adequate clo values can be determined.

Adequacy for ambient air temperature close to and higher than body temperatures will be discussed in a later paper.

Table I

CORRELATION OF CLIMATE ZONES, CLO VALUES, AND METABOLIC RATES

Name of Zone	Limiting Temperature	Adequate Clo Value	Necessary Metabolism for Matintaining Equilibrium with Adequate Clo Value	Clo Value	Necessary Metabolism for Maintaining Equilibrium with ½ Clo Deficiency	Clo Value	Necessary Metabolism for Maintaining Equilibrium with 1 Clo Deficiency
Hot Dry	Over 86°F.	0	52		-		-
Warm Dry	86°F. - 77°F.	½	62	0	150		-
	77°F. - 68°F.	1	66	½	102	0	770
Mild Dry	68°F. - 59°F.	1½	67	1	90	½	140
	59°F. - 50°F.	2	68	1½	85	1	110
Cool Dry	50°F. - 41°F.	2½	69	2	84	1½	103
	41°F. - 32°F.	3	70	2½	83	2	98
Cold Dry	32°F. - 23°F.	3½	70	3	81	2½	94
	23°F. - 14°F.	4	71	3½	80	3	91
Very Cold	14°F. - 5°F.	4	79	3½	89	3	102
	5°F. - -4°F.	4	88	3½	99	3	113
Extremely Cold	-4°F. - -13°F.	4	96	3½	107	3	125
	-13°F. - -22°F.	4	105	3½	119	3	135
	-22°F. - -31°F.	4	114	3½	127	3	147
	-31°F. - -40°F.	4	123	3½	139	3	159
Ultra Cold	Below -40°F.						

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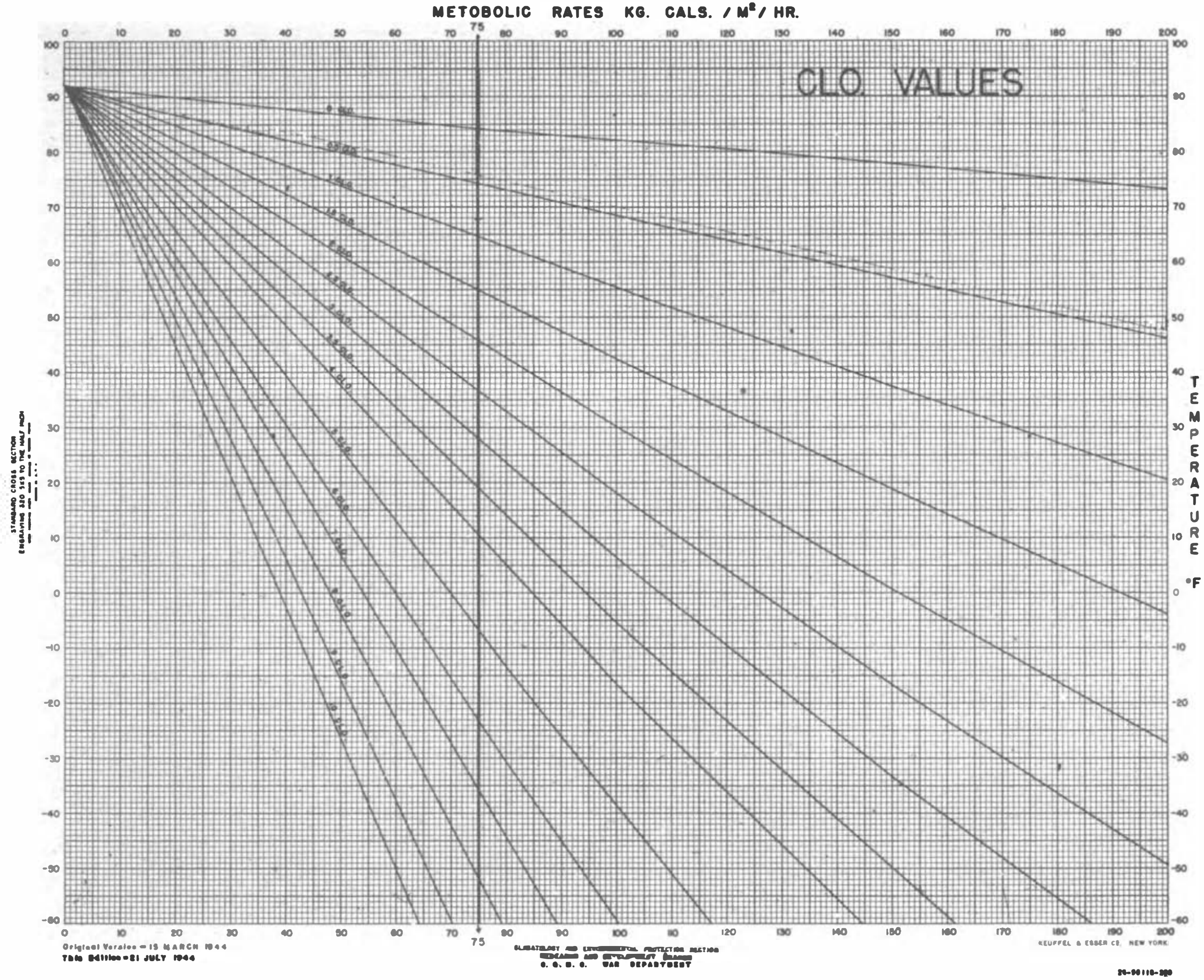
1. Graphical Representation of this Table is shown on Graph No. 4.


METOBOLIC RATES KG. CALS. / M² / HR.
0 10 20 30 40 50 60 70 75 80 90 100 110 120 130 140 150 160 170 180 190 200
CLO. VALUES
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2 CLO
2.5 CLO
3 CLO
3.5 CLO
4 CLO
5 CLO
6 CLO
7 CLO
8 CLO
9 CLO
10 CLO
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TEMPERATURE °F
Original Version = 15 MARCH 1944
This Edition = 21 JULY 1944
CLIMATOLOGY AND ENVIRONMENTAL PROTECTION SECTION
RESEARCH AND DEVELOPMENT BRANCH
O. Q. M. G. WAR DEPARTMENT
KEUFFEL & ESSER CO. NEW YORK

GRAPH NO. 1

Table I

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Warm Dry	86°F. - 77°F.	½	62	0	150		-
	77°F. - 68°F.	1	66	½	102	0	770
Mild Dry	68°F. - 59°F.	1½	67	1	90	½	140
	59°F. - 50°F.	2	68	1½	85	1	110
Cool Dry	50°F. - 41°F.	2½	69	2	84	1½	103
	41°F. - 32°F.	3	70	2½	83	2	98
Cold Dry	32°F. - 23°F.	3½	70	3	81	2½	94
	23°F. - 14°F.	4	71	3½	80	3	91
Very Cold	14°F. - 5°F.	4	79	3½	89	3	102
	5°F. - -4°F.	4	88	3½	99	3	113
Extremely Cold	-4°F. - -13°F.	4	96	3½	107	3	125
	-13°F. - -22°F.	4	105	3½	119	3	135
	-22°F. - -31°F.	4	114	3½	127	3	147
	-31°F. - -40°F.	4	123	3½	139	3	159
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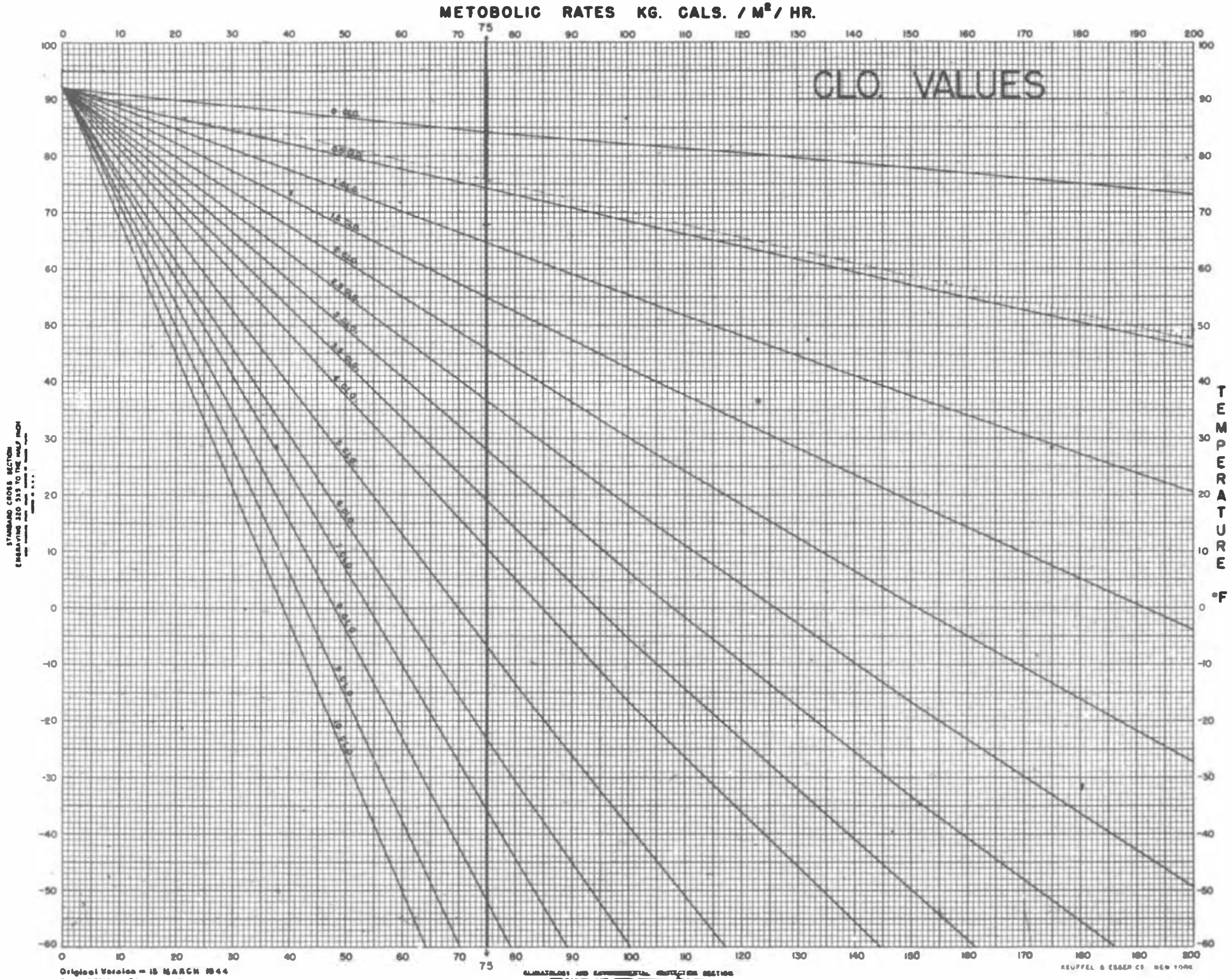

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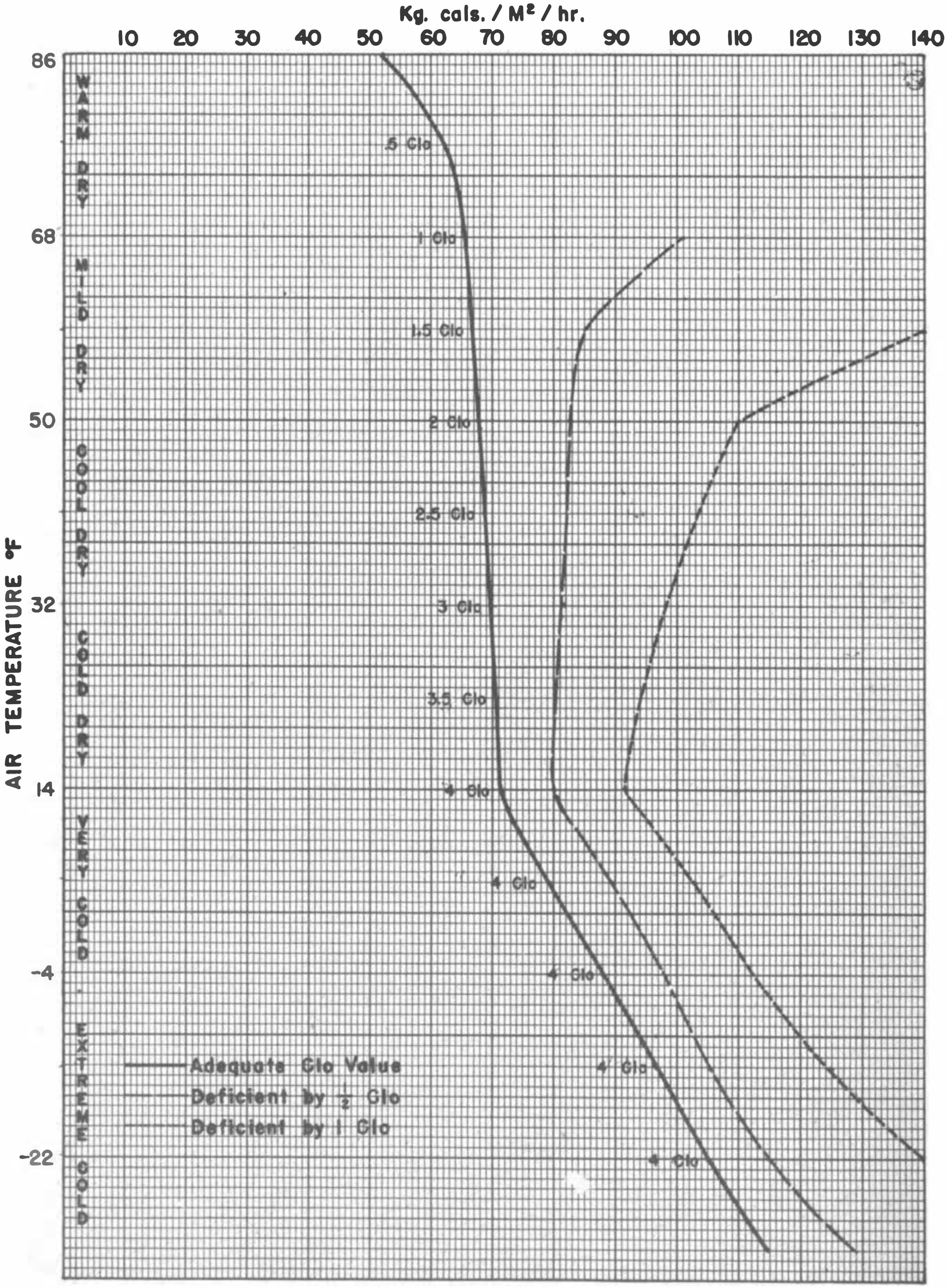
GRAPH NO. 1


Kg. cals. / M² / hr.
10
20
30
40
50
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70
80
90
100
110
120
130
140
AIR TEMPERATURE °F
86
68
50
32
14
-4
-22
WARM DRY
MILD DRY
COOL DRY
COLD DRY
VERY COLD
EXTREME COLD
.5 Clo
1 Clo
1.5 Clo
2 Clo
2.5 Clo
3 Clo
3.5 Clo
4 Clo
4 Clo
4 Clo
4 Clo
4 Clo
Adequate Clo Value
Deficient by ½ Clo
Deficient by 1 Clo

GRAPH NO. 4

PART II

Physical Test Methods

CONTENTS

Part II

I. Introduction
II. Tests for Physical Properties
  1. Tensile strength
  2. Tear strength
  3. Abrasion testing
  4. Shrinkage of wool hosiery; effects of shrinkproofing treatments
  5. Flexural rigidity
  6. Flexural fatigue
  7. Flame proofing
  8. Flash resistance
  9. Frictional properties
  10. Water repellency
  11. Buoyancy
  12. Thickness, compressibility, and compressional resilience
  13. Effective pressures in clothing
  14. Thermal insulation
  15. Resistance to diffusion of water vapor
  16. Rate of drying
  17. Air permeability

I. INTRODUCTION

This outline and discussion of textile testing methods has two purposes: (1) to promote the correlation of physical testing with the ultimate objective of clothing, the protection and service of the wearer; (2) to aid workers in separated laboratories to keep more closely in line in our work for the services, permitting more ready comparison and utilization of one another's work. It should be understood by anyone reading these test methods that we do not consider them final in the sense that each and every test method being used is regarded as completely satisfactory. In order to make some sort of evaluation and permit comparative testing to go ahead without delay, we adopted certain procedures which appeared to be as good as any that we were able to perform at the moment, although at the same time we recognized deficiencies and undesirable features which call for eventual improvement.

It is not the purpose of this outline to duplicate the standardizing work which has been promoted over many years by such agencies as the National Bureau of Standards, the A.S.T.M., and the A.A.T.C.C., and Canadian and United States government procurement agencies, but rather to aid in interpreting certain methods in terms of functional properties of clothing. Hence the actual methods will only be described when they are new, or different in important respects from standard methods, or when experience has indicated that an intial interpretation of the results of standard methods is needed. The reader is referred to the following list of published standard methods, which will be referred to by number throughout the outline:

1. Federal Standard Stock Catalog, Section IV, Pt. 5 Textiles; general specifications, test methods. CCC-T-191a, April 23, 1937. Supt. Documents, U.S. Govt. Printing Office, 5 cents.

2. Textiles, testing and reporting (4th Edition, 1944), 45 p. Commercial Standard CS 59-44. Supt. Documents, U.S. Govt. Printing Office, 10 cents.

3. Quartermaster Corps Tentative Specification, Test Methods for Textiles, PQD No. 447, 26 June 1944.

4. Test Methods and Ratings, by A. C. Goodings and P. Larose, A.C.A.M.R. Report No. C-2419, S.P.C. Report No. 100, Feb. 18, 1943. (National Research Council, Canada.)

5. Canadian Government Purchasing Standards Schedule of Methods of Testing Textiles 4-GP-2-1942.

6. ASTM Standards on Textile Materials, Committee D-13, October 1943 (and anually), American Society for Texting Materials, 260 S. Broad Street, Philadelphia, Pa., price $2.25.

7. Year Book of the American Association of Textile Chemists of Colorists--annual--from the Secretary AATCC, Lowell Textile Institute, Lowell, Mass.

The present outline is the result of consultations and correspondence between the laboratories at Ottowa and Toronto and at Washington, and more than one person has reviewed and contributed suggestions to every topic. The following individuals have participated:

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[1] Present address: Milton Harris Associates, 1246 Taylor St., N. W., Washington 11, D. C.

II. TESTS FOR PHYSICAL PROPERTIES

1. **TENSILE STRENGTH.** Standardized methods are now being used in most laboratories. These are described in several widely available references (1, 2, 3, 4, or 6). Where strength data is needed only as part of an over-all evaluation, the less precise but more convenient grab test can be used. Where more precise results on, for example, the influence of a finish on the degradation of cellulose are needed, the strip method based on constant thread count is more desirable.

Comment by H. F. Schiefer: ...the main justification for the strip test is when it is desired to obtain elongation or load-elongation relations.

Comment by P. Larose: Regarding tensile strength, it might be well to point out that the determination of strength is carried out not so much to gain an idea of the serviceability of the material, since we have no definite relation between strength and serviceability, but it is used rather as an index of quality, in particular when comparing several fabrics of the same type to be used for any one purpose where it is generally assumed that the fabric with the highest breaking strength is the most durable. Breaking strength is therefore included in specifications rather as a control of quality.

2. **TEAR STRENGTH.** Two methods have been standardized. The one usually used, in both Canadian and United States laboratories, is the tongue test, in which the pull is applied in the direction of the tear. One tear is made, between two tongues or strips of cloth, with the force applied in the tearing direction. Strip tear is often used as the descriptive term for this test. Tongue tear sometimes refers to another type of tear in which both sides of the tongue tear relative to the rest of the specimen, but this is not in current use in the laboratories represented. The details of the single-tear test are given in references 1, 3, or 6. In the trapezoid test, the pull is applied at right angles to the direction of the tear, as described in reference 6. These tests do not give a measure of what is needed to initiate a tear, but rather measure the force needed to continue the tear, once it has started.

Comment by A. C. Goodings: In testing work which we have been carring out for the R.C.A.F., we have been using the tongue test method as a measure of the tear strength. This was a purely arbitrary decision and in most cases the trapezoid test probably duplicates more closely what actually occurs. The results obtained by the trapezoid and tongue methods on the same fabric are widely different as the following data indicate.

	Tear Strength	
	Tongue Test lbs.	Trapezoid Test lbs.
Nylon fabric (parachute cloth)	5½	15
Rayon fabric	3½	5
Cotton fabric--tear in warp direction	2	3
Cotton fabric--tear in weft direction	3	6

However, either method, even though the results from the two do not parallel one another, will indicate whether a fabric has low resistance to tear or not and permit some sort of appraisal.

Comment by P. Larose: In the case of tearing strength, many of the remarks made for breaking strength also apply here, although tearing strength is not as widely used as breaking strength, since there is no reliable index to indicate the degree of serviceability to be expected from a fabric possessing a certain tearing strength. As for breaking strength, it is of more value in comparing two or more fabrics with one another.

3. ABRASION OR WEAR TESTING. This type of test is in a developmental state, and can not be regarded as satisfying an investigator. What is needed is more correlation between the results of actual wear, and the indications of physical tests. In general, this requires that men wear the clothing under controlled conditions, a procedure which is being developed by the Quartermaster Corps at Camp Lee. At the National Bureau of Standards, several types of wear test are used, for special purposes. The carpet wear test machine, developed by H. F. Schiefer and A. S. Best (Research Paper 315, Bureau of Standards J. of Research 6, 927-937 (1931), Supt. Documents, 10 cents) has been used to measure wear on pile fabrics. The Taber Abrader and an abrasion device developed by Industrial Byproducts and Research Corporation, have been used in tests of Army wool hose. The Wyzenbek machine is also in use at the National Bureau of Standards. The following description is taken from "Test Methods and Ratings," by A. C. Goodings and P. Larose (ref. 4).

> A sample of the material is abraded on a Wyzenbeek Abrasion Test Meter. The abrading medium is a No. 8 cotton duck. The pressure applied during the test is 3 lbs. and the tension on the fabric is 6 lbs. The test sample is subjected to a maximum of 40,000 double rubs or less, dependent upon the resistance of the fabric to the abrasive action. Where a quantitative measure of the effect of the abrasion treatment is required, this is determined in the case of most fabrics by the loss in tensile strength after a designated number of rubs. The criterion for the end point of the test is taken to be a loss in tensile strength of 40% or over. It is usually possible by visual examination at the end of every 10,000 double rubs on the machine to determine whether a sample is likely to have lost appreciably in strength or not, and testing for strength is then carried out or alternatively the abrading action continued.
>
> The appearance of a fabric cannot entirely be disregarded, although in some fabrics it may be found that while the action of the abrading machine has disturbed the surface of the cloth and damaged its appearance, the strength of the cloth may not be appreciably impaired. In such cases the amount of rubbing required to cause an undesirable destructive effect on the appearance is to be taken as the measure of the resistance to abrasion.
>
> In the case of pile fabrics a more suitable method of measuring resistance to abrasion than the effect on tensile strength is by the wearing down, and in cases plucking, of the pile. Thickness measurements provide a method for determining the abrasive action on the length of the pile. Such cases require separate consideration. Material is tested in both warp and weft directions.
>
> Note: The strength tests before and after the abrasion treatment are made by the Grab Test Method. This necessitates cutting the samples of width greater than that normally used in the Wyzenbeek Machine when examination by visual inspection is adopted. The purpose of this is in order

that the sample may later be placed in the jaws of the tensile strength testing machine at right angles to the direction in which the rubbing was carried out.

Comment by A. C. Goodings: Abrasion tests are notoriously poor in the reproducibility of results, and whether a No. 8 canvas duck is the best material to use as the standard abrading surface for all fabrics is very much open to question.

Comment by W/C Peter Webb: Because of the desirability of predetermining the life span of garments by means of the results of laboratory physical analysis, the Research and Development Branch, O.Q.M.G., set up an N.R.C. project, the objects being as follows:

a. To develop methods of measuring the degree of wear suffered by garments subjected to the test combat course.

b. To apply the same measuring methods as proved by paragraph "a" above, to salvage clothing.

c. To reduce new fabrics by means of laboratory apparatus to representative conditions of wear.

Specially controlled tests on the combat course have just been completed; following analysis of the results by the N.R.C. research workers, it is hoped that agreement can be reached on methods for measuring the effects of wear.
Correlation of results, obtained on machine testing for resistance to abrasion with those found in actual wear, is the first stage in selecting the proper type of measurement to be made on new fabrics.

Comment by P. Larose: At the recent meeting of Committee D-13 it was decided to change the name to "wear testing." The comments of W/C Webb actually apply to wear testing in general and not simply to abrasion testing. Wear is the result of a combination of actions applied to the fabric. It varies with the location of the fabric on the body. In the past there has been too much tendency to look on wear as a single property like breaking strength, whereas in fact it is a combination of properties. For this reason it is questionable whether any single test will ever siffice as a criterion of resistance to wear. The weight to be given to the various factors affecting wear, such as strain, flexing, rubbing, etc., would have to be determined. Moreover, the weight assigned to each of those factors will also vary with the location of the fabric on the body or on the use to which the fabric is put. The effect of light exposure, the effect of wetting, laundering, perspiration, all come into play in affecting wear. It would be difficult therefore to devise accelerative tests to give us the answer in a short time. The same experience has been met in connection with light fading experiments. Even the tests conducted at Camp Lee suffer to some extent from the acceleration. For these reasons I consider the search for comment "c" of Peter Webb as a "Will of the Wisp," except possibly for certain special items where the type of wear is well determined by usage.

4. SHRINKAGE OF WOOL HOSIERY AND EVALUATION OF SHRINKPROOFING TREATMENTS, by Milton Harris and Arthur L. Smith.

A description of a preliminary form of a device for measuring wool socks was given in Textile Research, 14, 150-151, 1944 (May). This one device fits socks of different sizes, but size 12 is usually used. The following test methods have been used in a program for evaluating shrinkproofing treatments of Army cushion sole socks, at the Textile Foundation laboratory at the National Bureau of Standards.

a. Measurement of socks: These measurements were made with a special device designed by the Textile Section of the National Bureau of Standards. This consists of a sock form so constructed that the toe portion slides freely out of the heel portion. A sock is placed on the form so that the heel gore is aligned with a fixed line, clamped in position, and subjected to a 5-lb. load at the toe. The length of the foot at this load is read directly in inches.

b. Shrinkage during washing: Washing is done in a standard, commercial, laundry wheel, 24 inches in diameter by 20 inches long, running at 30 to 32 rpm and reversing every five revolutions. Enough water containing 0.2% sodium carbonate is used to keep the level 2 inches above the bottom of the inside cylinder. Enough soap (Spec. P-S-566) is added to give a running suds.[2] Four pounds of socks are washed for 2 hours at 140°F, given two 5-minute rinses at 120°F, centrifuged, and dried without tension at room temperature.

c. Alkali-solubility test: One-gram (±0.1 g) samples, taken from the leg portion of socks, are dried at 105°-110°C to constant weight, W_i. Loosely stoppered 38 x 200 mm Pyrex test tubes containing 100 ml. of 0.4% (±0.004) sodium hydroxide are brought to temperature in a water bath maintained at 65° ±0.1°C. At 10-minute intervals, a group of four weighed samples is immersed in the alkali, each sample in a separate tube. In order to wet the samples thoroughly, they are stirred once as soon as they are put into the tubes, and once more 10 minutes later. After a group of samples has been in the hydroxide solution for an hour, all four tubes are removed from the bath and the contents of each tube poured, as rapidly as possible, through a separate disc of 100-mesh copper screen soldered to the bottom of a section of brass tubing 1 3/4 inches in diameter. The tubes are rinsed once or twice and the samples are washed on the screens by means of a divided stream of running water. After about 5 minutes of washing the screens are placed on a towel to absorb some of the excess water, after which the samples are removed. The fuzz which separates from the main body of the sample can be balled together by running the finger around the screen several times. The wet samples are either partially dried with a stream of hot air or allowed to dry overnight at room temperature. After this treatment they are again dried to constant weight, W_f. The general formula follows:

$$\frac{W_i - W_f}{W_i} \times 100 = \% \text{ alkali solubility}$$

When applied to the leg of cushion sole socks, these values are doubled to get them on the basis of all wool.

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[2] A running suds is a suds that comes halfway up the cylinder (always running downwards) when the top of the cylinder is moving away from the operator.

d. Stress-strain test: A wool fiber may be stretched 30% in water, relaxed for 24 hours, and restretched and the load required will be the same in both cases. If the fiber is chemically altered between the first and second stretching, the loads required will not be the same. This furnishes a sensitive method for estimating the damage done to the wool fiber without the complications involved in yarns or cloth. Equipment for this type of testing, however, is very highly specialized and is applicable to research only.

To make this measurement, a single wool fiber is fastened to two glass hooks with a chemically inert adhesive, soaked in distilled water about 24 hours, and stretched and relaxed at a constant rate.

The load and recovery curves are determined with a modified chainomatic balance that is automatically controlled through an electronic circuit. (For a complete description of the apparatus, see J. Research Nat'l. Bur. Standards 31, 25 (1943) RP 1546.)

A curve is obtained with an untreated fiber. This fiber is then placed in a perforated Saran capsule, sewed to a sock, and treated. A determination of stress-strain characteristics after this treatment gives another line where the ratio of the areas under the lines, i.e., the ratios of the amounts of work done in stretching the fiber, expressed in percent is known as the 30% index. If a fiber is chemically unchanged by treatment, this ratio will be about 99.

This measurement affords a very sensitive method of telling when something has happened to the fiber, but it does not tell what chemical reaction occurred nor does it predict any wearing qualities. These factors must be determined by correlation with other test methods.

5. FLEXURAL RIGIDITY. The rigidity of a fabric is related to the comfort and it is therefore important to have the rigidity as low as possible where comfort is an essential factor. Army motion or leg motion will be greatly impeded by the use of the rigid fabric. A garment made of a rigid fabric will feel more bulky and more heavy.

The work consumed in flexing a fabric and recovered in releasing it can be measured by an instrument, the flexometer, developed by H. F. Schiefer. (Research Paper 555, J. Research Nat'l. Bur. Standards 10, 647-57 (May 1933). Often, for comparative evaluation of clothing fabrics simpler devices for comparing stiffness can be used. One, used for measuring the stiffness of coated fabrics, especially at low temperatures, is similar to the compressometer, except that the sample is laid across two parallel bars. Pressure from the compressometer is applied by a third bar halfway between the two supports. Other methods of comparing stiffness depend on measuring the chord of the arc formed by a length of fabric supported at its center, or the tendency to hang down over the edge of a table.

6. FLEXURAL FATIGUE. The M.I.T. fold tester has been applied to fabrics. The results are described in "Note on flexural fatigue of textiles," by Herbert F. Schiefer and Paul M. Boyland. J. Research National Bureau of Standards 29, 69-71 (July 1942) RP 1485; and Tex. Res. 12, No. 11, 2-7 (Sept. 1942); and Rayon Tex. Monthly 23 (Nov. 1942) p. 62. The fold tester makes double folds, through an angle of 135°, at 200 folds per minute, with a suitable tension, such as 1.5 Kg

on the specimen 15 mm wide. There is a question as to whether military clothing made of wool or cotton ever wears out by flexural fatigue. However, flexural failure of nylon and cotton fabrics does appear in jungle boots, and more highly crystalline fibers such as linen or high tenacity rayon break sooner in this test than do more extensible fibers.

7. FLAME PROOFING. The A.S.T.M. method D626-41T is recommended. The extent of flashing on the specimen, and the duration of flame and afterglow are noted (Ref.6).

From "Test Methods and Ratings," by A. C. Goodings and P. Larose:

> In general a satisfactory degree of flame proofness is indicated by the following: No flashing on the length of the specimen shall occur. The duration of the afterflame shall not exceed 2 seconds. Afterglow at the edge of the charred area shall not exceed 20 seconds after the cessation of flaming. The charred length shall not exceed 4 inches.

<u>Comment by P. Larose</u>: Besides the strip method referred to, we also use what we call the surface burning test, which perhaps duplicates more closely the conditions that would be met with the flame striking the clothing. This is a method developed by the British Standards Institute and one that is described in our schedule of methods of testing textiles (Ref. 5).

Slightly different methods are described in reference 3, as used at the Philadelphia Quartermaster Depot.

8. TESTS FOR FLASH RESISTANCE, by J. A. Kitching.

The material to be tested is mounted in metal embroidery hoops 6 inches in diameter. A bar, 17 inches long and pivoted at its midpoint, is caused to rotate in a horizontal plane about a veritcal axis by means of a variable speed electric motor. To each end of the bar an embroidery hoop is bolted by its edge so as to lie in a plane tangential to the motion. The hoops are readily removable. Hoops carrying the material to be tested are revolved at various controlled speeds past a lighted gas jet directed at them horizontally. The gas jet consists of a micro burner for which the gas is supplied at controlled pressure (9 cms. on the gauge), the constancy of the flame being checked by means of a radiometer. The details of construction of the test equipment are arbitrary, but standard for all tests carried out. The slower the speed of the motor, the longer is the material exposed to the flame. After each exposure a new piece of material is mounted. The method of testing consists in the determination of speeds at which the material will just ignite and just fail to ignite. The midpoint between these two speeds is regarded as the ignition speed, and is expressed as the time taken for a single complete revolution of the hoops at this speed. It will be noted that the revolution time is proportional to the maximal time during which any point on the material, being revolved at that speed, is exposed to the flame.

This test is designed to reproduce in some measure the conditions likely to be encountered when a two-engined plane crashes on landing. It is presumed that the crew, in escaping from the plane, are briefly exposed to hot flame; and that if their clothes ignite they will be burned severely, but that if their clothes do not ignite those parts of their bodies which are covered will be sufficiently protected. Thus a flashing off of surface nap is unlikely to matter so long as the material does not catch fire. Material from which fire is easily extinguished is also likely to be better than material which burns freely when once alight.

On the basis of tests already done, a provisional rating has been attempted as follows:

Revolution time for ignition speed	Rating
0 - 19 secs.	1
20 - 39 "	2
40 - 69 "	3
70 - 99 "	4
100 - 150 "	5

The scores for higher ratings can only be determined by tests on less inflammable materials than those so far used. The indications from service experience are that fabrics with a flash resistance of 3 or higher give reasonably good protection.

Comment by A. C. Goodings: The original flash test used was essentially to determine the time which a material could be exposed to a standard flame without igniting and continuing to burn. This had limitations. For example, the case of net fabrics and flame-proofed materials posed difficulties in evaluation considered in the light of whether a man would suffer severe burns. Further tests were developed in which the test fabric was backed by some material such as nylon which would act as an indicator of temperature on the side of the fabric remote from the flame and permit a time evaluation of how long it took for a fabric exposed to a standard flame to reach a certain temperature. This, however, is not the whole story because it obviously is an important difference whether a fabric will ignite and blaze or whether it will not.

We are given to understand that the R.A.F. consider wool and silk to be bad in respect of flash resistance but we have not been able to show that wool is any worse than cotton in any of our tests. We feel there may be another explanation for the R.A.F. observations, namely, that at the hands and knees where the large number of burns occur, and which happened to be covered with wool or silk, the fabric is tight to the skin. In other words, there is a great deal of difference in flash protection given by a loose covering and one which is tight. However, we are now looking into tests which will more closely stimulate flash than tests which we have been using where a standard flame is employed and time is the variable factor.

9. FRICTIONAL PROPERTIES. An inclined plane method has been used in Canada, c.f. ACAMR Report No. C-2569, "The slipperiness of lining and related fabrics in flying suits," by A. C. Goodings and C. E. Coke, and the device described by A. A. Mercier, J. of Research Nat'l. Bureau of Standards, 5, 1930 (RP 196).

The method adopted was to measure the coefficient of friction between different fabric surfaces by determining the sliding angle. A sample of one of the materials to be examined is fixed to a block which is then placed on the second material attached to a board capable of being tilted to any angle. The angle of inclination of the board at which sliding will occur with approximately uniform velocity is measured, and the coefficient of friction is the tangent of this angle. The static friction, or the force required for sliding to begin, is slightly higher than the sliding friction, but the latter is the preferable measurement to make from a point of view of reproducibility of result, avoidance of irregular readings due to local variations in the material, and the probably greater significance of sliding friction over static friction relative to the matter under consideration. The pressure applied between the fabrics was approximately 0.1 lb. per sq. inch. The measurement is always made between two fabrics whose frictional properties when in contact require to be known, in other words, it is not the practice to use a standard surface against which to measure all other fabrics.

Another method employs the friction meter developed at the National Bureau of Standards; described in RP 1562, "A friction meter for determining the coefficient of kinetic friction of fabrics," by Edwin A. Dreby. J. Research NBS 31, 237-46 (Oct. 1943). This instrument is also in use at the Ontario Research Foundation, replacing the inclined plane. It measures the force transmitted from a moving layer of one fabric to a stationary layer of another.

Comment by P. Larose: The frictional properties of fabrics are of importance for such things as lining fabrics where it is a definite advantage to have the outer garment slip readily over the inner clothing. It has also a certain bearing on the comfort of the garments themselves. An outer garment that slips readily over the inner clothing will no doubt feel less bulky and more flexible than one offering appreciable resistance to such movement. On the other hand, slipperiness of the outer surface of a garment may be of advantage in decreasing the changes of snag.

10. WATER REPELLENT FABRICS, by A. M. Sookne.

The distinction should be observed between water proof fabrics in which a continuous film of water proof material, such as rubber, is supported by the fibers, and water repellent fabrics, in which the space between the fibers is not closed, but the surface characteristics have been altered to prevent wetting. The following discussion is primarily concerned with water repellent fabrics.

Tests for water repellency may be conveniently divided into the following categories:

1. Tests to determine resistance to wetting inherent in the yarns themselves (spray tests, immersion or absorption tests)
2. Air permeability tests.
3. Tests to measure resistance to penetration by hydrostatic pressure.
4. Tests to measure resistance to penetration by falling drops, streams or sprays.

Since it is the primary purpose of water repellent clothing to keep the wearer dry when exposed to rainfall or other water, these tests will be evaluated from that point of view.

Tests in group 1 bear no direct relation to the ability of a fabric to withstand rainfall. They are, however, useful in evaluating the efficacy of the hydrophobic finish given to the fibers. The standard AATCC spray test (ref. 7) is rapid and reliable, and can be usefully employed for this purpose. A dynamic absorption test is now being standardized by the Office of the Quartermaster General. It is more reliable than the standard AATCC absorption or immersion test, and should also prove helpful in this connection.

Air permeability tests (group 2) also bear no direct relationship to resistance to rainfall, since they obviously cannot provide an estimate of the efficacy of the finish, the effect of swelling on the pores of the wetted fabric, the shape and size distribution of the pores, etc. However, for any given type of fabric, the air permeabilities of a series of well treated samples (100 spray rating) are fairly closely related to their resistance to rainfall. Air permeability tests are also useful in providing a rough basis for choosing grey goods to be given water repellent treatments for specific purposes. The Schiefer-Boyland air permeability apparatus developed at the National Bureau of Standards, appears to be the most suitable machine available for routine laboratory use.

Of the simple routine tests, the hydrostatic pressure tests (group 3) are perhaps the most informative, since they measure a quantity which is influenced by both fabric construction and finish. Within any group of comparable fabrics, the hydrostatic pressure test provides a good indication of rainfall resistance. This is not the case, however, when fabrics of widely different construction are compared. Thus, a thick, resilient fabric will provide much better resistance to rainfall than a thin, flat fabric bearing a comparable finish and having the same resistance to hydrostatic pressure. The Suter tester (Procedure A, ASTM D583-40T) and the AATCC hydrostatic pressure tester (Procedure B, ASTM D583-40T) (see also ref. 7) are both in wide use in this country. The former is perhaps somewhat less convenient to use, and requires a larger sample.

The tests in group 4 are, by their very nature, most closely related to the utility of water repellent fabrics. They have the special advantage that they can be used to evaluate multi-layered combinations, which have been shown in practice to be especially desirable for water repellent rainwear. They are, however, the most difficult to perform, and the most time consuming of the several groups of tests. Of the several tests of type 4 that are available, the Du Pont Rain Tester and the Textile Foundation Drop-Penetration Apparatus appear to be best suited to testing the tightly-woven fabrics required for good resistance to rainfall. There is a good general relationship between the results of these two devices on tightly-woven fabrics. The Du Pont Rain Tester is simpler to operate and requires less time for measurement; it is more suitable for routine use. The Drop-Penetration Apparatus to be capable of revealing smaller differences between fabrics. The Bundesmann Tester appears to be too complicated for routine use, and is probably not sufficiently drastic to test the better fabrics in a reasonable length of time.

Tests of water repellency made on the unworn, unlaundered fabric are of questionable value. New fabrics are frequently calendered, which process gives them a high initial water repellency, much of which vanishes after one thorough wetting. In addition, many uncalendered fabrics lose a substantial portion of their initial water repellency after one wetting. It is recommended that water repellent fabrics be evaluated after one or three launderings of the type to which they will be subjected in use. Such a procedure provides a more reliable estimate of the performance of a water repellent fabric over its period of useful service than does testing the new fabric.

The Du Pont Rain Tester consists of a horizontal nozzle, the specifications for which appeared in the American Dyestuff Reporter 32, p. 88 (1943). A hydrostatic head of 2, 4, 6, or 8 feet is used to project the water against the cloth, which is backed by blotting paper such as that specified in the AATCC Immersion Test. The Textile Foundation drop-penetration apparatus allows 1 drop per second from each of a group of thirty capillaries to fall through a path about 5 feet 8 inches long, in which they are protected from drafts. The drops strike repeatedly at the same spots on the sample, inclined at 45°. Gauze or blotting paper may be used as backing, and weighed, or an electric signal used to indicate penetration. For the most severe tests, a hard backing may be used, with measurement of the amount of water penetrating in a given time. Drawings and descriptions of the apparatus can be obtained from Milton Harris Associates, 1246 Taylor Street, N. W., Washington, D. C.

Comment by P. Larose: It cannot be too strongly emphasized that what a water repellent treatment does is simply reduce a tendency of the fabric to wet out and that any water proofing properties (resistance to water penetration) are as much the result of the structural features of the cloth as that of the treatment. Any tests, therefore, that merely indicate the ease of wetting, such as the AATCC spray test are of no value in estimating the rain-proofness of fabrics.

11. BUOYANCY, by A. C. Goodings.

The following is the test method as set up and used by the sub-committee on protective clothing, R.C.A.F.

Test Method for Evaluating Buoyancy of Kapok and Kapok Substitutes for Fillers in Life-Saving Equipment.

(a) Density of packing. In testing the buoyancy of kapok, the fibrous mass is packed to a density equivalent to 3 lbs. of kapok per cubic foot of occupied space. In the examination of materials other than kapok a quantity of fibre is used such that the packing force exerted is equal to that required to compress 3 lbs. of kapok into a volume of 1 cubic foot. This quantity of fibre can readily be found in the following way: A glass cylinder approximately 3¼" in diameter and 6" in height is fitted with a circular metal plate of slightly smaller diameter than the corresponding internal dimension of the cylinder. Additional weight is added to the plate such that when a quantity of kapok under the total applied force (approximately 1/3 lb. per sq. inch) is contained in the cylinder to a depth of 4 inches, the density of the mass is equal to 3 lbs. per cubic foot. The weights of other fibres required to fill the same volume under the same load are then readily determined experimentally with the same equipment. In recording the results of tests, the weight of fibre per cubic foot of occupied space should be stated.

(b) Determination of buoyancy. A cylindrical bag approximately 3¼" in diameter and 4" in height is filled with the fibre to be examined, the weight of fibre per cubic foot to be used having been determined in the manner described under (a) above. The cylindrical bag is made of some open structure textile fabric such as mosquito netting or coarse cheese cloth. The bag and contents are then placed inside an open mesh (¼") wire cylinder of the same internal dimensions as the bag. To the bottom of the wire cylinder, but a little below its lower face so as not to prevent access of water to that face, is attached a lead sinker of approximately 2 lbs. in weight. The cylinder and contents are submerged in water to a depth of 12" measured from the upper face. The weight in water of sinker, cylinder and contents is determined at intervals over a 24-hour period, and the buoyancy is calculated by subtracting the observed weight from the submerged weight of the metal cylinder and sinker with no fibre enclosed.

At the end of the 24-hour immersion period the net bag and contents are removed and placed in a cylindrical jar of approximately 4-litre capacity fitted with a suitably tight fitting lid. One litre of water is added, and the jar and contents rotated about an axis through the mid-point of the sides. The rotation period is one hour. At the end of this time the bag and fibre content is removed and replaced in the wire cylinder and submerged to a depth of 12" as previously. Readings of the buoyant force exerted are again taken over a period of one hour.

The buoyant force is to be expressed in terms of pounds per cubic foot of fibre mass.

In certain cases it may be found desirable to extend examination of the buoyancy of a material to conditions of packing where the compressional forces are greater or less than the standard detailed above.

Complete evaluation of material for use as a filler in life-saving equipment should also include an examination of the susceptibility of the material to breakdown in the dry state, with consequent loss in buoyancy.

12. THICKNESS, COMPRESSIBILITY, AND COMPRESSIONAL RESILIENCY.

(a) Thickness: Thickness is of course important in the determination of bulk density whenever this is desired, but the main interest in thickness is probably due to the relation between thickness and thermal insulation. It has been shown that for most textile materials where the bulk density is above a certain minimum figure, that is, where the air spaces trapped by the fibers are quite small, that the thermal insulation is practically proportional to the thickness. This makes it possible to calculate the thermal transmission simply from the thickness. This is mentioned later in speaking of thermal transmission. The measurement of thickness is of course necessary in determining the compressibility of a material. Since the thickness of certain materials such as pile fabrics depends on the previous history of the material, it is important that this should be considered when measuring thickness.

The standard instrument is the compressometer, developed by H. F. Schiefer at the National Bureau of Standards. It is described in RP 561, J. Research NBS 10, 705-713 (1933). A new model has been developed recently, with a span of 8 inches. With a heavy spring, this is capable of exerting pressures up to 1 lb. per in.^{2} with the 5-inch diameter foot. With a light spring, and the large diameter foot, thicknesses can be measured at pressures as low as 0.005 lb/in^2. Different materials require different methods of measurement; for comparison with service conditions the thick, compressible materials, such as pile fabrics and loose sleeping bag materials, are better measured by the larger diameter instruments.

Thickness at low pressures can also be measured with a microscope, as described in reference 4:

> "The microscope must be fitted with a scale and vernier which allows the movement of the tube to be determined accurately. The microscope is first focussed on a plane surface placed on the stage of the microscope and subsequently focussed onto the surface of the light flat object exerting the required pressure on the top of the pile fabric, due correction being made for the thickness of the particular plate used which may be plastic, glass or other appropriate plane material. This method has the advantage that the instrument with which the measurement is carried out does not touch and therefore does not affect the pressure exerted on the fabric.
>
> "It has been found that the size of the plate exerting the pressure is not immaterial, probably due to an 'edge effect.' The plate adopted tentatively is a circular bakelite plate of 3" diameter."

Revised Method for Thickness and Compressibility, Contributed by P. Larose, from Subcommittee on Protective Clothing Reports Nos. 162 and 163.

After tests had been carried out on various kinds of fibers, it was concluded that the thickness becomes reasonably steady after 5 cycles of compression of a standard type. The relation between the thickness and the logarithm of the pressure is rectilinear, except possibly in the case of very low pressures in which it is difficult to make a measurement. Any divergences from the straight line usually occur in the low pressure end, and the thickness at 0.1 lb. is obtained by extrapolation in that case. The slope of the line is taken as an index of compressibility, but since the two reference points of 0.1 lb. and 1.0 lb. pressures can be used, the difference of the logs. is one and the measure then of the slope is simply the difference in thickness determined under these two pressures. Finally, the slope is divided by the original thickness at 0.1 lb. pressure. The thickness at a pressure of 0.1 lb/in^2 derived by extrapolation of the logarithmic line (and not by direct measurement) has been adopted as an index of thickness of a fabric. This value has been chosen because it had been shown previously that the fabric of a flying suit during wear is subjected for the most part to pressures of this order of magnitude.

b. Compressibility: The new measure of compressibility proposed above by Dr. Larose seems to be the most useful available. A comparison of compressibilities, in non-quantitative form, may be presented to the eye by the curve showing the relation between thickness and pressure. A conventional unit for compressibility has been used by Dr. Schiefer at the National Bureau of Standards, based on slopes determined from this arithmetical curve at arbitrary points. (See J. Research NBS 10, 705 (1933) RP 561, and J. Research NBS 32, 261-284 (1944).) In this, compressibility = (thickness at 0.5 lb/in^2 - thickness at 1.5 lb/in^2)/(thickness at 1.0 lb/in^2). Whereas the unit in the new definition is % change in thickness over the pressure range 0.1 to 1.0 lb/in^2, the older NBS unit was expressed in contracted form as in^2/lb, or in unabridged form as (inches change/inch thickness) per (lb/in^2).

Comment by P. Larose: As already indicated, thermal transmission depends on thickness and therefore a compressible material will have a varying degree of thermal insulation, depending on the pressure imposed. Since certain parts of the clothing are under pressure during use, it is important to gain an idea of the compressibility of the clothing materials in order to determine the relative merits in respect to thermal insulation. As in the case of thickness, compressibility will vary somewhat with the previous treatment of the fabric. Some of this effect is eliminated by measuring thickness after a certain number of compression cycles. However, this does not duplicate the effect of matting that takes place during use and which occurs over an extended period of time. This generally results in an increase in resistance to compression. The final thickness might be more or less than the original thickness, depending on the felting action and whether the material has a high degree of shrinkage or not. It is impossible to predict absolutely what the state of the material will be after use, unless all the factors that may affect it during use are known.

c. Compressional resilience: The compressional resilience is computed from the energy recovered and the energy utilized during compression at the National Bureau of Standards (see RP 561), whereas the Canadian laboratories use the ratio of the thickness after recovery from compression to the initial thickness. As with compressibility, the main interest arises from thermal properties, so comparison can be more directly made in terms of recovered thickness as percent of original thickness.

Comment by P. Larose: Any of the factors that may affect resilience have been pretty well covered in speaking of compressibility. We have found that by determining the compressibility after a certain number of preliminary compressions that there is little need for the determination of resilience itself.