IX. INDICES FOR ASSESSING HEAT STRESS AND STRAIN

During the past half century several schemes have been devised for assessing and/or predicting the level of heat stress and/or strain that a worker might experience when working at hot industrial jobs. Some are based on the measurements of a single environmental factor (wet bulb), while others incorporate all of the important environmental factors (dry bulb, wet bulb, and mean radiant temperatures and air velocity). For all of the indices, either the level of metabolic heat production is directly incorporated into the index or the acceptable level of index values varies as a function of metabolic heat production.

To have industrial application, an index must, at a minimum, meet the following criteria:

- Feasibility and accuracy must be proven with use.
- All important factors (environmental, metabolic, clothing, physical condition, etc.) must be considered.
- Required measurements and calculations must be simple.
- The measuring instruments and techniques applied should result in data which truly reflect the worker's exposure but do not interfere with the worker's performance.
- Index exposure limits must be supported by corresponding physiologic and/or psychologic responses which reflect an increased risk to safety and health.
- It must be applicable for setting limits under a wide range of environmental and metabolic conditions.

The measurements required, advantages and disadvantages, and applicability to routine industrial use of some of the more frequently used heat-stress/heat-strain indices will be discussed under the following categories: (1) Direct Indices, (2) Rational Indices, (3) Empirical Indices, and (4) Physiological Monitoring.

A. Direct Indices

1. Dry Bulb Temperature

The dry bulb temperature (t_a) is commonly used for estimating comfort conditions for sedentary people wearing conventional indoor clothing (1.4 clo including the surface air layer). With light air movement and relative humidity of 20 to 60%, air temperatures of 22°-25.5°C (71.6°-77.9°F) are considered comfortable by most people. If work intensity is increased to moderate or heavy work, the comfort air temperature is decreased about 1.7°C (3°F) for each 25 kcal (100 Btu or 29 W) increase in the hourly metabolic heat production. Conversely, if the air temperature and/or the metabolic heat production are progressively increased above the comfort zone, the level of heat stress and heat strain will increase.

Dry bulb temperature is easily measured, but its use when the temperature above the comfort zone is not justified except for work situations where the worker is wearing completely vapor- and air-impermeable encapsulating protective clothing. Even under these conditions, appropriate adjustments must be made when significant solar and long wave radiation are present [14].

2. Wet Bulb Temperature

The psychrometric wet bulb temperature (t_{wb}) may be an appropriate index for assessing heat stress and predicting heat strain under conditions where radiant temperature and air velocity are not large factors and where t_{wb} approximates t_a (high humidities). For normally clothed individuals at low air velocities, a wet bulb temperature of about 30°C (86°F) is the upper limit for unimpaired performance on sedentary tasks and 28°C (82.4°F is the upper limit) for moderate levels of physical work. As t_{wb} increases above these threshold values, performance deteriorates and accidents increase. The wet bulb temperatures under these hot, humid conditions have been used to predict risk of heatstroke occurring in South African and German mines [130].

Wet bulb temperature is easy to measure in industry with a sling or aspirated psychrometer, and it should be applicable in any hot, humid situation where t_{wb} approaches skin temperature, radiant heat load is minimal, and air velocity is light.

B. Rational Indices

1. Operative Temperature

The operative temperature (t_o) expresses the heat exchange between a worker and the environment by radiation and convection in a uniform environment as it would occur in an actual industrial environment. The t_o can be derived from the heat-balance equation where the combined convection and radiation coefficient is defined as the weighted sum of the radiation and convection heat-transfer coefficients, and it can be used directly to calculate heat exchange by radiation and convection. The t_o considers the intrinsic thermal efficiency of the clothing. Skin temperature must be measured or assumed. The t_o presents several difficulties. For convective heat exchange, a measure of air velocity is necessary. Not included are the important factors of humidity and metabolic heat production. These omissions make its applicability to routine industrial use somewhat limited.

2. Belding-Hatch Heat-Stress Index

The Belding and Hatch Heat-Stress Index (HSI) [152] has had wide use in laboratory and field studies of heat stress. One of its most useful features is the table of physiologic and psychologic consequences of an 8-hour exposure at a range of HSI values. The HSI is essentially a derivation of the heat-balance equation that includes the environmental and metabolic factors. It is the ratio (times 100) of the amount of body heat that is required to be lost to the environment by evaporation for thermal equilibrium (E_{req}) divided by the maximum amount of sweat evaporation allowed through the clothing system that can be accepted by the environment (E_{max}). It assumes that a sweat rate of about 1 liter per hour over an 8-hour day can be achieved by the average, healthy worker without harmful effects. This assumption, however, lacks epidemiologic proof. In fact, there are data that indicate that a permissible 8 liters per 8-hour day of sweat production is too high, and as the 8-hour sweat production exceeds 5 liters, more and more workers will dehydrate more than 1.5% of the body weight, thereby increasing the risk of heat illness and accidents. The graphic solution of the HSI which has been developed assumes a 35°C (95°F) skin temperature and a conventional long-sleeved shirt and trouser ensemble. The worker is assumed to be in good health and acclimatized to the average level of daily heat exposure.

The HSI is not applicable at very high heat-stress conditions. It also does not identify correctly the heat-stress differences resulting from hot, dry and hot, humid conditions. The strain resulting from metabolic vs. environmental heat is not differentiated. Because E_{req}/E_{max} is a ratio, the absolute values of the two factors are not addressed, i.e., the ratio for an E_{req} and E_{max} of 300 or 500 or 1,000 each would be the same (100); yet the strain would be expected to be greater at the higher E_{req} and E_{max} values.

The environmental measurements require data on air velocity which at best is an approximation under industrial work situations; in addition, t_a, t_{wb}, and t_r must be measured. Metabolic heat production must also be measured or estimated. The measurements are, therefore, difficult and/or time-consuming which limits the application of the HSI as a field monitoring technique.

The heat transfer coefficients used in the original HSI have been revised as a result of observations on clothed subjects, by McKarns and Brief [153]. Their modification of the HSI nomograph facilitates the practical use of the index, particularly for the analysis of factors contributing to the heat stress. The McKarns and Brief modification also permits the calculation of allowable exposure time and rest allowances at different combinations of environmental and metabolic heat loads; however, the accuracy of these calculations is affected by the limitations of the index mentioned above. HSI programs for a programmable handheld calculator are available.

3. Skin Wettedness (%SWA)

Several of the rational heat-stress indices are based on the concept that in addition to the sweat production required for temperature equilibrium (E_{req}) and the maximum amount of sweat that can be evaporated (E_{max}), the efficiency of sweat evaporation will also affect heat strain. The less efficient the evaporation, the greater will be the body surface area that has to be wetted with sweat to maintain the required evaporative heat transfer; the ratio of wetted to nonwetted skin area times 100% (SWA = E_{req}/E_{max}). This concept of wettedness gives new meaning to the E_{req}/E_{max} ratio as an indicator of strain under conditions of high humidity and low air movement where evaporation is restricted [16,22,26,136,143,154].

The skin wettedness indices consider the variables basic to heat balance (air temperature, humidity, air movement, radiative heat, metabolic heat, and clothing characteristics) and require that these variables be measured or calculated for each industrial situation where an index will be applied. These measurement requirements introduce exacting and time-consuming procedures. In addition, wind speed at the worksite is difficult to measure with any degree of reliability; at best it can generally be only an approximation. These indices are satisfactory as a basis for calculating the magnitude of thermal stress and strain and for recommending engineering and work practice controls; however, as procedures for routine environmental monitoring, they are too complicated, require considerable recording equipment, and are time-consuming.

C. Empirical Indices

Some of the earlier and most widely used heat-stress indices are those based upon objective and subjective strain response data obtained on individuals and groups of individuals exposed to various levels and combinations of environmental and metabolic heat-stress factors.

1. The Effective Temperature (ET, CET, and ET*)

The effective temperature (ET) index is the first and until recently, the most widely used of the heat-stress indices. The ET combines dry bulb and wet bulb temperatures and air velocity. In a later version of the ET, the Corrected Effective Temperature (CET), the black globe temperature (t_g) is used instead of t_a to take the heating effect of radiant heat into account. The index values for both the ET and the CET were derived from subjective impressions of equivalent heat loads between a reference chamber at 100% humidity and low air motion and an exposure chamber where the temperature and air motion were higher and the humidity lower. The recently developed new effective temperature (ET*) uses 50% reference relative humidity in place of the 100% reference rh for the ET and CET. The ET* has all the liabilities of the rational heat-stress indices mentioned previously; however, it is useful for calculating ventilation or air-conditioning requirements for maintaining acceptable conditions in buildings.

The ET and CET have been used in studies of physical, psychomotor, and mental performance changes as a result of heat stress. In general, performance and productivity decrease as the ET or CET exceed about 30°C (86°F). The World Health Organization has recommended as unacceptable for heat-unacclimatized individuals values that exceed 30°C (86°F) for sedentary activities, 28°C (82.4°F) for moderate work, and 26.5°C (79.7°F) for hard work. For the fully heat-acclimatized individuals, the tolerable limits are increased about 2°C (3.6°F).

The data on which the original ET was based came from studies on sedentary subjects exposed to several combinations of t_a, t_{wb}, and V_a all of which approximated or slightly exceeded comfort conditions. The responses measured were subjective impressions of comfort or equal sensations of heat which may or may not be directly related to values of physiologic or psychologic strain. In addition, the sensations were the responses to transient changes. The extrapolation of the data to various amounts of metabolic heat production has been based on industrial experience. The ET and CET have been criticized on the basis that they seem to overestimate the effects of high humidity and underestimate the effects of air motion and thus tend to overestimate the heat stress.

In the hot, humid mines of South Africa, heat-acclimatized workers doing hard physical work showed a decrease in productivity beginning at ET of 27.7°C (81.9°F) (at 100% rh with minimal air motion) which is approximately the reported threshold for the onset of fatal heatstroke during hard work [5,6]. These observations lend credence to the usefulness of the ET or CET as a heat-stress index in mines and other places where the humidity is high and the radiant heat load is low.

2. The Wet Bulb Globe Temperature (WBGT)

The Wet Bulb Globe Temperature (WBGT) index was developed in 1957 as a basis for environmental heat-stress monitoring to control heat casualties at military training camps. It has the advantages that the measurements are few and easy to make; the instrumentation is simple, relatively inexpensive, and rugged; and the calculations of the index are straightforward. For indoor use only two measurements are needed: natural wet bulb and black globe temperatures. For outdoors in sunshine, the air temperature also must be measured. The calculation of the WBGT for indoors is:

$$WBGT=0.7t_{nwb}+0.3t_g$$

for outdoors:

$$WBGT=0.7t_{nwb}+0.2t_g+0.1t_a$$

The WBGT combines the effect of humidity and air movement (in t_{nwb}), air temperature and radiation (in t_g), and air temperature (t_a) as a factor in outdoor situations in the presence of sunshine. If there is a radiant heat load (no sunshine), the t_g reflects the effects of air velocity and air temperature. WBGT measuring instruments are commercially available which give t_a, t_{nwb}, and t_g separately or as an integrated WBGT in a form for digital readouts. A printer can be attached to provide tape printouts at selected time intervals for WBGT, t_a, t_{nwb}, V_a, and t_g values.

The application of the WBGT index for determining training schedules for military recruits during the summer season has resulted in a striking reduction in heat casualties [155]. This dramatic control of heat casualty incidence stimulated its application to hot industrial situations.

In 1972 the first NIOSH Criteria for a Recommended Standard.... Occupational Exposure to Hot Environments [9] recommended the use of the WBGT index for monitoring industrial heat stress. The rationale for choosing the WBGT and the basis for the recommended guideline values was described in 1973 [156]. The WBGT was used as the index for expressing environmental heat load in the ACGIH TLVs - Heat Stress adopted in 1974 [2]. Since then, the WBGT has become the index most frequently used and recommended for use throughout the world including its use in the International Standards Organization document Hot Environments--Estimation of the Heat Stress on Working Man Based on the WBGT Index (Wet Bulb Globe Temperature) 1982 [3] (see Chapter VIII Basis for the Recommended Standard for further discussion of the adoption of the WBGT as the recommended heat stress index). However, when impermeable clothing is worn, the WBGT will not be a relevant index, because evaporative cooling (wet bulb temperature) will be limited. The air temperature or adjusted dry bulb temperature is the pertinent factor.

The WBGT index meets the criteria of a heat-stress index that are listed earlier in this chapter. In addition to the WBGT TLVs for continuous work in a hot environment, recommendations have also been made for limiting WBGT heat stress when 25, 50, and 75% of each working hour is at rest (ACGIH-TLVs, OSHA-SACHS, AIHA). Regulating worktime in the heat (allowable exposure time) is a viable alternative technique for permitting necessary work to continue under heat-stress conditions that would be intolerable for continuous exposure.

3. Wet Globe Temperature (WGT)

Next to the t_a and t_{wb}, the wet globe thermometer (Botsball) is the simplest, most easily read, and most portable of the environmental measuring devices. The wet globe thermometer consists of a hollow 3-inch copper sphere covered by a black cloth which is kept at 100% wettedness from a water reservoir. The sensing element of a thermometer is located at the inside center of the copper sphere, and the temperature inside the sphere is read on a dial on the end of the stem. Presumably, the wet sphere exchanges heat with the environment by the same mechanisms that a nude man with a totally wetted skin would in the same environment; that is, heat exchange by convection, radiation, and evaporation are integrated into a single instrument reading [157]. The stabilization time of the instrument ranges from about 5 to 15 minutes depending on the magnitude of the heat-load differential (5 minutes for 5°C (9°F) and 15 minutes for >15°C (59°F)).

During the past few years, the WGT has been used in many laboratory studies and field situations where it has been compared with the WBGT [158,159,160,161,162]. In general, the correlation between the two is high (r=0.91-0.98); however, the relationship between the two is not constant for all combinations of environmental factors. Correction factors ranging between 1°C (1.8°F) and 7°C (12.6°F) have been suggested. A simple approximation of the relationship is WBGT=WGT+2°C for conditions of moderate radiant heat and humidity. These approximations are probably adequate for general monitoring in industry. If the WGT shows high values, it should be followed with WBGT or other detailed measurements. The WGT, although good for screening and monitoring, does not yield data for solving the equations for heat exchange between the worker and the industrial environment, but a color-coded WGT display dial provides a simple and rapid indicator of the level of heat stress.

D. Physiologic Monitoring

The objectives of a heat-stress index are twofold: (1) to provide an indication of whether a specific total heat stress will result in an unacceptably high risk of heat illness or accidents and (2) to provide a basis for recommending control procedures. The physiologic responses to an increasing heat load include an increase in heart rate, an increase in body temperature, an increase in skin temperature, and an increase in sweat production. In a specific situation any one or all of these responses may be elicited. The magnitude of the response(s) will in general reflect the total heat load. The individual integrates the stress of the heat load from all sources, and the physiologic responses (strain) to the heat load are the biological corrective actions designed to counteract the stress and thus permit the body to maintain an optimal internal temperature. Acceptable increases in physiologic responses to heat stress have been recommended by several investigators [48,127,128]. It, therefore, appears that monitoring the physiologic strain directly under regular working conditions would be a logical and viable procedure for ensuring that the heat strain did not exceed predesignated values. Measuring one or more of the physiologic responses (heart rate and/or oral temperature) during work has been recommended and is, in some industries, used to ensure that the heat stress to which the worker is exposed does not result in unacceptable strain [127,128]. However, several of the physiologic strain monitoring procedures are either invasive (radio pill) or socially unacceptable (rectal catheter) or interfere with communication (ear thermometer). Physiologic monitoring requires medical supervision and the consent of the worker.

1. Work and Recovery Heart Rate

One of the earliest procedures for evaluating work and heat strain is that introduced by Brouha in which the body temperature and pulse rate are measured during recovery following a workcycle or at specified times during the workday [29]. At the end of a workcycle, the worker sits on a stool, an oral thermometer is placed under the tongue, and the pulse rate is counted from 30 seconds to 1 minute (P_1), from 1-1/2 to 2 minutes (P_2), and from 2-1/2 to 3 minutes (P_3) of seated recovery. If the oral temperature exceeds 37.5°C (99.5°F), the P_1 exceeds 110 beats per minutes (b/min), and/or the P_1-P_3 is fewer than 10 b/min, the heat and work stress is assumed to be above acceptable values. These values are for group averages and may or may not be applicable to an individual worker or specific work situation. However, these values should alert the observer that further review of the job is desirable.

A modified Brouha approach is being used for monitoring heat stress in some hot industries. An oral temperature and a recovery heart rate pattern have been suggested by Fuller and Smith [127,128] as a basis for monitoring the strain of working at hot jobs. The ultimate criterion of high heat strain is an oral temperature exceeding 37.5°C (99.5°F). The heart rate recovery pattern is used to assist in the evaluation. If the P_3 is 90 b/min or fewer, the job situation is satisfactory; if the P_3 is about 90 b/min and the P_1-P_3 is about 10 b/min, the pattern indicates that the physical work intensity is high but there is little if any increase in body temperature; if the P_3 is greater than 90 b/min and the P_1-P_3 is fewer than 10 b/min, the stress (heat + work) is too high for the individual and corrective actions should be introduced. These individuals should be examined by a physician, and the work schedule and work environment should be evaluated.

The field data reported by Jensen and Dukes-Dobos [163] corroborate the concept that the P_1 recovery heart rate and/or oral temperature is more likely to exceed acceptable values when the environmental plus metabolic heat load exceeds the ACGIH TLVs for continuous work. The recovery heart rate can be easily measured in industrial situations where being seated for about 5 minutes will not seriously interfere with the work sequence; in addition, the instrumentation required (a stopwatch at a minimum) can be simple and inexpensive. Certainly the recovery and work heart rate can be used on some jobs as early indicators of the strain resulting from heat exposure in hot industrial jobs. The relatively inexpensive, noninvasive electronic devices now available (and used by joggers and others) should make self-monitoring of work and recovery pulse rates practical.

2. Body Temperature

The WHO scientific group on Health Factors Involved in Working Under Conditions of Heat Stress recommended that the deep body temperature should not, under conditions of prolonged daily work and heat, be permitted to exceed 38°C (100.4°F) or oral temperature of 37.5°C (99.5°F). The limit has generally been accepted by the experts working in the area of industrial heat stress and strain.

Monitoring the body temperature (internal or oral) would, therefore, appear to be a direct, objective, and reliable approach. Measuring internal body temperature (rectal, esophageal, or aural) although not a complicated procedure does present the serious problem of being generally socially unacceptable to the workers.

Oral temperatures, on the other hand, are easy to obtain especially now that inexpensive disposable oral thermometers are available. However, to obtain reliable oral temperatures requires a strictly controlled procedure. The thermometer must be correctly placed under the tongue for 3 to 5 minutes before the reading is made, mouth breathing is not permitted during this period, no hot or cold liquids should be consumed for at least 15 minutes before the oral temperature is measured, and the thermometer must not be exposed to an air temperature higher than the oral temperature either before the thermometer has been placed under the tongue or until after the thermometer reading has been taken. In hot environments this may require that the thermometers be kept in a cool insulated container or immersed in alcohol except when in the worker's mouth. Oral temperature is usually lower than deep body temperature by about 0.55°C (0.8°F). There is no reason why, with worker permission, monitoring body temperature cannot be applied in many hot industrial jobs. Evaluation of the significance of any oral temperature must follow established medical and occupational hygiene guidelines.

3. Skin Temperature

The use of skin temperature as a basis for assessing the severity of heat strain and estimating tolerance can be supported by thermodynamically and field derived data. To move body heat from the deep tissues (core) to the skin (shell) where it is dissipated to the ambient environment requires an adequate heat gradient. As the skin temperature rises and approaches the core temperature, this temperature gradient is decreased and the rate (and amount) of heat moved from the core to the shell is decreased and the rate of core heat loss is reduced. To restore the rate of heat loss or core-shell heat gradient, the body temperature would have to increase. An increased skin temperature, therefore, drives the core temperature to higher levels in order to reestablish the required rate of heat exchange. As the core temperature is increased above 38°C (100.4°F), the risk of an ensuing heat illness is increased.

From these observations it has been suggested that a reasonable estimate of tolerance time for hot work could be made from the equilibrium lateral thigh or chest skin temperature [14,15,20,22,164,165]. Under environmental conditions where evaporative heat exchange is not restricted, skin temperature would not be expected to increase much if at all. Also in such situations, the maintenance of an acceptable deep body temperature should not be seriously jeopardized except under very high metabolic loads or restricted heat transfer. However, when convective and evaporative heat loss is restricted (e.g., when wearing impermeable protective clothing), an estimate of the time required for skin temperature to converge with deep body temperature should provide an acceptable approach for assessing heat strain as well as for predicting tolerance time.

4. Hypohydration

Under heat-stress conditions where sweat production may reach 6 to 8 liters in a workday, voluntary replacement of the water lost in the sweat is usually incomplete. The normal thirst mechanism is not sensitive enough to urge us to drink enough water to prevent hypohydration. If hypohydration exceeds 1.5-2% of the body weight, tolerance to heat stress begins to deteriorate, heart rate and body temperature increase, and work capacity decreases [32]. When hypohydration exceeds 5%, it may lead to collapse and to hypohydration heat illness. Since the feeling of thirst is not an adequate guide for water replacement, workers in hot jobs should be encouraged to take a drink of water every 15 to 20 minutes. The water should be cool 10°-15°C (50°-59°F), but neither warm nor cold. Drinking from disposable drinking cups is preferable to using drinking fountains. The amount of hypohydration can be estimated by measuring body weight at intervals during the day or at least at the beginning and end of the workshift. The worker should drink enough water to prevent a loss in body weight. However, as this may not be a feasible approach in all situations, following a water drinking schedule is usually satisfactory.

X. RESEARCH NEEDS

The past decade has brought an enormous increase in our knowledge of heat stress and strain, of their relation to health and productivity, of techniques and procedures for assessing heat stress and strain, and for predicting the heat-related health risks associated with various amounts of heat stress. In spite of this, there are several areas where further research is required before occupational heat-induced health and safety problems can be completely prevented.

A. Exposure Times and Patterns

In some hot industries the workers are exposed to heat most of the day; other workers may be exposed only part of the time. Although there is general agreement on the heat-stress/strain relation with resultant health and safety risks for continuous exposure (8-hour workday), controversy continues on acceptable levels of heat stress for intermittent exposure where the worker may spend only part of the working day in the heat. Is a 1-hour, a 2-hour, or an 8-hour TWA required for calculating risk of health effects? How long are acceptable exposure times for various total heat loads? Are the health effects (heat illnesses) and risks the same for intermittent as for continuous heat exposure? Do workers exposed intermittently each day to various lengths and amount of heat stress develop heat acclimatization similar to that achieved by continuously exposed workers? Are the electrolyte and water balance problems the same for intermittently as for continuously heat-exposed workers?

B. Deep Body Temperature

The WHO Scientific Group recommended that "it is considered inadvisable for a deep body temperature to exceed 38°C (100.4°F) for prolonged daily exposures (to heat) in heavy work" [48], and that a deep body temperature of 39°C (102.2°F) should be considered reason to terminate exposure even when deep body temperature is being monitored. Are these values equally realistic for short-term acute heat exposures as for long-term chronic heat exposures? Are these values strongly correlated with increased risk of incurring heat-induced illnesses? Are these values considered maximal which are not to be exceeded, mean population levels, or 95th percentile levels? Is the rate at which deep body temperature rises to 38° or 39°C important in the health-related significance of the increased body temperature? Does a 38° or 39°C deep body temperature have the same health significance if reached after 1 hour of exposure as when reached after more than 1 hour of exposure?

C. Electrolyte and Water Balance

The health effects of severe acute negative electrolyte and water balance during heat exposure are well documented. However, the health effects of the imbalances when derived slowly over periods of months or years are not known; nor are the effects known for long term electrolyte loading with and without hyper or hypohydration. An appropriate electrolyte and water regimen for long-term work in the heat requires more data derived from further laboratory and epidemiologic studies.

D. Identifying Heat Intolerant Workers

Most humans when exposed to heat stress will develop, by the processes of heat acclimatization, a remarkable ability to tolerate the heat. In any worker population, some will be able to tolerate heat better than others, and a few, for a variety of reasons, will be relatively heat intolerant. At present, the heat-tolerant individual cannot be easily distinguished from the heat-intolerant individual except by the physiologic responses to exposure to high heat loads or on the basis of $\dot{V}O_2max$ (<2.5 L/m). However, waiting until an individual becomes a heat casualty to determine heat intolerance is an unacceptable procedure. A short and easily administered screening test which will reliably predict degree of heat tolerance would be very useful.

E. Effects of Chronic Heat Exposure

All of the experimental and most of the epidemiologic studies of the health effects of heat stress have been directed toward short exposures of days or weeks in length and toward the acute heat illnesses. Little is known about the health consequences of living and working in a hot environment for a working lifetime. Do such long exposures to heat have any morbidity or mortality implications? Does experiencing an acute heat illness have any effects on future health and longevity? It is known that individuals with certain health disorders (e.g. diabetes, cardiovascular disease) are less heat tolerant. There is some evidence that the reverse may also be true; e.g., chronic heat exposure may render an individual more susceptible to both acute and chronic diseases and disorders [77]. The chronic effect of heat exposure on blood pressure is a particularly sensitive problem, because hypertensive workers may be under treatment with diuretics and on restricted salt diets. Such treatment may be in conflict with the usual emphasis on increased water and salt intake during heat exposure.

F. Circadian Rhythm of Heat Tolerance

The normal daily variation in body temperature from the high point in the early afternoon to the low point in the early morning hours is about 1°C (1.8°F). Superimposed on this normal variation in body temperature would, supposedly, be the increase due to heat exposure. In addition, the WHO report recommends that the 8-hour TWA body temperature of workers in hot industries should not exceed 38°C (100.4°F) [48]. The question remains: Is this normal daily increase in body temperature additive to the increase resulting from heat stress? Does tolerance to increased body temperature and the connected health risk follow a similar diurnal pattern? Would it be necessary to establish different permissible heat exposure limits for day and night shift workers in hot industries?

G. Heat-Strain Monitoring

The heat-stress indices and strain prediction techniques are useful for estimating what the level of strain is likely to be for a given heat-stress situation and a given worker population, but they do not permit a prediction of which individual or individuals will become heat casualties. Because of the wide interindividual tolerance to heat stress, predictions of when and under what circumstances an individual may reach unacceptable levels of physiologic and psychologic strain cannot be made with a high degree of accuracy. One solution to this dilemma might be an individual heat-load dosimeter or a physiologic strain monitor (e.g., body or skin temperature or heart rate). A physiologic strain monitor would remove the necessity for measuring and monitoring the thermal environment and estimating the metabolic heat production. Monitoring the body temperature of a worker on a hot job once an hour and removing the worker from the heat if the body temperature reaches a previously agreed upon level would eliminate the risk of incurring a heat-related illness or injury. A small worker-worn packet containing a sensor, signal converter, display, and alarm to monitor body temperature and/or heart rate is technically feasible. The problem, however, is worker acceptance of the sensors.

H. Accidents and Heat Stress

Are accidents more prevalent in hot industries and in the hotter months of the year? There are data [70,71] that show a relationship between industrial accidents and heat stress, but there are not enough data to establish heat stress limits for accident prevention in hot industries. Field evaluations, as well as laboratory studies, are required to correlate accident probability or frequency with environmental and job heat-stress values in order to determine with statistical validity the role of heat stress in industrial accidents.

I. Effects of Heat on Reproduction

It is a well-documented phenomenon in mammals that spermatogenesis is very sensitive to testicular temperature [125]. Raising testicular temperature to deep body temperature inhibits spermatogenesis and results in relative infertility. A recent study of male foundry workers suggests that infertility is higher among couples where the male member is a foundry worker exposed to high temperatures than it is among the general population [124]. There are many industrial situations, including jobs where impermeable or semipermeable protective clothing must be worn, in which the testicular temperature would be expected to approximate body temperature. If a degree of male infertility is associated with heat exposure, data are required to prove the relationship, and remedial or preventive methods must be devised. Whether heat acts as a teratogenic agent in humans, as it apparently does in animals, is another problem that requires more research.

J. Heat Tolerance and Shift Work

It has been estimated that about 30% of workers are on some type of work schedule other than the customary day work (9 a.m.-5 p.m.). Shift work, long days-short week, and double shifts alter the usual living patterns of the worker and result in some degree of sleep deprivation. What effect these changes in living patterns have on heat tolerance is mostly undocumented. Before these changes in work patterns are accepted, it is prudent that their health and safety implications in conjunction with other stress be known.

K. Effects of Clothing and Benefits of Cooling Garments

There are several versions of effective cooling clothing and equipment commercially available. All versions, although very useful in special hot situations, have one or more of the following disadvantages: (1) limited operating time, (2) restrictions of free movement of the worker, (3) additional weight that must be carried, (4) limited dexterity and movement of the hands, arms, head, and legs, (5) increased minimal space within which the individual can work, and (6) use with other protective clothing and equipment (e.g., for protection against chemical hazards). The maximum efficiency and usability of such systems have not been achieved. Research on systems that will minimize the disadvantages while maximizing the efficiency of the cooling- and heat-exchange capacities is needed.

L. Medical Screening and Biologic Monitoring Procedures

Data to substantiate the degree of effectiveness of medical screening and biologic monitoring in reducing the risk of heat-induced illnesses among workers in hot industries are, at present, not systematically recorded nor are they readily available in the open literature. Such data, however, must be made available in sufficient quantity and detail to permit an epidemiologic and medical assessment of their health and safety, as well as economic feasibility for health and safety control procedures in hot industries. Standardized procedures for reporting incidences of heat-related health and safety problems, as well as environmental and work-heat loads, assessment of control procedures in use, medical screening practices, and biologic monitoring procedures, if routinely followed and reported, would provide an objective basis for assessing the usefulness of medical screening and biologic monitoring as preventive approaches to health.