Studies in Solar Radiation and their Relationship to Biophysics and the General Problem of Climate and Health

By G. W. KENRICK *and* GEORGE DEL TORO, JR.

OUTLINE

I. INTRODUCTION

It is generally believed that man's physical and mental vigor diminish in the tropics, and that the change is particularly marked in the case of some individuals coming to the tropics from temperate or frigid climates. However, relatively little quantitative data, taken under carefully controlled conditions, is available to throw light on the exact nature of the changes which take place when individuals are brought to the tropics, nor on the factors which are of importance in producing these changes.[1]

A. *Factors of Importance in Acclimatization:* It should be noted that changes climatic in origin are not necessarily directly correlated with changes in immediate physical environment; they may be indirect in their interrelationships. That is, we may have:

1. Effects directly correlatable with the influence of solar radiation incident on the individual under observation.
2. Effects due to such climatic elements as temperature, wind velocities, humidity, precipitation, cloudiness, etc.
3. Effects due to parasites, the growth of which are conditioned largely by the factors enumerated in the preceding paragraphs.
4. Effects due to dietary changes, which may or may not be due to the climatic elements.
5. Effects due to psychological reactions conditioned by the factors just enumerated. These reactions may also be conditioned by occupational factors and prevalent attempted escapes (such as alcoholism), i.e., effects due indirectly to phenomena classifiable under the above and to attempts to adjust to frequently radical changes in social environment and habits.

B. *Aims of a Research Program on Acclimatization:* Broadly considered, a program of climate and health should seek to evaluate the relative importance of all these factors and mechanisms associated with the adaptations they require.

When these studies have advanced far enough, we hope to be able to:

1. Discuss quantitatively the mechanism of the changes involved in the adaptation of particular individuals to tropical environment.
2. Devise tests to predetermine with reasonable accuracy the degree of acclimatization which various individuals may be expected to display when subjected to a tropical environment possessing various combinations of elements outlined in items 1-5.*

It is evident that a successful solution of problem 2 would be of enormous economic value to private organizations and governmental agencies sending groups of men from temperate to tropical environments, since individuals differ widely in the success with which acclimatization is attained; and large economic losses (both to the individuals involved and their employers) result from unsatisfactory adaptations.

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* Preferably, these tests should be capable of predetermining the expected acclimatization prior to the arrival of the individual in the tropical environment.

In many respects, the problem is analagous to that of devising tests to determine the degree of adaptation which may be expected of candidates desiring to engage in high altitude work, such as aviation. This problem has already been the subject of considerable study.[3]

Evidently, before a satisfactory solution can be found for devising tests to predetermine the acclimatization of an individual, we must have a clear understanding of all the physiological changes which may occur in an individual under the stimulus of a tropical environment. This, in turn, requires an investigation into the relative importance of items 1-5, and the mechanism by which they function. It is evident that, until this is done, no satisfactory solution can be expected. It is probable that the acclimatization of individuals can be expressed only as an integral of separate acclimatizations associated with elements 1-5. Various individuals may be strong or weak in combinations of adjustments to the effects of direct solar radiation phenomena, lower atmospheric phenomena, psychological disturbances, parasites, etc.

Moreover, the general term "acclimatization to the tropics" can hardly be expected to be satisfactory since climatologists frequently group under the terms "tropics" regions differing to a very considerable extent in solar radiations, temperature, precipitation, humidity, wind circulation, vegetation, ethnological characteristics, social development, etc.; factors affecting in various ways the acclimatization of the individual. Distinct personal differences exist with respect to the relative importance of these factors so that valid generalizations can hardly be expected when they are grouped. Thus, under jungle conditions, rigorous requirements are made on all of the adaptations enumerated under items 1-5, while in regions subject to considerable immigration from the Temperate Zone less strain is placed upon the organism due to requirements enumerated under items 3-5, i.e., dietary problems, parasites and psychological factors resulting from radical changes in social environment. Groups may thus be found which acclimate to some types of "tropical" conditions, but not to all; and a separate consideration and analysis of the individual's reactions to the various elements enumerated and is hence a necessary preliminary to generalizations.

II. HISTORICAL DEVELOPMENT OF PROGRAM AT THE SCHOOL OF TROPICAL MEDICINE

Cognizant of the importance of fundamental physical data for application in the fields enumerated above, and as a preliminary to the development of a biological program to study the effects of all the factors enumerated the School of Tropical Medicine in 1935 engaged in the development of a Division of Biophysics to initiate work particularly directed toward a clarification of Items 1 and 2, i.e., solar radiation (ultraviolet), temperature, wind velocities, humidity, cloudiness, etc.

A. *Climatological and Solar Radiation Studies Initiated by Fassig:* To study these effects, it was desirable to obtain fundamental data relative to the climatology of Puerto Rico and the West Indies, including solar radiation values both in the visible and ultraviolet regions.

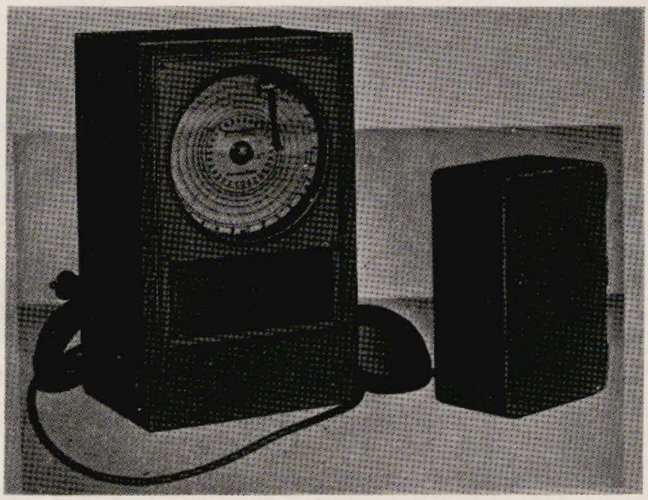

FIGURE 1: Photograph of Ultraviolet Recording Equipment Used at School of Tropical Medicine.

Therefore, on his retirement from active service in the San Juan office of the U. S. Weather Bureau in 1935, Dr. Oliver Fassig was appointed Visiting Professor of the School of Tropical Medicine and Research Associate of Blue Hill Observatory of Harvard University. Dr. Fassig proceeded to prepare comprehensive tables and charts for a text describing the results of climatological observations made during his long service in Puerto Rico.

Also, during his tenure at the School of Tropical Medicine, observations were initiated of total solar radiation intensity (undertaken by the U. S. Weather Bureau at their San Juan office), and of ultraviolet solar radiation (a series of observations undertaken by the School of Tropical Medicine). This ultraviolet series was begun after Dr.

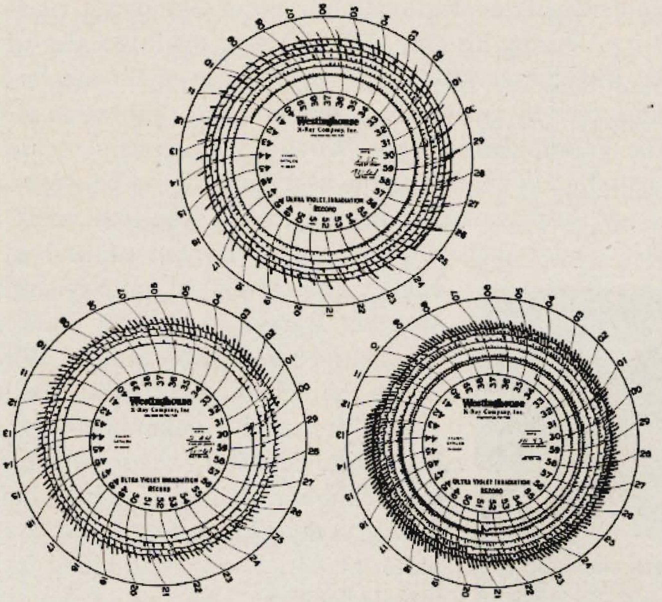

FIGURE 2: Circular Chart Record of Ultraviolet as Obtained using a Westinghouse Type W 6093 Recorder. (Ultraviolet Intensity is Measured by the Number of Clicks per Unit Time.)

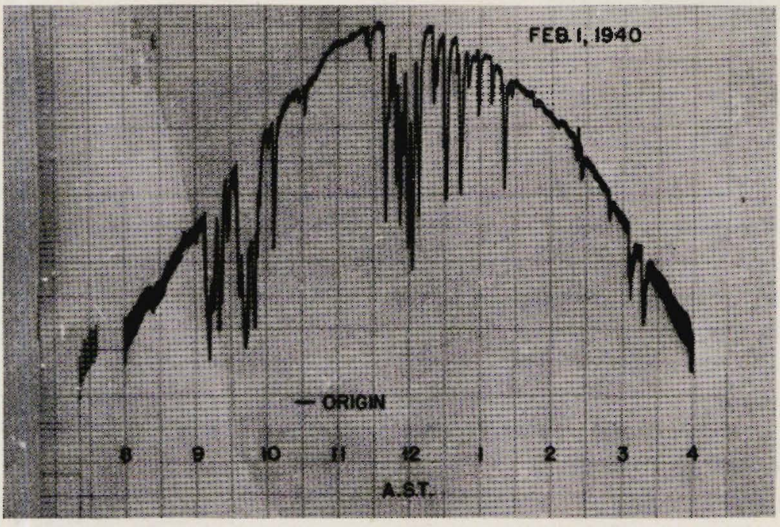

FIGURE 3: Sample Record Corresponding to the Click Record Shown in Fig. 2 as Obtained using Integrating Circuit and an Associated Leeds & Northrup Recording Galvanometer. Note improved ease of interpretation of the resulting record.

W. W. Coblentz of the National Bureau of Standards visited Puerto Rico in 1935. During his stay, Dr. Coblentz made a series of classical differential filter observations on the intensity of ultraviolet radiation in San Juan, thereby permitting a fundamental calibration of the readings of the Westinghouse Type W6093 photoelectric recorder which was purchased and installed as the best compromise between simplicity and accuracy then available (see Figure 1). The total solar radiation observations undertaken at the Weather Bureau utilized a standard Eppley unit, employed quite generally by the Weather Bureau for similar observations in the continental United States.[4] While working at the School of Tropical Medicine, Dr. Fassig prepared a voluminous set of tables and charts describing the results of his climatological observations. However, before completing a descriptive text to accompany this material, Dr. Fassig was killed in an automobile accident.

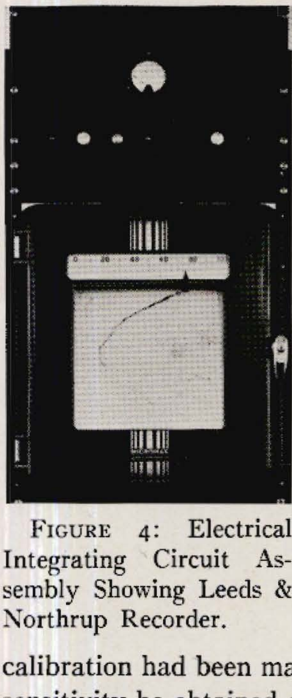

FIGURE 4: Electrical Integrating Circuit Assembly Showing Leeds & Northrup Recorder.

B. *Continuation and Extension of Studies:* The ultraviolet observations initiated during Dr. Fassig's work at the School of Tropical Medicine were continued under the direction of Dr. G. W. Kenrick, Professor of Physics of the University of Puerto Rico. In order to preserve continuity, he retained the optical characteristics of the equipment essentially in the form for which Coblentz's calibration had been made, but to insure the maintenance of a uniform sensitivity he obtained a standard mercury arc quartz of the Wehnoldt cathode type to permit frequent calibrations to be made on the sensitivity of the recording equipment. Through the courtesy of Dr. Coblentz, this standard was calibrated at the National Bureau of Standards. Dr. Kenrick also developed electrical counting circuits which greatly simplified the computational work formerly required by the click records, and permitted daily recordings without the constant attention of an operator (see Figures 2, 3 and 4).

During a visit to the United States in December, 1938, and January, 1939, Dr. Kenrick was also able to enlist the co-operation of Dr. Charles F. Brooks, Director of Blue Hill Observatory of Harvard University, and Mr. Robert G. Stone of that Institution. As a result of these arrangements, Mr. Stone, who is editor of the Bulletin of the American Meteorological Society, came to Puerto Rico in March, 1939, to continue work on the climatological text for which tables and charts had been prepared by Dr. Fassig. Substantial progress was made during the several months of Mr. Stone's visit, and it is hoped that during the coming year the text will be in form for publication.

C. *Some Related Publications:* A preliminary study based on some of the results obtained in the ultraviolet measurement program has been made in a publication by Kenrick and Ortiz[5] entitled "Measurements of Ultraviolet Solar Radiation in Puerto Rico," Transactions of the A.G.U. (Section of Meteorology), vol. 38, pp. 134-140, April, 1938. In the next section of this paper results obtained during the year 1939 are summarized and compared with observations made during the earlier period.

A rather detailed discussion of the vexing problems involved in intercomparing measurements of ultraviolet solar radiation taken at various points where it is desired to study bactericidal or other biological effects is contained in a paper in preparation which is entitled "Standardization Problems in the Intercomparison of Ultraviolet Solar Radiation Measurements," by G. W. Kenrick and George del Toro, Jr. This paper discusses the difficulties arising from the wide variety of characteristics found in the different types of ultraviolet recorders in current use, and intercompares the results of several which were borrowed and operated in Puerto Rico for cross-checks. The instrumental extensions and improvements in the Tropical Medicine equipment which have been made during the past two years are also described.

III. RESULTS OBTAINED FROM SOLAR RADIATION MEASUREMENTS

A. *Monthly Means of Diurnal Variation of Ultraviolet:* The ultraviolet data obtained at the School of Tropical Medicine using a Westinghouse type W6093 ultraviolet recorder is indicated in Figure 5, which shows the diurnal variability of the ultraviolet by months for two years starting November 1, 1937, and ending October 31, 1939.

In the lower curves, the mean values are computed using all hours at which observations were taken, while in the upper curve the peak values observed at the hour shown during the entire month are plotted. (To make these values more representative the mean of the two highest values is taken.)

It should be noted that the lower mean curves really give the com-

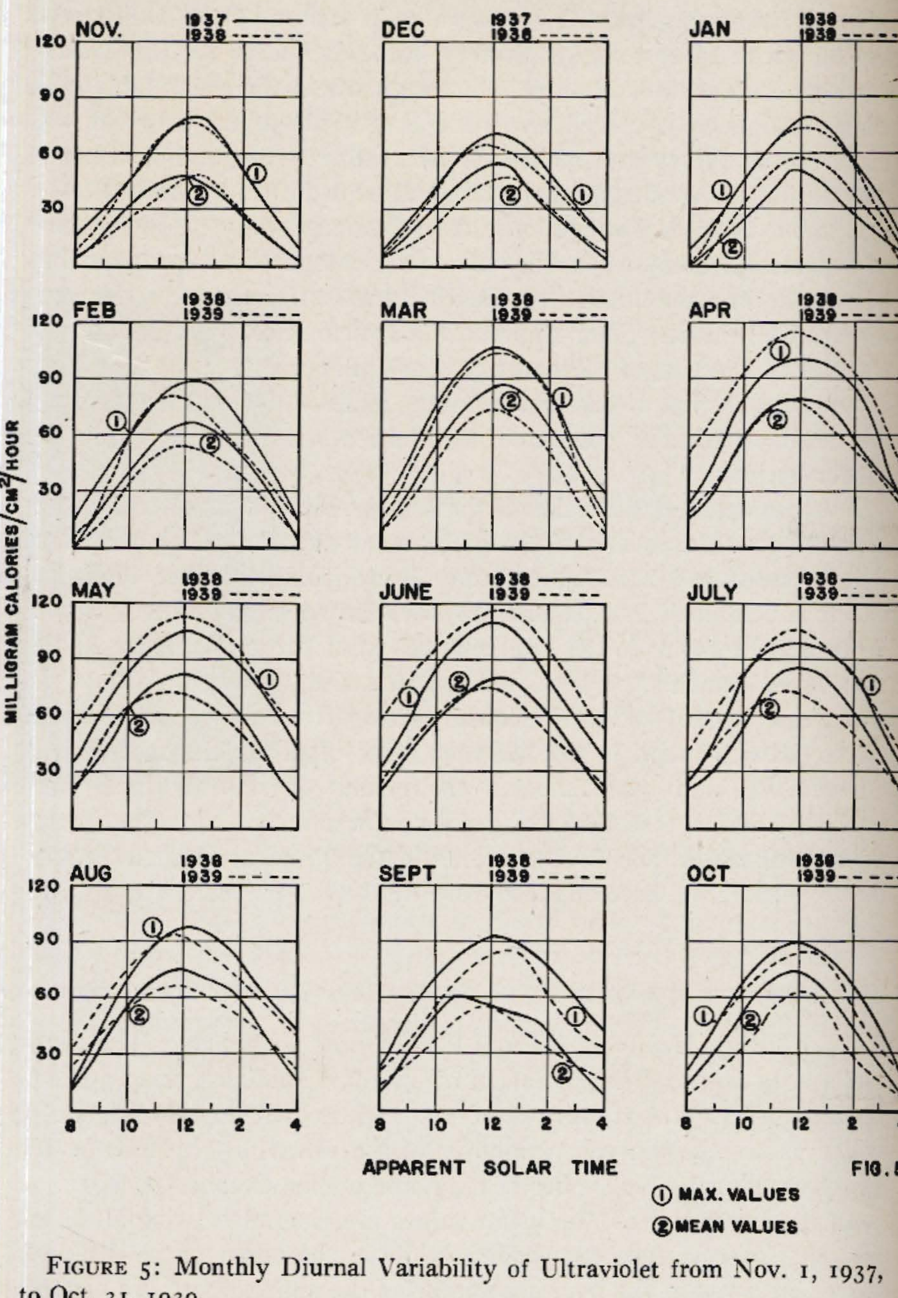

FIGURE 5: Monthly Diurnal Variability of Ultraviolet from Nov. 1, 1937, to Oct. 31, 1939.

bined resultant of stratospheric absorption and tropospheric cloudiness, while the upper values probably give a better idea of true stratospheric absorption. In the upper curves, all the points are not necessarily chosen from data taken on two days, but the clear periods are selected from any day on which high values occur.

It will be noted that the curves thus obtained show different seasonal characteristics. Thus, the peak values give a curve which approximately follows the mean monthly air mass variation, while the average curve is contaminated by cloudiness and precipitation so as to give low values in storm months. The agreement of the low values of the curve with cloudiness data is clearly indicated. Both curves show a tendency to higher spring values than for fall radiation at equal airmass. Two years are, of course, not an adequate period from which to draw conclusions as to whether this phenomenon may be considered typical or merely a chance variation. However, it is of interest to note that it is much more pronounced than the departure between the values for corresponding months for the two years examined in Figure 6. In this Figure, an average value of the diurnal variation in ultraviolet is plotted in solid lines for the first year of observations, and the second year values are in dotted lines in order that departures may be studied and an idea obtained as to how representative the values may be considered to be. It will be noted that the observations of peak values for the two years in general agree within less than 10% and these peak values are somewhat closer than the average values. This is in accord with what would be expected since, during the first year of observations, it was frequently necessary

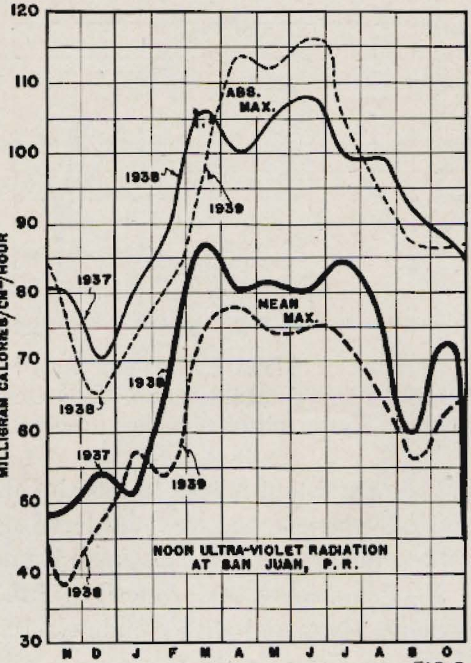

FIG. 6

FIGURE 6: Comparison of Peak Noon and Average Noon Maxima in Ultraviolet by Months during Nov. 1, 1937, to Oct. 31, 1939.

to omit very rainy days due to uncertain protection for the recording equipment. In the second year improved housing has permitted a more nearly continuous record. During the first year in cases where no observations were made these days were omitted from the averages recorded; therefore, in the second year the averages include a somewhat greater number of very cloudy and rainy days. Also, week-end values were available in the second year by use of the automatic recording techniques recently developed. In any case, the degree of cloudiness and rain probably would be expected to show more year to year variations than the peak values of ultraviolet as recorded under optimum clear sky conditions. It is not believed that the values for the two years recorded show any consistent year to year variations, but the persistent month to month characteristics, including the spring and fall phenomena, are considered significant. In the case of average values, the greater fall cloudiness is undoubtedly a major factor.

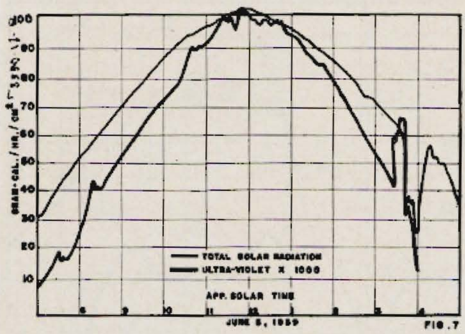

FIGURE 7: Cloud Phenomena for Ultraviolet and Total Radiation. Note temporary rise in ultraviolet due to cloud.

B. *Phenomena Associated with Cloudiness:* An interesting phenomena associated with cloudiness is indicated in the recorder record shown in Figure 7. In this case it will be noted that a peak occurs at the point indicated. Actually, as determined by observations at the time, this point corresponds to a cumulus cloud of small dimensions passing over the sun, thereby obstructing the direct sunlight radiation but actually increasing the ultraviolet radiation.

IV. APPLICATIONS FOR SOLAR RADIATION DATA

A. *Cooling Power Studies:* A very valuable application of solar radiation and climatic data is in connection with the intercomparison of climatic conditions with respect to the cooling power they afford to the individual. Cooling power is the rate at which heat can be taken from a body by its environment. This is a function of solar radiation, wind velocity, humidity and temperature, and should be divided into two classifications; i.e., wet cooling power and dry cooling power, both in shade and in sun. Cooling power increases rapidly when the perspiration point is attained, and the effect is particularly evident in cases where the humidity of the surrounding air is low. As the humidity approaches 100% the amount of increase in cooling power due to sweating is materially reduced. In both wet and dry cooling power, the effect of wind velocity is extremely marked. Studies on cooling power have been summarized by Mr. Stone, in a chapter of the book by Dr. Fassig and Mr. Stone which is now in preparation.

The cooling power is usually measured as the net rate of heat loss in reference to a standard body; usually either a glass thermometer or copper sphere.[6]

The Kata thermometer, invented in 1913 by Dr. Leonard Hill, a British hygienist, is the simplest form and has been the most widely used standard to determine the cooling power. This instrument is an alcohol filled short glass stem thermometer, graduated from a little above 100°F. to somewhat below 95°F. To take a reading this thermometer is heated in water to above 100°F. and exposed. The length of time required for it to cool from 100° to 95° is divided into a "factor" supplied by the manufacturer and multiplied by 97.5 (minus the air temperature). This gives the rate of cooling power in milligram calories per square centimeter per second. (Mg Cal/cm^2/sec.)

For the wet cooling power the same procedure takes place, except that the thermometer's bulb is covered with a moist muslin glove.

Since the normal body temperature is about 98°F., by using a cooling range from 100° to 95°, the Kata thermometer should give a fair indication of the rate of cooling of a human body under similar exposure. This, however, is not strictly true because the thermometer's bulb is small compared with a human body, and it also has a different behavior to radiation and surface temperature. It has been determined that the Kata thermometer gives a heat loss of ⅓ to 10 times higher than actually occurs from a normal, clothed human body for the same time and unit of area.

Nevertheless, cooling power figures should give a good basal intercomparison of the *strain the environment places on the body's thermal regulating mechanism* that governs the rate of body heat loss, skin temperature and subjective sensations of heat, cold and comfort.

Other instruments have been developed which reproduce somewhat more closely human body reactions but in general they are less convenient and more complicated and costly.[6] Measurements made with the Kata thermometer have permitted empirical formulae to be deduced by which the cooling power can be computed from fundamental meteorological data, notably wind velocity, wet and dry bulb tempera-

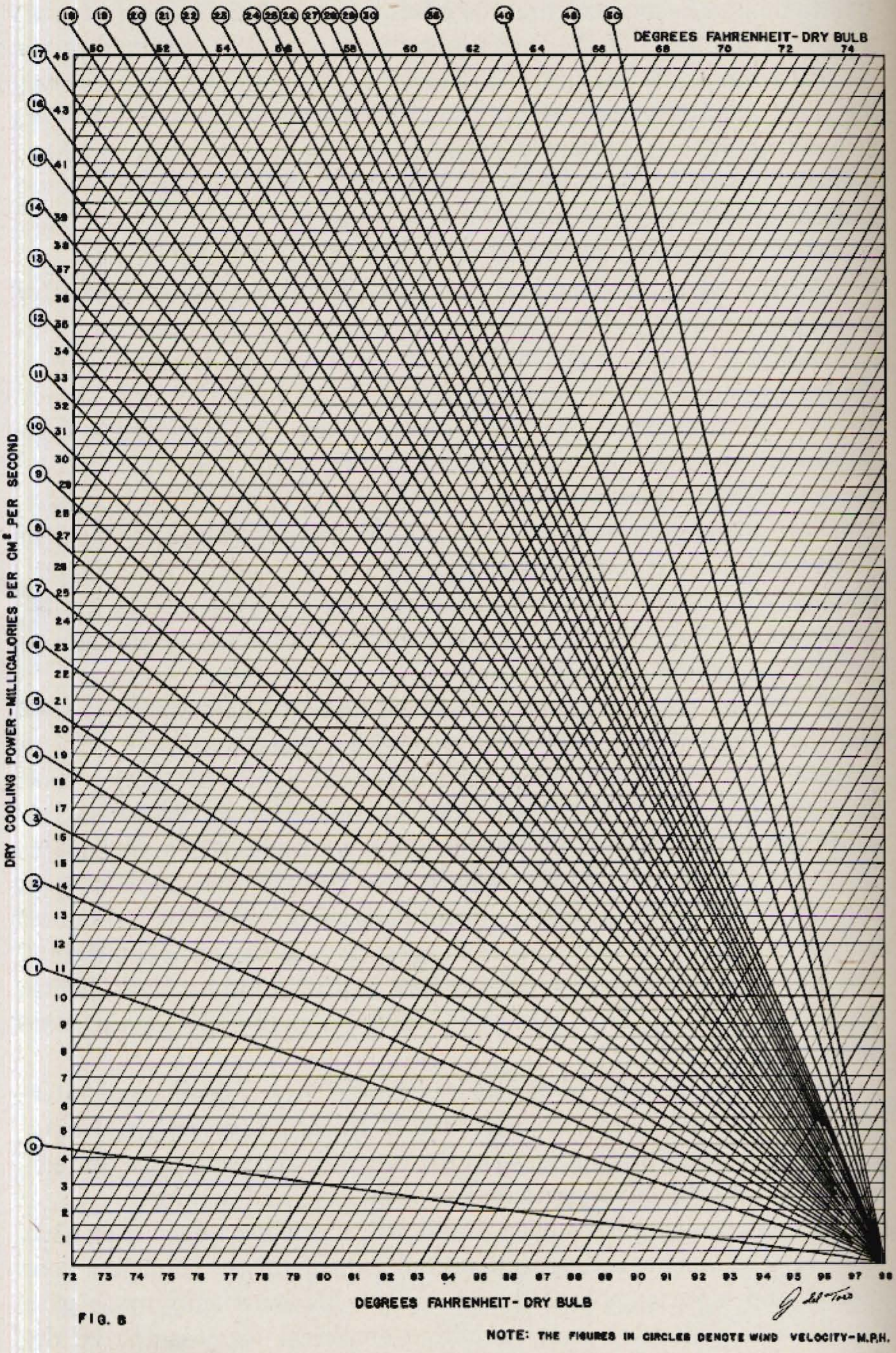

FIGURE 8: Dry Cooling Power Nomogram.

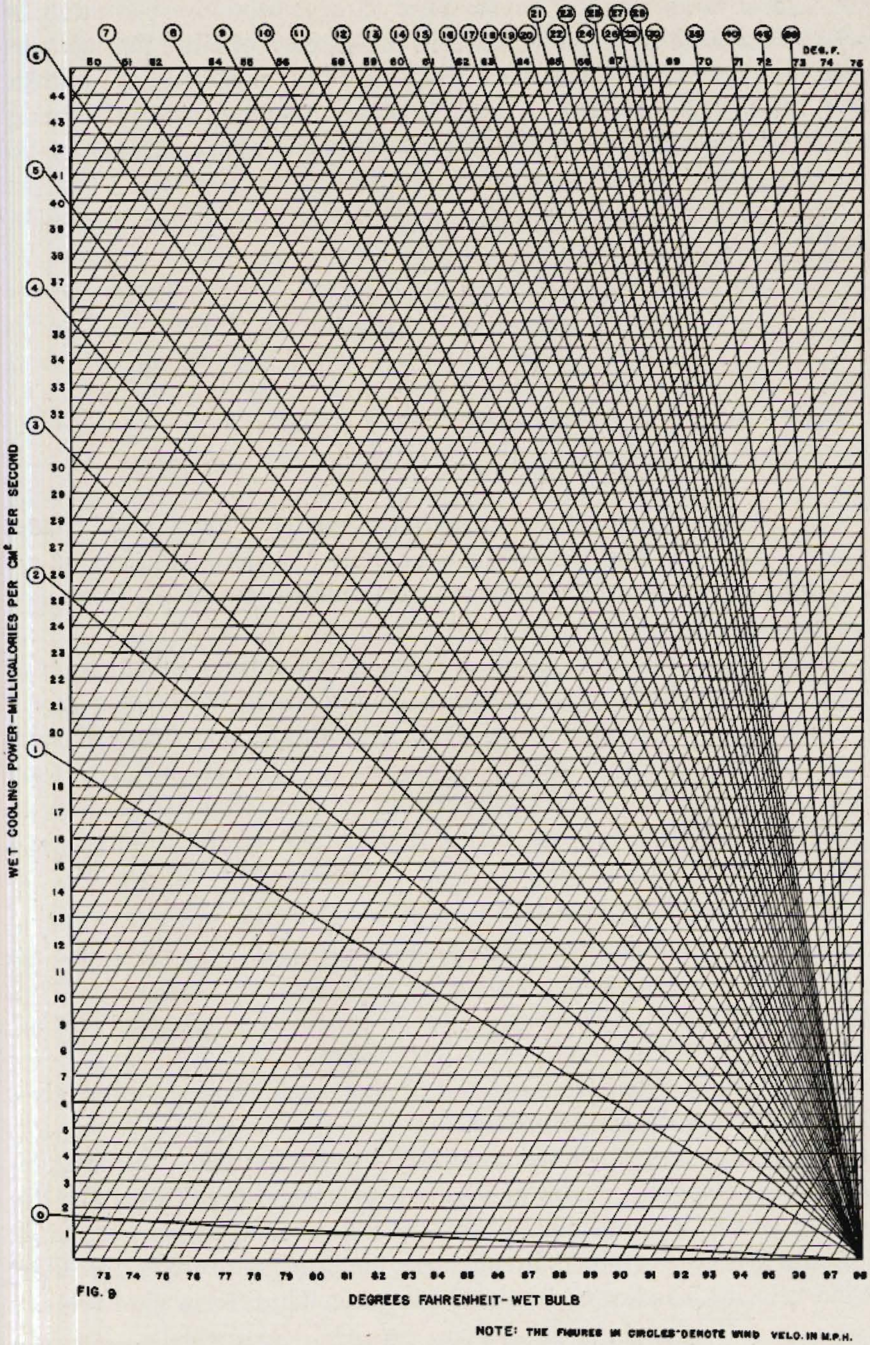

FIGURE 9: Wet Cooling Nomogram.

ture, solar radiation, etc. Given these data, it therefore becomes possible to estimate the cooling power in the absence of Kata thermometer measurements (which are hence frequently dispensed with). A number of formulae have been developed. However, the one most widely used by climatologists is due to Hill (7-8-9) and is approximately of the form:

$$H = (0.15 + 0.182\sqrt{V})\,(98^\circ - t)$$

Where: H = Dry cooling power in shade
V = Wind velocity in miles per hour
t = Dry bulb temperature in degrees F. . . . . (1)

$$H' = (0.06) + 0.47\sqrt[3]{V})\,98^\circ - t')$$

Where: H' = Wet cooling power in shade
V = Wind velocity in miles per hour
t' = Wet bulb temperature in degrees F. . . . . (2)

By use of those formulae the nomograms shown in Figure 8 and Figure 9 are drawn up. The nomograms facilitate the determination of the cooling power values for different geographical locations from past accumulated data.

As the solar radiation heats a body, its value in cooling power is negative. H. Lehman has developed a more extensive cooling power formula for a first order consideration of the direct effects of solar radiation, introducing a term to take account of this effect.[10] This term may be borrowed for use with the results obtained from Hill's formulæ. (Lehman's formula has conduction terms of similar form but slightly different constants.)

$$I_t = -0.155\,I_s - 0.54\,I_d \quad\text{. . . . . (3)}$$

I_t = negative C.P. due to radiation
I_s = direct solar radiation
I_d = diffused solar radiation
(All in mgc/cm²/sec.)*

I_t, when subtracted from the wet or dry shade cooling power, gives their respective values in sunlight.

Using the values predicted from Hill's shade formulæ, we have prepared the nomogram charts of Figure 8 to present graphically the dry cooling power in millicalories per square centimeter per second in ordinate against degrees Fahrenheit dry bulb temperature in abscissae. Wind velocity is indicated by the sloping line. Thus, for a wind velocity

* The U. S. Weather Bureau measures solar radiation in units of G.c./cm²/hr. which must be multiplied by .278 to convert it into mgc/cm²/sec.

of 10 miles per hour and 78°F. dry bulb temperature the cooling power is 14.7 mil. cal/cm²/sec. This chart summarizes the data computed with the aid of Formula No. 1. This formula is applicable to the computation of cooling power in the absence of marked perspiration, that is to say, when the temperature remains below about 75° or 80°F. Figure 9 shows a similar nomogram for wet cooling power as computed with the aid of Formula No. 2. Cooling power in mil. cal/cm²/sec. is plotted in ordinate against deg. F. wet bulb temperature in abscissae and wind velocity contours in sloping lines. For example, at a wet bulb temperature of 75°F. and a wind velocity of 5 miles per hour, the wet cooling power is 19.8 mil. cal/cm²/sec.

By reference to these charts, the important part played by air circulation, i.e., wind velocity, in the determination of both dry and wet cooling is obvious. This is probably the most important and at the same time the most uncertain parameter required in the use of these charts for the determination and the comparison of cooling power at various locations. The wind velocity varies considerably with height above the surface of the earth and with local topography. However, it is of course also noticed practically that cooling power varies widely in relatively limited geographical areas depending upon the exposure of the particular location, particularly to air circulation and sunshine.

Probably dry cooling power represents the simplest index of comfort and is more generally interpretable than wet cooling power, since even under sweating the degree of wetness of the body varies greatly between individuals and from time to time in the same individual. Also, under sweating, one evidences a variable degree of discomfort depending on his acclimatization to heat. The degree of cooling attained is also a rather critical function of his rate of sweating and wetness of the body and of the actual ventilation his clothing permits, but in various climates in terms of cooling power alone, they form a fairly good index of relative comfort. The above considerations make difficult any very accurate comparison of the relative comfort at various seasons for individuals acclimatized to different environments.

A computation of cooling power is shown in Figure 10 in which the mean monthly cooling powers of various months of the year are computed for San Juan on the basis of mean temperatures and wind velocities for the past thirty years. For instance, taking the month of January, we find the mean dry-bulb temperature to be 74.8°F. and the mean wind velocity to be 5.2 miles per hour. Using dry-bulb nomogram and these values, the cooling power is found to be 12.8 milg.

cal/cm²/sec. Using the wet-bulb nomogram in the same manner shows the wet cooling-power to be 20.4.

The above nomogram values are obviously values of cooling power in the shade, as the heating values of direct and diffused solar radiation have not yet been subtracted. These effects may be very important since they are frequently sufficient to lower the total cooling power

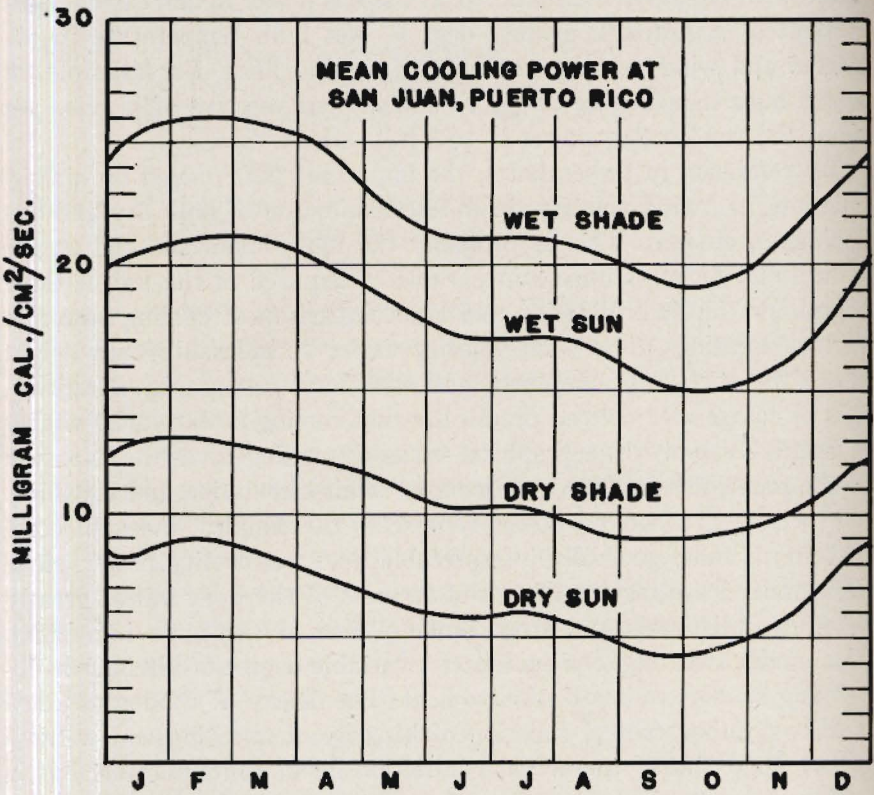

FIG. 10

FIGURE 10: Mean Monthly Cooling Power at San Juan, P.R.

values from those corresponding to a comfortable one to that of a very warm and oppressive climate. This of course corresponds to the ordinary qualitative experience of all of us as to the importance of shade to comfort in warm climates.

As a first approximation we may adopt terms of the form suggested by H. Lehman *loc. cit.*,[10] i.e. (see formula 3).

Unfortunately, most meteorological stations in the past have not measured the direct and diffused radiation separately, which is required

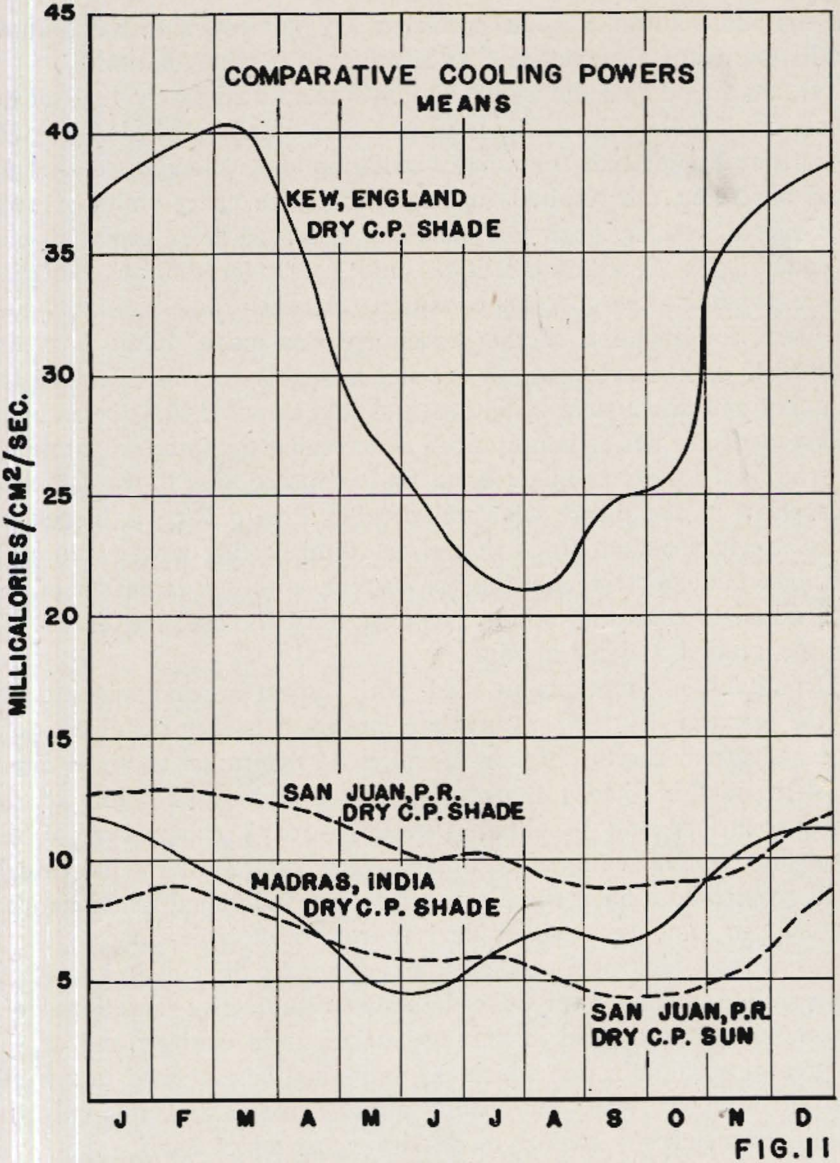

FIGURE 11: Comparative Cooling Powers of San Juan; Kew, England and Madras, India.

in the above formula. (The coefficient 0.155 I refers to the diffused radiation, while a coefficient 0.54 I_d refers to direct radiation.)

It was found that diffused radiation was approximately 12% of the total for cloudless days. These values were obtained by shielding the recording Eppley unit from direct radiation under cloudless conditions and observing the residual readings; therefore using limits of 12% for the highest or maximum values of observed solar radiation corresponding to cloudless conditions and 100% for diffused radiation corresponding to very cloudy conditions. Between these limiting values a linear interpolation of the percentage was made. While it is unfortunate that exact readings are not available for the effect of the diffused and direct solar radiation, it should be noted that the assumptions made are not as important in determining the intercomparability of the final results as might be at first supposed, due to the fact that the effect of the direct solar radiation in Puerto Rico is in general a relatively constant proportion of the total cooling power values indicated. We are still omitting the cooling effect of radiation of the individual to colder absorbing surfaces, such, for instance, as the sea or the ground and air at night.

If suitable assumptions are made with respect to wind velocity, and if the wet and dry temperatures are known, it is then possible to use the nomogram charts (Figures 8 and 9) to determine (both in direct sunlight and in shade) the cooling power at various points of the earth's surface and to obtain thereby a rough comparison of the probable relative comfort that would be encountered by the individuals as a group who inhabit these areas, however, individual reactions may actually in some cases widely deviate from these indications.

As in most biological problems, it is generally difficult to know how to translate cooling power values into human subjective sensations since these sensations depend in part on variations in clothing and on the degree of acclimatization which the individual has attained to a tropical environment, while the cooling power actually measures only the strain to which the cooling mechanism must adapt itself.

On page 94 of R. G. Stone's[12] appendix to Price's "White Settlers in the Tropics" he summarizes the situation as follows:

In general, in Western Europe a dry "kata" power of less than 5 may be either very warm or unbearably hot, 10-20 is pleasant, bracing, or slightly cool, and higher than 30 is cold. Between these intervals there is much overlapping of the scales for different climates.

For Vizagapatam, in India, Reddy[13] gives the following sensation scale for the dry "kata" (shade readings); "intolerable" 0.9 in summer; "sultry" 1.4 in summer and 2.7 in winter; "just tolerable" 2.9 in summer and 3.8 in winter; "fine, pleasant," 4.4 in summer and 3.8 in winter; "cool, bracing" 6.6 in summer and 7.8 in winter. These figures show a definite acclimatization to the small seasonal range of the cooling power in this climate. The wet "kata" averaged (for the entire year) 5.0 for "sultry," 8.0 for "just tolerable" and 9.6 for "fine, pleasant."

Table XVII of Stone's discussion presents a collected summary of values for mean monthly cooling power as measured or measured with the kata thermometer or computed by formulae for various stations in the tropics and also for stations in England and Canada.

Referring to Figure 10, it will be noted that in the case of San Juan, the months of August, September and October show a minimum of dry cooling power. This is apparently occasioned by the relatively low wind velocity encountered during this fall hurricane season. This curve agrees with the sensations derived from the writer's general experience that the early fall months are in general more uncomfortable than the corresponding period in late June and early July corresponding to a 90° solar zenith angle.

It will be noted that these fall months are the only months which give a cooling power as low as that classified as "warm" by the standards of acclimatization of Western Europe as quoted by Stone.

In Figure 11 the cooling power figures we have computed for San Juan are compared with temperate zone cooling power figures (for Kew, England) and tropical conditions (Madras, India).[14]

In each case the dry-shade cooling power is shown in the heavy line. The dotted line shows the San Juan dry-sun cooling power values (i.e., the values after the direct and diffused solar radiation have been subtracted from the shade cooling power figure).

It is of interest to note the values of cooling power for San Juan in direct sunlight are comparable with those for Madras in the shade. Under these conditions, the values of cooling power are below the region of reasonable comfort for nearly all periods during the year and pass into the range of values corresponding to distinctly oppressive temperature conditions.

B. *Studies of the Effect of Ultraviolet Radiation: The Critical Region:* Quantitative studies of ultraviolet solar radiation, as received at the surface of the earth, are particularly difficult because practically all of the observed effects are due to a small residual between opposing factors. Hence, slight changes in one of these factors may profoundly alter the magnitude of the important component of ultraviolet light

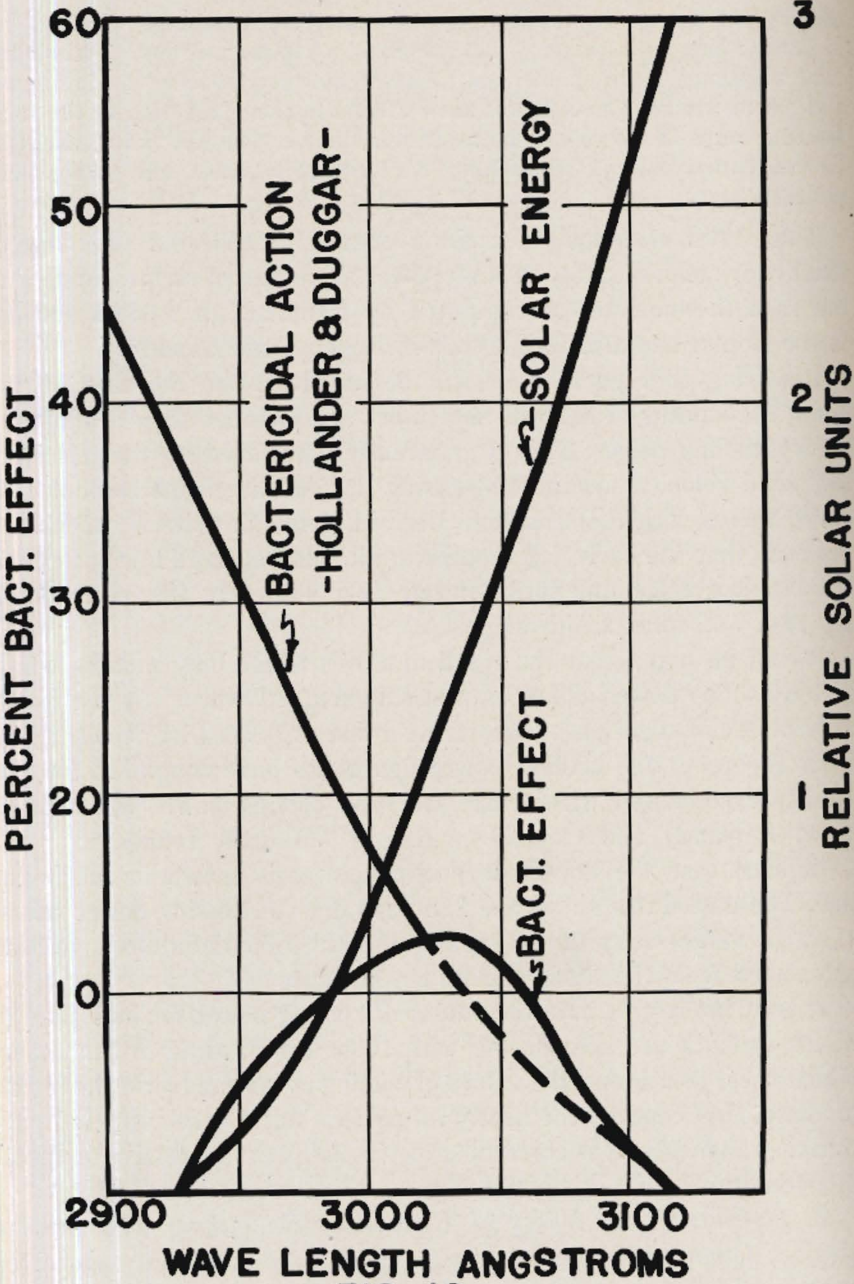

FIG. 12

FIGURE 12: Bactericidal Effect of *Trichophyton mentagrophytes* and Corresponding Product Function with Solar Radiation.

received. Let us review this situation in greater detail with the aid of some illustrative figures.

Ultraviolet light is of interest to the biologist partly because of its bactericidal and mutational action, and its importance in the production of Vitamin D.[15] (For convenience, we will refer to the efficiency of production of these phenomena as "bactericidal efficiency," and not enumerate each time in detail.)

Most of these phenomena appear to be associated with photochemical phenomena.[17] Work with artificial sources proves that the short wavelengths are profoundly more effective in most of these phenomena. Thus, the lethal effect of *Trychophyton mentagrophytes* investigated by Hollaender and plotted in Figure 12 is most effectively produced by ultraviolet wavelengths of approximately 2600 Å.[16] However, reference to Figure 12 also shows approximately the intensity distribution of sunlight as received at the earth's surface. Actually, the form of this curve will vary slightly at its short wavelength and due to changes in ozone absorption phenomena. These phenomena profoundly affect light components of wavelength shorter than 3100 Å, but have little effect on components above 3100 Å.

However, the bactericidal curve of Hallaender falls off so rapidly at wavelengths above 3000 Å that light components of wavelengths above this limit have a rapidly diminishing biological effect, since their bactericidal efficiency falls off more rapidly than the light intensity grows (despite the fact that this intensity is increasing extremely rapidly with wavelengths at this point). Likewise, wavelengths shorter than 2900 Å have little effect because the light intensity is falling off faster than the bactericidal action is increasing (despite the fact that this efficiency is increasing extremely rapidly as the wavelength decreases).

Evidently, under these conditions the significant curve is the product function shown by the heavy line; i.e., the product of the intensity of the various wavelengths' components by their efficiency. Since the two curves of which the product is taken so nearly fail to overlap at all, it is evident that anything slightly affecting the form of the curves in their overlapping portions will disproportionately affect the form of the product function. This is precisely the situation with respect to the ultraviolet light components. Actually, the energy in these components having wavelengths shorter than 3100 Å accounts for only .001 of the total energy of solar radiation; yet it accounts for practically *all* of the phenomena we know as "ultraviolet light phenomena." Now the light energy in the received solar radiation at the earth's surface drops off extremely rapidly below 3000 Å, not because of any paucity in these components as radiated from the sun, but because this wave-length region is heavily absorbed in the earth's atmosphere due to its efficiency in changing the oxygen in the lower stratosphere to ozone. Since this ozone production has been found to be correlated with

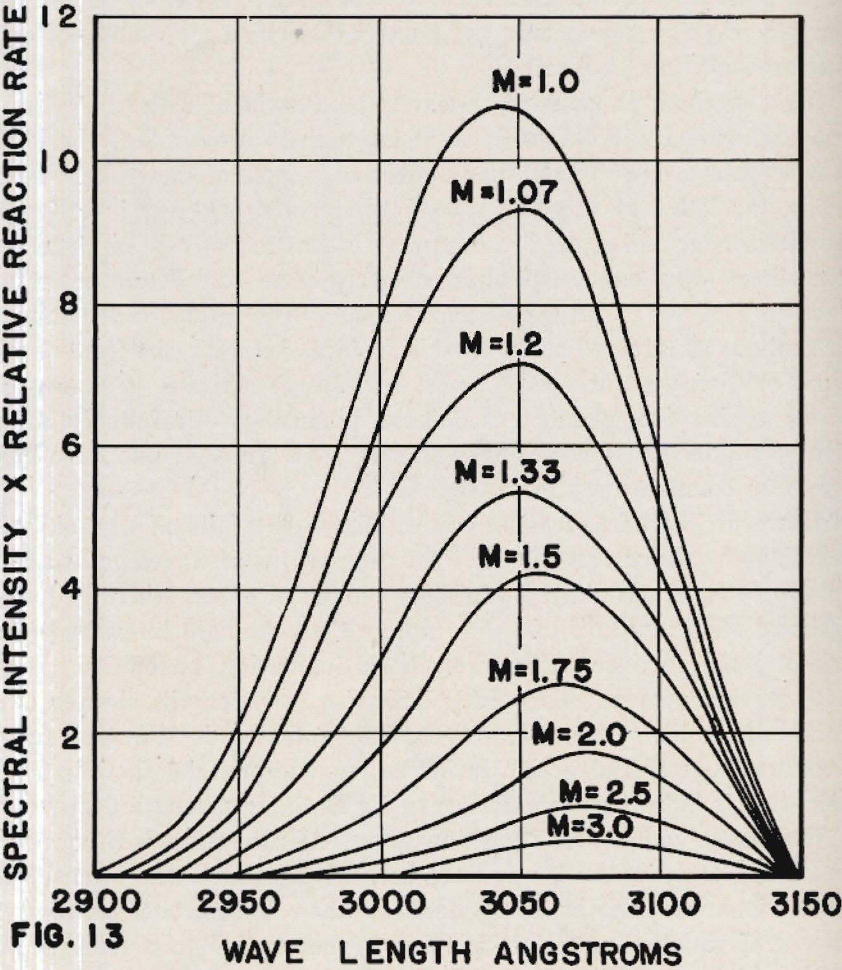

FIG. 13

FIGURE 13: Average Product Function of Bactericidal Activity by Solar Spectral Energy as a Function of Wavelength (Courtesy of Dr. Brian O'Brien).

weather, the paths of the research meteorologist and biologist merge, for slight changes in atmospheric ozone result in large changes in ultra-violet light components, and hence the bactericidal efficiency of sun-light.[16]

A more accurate product curve similar to that shown in Figure 12, but arising from a more comprehensive set of data, is shown in Figure 13 (courtesy of Dr. Brian O'Brien).

The delicacy of this ultraviolet ozone absorption cut-off vs. bactericidal efficiency* balance is the reason why various geographical regions differ so much more in natural ultraviolet radiational characteristics than they do in total radiation. It is also a pitfall which must be very carefully watched lest "ultraviolet measurements" do not really measure the significant ultraviolet. (See section V.)

V. INTERCOMPARISON OF ULTRAVIOLET MEASUREMENT EQUIPMENT

A. *Importance of Uniform Standards:* The considerations outlined in section IV B serve to emphasize the care which must be observed in taking of biologically significant ultraviolet solar radiation measurements, if the results are to be comparable and useful to the biologist.

As we have seen, only about .001 of the total solar radiation is of importance, i.e., the radiation extending from about 3100 Å to 2900 Å and careful attention must be given if the reported intensities of ultraviolet energy are really to represent ultraviolet energy within a narrow band. Since the earth's atmosphere effectively eliminates energy below 2900 Å, observations taken on natural sunlight would not contain energy components of shorter wavelengths than this natural cut-off limit; but when photoelectric recording equipment such as utilized in the taking of the data reported in section III is employed, considerable difficulty is experienced from solar energy of wavelengths longer than 3100 Å.

A first approximation to a solution of this problem is found by choosing photoelectric cells, the response of which falls off very rapidly above 3100 Å; but, just as in the case of the product of bactericidal activity shown in the curves referred to in the previous section, a small residual response in this range contributes considerably to the product function of cell response by solar energy, due to the rapid increase in solar energy at wavelengths above 3100 Å. Inasmuch as various photoelectric cells vary considerably in their energy-wavelength response curves, great care must be taken in intercomparing data taken with different photoelectric cells even when the general form of the associated equipment is quite similar.

* This is probably only a coincidence such as that of "large rivers flowing past big cities." Actually it is an axiom of natural selection. Users of artificial ultraviolet sources should note that mercury sources are rich in short-wave components far below the wavelength of atmospheric cut-off which is also the wavelength limit to which nature has adapted many biological organisms to survive. Hence very dangerous erythomal burns and other effects are much more likely to be encountered with artificial source when carelessly or unintelligently handled.

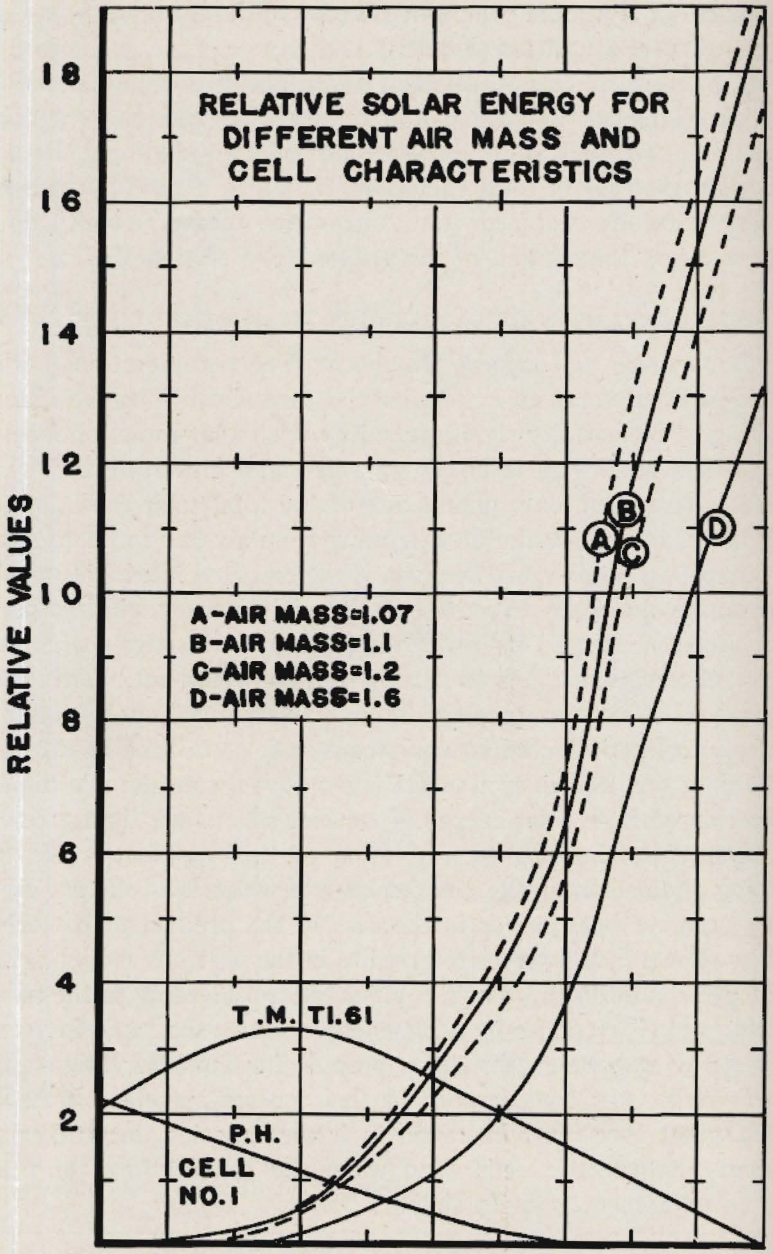

FIG. 14

FIGURE 14: Relative Solar Energy for Different Airmass and Cell Characteristics.

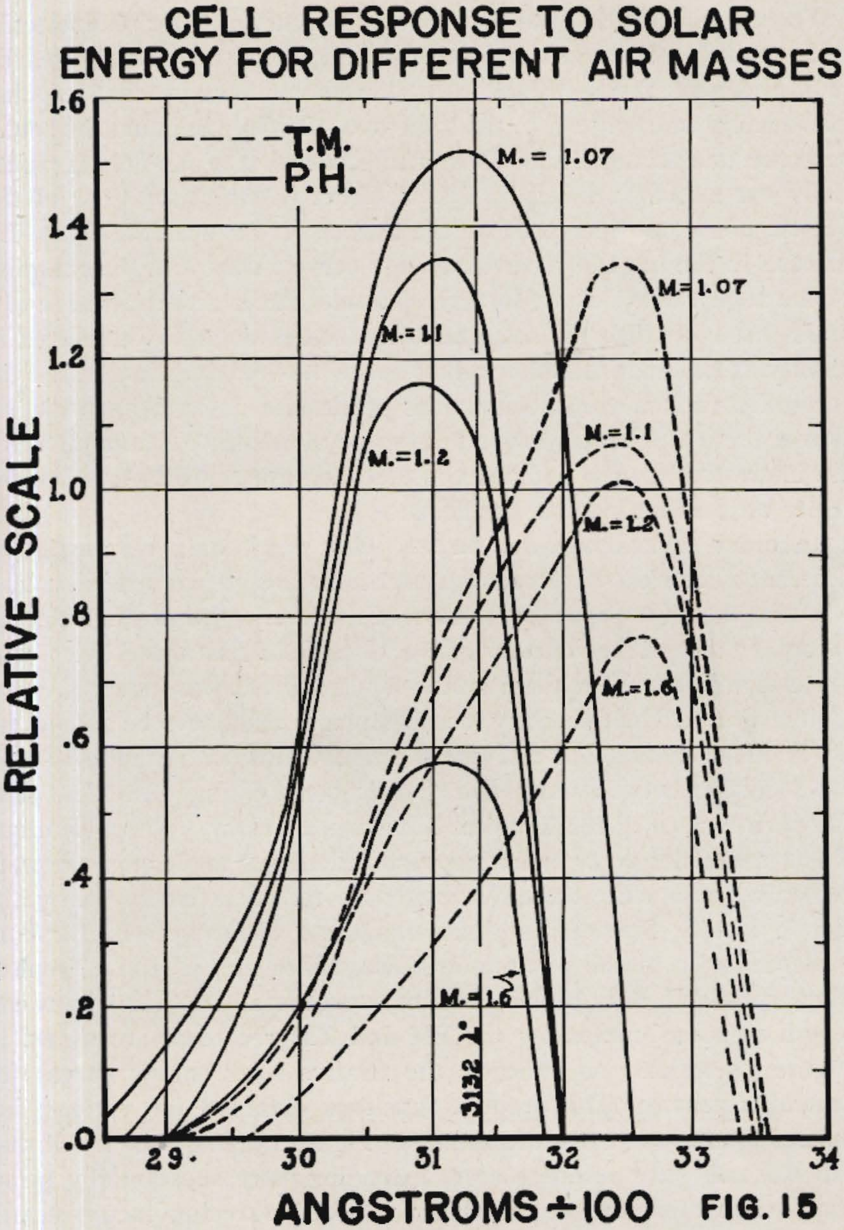

FIGURE 15: Cell Response to Solar Energy for Different Air Masses.

Fortunately, if the form of the response curve of the photoelectric cells employed is known, a first order correction may be secured by multiplying the results by the ratio of the area of the product response curve below, say, 3132 Å to the total area, thereby obtaining the actual response due to ultraviolet components below 3132 Å. This is essentially the method utilized by Dr. Coblentz in his calibrations of the Westinghouse recorder used at the School of Tropical Medicine. Inasmuch as the form of the solar energy curve varies with the obliquity of the solar radiation due to variable atmospheric absorption, the airmass through which the solar radiation passes must be considered in specifying the solar radiation curve; hence the product function and the correction factors are also functions of airmass. A detailed consideration of these problems is beyond the scope of this section, and the readers interested in their detailed consideration are hence referred to the paper on Standardization Problems.

In order to evaluate the success with which data obtainable by different photoelectric recording systems can be intercompared, a loan was obtained of a more recent model of the Westinghouse photoelectric recorder through the courtesy of the U. S. Public Health Service, who are utilizing several of these units for ultraviolet measurements in the United States. Unfortunately, the equipment could not be spared for an extended period, but tests were conducted at the School of Tropical Medicine between August 1 and August 23, 1939. In these tests the performance of the Tropical Medicine Type 6093 with a titanium TI-61 cell and a polar mounting with limited sky angle aperture were compared with one of the Westinghouse recorders employed by the Public Health Service. In discussing these tests, we will for convenience refer to the photoelectric assemblies as the TM (Tropical Medicine) and PH (Public Health) recorders. The relative wavelength response curves for the PH and TM recorders are shown in Figure 14 which also indicates the relative solar energy curves for several airmasses. The product functions obtained for various airmasses for the two units are shown in Figure 15. It will be noted that the PH unit gave response areas extending more substantially below the 3132 Å reference level, and hence required correction factors nearer unity than the TM unit.

In normal operation the PH unit as shown in the photograph of Figure 16 is maintained in a horizontal plane with all the bulb exposed, while the TM unit is mounted in a polar mounting which keeps a small quartz window admitting the light normal to the direct solar radiation. It was recognized that differences in sky angle and solar

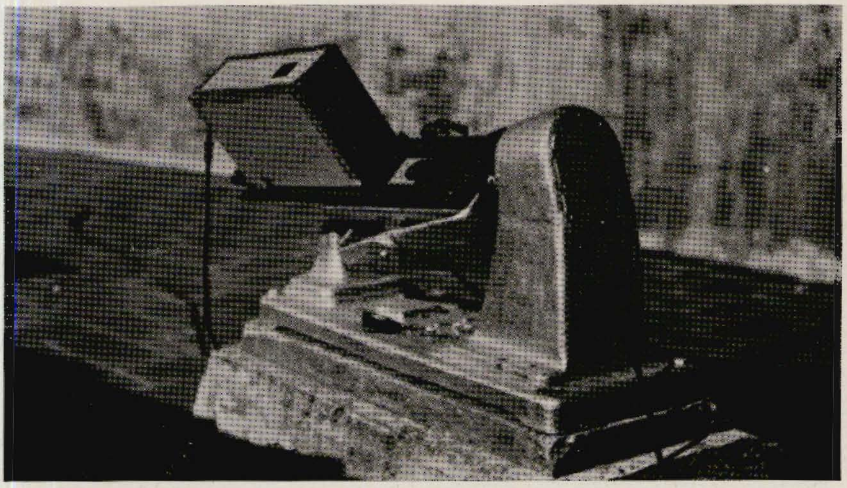

FIGURE 16: Normal Operating Position of PH Unit.

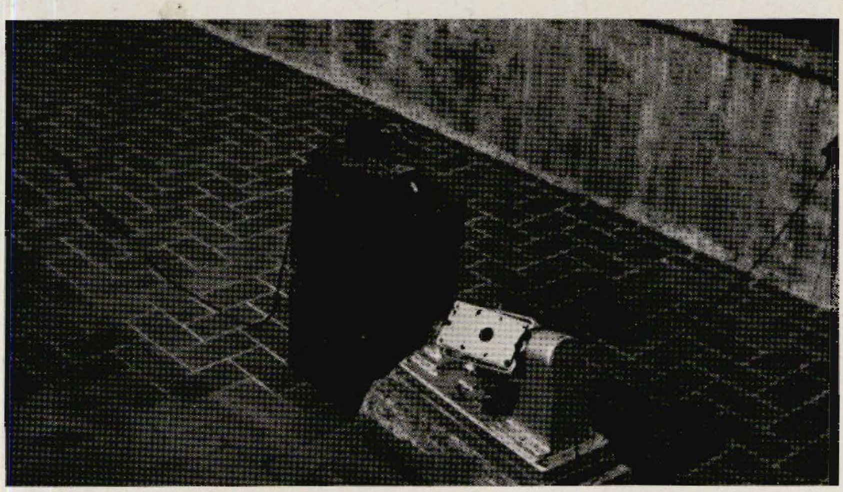

FIGURE 17: PH Cell Mounted on Heliostat.

radiation incidence were likely to affect the form of the observed curves as well as the conversion factors, and several tests were hence made in which the PH recorder was rotated with polar mounting both shielded and unshielded and with an aperture comparable to the TM recorder.

The arrangements corresponding to these three series of tests are shown in Figures 16, 17 and 18. In both the TM and PH units the intensity of ultraviolet is measured by the number of discharges per second of a condenser charged by the photoelectric current and discharged through a gaseous trigger tube which ignites when the voltage across the condenser reaches an assigned value. The intensity of the ultraviolet radiation is therefore recorded in terms of clicks per unit time. The actual number of clicks observed in tests A, B and C are shown in Figure 19, and these tests, expressed in percent of mean click rate for each series, are shown in Figure 20. It should be noted that differences in mean click are not necessarily of fundamental importance, since, if the correction factor between the two recorders

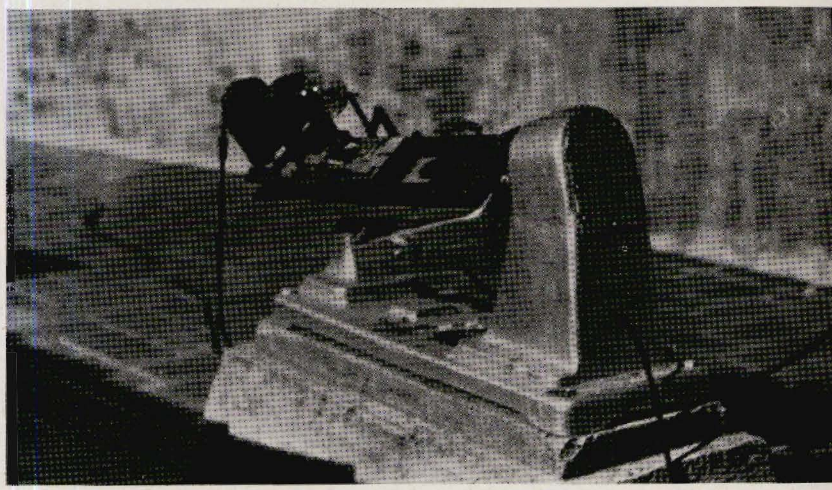

FIGURE 18: PH Cell Mounted on Heliostate and Shielded.

is constant, a suitable factor may be introduced in the intercomparison of records. However, a further complication is introduced by the difference in the response characteristics of the cells utilized in these two units, i.e., by the degree to which they respond to radiation corresponding to wavelengths longer than 3132 Å. A closer correspondence is hence obtained if the clicks per hour are multiplied by the fraction of the photoelectric product response curve corresponding to energy below 3132 Å. The results of such a reduction of the clicks per hour is shown in Figure 21, and the result when these click rates are expressed in percent of mean click rate is shown in Figure 22. It will be noted that, when these corrections have been applied, the correspondence between the two records is quite gratifying. The precision of Series C was somewhat impaired by problems of cloudiness and rain during the period reserved for this series of tests, but the correspondence is still the best obtained. This is, of course, due to the fact that during these tests the equipment was being operated under as nearly

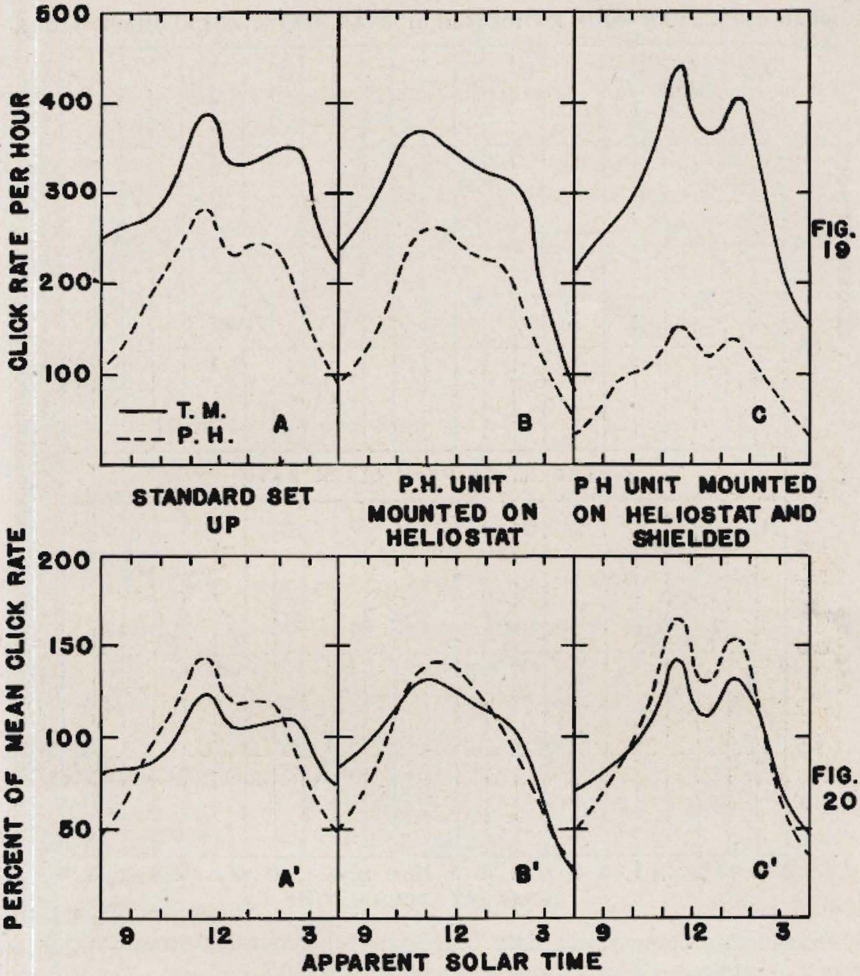

FIGURE 19: Comparison of the Records Obtained with Tropical Medicine and Public Health Recorders.

FIGURE 20: Data of Figure 20 reduced in terms of diurnal average values.

A—Normal operating position for Public Health Recorder (horizontal).

B—Public Health Recorder rotating on telescopic mounting (unshielded).

C—Public Health Recorder rotating on telescopic mounting (with equivalent sky angle aperture with Tropical Medicine Recorder).

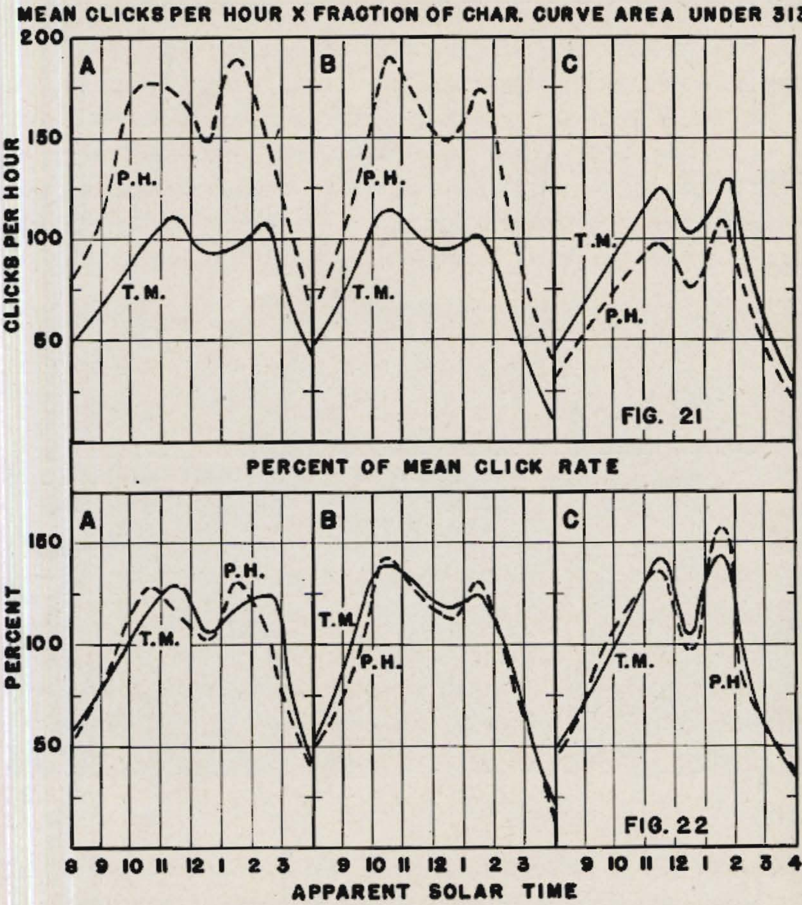

FIGURE 21: Comparative data of Figure 20 (reduced to mean clicks per hour) (Fraction of Char. Curve Area under 3132 A)

FIGURE 22: Comparative data of Figure 22 reduced to percent of mean click rate.

as possible comparable conditions with respect to received sky angle, aperture, etc. The percentages of the area under the product function curve resulting from the product of the cell response by the solar radiation for corresponding airmass are shown in Table 1. (See Figure 15.)

These data were necessary for the computation of the curve shown in Figure 21. Unfortunately, the duration of the test was limited to the period indicated by the necessity of utilizing the PH recorder for other work in the United States during September. However, the agree-

TABLE I

Cell	*Air Mass*	*Per cent area under 3132 A.*	*Corresponding app. solar time S. J.*
PH	1.07	62.6	11 to 12 and 12 to 1
PH	1.1	77.2	10 to 11 and 1 to 2
PH	1.2	79.6	9 to 10 and 2 to 3
PH	1.6	76.8	8 to 9 and 3 to 4
TM	1.07	28.0	11 to 12 and 12 to 1
TM	1.1	31.2	10 to 11 and 1 to 2
TM	1.2	30.4	9 to 10 and 2 to 3
TM	1.6	21.2	8 to 9 and 3 to 4

ment obtained between observations was considered encouraging and was taken to indicate the possibility of making reasonably reliable comparisons between observations being made in the continental United States and in Puerto Rico.

VI. SCOPE AND APPLICATIONS OF A MEASUREMENT PROGRAM: SUMMARY

A. *Desirable Scope for a Radiation Measurement Program:* It is believed that a measurement program should be developed so as to provide comparable physical and climatological data of the widest possible application to biological problems.

Much clarification is desirable with reference to the biological importance of various types of radiation as, for instance, infra-red, visible, ultraviolet radiation, cosmic radiation, etc.

Unquestionably, each of these regions has its importance in problems of climate and health, although the mechanisms may well be quite distinct. Thus, infra-red and visible radiations are probably the major contributors to problems of heating and cooling. (A possible line of attack for rendering such data biologically comparable is summarized in section IV-A).

Ultraviolet radiation finds an important place due to its bactericidal properties as well as its effects in the skin and on the control of specialized body functions (Vitamin D production from ergosterol, etc.). In addition, recent work, such as that of Hollaender (see Section IV-B), has indicated that terrestrially received ultraviolet solar radiation may be on the border line of the radiational region responsible for mutations. Since the biological importance of radiation *components* is increasing very rapidly just at the region of atmospheric cut-off, this region is a critical function of atmospheric ozone which in turn varies with latitude.

Cosmic rays represent an interesting and as yet little explored spectral region which may contribute to as yet little understood biologically significant phenomena (particularly in the field of genetics). Thus, this region may have an extremely important rôle to play in the phenomena of mutations, a rôle which may indeed be of predominant interest if this radiation increases in intensity.

B. *Summary of Paper:* The purpose of this paper has been to present solar radiation data of interest to general problems of climate and health and to indicate applications to some of the problems to which the writers believe such a program should contribute. To be most useful, a measuring program should provide data comparable with that available from other points. This problem has been considered briefly in the sections of this paper which discuss the development of significant standards and comparative tests of ultraviolet measuring equipment carried out through the kind co-operation of the U. S. Public Health Service. A related publication in preparation considers these problems in greater detail.

In brief, this paper describes work which aims to contribute quantitative physical data useful in biological problems, particularly those related to problems of climate and health. The development of such data is a very necessary forerunner to any fundamental solution of these problems: "Until we can measure, we do not know."

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