VIII. BASIS FOR THE RECOMMENDED STANDARD

The research data and industry experience information upon which the recommendations for this standard are based were derived from (a) an analysis of the published scientific literature; (b) the many techniques for assessing heat stress and strain that are currently available; (c) suggested procedures for predicting risk of incurring heat-related disorders, of potentially unsafe acts, and of deterioration of performance; (d) accepted methods for preventing and controlling heat stress; and (e) domestic and international standards and recommendations for establishing permissible heat-exposure limits.

The scientific basis for the recommendations has been discussed in Chapters III through VII. In Chapter VIII some special considerations which heavily influenced the form and emphasis of the final recommended criteria for this standard for work in hot environments are discussed.

A. Estimation of Risks

The ultimate objective of a recommended heat-stress standard is to limit the level of health risk (level of strain and the danger of incurring heat-related illnesses or injuries) associated with the total heat load (environmental and metabolic) imposed on a worker in a hot environment. The level of sophistication of risk estimation has improved during the past few years but still lacks a high level of accuracy. The earlier estimation techniques were usually qualitative or at best only semiquantitative.

One of the earlier semiquantitative procedures for estimating the risk of adverse health effects under conditions of heat exposure was designed by Lee and Henschel [129]. The procedure was based on the known laws of thermodynamics and heat exchange. Although designed for the "standard man" under a standard set of environmental and metabolic conditions, it incorporated correction factors for environmental, metabolic, and worker conditions that differed from standard conditions. A series of graphs was presented that could be used to semiquantitatively predict the percentage of exposed individuals of different levels of physical fitness and age likely to experience health or performance consequences under each of 15 different levels of total stress. Part of the difficulty with the earlier attempts to develop procedures for estimating risk was the lack of sufficient reliable industry experience data to validate the estimates.

A large amount of empirical data on the relationship between heat stress and strain (including death from heatstroke) has accumulated over the past 40 years in the South African deep hot mines. From data derived from laboratory studies, a series of curves has been prepared to predict the probability of a worker's body temperature reaching dangerous levels when working under various levels of heat stress [130,131]. Based on these data and on epidemiologic data on heatstroke from miners, estimates of probabilities of reaching dangerously high rectal temperatures were made. If a body temperature of 40°C (104°F) is accepted as the threshold temperature at which the worker is in imminent danger of fatal or irreversible heatstroke, the estimated probability of reaching this body temperature is 10^{-6} for workers exposed to an effective temperature (ET) of 34.6°C (94.3°F), 10^{-4} at 35.3°C (95.5°F), 10^{-2} at 35.8°C (96.4°F), and $10^{-0.5}$ at 36.6°C (97.9°F). If a body temperature of 38.5°-39.0°C (101.3°-102.2°F) is accepted as the critical temperature, the ET at which the probability of the body temperature reaching these values can also be derived for 10^{-1} to 10^{-6} probabilities. These ET correlates were established for conditions with relative humidity near 100%; whether they are equally valid for these same ET values for low humidities has not been proven. Probabilities of body temperature reaching designated levels at various ET values are also presented for unacclimatized men [5,130,131]. Although these estimates have proven to be useful in preventing heat casualties under the conditions of work and heat found in the South African mines, their direct application to industrial environments in general may not be warranted.

A World Health Organization (WHO) scientific group on health factors involved in working under conditions of heat stress concluded that "it is inadvisable for deep body temperature to exceed 38°C (100.4°F) in prolonged daily exposure to heavy work. In closely controlled conditions the deep body temperature may be allowed to rise to 39°C (102.2°F)" [48]. This does not mean that when a worker's t_{re} reaches 38°C (100.4°F) or even 39°C (102.2°F), the worker will necessarily become a heat casualty. If, however, the t_{re} exceeds 38°C (100.4°F), the risk of heat casualties occurring increases. The 38°C (100.4°F) t_{re}, therefore, has a modest safety margin which is required because of the degree of accuracy with which the actual environmental and metabolic heat load are assessed.

Some safety margin is also justified by the recent finding that the number of unsafe acts committed by a worker increases with an increase in heat stress [70]. The data derived by using safety sampling techniques to measure unsafe behavior during work showed an increase in unsafe behavioral acts with an increase in environmental temperature. The incidence was lowest at WBGT's of 17°-23°C (62.6°-73.4°F). Unsafe behavior also increased as the level of physical work of the job increased [70].

B. Correlation Between Exposure and Effects

The large amount of published data obtained during controlled laboratory studies and from industrial heat-stress studies upholds the generality that the level of physiologic strain increases with increasing total heat stress (environmental and metabolic) and the length of exposure. All heat-stress/heat-strain indices are based on this relationship. This generality holds for heat-acclimatized and heat-unacclimatized individuals, for women and men, for all age groups, and for individuals with different levels of physical performance capacity and heat tolerance. In each case, differences between individuals or between population groups in the extent of physiologic strain resulting from a given heat stress relates to the level of heat acclimatization and of physical work capacity. The individual variability may be large; however, with extreme heat stress, the variability decreases as the limits on the body's systems for physiologic regulation are reached. This constancy of the heat-stress/heat-strain relationship has provided the basic logic for predicting heat-induced strain using computer programs encompassing the many variables.

Sophisticated models designed to predict physiologic strain as a function of heat load and as modified by a variety of confounding factors are available. These models range from graphic presentations of relationships to programs for handheld and desk calculators and computers [132,133]. The strain factors that can be predicted for the average worker are heart rate, body and skin temperature, sweat production and evaporation, skin wettedness, tolerance time, productivity, and required rest allowance. Confounding factors include amount, fit, insulation, and moisture vapor permeability characteristics of the clothing worn, physical work capacity, body hydration, and heat acclimatization. From some of these models, it is possible to predict when and under what conditions the physiologic strain factors will reach or exceed values which are considered acceptable from the standpoint of health.

These models are useful in industry to predict when any combination of stress factors is likely to result in unacceptable levels of strain which then would require introduction of control and correction procedures to reduce the stress. The regression of heat-strain on heat-stress is applicable to population groups, and with the use of a 95% confidence interval can be applied as a modified form of risk prediction. However, they do not, as presently designed, provide information on the level of heat stress when one worker in 10, or in 1,000, or in 10,000, will incur heat exhaustion, heat cramps, or heatstroke.

C. Physiologic Monitoring of Heat Strain

When the first NIOSH Criteria for a Recommended Standard....Occupational Exposure to Hot Environments document was prepared in 1972, physiologic monitoring was not considered a viable adjunct to the WBGT index, engineering controls, and work practices for the assessment and control of industrial heat stress. However, recently it has been proposed that monitoring body temperature and/or work and recovery heart rate of workers exposed to work environment conditions in excess of the ACGIH TLV could be a safe and relatively simple approach [117,127,128]. All the heat-stress indices assume that, providing the worker population is not exposed to heat-work conditions that exceed the permissible value, most workers will not incur heat-induced illnesses or injuries. Inherent in this is the assumption that a small proportion of the workers may become heat casualties. The ACGIH TLV assumes that nearly all healthy heat-acclimatized workers will be protected at heat-stress levels that do not exceed the TLV.

Physiologic monitoring (heart rate and/or oral temperature) of heat strain could help protect all workers, including the heat-intolerant worker exposed at hot worksites. In one field study, the recovery heart rate was taken with the worker seated at the end of a cycle of work from 30 seconds to 1 minute (P_1), 1-1/2 to 2 minutes (P_2), and 2-1/2 to 3 minutes (P_3). Oral temperature was measured with a clinical thermometer inserted under the tongue for 4 minutes. The data indicate that 95% of the time the oral temperature was below 37.5°C (99.5°F) when the P_1 recovery heart rate was 124 b/min or less, and 50% of the time the oral temperature was below 37.5°C (99.5°F) when the P_1 was less than 145 b/min. From these relationships, a table for assessing heat strain and suggested remedial actions was developed. If the P_3 heart rate is lower than 90 b/min the work-heat-stress conditions are satisfactory; if the P_3 approximates 90 b/min and/or the P_1-P_3 recovery is approximately 10 b/min, it indicates that the work level is high but there is little increase in body temperature; if P_3 is greater than 90 b/min and/or P_1-P_3 is less than 10 b/min, it indicates a no-recovery pattern and the heat-work stress exceeds acceptable levels; corrective actions should be taken to prevent heat injury or illness [127,128]. The corrective actions may be of several types (engineering, work practices, etc.).

In practice, obtaining recovery heart rates at 1- or 2-hour intervals or at the end of several workcycles during the hottest part of the workday of the summer season may present logistical problems, but available technology may allow these problems to be overcome. The pulse rate recording wristwatch that is used by some joggers, if proved sufficiently accurate and reliable, may permit automated heart rate measurements. With the advent of the single use disposable oral thermometer, measuring oral temperatures of workers at hourly intervals should be possible under most industrial situations without interfering with the normal work pattern. It would not be necessary to interrupt work to insert the thermometer under the tongue and to remove it at the end of 4 to 5 minutes. However, ingestion of fluids and mouth breathing would have to be controlled for about 15 minutes before an oral temperature is taken.

Assessment of heat strain by monitored physiologic responses of heart rate and/or body temperature using radiotelemetry has been advocated. Such monitoring systems can be assembled from off-the-shelf electronic components and transducers and have been used in research in fire fighting and steel mills and are routinely used in the space flight program [134,135]. However, at present they are not applicable to routine industrial situations.

The obvious advantage of such an automated system would be that data could be immediately observed and trends established from which actions can be initiated to prevent excessive heat strain. The obvious disadvantages are that it requires time to attach the transducers to the worker at the start and remove them from the worker at the end of each workday; the transducers for rectal or ear temperature, as well as stick-on electrodes or thermistors, are not acceptable for routine use by some people; electronic components require careful maintenance for proper operations. Also, the telemetric signals are often disturbed by the electromagnetic fields that may be generated by the manufacturing process.

D. Recommendations of U.S. Organizations and Agencies

1. The American Conference of Governmental Industrial Hygienists (ACGIH)

The American Conference of Governmental Industrial Hygienists (ACGIH) TLVs for heat-stress refers "to heat stress conditions under which it is believed that nearly all workers may be repeatedly exposed without adverse health effects" [2]. The TLVs are based on the assumptions that the (1) workers are acclimatized to the work-associated heat stress present at the workplace, (2) workers are clothed in usual work clothing, (3) workers have adequate water and salt intake, (4) workers should be capable of functioning effectively, and (5) the TWA deep body temperature will not exceed 38°C (100.4°F). Those workers who are more tolerant to work in the heat than the average and are under medical supervision may work under heat-stress conditions that exceed the TLV, but in no instance should the deep body temperature exceed the 38°C (100.4°F) limit for an extended period. The TLV permissible heat-exposure values consider both the environmental heat factors and the metabolic heat production. The environmental factors are expressed as the WBGT and are measured with the dry bulb, natural wet bulb, and black globe thermometers. The metabolic heat production is expressed as work-load category: light work = <200 kcal/h (<800 Btu/h or 230 W); moderate work = 200-350 kcal/h (800-1400 Btu/h or 230-405 W); and heavy work = >350 kcal/h (>1400 Btu/h or 405 W). The ranking of the job may be measured directly by the worker's metabolic rate while doing the job or estimated by the use of the work-load assessment procedure where both body position and movement and type of work are taken into consideration. For continuous work and exposure, a WBGT limit value is set for each level of physical work with a decreasing permissible WBGT for increasing levels of metabolic heat production.

The TLV permissible heat-exposure values range from a WBGT of 30°C (86°F) for light work, 26.7°C (80°F) for moderate work, to 25°C (77°F) for heavy work for continuous exposure based on a 1-hour TWA for WBGT and work load. These values are comparable to those in the ISO Standard 7243 [3]. In addition to the permissible heat-exposure threshold limit values for continuous work, the ACGIH Heat Stress TLV contains values for various rest-work regimens: 75% work, 25% rest each hour; 50% work, 50% rest each hour; and 25% work, 75% rest each hour for light, moderate, and heavy work, respectively. These TLVs assume that the rest environment is approximately the same as that at work. Appendix B of the ISO 7243 contains a similar set of values for rest-work regimens where the rest environment is similar to the work environment.

The ACGIH TLVs for heat stress which were adopted in 1974 forms the basis for the ISO standard on Heat Stress of 1982 (discussed in Chapter VIII-E).

2. Occupational Safety and Health Administration (OSHA) Standards Advisory Committee on Heat Stress (SACHS)

In January 1973, the Assistant Secretary of Labor for Occupational Safety and Health (OSHA) appointed a Standards Advisory Committee on Heat Stress (SACHS) to conduct an in-depth review and evaluation of the NIOSH Criteria for a Recommended Standard....Occupational Exposure to Hot Environments and to develop a proposed standard that "would establish work practices to minimize the effects of hot environmental conditions on working employees" [7]. The purpose of the standard was to minimize the risk of heat disorders and illnesses of workers exposed to hot environments so that the worker's well-being and health would not be impaired. The 15 committee members represented worker, employer, state, federal, and professional groups.

The recommendations for a heat-stress standard were derived by the SACHS by majority vote on each statement. Any statement which was disapproved by an "overwhelming majority" of the members was no longer considered for inclusion in the recommendations. The recommendations establish the threshold WBGT values for continuous exposure at the three levels of physical work: light <200 kcal/h (<800 Btu/h), 30°C (86°F); moderate 200-300 kcal/h (804-1200 Btu/h), 27.8°C (82°F); and heavy >300 kcal/h (>1200 Btu/h), 26.1°C (79°F) with low air velocities up to 300 fpm. These values are similar to the ACGIH TLVs. When the air velocity exceeds 300 fpm, the threshold WBGT values are increased 2.2°C (4°F) for light work and 2.8°C (5°F) for moderate and heavy work. The logic behind this recommendation was that the instruments used for measuring the WBGT index do not satisfactorily reflect the advantage gained by the worker when air velocity is increased beyond 300 fpm. Data presented by Kamon et al. [136], however, questioned the assumption, because the clothing worn by the worker reduced the cooling effect of increased air velocity. However, under conditions where heavy protective clothing or clothing with reduced air and/or vapor permeability is worn, higher air velocities may to a limited extent facilitate air penetration of the clothing and enhance convective and evaporative heat transfer.

The recommendations of the SACHS contain a list of work practices that are to be initiated whenever the environmental conditions and work load exceed the threshold WBGT values. The threshold WBGT values and work levels are based on a 120-minute TWA. Also included are directions for medical surveillance, training of workers, and workplace monitoring.

The threshold WBGT values recommended by the OSHA SACHS are in substantial agreement with the ACGIH TLVs and the ISO standard. The OSHA SACHS recommendations have not, however, been promulgated into an OSHA heat-stress standard. Following any one of the three procedures would provide equally reliable guidance for ensuring worker health and well-being in hot occupational environments [137].

3. American Industrial Hygiene Association (AIHA)

The American Industrial Hygiene Association (AIHA) publication Heating and Cooling for Man in Industry, Chapter 2, "Heat Exchange and Human Tolerance Limits" contains a table of "Industrial Heat Exposure Limits" for industrial application [138]. The limits of heat exposure are expressed as WBGT values for light, moderate, and heavy work when the exposure is continuous for 50 minutes of each hour for an 8-hour day and for intermittent work-rest when each work period of 3 hours, 2 hours, 1 hour, 30 minutes, or 20 minutes is followed by 1 hour of rest. In establishing the heat-exposure limits for intermittent work-rest, it was assumed that the worker would rest in an environment that was cooler than the work area. It is also emphasized in the report that under conditions of severe heat where the work periods are limited to 20 or 30 minutes, experienced workers set their own schedules and work rate so that individual tolerances are not exceeded.

The maximum heat exposure limits for each of the work categories are, for continuous work, comparable to the TLVs and the ISO standard described in Chapter VIII-E.

For intermittent work, direct comparisons are difficult because of the differences in assumed rest area temperatures. However, when corrections for these differences are attempted, the ISO and the ACGIH TLV values for 75/25 and 50/50 work-rest regimens are not very different from the AIHA values. These limits support the generalizations that workable heat-stress exposure limits, based on the WBGT and metabolic heat-production levels, are logical and practical for use for industrial guidance [137].

4. The Armed Services

The 1980 publication (TBMED 507, NAVMED P-5052-5 and AFP 160-1) of the Armed Services, "Occupational and Environmental Health, Prevention, Treatment, and Control of Heat Injury" [139], addresses in detail the procedures for the assessment, measurement, evaluation, and control of heat stress and the recognition, prevention, and treatment of heat illnesses and injuries. Except for the part in which problems specific to military operations are discussed, the document is applicable to industrial-type settings.

The WBGT index is used for the measurement and assessment of the environmental heat load. It is emphasized that the measurements must be taken as close as possible to the location where the personnel are exposed. The threshold levels of WBGT for instituting proper hot weather practices are given for the various intensities of physical work (metabolic heat production). The WBGT and metabolic rates are calculated for a 2-hour TWA. The threshold WBGT values of 30°C (86°F) for light work, 28°C (82.4°F) for moderate work, and 25°C (77°F) for heavy work are about the same as those of the ISO standard and the ACGIH TLVs. However, these are the thresholds for instituting hot weather practices rather than limiting values. The mean metabolic rates (kcal/h or W) for light, moderate, and heavy work cited in this Armed Services document are expressed as TWA mean metabolic rates and are lower than the values generally used for each of the work categories.

Except for the problem of the metabolic rates, this document is an excellent, accurate, and easily used presentation. Engineering controls and the use of protective clothing and equipment are not extensively discussed; however, on balance it serves as a useful guide for the prevention, treatment, and control of heat-induced injuries and illnesses. In addition, it is in general conformity with the ISO standard, the ACGIH TLVs, and most other recommended heat-stress indices based on the WBGT.

5. American College of Sports Medicine (ACSM)

In July 1984, the American College of Sports Medicine (ACSM) published a position statement on "Prevention of Heat Injuries During Distance Running" [140]. To be competitive, the long distance runner must be in excellent physical condition, exceeding the physical fitness of most industrial workers. For long distance races such as the marathon, the fastest competitors run at 12 to 15 miles per hour, which must be classified as extremely hard physical work. When the thermal environment reaches even moderate levels, overheating can be a problem.

To reduce the risk of heat-induced injuries and illnesses, the ACSM has prepared a list of recommendations which would serve as advisory guidelines to be followed during distance running when the environmental heat load exceeds specific values. These recommendations include (1) races of 10 km or longer should not be conducted when the WBGT exceeds 28°C (82.4°F); (2) all summer events should be scheduled for early morning, ideally before 8 a.m. or after 6 p.m.; (3) race sponsors must provide fluids; (4) runners should be encouraged to drink 300-360 mL of fluids 10 to 15 minutes before the race; (5) fluid ingestion at frequent intervals during the race should be permitted with water stations at 2-3 km intervals for races 10 km or longer, and runners should be encouraged to drink 100-200 mL at each water station; (6) runners should be instructed on recognition of early signs and symptoms of developing heat illness; and (7) provision should be made for the care of heat-illness cases.

In these recommendations the WBGT is the heat-stress index of choice. The "red flag" high risk WBGT index value of 23°-28°C (73.4°-82.4°F) would indicate all runners must be aware that heat injury is possible, and any person particularly sensitive to heat or humidity should probably not run. An "amber flag" is moderate risk with a WBGT of 18°-23°C (64.4°-73.4°F). It is assumed that the air temperature and humidity and solar radiation are likely to increase during the day.

E. International Standards and Recommendations

1. The International Organization for Standardization (ISO)

In 1982 the International Organization for Standardization (ISO) adopted and published an international standard on "Hot Environments - Estimation of the Heat Stress on Working Man Based on the WBGT Index (Wet Bulb Globe Temperature)" [3]. The standard, as published, was approved by the member bodies of 18 of the 25 countries who responded to the request for review of the document. Only two member bodies disapproved. Several of the member bodies who approved the documents have official or unofficial heat-stress standards in their own countries, i.e., France, Republic of South Africa, Germany, and Sweden. The member bodies of the United States and the U.S.S.R. were among those who neither approved nor disapproved the document. The vote of each member body is supposedly based on a consensus of the membership of its Technical Advisory Group. Although the U.S. group did not reach a consensus, several of the guidelines in the ISO standard were recommended by the NIOSH workshop [141] to be included in an updated criteria document.

The ISO heat-stress standard in general resembles the ACGIH TLV for heat stress adopted in 1974. The basic premise upon which both are based is that no worker should be exposed to any combination of environmental heat and physical work which would cause the worker's body core temperature to exceed 38°C (100.4°F). The 38°C is based on the recommendations of the World Health Organization's report of 1969 on health factors involved in working under conditions of heat stress [48]. In addition, the ISO standard is based on the WBGT index for expressing the combination of environmental factors and on reference tables (or direct oxygen consumption measurements) for estimating the metabolic heat load. The ISO standard includes a table for the classification of metabolic heat with examples of activities characteristic of each of the five metabolic rates (rest, low metabolic rate, moderate metabolic rate, high metabolic rate, and very high metabolic rate). The upper permissible WBGT value for each of these work categories is presented for both the heat-acclimatized and for the heat-unacclimatized worker. For the heavy and very heavy work categories, the WBGT values are further subdivided into "no sensible air movement" and for "sensible air movement" categories.

The ISO standard index values, as do most other recommended heat-stress limit values, assume that the worker is a normal healthy individual, physically fit for the level of activity being done, and wearing standard summer weight workclothing with a thermal insulation value of about 0.6 clo (not including the still air layer insulation). Deviations in health status, physical fitness, and type and characteristics of clothing worn will require a modification of the permissible WBGT index values. The ISO WBGT index values are also based on the hypothesis that the environment in which any rest periods are taken is essentially the same as the worksite environment, and that the worker spends most of the workday in this environment.

The environmental measurements specified in the ISO standard for the calculation of the WBGT are (1) air temperature, (2) natural wet bulb temperature, and (3) black globe temperature. From these, WBGT index values can be calculated or can be obtained as a direct integrated reading with some types of environmental measuring instruments. The measurements must, of course, be made at the place and time of the worker's exposure.

The ISO standard brings together, on an international level, heat-stress guidelines which are component parts of the many official and unofficial standards and guidelines set forth nationally. Basically a general conformity between the many proposed standards.

A disturbing aspect of the ISO standard is that the "reference values correspond to exposures to which almost all individuals can be ordinarily exposed without harmful effect, provided that there is no preexisting pathological condition." This statement implies that in the specified nonpathologic population exposed to the standard index values of heat stress, some individuals could incur heat illnesses. What proportion of the population is "almost all?" How many heat illnesses are acceptable before corrective actions are taken? How are these less tolerant workers identified?

The problem of how to identify those few individuals whose low heat tolerance places them at high risk before their health and safety are jeopardized in a hot work environment is not addressed. The ISO standard does not address the problem of using biologic monitoring as an adjunct approach to reducing the risk of heat-induced illnesses.

The ISO standard includes one condition that is not addressed in some of the other standards or recommendations. A correction factor for air velocity during high metabolic heat production is introduced to compensate for the effect of air velocity on sweat evaporation rate. When there is no perceptible air movement, the WBGT index value is 1°C (1.8°F) lower than where there is a perceptible air movement for high metabolic rate (200-260 W/m^2) and 2°C (3.6°F) lower for very high metabolic rate (>260 W/m^2). This appears to be a reasonable correction; however, rarely in industrial situations does a "no sensible air movement" occur except possibly in confined enclosures. The movement of the torso and the limbs, especially during hard work, in itself will create an effective air movement. Consequently, it may be questioned whether an air movement correction is really necessary.

2. ISO Proposed Analytical Method

The ISO Working Group for the Thermal Environment has prepared a draft document "Analytical Determination of Thermal Stress" which, if adopted, would provide an alternative procedure for assessing the stressfulness of a hot industrial environment [142]. The method is based on a comparison between the required sweat production as a result of the working conditions and the maximum physiologically achievable skin wettedness and sweat production. The standard requires (1) calculating the sweat evaporation rate required to maintain body thermal balance, (2) calculating the maximum sweat evaporation rate permitted to the ambient environment, and (3) calculating the sweat rate required to achieve the needed skin wettedness. The cooling efficiency of sweat as modified by the clothing worn is included in the calculation of required skin wettedness.

The data required for making the calculations include dry bulb air temperature, wet bulb temperature, radiant temperature, air velocity, metabolic heat production, vapor and wind permeability, and insulation value of the clothing worn. From these, the convective, radiative, and evaporative heat exchange can be calculated using the thermodynamic constants. Finally, E_{req}/E_{max} can be expressed as sweat production required to wet the skin to the extent necessary (skin wettedness required). This approach basically is similar to the new effective temperature (ET*) proposed by the scientists at the Pierce Foundation Laboratories [143].

The computer program for calculating the required sweat rate and the allowable exposure time is written in BASIC computer language. It may require adaptation of the program to fit a particular user computer system. The major disadvantages with this proposed approach to a standard are essentially the same as those of other suggested approaches based on detailed calculations of heat exchange. The separate environmental factors, especially effective air velocity, are difficult to measure with required accuracy under conditions of actual industrial work situations. Air velocity, in particular, may vary widely from time to time at a workplace and at any time between short distances at a workplace. For routine industrial use, this proposed procedure appears to be too complicated. Furthermore, a number of assumptions must be made for the variables needed to solve the equation, because the variables cannot or are not easily measured directly, e.g., mean skin temperature is assumed to be 35°C (95°F) but may be lower or higher, and the convective and radiant heat transfer coefficients, which are assumed to be constant, vary with body posture. These and other assumed values detract from the usefulness of the predictions of heat strain.

On the positive side, the equations are well suited for deciding on the most efficient approach to reducing total heat load (e.g., environmental vs. metabolic heat). The ISO draft standard recommends limits in terms of hourly TWA values and 8 hours of exposure. The criterion for the 8-hour exposure is the amount of body water that can be lost by sweating and can be replaced without excessive hypohydration. These 8-hour values, expressed as total sweat production, are 3,250 mL for unacclimatized and 5,200 mL for acclimatized workers. An 8-hour sweat production of 2,500 mL and 3,900 mL, respectively, for the unacclimatized and the acclimatized workers are considered to represent a level of heat stress at which some countermeasures should be initiated. Hourly limits based on these 8-hour recommended action limits would be reduced by about 35%. If workers were exposed to heat each hour at the maximum hourly level in terms of the required sweat index, they would reach the 8-hour sweating limit after about 5 hours of exposure. These recommendations are supported by data from several western and eastern countries and from the United States, including the NIOSH studies.

The suggested physiologic strain criteria for thermal exposure limits based on average values are summarized in Table VIII-1.

TABLE VIII-1.--Criteria for thermal limits based on average values

	Heat (nonacclimatized) Alert	Heat (nonacclimatized) Danger	Heat (acclimatized) Alert	Heat (acclimatized) Danger
Heat storage kcal	58	70	58	70
Rectal temp increase °C (°F)	0.8 (1.4)	1 (1.8)	0.8 (1.4)	1 (1.8)
Skin temp increase °C (°F)	2.4 (4.3)	3 (5.4)	2.4 (4.3)	3 (5.4)
Sweat rate, max rest g/h	260	390	520	780
Sweat rate, max work g/h	520	650	780	1040
Max 8h sweat production to prevent excessive dehydration	2.60	3.25	3.90	5.20
Skin wettedness, rest	0.85		1.0	
Skin wettedness, work	0.50		0.85	

Adapted from Reference 16.

F. Foreign Standards and Recommendations

Several nations have developed and published standards, recommendations, and guidelines for limiting the exposure of workers to potentially harmful levels of occupational heat stress. These documents range from official national position standards to unofficial suggested practices and procedures and to unofficially sanctioned guidelines proposed by institutions, research groups, or individuals concerned with the health and safety of workers under conditions of high heat load. Most of these documents have in common the use of (1) the WBGT as the index for expressing the environmental heat load and (2) some method for estimating and expressing the metabolic heat production. The permissible total heat load is then expressed as a WBGT value for all levels of physical work ranging from resting to very heavy work.

1. Finland

A heat-stress limits guide has been recommended which is not, however, an official national standard for Finland. The guide conforms to the ACGIH TLV for heat stress [144]. To evaluate the heat exposure, the WBGT method was used, because it was considered to be the best internationally documented procedure, and because it is simple and suitable for use in the field.

The limits presented in the Finnish guidelines are (as are the ACGIH TLV) based on the assumption that the worker is healthy, heat acclimatized, properly clothed, and provided with adequate water and salt. Higher levels of heat exposure are permitted for workers who show unusually high heat tolerance.

2. Sweden

The Department of Occupational Safety, General Bureau TAA 3, Collection of Reports AFS 198X, Report No. 4, 1981-09-11, Ventilation of Work Rooms [145], although mainly concerned with workroom heating, cooling, and ventilation to achieve thermal comfort and no health hazards, does specify "highest permissible heat exposure" which should not be exceeded. The maximum heat exposure is based on an hourly TWA for each of the various levels of physical activity: sitting, light, medium heavy, and heavy. For each activity level, the maximum environmental heat load is expressed in WBGT units: 28°, 25°, and 23°C (82°, 77°, and 73°F) for the light, medium heavy, and heavy activity levels, respectively. The activity levels in watts or kcal/h are not given. Consequently, it is difficult to compare exactly the presented maximum heat exposure levels with those of the ISO or ACGIH TLV.

If it is assumed that the activity levels are comparable to those of the ISO and ACGIH TLV, then the Swedish maximum heat-stress levels are about 2°C (3.6°F) lower for each activity. The Swedish WBGT (SWBGT) for air velocities less than 0.5 m/sec is calculated from the formula $SWBGT = 0.7t_{wb}+0.3t_a+2$. The added 2 is a correction factor when the psychrometric wet bulb temperature is used instead of the natural wet bulb temperature.

3. Romania

Chapter X, "Microclimate, Ventilation and Heating" of the Occupational Health Protection Standards of the Romanian Republic [146] provides data on air movement requirement and average maximum acceptable air temperature (t_a) for various levels of physical work (light = 150 kcal/h, average = 151-300 kcal/h, heavy = >300 kcal/h) and various levels of radiant heat load (600, 1200, 1800 kcal/h); relative humidity should not exceed 60%. In addition, several engineering controls, work practices, and types of personal protective equipment are listed. These control procedures are comparable to those provided in other heat-stress standards and recommendations. The maximum listed air temperatures and required wind speeds range from 28°C (82.4°F) and 1 m/sec for light work and low radiant heat to 22°C (71.6°F) and 3 m/sec for heavy physical work and high radiant heat. To convert the t_a, V_a, and the various levels of radiant heat and the metabolic heat load into WBGT, CET or comparable indices for direct comparison with other standards and recommendations would require considerable manipulation. The standard specifies that the microclimatic conditions at the worksite must be such that the worker can maintain thermal equilibrium while performing normal work duties. The body temperature accepted for thermal equilibrium is not specified. No mention was made of state of acclimatization, health status, clothing worn, etc., as factors to be considered in setting the heat stress values.

4. U.S.S.R.

The U.S.S.R. heat-stress standard CH245-68, 1963 [147] defines acceptable combinations of air temperature, humidity, air speed, and radiant temperatures for light, medium heavy, and heavy work loads. In general format, the U.S.S.R. and Romanian standards are comparable. They differ, however, in several points: (1) for medium heavy work the U.S.S.R. uses 150-245 kcal/h while Romania uses 150-300 kcal/h; (2) for heavy work the values are >250 kcal/h for the U.S.S.R. and >300 kcal/h for Romania; (3) for light work and radiant heat <600 kcal/m^2/h the U.S.S.R. t_a is 22°-24°C (71.6°-75.2°F) at air velocity of 0.5-1 m/sec while the Romanian t_a is 28°C (82.4°F) at air velocity of 1 m/sec; (4) for the heavy work and radiant heat >1200 kcal/h the U.S.S.R. t_a is 16°C (60.8°F) with air velocity of 3 m/sec while the Romanian t_a is 22°C (71.6°F) at air velocity of 3 m/sec; and (5) for all combinations of work and radiant heat loads in between these extremes the U.S.S.R. t_a is consistently 2°C (3.6°F) or more below the Romanian t_a at comparable air velocities. The U.S.S.R. standard suggests that for high heat and work load occupations, the rest area for the workers be kept at "optimum conditions." For radiant heat sources above 45°C (113°F), radiation shielding must be provided. State of acclimatization, physical fitness, health status, clothing worn, provision of water, etc., are not addressed as factors that were considered in establishing the heat-stress limits.

5. Belgium

The Belgium Royal Decree [148] concerning workplace environments contains a section on maximum permissible temperature in indoor workplaces acceptable for very light (90 kcal/h), light (150 kcal/h), semiheavy (250 kcal/h), and heavy work (350 kcal/h). The work category energies are comparable to those used in the ISO standard. It is specified that if the workers are exposed to radiant heat, the environmental heat load should be measured with a wet globe thermometer or any other method that will give similar effective temperature values. The maximum temperatures established for the various work intensities are the same as those of the ISO and the ACGIH TLV, but the values are stated in terms of ET.

Based on the advice of an industrial physician and agreement of the workers' representative to the Committee of Safety, Health and Improvement of the Workplace, the maximum permissible temperature may be exceeded if (1) exposure is intermittent, (2) a cool rest area is available, and (3) adequate means of protection against excessive heat are provided. The decree also provides that for outside work in the sun, the workers should be protected from solar radiation by an adequate device.

The industrial physician is given the responsibility for ensuring heat acclimatization of the worker, selection and use of protective devices, establishing rest times, and informing workers of the need for an adequate fluid intake. The employer is responsible for providing engineering controls for convective heat by ventilation and radiant heat by shielding, reflective protective clothing, or clothing with incorporated cooling.

If engineering controls are not adequate, a reduction in exposure time to the excessive heat is recommended. This reduction in exposure is accomplished by varying the work-rest cycle. The rest area temperature must be below 30°C (86°F). A table is provided for work-rest cycles for various environmental heat loads at each of the levels of physical work. For 10 minutes of rest in each 2-hour work period, the maximum effective temperatures are 30.1°, 26.8°, and 25.1°C (86.1°, 80.23°, and 77.2°F) for light, semiheavy, and heavy work, respectively. At the other extreme, only 5 minutes of work is permitted when the effective temperature is 33°, 32°, and 31.5°C (91.9°, 89.6°, and 88.7°F) for light, semiheavy, and heavy work, respectively. These values are relatively comparable to the WBGT values listed in the ACGIH TLVs for similar work loads.

6. Australia

Rule 1 of the Factories (Health and Safety) Regulations, Factories and Shops Act of 1960-1973, as revised by order of Council, November 1973, sections (8)(b) through (8)(d), (9), and (10) [149] contain general statements pertaining to temperature, air movement, and humidity for hot working areas in factories. In those factories that are not air conditioned, the inside globe temperature shall not exceed 25°C (77°F) when the outside temperature is 22.2°C (72°F) or below, or the inside globe temperature shall not exceed the outside temperature by more than 2.8°C (5°F) when the outside temperature is above 22.2°C (72°F).

Minimum air movement is specified only for dressing and dining areas, and humidities are specified only for areas that are air conditioned. These Australian rules are very general but do contain a provision that if in the opinion of an inspector "the temperature and humidity is likely to be injurious to the health of a worker, the inspector may require that remedial measures shall be taken." These remedial measures include plant alterations and engineering controls. Recently, however, the Australian member body of ISO voted for the adoption of the ISO standard. Recently, the Victorian Trade Hall Council published guidelines on working in heat [150]. The suggested guidelines which closely follow the ACGIH TLVs for heat stress [2] included a summary of (1) what is heat stress, (2) effects of heat stress, (3) heat illnesses, (4) measurement of heat stress, (5) protective measurements against heat stress, (6) medical requirements under heat-stress conditions, (7) acclimatization to heat, and (8) regulations governing hot work. The Australian Health and Medical Research Council also adopted these guidelines. An unusual feature is the recommendation that "hazard money" should not be an acceptable policy but that "a first priority is the elimination of the workplace hazards or dangers and the refusal to accept payment for hazardous or unsafe work."

7. Japan

The <u>Recommendations on Maximum Allowable Concentrations of Toxic Substances and Others in the Work Environment, 1982</u> published by the Japanese Association of Industrial Health contains a section on "Maximum Allowable Standards for High Temperatures" [151]. These recommendations are designed as guidelines for protecting the worker from health hazards in the hot work environment but do not have official governmental endorsement. In this way they are comparable to the ACGIH TLVs.

The section on maximum allowable standards for high temperatures sets the environmental heat-stress limits in WBGT and Corrected Effective Temperature (CET) units for five intensities of physical work ranging from extremely light (130 kcal/h) to heavy (370 kcal/h). When the permissible maximum allowable WBGT values are compared to the ACGIH TLVs for similar levels of physical work, they are essentially equal and are also comparable to the ISO recommended heat-stress limits.