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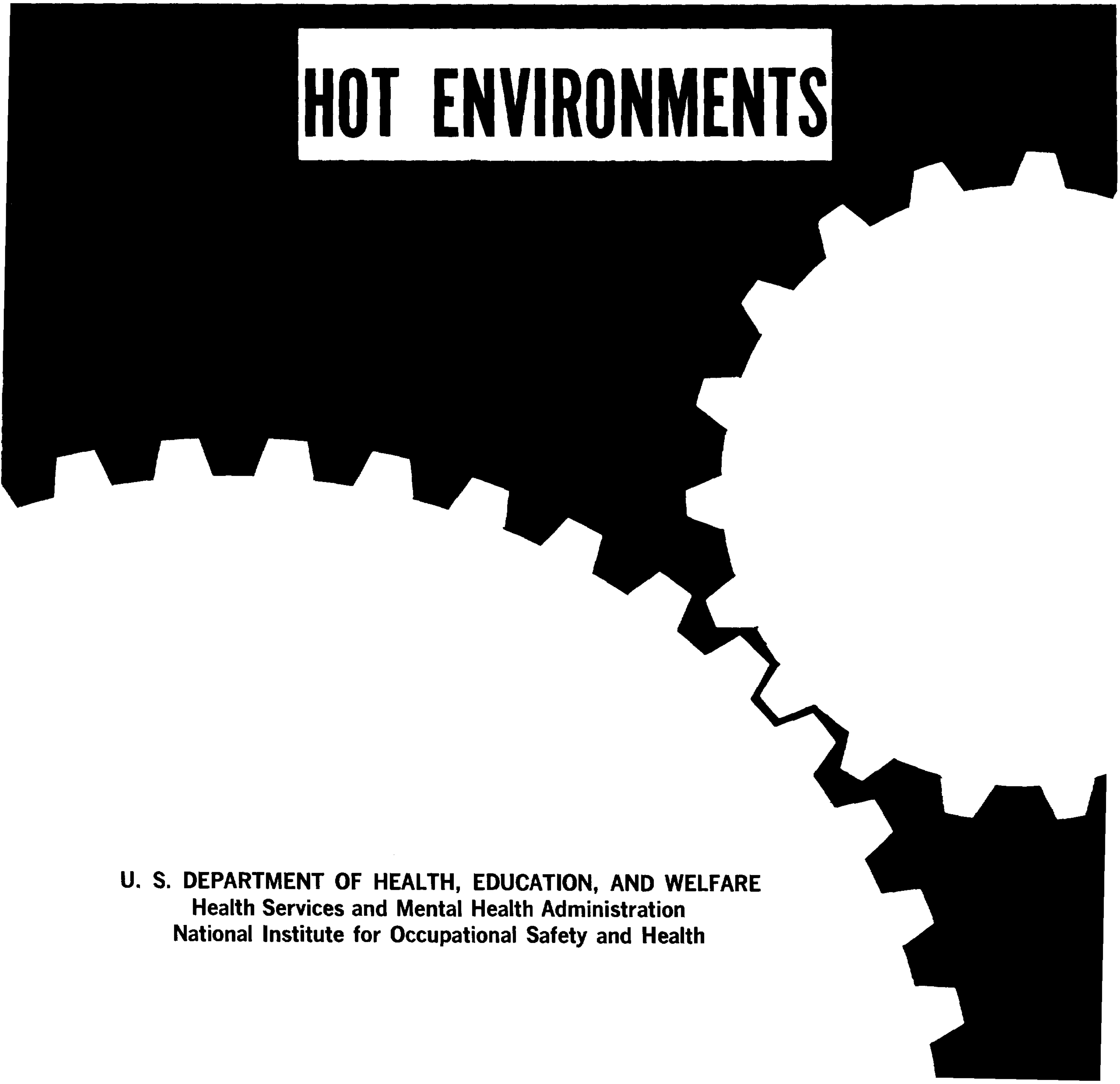
OCCUPATIONAL EXPOSURE
TO
HOT ENVIRONMENTS



U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Health Services and Mental Health Administration
National Institute for Occupational Safety and Health

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U. S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
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1972

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PREFACE

The Occupational Safety and Health Act of 1970 emphasizes the need for standards to protect the health of workers exposed to an ever increasing number of potential hazards at their workplace. To provide relevant data from which valid criteria and effective standards can be deduced, the National Institute for Occupational Safety and Health has projected a formal system of research, with priorities determined on the basis of specified indices.

It is intended to present successive reports as research and epidemiologic studies are completed and sampling and analytical methods are developed. Criteria and standards will be reviewed periodically to ensure continuing protection of the worker.

I am pleased to acknowledge the contributions to this report on heat stress by members of my staff and the valuable constructive comments by the Review Consultants on Heat Stress to NIOSH. The NIOSH recommendations for standards are not necessarily a consensus of all the consultants and professional societies that reviewed this criteria document on heat stress. A list of the NIOSH Review Committee and Consultants appears on pages iii and iv.

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The Office of Research and Standards Development, National Institute for Occupational Safety and Health, had primary responsibility for development of the criteria and recommended standard for hot environments. Steven A. Coppola served as criteria manager and Dr. Austin Henschel had NIOSH program responsibility for development of the document.

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CRITERIA DOCUMENT: RECOMMENDATIONS FOR AN OCCUPATIONAL EXPOSURE STANDARD FOR HOT ENVIRONMENTS

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I. RECOMMENDATIONS FOR A STANDARD FOR WORK IN HOT ENVIRONMENTS

The National Institute for Occupational Safety and Health (NIOSH) recommends that employee exposure to heat in the workplace be controlled by requiring compliance with the work practice standard set forth in the following sections. Adherence to the precautionary procedures prescribed will prevent acute or chronic heat disorders and illnesses and heat induced unsafe acts, and will reduce the risk of harmful effects due to the interactions between excessive heat and toxic chemicals and physical agents. The standard is amenable to techniques that are valid, reproducible, and presently available. It will be reviewed and revised as necessary.

Section 1 - Definitions

(a) Acclimatization to heat means a series of physiological and psychological adjustments that occur in an individual during his first week of exposure to a hot environment so that thereafter the individual is capable of working in a hot environment without excessive strain.

(b) Unimpaired mental performance means the ability of an employee to cope with conditions where safety and health depend on constant alertness because he has to make critical decisions, fine discriminations, or fast and skillful actions.

(c) Intermittent heat exposure means exposure to hot environmental conditions which continues no longer than fifteen minutes without an interrupting interval spent either spontaneously or according to a prescribed schedule in a cooler environment.

(d) Continuous heat exposure means any exposure to hot environmental conditions which is not an intermittent exposure.

(e) Hot environmental condition means any combination of air temperature, humidity, radiation and wind speed that exceeds a Wet Bulb Globe Temperature (WBGT) of 79°F.

Section 2 - Applicability

The provisions of this standard are applicable to all places of employment, indoors and outdoors, and to all employees except those who are required to wear impermeable protective clothing.

Section 3 - Work Practices

(a) For sedentary jobs where continuous unimpaired mental performance is required, no employee shall be exposed to conditions which exceed the limits set forth in Figure I-1.

(b) No employee should be permitted to work without protective observation at high heat stress levels.

(c) When exposure of an employee is continuous for one hour or intermittent for a period of two hours and the time-weighted average WBGT exceeds 79°F for men or 76°F for women, then any one or combination of the following practices shall be initiated to insure that the employee's body care temperature does not exceed 100.4°F:

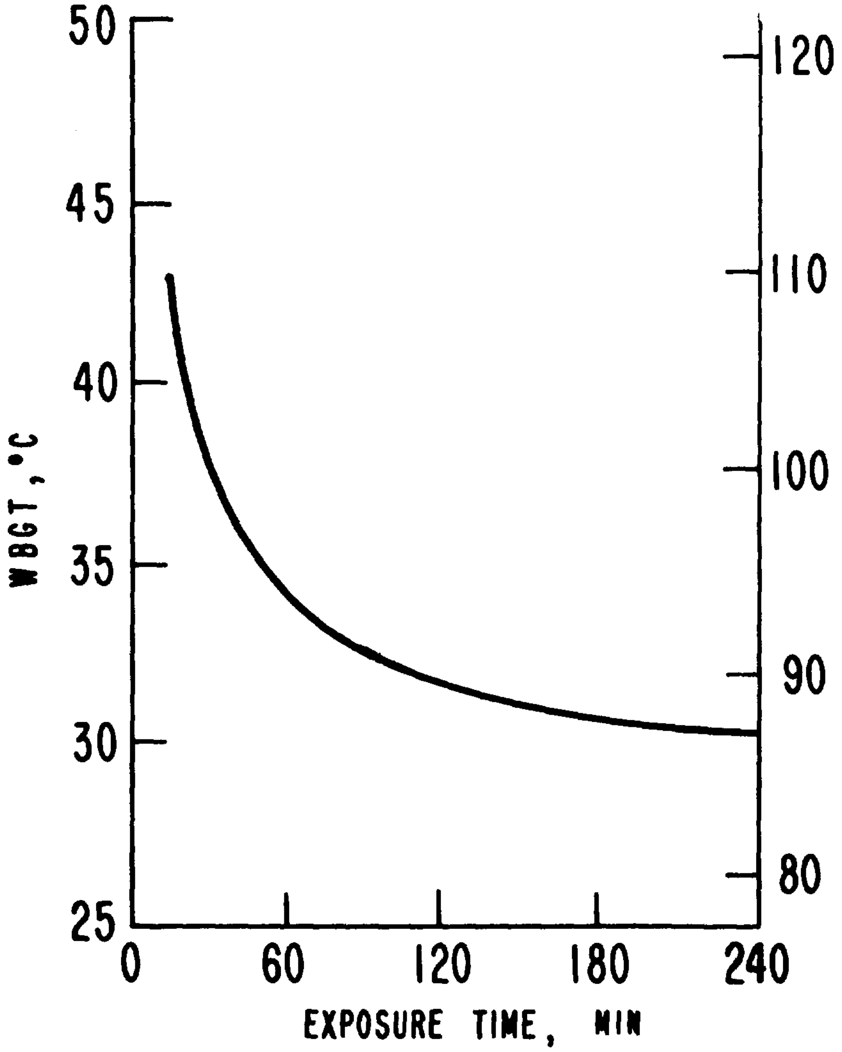

FIGURE I-1. UPPER LIMITS OF EXPOSURE FOR UNIMPAIRED MENTAL PERFORMANCE

(i) Acclimatization

(1) Unacclimatized employees shall be acclimatized over a period of 6 days. The acclimatization schedule shall begin with 50 percent of the anticipated total work load and time exposure on the first day, followed by daily 10 percent increments building up 100 percent total exposure on the sixth day.

(2) Regular acclimatized employees who return from nine or more consecutive calendar days of leave, shall undergo a four day acclimatization period. The acclimatization schedule shall begin with 50 percent of the anticipated total exposure on the first day, followed by daily 20 percent increments building up to 100 percent total exposure on the fourth day.

(3) Regular acclimatized employees who return from four consecutive days of illness should have medical permission to return to the job, and should undergo a four day re-acclimatization period as defined in (2) above.

(ii) A work and rest regimen shall be implemented to reduce the peaks of physiological strain and to improve recovery during rest periods.

(iii) The total work load shall be evenly distributed over the entire work day when possible.

(iv) When possible hot jobs shall be scheduled for the coolest part of the work shift.

(v) Regular breaks, consisting as a minimum of one every hour, shall be prescribed for employees to get water and replacement salt. The employer shall provide a minimum of 8 quarts of cool potable 0.1 percent salted drinking water or a minimum of 8 quarts of cool potable water and salt tablets per man per shift. The water supply shall be located as near as possible to the position where the employee is regularly engaged in work, but never further than 200 feet* therefrom.

(vi) Appropriate protective clothing and equipment shall be provided and used.

(vii) Engineering controls to reduce the environmental heat load shall be utilized.

Section 4 - Environmental Measurements

(a) The WBGT index used as the parameter in determining the environmental conditions for implementation of work practices shall be calculated by the following equations:

For indoor exposure, or outdoor exposure with no solar load:

$$\mathrm{WBGT} = 0.7\ \mathrm{WB} + 0.3\ \mathrm{GT}$$

For outdoor sunlit exposure:

$$\mathrm{WBGT} = 0.7\ \mathrm{WB} + 0.2\ \mathrm{GT} + 0.1\ \mathrm{DB},$$

where WB = the natural wet-bulb temperature obtained with a wetted sensor exposed to the natural air movement (unaspirated)

GT = globe thermometer temperature

DB = dry-bulb temperature

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*Except where a variance had been granted.

(b) The time-weighted average WBGT shall be determined by the equation:

$$\text{Av. WBGT} = \frac{(\text{WBGT}_1) \times (t_1) + (\text{WBGT}_2) \times (t_2) + \text{---} (\text{WBGT}_n) \times (t_n)}{(t_1) + (t_2) + \text{-------------} (t_n)}$$

where WBGT_1, WBGT_2, WBGT_n, are calculated values of WBGT for the various work and rest areas occupied during total time period; t_1, t_2, t_n are the elapsed times in minutes spent in the corresponding areas which are determined by a time study.

(i) Where exposure to environmental conditions is continuous for several hours or the entire work day, the WBGT shall be calculated as an hourly time-weighted-average.

(ii) Where exposure is intermittent, the WBGT shall be calculated as a two-hour time-weighted average.

Section 5 - Medical

(a) All employees who are 45 years of age and older and who have not had previous occupational exposure to heat shall not be assigned to jobs where the environmental conditions equal or exceed 79°F WBGT for men and 76°F WBGT for women, until they are acclimatized.

(b) All personnel who are to be assigned to hot jobs for the first time shall be evaluated by a physician prior to assignment to assure that the individual can cope with the hot environment. In the examination special emphasis should be on the cardiovascular, renal, hepatic, endocrine, and respiratory system and the skin. The examination should also include a complete medical history of the worker with specific emphasis on previous heat-related disorders or illnesses.

(c) All employees exposed to hot environmental conditions should be given a periodic physical examination every 2 years for employees under age 45, and every year for employees 45 years of age or older, that should include all components of the preplacement examination.

(d) There shall be a person available during working hours, who shall have had first aid training in recognizing the signs and symptoms of any heat disorder or illness.

Section 6 - Apprisal of Employees of Hazards from Exposure to Excessive Heat

Each employee who may be exposed to environmental conditions that exceed the prescribed limits shall be given training in health and safety procedures through a program that shall include the following as a minimum:

(a) Information as to water intake for replacement purposes.

(b) Information as to salt replacement.

(c) Importance of weighing each day before and after the day's work.

(d) Instruction on how to recognize the symptoms of heat disorders and illnesses, including dehydration, exhaustion, heat syncope, heat cramps, salt deficiency exhaustion, prickly heat, and heat stroke.

(e) Information as to special caution that shall be exercised in situations where employees are exposed to toxic agents and/or other stressful physical agents which may be present in addition to and simultaneously with heat.

(f) Information concerning heat acclimatization. The information shall be kept on file and readily accessible to the worker at all places of employment where he may be exposed to excessive heat.

Section 7 - Warning Sign

The following warning sign shall be appropriately located at one or more places to be noticed by any one entering an area where environmental conditions are 86°F WBGT or above.

WARNING

HEAT STRESS AREA

Section 8 - Monitoring

(a) A WBGT profile shall be established for each work place for winter and summer seasons to serve as a guide for deciding when work practices shall be initiated to conform with the requirements of the standard. The first profile shall be established within 3 months of the effective date of this standard.

(b) After the WBGT profiles have been established, monitoring shall be conducted once during July and August of each year.

Section 9 - Recordkeeping

(a) The following records shall be maintained:

(i) Medical records for each employee.

(ii) Records of acclimatization as required by Section 3(c)(i).

(iii) Records of the WBGT for each work area as specified in Section 8.

(b) Records required by provisions (i) and (ii) above shall be maintained for a period of the employee's employment and for one year thereafter.

(c) Records of the WBGT as specified in (iii) above shall be maintained for a period determined by the Secretary of Labor with consultation with the Secretary of Health, Education, and Welfare.

II. INTRODUCTION

This report presents the criteria and the standard based thereon which were prepared to meet the need for preventing occupational diseases arising from exposure to industrial heat. The necessary relevant data are made available for use by the Secretary, Department of Health, Education, and Welfare in accordance with the provision of the Occupational Safety and Health Act of 1970 requiring the development of criteria by "The Secretary, Department of Health, Education, and Welfare... on the basis of such research, demonstrations, and experiments and any other information available to him... to effectuate the purposes of this Act."...,"... by providing medical criteria which will assure insofar as practicable that no employee will suffer diminished health, functional capacity, or life expectancy as a result of his work experience"...

The National Institute for Occupational Safety and Health (NIOSH), after a review of data and consultations with others, formalized a system for the development of criteria upon which standards can be established to protect the health of workers from exposure to hazardous chemical and physical agents. It should be pointed out that any recommended criteria for a standard should enable management and labor to develop better engineering controls and more healthful work practices and should not be used as a final goal.

These criteria for a standard for industrial heat are one of the first of the criteria developed by NIOSH. The criteria and standard speak only to work in a hot environment as applicable under the Occupational Safety and Health Act of 1970. These criteria were developed to assure that the standard based thereon would: (a) protect against heat induced illnesses; (b) be amenable to techniques that are valid, reproducible, and available to industry and official agencies; and (c) be attainable with existing technology. This recommended work practices standard is designed to prevent primary heat disorders, heat induced unsafe acts, and harmful effects which may arise from the interactions between heat and toxic chemicals and physical agents.

This recommended standard is based upon the best currently available information. Research is continuing both in NIOSH and in industry to provide necessary data for a more detailed standard. The recommended standard is essentially a work practices standard. The environmental measurements are not intended as an upper limit for occupational exposure, but only as a level at which work practices must be implemented. Such research will serve to validate other methods for incorporation into this recommended standard. Additional criteria are hoped to be recommended to augment this recommendation in the future.

III. BIOLOGIC EFFECT OF EXPOSURE

Extent of Exposure

Several field studies have been performed to assess the extent of heat stress to which workers in different occupations in the United States are exposed and to determine the extent of physiological strain which develops as a consequence of this exposure.

The field studies performed by the U.S. Public Health Service[1,2,3,4] investigated conditions in ferrous and non-ferrous metal factories, in glass and chemical industries, as well as in surface coal mining, dam building and other outdoor operations involving mainly heavy equipment operation. Minard et al.[5] recently reported their observations on steel workers.

The pertinent results of these field studies are summarized below.

The workers in hot jobs are a highly select population. Workers who feel that they cannot cope with the prevailing heat stress change their job for a less demanding one. As a result of this natural selection process, the majority of the workers in hot jobs have high levels of physical performance and capacity and are highly adaptable to work in heat.

Heat disorders are more likely to occur at times when the workers are unacclimatized as during the first hot spell in the summer or when physical fitness is diminished as on Mondays after a leisurely weekend or the first day after a vacation, or return to work after an illness.

Because jobs in hot environments may be better paid than other jobs, it often happens that workers try to stay with the hot job even after their health or fitness becomes inadequate for the job. Since there is no obligatory standard for physical fitness for these jobs and since periodic medical examinations have been haphazardly done in many industries, if done at all, these workers stay on the job and run a high health risk.

Oral temperatures in excess of 99.6°F (corresponding to a deep body temperature of 100.4°F) or first-minute recovery heart rates in excess of 110 have been very seldom observed. They occurred mainly in jobs where the environmental conditions exceeded the upper limit prescriptive zone (ULPZ), (see part V) particularly if the workers worked overtime or worked two shifts in sequence.

There are many work practices in industry which are unofficial and are aimed at ameliorating the workers heat strain on excessively hot days. Such practices are:

1. Only the unavoidable operations are performed. Other less important jobs are postponed.

2. Workers involved in auxiliary jobs are reassigned to help out those who work in the hot areas.

3. The younger and more fit take over some of the work from the older and less fit.

These practices, if not recognized, may give the wrong impression that the old and less fit worker tolerates the work in heat as well as the younger and more fit.

Most workers in hot jobs drink less water than they lose by sweating. According to many laboratory and field studies, this affects physical fitness adversely, particularly if the water loss is more than 1.5% of total body weight.[6] Such dehydration could be prevented by:

1. Making drinking water of good quality easily accessible to the worker.

2. Providing a 0.1 percent salt solution as drinking water, available from drinking fountains which cool the water.

3. Providing salt tablets for salt supplementation to the workers.

4. Advising the worker about the significance of drinking water often in small installments and using much salt on food when he is exposed to hot working conditions.

In many jobs the workers' heat exposure could be substantially reduced by relatively simple measures, such as wearing certain protective clothing, turning on all available fans and opening all windows, distributing the job more evenly during the workday and breaking up the work cycles into shorter work-rest cycles. Unfortunately, either because of ignorance or carelessness, the workers often expose themselves to greater heat stress than would be necessary.

Often with little expense the climatic conditions could be ameliorated or the work load diminished.

Early Historical Reports

Nearly 70 years ago concern for the health of the Cornish Tin Miners lead to one of the first studies of the effects of heat on the health of workers and stimulated the search for a method of expressing in simple terms the impact of a hot working environment. Except for the studies of Bedford,[7] on the effects of atmospheric conditions on the industrial worker, little progress was made until shortly before and during World War II. In the late 1930's the interest was directed toward the industrial worker and the health and safety consequences of working in hot industries. The classical research of Bazett,[8] Bedford,[7] Dill,[9] Drinker,[10] Talbott,[11] Yaglou[12] and several others identified the acute and chronic heat disorders and their dependence on the intensity of the heat stress. Recommendations for engineering controls and medical prevention and treatment were made which are still pertinent to the solution of today's industrial heat stress problems. Military operations in the tropics and the African Campaign of World War II stimulated a major research effort on the physiological consequences of exposure to high temperatures. Much of the vast quantity of basic information on acclimatization, water and salt requirements, heat disorders and permissible exposure levels developed during that period has been presented by Adolph et al.,[13] Newburgh,[14] and the Medical Research Council of England.[15] The Thermal Standards in Industry,[12] published in 1947, recommended limits and procedures which are considered valid and applicable in today's industries.

During the past 25 years much effort has centered around the problem of expressing in relatively simple terms the total impact of the hot working environment upon the worker. Several attempts have been made to formulate a predictive scheme which would translate the heat load into biologically meaningful values. These predictive schemes can be roughly grouped into: (a) those that sought a device which would respond to the major environmental factors in a manner similar to man's, (b) those based upon measured human responses which could be used to evaluate combinations of environmental conditions, and (c) those based on calculations to determine whether it is possible to maintain thermal balance under any combinations of the climatic factors and work intensity and if so, how much physiological strain is involved. Each approach has its logic as well as its failings. A detailed discussion of the more important of the indices for estimating the biologic impact of a hot environment is presented later in the text.

Epidemiological Studies

Neither prospective nor retrospective epidemiological studies have been made in which the health experiences of workers have been correlated with the length and intensity of heat exposure at the work site during the working life of the individuals. Health data for retrospective studies could probably be found in the health and medical records of some insurance companies and larger industries. Particularly lacking in most of the morbidity and mortality reports, however, are measurements of the level of heat exposure and the time spent on the hot jobs.

Health experience statistics for some hot industries have been reported over the past 50 years.[16,17,18,19,20,21,22] In a study of 23,000 coal miners,[18] lost time due to sickness was 63 percent higher in miners working at temperatures above 80°F. than in those working at temperatures of 70°F. or less. Death rate increase of about 35 percent was reported in 1937[20] for miners working hotter mines. In another study, Britten and Thompson,[21] found organic heart defects were more frequent in foundry workers. Enlarged hearts and arteriosclerosis were found more often among steel and glass workers. The frequency of industrial accidents increases in higher temperatures but the increase is mostly in minor accidents. It is not possible to generalize these reports of heat experience in chronic heat exposure in industry several decades ago to present-day industry. However, personal communications and experiences of medical and scientific personnel suggest that chronic exposure in hot working environments can have serious health and safety consequences.

The acute effects of heat on health and safety have been documented by literally hundreds of carefully controlled laboratory and field studies. The incidence of heat illness in young men in industry and military service who were not acclimatized to heat has been reported in several studies to be between 1.5 and 3.5 per 1000 at risk in the United States, under conditions of environmental heat and work loads which approximate the 1971 ACGIH TLV for Heat Stress. Age, sex, individual tolerance and many other factors will influence the incidence rate.

Effects of Heat

Environmental heat (or resistance to removal of metabolic heat) leads to well-documented reactions in human beings: increased cardiovascular and respiratory activity, increased body heat content, sweating, etc. If the heat load is excessive or prolonged, then frank heat disorders result. In this section subpathological effects will be considered which may modify performance, behavior or responses to other simultaneously imposed stresses.

Physical performance is affected by heat. Heat stress involves cardiovascular strain, e. g., demands are made for blood flow to the periphery for thermo-regulatory purposes. Cardiac output, therefore, is not totally available to active muscles. The competition increases with increasing heat load when the combined demands exceed the maximum cardiac output, the upper limits of tolerance are reached, and work output must of necessity be reduced.[23] These conditions may obtain under emergency conditions or in highly motivated individuals. Such motivation can lead to overstrains.[24] That real limits of endurance exist was demonstrated quantitatively by Wyndham et al.[25] Productivity of mining recruits varied with quality of their supervision up to saturated environments of 28.9°C (93°F). Further increase to a saturated environment of 35.5°C (95.8°F) resulted in almost total cessation of productive work.[26] Other examples of heat-limited work are given in Leithead and Lind.[16] Because of these experiences and those of Minard et al.,[27] upper limits for unrestricted work have been set at environments near the 29.5°C (85°F) effective temperature (ET) level. The Wet Bulb Globe Temperature Index was derived from the ET concept (see Section V); the recent tentative TLV for heat[28] specifies 30°C WBGT as the upper limit for continuous moderate work (approximately 200 Kcal/hr for acclimatized men).

Recently, the tentative TLV has been challenged as being too conservative.[29] Experience shows that often men have worked effectively for years in environments and at metabolic rates exceeding those suggested by the TLV with no apparent detrimental effects. Indivdual differences in heat tolerance and selection may in part account for this, errors in establishing time weighted average values for the metabolic costs of physical tasks and the environmental heat load may also prove to be partially responsible,[30,31]especially in the heavier jobs.

It should be noted that decrement in performance was not especially noted in the above cited references up to the 30°C ET (or WBGT) levels for tasks involving large muscle groups in gross efforts, e.g., marching, shoveling, heavy work in the hot industries. Lower levels of heat may adversely affect the efficiency with which the heavy tasks are performed[32] or may interfere with accomplishment of more skilled manipulative or psychological tasks.[23] Some of the factors that influence performance in the heat have recently been reviewed.[33]

Psychological performance is also affected by heat. Pepler has reviewed the effects of heat on skilled tasks (tracking, telegraphy) or mental tasks (learning).[34,35] Qualitatively, there is no doubt that heat interferes with these types of activities. It is interesting to note that sensorimotor coordination deteriorates more rapidly in cold than hot environments.[35]

It is common experience that heat exposures accelerate the onset of fatigue; prolonged hot conditions (e.g., summer heat waves) may further contribute to general fatigue by robbing the individual of sound sleep.[35] One effect, whether from heat directly or as an indirect effect of fatigue is that accuracy of response deteriorates.[36] Studies by Duggar[37] of a delicate assembly task indicated that though production of good pieces was maintained (subjects on incentive pay), the quantity of scrap increased somewhat. Thus, the workers were actually having to work harder in the heat to maintain production, a further indication of lowered efficiency.

More recently, Pepler has studied the effects of air conditioned versus non-air conditioned classrooms on the process of learning.[38] There seems to emerge statistically that even relatively slight increases in environmental temperatures affect learning adversely.

Several psychomotor tasks were examined in comfortable and warm environments (up to 80°F, 60 percent RH) by Griffiths and Boyce.[39] Examination of the results revealed an optimum performance at a temperature similar to the optimum comfort temperature. As Hatch points out,[40] the establishment of criteria for upper levels of heat exposure which has as its primary goal to maintain physiological well-being and health should be determined by medical personnel. Below this level, the major considerations are in the province of management: decisions relative to productivity, employee relations and the like, except perhaps as these less-than-injurious exposures may influence accidents.

Wherever there exists molten metal, hot surfaces, steam, etc., there exists the potential hazards of accidental contact of the worker with the hot object. Burns of varying severity result. Often the accident will be caused by a secondary agent, such as water escaping into molten metal, malfunction of pressure relief valves on water heaters and the like. Aside from the direct burn hazard of heat and hot objects, environmental heat appears to increase the frequency of other kinds of accidents in general.

Mechanically, the heat may tend to promote accidents due to slipperyness of sweaty palms or interfering with vision through fogging of safety glasses. Beyond these obvious effects, accidents have been documented to increase in hot jobs (e.g., Vernon et al.[18]). A striking demonstration of environmental effect on accident rates was compiled from records of a steel mill over a four-year period (Figure 1).[41] There is a definite parallelism between weather and accident frequency. The accident peaks, however, exhibit a downward trend over the years, most likely reflecting the efforts of intensive safety programs. Belding et al. have suggested the weather effect may be due to reduced general tonus of bodily activities and alertness related to high environmental temperatures. Again, increased bodily temperature and discomfort increase irritation, anger, and other emotional states which may induce workers to commit rash acts or divert attention from hazardous tasks.[42] In extreme heat, emotions may spill over into fights[16] or other manifestations of emotional crises, e.g.[43]

At lesser stresses, more subtle disturbances in emotional state, e.g., depression, may be evident. Extensive folklore has been generated around the deleterious effects of the "Foehn" of Europe, the "Sharav" of Israel, and other warm "ill winds".[44] While the correlation between these climatic changes and illness seems real, the aetiology remains controversial.[45] Intuitively, disturbed emotional states should reduce alertness on the job, setting the stage for accidents.[46]

Effects of stresses in the occupational environment have been the subject of many quantitative studies. From these, threshold limit values (TLV) were derived, values which have served well as guides to reduce occupational exposures.

In general, the TLV's were established from experiments with single stress exposures. Often, however, more than one stress will occur and, in fact, it will be the rare case where only one stress obtains. There has been an increasing awareness of the alteration in physiological response to a stress where other stresses are present. Because of the ubiquitous nature of heat stress, it has received attention as a potentiator or mediator of response to other physical and toxic agents; and it certainly influences the course of diseases.

In combination, heat (85°F, ET) and carbon monoxide (100 ppm) have been shown to have a greater deleterious effect than either stress alone.[47] It is difficult to quantitate the effect; manifestations included inability to complete the four-hour exposure, irritability, and, occasionally, syncope. The effects were more pronounced in women than in men. The subjects reported persistent headaches, anorexia, irritability, depression, and general malaise. These postexposure symptoms were markedly more severe after exposure to heat and CO than after exposure to either alone. It is interesting to note that these were physiological disturbances and that the more severe occurred in the hours following the exposures. No decrement in performance on a battery of psychomotor tests (e.g., tracking tasks) was seen from either of the stresses alone or in combination during the exposure. It would be interesting to test the subjects on the psychomotor tasks at intervals after the exposures.

According to Baetjer,[48] heat also influences the effect of drugs on experimental animals. Certain substances, e.g., coal tar, cresols, create exceptional photosensitivity of the skin. Even a short exposure in the late afternoon when the sun is low is likely to produce severe sunburn.[49] These problems are primarily associated with ultraviolet radiation and so are limited to outdoor workers.

These data indicate the complexity of the interactions of multiple stresses. They raise fundamental questions as to the validity of those TLV's based on single stress experiments for toxic substances in the presence of heat.

Renshaw [50] investigated the effects of noise (41, 80, 90, and 100 dBA) and heat (72, 78, 84, and 90°F ET) on performance on a 5-Choice Serial Reaction Task. The effect of heat on "gaps" was statistically significant. Subjects committed 18 percent more gaps at 90°ET than at 72°ET at the same noise level.

It has been a common observation that mortality increases during prolonged hot spells, e.g., St. Louis, 1966.[51] Similarly, the frequency of illinesses seems to be dependent on the heat load. There are numerous instances cited in the literature where increases in dispensary visits, etc., accompany hot weather, even as do accidents (as noted above). Pepler [34]reviewed a number of experiences reported by the several military services of Great Britain. The illnesses, aside from frank heat illnesses, ran the gamut of nonspecific complaints, general malaise, and even psychoneurotic illnesses.

Bannister[52] observed that injection of a bacterial pyrogen caused a sudden cessation of sweating lasting upwards of an hour. This suggests that concurrent infections may predispose an individual to greater sensitivity to heat stress.

Heat alters the number of free alveolar macrophages in rats.[48] While somewhat afield from the problem under review here, the implications are that there are many subtle little understood physiological adjustments to heat stress whose role in rendering a worker on hot jobs more or less resistant to bacterial invasion is unknown.

Correlation of Exposure and Effects

The physiological and medical consequences of exposure to heat are not directly proportional to the intensity throughout the entire range of heat stress. Over a rather large range of temperatures, physiological functions are independent of the temperature. In the environment driven zone (EDZ See Part V) the physiological strain increases exponentially so that at high levels of heat stress a small incremental increase in stress results in a large increase in strain. The safety factor becomes progressively smaller as the total heat-work stress is increased. Consequently, as the heat stress becomes higher, more care and precaution must be exercised to insure the health and safety of the worker.

Many factors, which can exist in limitless combinations, interact to determine relationships between exposure and effects. The more important of these factors include the Environmental Factors, the Human Factors, and the Task Factors (Table I). The impact of some of these factors on performance and heat tolerance has recently been reviewed.[33] It is emphasized that for any specific environment-worker-job situation the total stress and health and safety consequences can be brought to acceptable and desirable levels by adequate control of one or more of the factors.

One of the most dramatic and successful physiological mechanisms possessed by man is his ability to increase his tolerance to work in heat. The physiological and psychological processes involved in acclimatization to heat have been described in many technical papers and several comprehensive reviews.[16,53,54] Acclimatization to heat is a series of physiological adjustments that occur when one who is accustomed to working in a temperate environment is suddenly placed in a hot environment. These physiological adjustments which occur over a period of one to two weeks reduce the strain experienced on the initial exposure to heat. The physiological changes during acclimatization which are most easily observed are the responses of the body temperature and pulse rate, both of which increase during the first day of heat exposure and then progressively decrease with each succeeding day of exposure. The sequence is shown in Figure 2. On first day of exposure to heat, ability to perform muscular work is impaired, body temperature and pulse rates are increased and lassitude and discomfort is experienced. When the conditions are extremely severe, acute heat disorders may occur. After the major part of acclimatization has taken place, work in the heat can be performed with little strain and a major reduction in distress. The exposure-effects relationships, therefore, are strongly dependent on the state of acclimatization of the individual.

Medical Considerations

The three major clinical disorders resulting from excessive heat stress on susceptible workers are: (1) heat stroke, from failure of the thermoregulatory center; (2) heat exhaustion, from depletion of body water and/or salt; (3) heat cramps, from salt loss and dilution of tissue fluid.

Other clinical entities from heat effects are heat syncope, heat rash, anhidrotic heat exhaustion, heat fatigue-transient, and heat fatigue-chronic.[16] (See also Figure 3.)

1. Heat Stroke

a. Diagnostic criteria: Heat stroke (the term sunstroke is obsolete) is the most serious of the heat disorders, constituting a medical emergency of major magnitude.

The three cardinal signs of heat stroke are: (a) hot dry skin: red, mottled, or cyanotic; (b) hyperthermia: a body temperature usually of 106°F or higher and rising; (c) brain disorders: mental confusion, delirium, loss of consciousness, convulsions, and coma.

b. Treatment: Heat stroke is uniformly fatal unless treated promptly and adequately. Treatment consists in rapid cooling of the body preferably by immersion in chilled water accompanied by vigorous massage of the skin or alternatively by wrapping the unclothed body of the patient in wet sheets and fanning vigourously with cool dry air. First aid treatment of the victim should always be initiated immediately and not delayed while waiting for transportation to a medical facility. First aid consists in moving the patient to a cool area and thoroughly soaking the clothing with cold water and fanning to increase convective cooling. Definitive medical treatment required rapid cooling until body temperature is reduced to 100-102°F, then monitoring body temperature to avoid overcooling and to detect recurrent rise, and treating shock if present. Major complications are renal failure, hepatic failure, hemorragic disorders, and myocardial impairment. These complications as well as the permanent brain injury which is a frequent sequela are in part consequences of prolonged and uncontrolled hyperthermia and in part the result of tissue hypoxia when shock supervenes. These complications can be avoided by prompt and effective emergency treatment.

In four groupings of cases surviving long enough to be admitted to a hospital for treatment and reported in the medical literature, the mortality rate increased in direct ratio with the increased temperature on admission (Minard and Copman, 1963):[56]

Admission Temperature (°F)	No. of Cases	Mortality Rate (%)
106	188	14.9
106-108	122	20.5
108-110	155	34.2
110 or over	118	61.0

Because thermal injury to vital tissues, particularly the brain, is a rate limited process depending both on degree of temperature elevation and time, injury can occur even at relatively low body temperature; e.g., 105°F if hyperthermia is prolonged. By the same token, survival with complete recovery is possible at extreme hyperthermia; e. g., 108 or above, if cooling is prompt and effective.

Malamud, Haymaker, and Custer [55] who described a wide range of premortem brain disorders in 125 fatal cases of heat stroke occurring in military trainees in World War II, state that "damage to the central nervous system was manifest from the onset and persisted to the end. In cases of longer duration, dementia, asphasia, or hemiplegia indicated that the effect on the central nervous system was probably lasting and irreversible. A direct relationship between the nervous manifestations and the degree and duration of hyperthermia was always evident."

Early recognition and treatment of heat stroke can prevent both death and permanent brain damage. Between 1956 and 1960, twenty-one cases of heat stroke in the Marine Corps recruits were admitted to the dispensary at the Marine Corps Recruit Depot, Paris Island, South Carolina, with rectal temperatures ranging from 105.5 to 109.6°F (mean 107.1°F, S. D.1.08°F). All recovered. Eighteen completed both recruit and advanced training. Three were medically discharged. Of these, one who had presented a long history of heat intolerance dating from childhood recovered with no sequelae. In the other two, the clinical course of recovery had been complicated by acute renal failure. Although renal function in both eventually returned to normal, it was the opinion of the physical evaluation board that the risk of recurrent renal disease would be less incivilian life.

c. **Underlying** mechanisms: Hyperthermia in heat stroke results from suppression of sweating, which may be gradual or abrupt in onset. Failure of the principal mechanism for dissipation of body heat under heat stress, i.e., cooling by sweat evaporation, leads to storage of body heat, the rise in body temperature being more rapid in individuals whose heat production is elevated during work. The upward spiral of body temperature is accelerated by the Q_{10} effect, the rate of metabolic heat produced in tissue cells being increased between 2 and 3X for each 10°C rise in temperature. Why the central thermoregulatory drive for sweating fails is not known; a reduced response, or "fatigue" of the sweat glands, to the central drive may be a contributing factor.

Heat hyperpyrexia is a term sometimes applied to cases of thermoregulatory disorder in which body temperature is elevated to 105 or 106°F, but sweating is still evident and disorders of consciousness are mild or absent. These cases of hyperthermia may represent early stages of heat stroke or a transitional stage between milder heat disorders, such as heat exhaustion, and heat stroke. Treatment by active cooling is indicated unless rest in a cool area leads to immediate and positive signs of recovery.

d. Predisposing factors: In industrial workers and military trainees, the primary underlying factor in heat stroke is lack of acclimatization often associated with poor physical fitness and/or obesity. Precipitating factors are prolonged exertion under heat stress with inadequate time allowances for rest and recovery.[57] Recent alcoholic overindulgence in otherwise seasoned workers has been identified as a probable factor in some cases.[58] In elderly individuals living in poorly ventilated housing, the risk of heat stroke during prolonged heat waves in northern cities is greates in those with a history of chronic cardiovascular or cardiorespiratory disease.[51] In such cases impaired circulatory capacity to transport heat from body core to the skin is the underlying cause of hyperthermia and thermoregulatory failure rather than elevated metabolic heat production during work.

2. Heat Exhaustion

a. Diagnostic criteria: The diagnostic term "heat exhaustion" encompasses disorders which may vary in etiology, but manifest similar clinical signs and symptoms. These are chiefly weakness or extreme fatigue, giddiness, nausea, and headache in persons working in the heat, or often while resting between bouts of work. The skin is clammy and moist, indicating that sweating remains active. The complexion may be pale, muddy, or flushed. Oral temperature may be normal or low, but rectal temperature is usually elevated (99.5 to 101°F). If sitting, the patient may faint on standing with a weak thready pulse and low blood pressure. The underlying disorder in heat exhaustion is depletion of body water due either to restricted water intake, or to deficient salt intake, or more often to both. In the water restriction type, urine is highly concentrated and small in volume; thirst is a prominent symptom. In the salt deficiency type, circulatory insufficiency is more extreme, urine is more dilute, larger in volume, but chlorides are absent ($<$ 1 gm/liter). Thirst is less evident. Blood electrolytes may be slightly elevated with hemoconcentration in the water restriction type and somewhat below normal in the salt deficiency type. Laboratory facilities are often not available to differentiate the two types. Results of blood analysis, however, are not essential in making a diagnosis of heat exhaustion as this can be determined on the basis of the clinical signs and symptoms noted above.

b. Treatment: Treatment is based on correcting dehydration which is the underlying disorder common to both types of heat exhaustion. Many mild cases recover spontaneously following rest in a cool area and taking water. The severe case of heat exhaustion should be removed to a treatment facility. Dehydration is corrected by administering salted fluids by mouth. If the patient is unconscious or vomiting, normal saline is infused intravenously. He should be kept at rest until the urine volume and salt content indicate that salt and water balances have been restored. Recovery is complete and usually rapid except in cases of extreme salt depletion in which several days of treatment may be required.

c. Underlying mechanism: Physiological control mechanisms involving the hypothalamus, the posterior pituitary gland, the adrenal cortex and volume receptors in the vascular system and the kidney regulate the osmolarity and volume of ex-racellular fluid. With restricted water intake combined with losses of water and salt in the hypotonic sweat, extracellular fluid tends to become hypertonic. Excess salt is excreted via the kidney with maximum reabsorption of water through mediation of ADH.

Osmolarity is maintained but at the cost of reduced volume of extra and intracellular fluid. In salt deficiency with continued intake of water, extracellular fluids tend to be diluted. Osmolarity is maintained by reduced renal reabsorption of water and retention of salt through release of aldosterone, acting both on the kidney and on the sweat glands. Intracellular fluid volume may increase. These compensatory mechanisms lead to dehydration from negative water balance. The effect is to reduce circulating blood volume.

In both types of dehydration, there is a contraction of circulating blood volume, more marked in the salt deficiency type. Thus, under heat stress, circulatory insufficiency results from the competing demands for blood flow to the skin to dissipate heat and for blood flow to the active muscles, with consequent weakness, hypotension, and syncopal symptoms.

d. Predisposing factors: In unacclimatized men working in the heat, salt concentrations in sweat tend to be high. Dietary intake of salt, particularly if heat strain results in impaired appetite, may be inadequate to balance losses in the sweat. Drinking salted water (0.1 percent) is the best method for supplementing salt intake. Also, lack of acclimatization in men losing up to several liters of sweat per day often leads to voluntary dehydration, a term indicating that the thirst mechanism fails to provide an adequate stimulus to drink water in sufficient quantities to balance the losses in sweat. Workers should be instructed to drink more than necessary to satisfy thirst. Failure of supervisors to provide ready access to water, or to provide breaks at frequent intervals, may lead to degrees of dehydration which cannot readily be compensated because the volume of water necessary to be ingested causes gastric distention and distress.

3. Heat Cramps

a. Diagnostic criteria: Heat cramps is a heat disorder characterized by painful spasms in skeletal muscles of workers who sweat profusely in the heat and drink large volumes of water without replacing salt losses. The muscles involved may be in the arms, legs, or abdomen, those used in performing the job being chiefly affected. Onset may be during or after work hours.

b. Treatment: Salted liquids may be given by mouth or hypertonic saline infused intravenously for more immediate relief.

c. Underlying mechanisms: Water intake with continuing salt loss in sweat leads to dilution of the extracellular fluid. Osmotic transfer of water into active muscle fibers causes spasm. Fatigued muscles are the most vulnerable.

d. Predisposing factors: Water intoxication of this type may be observed in seasoned workers as well as in unacclimatized new employees. Prevention is by instructing workers to use more salt at meal times, or by providing 0.1 percent salt in drinking water during work. Salt tablets as a supplement are less desirable because of individual intolerance to solid salt and possible excessive salt loading. Salt should never be taken during hot work unless ample water is also available.

4. Other Clinical Entities

a. Heat syncope: A minor disorder characterized by syncope in unacclimatized workers standing erect and immobile in the heat. Pooling of blood in dilated vessels of skin and lower part of the body results in inadequate venous return to the heart and cerebral ischemia. Recovery of the patient is prompt when recumbent. Intermittent activity to assist venous return prevents the occurrrence.

b. Heat rash: Heat rash, commonly known as prickley heat, results from imbibition of water by keratin and plugging of the orifices of sweat ducts, which leads to inflammation of the glands, and is observed as tiny red raised vesicles in the affected area. It results from unrelieved exposure to humid heat with the skin being continuously wet with unevaporated sweat. It is important because if extensive, or complicated by infection, discomfort from heat rash may not only interfere with restful sleep and impair efficient performance, but can result in temporary total disability. Heat rash is prevented by providing cooled recovery or sleeping quarters to allow the skin to dry between heat exposures.

c. Anhidrotic heat exhaustion: Rarely seen in peacetime, this disorder was observed in military personnel stationed in hot climates in World War II and was characterized by areas of nonsweating skin on the trunk, and limbs which showed a papilliform eruption, like gooseflesh, on heat exposure. This was termed miliaria profunda and represented obstruction of sweat gland ducts deep in the skin. Hyperhidrosis of the face was a characteristic finding. If the nonsweating areas were extensive, impaired evaporative cooling led to heat intolerance with symptoms of heat exhaustion and moderate hyperthermia. There was usually a history of extensive heat rash, with occasional further skin trauma by sunburn.

Associated with the skin disorder and heat intolerance was polyuria, a high cloride concentration in sweat, and a lowered blood chloride. There was no specific treatment but return to cooler climates led to gradual recovery. An extensive review of the etiology of this disorder and miliaria rubra as well as the possible role of endocrine or other systemic factors has been published.[59]

d. Heat fatigue - transient: This term applies to the impairment in performance of complex sensorimotor, mental, or vigilence tasks on exposure to heat. The decrement in task performance produced by heat exposure is greater in unacclimatized and unskilled workers. Discomfort and physiological strain rather than physiological failure of regulatory mechanisms are the major underlying factors. Acclimatization and training for work in the heat reduce the degree of impairment.

e. Heat fatigue - chronic: Formerly termed tropical fatigue, this designates a long term impairment in work performance and social behavior in workers and military personnel transferred from temperate home environments for long residence in tropical latitudes. Factors of boredom and isolation from the customary social environment interact with the physiological strain imposed by unremitting climatic heat and humidity to cause psychological strain and behavioral disorders, including lack of motivation for work, lowered standards of social conduct (e.g., alcoholic overindulgence), inability to concentrate, etc. Prevention is based on selection of personnel for such assignment and on their prior orientation to life abroad (customs, climate, living conditions, recreational opportunities).

The objectives of a preventive program are to prevent clinical disorders from heat stress and also to prevent aggravation of existing impairments by heat and to maintain optimum health and work efficiency. The objectives can be accomplished through the following procedures: pre-placement and periodic medical examination, acclimatization of workers to heat, and monitoring of oral temperature and heart rate.

IV. ENVIRONMENTAL DATA AND CONTROL

Methods for control of occupational exposures to heat must be adapted to the nature of the heat stress, and if chosen properly, can be expected to ameliorate resulting physiologic strains. Control of heat hazards has been discussed in several publications. Engineers may wish to consult a comprehensive monograph issued by the American Industrial Hygiene Association [60] which offers some details not provided here, in particular on thermal control of large factory spaces by ventilation. Engineering aspects of ventilation are also given in the ASHRAE Guide and Data Book.[61]

Earlier, Hertig [62] and Hertig and Belding [63] discussed methods of heat control. Wason [64] provided a comprehensive treatment of many aspects of the subject.

The ultimate goal of heat control engineering may be to create a climate of work in which true thermal comfort prevails. However, this seldom is achievable when large furnaces or sources of steam or water are present in the work area. In compromising with his ideal of providing comfort, the engineer may rationalize his shortcomings with the knowledge that man evolved as a tropical animal; he is well-endowed with physiologic mechanisms to cope with substantial levels of heat stress, particularly if he is acclimatized. It has been suggested that some exercise of these natural mechanisms among healthly individuals may, as in the case with physical exercise, have beneficial effects. This type of justification of hot working conditions is less warranted when jobs demand use of mental or perceptual facilities or of precise motor skills. In such cases thermal discomfort can distract attention; also, heat tolerance of physically inactive workers is less in some respects than for those whose duties require physical activity.

Analysis of the Problem and Options for Control

Before initiating control measures the engineer will wish to identify the components of the heat stress to which the worker is exposed in current operations or is expected to be exposed in new operations. This information can be used as a basis for rational selection of the means of control, and together with similar data obtained following adoption of control measures to demonstrate the effectiveness of corrective actions that have been taken.

Heat stress for the individual worker depends on: (a) the bodily heat production, or metabolic heat, M, of the tasks which he performs; (b) the number and duration of exposures; (c) the heat exchanges as affected by the thermal environment of each task; namely, (R) (Radiant Heat Exchange), (c) (Convective Heat Exchange), and (E) (Evaporative Heat Loss) as affected by tw (temperature of surrounding objects), v (air velocity), ta (air temperature), Pa (vapor pressure in the air) and Ps (vapor pressure on the skin); (d) thermal conditions of the rest area, and (e) the clothing that is worn.

Items (a) and (b) represent elements of behavioral control; (c) and (d), environmental control; and (e) may be regarded as a combination of both.

The approach toward control may involve modification of one or more of these determinants of heat stress. The challenge is to select specific methods for attack which will be both feasible and effective. Serious errors can result from resorting to some single pet engineering solution.

Consider the consequences of ducting outside air to the task site. This air usually is blown at the worker at a temperature as warm as the upper reaches of the shed where the ducts have been installed. This will enhance cooling by evaporation of sweat, but if the air is warmer than the skin (35°C, 95°F), it will increase the convective heat load. Consideration of the trade off between needed heat loss and increased heat gain is essential. The same goal might be achieved less expensively with portable fans.

In some situations the real mistake may be the failure to recognize that the heat problem derives from radiant load from a furnace which is not decreased by air movement. This mistake has been made less frequently in recent years, but elaborate ducting across the ceilings of older plants exist as testimony to use in the part of this inappropriate action.

Effectiveness of means used to control the five listed determinants of heat stress can be compared.

First to be discussed is decreasing the physical work of the task. Metabolic heat, M, can comprise a large fraction of the total heat load. However, the amount by which this factor may be reduced by control often is quite limited. This is because an average sized man who is simply standing quietly while pushing buttons will produce heat at a rate of 100 Kcal/hr whereas one who is manually transferring fairly heavy materials at a steady pace will seldom have a metabolic rate higher than 300 Kcal/hr and usually not more than 250 Kcal/hr.[65] Obviously, control measures, such as partial mechanization, can only reduce the M component of these steady types of work by 100 to 200 Kcal/hr; nevertheless, mechanization can also help by making it possible for the worker to be more isolated from the heat source, perhaps in an air conditioned booth.

Tasks such as shovelling which involve metabolic heat production at rates as high as 500 or 600 Kcal/hr require that rest be taken one-half to two-thirds of the time simply because of the physical demands of the labor. Thus, the hourly contribution of M to heat load will seldom exceed 300 Kcal/hr. It is obvious that mechanization of such work can increase worker productivity by making possible a decrease in the time needed for rest.

The second modifier warranting discussion is modifying the number and duration of exposures. When the task in a hot environment involves work that is a regularly scheduled part of the job, the combined experience of workers and management will have resulted in an arrangement which makes the work tolerable most of the time for most of the workers. For example, the relief schedule for a task which involves manual transfer of hot materials may involve two workers only; because of the heat and depending on the duress, these two workers alternate at intervals from five minutes up to an hour, which have been determined empirically. Under such conditions overall strain for the individual will be less if the cycles are short.[66] Where there is a standardized quota of hot work for each man, it is sometimes lumped at the beginning of the shift. This arrangement may be preferred by workers in cooler weather; however, there is evidence that the strain of such an arrangement may become excessive on hot days. The total strain will be less, evidenced by fewer heart beats, if the work is spread out. Significantly large variations in work site temperature usually occur during the work day. A typical continuous recording is shown in Figure 4.

The stress of hot jobs is also dependent on vagaries of weather. A hot spell or an unusual rise in humidity may create overly stressful conditions for a few hours or days in the summer. Non-essential tasks should be postponed during such emergency periods, in accordance with a prearranged plan. Also, assignment of an extra helper can importantly reduce heat exposure of members of a working team. However, there is danger in this practice when novices are utilized.

Many of the critically hot exposures to heat faced by employees in industry are incurred irregularly, as in furnace repair or emergencies, where levels of heat stress and physical effort are high and largely unpredictable, and values for the components of the stress are not readily assessable. Usually such exposures will force progressive rise in body temperature. Ideally, such physiologic measurements as body temperature and heart rate would be monitored and used as criteria for limiting such exposures on an _ad hoc_ basis. Practically, however, the tolerance limits have been based on experience of the worker as well as of his supervisor. Fortunately, for most workers, perception of fatigue, faintness, or breathlessness may be relied upon most of the time for bringing individual exposures to a safe ending.

The highly motivated individual, particularly the novice who desires acceptance, is at greater risk. In the same spirit, foremen should respect the opinion of an employee when he reports that he does not feel up to work in the heat at a particular time. Non-job personal factors such as low grade infection, a sleepless night, or diarrhea (dehydration affects sweating) which would not affect performance on most jobs, may adversely affect heat tolearance.

Perhaps the best advice that can be offered for control of irregular exposures is (a) that formal training and indoctrination on effects of heat be provided both supervisors and workers, and (b) that these include directions to the effect that each exposure should be terminated before physical distress is manifest. There is abundant evidence that the physiological strain of an exposure which raises body temperature above 38°C is such as to contraindicate further exposures during the same day; it may take hours for complete recovery. More work can be achieved during several shorter exposures and with less overall strain.

The third modification to be discussed is modifying the thermal environment. The environmental engineer will usually identify important sources of heat stress in a qualitative sense, without resort to elaborate measurements. Thus, his experience will suggest that when air is static and the clothes of the workers become wet with sweat, it will help to provide a fan.

Nevertheless, we reiterate the advantages in making a quantitative analysis of the heat stress (and where possible the resulting strains) on workers. The effects of various approaches to control can be predicted, and improvements in thermal conditions at the workplace can be documented for higher levels of management based on measurements made before and after action has been taken.

We cite concrete examples to illustrate how the quantitative analytic approach may be used.

Case I. A case which is encountered frequently under ordinary conditions of hot weather.

Let us assume a laundry where the humidity is high (Pa = 30 mm Hg) despite the operation of a small exhaust fan on the wall. There is no high level heat source so the temperature of the solid surround (reflected in Tg) is about the same as that of the air.

In the simplest situation we take Ta and Tg equal to the temperature of the skin, which may be assumed to be 35°C (95°F). This means heat exchange by R and C is zero. Let us examine the case on the basis that exposure is continuous and the average physical work is moderate (M = 200 Kcal/hr). The heat load, EREQ, is then,

$$M + R + C = EREQ$$
$$200 + 0 + 0 = 200$$

The workers wear minimum clothing. The air speed is low, 15 m (50 ft) per minute. Analysis for the seminude condition yields an indication of maximum evaporative capacity:

$$EMAX = 2.0\ V^{0.6}\ (42 - Pa)$$, where 42 mm Hg is Ps of completely wetted skin at 35°C.

$$EMAX = 2 \times 8.7\ (42 - 30) = 200\ \text{Kcal/hr}$$

Nominally, a worker under these conditions is just able to maintain bodily heat balance if he keeps his skin completely wet. To do this he must sweat extravagantly, which means some dripping. It is easy to see why the workers wear as little clothing as possible. Wearing a long-sleeved work shirt and trousers would reduce EMAX by about 30% or 13 Kcal/hr. The resulting excess of heat load over EMAX would result in rise of body temperature and it can be estimated that the limit of tolerance would be reached in about an hour.

When, as in this case, the heat load is itself moderate, the attack of the control engineer should be aimed at increasing EMAX. In most such situations the management or the workers might find it expedient to bring in fans for spot "cooling." Note that since EMAX is 0.6 root function of air speed, tripling of air movement across the skin would result in doubling of EMAX. In this case an increase from 15 m/min to 45 m/min is easily achieved and it is predicted that such air speed will raise EMAX to 400 Kcal/hr. Sweat required would be reduced to about 0.35 liters/min and would be evaporated at nearly 100% efficiency; the skin will no longer be dripping wet. It is clear that this control measure has limitations. If air speed were already 45 m/min, tripling would produce a wind which could disrupt operations.

A more effective permanent approach would be to replace the small exhaust fan with exhaust hoods opening over the moisture source. Adequate make-up air would have to be provided.

If outside high humidity rather than a large inside source of hot water were creating inside conditions similar to those of this case, the obvious solution would be installation of mechanical air conditioning. This would be an expensive solution for Case I.

Case II. Selected to show how the wearing of clothing can be advantageous and the presence of high air speed a liability under very hot, dry conditions.

Assume Ta = 45°C (113°F), Tg = 48°C (118°F), v = 100 m (330 ft) per minute, and Pa is low, 10 mm Hg. We use the same M as in Case I.

Long-sleeved shirt and trousers are worn.

$$M + R + C = EREQ \quad EMAX$$
$$200 + 132 + 96 = 428 \quad 615 \text{ Kcal/hr}$$

Suppose the worker wore only shorts under these circumstances. R, C, and EMAX would be increased:

$$M + R + C = EREQ \quad EMAX$$
$$200 + 220 + 160 = 580 \quad 1020 \text{ Kcal/hr}$$

The total heat load is increased about 150 Kcal/hr. This means an increase in the requirement for sweating of about 0.26 liter per hour, making a total requirement of 1.0 liter per hour as compared with 0.74 liter/hr when wearing shirt and trousers.

Thus, under conditions where Tw and Ta are above 35°C and Pwa is low the wearing of full clothing can provide a thermal advantage; the extent of this advantage must be assessed. In examining the above model it will be apparent that there is an optimum amount of clothing in such situations. This is the amount which reduces EMAX to a value slightly in excess of EREQ. The long shirt and trousers are just about right for this purpose under the given conditions of forced inlet air.

With low Pa as in a semi-arid area, a more satisfactory solution probably could be reached through installation of an evaporative cooler. In Case II, inside temperature was usually 5°C hotter than outside, due to process heat and insulation on the roof of the shed. Assuming outside Ta does not exceed 40°C (104°F) and Pa is about 10 mm Hg, the temperature of the outside air drawn through a water spray washer in large volume could be reduced to approximately the prevailing out-of-door Twb, namely 22°C (72°F). Most of the wash water could be recycled. Pa of the conditioned air would be raised from 10 to 20 mm Hg. If temperature of the work space were reduced by this means to 30°C, a conservative estimate of the components of heat stress for clothed workers would be about

$$\begin{array}{c} M + R + C = EREQ\ EMAX \\ 200 + 100 - 200 = 100\ 400\ \mathrm{Kcal/hr} \end{array}$$

Case III. Chosen to illustrate the dramatic reduction in heat load achievable by provision of appropriate shielding when radiation from a furnace is substantial.

Practical examples of the reduction in radiant heat load achievable by these means are provided by Lienhard, McClintock, and Hughes[67], by Haines and Hatch[68], and by others[64,69]. This case is chosen from the first of these references because the situation is real and physiological as well as environmental data are available. The task is that of skimming dross from molten bars of aluminum.

The worker stands at the task. Manipulation of a ladle involves moderate use of shoulder and arm muscles and requires an M of about 200 Kcal/hr. The environmental temperatures before the corrective action were reported as Tg = 71°C (161°F), Ta = 47.8°C (118°F), and Twb = 30.5°C (87°F). The air speed was 240 m/min (800 fpm) as a result of forced ventilation directed at the worker from an overhead duct. Note that the humidity was very high (Pa = 24 mm Hg) which is characteristic of the local climate. In terms of heat load and EMAX the situation was:

$$\begin{array}{c} M + R + C = EREQ\ EMAX \\ 200 + 830 + 210 = 1240\ 580\ \mathrm{Kcal/hr} \end{array}$$

It is obvious from the deficiency of evaporation and the enormous load that the workers, despite full clothing and a face shield, were able to perform this task only for a few minutes at a time. Heat exhaustion was not uncommon (and might partly be attributable to the difficult hot conditions prevailing in the nearby rest area).

Engineers undertook control of this heat exposure by interposing finished aluminum sheeting between the heat source and the worker. Infrared reflecting glass at face level permitted seeing the task and space was left for access of the arms in using the ladle. As a result of these measures it was recorded that both Tg and Ta were reduced to 43°C (110°F). The same air speed was present as before and if we assume the same Pa we obtain:

$$\begin{array}{c} M + R + C = EREQ \quad EMAX \\ 200 + 53 + 130 = 383 \quad 580 \text{ Kcal/hr} \end{array}$$

By this action to reduce R, the heat load was brought to a level that is reasonable for prolonged work, but did not completely eliminate the heat stress. The predicted requirement for sweating to maintain heat balance was reduced to about 0.7 liter/hr from the previously impossible-to-sustain level of 2.1 liters/hr. (The before and after average levels actually observed for two workers were not far from these predictions, namely 1.1 and 2.1 liters/hr. The same two subjects also showed a marked reduction in heart rate, as a result of the changes, from an average of 146 to 108 bears/min.)

The percent reduction of the radiant load can be taken as a measure of the effectiveness of the reflective shielding, and in this instance approximates 85%. Large errors in the stimate of R are possible at extremely high globe temperatures, but in this case it appears that the maximum relief that could be expected from shielding was achieved. Haines and Hatch reported smaller reductions in R of 51 to 74% from interposing a sheet of aluminum at eleven different work sites in a glass factory. Others have shown reduction of 90% or more under ideal conditions not likely to prevail on the plant floor.

While in Case III we have dealt with some aspects of control of R by shielding, the two other classical approaches of industrial hygiene engineering, namely, control at the source and control at the man, offer possibilities which must be considered.

Application of insulation on a furnace wall can reduce its surface temperature and thereby the level of R. A by-product of such treatment is a saving in fuel needed to maintain internal furnace temperatures. Application of a polished metallic surface to a furnace wall will also reduce R. However, a polished metallic surface will not maintain its low emissivity if it is allowed to become dirty. A layer of grease or oil one molecule thick can change the emissivity of a polished surface from 0.1 to 0.9. And the emissivity of aluminum or gold paints for infrared is not necessarily indicated by their sheen. If the particles are smaller than about one micron they emit almost like a black body. (The same is true for fabrics coated with very fine metallic particles.)

Equal or even more effective reduction of R is achievable with nonreflective barriers through which cool water is circulated.

The engineer is frequently baffled in shielding by the fact that access to the heat source is required for performance of the task. We have seen various solutions to this problem. One is a curtain of metal chains which can be parted as required and which otherwise reduces emission like a fireplace screen. Another is a mechanically activated door which is opened only during ejection or manipulation of the product. And finally, remotely operated tongs may be provided, taking advantage of the fact that radiant heating from an open portal is limited to line of sight and falls off as the reciprocal of the square of the distance from the source.

The fourth modification to be discussed is that of thermal conditions of the rest area. Brouha[66] states "it is undeniable that the possibility of rest in cool surroundings reduces considerably the total cost of work in the heat." There is no solid information on the optimum thermal conditions for such areas but there are laboratory data which support setting the temperature near 25°C (77°F). This feels chilly upon first entry from the heat, but adaptation is rapid.

The placement of these areas is of some importance. The farther they are from the workplace, the more likely that they will be used infrequently or that individual work periods will be lengthened in favor of prolonged rest periods.

Incidentally, the same principle applies for positioning of water fountains. When they are remote from the worker, substantial dehydration is more apt to occur. The proper temperature for drinks under hot conditions is often asked. There is no scientific answer, but most men will not willingly drink fluids that are close to body temperature. They welcome chilled water and recognize that frequent small drinks are better than large draughts.

The final modification to be discussed is clothing. Heat stress usually may be altered substantially through selective wearing of clothing. In the heat, as in the cold, the thermal function of clothing is to reduce heat transfer between the individual and his environment.[14] Clothing may reduce transfer by radiation, by convection, and by evaporation of sweat.

Whether clothing will represent an advantage depends not only on its design but on the characteristics of the particular thermal environment in which the work is being performed.

1. Conventional work clothing:

We first examine what is known about the effects of ordinary work clothing consisting of work shirt and trousers. These will be of flame retardant material if fire or sparks are in the working area. Other items normally will include cotton underwear, socks (which in hot weather are better if of medium to heavy weight), perhaps gloves, and perhaps a hard hat. The wearing of long underwear, woolen or cotton, represents a special case which is dealt with later.

The effect of such clothing in interfering with heat loss by R+C is substantial and can be illustrated. For a man doing moderately hard physical work (1200 Btu/hr) and wearing only shorts, comfort temperature would be about 70°F. In work clothing comfort temperature might well be 55°F. If the environmental temperature actually was 70°F, the cost of wearing clothing, in terms of heat stress, would be equivalent to an added sweat rate of at least one-half pint per hour.

Laboratory studies clearly indicate that ordinary work clothing will reduce radiant heat transfer by 30 to 40 percent.[70] Theory yields a similar reduction for transfer by convection. And recent studies demonstrate that this clothing will reduce the potential for evaporating sweat by about 40 percent.

There are two important implications of these findings. Only the first is common experience. In warm environments, below skin temperature, wearing of clothing decreases heat loss and comfort. This is particularly true when humidity is high or the air is static. This disadvantage may become an advantage when air temperature and/or radiant temperature exceeds skin temperature. Then clothing reduces heat gain to the body. For example, on a 95°F day the radiation from the sun under a clear sky can represent the equivalent of a 20°F increase in air temperature for the seminude body.[14] This load can be reduced to the equivalent of 8°F by conventional work clothing (to even less with near-white clothes). Heavier clothing would reduce R even more, but this advantage is nulified at the point such clothing interferes with evaporation of sweat. In arid climates adequate evaporation seldom is a problem, particularly with good air movement, but in an industrial plant with the high radiant heat from a furnace the limits on evaporation may preclude heavy clothing for prolonged tasks.

The implication of the above is that radiant heat which was tolerable for a worker wearing shirt and trousers would be excessive for a man in shorts. This has been demonstrated in the laboratory.[70] A mean radiant temperature of 205°F was used in simulation of a task involving four-minute exposures interspersed with two-minute relief periods. This was tolerable when clothes, but intolerable when nude. The radiant load became just tolerable when reduced in intensity by about 30 percent. As mentioned in the preceding section, the color of skin or of clothing is immaterial in these exposures; they are black to infrared heat.

The highest local skin temperatures readily tolerable under such conditions depends on the amount of body surface area affected. For large areas such as the back it is about 105°F; for smaller areas such as a hand it may be 110°F. As an average for the whole body of an individual at work for prolonged periods, 95°F is about the limit; with higher average skin temperatures, a rise in internal body temperature may be expected. Additional information on time-tolerance relationships appears.[71]

Long winter-weight underwear has been adopted by many workers who move in and out of very hot environments. This makes sense to the extent that the extra layer provides a substantial buffer against extremes of heat gain (and loss, which is a factor in open sheds in wintertime). In humid summer weather the practice is less justified, unless there is ready access to air conditioned areas for recovery, because the underwear interferes with evaporation of sweat from the skin. The ounce-by-ounce efficiency of evaporation of sweat from clothing is considerably less than from the skin, more sweat must be produced to maintain heat balance and little or no more can be evaporated.

It is obvious that ordinary work clothing itself moderates extremes of transient heat exposures, but this is to a lesser extent than when long underwear is worn.

2. Special Clothing:

This may take various forms. For example, the wearing of infrared reflecting face shields may be indicated when radiant heat is high. In frequent handling of hot materials, it is good practice to provide several pairs of oversize insulative gloves, these having wide gauntlets for easy entry without using both hands.

For very hot exposures, as in relining furnaces, thick insulative clothing is appropriate. This acts as a heat "sponge." This sponge may be more effective if made of high density materials (asbestos in the recent past) because of the higher heat capacity, but insulation with minimum weight is best imparted by a thickness of trapped, still air. It is obvious that for relatively longer intervals of exposure, high density and highest feasible thickness should be sought. The protective value of such clothing is enhanced by aluminizing its surface and sometimes interlining foil between insulative layers.

3. Aluminized Reflecting Clothing:

When shielding against radiant heat loads cannot be accomplished by fixed barriers, aluminized clothing components may often be used to advantage. The aluminum is vacuum deposited on the surface of the fabric. Interposition of such coated fabrics between a 600° to 1100°F source and a black globe has resulted in reflection of 90% of incident energy.[60]

However, in a study using reflective clothing items while working in the 205°F radiant heat mentioned above, efficiency was found to be much less. Ordinary work clothing yielded 40 percent protection, an aluminized apron about 50 percent and a full aluminized suit about 60 percent. In intermittent work at high humidities the full suit proved a handicap because of its interference with evaporation of sweat. The use of full reflective clothing can sometimes be avoided. For example, fixed shielding to waist level may make possible use of only an aluminized jacket. Or a worker who faces the heat source may resort to a long metallic apron. When the coverage with reflective clothing is only partial, there is much more opportunity for evaporation of sweat.

It is obvious that an aluminum finish, as on the palmar surface of an insulative glove, will be of little use in handling materials.

4. Thermally Conditioned Clothing:

Numerous ideas have been incorporated in special clothing for maintaining comfort in extreme heat (or cold). Some systems supply appropriately cool air from a mechanical refrigerator to points under a jacket or coveralls. When air from a remote source is used, there are two problems. One is the gain of heat through the walls of the supply tubing. This problem has been solved in some cases by using porous tubing which will leak an appropriate amount of supply air to keep the walls suitably cool. The other problem is distribution of the air through the suit. With a simple, single orifice it is difficult to cool a sufficient area of skin and the area cooled may be too cold. Provision of several orifices, though better, will create bulk and restrict mobility.

In fact, the restriction of movement resulting from tethering the worker to a supply line will often contraindicate this type of system. When such a line is used, there should always be a simple quick disconnect for use in emergency.

The vortex tube source of cool air has been used successfully in some situations.[62] The device is carried on the belt. Air introduced tangentially at high velocity is forced into a vortex, which results in two separable streams of air, one cold which is distributed under the suit, the other hot which is discarded. Compressed air requirements to operate the vortex system are large.

Self-contained sources of conditioned air which can be backpacked have also been developed. One involves a liquid refrigerant which is sealed into a finned container. After being cooled in a deep freeze, the container is placed in the pack. A small battery-driven fan circulates air across the fins and into the suit. A single charging of this device may extend tolerance for relining furnace walls from several minutes to 30 or 60 minutes.

More sophisticated devices employ a closed system with liquid as the coolant and a fairly elaborate network of small tubes for distribution.

The nuisance factor must be considered for all such devices. Men will not go to the trouble of donning them unless they recognize more than a marginal advantage. On the other hand, with such devices, it has sometimes been possible to change hot tasks which required long rest pauses and multiple workers into single worker, continuous duty operations.

V. DEVELOPMENT OF STANDARD

Basis for Previous Standards

There are a great number of recommendations for permissible exposure limits to work in hot environments. The recommended limits were expressed in terms of different indices, most of which were designed to consolidate into a single value the four climatic factors, air temperature, humidity, radiant heat, and wind velocity, and often the work load as well. Some other indices expressed the recommended exposure limits in values on a scale which was the result of a ratio with an upper limit value of 100.[77,81] Again other indices expressed the limits in terms of magnitude of one or more physiological responses. All these indices were recently evaluated.[72,73,74] Also, the World Health Organization (WHO) convened a panel of experts to review the heat stress indices.[46] They found shortcomings in all the existing indices as well as in the proposed upper limits set forth in each of these indices.

A. Validity of Indices

Most of the indices are derived from laboratory experiments, thus their relevance to industrial conditions is questionable. Furthermore, the subjects observed in these laboratory studies were mainly young university students or military personnel or, as in Wyndham's[76] studies, Bantu miners. The responses of such a subject group may not be identical to responses of an industrial worker population. An important problem is whether the severity of physiological strain correlates with the scale of different indices. Peterson[74] showed in his study that while some indices correlate well with some physiological responses, none of them correlates well with all physiological responses. He recommends the use of at least three indices simultaneously to evaluate adequately the heat strain of an exposed man.

Another problem plaguing some indices is that in order to make them simple enough for use in industry, certain assumptions had to be made which were by no means proven and equations had to be simplified which further reduced the accuracy of the index.[16]

B. Validity of Proposed Limits

A number of limits, such as recommended by Yaglou and Minard,[75] Brief,[60] and Wyndham[76] in terms of the WBGT or ET indices are empirical and are intended to reduce the frequency of heat casualties. Such criteria are not applicable to industrial workers because they do not give a satisfactory margin of safety.

Another common objection which has been raised against almost all earlier proposed limits is that they are not based on observations of industrial worker populations. Those limits mentioned in the foregoing paragraph are based on data obtained on marine recruits[75] and Bantu miners,[76] who are young, physically fit people and are exposed only for 1 - 2 years to hot working conditions. In addition most of the limits are based on the averages of the observations; thus the limits are theoretically safe only for 50% of the observed population.

The only index[77] which recommends specific allowances for individual differences in age, sex, fitness, body build, acclimatization, hydration, and other conditions which may reduce tolerance to work in heat without causing apparent diseases is the Relative Strain Index. Unfortunately, these recommendations are too vague to be used as bases for an industrial standard. They were originally prepared for use in Civil Defense Shelters.

The first U. S. standard[78] for work in hot environments dates back to 1941, when a Committee on Atmospheric Comfort published their report entitled Thermal Standards in Industry. The criteria of this standard are not spelled out clearly and the permissible exposure limits are intended only as a guide. The Committee recommended that each indusry must develop its own standard because of the complexity of industrial work and the individual differences between workers. As general criteria the Committee quoted comfort and health of individuals, their work output, and their physiological and psychological reaction to work. They applied the Effective Temperature (ET) as the index with which to express their proposed limits. However, since the ET does not include the work load factor, they limited themselves to exposure limits for only two levels of work. The higher level is given at 432 Kcal/hr and the lower is given only in qualitative terms as "light sedentary activities." As far as women are concerned, there is only a comment stating that females are less fit than males. However, since the criteria by which they arrived at these limits are not described, this recommended standard could not be used as a basis for a NIOSH recommendation. Brouha[66] and later Fuller[79] recommended limits based on the concept of accumulation of cardiovascular strain. Their limits are based on the concept that the first minute post exercise recovery heart rate (P_1) should not exceed 110 beats per minute, and that within 3 minutes recovery time the pulse rate should decrease at least by 10 beats per minute. The recovery heart rate is estimated by counting the pulse rate during the second thirty seconds of any given minute during recovery and multiplying this count by two. The validity of this principle seemed to be upheld in recent studies in industry.[29]

The WHO panel of experts[46] recommended that a deep body temperature of 38°C should be considered as the limit of permissible exposure to work in heat. This is also in agreement with several observations which showed that above a body temperature of 38°C the probability of suffering a heat disorder or illness gradually increased.[79a] This is also in agreement with Lind's studies on the prescriptive zone.[80]

Considerations for a Recommended Standard

The principal criteria for a heat stress index for industrial use are:

1. Applicability should be proven in industrial use.
2. All important factors should be included.
3. The measurements and calculations required should be simple.
4. The included factors should have a valid weight in relation to total physiologic strain.

5. Applicable and feasible for setting regulatory limits.

There are four indices which satisfy the first criterion: the Effective Temperature (ET), WBGT index,[75] the HSI of Belding and Hatch,[81] and the Predicted Four Hour Sweat Rate (P4SR).[82] All of these indices include the four climatic factors: air temperature, humidity, radiant heat, and wind velocity. However, the work load is not included in the ET and WBGT. This fact weighs in favor of HSI and P4SR. On the other hand, the calculation of these latter two indices is much more complicated than that of ET and WGBT, even when the available monograms are used. Between ET and WBGT, the latter one wins out in simplicity of calculation. Another aspect which makes WBGT more desirable is that while wind velocity must be measured for the other three indices, for WBGT this is not required. This is a very important consideration in view of the difficulty NIOSH has experienced in field studies[1] in establishing an hourly time-weighted average value for this factor. One important reason for this is that as man moves around while performing his job, he is exposed to wind velocities which vary considerably and often suddenly.

As far as the fourth criterion is concerned, all four indices have some shortcomings, as pointed out in the previous section. Thus, from this point of view, none of the four indices has an advantage over the other.

The HSI has many advantages from the point of view of the fifth criterion, the greatest one being that it makes it possible to calculate the allowable exposure time as well as the minimum recovery time for a given heat stress condition.[83]

The studies performed by Lind[80] on the prescriptive zone (PZ) were used as a basis for the determination of the environmental conditions (including different combinations of climatic and work load), which can be tolerated by 95% of the worker population with body temperatures not in excess of 38° C.

The essence of this principle is shown in Figure 5. Each point on the graph represents the result of an experiment lasting until the rectal temperature of the observed subject reached a steady state. This took about 30-to-60 minutes depending on the intensity of the combined heat-work exposure. It becomes apparent from the graph that up to a certain level of effective temperature (ET) the equilibrium rectal temperatures follow a straight horizontal line, i.e., they do not increase, no matter how much the ET is increased in the heat chamber. However, the rectal temperature is higher when the work rate is higher. Thus, in this range of environmental heat the rectal temperature is determined only by the work intensity. This range is called the prescriptive zone (PZ).

Over a certain level of environmental heat each of the three curves in the graph show a sudden turn upward, indicating that over this level the equilibrium rectal temperatures increased each time the climatic conditions became hotter. Thus, in this range of environmental heat the deep body temperature becomes sensitive to changes in climatic conditions and man can easily lose his ability to maintain an equilibrium temperature, thus leading to heat disorders. This range of climatic conditions is called the environment driven zone (EDZ). The environmental temperatures at the border between the PZ and EDZ are called the upper limit of prescriptive zone (ULPZ).

The value of the ULPZ varies for different individuals. It is higher for men who are acclimatized to heat, by approximately 4.0°F ET, and is lower the more clothing an individual wears.

To make sure that 95% of a heat acclimatized population wearing worker uniforms will not have a rectal temperature in excess of 38°C, it must be established at what level of environmental heat will the 5 percentile man reach his ULPZ, and this value has to be corrected for the level of acclimatization and clothing. This ULPZ was found in a paper of Lind and Liddell[84] in which they tested the ULPZ of a group of 128 men of average physical fitness. Figure 6 shows that about 95% of the men could reach an equilibrium deep body temperature in the 3-hour exercise test if the climatic conditions did not exceed 80.5°F. Thus, at a work load of 300 Kcal/hr the 5 percentile man's ULPZ lies about 1.0°C lower than that of the subjects' observed by Lind in his first study of the PZ.[80] This result was adopted as a guideline to correct the ULPZ values orginally recommended by Lind as shown in Figure 7. As can be seen, it was assumed that a larger correction is required at higher levels of work load when the rectal temperature in the PZ is already very close to 38°C and no correction was applied at the lowest level of work load where the rectal temperature in the PZ is much lower than 38°C. Another justification for applying this upward adjustment for heavy work and downward adjustment for light work comes from the study of Kraning et al.[85] In this study evidence was presented that the heat generated by work metabolism causes about twice as much strain on the cardiovascular system as the same amount of heat taken up from the environment. Studies performed by NIOSH have confirmed these findings.

Corrections would also be needed for clothing because Lind's subjects were tested wearing shorts and sneakers only whereas the workers in hot industries wear underwear and work uniforms as well as boots. This would require a lowering of the ULPZ value. However, an increase would be permitted because it is assumed that the workers in hot jobs will be acclimatized. These two factors then cancel out each other. The ULPZ values read from the abscissa in Figure 7 are expressed in terms of basic ET. They were converted by using Minard's[86] graph showing the correlation between ET and WBGT. In this graph, however, the normal ET is stated for semi-nude men. Thus the ULPZ values read from Figure 7 were first converted to normal ET values, then to WBGT values.

Justification for using time-weighted average hourly work-load values for intermittent work comes from another study by Lind.[87] The results showed that from the point of view of the ULPZ it does not matter whether a certain hourly amount of work is performed at a lower rate continuously or at a higher rate but interrupted with rest periods.

The permissible exposure limits for heat stress cannot be based on 8-hour average values because if excessive exposure persists for longer than 1 hour, the worker may accumulate enough heat in his body to cause him to suffer an acute heat disorder or heat illness; thus in continuous heat exposure, hourly averages are necessary. However, if the exposure is intermittent the accumulation of heat will be slowed down; thus, it is permissible to average the exposure every 2 hours.

The ULPZ was found to be the same for men of different ages, thus no correction for age is required according to Lind et al.[88] However, when older men are exposed to strenuous heat load an increased caution is advisable because of their lowered physiological capacities and increased susceptibility to diseases.

A sex difference in the pattern and magnitude of physiological responses to work in heat has been demonstrated. Whether the observed differences in the responses reflect real differences in heat tolerance or in work performance is not fully proven (see references 33, 43, and 89 thru 96).

In resting-in-heat studies the young female subjects had a higher body temperature and a lower sweat production than did the young males for the same heat exposure.[89]The onset of sweating occurred at a higher body temperature in the females, which resulted in a time delay in the onset of sweating during both severe and mild heat stress. Actual tolerance time in the severe heat was shorter in the females even though the maximum endurable body temperature was the same in both sexes. The symptoms present when an individual collasped from the heat stress were comparable even though the females found the stress intolerable sooner with work-in-stress. Women started to sweat at a higher skin temperature and had a lower sweat production for any specific heat load. Calculated skin temperatures at the onset of sweating were about 4°F higher in female than male subjects and for equal sweat rates the skin temperature was 1.8°F lower in the males.

In spite of the greater strain in women, they are capable of effective heat acclimatization. However, even after acclimatization the sweat rate is lower in the females, and they may have more subjective distress. Resistance to naturally occurring heat waves seems to be lower in women. Apparently there is no real difference in the degree of acclimatization that can be reached in men and women, but they may achieve equal acclimatization in different ways using different configurations of components of the regulating process.

The question arises whether the lower sweat production in females may be due to fewer active sweat glands during the heat exposure. Both the total number of sweat glands and the number per unit area of skin surface are greater in females. In lean females one hundred sweat glands per square centimeter of skin were counted while fifty-nine per square centimeter were found in males. In obese females there were seventy-five per square centimeter and in obese males, forty-seven per square centimeter. A recent WHO report questions this difference in sweat rates after acclimatization.[96a]

Differences in pulse rate responses to a standard work-in-heat test between both young and old men and women have been found.[46] At the lower levels of work the women had pulse rates ten to twelve beats per minute higher than the men. For the high levels of work the differences were twenty to thirty beats per minute higher in the females. The higher pulse rates in the women reflect both the heat stress and the physical work and are higher in the women mainly because the work is relatively harder for them. Oxygen consumption expressed as milliliters per kilogram of body weight was about 15 to 20% higher in women than in men. The highest level of physical work used in the test required about 43% of the predicted maximum aerobic capacity for the older men, 30% for the young men, 66% for the older women, and 44% for the younger women.

Wing[97] reviewed the results of 15 studies performed in different laboratories on the effect thermal stress has on mental performance. It is quite apparent from these studies that thermal stress is an important factor where the worker has to make critical decisions, make fine discriminations, or has to perform fast and skillful actions because safety will depend on constant alertness. The number of errors made will increase if the worker is exposed to heat even before body temperature or pulse rate reaches critical levels.

Figure I-1 in the recommended standard is adapted from Wing's[97] review paper. Although Wing recommended these limits only as tentative upper performance limits, they are considered to be the best presently available. Since Wing's values were expressed in ET, they were converted by using Walters'[98] graph on correlation between ET and WBGT.

As shown in Figure I-1 of the recommended standard, unimpaired mental performance can be maintained below 86°F WBGT for 4 hours and probably even longer, although this needs experimental confirmation. Since environmental conditions above 86°F WBGT are permissible only for jobs with a work load below 200 Kcal/hr for men and below 150 Kcal/hr for women, Figure I-1 of the recommended standard has to be taken into consideration only in sedentary jobs.

It is impossible that for unimpaired mental performance as work loads above 200 Kcal/hr, the 86°F WBGT may be too high. However, there are no data available either supporting or contradicting this assumption.

Since then this problem was investigated in several studies and discussed at two Workshop sessions at the University of Pittsburgh. At these workshops the leading experts in problems of industrial heat stress agreed that the Brouha method should be used as a means of monitoring cardiovascular strain in industry.

Figure 8 shows data obtained in PHS field studies on the dehydration of workers exposed to hot environments. There is a correlation between daily sweat loss and dehydration: the higher the sweat loss the more dehydrated the worker will be at the end of the work shift. However, this correlation was quite different in the four plants. The heavy equipment operators sweated the least, but dehydrated most. At about the same level of daily sweat loss, the foundry men and chemical plant workers dehydrated significantly less. Finally, the aluminum reduction workers whose daily sweat loss was the highest did not dehydrate more than workers of the chemical plant.

When analyzing for causes of the differences in the extent of dehydration, it was discovered that aluminum reduction plant workers were supplied from their drinking fountains a 0.1% salt solution. Thus, it was made sure that the salt they lost by sweating was replaced each work day. For the chemical plant workers and the foundry men salt tablets were available at the drinking fountains. The heavy equipment operators were not supplied with any additional salt, except that salt ingested with their midday lunch.

These results suggest that salt supplementation may play an important role in preventing dehydration.

Another difference between the working condition of the heavy equipment operators and the workers of the other three plants was in the availability of drinking water. Whereas the heavy equipment operators had to go out of their regular path and disembark from their vehicles to have a drink of water, all the workers in the rest of the plants had to do was to go a few steps to the nearest drinking fountain. This circumstance may have also contributed to the higher level of dehydration of the heavy equipment operators. Indeed, it was observed that the workers were not drinking as often as necessary to replace their water loss if they had to make some effort to reach the source of water. These results indicate the importance of making drinking water available close to the job site and recovery places where the workers' daily sweat loss exceeds 2 liters.

In Figure 8 a horizontal broken line is drawn at the 1.5% dehydration level. This is done because the results of earlier NIOSH studies suggested that if the level of dehydration exceeds 1.5% of body weight the physiological responses, such as the body temperature and heart rate, start to increase, indicating an increase of strain. In this respect it may be worth mentioning that among the heavy equipment operators the accident frequency was double that observed at other locations where the same operations were performed, but in comfortable climatic conditions.

It may be assumed that the dehydrated heavy equipment operators, unaware of their diminished performance capacity, may have been unable to react fast enough and correctly in situations where sudden action would have been necessary to prevent an accident. This again may be interpreted as a warning as to the importance of proper fluid and salt replacement in hot jobs.

Summary of the Basis for the Work Practices Standard

The work of Linde,[80,84] in the development of the prescriptive zone (PZ) is undoubtedly the basis for the best approach for the development of an environmental standard for heat stress because it combines both the climatic and work load conditions that are imposed upon the worker in hot industries. There are, however, a number of practical shortcomings and unresolved questions related to this approach.

These unresolved questions which will require additional research to validate the hypotheses presently proposed as the best technique for evaluation of heat stress conditions dictates the necessity for the development of the work practices standard as outlined in this document as opposed to an environmental standard. The additional research is such that it would be impossible to utilize an environmental standard at this time without stringent limitations being placed upon both the worker and management. Such an approach would be unrealistic.

The validation of the Upper Limit of Prescriptive Zone (ULPZ) concept is essential. It is necessary that this approach be validated with additional data from a normal industrial work force. More data is needed on age and sex distribution of the work force. Another shortcoming that must be clarified is effect of the process of natural selection that normally occurs in the industrial situation where the worker himself determines his ability to endure high heat stresses. This particular consideration is one which may have resulted in heat stress standards in the past that were unrealistic for an industrial population. The intermittent exposures that are normal in the industrial population represent another significant factor which was not thoroughly considered in the previous recommendation. The lack of data regarding intermittent exposures to heat is one of the major unresolved questions of the effect of heat stress on the work force. Differences in sweat loss under a wide variety of industrial conditions still has also not been thoroughly studied. In addition, the wide variety of work loads and the intermittency of work loads that are normal in industrial operations have a major effect upon heat stress. This also must be studied prior to the development of a practical environmental heat stress level. The previous studies have been conducted with soldiers,[75] usually stripped to the waist, or have been under conditions where the subjects are stripped to the waist or are wearing minimal amounts of clothing.[76] This must also be considered in relationship to the normal work clothes of the industrial worker, as well as any other protective clothing that such a worker may be wearing.

All of the above factors can have a significant impact upon the level of heat stress to which a worker might be permitted to be exposed without adverse affects. At this time, such factors without sufficient validation would result in severe limitations on any environmental levels that might be proposed. The information does exist, however, to allow for environmental measurements that can be utilized to initiate work practices that will protect the industrial worker. Additional research is being conducted with regard to how the questions, indicated above, might be resolved.

Environmental Measurements

The climatic conditions are expressed in wet-bulb globe temperature (WBGT) on both the Fahrenheit and Centigrade scales.

Assessment of the WBGT Index

The numerical value of the WBGT Index is calculated by the following equations:

1. Indoors or outdoors with no solar load

   $WBGT = 0.7\ WB + 0.3\ GT$

2. Outdoors with solar load

   $WBGT = 0.7\ WB + 0.2\ GT + 0.1\ DB$

   Where WB = natural wet-bulb temperature obtained with a wetted sensor exposed to the natural air movement (unaspirated)

   GT = globe thermometer temperature

   DB = dry-bulb temperature

The time-weighted average WBGT shall be determined by the equation:

$$\text{Av. WBGT} = \frac{(\text{WBGT}_1) \times (t_1) + (\text{WBGT}_2) \times (t_2) + \ldots.(\text{WBGT}_n) \times (t_n)}{(t_1) + (t_2) + \ldots.(t_n)}$$

where

WBGT_1, WBGT_2, ... WBGT_n are calculated values of WBGT for the various work or rest areas occupied during the total time period. t_1, t_2,... t_n are the elapsed times in minutes spent in the corresponding area. This same equation shall be used to calculate the average WBGT for a workman who toils at various work stations at various work rates and/or under different environmental conditions.

Time-weighted average WBGT values should be calculated on an hourly basis in continuous heat exposure and on a two-hourly basis in intermittent heat exposure.

Instrumentation

The instruments required for determining the WBGT Index are a natural wet-bulb thermometer, a globe thermometer, and when outdoors in sunshine, a dry-bulb thermometer.

A satisfactory wet-bulb thermometer may be constructed using a mercury-in-glass thermometer having a range of 30 to 120°F with 0.5°F graduations, and guaranteed to be accurate within ± 0.5°F throughout its range. A centigrade thermometer of comparable accuracy may also be used. A highly absorbent woven cotton wick shall cover the thermometer bulb and at least 1-1/4 inches of the thermometer stem above the bulb. The lower end of the wick shall be immersed in a reservoir of distilled water. There shall be one inch of wetted wick exposed to the air between the top of the reservoir and the bottom of the bulb. The wick should be wet to the top at all times. Under unusually hot or dry conditions this may be difficult to achieve, and special provisions may be necessary, such as an auxiliary water supply or manual wetting.

The globe thermometer should consist of a 6-inch diameter thin copper sphere, the outside of which is painted a matte black. Either Krylon No. 1602 Ultra Flat Black Enamel or 3 M No. 101-C10 Nextel Black Velvet coating is available in spray cans and will provide an satisfactory surface. A mercury-in-glass thermometer, having a range of 30 to 220°F with 1°F graduations and guaranteed to be accurate to ± 1°F, should be inserted through the shell with the thermometer bulb located at the center of the globe. The thermometer mounting and the globe support may be arranged in several ways. One convenient method is to use a globe having a spud with a 1/4 inch pipe tapping. The thermometer can be inserted through a hole drilled through the spud and supported at the proper height by a ring of rubber tubing, and the complete assembly can be supported by a clamp around a 1/4 inch nipple screwed into the spud. Another satisfactory method is to insert the thermometer through a rubber stopper in a hole in the top of the globe. The globe is then supported from the bottom by a 3/16 inch rod threaded into a matching spud. The globe thermometer should be allowed 20 minutes to reach equilibrium.

When a dry-bulb temperature is necessary it may be obtained with a mercury-in-glass thermometer as specified above for the wet-bulb thermometer. The dry-bulb thermometer should be shielded from solar radiation, but shielding must be applied in such a manner that air circulation over the thermometer bulb is not restricted.

Mercury-in-glass thermometers have been indicated as the sensing elements in the above described instruments. Thermocouples, thermistors, or any other sensors which will provide the same accuracy are equally acceptable. In some cases these may have an advantage over the ordinary thermometer in that the signals from such sensors may be readily recorded.

A suggested arrangement of the instruments is given in Figure 9. Further instrument details and techniques for their use may be found in references.[99,100,101]

In addition to the above described instrumentation which requires the calculation of the WBGT index value, there are instruments described in the literature[98,102,103] or available on the market which sense the required temperatures and automatically integrate them to give a readout in WBGT. Another such instrument is currently (March, 1972) being developed by NIOSH.

Instrumentation for the determination of the WBGT Index should always be located so that the readings obtained will be truly representative of the environmental conditions to which the workman is exposed. Sensors should be at about the mean height of the worker, and due consideration should be given to the location of radiation sources and the direction of air movement. A record shall be maintained of the WBGT Index observed at each of the various hot work sites.

Medical

The purpose of the pre-placement examination of persons applying for hot jobs is the same as for evaluating the health status of a prospective employee for any job, namely, to determine his mental, physical and emotional qualifications to perform his job assignment with reasonable efficiency and without risk to his own health and safety or to that of his fellow employees.[104]

The examining physician, however, will recognize the particular requirements for persons whose jobs involve significant heat exposure. He should be probing in taking the employees' history, both medical and occupational, in order to discern possible evidence of intolerance to heat either occupational or off the job.

By the same token, a history of successful adaptation to heat exposure on previous jobs is perhaps the best criterion on which to predict effectiveness of a worker's future performance under heat stress, assuming that levels of work demands and heat exposure are equivalent and that no significant alteration has occurred in his health status since his previous employment.

For new employees without previous occupational exposure to heat, they should not be assigned to hot jobs where the environmental conditions exceed 79°F WBGT for men and 76°F WBGT for women until they are acclimatized. It has been established that both heat tolerance and also physical work capacity decline with age.[105,106]

During both the history taking and the physical examination, the examiner should direct careful attention particularly to detect evidence of chronic functional or organic impairments not only of the cardiovascular system but also of the kidneys, liver, endocrines, lungs, and skin. Significant disease of any of these systems should be disqualifying for new employement on jobs involving severe heat exposure, or for those previously employed on such jobs if the disease is progressive despite treatment.

Careful inquiry should be made on use of drugs, particularly hypotensive agents, diuretics, antispasmodics, sedatives, tranquilizers, and antidepressants as well as the abuse of drugs, particularly amphetamines, hard narcotics, and alcohol. Many of these drugs impair normal responses to heat stress and others alter behaviour, thus, exposing the employee or fellow workers to health and safety hazards. Evidence of therapeutic use of one or more of these categories of drugs or personal abuse of alcohol and other drugs should be disqualifying.

Other qualifications depend on the job demands independently from heat exposure, for example, statutory requirements to qualify as a vehicle operator, craneman, locomotive engineer, etc., would obviously need to be met as well as nonstatutory requirements for jobs in a particular industry. A glucose tolerance test, renal clearance studies, X-ray examination of the renal pelvis and biliary system with contrast media, pulmonary function tests and other special tests are recommended when indicated in addition to routine 12-lead ECG 14" x 17" chest X-ray, and the usual blood and urine analyses.

Workers employed on jobs which regularly expose them to levels of heat stress which have been determined to approach or equal permissible limits prescribed by the heat standard should be examined periodically on an annual basis or more frequently if indicated. The examination should be conducted during the summer season. In employees after the age of forty-five, physical and laboratory examinations should be designed to detect conset of chronic impairments of the cardiocirculatory and cardiorespiratory systems and also to detect metabolic, skin, and renal disease. In cases of older employees who had not undergone the pre-placement examination, and whose health records indicated pre-existing chronic diseases of the systems referred to in the section on pre-employment examination, the examination should determine the extent to which such impairments have progressed. For all employees on hot jobs undergoing periodic examination, any history of acute illness or injury, either occupational or nonoccupational, during the interval between examinations, should be carefully evaluated. Repeated accidental injuries on the job or frequent sick absence should alert the physician to possible heat intolerance of the employee or the possibility of an aggravating stress with heat in combination, such as CO. Nutritional status should be noted and advice offered to correct overweight.

In industrial establishments in which heat stress approaches or equals permissible limits only during the summer season, periodic examinations should be administered during the summer. In establishments in which heat stress at the permissible level occurs throughout the year, the periodic examination can be administered at any time regardless of season. The first periodic examination of workers already employed on hot jobs who had not undergone the pre-placement examination required for new employees should be conducted within a year. Guidelines for qualifications should be the same as for new employees but with due allowance made for successful performance on the job, which as indicated earlier is perhaps the most important criterion in evaluating a worker's capacity to adapt to heat stress on the job.

In cases of those previously employed but with a record of health impairment or significant impairments found first on periodic examinations, the examiner should determine whether pre-existing impairments had been effectively controlled by treatment. If progressive, despite treatment, these findings should disqualify the employee from continuing on the same job. In case of impairments detected for the first time, the examiner should evaluate these in light of possible aggravation by heat stress. If such a likelihood exists, the employee should be reevaluated periodically at intervals shorter than those recommended for routine periodic examinations.

For a new employee undergoing his first periodic examination, the examiner should note evidence of heat intolerance, including a history of repeated accidental injury on the job, episodes of heat disorder, or frequent sick absence. In such cases, the examiner should assess the employees capacity to continue on the same job and consider recommending his transfer if indicated.

The supervisor and selected personnel should be trained in recognizing the signs and symptoms of heat disorder and in administering first aid. As described earlier, the most serious emergency is heat stroke signaled by the signs of dry, hot, red, or mottled skin, mental confusion, delirium, convulsions, or coma, and a high and rising rectal temperature, usually 106°F and above but occasionally lower, between 104 and 106°F.

First aid treatment requires immediate removal to a cooler area, soaking the clothing in cold water, and fanning vigorously. The final treatment is conducted in a medical facility but first aid must not be delayed.

In severe heat exhaustion, the victim may faint on standing, but unlike heat stroke the skin is wet and cool. He should be given water by mouth if conscious, and transported to the medical facility without delay.

Medical facilities to treat heat disorders should be as close as possible to work areas. Qualified personnel as appropriate must be available. In treating heat stroke an air conditioned room should be available, and provided with a tub and ice for immersion and massage treatment or a suitable table on which the patient may be placed, wrapped in wet sheets, and exposed to vigorous fanning. A special table is described by Leithead and Lind, 1964.[16]

Chlorpromazine, as an adjuvant to cooling treatment, may be administered in dosages of 25 to 50 mg I.V. This tends to reduce shivering and increases rate of heat dissipation.

Body temperature should be measured every 3 to 5 minutes and cooling interrupted when the rectal temperature reaches a level of 100 to 101°F. Monitoring is then continued to detect recurrence of hyperthermia or continued drop in temperature to hypothermic levels. This is avoided by reducing heat loss with blankets.

Shock may be present on admission to the medical facility. This is often corrected by the cooling treatment. If shock persists after adequate cooling, treatment should include oxygen inhalation, with careful administration of I.V. fluids, and use of pressor agents. With prompt first aid and emergency treatment by cooling, shock will rarely be a complication.

Heat exhaustion is treated by oral administration of salted liquids or by I.V. infusion of normal saline if the patient is unconscious or vomiting.

In heat cramps, treatment is by I.V. infusion of normal saline, with rapid administration of 250 ml within 5 to 10 minutes. The patient then continues to replace body salt by ingesting salted foods and liquids. In moderate to severe cases bed rest for 24 hours is indicated.

Apprisal of Employees of Health and Safety Practices in Hot Environments

Exposure to hot environmental conditions can lead to primary heat illnesses, to unsafe acts, or to increased susceptibility to toxic chemicals and physical substances. Through the application of basic health and safety procedures, the individual may by proper precautions reduce the likelihood of ill effects from a hot work environment. Each employee who may be exposed to heat and each supervisor should through a safety training and indoctrination program be made aware, as a minimum, of the points discussed below:

It is essential that water intake during the workday should about equal the amount of sweat produced. Work in a hot environment may result in sweat productions of 1 to 3 gallons a day. If this water lost in the sweat is not replaced, dehydration with its debiliating effects will result. Thirst is an inadequate drive to stimulate one to drink that much more water. An ample supply of cool water readily available to the workers is required and the worker should be encouraged to take a drink of water each 15 to 20 minutes preferably using disposable paper cups rather than drinking directly from the fountain.

Large amounts of salt may be lost in the sweat particularly by the individual not acclimatized to heat. The salt must be replaced daily to prevent heat induced salt deficiency heat illness.

The acclimatized individual looses much less salt in his sweat. Salt can be replaced by liberally salting ones food or by using a 0.1% salt solution drinking water. About 1 level tablespoon of table salt to fifteen quarts of water will make a 0.1% salt solution. Enteric coated salt tablets may also be used; however, they must be taken with ample water to prevent gastric irritation. It is particularly important that salt depletion is prevented by supplemental salt intake during the first few days of heat exposure when the worker is not yet acclimatized.

Each employee exposed to heat should weigh himself at the beginning and end of the workday to insure that fluid intake has been sufficient to prevent serious dehydration. Weight loss at the end of the workday should not exceed 1.5% of the worker's body weight.

Each employee should be instructed on how to recognize the symptoms of heat disorders and illnesses including dehydration exhaustion, heat syncope, heat cramps, salt deficiency exhaustion, prickly heat and heat stroke. Recognition of early warning signs so that corrective or evasive action can be taken is one of the best means of preventing health damage. The major heat disorders are shown in Figure 3 and have been discussed in the section on Medical Considerations.

The most prevalent of the heat disorders is undoubtedly heat syncope (possibly along with heat edema) which is seldom a debilitating disorder. Fainting may follow prolonged standing, sudden postural changes, unaccustomed exercise, particularly if the exercise involves stooping or heavy lifting or standing upright after exercise. Fainting of this nature is not unusual in hot surroundings and in heat unacclimatized individuals. It is seldom reported among those who are accustomed to and experienced in living in hot climates, a fact that can be related partly to the development of acclimatization and partly to "learning to live with hot climates".

Heat syncope is usually self-limiting, since recovery follows assumption of the recumbent position; but if an individual faints in a confined area and is unable to fall down, death can and does result. Fainting at the job site can also have serious safety consequences. Treatment of the patient involves removal to cool surroundings where he or she is allowed to rest. The disorder is readily prevented by education of the unacclimatized as to the causes of the disorder, by careful introduction of the uninitiated to the problems associated with lack of acclimatization, and by grading the amount of work until acclimatization is achieved.

It is not possible to assign specific levels of heat stress in which heat syncope may be expected; the reasons for this lies in the wide degree of individual variation on exposure to heat and the relatively different response of individuals to work in the heat depending on 1) their physical condition and 2) their state of acclimatization. Hence, heat syncope is an unpredictable disorder, but is preventable by proper indoctrination and education in sensible "hot-weather hygiene".

Other important problems are disorders of water and electrolyte balance. The principle disorders in this category are water-depletion heat exhaustion and salt-depletion heat exhaustion. Neither need occur in industry. Both disorders occur following continued heavy sweating. It is not uncommon for industrial workers to lose 10-12 liters (20-25 pints) of sweat each day[107] and if that much water is not replaced, water depletion occurs. Irrespective of whether water depletion occurs rapidly (e.g., in a day) or progressively (over many days), the end result is the same. In extreme examples, as for men lost in a desert with no water to drink to replace sweat losses, death can occur in 12 hours and is usually inevitable within 48 hours.[16] Even for individuals in a temperate climate, such as castaways at sea, water deprivation will usually result in death in 7-10 days. Death from water depletion will occur if 9-10 liters (18-20 pints) is lost from the body, and loss of 4 liters (8 pints) without replacement leads to intense thirst, a rapid heart rate, and a high body temperature. Water intake must equal the water loss by sweat if this disorder is to be avoided; workers exposed to hot climates must be encouraged to drink an ample supply of water or flavored drinks which must be readily available to them. Again, there is no specific environmental condition above which this disorder occurs, since it depends simply on the replacement of the fluid loss which occurs even in comfortable conditions; however, the hotter the environment is, the greater is the fluid loss by sweating and the worker will thereby come closer to water depletion.

Salt is also lost in the sweat. The concentration of salt in the sweat is higher in unacclimatized men than in acclimatized men, but the concentration also depends on the dietary salt intake, which is usually in excess of the body's needs.[107] If salt lost in the sweat exceeds the dietary intake, a salt depletion occurs. If this is not corrected, a vicious cycle can occur, since salt depletion can lead to loss of appetite and nausea, leading in turn to a further salt depletion; moderately severe salt depletion results in vomiting and diarrhea, with further loss of salt. If this cycle is not interrupted, death inevitably follows. Those who suffer salt depletion complain of weariness and weakness and may suffer muscle cramps; headaches, giddiness, and other symptoms are common. While those who are not acclimatized are at greatest risk, the disorder can occur in any individual who sweats a lot and whose dietary salt intake is low. Supplementary salt of 5 to 15g daily may be required by unacclimatized men to avoid salt depletion. though this may be reduced by half or more after 10 days of work in the heat. While at least some of this supplementary salt can be obtained by the additional salting of food, it may be necessary to supply salted drinks or salt tablets to be taken with drinking water.

The most severe heat disorder is heatstroke, the mortality rate for which has been found to be between 25% and 75%.[16] The variability in mortality depends on the length of time elapsing between the onset of the disorder and the start of treatment and the highest body temperature attained during the episode. Heatstroke always constitutes an urgent medical emergency, in which the basic requirement is to cool the patient rapidly.

Heatstroke is a state of thermoregulatory failure usually of sudden onset, following exposure to hot environments, and is characterized by a disturbance of the central nervous system (often expressed as convulsions), by a failure of sweating (so that the skin is hot and dry), and by a high deep body temperature. The body temperature at the time of onset of the disorder is usually in excess of 40.5°C (105°F) although cases have been reported at 39.5°C (103°F). The treatment of heatstroke must be vigorous and immediate, under the careful control of a physician.

The environmental conditions in which heatstroke has been reported have been plotted on a psychrometric chart (Figure 10) and are surprisingly low.

But the values reported do not include the degree of radiant heat load, nor do they disclose the rate of work of the victims prior to the onset of the disorder; both of these contributions to the total heat load were probably high in many cases. Nevertheless, heatstroke has been known to occur in environmental conditions that are not particularly severe. Additional contributory causes can be of many origins - heavy clothing, water depletion, age, cardiovascular, or other concurrent disease, obesity, hard physical work, etc. It is not uncommon for heat disorders to co-exist and for one to predispose the individual to another. But heat syncope and heatstroke are mutually exclusive - syncope will in this event protect the individual from the more severe disorder.

This brief summary of heat disorders outlines the origins of and the methods of prevention of the commoner disorders; further and detailed information is available in the extensive review by Leithead.[16]

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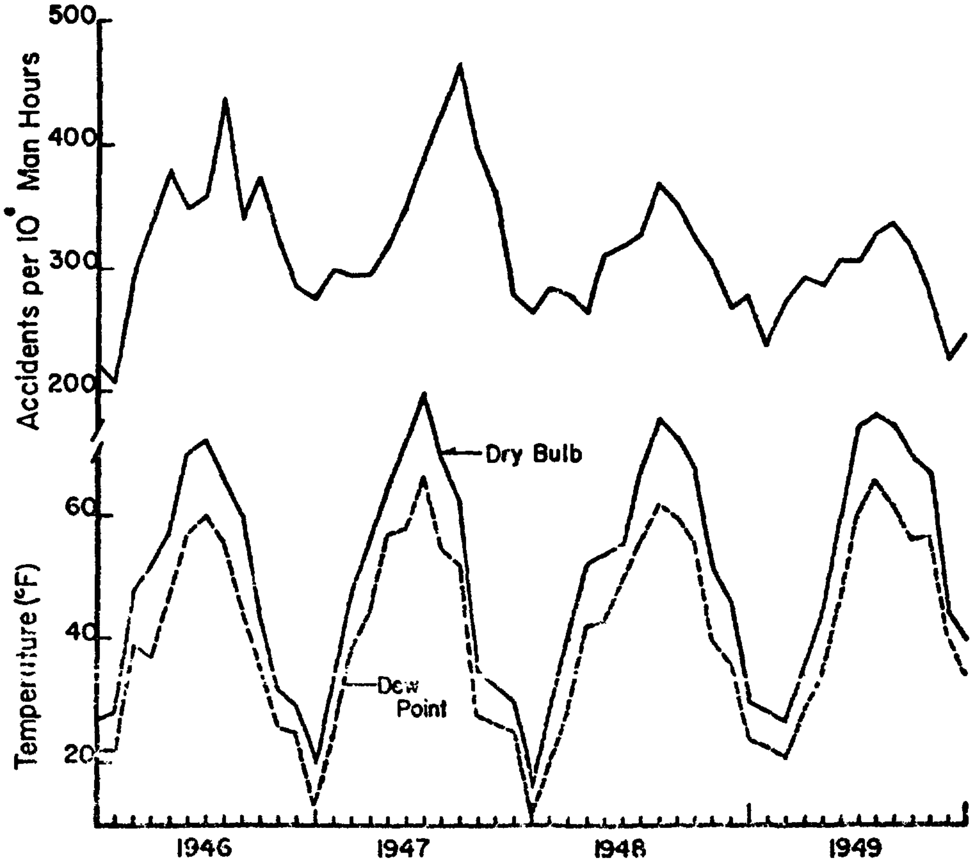


FIGURE 1. WEATHER AND ACCIDENT FREQUENCY IN A STEEL MILL. McMahon and Belding

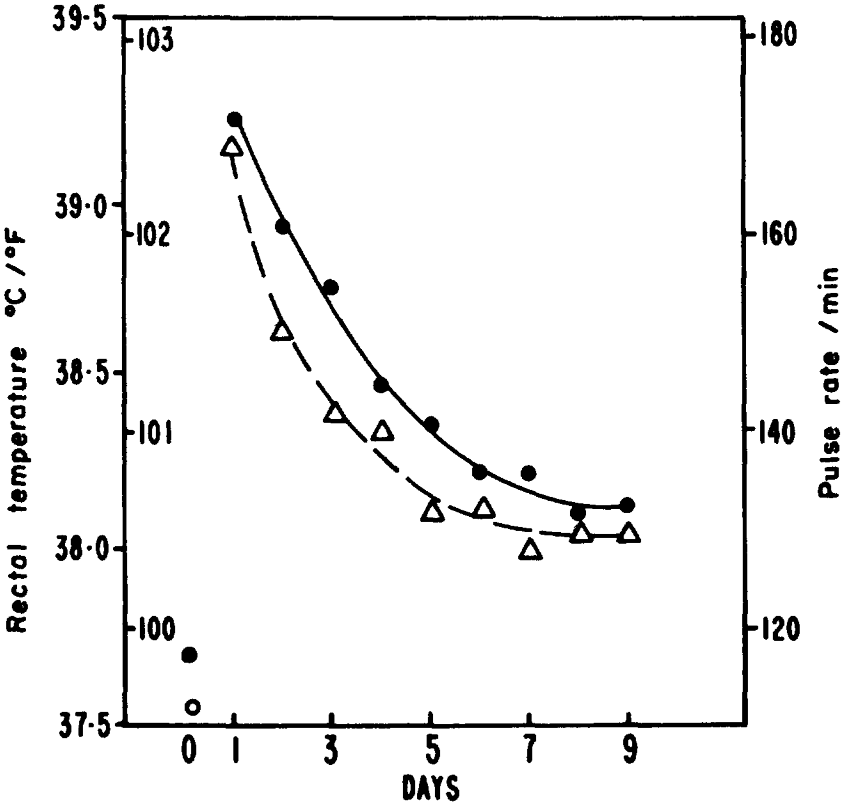


Fig. 2. Typical average rectal temperatures(●) ——
and pulse rates (△).— —

on successive days of exposure to heat
and work .

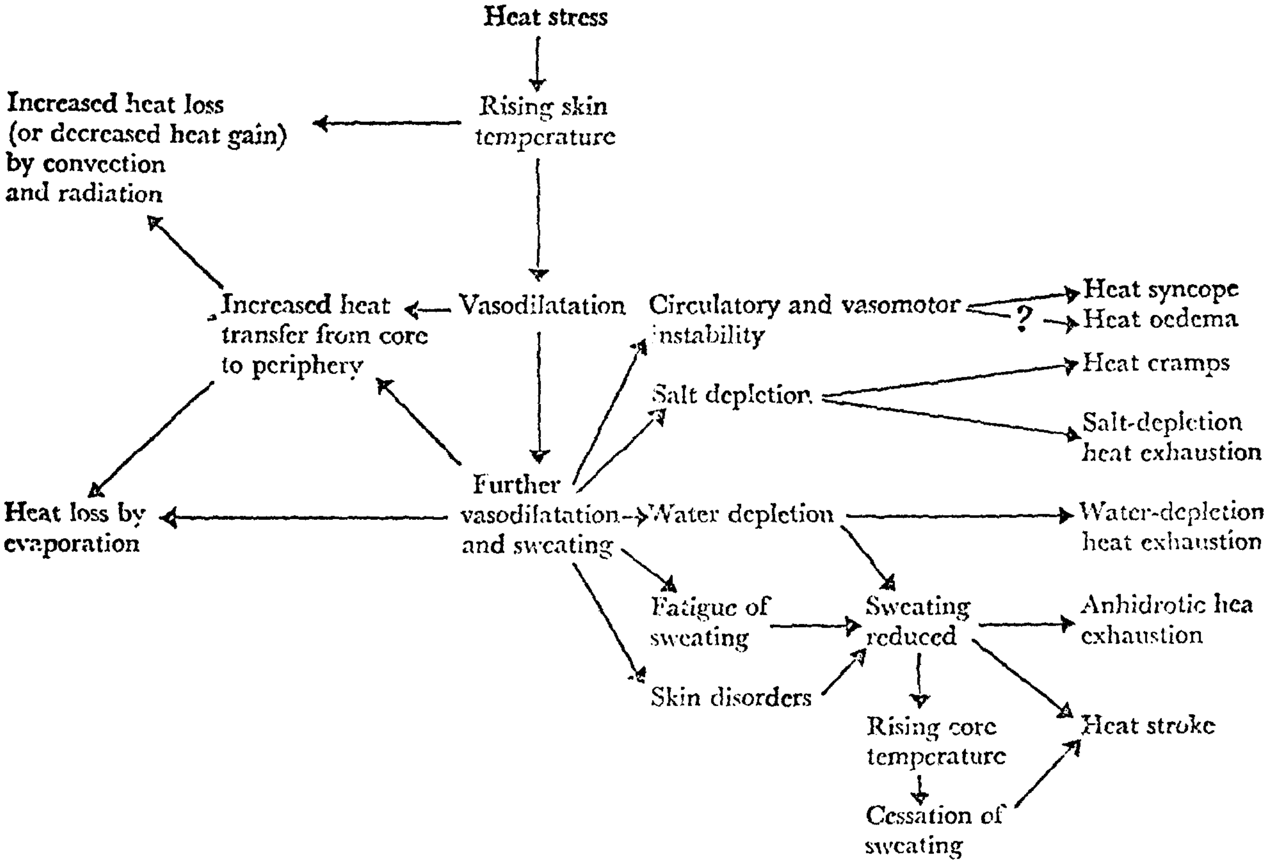


Figure 3. Heat Stress and Heat Disorders

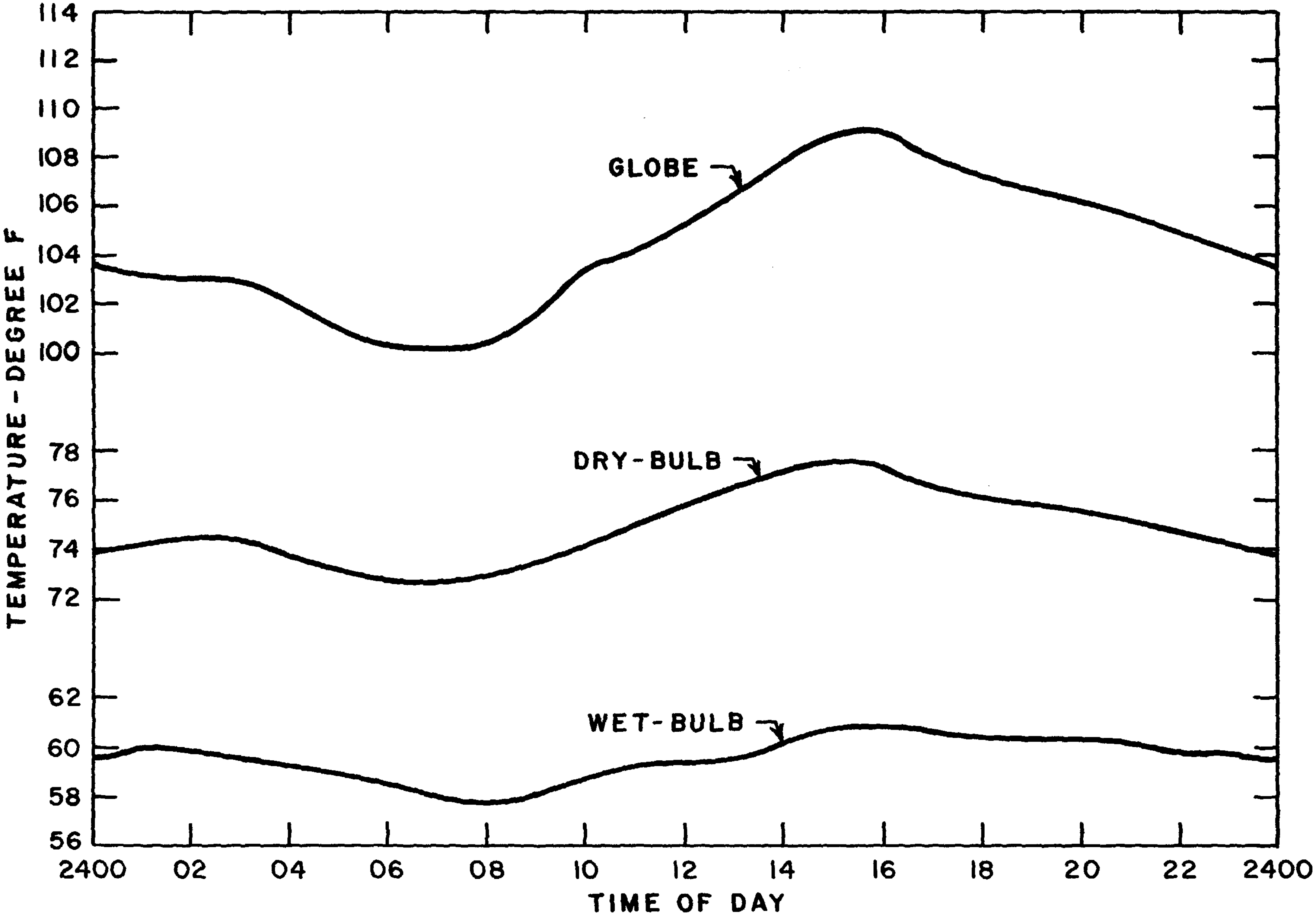


Fig. 4. Glass Plant - Average daily temperature cycles at points A_1 (December 3-19, 1963)

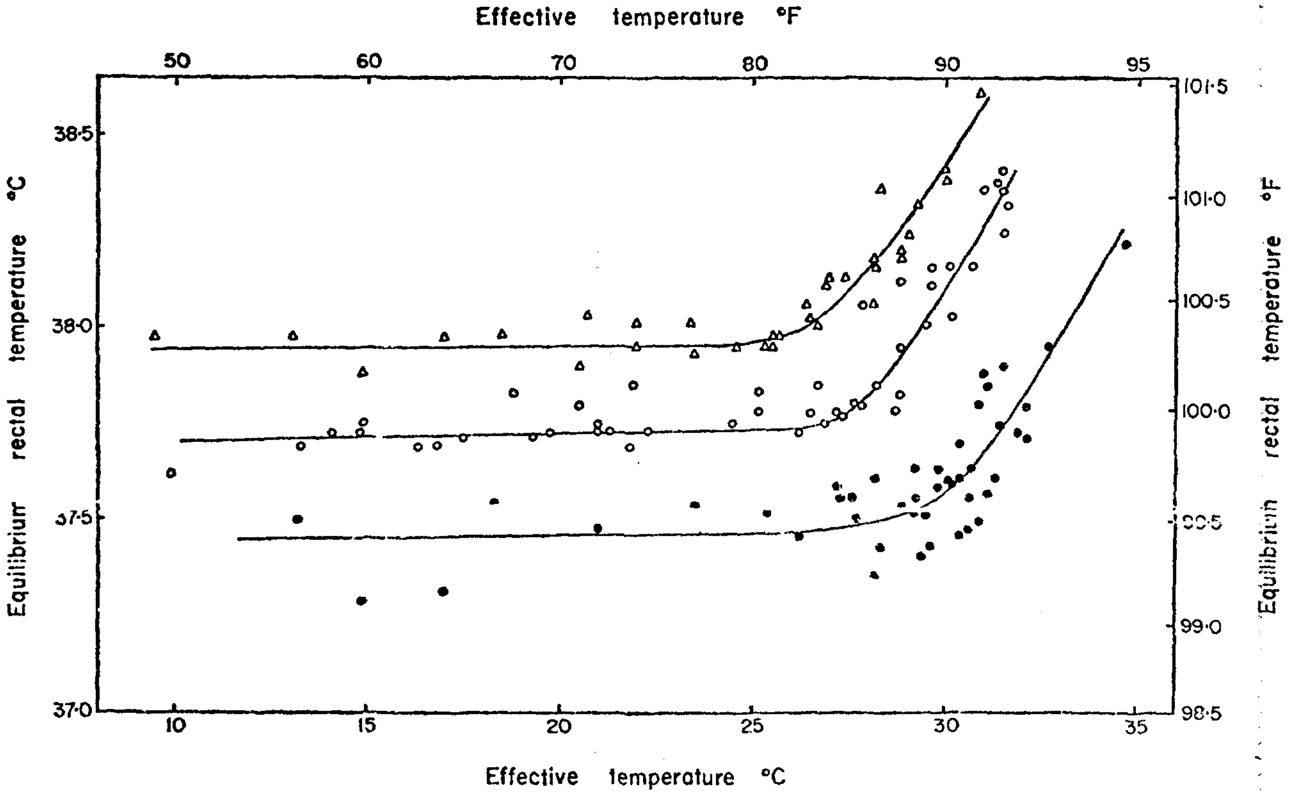


Fig. 5. —The levels of rectal temperature equilibrium of one subject working at 180 (●), 300 (○) and 420 (△) kcal./hr. in a wide range of climatic conditions.

(From: Lind (1963), *J. appl. Physiol.* 18, 31.)

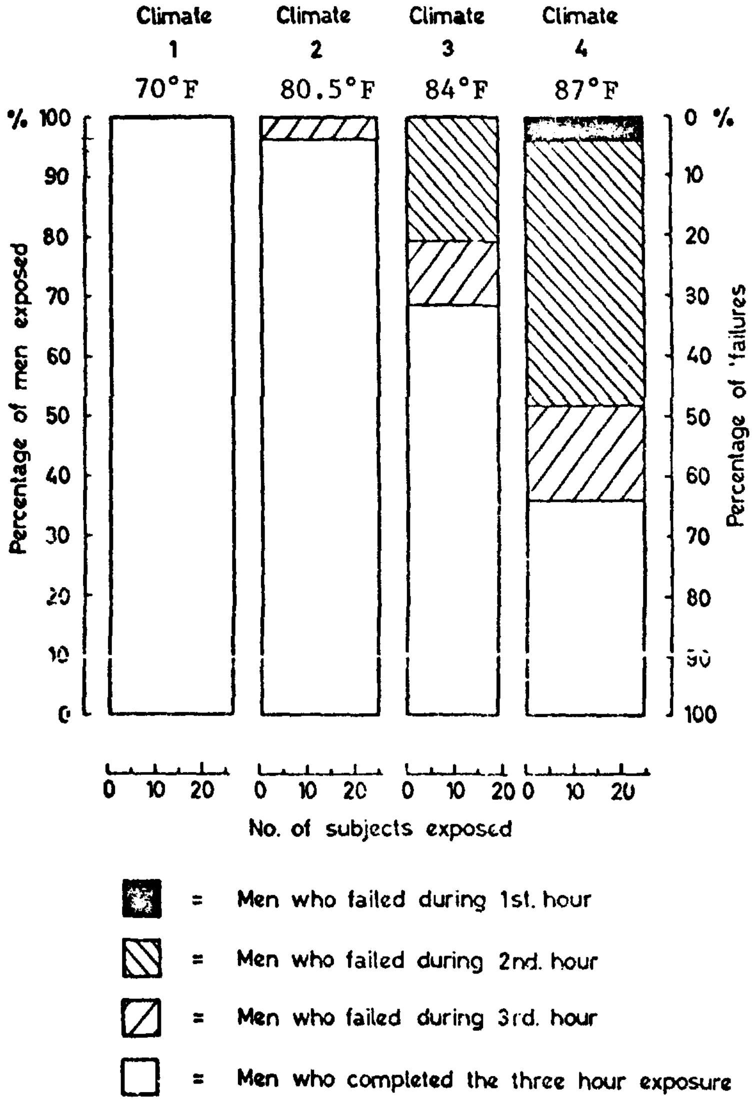


FIGURE 6

The numbers of men who reached a Deep body (rectal) temperature of 102·5°F and/or a pulse rate of 180 beats/min. while working at an energy expenditure of 300 kcal/hr. continuously for 3 hours in one of 4 different climates with Effective temperatures of 70, 60·5, 84 and 87, °F.

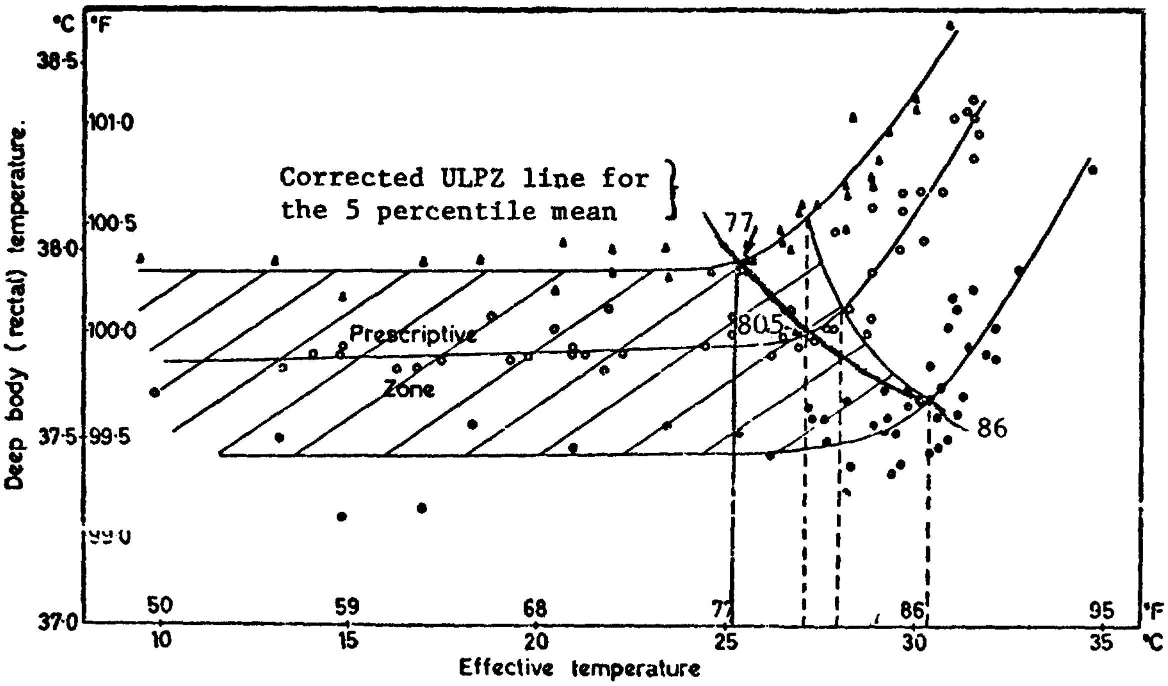


Figure 7. The deep body (rectal) temperatures of one subject working at energy expenditures of 180 (●), 300 (o) and 420 (▲), Kcal/hr, in a wide range of climatic conditions. (C.E.T.)

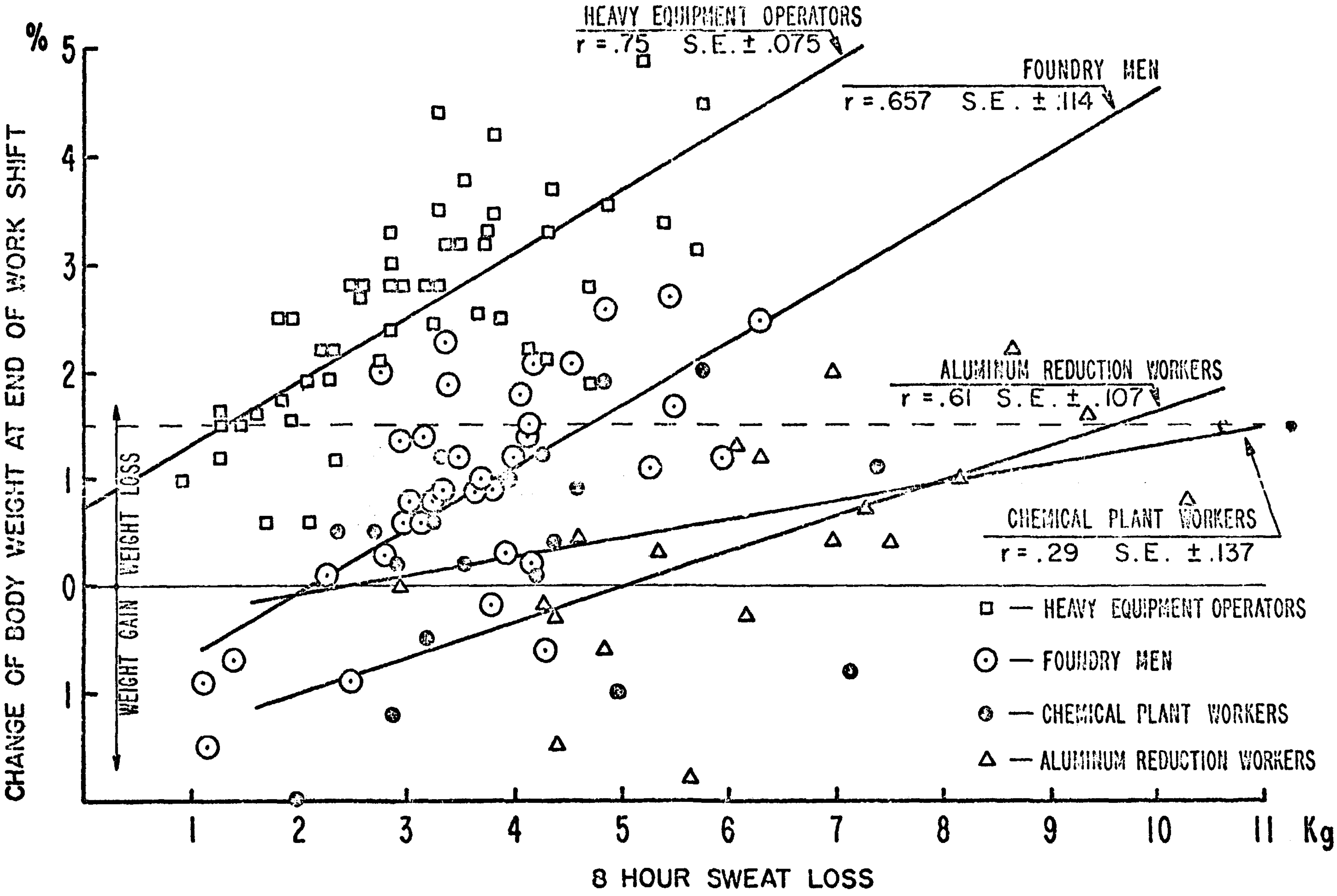

HEAVY EQUIPMENT OPERATORS
r = .75 S.E. ± .075
FOUNDRY MEN
r = .657 S.E. ± .114
ALUMINUM REDUCTION WORKERS
r = .61 S.E. ± .107
CHEMICAL PLANT WORKERS
r = .29 S.E. ± .137
□ — HEAVY EQUIPMENT OPERATORS
⊙ — FOUNDRY MEN
● — CHEMICAL PLANT WORKERS
△ — ALUMINUM REDUCTION WORKERS
CHANGE OF BODY WEIGHT AT END OF WORK SHIFT
%
5
4
3
2
1
0
1
WEIGHT LOSS
WEIGHT GAIN
8 HOUR SWEAT LOSS
1
2
3
4
5
6
7
8
9
10
11
Kg

Figure 8.

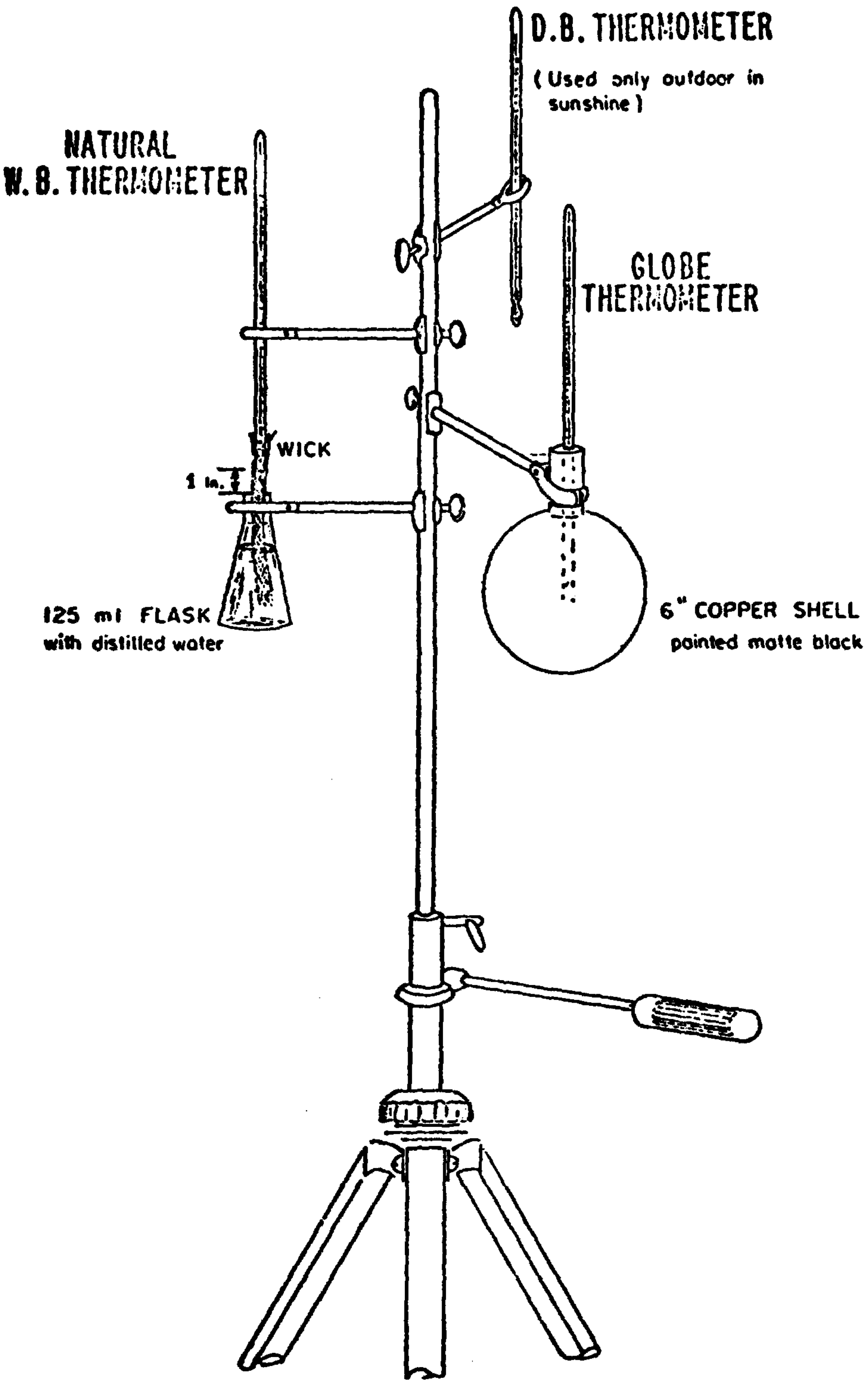
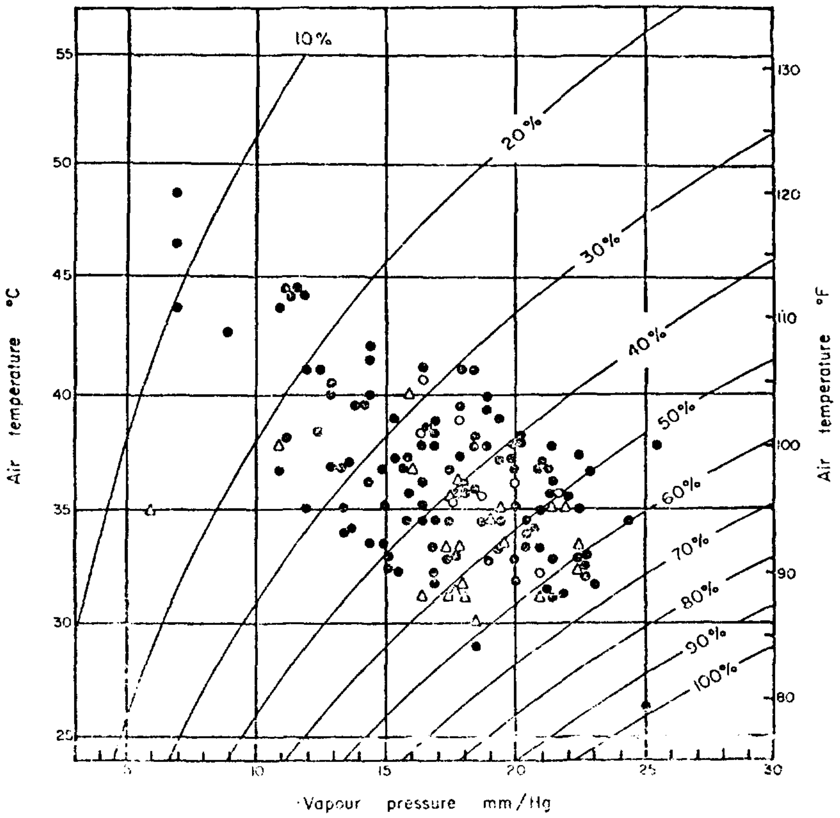


Figure 9. Suggested Instrument Arrangement for Environmental Measurements



- Δ Subject engaged in heavy exercise in sun, or had completed march of 15 to 25 miles during day.
- ● Subject engaged in average activity in sun, i.e. drill, guard duty, or relatively short march; activity not known in few cases.
- ○ Subject indoors during day.
- % Relative humidity.

Fig. **10**. -Humidity and maximum temperature (at nearest weather station) on days of onset of cases of fatal heatstroke in U.S. Army, 1942-44.

(From: Shickele, E. (1947), Environment and Fatal Heat Stroke, *Milit.Surg.*,**100**, 235.)

TABLE I

Factors Important in Determining Exposure-Effects Relationships

Environmental Factors	Human Factors	Job Factors
Temperature	Age	Complexity of Task
Humidity	Sex	Duration of Task
Wind	Physical Fitness	Physical Load
Long Wave Radiation	Body Build	Mental Load
Solar Radiation	Health	Perceptual-motor Load
Dust	Acclimatization	Sensorimotor Load
Aerosols	Nutrition & Hydration	Skill Required
Gases	Motivation	
Fumes	Training	
Barometric Pressure	Physical Capabilities	
Clothing	Mental Capabilities	
	Emotional Stability	
	Ethnic Characteristics	

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