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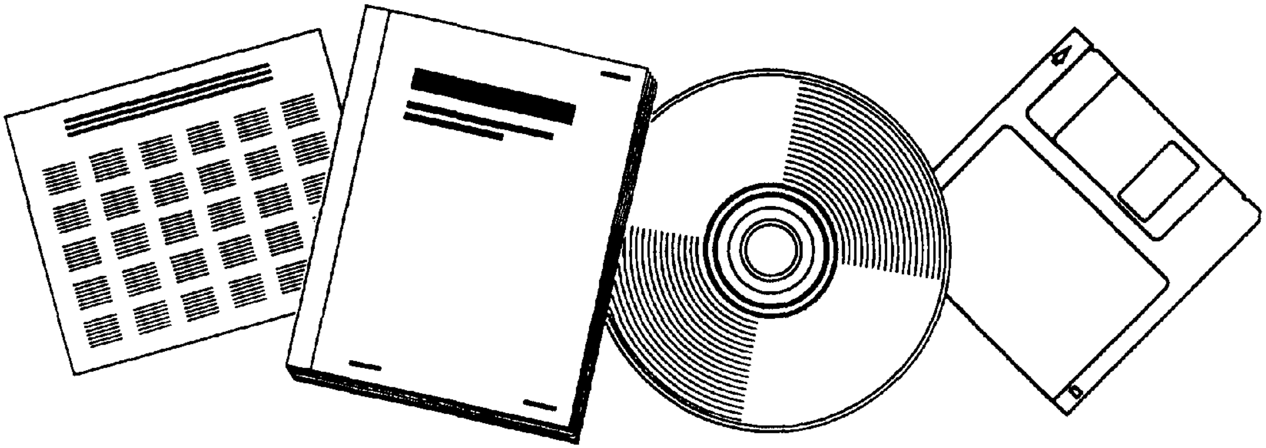

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Papers and reports from the 1979 Workshop on Recommended Heat Stress Standards are presented. The workshop participants included experts from industry, labor, OSHA, and academia, and was conducted under the auspices of NIOSH. Papers were presented on topics such as heat stress tolerance testing, comparison of heat action stress levels, and design of work rest schedules for hot jobs. Preemployment selection criteria for hot job workers also are discussed along with accident prevention methods. Recommendations are included for an improved heat stress standard and for additional research.

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FOREWORD

In September 1979 NIOSH convened a Workshop to which experts from industry, labor, OSHA, and academia were invited. A mandate of the Workshop was to review advances in instrumentation and knowledge concerning the effect of heat stress on workers' safety and health. An additional mandate was to recommend solutions for the problems which arise in connection with the practical application of various heat stress standards previously developed by NIOSH or other scientific groups. In addition, the participants of the Workshop were asked to identify research required for improving the NIOSH heat stress standard and its application by occupational health professionals. These proceedings contain the deliberations and recommendations developed by the Workshop participants.

Anthony Robbins, M.D.
Director
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PREFACE

This workshop was convened under the auspicies of NIOSH for the purpose of exploring new approaches which would enable the establishment of a simple, nevertheless safe, heat stress standard. The problems which stand in the way of such a standard are common to many other health or safety standards, such as the question: "What is the level of heat exposure which can be tolerated without harmful health effects?" However, in the case of heat stress this problem becomes greatly magnified because heat stress is not a single agent, such as is noise or a toxic substance, but a composite of several factors, the most important ones being the four climatic factors (air temperature, mean radiant temperature, humidity, and wind speed), the metabolic heat generated inside the body due to physical work, the level of acclimatization to heat, other host factors, and the clothing worn by the workers. These and other variables can occur in all possible combinations in a given heat exposure situation. Thus, tolerance limits cannot be expressed as a single number unless the variables are inserted in a mathematical equation in which each variable is weighted in accordance with its contribution to the resulting physiological load on the exposed person. Such mathematical formulations are called heat stress indices; there are numerous heat stress indices described in the pertinent literature, each of them applying different assumptions and simplifications in order to keep the necessary calculations within manageable limits.

One assumption which is common to all heat stress indices is that the environmental variables can be measured fairly accurately. This is true within the laboratory, but not at the job site. Most difficult to monitor is wind speed. The Wet Bulb-Globe Temperature (WBGT) Index does not require measuring the wind speed because it relies on the wind speed sensitivity of its two temperature gauges, the natural wet bulb thermometer and the globe thermometer. The equation by which it is calculated is also very simple, consisting of only two multiplications and one addition. The WBGT Index also shows fairly good correlation with the resulting physiological load in terms of heart rate and body temperature response. This is why NIOSH chose the WBGT Index for monitoring heat stress in the recommended standard submitted to OSHA in 1972. Although OSHA did not promulgate the heat stress standard as a mandatory regulation, many industries in the U.S.A. and abroad started to use the WBGT Index for heat stress monitoring and in some countries it was adopted as the standard method.

Subsequently, the WBGT Index was criticized for not predicting human responses with great enough accuracy and also for being still too complicated for general use in industry. Direct reading instruments which appeared on the market recently eliminated the need for calculating the index, but they are considered too expensive for general use. On the other hand, other indices which predict human responses more accurately are far more complicated to calculate. Computers can make calculations of any index fairly simple, but the accuracy of the mathematical equations for predicting a worker's physiological response to a given heat load on the job, is not yet established.

Another way of simplifying heat stress monitoring is to use an instrument which is a human analog. The Wet Globe Thermometer, also called the Botsball by its developer, James Botsford, is such an instrument. The claim has been recently made that this instrument exchanges heat with the environment in a manner similar to that of a human being. Indeed the Wet Globe Temperature (WGT) shows a fairly good correlation with WBGT readings, although this correlation varies with wind speed and mean radiant temperature. The cost of a Botsball is about one-tenth that of a WBGT direct reading instrument. There is no need for calculations because the WGT is read directly from a dial thermometer. One of the questions which was thus posed and was discussed at this Workshop is *"How much accuracy can be sacrificed for the sake of simplicity?"*

Another important question discussed at the Workshop was whether the heat tolerance of women differs from that of men and if so, whether different exposure limits would be justified for men and women. Based on the data of the available literature, NIOSH in 1972 recommended lower action levels for women than for men. Subsequently, the Standards Advisory Committee on Heat Stress (SACHS) convened by OSHA did not recommend separate limits for men and women; neither did the Physical Agents Committee (PAC) of the American Conference of Governmental Industrial Hygienists (ACGIH) when they issued the TLV for heat stress in 1973. Recent NIOSH sponsored studies support the stand taken by the OSHA-SACHS and ACGIH-PAC that separate levels for men and women are not needed.

The question "How heat exposure affects psychomotor performance?" has been dealt with by many investigators and the results described by different authors vary greatly, some contradicting the findings of others. NIOSH recommended in 1972 a set of exposure time limits for jobs in which maintenance of undisturbed mental performance is critical from the point of view of safety. The OSHA-SACHS and the ACGIH-PAC did not cover this problem in their recommendations. Thus the need for separate heat exposure limits from point of view of safety was another problem this Workshop had to discuss.

The heat stress standards recommended by NIOSH and the OSHA-SACHS do not specify maximum permissible exposure limits (PELs), they identify only action levels above which certain mandatory preventive practices are required. In contrast, the ACGIH TLVs are considered to be PELs above which workers should not be exposed. To decide whether action levels are satisfactory for a heat stress standard or whether PELs should be established was one of the most difficult problems this Workshop faced.

It cannot be expected that a Workshop like this finds answers to all of these and other complicated issues surrounding the establishment of a heat stress standard. However, the airing of the problems within a group of experts from government, industry, labor and academic institutions resulted in the identification of solutions which may be acceptable to all the parties involved. There was also an agreement on the most important research gaps which have to be filled in order to come up with a better heat stress standard. Thus, this Workshop must be considered as an important step in the direction of developing an acceptable revised and updated heat stress standard.

ABSTRACT

A workshop on Recommendation for a Heat Stress Standard was convened by NIOSH on September 17-19, 1979. Invited papers were presented the first day of the Workshop and were directed to recent developments and considerations of: (1) comparison of proposed heat stress action lines as recommended by ACGIH, AIHA, OSHA and ISO; (2) physiological monitoring of heat strain; (3) heat stress tolerance testing; (4) preplacement and periodic medical examinations; (5) design of rest-work regimen; (6) prediction of heat strain; (7) personal monitoring of heat stress; and (8) mathematical methods for predicting physiological responses to work in hot environments by the use of a pocket size computer.

During the second day of the Workshop the participants were divided into five Working Groups, each discussing one of the following questions: (1) Should the heat stress standard recommended by NIOSH remain a "Work Practices Standard" or should it be changed to one limiting heat exposure to permissible exposure limits (PELs)? What work practices should be mandatory? (2) What heat stress index and measuring techniques should be adopted in the standard? How should the work-rest regimen be determined? When and under what conditions should environmental, metabolic and medical monitoring be required? (3) Should preemployment selection criteria be adopted? (4) Should there be different considerations given in the standard to workers of different age, sex, and physical work capacity? (5) Should accident prevention aspects be included in the heat stress standard?

During the last day of the Workshop the chairpersons of the Working Groups presented the conclusions reached in their respective groups concerning their topic of discussion and made recommendations for future research. This was followed by a plenary debate on the chairpersons' reports.

There was a unanimous agreement on the need for an action level type of standard. It was also agreed by most of the participants that the action level should be expressed in units of Wet Globe Temperature (WGT), as well as in equivalent values of Wet Bulb-Globe Temperature (WBGT) and Effective Temperature (ET). There should be three action levels established, one each for low, moderate, and heavy work. At environmental conditions above the three action levels, work practices that include environmental monitoring and engineering controls should be instituted.

The selection of work practices and engineering controls to be used should be the joint responsibility of management and labor.

However, management should be required to prepare a written procedure describing the measures to be applied in the plant to insure the prevention of heat induced illnesses. This document should conform to the guidelines contained in the updated heat stress standard and should address, but not be limited to the following considerations: (1) acclimatization procedures; (2) availability of potable water; (3) sudden increases in climate temperature (sudden heat wave); (4) scheduling hot jobs to cooler parts of the day; (5) allowing workers at hot jobs to disrupt work because of extreme discomfort or feeling of impending heat illness; (6) procedures for jobs identified as extreme heat exposure; (7) preplacement and periodic medical evaluation of workers ability to work in the heat.

It was further recommended that engineering controls, work/rest regimen, and protective clothing and equipment be used to maintain the Belding-Hatch Heat Stress Index value at or below the value of 50. However, for monitoring the environmental heat load, other scientifically validated heat stress indices would be acceptable. Physiological monitoring of heart rate and/or body temperature to insure acceptable levels of strain were not exceeded was considered as an alternative to environmental monitoring.

A separate permissible exposure limit (PEL) line above the action level line was favored by the majority, but some of the participants thought that a single action level line would suffice. The magnitude of the safety margin necessary and the percent of the work population that should be protected was discussed at length without a final agreement being reached. It was agreed that the level of protection and the population to be protected was basic to the decision on the shape and position of the action line and the PEL.

CONTENTS

ACKNOWLEDGEMENTS

This Workshop Meeting was the result of cooperative efforts contributed by individuals both within and outside NIOSH. We wish to express our appreciation for the valuable material presented by the authors of the invited papers who responded enthusiastically on a relatively short notice. We are thankful to the leaders of the Working Groups as well as to those who volunteered to act as rapporteurs. This Workshop could not have achieved the desired progress without their expert leadership in clarification of problems and conscientious reporting of the expressed views by the members of the Working Group. The most difficult task rested on the moderator of the plenary sessions. We thank Dr. O'Neil Banks for accepting this task and accomplishing it with tact and great skill so that consensus was reached on several difficult questions. We thank Dr. Elliott Harris and Dr. Barry Johnson, the Director and Deputy Director of the Division of Biomedical and Behavioral Science of NIOSH, for their encouragement and support.

We express special thanks to all those who gave their best effort for making this Workshop a success by handling the administrative tasks and preparing most efficiently the physical facilities, thus assuring a creative atmosphere for the Workshop. This included two members of the NIOSH Physiology and Ergonomics Branch; Mr. Ralph James and Mrs. Mary Swenk, as well as two officials of Verve Research Corporation, Ms. Jo Anne Hariston and Ms. Cecily Robbins. We also recognize the invaluable expert advice and personal effort of Mr. Russ Hinton, Printing Specialist, NIOSH in bringing these proceedings into publication.

OPENING REMARKS

OPENING REMARKS

ELLIOTT HARRIS, PH.D.

The Occupational Safety and Health Act of 1970 was passed into law "to assure safe and healthful working conditions for all workers." The Act established NIOSH and charged it with the responsibility of performing research and field investigations on the health and safety effects of physical and chemical agents found in the workplace. Based on its research and on an evaluation of all other pertinent data, NIOSH was mandated to prepare for the Occupational Safety and Health Administration (OSHA) recommended standards for acceptable levels of those harmful agents to which the worker may be exposed at the work site. OSHA must submit the NIOSH recommendations to a thorough examination, mainly from the point of view of enforceability. Next, the recommended standard has to be scrutinized in public hearings until, ultimately, these recommendations result in the promulgation of an enforceable standard by OSHA.

In 1972 NIOSH sent a recommended Heat Stress Standard to OSHA. This recommended standard described work practices to be followed in hot work areas, as opposed to setting strict levels that should never be exceeded. The standard was generally accepted as good and scientifically defensible. However, it was considered by some that the implementation and enforcement of the standard would be difficult, and that the measurements were too complex and specialized.

Now, after seven years, NIOSH is calling for a thorough review of its recommended standard. The goal of this Workshop is to discuss ways to modify the NIOSH recommendations to make them more practical and easily applied. We would like a recommended standard and, if possible, a simplification of the methodologies. Ideally, this recommended standard would be generally utilizable throughout industry and would not require highly specialized methodology and highly technically trained personnel.

One of the things I would like for you to consider is the establishment of a safety factor within the standard. What are the limits that you would like to recommend? How much of a safety factor would you consider essential to those limits?

With that, I wish you the best of luck, and I want to thank you in advance for your participation here.

F. DUKES-DOBOS, M.D.

It may surprise some of you to learn that this is the second Cincinnati Workshop on the Heat Stress Standard. The first workshop took place almost nine years ago under the sponsorship of the Bureau of Occupational Safety and Health (BOSH). BOSH was one of the forerunner agencies of NIOSH. The seven consultants invited to the first workshop were Dr. Harwood Belding, Mr. Robert Confer, Dr. Pharo Gagge, Dr. Bruce Hertig, Dr. Douglas H. K. Lee, Dr. Alexander Lind, and Dr. David Minard. There were five participants from BOSH — Mr. Walter Carlson, Dr. Austin Henschel, Mr. Clark Humphreys, Mr. Herbert Jones, and myself acting as the convenor. Only a few of these individuals are here today at this workshop. They are Austin Henschel, Herb Jones, David Minard, and myself.

At this time I would like to pay tribute to one of the participants of the first workshop who, unfortunately, is not here today. The person of whom I speak is well known in the United States and around the world for his important contributions to environmental physiology — the science on which all heat stress indices are based. He was best known for the heat stress index that he developed together with Professor Hatch: "The Belding-Hatch Heat Stress Index." Together with Dr. Minard, he also worked on the application of the Wet-Bulb Globe Temperature (WBGT) index for the Navy recruits.

Dr. Harwood Belding's passing away was a great loss to environmental physiology and personally to everyone who knew him. He was a great scientist, a charismatic leader, and a most stimulating and delightful human being.

Those of us from the first workshop who are here again can look back on the past nine years as a period of interesting developments, many of which closely followed the recommendations of the first workshop. Let me review some of the highlights contained in the report of this workshop.

- The new method of setting heat stress standards, as developed by the BOSH Laboratory of Physiology and Ergonomics and recommended as a heat stress standard in surface coal mining operations, was considered to be the best available method for setting heat stress standards for industry in general.
- Concern was expressed that the recommended limit values may be too conservative, although experimental data available to date suggest that the limits are correct if 95% of the heat-acclimatized worker population is to be protected against health damage due to excessive heat exposure. The heat stress standard that was presented to the first workshop is essentially the

same as the one that later became the American Conference of Government and Industrial Hygienists (ACGIH) Threshold Limit Values (TLV) for Heat Stress (Figure 1).

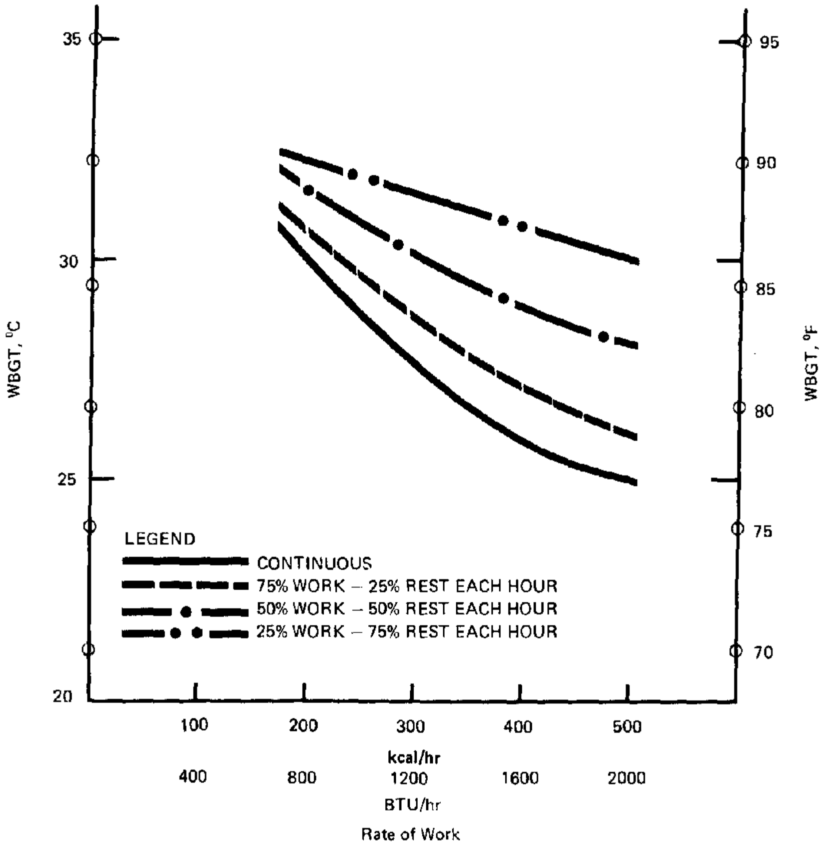

Figure 1. Permissible heat exposure threshold limit value

- It also was suggested that the issue of legally binding heat stress standards should be postponed as long as possible until: (a) more data can be obtained on the energy requirement of different industrial work activities; (b) further data can be obtained concerning the heat tolerance of different worker populations in the U.S.; (c) better instruments and techniques can be developed for monitoring the environment and the workers' physiological responses; (d) more can be learned on the relationship between different types of heat stress conditions and the level of developing physiological strain; and (e) pilot studies can be performed on the impact of applying a heat stress standard on different industrial operations.

- The panel suggested that the ACGIH and the American Industrial Hygiene Association (AIHA) should proceed as fast as possible with issuing an interim heat stress standard based on the BOSH recommendations for surface mining operations, as improved by the suggested modifications.
- It was thought that this will give initiative to the industry to try out the recommended standard in practice and also to develop instruments and methods that would make the monitoring of a standard simpler.
- It was considered highly important to instruct industry that when reporting on accidents or illnesses, it should report whether the worker was exposed to heat stress on the job. At the present too many heat illnesses may not be identified as such, but diagnosed only according to the prevailing symptoms, such as "circulatory failure," "muscle cramps," "indigestion," and "vomiting," etc.

To what extent have these recommendations of the first workshop been implemented? The first workshop recommended that the heat stress exposure limits originally intended only for surface coal miners be adopted for all hot jobs. The ACGIH followed this suggestion by adopting these exposure limits as the TLV for Heat Stress.

The AIHA agreed partially with the workshop report by recommending the use of the WBGT index for environmental monitoring of hot jobs in their manual for *Heating and Cooling for Man in Industry*. However, they recommended the set of limits that had been established for the ESSO Corporation by Richard Brief. Dr. Austin Henschel will give you more information on these limits later; specifically how they compare with the limits developed in the BOSH laboratory.

The prediction made by the participants of the first workshop, that industry will be stimulated by the ACGIH TLV for heat stress and by the AIHA publication to try the recommended standard in their hot plants, indeed came true, as proven by the numerous WBGT instruments sold by Bendix, RAECO, Reuter-Stokes, Yellowsprings Instruments, and others. These companies responded to industry's growing demands for better instrumentation by developing direct reading WBGT instruments. In addition, the Reuter-Stokes Company succeeded in reducing the equilibration time of their black globe thermometer from about 20 minutes to 3 to 5 minutes. A fast-reacting, direct-reading instrument represents significant progress for environmental monitoring.

The last item quoted from the first workshop's report emphasized the importance of making sure that industry reports all accidents and illnesses connected with heat exposure. There was some progress in this direction, too. As a result we had the opportunity to analyze the circumstances surrounding four fatal and one nonfatal heat casualties that occurred in different industries during the past two years.

The environmental data we obtained concerning the severity of heat exposure prevailing on the hot jobs where the heat casualties occurred are presented in Table 1. Complete metabolic and environmental data were obtained for the jobs at job sites occupied by cases 1 and 2 several days after the heat stroke incidents occurred. Environmental data only were obtained at job sites for cases 3, 4 and 5. The environmental heat load at rest and work areas in terms of WBGT were all quite high. Unfortunately, because of lack of complete data, the time-weighted averages (TWA) for environmental and metabolic heat load could be calculated for only cases number 1 and 2, both of which were fatal. The TWA WBGT substantially exceeded 90° F in both cases; environmental heat loads like these are stressful even for the resting worker. In the other three cases the TWA WBGT was not as high on the day of our observations. However, as shown in Table 2, the out of door temperatures were cooler on the days of our observations than on the days when the casualties occurred, except in case number 1; thus the job site temperatures were also hotter on the days of casualties. As a matter of fact, it was established from

Table 1

Environmental Heat and Work Load on the Days of the On-site Studies and Outcome of Casualty

	Environmental Heat				
Case No.	**At Rest and Work Areas Ranges in °F WBGT**	**Hourly Time-Weighted Avg °F WBGT**	**Work Load Categories**	**Metabolic Cost of Work Time-Weighted Average kcal/hr**	**Outcome**
#1	80-105	94	Light	112	Fatal
#2	76-128	98	Moderate	295	Fatal
#3	84-110	Exceeds 79	Moderate	—	Fatal
#4	84-110	Exceeds 79	Moderate	—	Fatal
#5	95 (Work Place Only)	90 (Estimated)	Heavy 75% Work-25% Rest	—	Recovered

U.S. Weather Service data that each heat casualty occurred during a heat wave. This suggests that the workers did not have time to acclimatize to the unusually high heat load that prevailed on the day of the casualty.

Table 2

Outdoor Temperatures on the Days of the Heat Casualties and on the Days of the On-site Studies (U.S. Weather Service)

Case No.	Range of Outdoor Temperatures °F DB	
	On Day of Casualty	**On Day of On-Site Study**
#1	75-99	74-101
#2	91-81	85-78
#3	100-94	94-71
#4	100-94	94-71
#5	96 (Max)	90 (Max)

I would like to emphasize that the 94°F TWA WBGT temperature that probably prevailed in case 1 is only 4° above the ACGIH TLV level. I want to emphasize this because some believe the ACGIH TLV is too restrictive, and that the safety margin is too large.

The host factors (physical fitness and health status) of the workers who were heat casualty victims are shown in Table 3. In each case there were indications that the victims may have been at a higher than average risk because of lack of acclimatization (cases 2 and 5); because of change of medical status (case 2 just returned from alcohol withdrawal treatment, case 3 had a recognized alcohol problem, case 5 had a hemorrhoid operation ten days before); because of lack of physical fitness (cases 1 and 5); overweight and probable dehydration (case 1); case 4 returned to work two and one-half weeks before the incident, after fifteen months of sick leave and he was overweight; and case 3 had heat exhaustion on a previous day but was cleared for work by the nurse. In addition, the impaired hearing and speech of case 1 contributed to the increased risk, because of the difficulty of communicating with his co-workers and supervisors. For instance he stayed on the job site during a breakdown period instead of joining his co-workers in the work-rest area on the day of his fatal heat injury. These findings emphasize the importance of selecting workers for hot jobs by periodic medical examinations and by preplacement medical examinations.

Table 3

Host Factors

Case No.	Acclimatization	Medical History	Physical Fitness	Age Sex	Work History
#1	Acclimatized	Impaired Hearing and Speech	Overweight, Probably Dehydrated	21 Male	—
#2	2nd Day on Hot Job	Just Returned from Alcohol Withdrawal Treatment	Slightly Overweight	21 Male	—
#3	Acclimatized	Had a Recognized Alcohol Problem	Was **Not** Under the Influence	52 Male	Employed 24 Years in Hot Plant
#4	Acclimatized	Rheumatoid Arthritis, Cleared for Work by Factory Dispensary	Returned to Work 2½ Weeks Ago After 15 Months Sick, Overweight	56 Male	Employed 24 Years in Hot Plant
#5	2nd Day on Hot Job	Hemorrhoid Operation 10 Days Previous	Heat Exhaustion on Previous Day Cleared by Nurse For Work	Late 20s (Estimate) Male	Employed in Same Plant for 15 Months Not in Hot Job

There was argument in the past about the feasibility of giving preplacement medical examinations for all job applicants in hot plants. It was assumed that, to establish an individual's heat tolerance, an exercise test in a heat chamber was necessary. However, as we will hear later from Dr. Esar Shvartz, a simple exercise test may be satisfactory for this purpose. Thus, it would be possible in any physician's office to test workers for their heat tolerance and to advise those who have less than average heat tolerance about the potential health risks associated with working in hot plants.

I see an opportunity to stimulate industry to introduce such a selection procedure by adopting higher permissible exposure limits for plants where workers undergo the medical selection test and are kept under continuous medical surveillance by periodic medical examinations. I ask you to take this item into consideration tomorrow, when you discuss what permissible exposure limits should be included in a heat stress standard; and also, when you discuss the need for preplacement and periodical examinations.

The analysis of these heat casualties yielded a number of other interesting facts, one of which was that in three out of four fatal cases the victims were able to leave the job site before they collapsed. The victims collapsed either on the way out of the plant or on the way home. This fact makes one wonder how many fatal heat stroke cases may have eluded recognition due to similar circumstances where the worker collapsed outside the plant and whose immediate heat exposure history was not known to those who witnessed the collapse. Unfortunately it might never become known that such a worker came from a hot workshop, since the victim may not regain consciousness.

Another interesting fact that came out of the analysis of the heat casualties was, that in the plants where the heat casualties occurred, one or more preventive work practices were employed. For instance, drinking water and salt tablets were available in most places. Some kind of ventilation was also installed, although its effectiveness for providing cooling may be questionable.

This brings up an important problem of whether the application of only one preventive work practice gives enough protection to the employee in a hot job. The standard recommended by NIOSH stipulates that the introduction of *one or more* work practices listed in the standard is acceptable from the point of view of compliance. The Standard Advisory Committee on Heat Stress, which was convened by OSHA to critically evaluate the NIOSH criteria document, recommended a change in this stipulation by recommending a requirement that a set of preventive work practices must be applied in all hot jobs.

In the first workshop's report, it was suggested that the promulgation of a mandatory heat stress standard should be postponed until more knowledge is accumulated on different aspects of human tolerance to heat, and the instruments and techniques for monitoring heat stress and strain are improved. I can see the intention behind this suggestion. During these past nine years a large amount of information has been obtained and progress made on both points. I wonder, how much longer must the issuance of a heat stress standard wait?

In this respect, NIOSH did not comply completely with the wishes of the consultants at the first workshop. NIOSH, as Dr. Harris said, issued a criteria document for heat stress shortly after the first workshop and recommended that OSHA promulgate the standard proposed in the document. However, the recommendation of the first workshop not to issue a mandatory standard prevailed in spite of the NIOSH action. One of the reasons mentioned for not promulgating the standard was the belief that both complying with and enforcing the recommended standard would be very difficult.

One of the reasons for inviting you to this workshop is to ask your advice on how to make the heat stress standard easier to comply with and easier to enforce, without losing its effectiveness.

The heat stress standard contained in the NIOSH criteria document differed greatly from the ACGIH TLV. First, it did not describe permissible exposure limits (PELs). Instead it identified two action levels in terms of environment of the jobs, one for females and another for males (76°F and 79°F WBGT respectively). Subsequently, the OSHA Standards Advisory Committee recommended six threshold WBGT values, based on the physical work demands of the job. In Table 4 the threshold WBGT

Table 4

Threshold WBGT Values

Workload	**Threshold WBGT Values Degrees F (C)**	
	Low Air Velocity (Up to 300 fpm)	**High Air Velocity (300 fpm or above)**
Light (Level 2) (200 kcal/hr or below)	86 (30.0)	90 (32.2)
Moderate (Level 3) (201 to 300 kcal/hr)	82 (27.9)	87 (30.6)
Heavy (Level 4) (above 300 kcal/hr)	79 (26.1)	84 (28.9)

values adopted by the OSHA Standard Advisory Committee are presented.

It is one issue if the energy requirement values are needed only for determining whether the action levels have been exceeded. It is another issue if these values are needed to determine if PELs are exceeded. In the latter case the accuracy of the energy requirement measurements is much more critical than in the former because the action levels have a much larger safety margin than the PELs. Thus, in the case of action levels, a rough estimate by the use of energy expenditure tables is acceptable while in the case of PELs an accurate measurement of the energy expenditure is necessary.

The OSHA threshold WBGT values recommended higher action levels for conditions where the wind speed exceeds 300 fpm (Table 4). This recommendation of the OSHA Standards Advisory Committee was based on theoretical considerations. However, recent studies performed by Dr. Eliezer Kamon showed that wind speeds over 300 fpm do not give more cooling to the worker than WBGT values indicate. Thus, setting separate higher action levels for conditions of high wind speed would appear to serve no useful purpose. However, further studies are necessary to investigate this problem under conditions of exposure to radiant heat.

Another interesting development during the past nine years is that the ACGIH TLV for heat stress has been adopted as a guideline in several other countries. The Swedish heat stress standard is a replica of the ACGIH TLV, except that, instead of the natural wet-bulb thermometer, they recommend the use of a psychrometric wet-bulb thermometer. The Belgian regulation adopted the ACGIH TLV values, but prescribed them as Corrected Effective Temperature values (CET), which are slightly different from the WBGT. The CET has the disadvantage that the wind speed has to be measured separately; this is very difficult to do accurately in the industrial setting where the wind speeds may fluctuate over a wide range in a short time or distance. In addition, the use of the CET nomogram has a number of disadvantages compared to the calculation of the WBGT index.

Recently, the International Standard Organization (ISO) adopted the ACGIH TLV, with some minor modifications, as a draft standard. This means that the standard will be sent out to all member countries of the ISO for trial and comments over a period of the next five years. The ISO expert panel that adopted the ACGIH TLV as a draft standard recognized the inaccuracies of the WBGT index. However, they came to the conclusion that the simplicity of this index outweighs, in importance, the inaccuracies, particularly in view of the great variability of all other relevant factors in the everyday routine of industrial work. The ISO's expert panel is now in the process of adopting another draft standard for heat stress based on the Required Sweat Index developed in France by Drs. Metz and Vogt. This standard will be recommended as an analytical method for determining more accurately the environmental heat load, but it requires complex calculations. The same ISO expert group is also working on the development of a draft standard for measuring the energy requirement of physical work in industry.

I hope this workshop will adopt recommendations that will benefit the workers in hot industries when the recommendations are implemented by NIOSH and OSHA, as well as in the hot industries. Hopefully, nine years from now the person standing in this place can say, "Ladies and Gentlemen, we followed the recommendation of the Second Heat Stress Workshop in Cincinnati, and as a result we were able to eliminate cases of heat stroke in this country, and to reduce other heat related illnesses to a very low level."

I wish you good luck in your deliberations; have a pleasant stay here.

O. M. BANKS, PH.D.

Over the years until July 23, 1978, I had no more or less involvement in heat stress than the average industrial hygienist. July 23rd was a rather hot Sunday in Maryland, at the end of a hot spell. The temperature was hitting 101°F (38.3°C) at the Baltimore/Washington International Airport. A little after 10:00 that evening, after returning from a day on Chesapeake Bay, I received a phone call from Baltimore City Hospital. I was informed they had two heat stress patients, and they did not know if either one would make it through the night.

That precipitated a number of investigations. The essential facts were: patient #1, a steel worker in the basic oxygen furnace area, became a casualty on July 23, 1978. He arrived at work at 2:10 p.m. At 6:25 p.m. a call was placed to the dispensary. He rode to the dispensary in a car and was conscious, discussing the Orioles baseball game on the way. At the dispensary he began to be confused. An i.v. was attempted. He became combative and would not allow his clothes to be removed. The company police were called. Ten milligrams of Valium were administered. His axillary temperature was measured; according to the physician it was 106°F (41.1°C). According to the physician's assistant, it was off the thermometer, which means an axillary temperature higher than 108°F (42.2°C).

At 6:59 p.m. a Baltimore County ambulance was called. It arrived at 7:01 p.m. According to the ambulance drivers, there was no ice on the patient at that time. The company physician said two to three bags of ice had been placed on the head, trunk and legs. The ambulance drivers requested wet sheets and bags of ice for use while transporting the patient to the hospital, since they did not have these in the ambulance. They had not been alerted to the nature of the injury when they were called.

At 7:20 p.m. the ambulance reached Baltimore City Hospital. The patient's rectal temperature at that time was over 108°F (42.2°C); his blood pressure was 140/80 mm Hg. He was immediately immersed in ice water. Baltimore City Hospital maintains a bathtub which is filled with ice and water for immersion of heat stroke patients. He was kept in the ice water bath until his rectal temperature reached 102°F (38.9°C). At that point he was removed from the bath.

Probable aspiration and left-sided focal seizure was the assumed diagnosis at that point. He regained consciousness on day two. The diagnosis was persistent acidosis. He was intubated, but a respirator was not used. On day four he was extubated and he was alert; day 6 he developed left side atelectasis; day 9, there was cardiopulmonary arrest. Consciousness was lost and never regained. In October 1978 he was transferred to a long-term care facility, where he died in December 1978 of hyperthermia with complications. Prior to this episode he had suffered from arthritis and had prior alcohol problems two years before. There was no evidence of alcohol involvement on July 23, 1978. He was hypertensive and on medication. He weighed over 200 pounds. He wore long underwear and heavy clothing in the course of his work on that day.

Case #2 also involved a steel worker, this time in the open hearth area. He arrived for work at 3:00 p.m. There was some question among his fellow workers as to his ability to work. He had been on sick leave for three months with a problem involving his knee. He had been back at work for two weeks, during which time he had worked a total of seven days.

At 8:55 p.m. a call was made to the dispensary. The man was in a coma. At 9:10 p.m. he was taken unconscious to the dispensary. His pupils were sluggish but reacted to light; breathing was labored; blood pressure was 90/60 mm Hg. His clothes were removed; an i.v. inserted and oxygen administered. His axillary temperature was off the scale, more than 108°F (42.2°C). According to the physician, ice bags were placed over the entire body.

At 9:16 p.m. a Baltimore County ambulance arrived. The ambulance driver reported that there was no ice on the patient. They requested wet sheets and ice, since they had not been alerted to bring them. At 9:40 p.m. the ambulance arrived at Baltimore City Hospital. Rectal temperature was above 108°F (42.2°C); blood pressure was 70/0; there were no spontaneous reactions or movements; and there were decreased reflex actions. He was treated with ice water immersion until his temperature reached 101°F (38.2°C) to 103°F (39.4°C). According to the hospital records, he suffered pulmonary edema, generalized seizure, acute renal failure, acidosis, hyperglycemia, gastrointestinal bleeding, disseminated intra-vascular coagulation, refractory elevated temperature, unresponsive hypertension, severe hypoxia, and unreponsive capillary leak syndrome. He died on day two, July 25, 1978.

The factors in this case were questionable acclimatization, long underwear, and heavy clothing. He reportedly wore a heavy wool jacket, buttoned up during the entire day. He took his rest breaks outside where, according to the report, he slept in a wheelbarrow in temperatures ranging from 101°F (38.2°C) to 102°F (38.9°C). He was also hypertensive and on medication.

Subsequently, we became aware of a third case on June 30, 1978: a concrete finisher who worked for a construction company. He was a temporary employee, working on days when there was work for him. According to reports, he arrived at work at 7:30 a.m. The company reported that at 8:07 a.m. he was intoxicated. He reportedly slept under a tree at noontime. From 4:30 to 6:00 p.m. he was dumping cement. According to the union reports he was dumping gravel and shoveling all afternoon.

At 6:00 p.m. an ambulance was called and he was taken to St. Joseph's Hospital, where his rectal temperature was measured at more than 110°F (43.3°C). His blood alcohol level was negative. He never recovered consciousness. He was placed on a respirator and transferred to a long-term care facility, where he died on December 4, 1978. The diagnosis was hyperthermia with complications. The medical examiner's report showed sclerosis of the cerebellum, bronchial pneumonia, pulmonary thrombosis, decubitus ulcers, cardiomegaly of 550 grams, and mycardial fibrosis.

Maryland Occupational Safety and Health (MOSH) issued a citation for willful and serious violations of the general duty clause applying in cases 1 and 2. These citations were contested. A hearing was held from December 11-15, 1978. The opinion of the hearing officer has not yet been received. Case 3 did not come to our attention until after the death of the worker in December. Sufficient evidence could not be obtained for a citation.

We considered the situation with respect to the difficulty involved in setting a standard, and we also considered an emergency temporary standard. Instead, in May 1979, we co-sponsored a symposium on heat stress with the Safety Council of Maryland. An interview was held on local television in connection with this. Posters on heat stress were prepared and disseminated for use in the work place. A publication entitled "Working Persons Guide to Prevent Heat Stress" was made available. About 5,000 of these were distributed throughout the state.

A more technical brochure, "What Employers Should Know About Heat Stress," was prepared and distributed by direct mail to 350 employers throughout the state. To clarify this we prepared a 30-second public service television commerical, which was released to the local television stations in July 1979. We had two more interviews with local television news teams involving not only an interview with a professional, but also coverage of a heat stress survey taking place in the field. The segment included illustrations of hot jobs and the precautions that need to be taken in the summer when it is hot.

We conducted industrial hygiene inspections at selected high risk places of employment, as well as in response to complaints resulting from a public information campaign. We received such a large number of these complaints that we developed a screening questionnaire to gather information to help set a priority for complaints and to decide which ones were valid complaints involving health risk situations versus complaints that were primarily an issue of comfort.

We have investigated a number of cases of heat strain or heat exhaustion occurring both in 1978 and this summer. We have not found any other fatal cases. One of the factors these cases demonstrate is the need for better quality emergency treatment, including the more rapid cooling of workers.

The cases that we have had are very similar to the ones that Dr. Dukes-Dobos showed. The factors, such as hypertension, references to alcoholism, overweight, and arthritis, generally were very similar. There seem to be certain predisposing factors. High environmental temperatures and, frequently, inadequate emergency medical treatment were involved in the fatal cases.

We feel very strongly that something must be done. I believe that the technical questions of how best to measure heat stress might be much less important than having something to protect the workers. We feel there is a desperate need for a heat stress standard. If there is no OSHA standard before the summer of 1980, Maryland will be forced to adopt one independently to protect the workers of our state.

In the case of the steel workers, their heat exposure was clearly excessive, not only by the Wet Bulb Globe Thermometer criterion, but also by every other criterion for judging heat stress that has subsequently been proposed. There was no question that they were overexposed and that they are dead as a result.

ROGER STEPHENS, PH.D.

I have very few words to add to those that already have been said. Essentially, someone must assume the responsibility if we are to issue a heat standard. That is my pleasure, or my burden, depending upon how you look at it. If I look at the track record of the heat stress standard, it looks like quite a burden. But something needs to go on the books. Having spent time in academia, I know it is almost impossible to have a number of academic and other people agree consistently on anything.

Most of us are here for three days. Hopefully, we can adopt an attitude of cooperation, so that we can leave with recommendations that are at least somewhat realistic. Then, I will do my best to administer these recommendations and get them through the political system. If we can adopt a constructive approach, maybe we can develop a useful standard before another decade goes by.

Good luck to all of you. It will make my responsibility much easier if we can do something productive. Thank you.

Part I

INVITED PAPERS

COMPARISON OF HEAT STRESS ACTION LEVELS

A. Henschel, Ph.D.

ABSTRACT

The Wet-bulb Globe Temperature (WBGT) index is widely used throughout the Western World to assess the levels of heat stress in industrial situations. It is recognized as a convenient and easily used index of heat stress, but it is not completely adequate as a method for calculating heat load in order to recommend engineering controls.

For continuous work in heat, the recommended WBGT action levels for various levels of physical work are about the same for all groups who base the levels on the WBGT. For intermittent work in heat, the situation is very confused because of the difficulty in comparing situations where the length of the rest and work periods both vary, where the rest-to-work ratios vary, and where the WBGT values in the rest and the work areas also vary. Additional laboratory and field research is needed before an action level WBGT for intermittent work in the heat can be agreed upon.

I have three points to make today. One is to compare the proposed action levels for continuous work in the heat. There are a number of organizations that have proposed a WBGT action level for continuous work. Second, is to compare the few action levels that have been proposed for intermittent work. And third, I want to raise the following question: Can the same index be used for hot dry conditions as for hot humid conditions to determine what the action levels are to be?

For continuous work in heat there is little disagreement on the heat stress action levels even though this may not appear to be true from a casual look at the proposed levels. There are many methods for expressing the level of heat stress. The one most widely used throughout the world is the wet-bulb globe temperature (WBGT). All who use the WBGT recornize that it is a convenient and easily used method that is useful as an index of heat stress, but it is inadequate as a method for calculating heat load for recommending engineering heat control procedures.

The WBGT is used as the action level index both officially and unofficially in many areas of the world. The action levels proposed by ACGIH TLV, AIHA, ISO, OSHA,* and several of the European countries, including Norway, Sweden, and Belgium, are based on the WBGT. When the action level WBGT for different levels of work intensity are plotted, the various proposed levels are identical (See Figure 1). The only serious deviation is the OSHA proposed levels for high wind speeds. Recent laboratory experiments have shown that the high wind speed corrections may not be necessary. This, then, puts all the action levels in close agreement for continuous work in the heat. It would also suggest that further studies to establish action level heat stress values for continuous work in temperate areas of the world are not urgently needed. This assumes that adequate methodology is available to reasonably estimate the level of metabolic heat production for each industrial job. A well-controlled validation study in one or more hot industries would probably be useful. It might help make us all more comfortable in accepting the WBGT continuous work action levels that have achieved worldwide support.

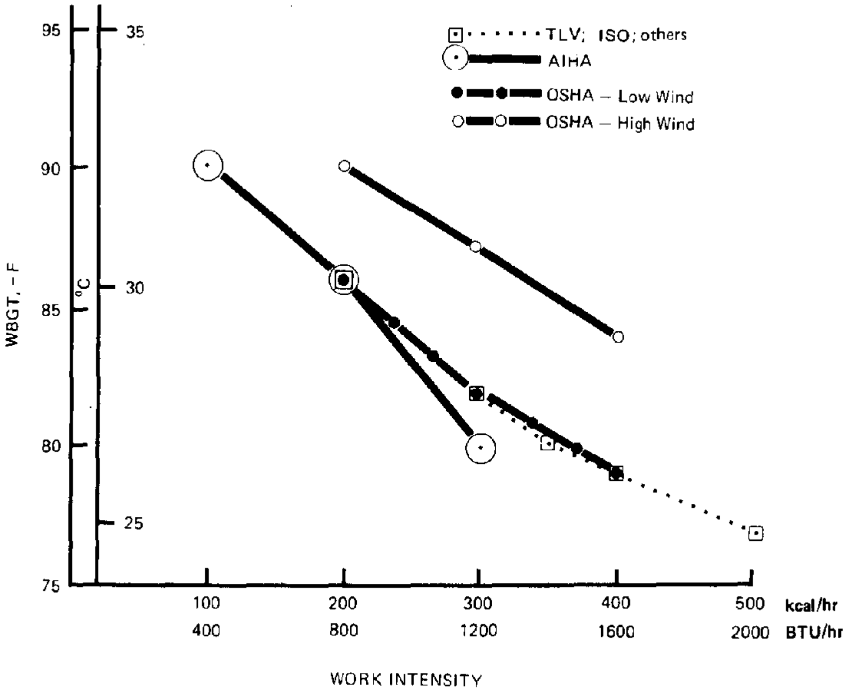

Figure 1. WBGT for continuous work in the heat

For intermittent work in heat, the situation is very confused because of some major problems. It is very difficult to measure

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*OSHA Standards Advisory Committee.

the pattern of heat exposure in intermittent work. We really do not know the relative physiological impact of short versus long exposures, and to what extent the temperature of the rest area counteracts the conditions in the work area. The rest-work regimen, with the interacting and counteracting effects of the total rest and work stresses, are still mostly unknown. Factors such as the differences in WBGT between rest and work areas, the length of the work and the rest periods, the proportion of the total time that is spent in the work and in the rest area, and the severity of the physical work, are all important.

The ACGIH TLV and the AIHA both have produced WBGT action levels for different rest-work proportion regimens (See Figure 2). For the lower metabolic levels (200 kcal./hr.) the

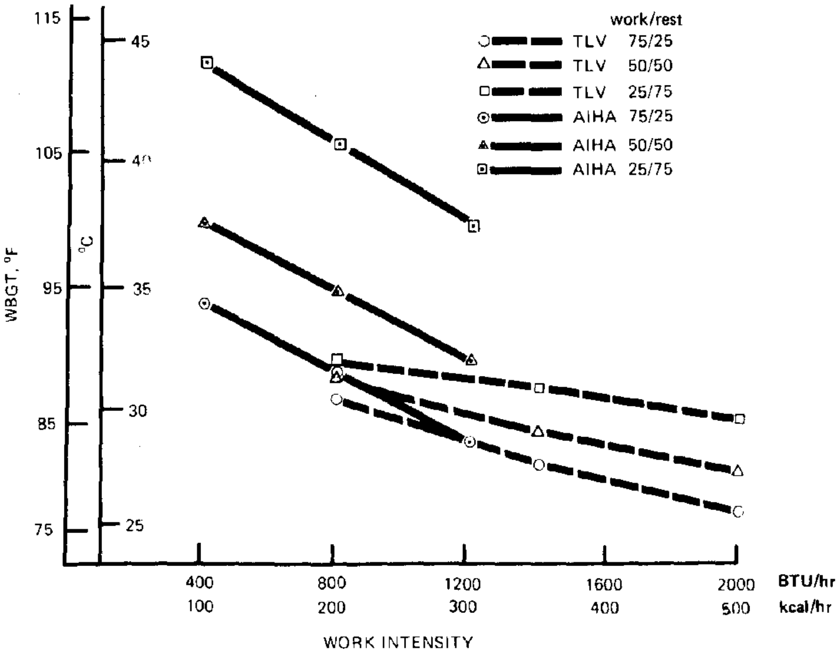

Figure 2. WBGT for intermittent work in the heat

AIHA action levels are from 1 to 8°C WBGT higher than the ACGIH TLV, with the greater difference occurring at the 25% work — 75% rest regimen. However, the TLV and the AIHA action levels are based on different rest area environmental condition assumptions. The TLV assumes the rest area has the same environmental conditions as the work area. The AIHA assumes a cool rest area of about 24°C WBGT (about 25.5, 24, 19.5°C WBGT for work levels of 400, 800, and 1200 BTU/hr., respectively).

When the ACGIH TLV action levels are calculated with an assumed rest area temperature of 75° WBGT, the action level work area WBGTs for the 50%-50% rest-work and the 75%-25% rest-work become considerably higher than the AIHA levels (See Figure 3). This same general relationship of less restrictive action levels for the ACGIH TLV are apparent when the AIHA values are calculated assuming the rest area has the same conditions as the work area (See Figure 4).

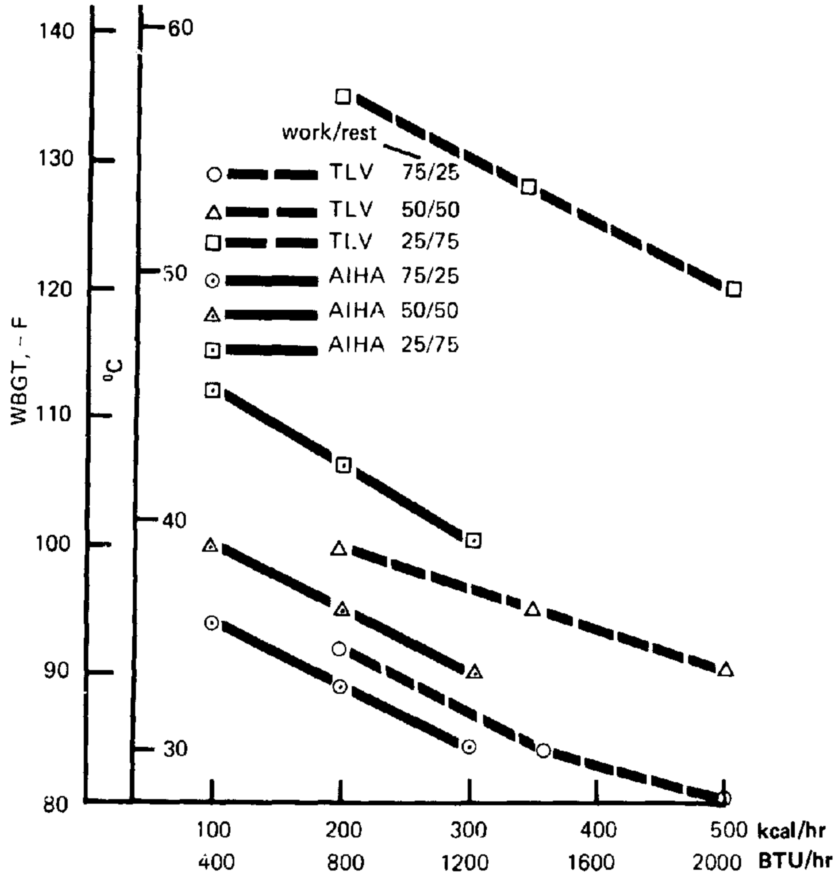

Figure 3. WBGT for intermittent work in the heat; rest area 75 °F (24° C)

It appears that we do not now have enough data to establish action levels for intermittent heat exposures. This applies regardless of the heat stress measuring procedure used.

Which heat stress index to use is still a point of some controversy. The WBGT has been generally accepted as the method

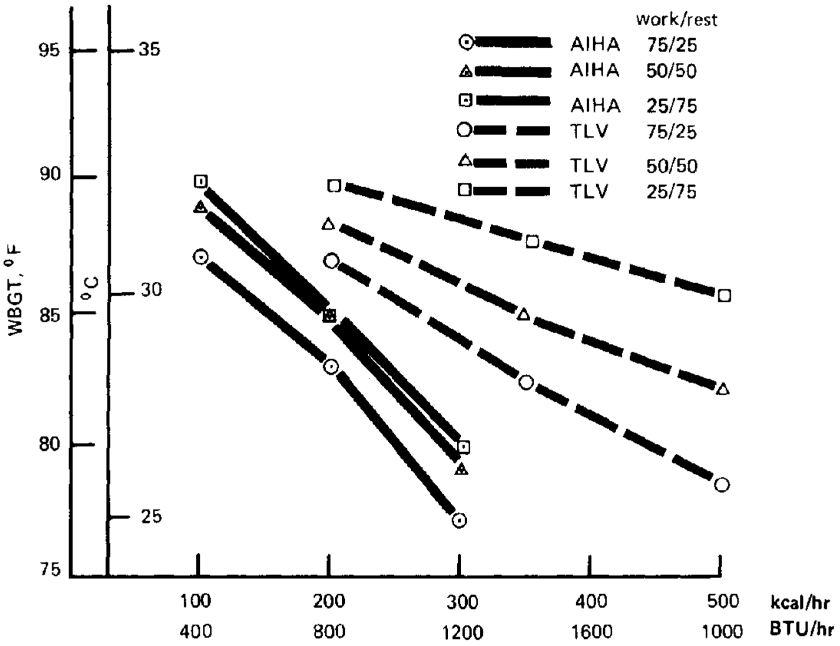

Figure 4. WBGT for intermittent work in the heat when TWA
WBGT is Equal in Work and Rest Area

of choice for estimating the overall stressfulness of the environment. It has limited value as a basis for designing environmental controls. For engineering control design, one of the rational heat stress indices must be used. All of the environmental parameters (temperature, humidity, air velocity, long wave radiation and solar radiation) need to be measured separately.

It has been questioned whether the WBGT or any of the other empirical indices are equally valid for high humidity environments as they are for the dry or moderately humid areas typical of most of the USA and Europe. We recently did a laboratory study in which eleven rational and empirical heat stress indices were compared under conditions of high humidity (vapor pressure averaged about 30mm Hg. and air temperature about 36°C). The study report will shortly appear in the American Industrial Hygiene Journal. Heat stress as expressed by the index number was correlated with the change in each of the four physiological parameters (heart rate, rectal temperature, skin temperature and sweat production). In general, the rational indices correlated better with the physiological responses than did the empirical indices. Except for mean skin temperature, the ET, CET, WGT, WBGT, and the OT did not reach the arbitrary cut-off level of R=0.70. Of the 11 indices, the relative strain index was the only one that correlated significantly with all four physiological parameters (See Table 1).

Table 1

Correlation Coefficients of Heat Stress Versus Strain Indices

HEAT STRESS INDICES	HEAT STRAIN INDICES			
	Heart Rate (HR)	**Incremental Rectal Temp. (ΔT_r)**	**Mean Skin Temp. (T_s)**	**Sweat Loss (SL)**
RI	0.85	0.69	0.70	0.83
RS	0.78	0.72	0.73	0.84
P_4SR	0.74	0.62	0.66	0.78
$HSI_{BH\&BC}$	0.72	0.68	0.60	0.75
HSI_{CP}	0.71	0.65	0.84	0.72
HSI_{BH}	0.69	0.65	0.54	0.72
ET	0.64	0.65	0.86	0.70
CET	0.62	0.64	0.86	0.69
WGT	0.61	0.65	0.87	0.67
WBGT	0.59	0.61	0.86	0.67
OT	0.41	0.45	0.72	0.51

RI — Reference Index
RS — Relative Strain Index
WBGT — Wet Bulb Globe Temperature Index
WGT — Wet Globe Temperature Index
ET — Effective Temperature Index
HSI_{BH} — Heat Stress Index of Belding & Hatch
CET — Corrected Effective Temperature Index
$HSI_{BH\&BC}$ — Heat Stress Index (Revised)
P_4SR — Predicted Four-Hour Sweat Rate Index
HSI_{CP} — Heat Stress Index C. Pulket
OT — Operative Temperature Index

We then ran a multiple correlation analysis using only those physiological parameters that contributed significantly to the correlation. Again, the rational indices did better than the empirical indices (See Table 2). An interesting and unexpected observation, however, was the rather high multiple correlation coefficients of the CET and WGT and the much lower value for the WBGT.

On the basis of our data, we would have to conclude that the WBGT would not be the index of choice for hot humid areas of

Table 2

Multiple Correlation Coefficient of Stress and Strain Indices

Incremental Heat Stress Indices	INCREMENTAL HEAT STRAIN INDICES							
	ΔHR	ΔT_r	ΔT_s	ΔVO_2	ΔSL	ΔE	R[a]	CL[b]
RS	X			X	X		.88	.82
RI	X[c]		X	X		X	.85	.78
$HSI_{BH\&BC}$	X			X		X	.82	.73
HSI_{BH}	X			X		X	.81	.71
CET	X					X	.80	.69
WGT	X			X	X		.79	.68
P_4SR	X			X	X		.79	.69
ET	X		X				.75	.62
HSI_{CP}	X				X		.75	.60
WBGT	X		X				.73	.59
OT		X			X		.59	.39

[a] R is multiple correlation coefficient calculated using independent variables indicated.

[b] CL — The lower 5% confidence level.

the world and that the CET or WGT would be more useful. If these findings stand up under further research, it would suggest that we consider the use of two indices for estimating the stressfulness of a hot environment — one for moderate and low humidity conditions, and one for hot humid conditions.

QUESTIONS, ANSWERS, AND COMMENTARY

DR. DUKES-DOBOS: Which is more restrictive, the TLV or the AIHA?

DR. HENSCHEL: The AIHA is more restrictive. It becomes more restrictive than the ACGIH TLV when one recalculates it on the basis of the rest area and work area having the same WBGT values.

In some studies we have done, we have found that very high exposure levels are permissible if the exposure time is not too long and if the rest period is in a cool environment. In one of the studies, the work site heat stress was extremely high, above the action level for continuous work, but the individuals worked only approximately 20 minutes of each hour. The remainder of the hour was spent in a rest environment of about 75°F (24°C). These people showed no physiological strain. Apparently, this work-rest combination was such that there was really no net change in body temperature occurring. The pulse rates also did not go up very much. That is, the heat capacity of the system, the body, and the heavy clothing that the men wore was adequate to keep the individuals internally in heat balance in spite of the fact that they were exposed to high heat stress for part of each hour.

There are so many things involved, such as the level of physical work, the level of heat stress, and the ratio between rest and work time. If, out of every hour, one works ten minutes in a hot environment and rests ten minutes in a cool environment, does that produce the same physiological strain as working 30 minutes and then resting 30 minutes? Is it better to work one hour and rest one hour? The data to date suggest that the effects will be vastly different. It has been adequately shown for physical work that during an hour one can accomplish the same amount of physical work by different rest-work cycles. One situation may result in a heart rate that may be as high as 150 or 160 beats per minute. In another situation where the rest-work cycles are short, the heart rates at the end of the hour may be no higher than 110. Yet during the hour the same amount of physical work is accomplished. We have to put effort into determining the physiological strain of different rest-work regimens in terms of level of heat stress and level of physical work. We know very little about it. This may indicate the direction of future work in the areas of heat stress.

DR. HORVATH: I wonder if indices take proper account of the fact that there are basic anthropometric differences in individuals. When you start comparing Asians with Americans you certainly cannot make the same comparisons.

DR. HENSCHEL: We chose university students; male Caucasians who were the same size. We were very selective in terms of body size and general levels of physical fitness. None were obese. They were average college students, about 21 or 22 years old.

DR. HORVATH: The body surface area of Caucasians is quite different from that of Orientals and Asiatics, and therefore it is not likely to have the same relevance.

DR. HENSCHEL: That's right. It raises two points that I think are interesting. One of them is that small differences of 2°C in temperature, from 34° to 36°C, actually showed up in the physiological responses. Changes in 3 to 5 millimeters of mercury water vapor pressure showed up as changes in physiological responses.

MR. FULLER: Would you comment about the ACGIH TLV for continuous work, which shows up to 500 kilocalories per hour? Is anybody able to work at that level?

DR. HENSCHEL: I think it is relatively unimportant because we are talking of the extreme. It does not mean that people are going to work at that level, but it is extrapolated to that point to cover all cases that might happen under even a very rare situation.

MR. FULLER: In terms of the eight-hour workday, I think the maximum that a person will work is no more than one-third of his maximum capacity. If that is the case, it would be best to show that on the continuous curve so nobody gets the idea that a person is going to work that hard in industry, a reasonable 8-hour work day is more likely to be 300 kilocalories per hour.

DR. SHVARTZ: I would like to follow up on this comment about the 500 kilocalories per hour. When doing work for eight hours at this level, the core temperature is going to be much higher than 38°C (100.5°F). So the line of continuous work should probably be shifted to the left a little bit and lowered. It could be that the data is based on bicycle ergometer work, where core temperature tends to be lower. I think in most situations that we are talking about, such as walking or lifting, the core temperature would be higher. Five hundred kilocalories per hour is over 50% of $\dot{V}O_2$ max, for most people.

We compared responses to continuous work several times; for example, three hours of work at 300 kilocalories per hour at the same WBGT level of 33°C (91.5°F). One test was conducted in South Africa at a humidity of 90% and another occurred at 50% humidity. The physiological responses are exactly the same.

DR. DUKES-DOBOS: I would like to answer part of this question concerning the 500 kilocalories. I do not think we have to worry too much about this. If we talk about time-weighted hourly averages, we will very rarely find industrial workers doing this. Actually, these curves are based on experiments where the maximum exposure was 420 kilocalories. The extension to 500 was an extrapolation.

DR. KAMON: From my experience in industry, I saw that workers rarely work more than 50% of the time unless they are paced or regulated somehow. I would say they work 40% of the time, even if we take it on an hourly basis. I wonder if our limit should be 300 kilocalories, particularly if we want to limit rectal temperature for prolonged work.

Also, I have a question for Dr. Dukes-Dobos. You showed a

WBGT of above 90°F (32.2°C). On what time-basis was this designed?

DR. DUKES-DOBOS: The time-weighted average WBGT value was for one hour during the time when the heat casualty occurred.

DR. RAMSEY: Dr. Henschel, what were the air velocities that you utilized?

DR. HENSCHEL: The high one was 90 meters per minute and the low ones were 10 and 50.

DR. RAMSEY: How many subjects were there?

DR. HENSCHEL: There were nine subjects.

DR. HOLLETT: I think it is significant that a continuous curve at eight hours' exposure would have to be directed at the average for the day. Typically, you will find that heat exposure in a one- or two-hour period may be higher than the average. You have to weigh in the resting period and its effect if it is different from the work environment. If you did not address it in the continuous curve, it would be difficult to predict the heat stress for short periods. You might find that the work rate is higher during that short period of time. Looking at the numbers on Dr. Dukes-Dobos' curve where there is high stress in a one-hour period, that is a significant fact.

DR. HORVATH: I think we are being unrealistic. I do not know whether you have ever been in a factory and watched anyone work. There is no such situation as the one you are describing.

MR. HOLLETT: I did not say a level. I said there are higher levels for shorter periods of time than the eight-hour average. The initial comments seemed as though they stressed an eight-hour average. There might be cases where a great deal of work is done in one or two hours, and then for six hours there is light work.

DR. HORVATH: In the eight-hour studies that we did a number of years ago, we were unable to do this for more than one day. In other words, 35 to 40 percent of the maximum capacity work level can be accomplished in one day. People may do this for two or three days in a row. In these experimental situations we may lose the subjects by the third day. Consequently, the percentage of maximum capacity at which people work day after day is 20%, under most circumstances.

MR. HOLLETT: I think I did have a specific set of circumstances in mind where you do not have continuous work activity. Instead, you have a pacing effect due to the process. There are certain functions that have to be performed within a period of time, and they must pace their work more, much like what you were talking about.

DR. GONZALES: What was the wet bulb temperature or the ambient water vapor pressure?

DR. HENSCHEL: 25, 29 and 30 mm Hg.

DR. GOLDMAN: Even with fit troops working as hard as we can get them to work, we feel they do not work hard if they have to work for long periods of time. On our work they will work at 45% of maximum capacity for two to three hours, assuming they are extremely motivated with a six pack of cold beer and the rest of the day off. We have also found that females work at the same rate as males in terms of percent of maximum work capacity.

THE EFFECTIVENESS OF PREVENTIVE WORK PRACTICES IN A HOT WORK SHOP

F. H. FULLER, C.I.H. and P. E. SMITH, JR., M.A.

ABSTRACT

This paper critiques the evaluation of hot jobs by thermal stress measurements with subjective assessment of metabolic rates, and suggests an alternative, simple, straightforward, and economical method using heart rate and oral temperature measurements.

An example is given that describes use of physiological measurements for confirming the adequacy of work practices controls in a hot work shop. Tentative criteria for acceptability are suggested.

In the Du Pont Company, as in any industrial company, there are potential heat stressful situations. Fortunately, many, but not all, of them are handled simply by self-regulation of work and rest. I am going to tell you how we evaluated one such situation to determine the optimum method of control and how we later re-evaluated the job using physiological measurements to confirm the adequacy of the controls installed. This example will serve to ilustrate four specific points, namely:

(1) Air conditioned rest areas are an effective means for controlling heat stress situations.

(2) The evaluation of hot jobs by stress measurements and subjective evaluation of metabolic rate, which is the usual technique for applying heat stress criteria, such as the ACGIH WBGT TLV for environmental heat stress levels, is difficult and time consuming, and it requires highly developed judgmental ability. Furthermore, the application of such a standard is restrictive, uneconomic, and not fully protective. With the current state of the art, we do not believe a practical heat stress standard can be developed. Such stress data are useful and are needed by the engineer, but only as guidelines.

(3) In contrast, the evaluation of heat *strain* based upon measurements of the *individual's* heart rate and oral temperature is relatively simple and inexpensive. But heart rate and oral temperature criteria for excessive strain need to be confirmed. These measurements may be used to provide guidance for placement of the individual in accordance with his own heat tolerance. Also, heart rate recovery measurements may

be used to predict the onset of fatigue.

(4) If a heat stress standard is promulgated, we propose that the standard allow the use of physiological measurements of heat strain to determine the acceptability of a job environment situation for the individual.

Now, let's examine the hot job example which, along with other hot job evaluations, provides the basis for the conclusions just presented.

- The job involves four shifts of 8 men each.
- Dry bulb and globe temperature measurements were made at each of the 5 work positions.
- The absolute humidity was measured for the shop area and was used to determine the psychrometric wet bulb for each of the sampled locations.
- Air movement was sampled at appropriate locations.
- From these data, corrected effective temperatures (CET) were determined for each of the 240 work positions.
- Time-activity studies were made for representative work units, and metabolic cost estimates were assigned to each element.
- From the above, time-weighted average temperatures and work metabolic rates were computed, providing the data for determining point "W" on the ACGIH WBGT TLV[1] (Figure 1). The scale for corrected effective temperature (CET) has been added because it is more useful for engineers. This scale is based on the regression published by Walters[2] (1968).

The location of point "W" dictates that a rest period is required for this job.

- Point "R" shown on Figure 1 corresponds to the metabolic rate for rest of 400 Btu/hr. To attain a satisfactory work-rest cycle, and to include an appropriate factor of safety, the size of the work crew was increased from 8 to 10 men, permitting the work cycle to be completed in 20 minutes, followed by 40 minutes of rest. The resulting time-weighted averages are 700 Btu/hr and 79.2°F CET. This point plots as "TWA" on the line connecting "W" and "R". Note that the point TWA is 1/3 of the distance from R to W, and is well below the solid line labeled continuous work, the appropriate curve for use when applying time-weighted average values.

Note that these measurements were made on a peak temperature day and that numerous measurements were required. We have a procedure that enables us to estimate the peak exposure levels from measurements at two different and lower temperature levels, so that we are not restricted to evaluations of heat stress on only the hotter days. This may introduce some error. Numerous measurements are required in any event, and estimating the work rate

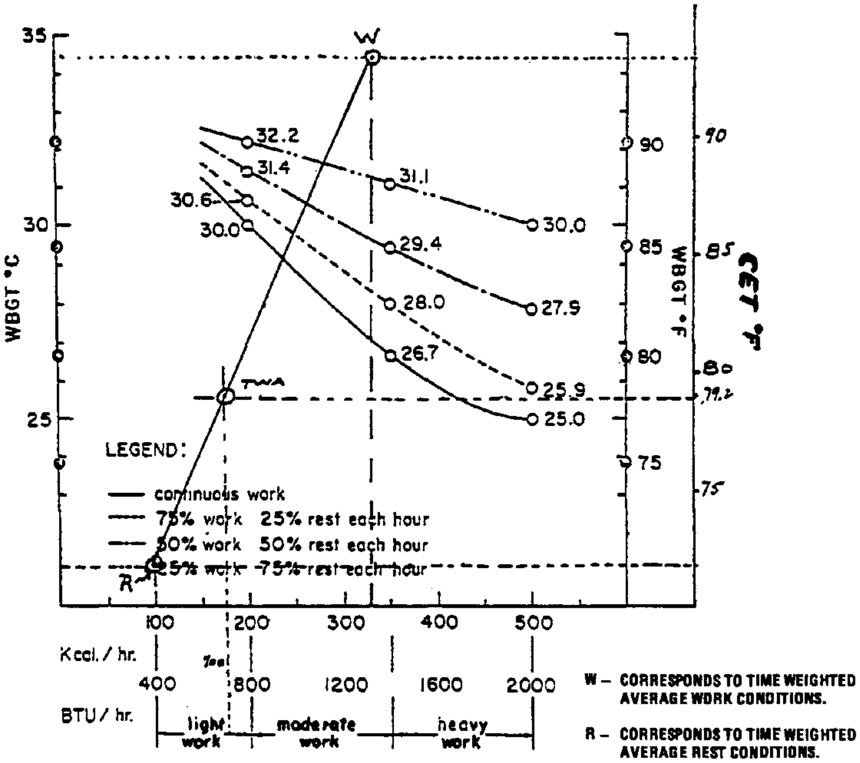

Figure 1. TWA work and temperature conditions – hot day

is difficult. Furthermore, because of the judgmental factor and differences in individuals, one must allow a considerable safety factor in the application of heat stress criteria such as the ACGIH TLV, which, we understand, was based upon the *average* response of a number of heat acclimatized individuals.

In recent years, we had the opportunity to evaluate the effectiveness of this method by on-the-job measurements of physiological responses of the individual workers. These measurements confirmed the adequacy of the air conditioned rest period for preventing excessive heat strain. What these measurements showed was:

- The individual physiological strains resulting from exposure to the conditions described previously vary over a range of at least ± 15 per cent. All were acceptable, however. That is, no one exceeded the recommended criteria set fort in the ACGIH TLV for heat stress.
- The variability in response may be shown as an elliptical area centered on the point TWA.

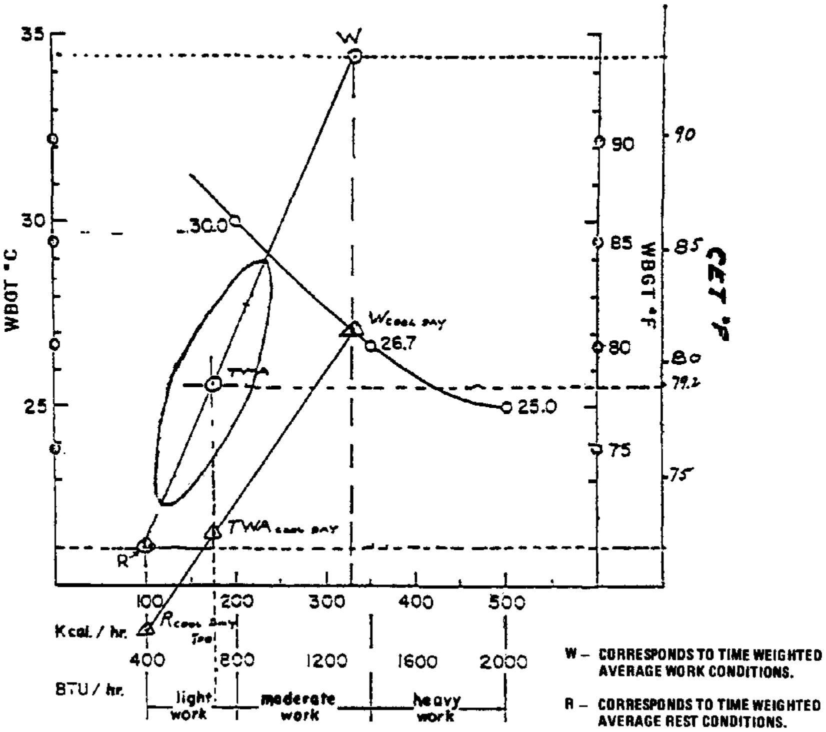

Figure 2. TWA work and temperature conditions – hot and cool day

- This area is depicted qualitatively and arbitrarily in Figure 2. (Note: The true area may be larger or smaller for a given situation.)

This indicates some workers will be working below their most effective level and production may be less than optimum. But more importantly, depending upon the expertise of the engineer in applying heat stress criteria, there could be some workers who, in fact, would not be able to perform the job safely.

I would like to discuss a simple, direct, and inexpensive method for evaluating heat strain situations by the measurement of body temperature and recovery heart rates of the individual worker. I will also discuss the technique and method for determining criteria for evaluating heat strain.

Body temperature and heart rate are measured using the recovery heart rate technique developed by Brouha (1960).[3] This is conveniently done as follows:

- At the end of a cycle of work, the operator goes to a nearby location and sits on a stool or straight chair. At the moment the worker is seated the observer starts a stopwatch and places a thermometer in the workers' mouth, being careful to position it under the tongue and to caution the operator to keep his mouth closed and not attempt to talk. At 30 seconds the observer begins a pulse count, having previously palpated the radial pulse. This count is continued until one minute. The 30-second count is multiplied by 2 and recorded as P_1. At one minute and 30 seconds the count is resumed until two minutes, multiplied by 2 and recorded as P_2. P_3 is obtained by counting again from two minutes and 30 seconds to three minutes. After P_3 is recorded, the thermometer is removed from the mouth, read, and the temperature recorded. The worker is questioned concerning any unusual happenings during the last work cycle. This concludes the observations.

- This technique has been successfully applied to continuous jobs by providing a relief operator who takes over for the regular operators while the measurement is being made.
- With relatively little training, plant nursing personnel have been able to gather excellent data, and we recommend the use of such personnel since they are usually well known and well accepted by the work force.

At this time, I will discuss application of heart rate and oral temperature measurements, to evaluate acceptability of the hot job described previously.

The ACGIH TLV for heat stress states that the acceptable upper limit for deep body temperature in acclimatized workers is 38°C (100.4°F). This provides the necessary guide for evaluating strain measurements.

- Many investigators prefer to use oral temperatures for monitoring strain in industrial workers, and provide a margin of safety by accepting a 1°F rise, to 99.6°F (37.5°C), as representing a satisfactory upper limit.
- This conservative approach recognizes the fact that few industrial jobs require metabolic levels in excess of three or four times the resting level, resulting in a lower body temperature at the upper limit of the prescriptive zone, as defined by Lind (1963).[4]

Recovery heart rates provide additional useful information. Acceptable heart rate criteria may be related to body temperature using regression techniques. This will be illustrated using recovery heart rate and oral temperature data obtained on the workers previously discussed.

Because of the limited number of observers, the 10-man work crew was divided into two groups of five men. Each group was observed on alternate hours. The data presented in Figure 3 represent the averages of the individual observations made during each two-hour period of the eight-hour shifts. These are shown

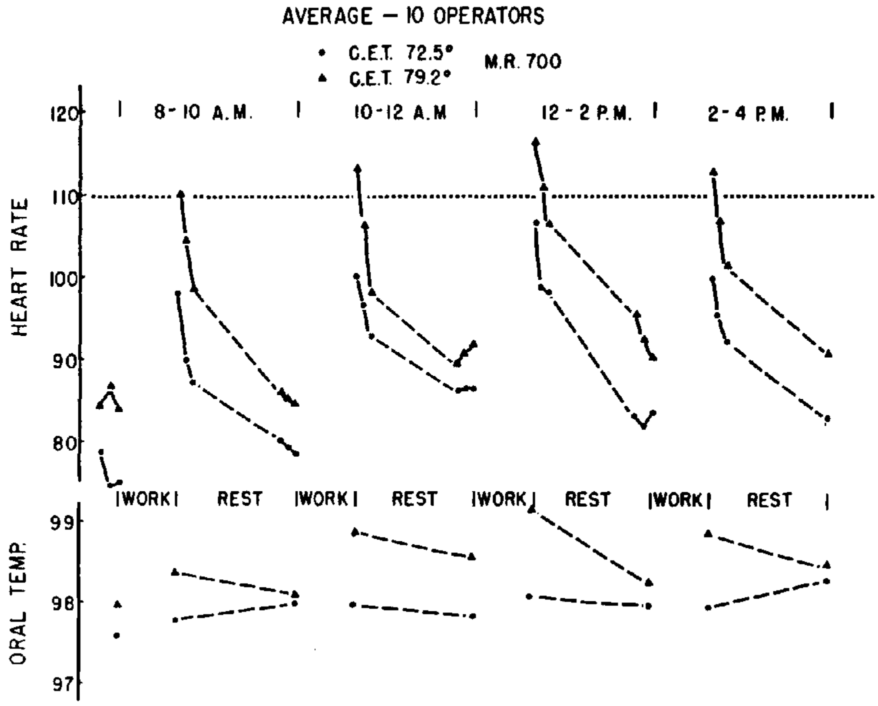

Figure 3. Recovery heart rates

separately for the cool and hot days. The gross time scale is divided to represent the 20-minute work and 40-minute rest periods. At the beginning and end of each rest period, the scale is expanded to show the average P_1, P_2, and P_3 values obtained for the end of each 2-hour work period. Average oral temperatures are shown for the beginning and end of each rest period. All oral temperatures were below the 99.6°F criterion. Also, the after-work P_1 pulse rate values reached a peak during the 12 p.m. to 2 p.m. observation period. This coincides with the hottest part of the day and includes the post-luncheon digestive period. The two effects are integrated by this technique, as are other effects, such as interrupted rest periods. All post-rest heart rate averages are at acceptable levels, indicating adequate recovery from the preceding work.

The elevated oral temperatures at the end of the shift arise because of an inadequate rest period at the end of the day's work. We did not feel that we could ask the last group of workers to sit for a full 40 minutes before releasing them to go to their showers. The additional stress imposed on the hot days is obvious in both the heart rate and oral temperature averages.

In a recent paper, Horvath and Colwell[5] quote from the

NIOSH criteria document "Occupational Exposure to Hot Environments," the following: ". . . first-minute recovery heart rates in excess of 110 have been very seldom observed." In contrast, they note that in their own studies of aluminum workers, and in those conducted by Brouha and Frank Brent in the Aluminum Company of Canada, first-minute recovery heart rates well in excess of 110 are very common. This level of 110 is indicated by a dashed line on Figure 3.

Frank Brent,[6] who worked with Brouha and later succeeded him as Medical Director of ALCAN, makes this comment: "Brouha adopted a figure of 110 beats per minute as the group average P-1 value which represented a comfortable and safe response to a good work output. So entrenched did this figure of 110 become that many people unfortunately acquired the mistaken idea that if the heart rate at any time exceeded the 110 per minute figure, the physical effort involved was inhumane and definitely dangerous to health." We heartily endorse Horvath's and Colwell's conclusion that the criteria document should be corrected to reflect Brent's explanation of P-1.

In a series of classical experiments Nielsen[7] demonstrated, and later confirmed[8], that over a wide range of environmental temperatures the level to which body temperature rose during work was entirely dependent on the rate of work. The environments investigated extended from about 40° to 80°F ET. Lind[4] recognized this as the now familiar prescriptive zone.

In his own studies, Lind extended the environments examined systematically to a point just below 95°F ET. His data show that somewhere above 77°F ET, depending on the metabolic work level, body temperatures depart from the fixed levels noted by Nielsen and climb with increasing slope toward a point at which acute and chronic heat disorders and illnesses will be induced. Thus, in defining the prescriptive zone, he has also defined what has been called the "Stress-free Zone" or the "Tolerance Zone."

As Brent points out, Brouha presents $P_1 = 110$ as a first minute recovery heart rate below which one need have no concern for heat stress or excessive work demands. He is thus attempting to define, in recovery heart rate terms, the lower limit of the transition zone in which interest lay, or, the upper limit of the prescriptive zone.

The significance of the dotted line in Figure 3 at 110 beats per minute should now be obvious. At the CET of 72.5°F the groups studied remained within the prescriptive zone. At a CET of 79.2°F they moved increasingly into the transition zone. The question as issue is: how far into the transition zone can they be permitted to move?

The data of Figure 3 have been subjected to regression analysis, and the results are shown in Figure 4. In this analysis, data obtained on cool and hot days were handled separately, producing the two regression lines shown. The regression equation for the hot weather data is OT = 95.95 − 0.0025 HR. The quantity 100 r^2 denotes the percent variance common to both oral temperature (OT) and P_1, where "r" is the regression coefficient. Note that on the cool days this is 2%, while for the hot weather data it rose to 68%. The higher this value, the more powerful the correlation of these dependent strain variables upon the common environmental results. These values lend support to the viewpoint that Brouha intended $P_1 = 110$ to represent the upper limit of the prescriptive zone.

Regression techniques permit the determination of the 95% confidence limits for the individuals involved in our studies. The upper of these is shown in Figure 4. It can be seen that the 99.6°F

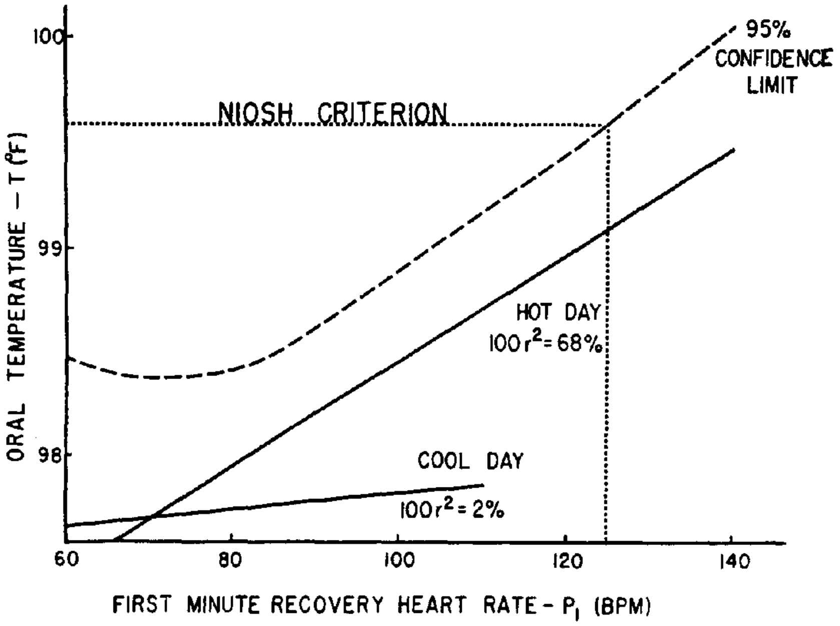

Figure 4. Regression, T on P_1

criterion line for oral temperature intersects the confidence limit at a P_1 value of about 124. In effect, this says that 95% of the times that one finds a P_1 value of 124, the oral temperature will be at or below 99.6°F. The extended regression line intercepts the criterion line at 144 beats per minute. Fifty percent of the individuals with $P_1 = 144$ bpm will have oral temperatures at or below 99.6°F.

The discussion to this point has been concerned with group averages. One concludes that this may be performed even during the hot weather without violating the criterion that oral temperature should not exceed 99.6°F at the end of a full work cycle. To gain further information, it is necessary to examine individual recovery patterns. While not shown, all of the oral temperatures at the end of the two-hour work-rest cycle were satisfactory.

As mentioned previously, heart rate data provide important supplemental information to an oral temperature survey.

- In the prescriptive zone both heart rates and body temperatures will increase with increased metabolic work.
- Heart rate will respond with a lag measured only in seconds, while the lag in body temperature increase is from 30 minutes to 1 hour, since the heat generated in the working muscles is stored there and released only slowly to the bloodstream.

Thus, heart rate can be used as an earlier indicator of the insults on the system from short-term exposure situations.

We have developed a tentative heart rate pattern classification scheme, based on a review of Brouha's work, to enable evaluation of short- or long-term hot jobs. This scheme provides a method for evaluating the job environment by individual heart rate recovery patterns. More work is suggested to refine this scheme, shown here in Figure 5.

Figure 5

RECOVERY HEART RATE BEATS PER MINUTE

PATTERNS	**P_3**	**P_1-P_3**
Satisfactory (S)	< 90	—
High (H)	$\geqq 90$	$\geqq 10$
No Recovery (N)	> 90	< 10

- Satsifactory patterns need no further comment.
- High recovery patterns indicate work at a high metabolic level with little or no accumulated body heat. Individual jobs showing this condition require further study.
- No recovery patterns indicate too much personal stress.

Individuals showing "no recovery" heart rate patterns and/or elevated oral temperatures above 99.6°F following the rest period should be re-examined intensively, preferably by a physician familiar with the work area. Their high reactions can frequently be found due to the following:

- Inefficient utilization of their rest period,
- Illness, or
- Moonlighting.

On the other hand, if more than a few of the workers show too high strain reactions, the job environment may require modification:

- By improving workplace conditions by engineering controls, if practicable,
- By adding extra men to the work crew in hot weather, or
- By modifying the work-rest pattern.

Following is a summary of the points made at the beginning of this presentation:

(1) Air-conditioned rest areas provide an effective means of controlling potential heat stress situations. This confirms the time weighting concept in applying heat stress guidelines.

(2) Application of heat stress criteria such as the ACGIH TLV to evaluate hot jobs is difficult, time-consuming, expensive, and requires highly developed judgmental ability. Furthermore, such criteria are restrictive and may not be fully protective.

(3) Evaluation of hot jobs by heart rate and oral temperature measurements of the individual is simple, straightforward, and economical. While oral temperature criteria are well established, more study is needed to refine the suggested classification of heart rate recovery patterns. Heart rate recovery patterns are more useful than oral temperature for evaluating acceptability of short-term exposures.

(4) With the current state of the art we do not believe a practical heat stress standard can be developed. Nevertheless, heat stress criteria are needed by the enginers. If published, the criteria should be in the form of guidelines only. If a heat stress standard is promulgated, we propose that it allow the use of physiological measurements of heat strain for demonstrating acceptability of the job environment, and as an alternative to a specific WBGT level at which it is necessary to implement work practices.

REFERENCES

1. American Conference of Governmental Industrial Hygienists, Cincinnati, Ohio, "Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1978."
2. Walters, J. D., "A Field Assessment of a Prototype Meter for Mea-

suring the Wet-Bulb Globe Temperature Index," *British J. Industrial Med.*, 25:235-240 (1968).

3. Brouha, L., *Physiology in Industry,* Pergamon Press, (New York, 1960).
4. Lind, A. R., "A Physiological Criterion for Setting Thermal Environmental Limits for Everyday Work," *J. Appl. Physiol.*, 18:51-56 (1963).
5. Horvath, S. M., and M. O. Colwell, "Heat Stress and the New Standards," *J. Occupational Medicine,* 15:524-528 (1973).
6. "Criteria for a Recommended Standard. Occupational Exposure to Hot Environments," U.S. Dept. of Health, Education, and Welfare, NIOSH (1972).
7. Nielsen, M., "Die Regulation der Koerpertemperaturbei Muskelarbeit," *Skand, Arch. Physiol.,* 79:193-230 (1938).
8. Nielsen, B. and M. Nielsen, "Body Temperature During Work at Different Environmental Temperatures," *Acta Physiol. Skand,* 56:120-129 (1962).

BIBLIOGRAPHY

1. Bedford, T., Basic Principles of Ventilation and Heating, 2nd Edition, Lewis, (London, 1964).
2. Fleisher, W. L., H. E. Stacey, Jr., F. C. Houghton, and M. B. Ferderber, "Air Conditioning in Industry," *ASHVE Trans. 45,* ASHVE Journal Section, Heating, Piping and Air Conditioning, pp. 1-22 (1939).
3. MacPherson, R. K., "Physiological Response to Hot Environments," *Medical Research Council Sp. Report No. 298,* H.M.S.O. (London, 1960).
4. Mosher, H. A., "When is Complete Air Conditioning of the Modern Factory Advisable?," *Heating, Piping and Air Conditioning,* July 1945.
5. Stephenson, R. R., "Time-Weighted Averages as Seen by the Industrial Engineer," presented at the Symposium on Standards for Occupational Exposures to Hot Environments, Pittsburgh, PA, pp. 77-85 (1973), HEW Pub'l. No. (NIOSH) 76-100.

QUESTIONS, ANSWERS, AND COMMENTARY

DR. DUKES-DOBOS: Please explain the "W" on the top of Figure 1.

MR. FULLER: "W" represents the metabolic rate of the work, which is some 325 kilocalories per hour.

DR. DUKES-DOBOS: Is that an extrapolation?

MR. FULLER: Yes. The employee was working at 325 kilocalories per hour for 20 minutes, and rested at 100 kilocalories for 40 minutes. So in connecting the two lines we get the line "TWA."

DR. DUKES-DOBOS: Is this an hourly time-weighted average?

MR. FULLER: Yes. The cycle was repeated hourly.

DR. KAMON: Referring back to Brouha, he found there was a creeping effect. In other words, from cycle to cycle the heart rate increases. This is why he suggested these values. Did you see that from cycle to cycle, each time they take rest, the heart rate is higher?

MR. FULLER: It went up during the middle of the day.

DR. KAMON: From experience, I know that for workers in the middle of the shift the heart rate always goes up. You can set any limit you want but there is always a temporary rise and then it comes down. I do not know why.

DR. HORVATH: The answer is very simple. There is a diurnal rhythm in body temperature. From 3:00 p.m. to 5:00 p.m. the body temperature is highest. For a fixed workload, at that time it is accompanied by a higher heart rate. That has been demonstrated for a number of years. It has not been a real problem.

DR. KAMON: You can expect a creeping effect.

MR. FULLER: I believe that Lucian's work on the ergometer was continuous work in the laboratory.

DR. KAMON: Work and rest, work and rest.

MR. FULLER: It was a work and rest cycle that was repeated, not continuous.

MR. SMITH: Lucian did a lot of work with the Aluminum Company of Canada, where the operations were strictly cycled. The workers came out and did their work, then they took a good rest break in an air conditioned rest area. It is much the same kind of time study.

MR. FULLER: The work rate was up to 325 kilocalories, which is high, but work periods were only about 20 minutes long.

MR. SMITH: One of the points that I would like to get across is the discriminatory nature of that abrupt cutoff. That is what the elliptical diagram was intended to show. If you move that circle to where they are working up to the continuous line, some of those people are overstressed, and some of them are understressed. You can move TWA up to the line of continuous work where 50% are going to be overstressed and 50% are going to be understressed. The emphasis is on biological monitoring, namely, heart rate and body temperature, which is the only way to tell whether the person is properly controlled. The circumstances under which the person is working do not make a difference.

MR. FULLER: The suggestion we wanted to make here is: If a heat stress standard or an action level is specified, we suggest giving the user the right to use physiological monitoring, which we think is more protective.

DR. HENSCHEL: I wonder if using the change in the heart rate would give you more consistent relationships, rather than using the absolute values, because there are large differences in pulse rates among people. So if you use your starting pulse rate as the base, and then you just work with the changes, you might find it more sensitive.

MR. FULLER: It might be more sensitive. We wanted to see what happened for each individual. All met the criterion of the rise in body temperature to below 99.6°F after the two-hour work-rest cycle.

MR. SMITH: The problem here is that the group is looking for some criteria to evaluate plants and to determine if a plant needs study. The more you try to divide the heart rate up, the more involved it gets.

MR. FULLER: I will attest to the fact that it is about the only measurement usable in a typical industrial job where employees wear protective clothing. We have used this technique and have established the safe times for staying in protective clothing. In some cases we cannot give the man any supplied air in the clothing.

DR. DUKES-DOBOS: In your paper you state that TLV was based on average values, but it is actually based on a 95th percentile of the population response.

DR. GOLDMAN: That raises a question. TLV is based on 95% of the population. Referring back to the casualties reported in the opening remarks, what percent of the population did they represent, and do you think it is feasible to develop a standard that will protect them without completely degrading the entire work force?

DR. BANKS: You are definitely talking about people who are in the five percent that are not covered. I think this is why any practical standard must be an action level with the requirement that anyone exposed above this action level must have physiological fitness assessment, as well as heat stress measurements, to give adequate protection. I think the number for the action level will have to be set low enough to protect 99.99, of not 100, percent of the exposed people. There is going to be some screaming from industry. But that's only going to be an action level, not a level that would result in any citations for exposure. People could be exposed above the action level with no problems, as long as there is an adequate check for the individual's physiological fitness and for the amount of strain.

DR. GOLDMAN: Were those considered in the citations your department issued?

DR. BANKS: They were based on the fact that board-certified industrial hygienists had no idea that there was so much heat stress. Some were not aware that workers who were so unfit to work in hot environments were being subjected to the stress. As an end result, there were several heat fatalities.

DR. ZENZ: I appreciate your company's support for work practices. I would like to mention society's views on this. We do not know the incidents of heat stress throughout the United States. You have a good handle on what is going on in Maryland. In Wisconsin we do not, despite the fact that we have a lot of data. Wisconsin recently reversed itself with the motorcycle helmet use law. I think motorcycle deaths are about a thousand to one, compared to heat deaths. I just bring this out as food for thought. The criteria documents that you have are extremely well done but do not allow, and perhaps cannot allow, room for professional clinical judgment. You have to have a latitude in these judgments. Please consider that in your deliberations.

HEAT STRESS TOLERANCE TESTING

Esar Shvartz, Ph.D.

ABSTRACT

Two tests for the prediction of heat tolerance are presented. One test consists of 15 minutes of exercise at a load of 80 watts at room temperature while wearing shorts. Heart rate and rectal temperature are recorded at the end of exercise and a composite score is used to predict heat tolerance. The other test consists of 10 minutes of exercise at the desired condition of work load, heat stress, and clothing. Heart rate is recorded at 5 and 10 minutes of exposure and the difference in heart rate between these points is used to predict tolerance time. Data are presented suggesting that heat tolerance could be predicted from a short exercise test performed at room temperature while wearing a hoodless vapor-barrier garment, and where only heart rate is considered.

When unacclimatized individuals are exposed to work in heat, they show high heart rates and rectal temperatures that result in excessive physiological strain and early exhaustion. But acclimatization to heat for just a few days results in improvement in the cardiovascular and body fluid responses so that work in heat can be performed for prolonged periods without exhaustion. There are very large individual differences in responses to heat. Heat tolerance is related to physical fitness; to body weight, e.g., heat intolerance is lower in the very thin and the very overweight individuals; to age; and to many other factors. For example, in a recent study we found that heat intolerance was related to low blood values, lower water intake during acclimatization, less shift of sweat rate to the legs during acclimatization, low resting blood pressure and plasma volume values, and to high resting plasma activity values.

The problem is how to predict the heat tolerance of an individual, since some people can be expected to be heat intolerant. Considering the health hazards and costs involved if heat intolerant individuals are allowed to work unsupervised in heat, it is obvious that a test to predict heat tolerance would be very useful. A routine medical examination may tell little about a healthy individual's ability to tolerate heat. None of the parameters mentioned above have been found to predict individual heat tolerance even though they may be factors in overall heat tolerance.

Among Bantu laborers in the gold mines of South Africa, about 25 percent show poor responses to heat in an unacclimatized condition, while only 2 percent have been found to be heat intolerant in the acclimatized condition. Similar results, in terms of the percentages of people who are heat tolerant or heat intolerant, were found among young Israeli men. Whether these findings can be extrapolated to all races and nationalities is not certain.

Limited success in predicting heat tolerance by using submaximal heart rate during exercise at normal room temperature has been attained (1, 2). This would have been a very simple and useful method to predict heat tolerance. When this possibility was considered, however, it became clear that heart rate alone (responses in temperate conditions) could not accurately predict heat tolerance because it also reflects physical endurance fitness, which is only partially related to heat tolerance (14). Table 1 shows good correlation coefficients between submaximal heart rates recorded in temperate conditions and in heat; but these correlations are not good enough for individual predictive purposes.

Table 1

Correlation Coefficients Among Responses at 23°C and in Heat

	Condition	**r**
	T_{re} vs. T_{re} at rest	0.85
	vs. T_{re} in heat	0.80
	vs. HR at 23°C	0.68
23°C	vs. HR in heat	0.62
	HR vs. HR in heat	0.77
23°C	vs. T_{re} in heat	0.63
	SR vs. SR in heat	0.81
	T_{re} vs. T_{re} at rest	0.62
Heat	vs. HR in heat	0.73

HR = heart rate; T_{re} = rectal temperature and S.R. = sweat rate. Responses are after 1 hour of exercise at 40 watts at 23°C, and after 3 hours of exercise at 40 watts at 40°C DB, 30°C WB. Adapted from Shvartz, et al. (11).

PREDICTING HEAT TOLERANCE FROM HEART RATE AND RECTAL TEMPERATURE AT ROOM TEMPERATURE

To accurately predict heat tolerance from a test administered in temperate conditions, it is necessary to consider core temperature in addition to heart rate. Ample data indicate that heart rates and rectal temperatures recorded at room temperature could be used for this purpose. Heat acclimatized men showed lower heart rates and rectal temperatures after one hour of exercise at 35 watts at 23°C than unacclimatized ones (3). When these heart rate and rectal temperature responses were combined into a single score, they correlated well ($r = 0.84$) with the same responses after 4 hours of work in heat. Similar relationships were found in another study when heart rate and rectal temperature at 24°C were considered after 30 minutes of exercise (10). In another study (11) 20 physically trained, 20 physically untrained, and 10 heat intolerant men (who had suffered from heat-stroke on previous occasions) were administered a 3-hour work-heat test — 40 minutes of exercise at 40 watts at 40°C DB and at 30°C WB, and 30 minutes of exercise at 40 watts at 23°C. The untrained subjects were tested again after 8 days of heat acclimatization. The heat intolerant subjects showed the highest heart rate and rectal temperature responses in heat and at 23°C, while the responses of the heat acclimatized subjects were the lowest in both conditions (Figure 1; Tables 2, 3). The correlation coefficient between combined heart rate and rectal temperature scores at 23°C and in the heat was $r = 0.91$.

Responses of the above thirty-five subjects (untrained, trained, but unacclimatized), twelve of these subjects after undergoing acclimatization, and four heat-intolerant subjects were also recorded after 15 minutes of exercise at 80 watts at 23°C. Again, the lowest heart rate and rectal temperature responses were obtained by the heat acclimatized subjects in the temperate and hot environment and the highest were shown by the heat intolerant subjects (Table 4).

A 15-minute test seems to be the optimum test right now to predict heat tolerance. It is strenuous enough so that heart rate and rectal temperature increases are high enough for predictive purposes. Such a simple and practical test for the prediction of heat tolerance has been described (15). It consisted of bench-stepping for 15 minutes on a bench 30 centimeters high, at the rate of 24 steps/minute. Heart rates and rectal temperatures are recorded at the end of the test. A composite derived score based on heart rate score + rectal temperature score /2 can accurately predict responses to heat (Table 5; Figure 2). The equal weighting given to heart rate and rectal temperature in this predictive method is based on the results of many experiments under a wide range of heat stress conditions. It was found that high heart rate and rectal temperatures were equally responsible for exhaustion.

The above predictive test is based on the fact that thermal responses in temperate and hot environments are related. A heat

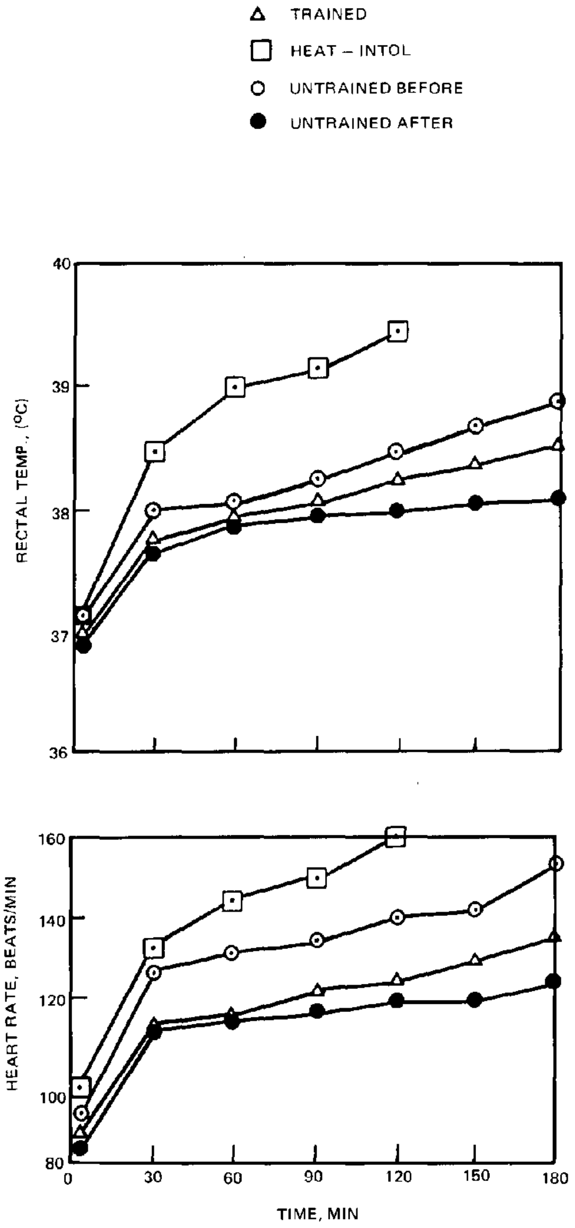

Figure 1. Responses in heat (means) of 20 trained men 20 untrained men before and after acclimatization, and 10 heat-intolerant men. From Shvartz et al. (11)

Table 2

Sweat Rate and Oxygen Uptake of Subjects in Heat

Group		Sweat rate, ml/m². hour 1	2	3	Oxygen Uptake, l/m². min.
Trained (N-20)		384 ± 137	342 ± 92	311 ± 76	0.666 ± 0.14
Untrained (N-20)	B.	355 ± 127	312 ± 63	264 ± 121	0.683 ± 0.15
	A.	357 ± 83	380 ± 170	313 ± 105	0.576 ± 0.05
Heat-intolerant (N = 10)		357 ± 24	370 ± 82		0.570 ± 0.22

Data are means ± SD. B and A = before and after 8 days acclimatization, respectively. 1, 2, 3 refer to hours of exposure. The heat-intolerant subjects (previous heat-intake patients) could not complete the third hour exposure. Conditions are as in Table 1. From Shvartz, et al. (11).

Table 3

Responses to Exercise at 23°C

Group		Heart rate, beats/min.	Rectal temp, °C	Sweat rate, ml/m². hour	Oxygen Uptake l/m². min.
Trained (N-20)		100 ± 10	37.9 ± 0.3	156 ± 52	0.625 ± 0.06
Untrained (N-20)	B.	116 ± 13	38.0 ± 0.4	140 ± 46	0.656 ± 0.11
	A.	98 ± 8	37.6 ± 0.2	100 ± 63	0.583 ± 0.04
Heat-intolerant (N-10)		121 ± 22	38.3 ± 0.2	157 ± 50	0.591 ± 0.08

Data are means ± SD after 1 hour of exercise. B and A are as in Table 2. From Shvartz et al. (11).

Table 4

Responses to Exercise at 23°C and in Heat

Group		Heart rate, beats/min.	Rectal temp, °C	Sweat rate, ml/m^2. hour	Oxygen Uptake ml/m^2. min.
	23°C	134.2*	38.0*	444	1.92
Unacclimated		± 17.7	± 0.26	± 79	± 0.23
(N-35)	Heat	146.5*	38.7*	545	1.20
		± 17.9	± 0.51	± 136	± 0.26
Acclimated	23°C	120.5*	37.7*	368*	1.80
(N-12)		± 10.5	± 0.20	± 91	± 0.20
	Heat	122.1*	38.2*	632*	1.04*
		± 9.4	± 0.33	± 109	± 0.10
Heat-intolerant	23°C	158.0*	38.3*	457	1.86
(N-4)		± 4.0	± 0.10	± 70	± 0.13
	Heat	167.1*	39.5*	575	1.11
		± 11.1	± 0.33	± 27	± 0.04
		0.68	0.62	0.59	0.68

Data are means ± SD. Heart rate and rectal temperature are final responses after 15 minutes of exercise at 80 watts at 23°C, and after 3 hours of exercise at 40 watts in heat (40°C DB, 30°C WB). Sweat rates in heat are average responses for the 3-hour exposures. Correlation coefficients are between responses at 23°C and in heat. $^*P<0.05$ compared with each of the other 2 groups. From Shvartz et al. (15).

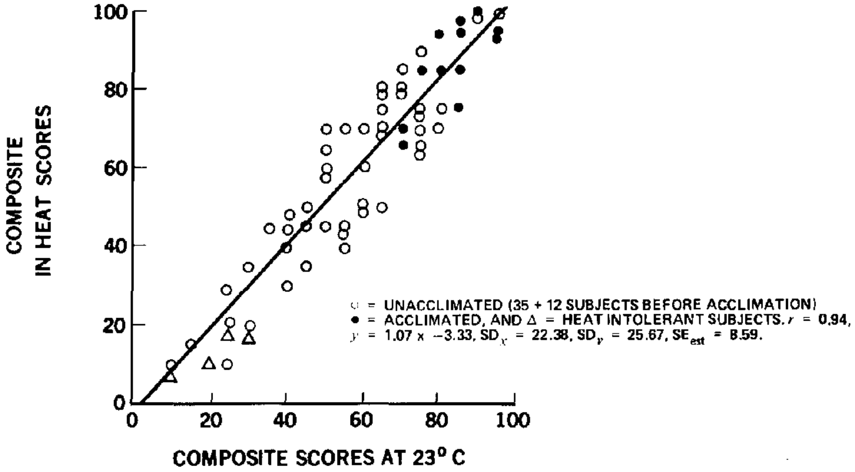

Figure 2. Composite scores of heart rate and rectal temperature at 23° C and in heat. From Shvartz et al. (15)

Table 5

Scores and Composite Scores for Heart Rate and Rectal Temperature Responses to Exercise at 23°C and in Heat

			Rectal Temperature, °C									
		23°C:	−37.5	37.6	37.7	37.8	37.9	38.0	38.1	38.2	38.3	38.4+
				38.0	38.2	38.4	38.6	38.8	39.0	39.2	39.4	39.6+
		Heat:	−37.9	38.1	38.3	38.5	38.7	38.9	39.1	39.3	39.5	
		Score:*	100	90	80	70	60	50	40	30	20	10
Heart rate, beats min^{-1}												
23°C	**Heat**	**Score***	**Composite Scores**									
-105	-110	100	100	95	90	85	80	75	70	65	60	55
106-113	111-118	90	95	90	85	80	75	70	65	60	55	50
114-121	119-126	80	90	85	80	75	70	65	60	55	50	45
122-129	127-134	70	85	80	75	70	65	60	55	50	45	40
130-137	135-142	60	80	75	70	65	60	55	50	45	40	35
138-145	143-150	50	75	70	65	60	55	50	45	40	35	30
146-151	151-158	40	70	65	60	55	50	45	40	35	30	25
152-159	159-166	30	65	60	55	50	45	40	35	30	25	20
160-167	167-173	20	60	55	50	45	40	35	30	25	20	15
168 +	174 +	10	55	50	45	40	35	30	25	20	15	10

*Scores for heart rate or rectal temperature responses to exercise at 23°C or in heat. In each environment, heart rate score + rectal temperature score/2 equal the appropriate composite score. From E. Shvartz, et. al., (15).

intolerant person whose cardiovascular and thermoregulatory systems cannot adapt to heat stress shows high heart rate and rectal temperature when exercising in a temperate environment because such responses reflect poor cardiovascular and thermoregulatory systems. It should be emphasized, however, that heart rate alone (recorded in temperate conditions) cannot accurately predict heat tolerance (Tables 1, 4). Submaximal heart rate indicates endurance fitness, which is related to heat tolerance but cannot accurately predict it. The addition of a core temperature measurement is needed for this purpose, because core temperature (recorded in temperate conditions) indicates the efficiency of the thermoregulatory system.

The above predictive test (Table 5; Figure 2) consists of 15 minutes of hard exercise (about 1.9 l O_2/min.), conditions where the rectal temperature reaches high enough levels (mean of 38.0°C) to be of predictive value. There is a need to determine if tests of 10- or 20-minute duration could be used for the same purpose; if oral temperature can be used instead of rectal temperature; what modification, if any, is needed for tests for women; and the validity of such a test or tests with respect to deacclimatization, age, and clothing.

THE POSSIBILITY OF USING HEART RATE ONLY FOR THE PREDICTION OF HEAT TOLERANCE

As with any other predictive test, especially in an industrial situation, a preemployment test to predict heat tolerance should be simple, short in duration, valid, and reliable. Therefore, if heart rate alone could be used for this purpose, it would simplify the administration of the test. As discussed earlier, heart rate recorded during the performance of submaximal work in a temperate environment does not reflect all the physiological processes that determine heat tolerance. There is, however, indirect evidence to suggest that an exercise test performed in temperate conditions while wearing a vapor-barrier garment, where heart rate is recorded could be used to predict heat tolerance. In one study seven subjects attempted to exercise for 2 hours at 5 ambient temperatures ranging from 25° to 50°C, while wearing vapor-barrier garments that covered the entire body (5). Because of the high peripheral heat storage that occurs in these conditions, rectal temperature was not related to exhaustion, but heart rate was. Heart rate at 10 minutes of exposure ranged from 96 beats per minute at 25°C to 132 beats per minute at 50°C. The corresponding values at 20 minutes of exposure were 100 and 160 beats per minute, respectively. In another study (13), nine men underwent 6 successive days of exercise at 37°C DB, 17°C WB, while wearing vapor-barrier clothing covering the entire body except the face. Tolerance times increased from 41 minutes on the first day to 54 minutes on the sixth day, with heart rates at 20 minutes of exposure of 160 and 140 beats per minute, respectively (Figure 3).

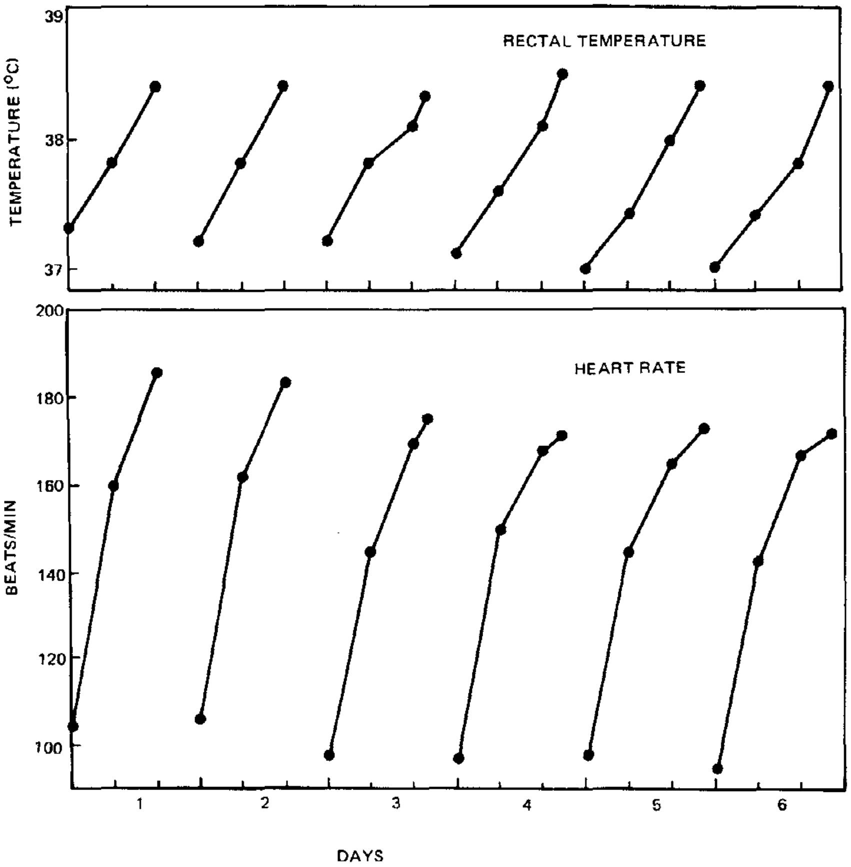

Figure 3. Responses during 6 days of exposure to 37° C while wearing vapor-barrier clothing. From Shvartz et al (13)

These data indicate that heart rate, recorded after a short period of work while under a thermal stress, reflects heat tolerance and state of heat acclimatization. Heart rate recorded after a short period of exercise in temperate conditions, while wearing vapor-barrier clothing covering the whole body except the face or head, might be sensitive enough to accurately predict heat tolerance. The vapor-barrier clothing would prevent sweat evaporation over the covered body areas, thus simulating a warm environment, while the exposed face or head would allow some determination of sweating efficiency. Most of the heat lost by the evaporation of sweat could not be measured. However, it is known that heat tolerant men show lower resting heart rates and rectal temperatures than heat intolerant ones. Thus, a heat intolerant individual with high resting heart rate and rectal temperature values and with low sweating efficiency over the head area can be expected to show a higher heart rate after 10, 15, or 20 minutes of exercise while wearing a vapor-barrier garment without a hood, than a heat tolerant individual with low resting heart rate and rectal temperature values and with high sweating efficiency. The advantage of predicting heat tolerance from heart rate recorded after a short period of exercise at room temperature while wearing a vapor-barrier garment, over that where only shorts are worn, is that, in the first case, a thermal stress is simulated to which heart rate alone may be sensitive.

PREDICTING HEAT TOLERANCE FROM HEART RATES AT 5 and 10 MINUTES OF EXPOSURE

Thirteen of the author's heat studies, where tolerance times and responses at 5 and 10 minutes of exposure were recorded, were reviewed (references 4 through 10 and 12 through 17). These studies included 18 different combinations of work loads, clothing, heat stress levels, and status of acclimatization of subjects. Tolerance times ranged from 30 minutes to 3.2 hours. When the difference in heart rate at 10 and 5 minutes of exposure was plotted against tolerance time, a power curve was obtained (Figure 4). Tolerance time could then be predicted from the heart rate difference, with a standard error of estimate of 10 minutes.

Figure 5 shows the good relationship between the observed and the predicted tolerance times. This relationship is made possible because tolerance time (heat tolerance) is directly related to the slope of the exponential increase in heart rate that occurs during the initial period of exposure to heat. Considering the slope of the curve, the heart rate change (or heart rate at 10 minutes minus heart rate at 5 minutes) constitutes a better predictive method than heart rate at a given point, because the former method can accommodate a wide range of climatic, exercise, and clothing conditions. Heart rate at a given time period of 5 or 10 minutes is more sensitive to work load than to the other factors.

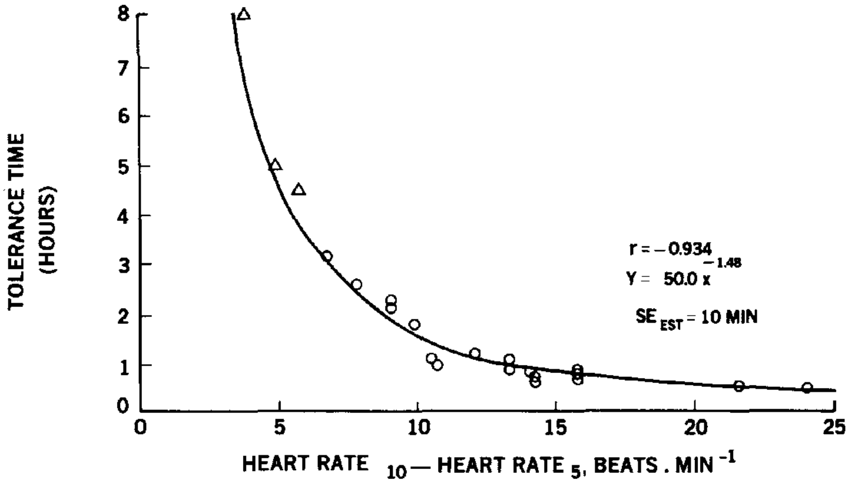

Figure 4. Heart rate at 10 minutes—heart rate at 5 minutes versus tolerance time indicates tolerance times of subjects who were stopped after 4 hours of exposure in a non-exhaustive condition.

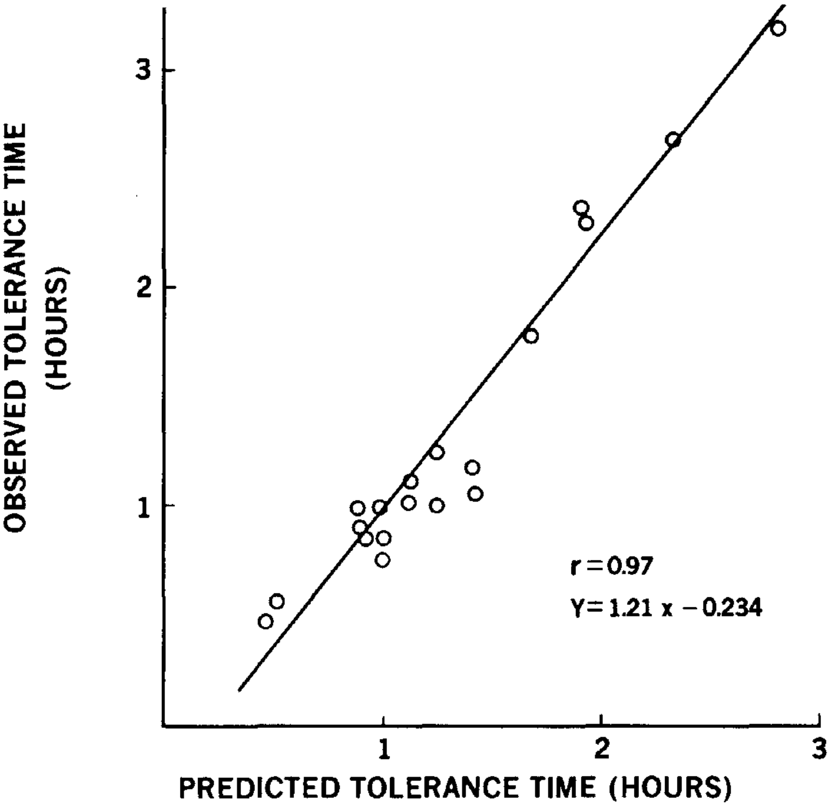

Figure 5. Predicted (Figure 4) versus observed tolerance times.

Accordingly, heat tolerance (exhaustion or tolerance time) can be predicted from a 10-minute test where heart rate is recorded after 5 and 10 minutes of exposure. The relationship between tolerance time and heart rate difference can also be expressed according to the equation:

$$TT = \frac{50}{HR_{10-5} \cdot \sqrt{HR_{10-5}}}$$

where TT = tolerance time in hours; and HR_{10-5} is the difference between heart rate in beats per minute, at 10 and 5 minutes of exposure. The obvious disadvantage of this method is that the desired conditions of heat stress, work load, and clothing have to be simulated. In many industrial conditions, with standard heat stress and work load levels and certain clothing requirements, this should not constitute a serious problem.

More work is needed to validate, and possibly to improve, this prediction method. It is very likely that a test consisting of 10 minutes' exposure to a standard combination of heat stress, work load, and clothing could be used to predict tolerance to a wide range of climatic, exercise, and clothing conditions.

REFERENCES

1. Hausmann, A., D. Belayew, and J. Patigay. Selection criteria for rescue workers operating in hot atmospheres. Rev. Inst. Hyg. Mines. 21:36-48, 1966.
2. Levenne, L., and D. Belayew. Exercise tolerance test at room temperature for the purpose of selecting rescue teams for training in hot climate. Rev. Inst. Hyg. Mines. 21:48-58, 1966.
3. Shvartz, E. Physical performance of heat-adapted individuals. In *Environmental Biology,* edited by Bhatia, Chhina, and Singh, New Delhi: Interprint. 1976, Chap. 20.
4. Shvartz, E., M. Aldjem, J. Ben-Mordechai, and Y. Shapiro. Objective approach to a design of a whole body water-cooled suit: *Aerospace Med.* 45:711-715, 1974.
5. Shvartz, E., and D. Benor. Heat strain in hot and humid environments. *Aerospace Med.* 43:852-855, 1972.
6. Shvartz, E., D. Benor, and E. Saar. Acclimatization to severe dry heat by brief exposures to humid heat. *Ergonomics* 15:563-571, 1972.
7. Shvartz, E., D. Benor, and E. Saar. Natural acclimatization to work in severe heat. *Aerospace Med.* 43:637-640, 1972.

8. Shvartz, E., A. Bhattacharya, S. J. Sperinde, D. Sciaraffa, and W. Van Beamont. Sweating responses during heat acclimation and moderate conditioning. *J. Appl. Physiol.: Respirat. Exercise Environ. Physiol.* 43:678-683, 1977.
9. Shvartz, E., and A. Magazanik. Tolerance to heat following cold stress. *Aerospace Med.* 44:725-729, 1973.
10. Shvartz, E., Z. Glick, and A. Magazanik. Responses to temperate, cold and hot environments and the effect of physical training. *Aviat. Space Environ. Med.* 48:254-260, 1977.
11. Shvartz, E., A. Meroz, Magazanik, and Y. Shapiro. Prediction of heat tolerance and V_{02} max from heart rate and rectal temperature. Proc. Intern. Congress on Physical Activity Sciences, Quebec City, Canada, 1976.
12. Shvartz, E., E. Saar, N. Meyerstein, and D. Benor. A comparison of three methods of acclimatization to dry heat. *J. Appl. Physiol.* 34:214-219, 1973.
13. Shvartz, E., E. Saar, N. Meyerstein, and D. Benor. Heat acclimatization while wearing vapor-barrier clothing. *Aerospace Med.* 44:609-612, 1973.
14. Shvartz, E., Y. Shapiro, A. Magazanik, A. Meroz, H. Birnfeld, A. Mechtinger, and S. Shibolet. Heat acclimation, physical fitness, and responses to exercise in temperate and hot environments. *J. Appl. Physiol: Respirat. Exercise Environ. Physiol.* 43:678-683, 1977.
15. Shvartz, E., S. Shibolet, A. Meroz, A. Magazanik, and Y. Shapiro. Prediction of heat tolerance from heart rate and rectal temperature in a temperate environment. *J. Appl. Physiol: Respirat. Exercise Environ. Physiol.* 43:684-688, 1977.
16. Shvartz, E., N. B. Strydom, and H. Kotze. Orthostatism and heat acclimation. *J. Appl. Physiol.* 39:590-595, 1975.
17. Shvartz, E., C. H. Wyndham, and N. B. Strydom. Orthostatic responses in Caucasians and Bantu. *Aviat. Space Environ. Med.* 40:1343-1348, 1975.
18. Strydom, N. B. Age as a causal factor in heat stroke. *J. S. African Inst. Mining Met.* 72:112-114, 1971.
19. Strydom, N. B., C. H. Wyndham, and A. J. S. Benade. The responses of man weighing less than 50 kg to the standard climatic room acclimatization procedure. *J. S. African Inst. Mining Met.* 72:101-104, 1971.
20. Wyndham, C. H., N. B. Strydom, A. J. S. Benade, A. J. van Rensberg, and G. G. Rogers. Heat stroke risks in unacclimatized and acclimatized men of different maximum oxygen intakes working under hot and humid conditions. Chamber of Mines Research Report No. 12/72, Johannesburg, South Africa: Chamber of Mines of South Africa, 1972.

QUESTIONS, ANSWERS, AND COMMENTARY

DR. DUKES-DOBOS: I think this last part of your presentation was particularly interesting. Where did you get this idea that only half of the time to exhaustion is desirable for safety purposes? Did you test the conditions that are at the permissible TLV?

DR. SHVARTZ: No, I did not consider testing at the TLV. I said half because exhaustion occurs, in heat or not in heat, at heart rates of about 170 to 180 beats per minute, and rectal temperature of about 39.5°C to 39.6°C. The heart rate increased from a resting value of 60 or 70 to three times that when they became exhausted. When the heart rate is increased twice the resting level, it is at the upper level of permissible limits, 120 or 130 beats per minute. Rectal temperature is about the same; about 38.2°C is the upper level of permissible limits. If you are exhausted after 8 hours, heat strain should be about half of that. I tried to extrapolate to see how it could possibly fit into the permissible range.

MR. FULLER: Have you published these data?

DR. SHVARTZ: The first part on predicting heat tolerance from heart rate and rectal temperature was published a couple of years ago in the *Journal of Applied Physiology*. The rest of it is more or less new data.

DR. KAMON: This use of rate of change can be very applicable. There are several recent papers that show a correlation between heart rate and rectal temperature, based on the rate of change. In industry, work is cyclic, that is, within half an hour a worker would work at different heat stress levels. If it could be converted to five minutes instead of ten minutes, one could spot-check the worker at intervals under stressful conditions. By doing this, one could get heart rates on intervals, and, from the slope, predict tolerance.

DR. SHVARTZ: It could be. This is more or less preliminary work. I think it needs to be validated just to show that the possibility exists of using rate-of-change of heart rate.

DR. GOLDMAN: Back in the *Journal of Applied Physiology*, in 1965, Patigay and I showed that you could use a ten-minute change in heart rate to predict tolerance time for people exposed to warm temperatures during work. You can also use rate of rise of heart rate in beats per minute per hour as a very nice prognostic method.

DR. SHVARTZ: Yes, but the heart rate alone cannot be used as a screening test, because we are not interested in screening of heat intolerant individuals to determine the heat tolerance or heat intolerance of those individuals. What possibly can be done is to take a heart rate during a short exercise test. The slope of heart rate increase could predict tolerance time and heat tolerance.

DR. GOLDMAN: Or the rise after ten minutes could be the response time of heart rate.

DR. SHVARTZ: Yes, it could, but I think the difference between these two points indicates a slope of heart rate increase, more than just heart rate. And, according to our data, it is a better predictive method.

MR. BRUSTEIN: Do these tests of heart rate 10 minus 5 require the use of the vapor-barrier?

DR. SHVARTZ: No, not at all. We did that in a very wide variety of conditions: all kinds of heat stress, workload, clothing, and status of subjects.

DR. ZENZ: I wish to reiterate and perhaps emphasize the simplicity of your testing method. You mentioned the South African activities in the Chamber of Mines. They now acclimatize their workers, before going to work, in four days in the large climatic chambers on a step test procedure. It is rather complicated because they run these things around the clock on three shifts.

DR. SHVARTZ: They do the four days of acclimatization because they found that a high intake of vitamin C decreased acclimatization time from eight days to four days. This seems to be the general practice now in the gold mines of South Africa.

PRE-EMPLOYMENT AND PERIODIC MEDICAL EXAMINATIONS FOR WORKERS ON HOT JOBS

David Minard, M.D.

ABSTRACT

Work practices to reduce risk of heat related disorders in employees assigned to hot jobs include pre-employment (or preplacement) and periodic medical examinations. The examining physician must make detailed inquiry into past episodes of heat intolerance. By the same token, evidence of good adaptation to heat in past employment is an important criterion in predicting successful performance in a new job under heat stress. Serious health impairments, particularly of the cardiovascular system, respiratory system, and skin, are basis for rejection. Other impairments, if under adequate treatment, may not be disqualifying. Exercise tests before employment may have value in predicting performance on hot jobs. Periodic examinations as well as physiological monitoring on the job are useful in evaluating the success of work practices.

As stated in the criteria document on *Occupational Exposure to Hot Environments* (1): "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." This comes from a statement out of scope, function, and purposes of an occupational health program in industry and was promulgated by the AMA Council on Occupational Health.

Except in phraseology that would include both male and female applicants, this statement expresses the intent of the following recommendations.

EMPLOYEES REQUIRING PRE-EMPLOYMENT AND PERIODIC MEDICAL EXAMINATIONS

A. Category 1

1. This designates employees whose jobs require continuous or intermittent work on hot jobs for 2 hours or more during a

work shift. Methods for estimating work level and heat exposure level are given in reference 2. Table 1 from reference 2 gives threshold WBGT values at which work practices will be initiated for light, moderate, and heavy work. As seen in Table 1, the threshold WBGT is lower at low air velocity. This compensates for the WBGT index, which underrates the deleterious physiological effects of low air velocity at high levels of heat stress (3).

2. The Standards Advisory Committee on Heat Stress (2) recommended preplacement and periodic medical examinations only for employees performing at work level 4 (i.e. above 300 kcal/hr.).

3. In the opinion of this writer, employees working at or above the heat exposure levels shown in Table 1 require these examinations regardless of work level, because an employee performing light work (level 2) under high heat stress (e.g., WBGT 90 and high air velocity) will experience a degree of heat strain equivalent to that of any employee working hard (level 4) under lower heat stress (e.g., WBGT 79 and low air velocity). In principle, their risks of incurring a heat related disorder are the same.

Table 1

Threshold WBGT Values*

	Threshold WBGT Values, Degrees F	
Workload	**Low air velocity (Up to 300 fpm)**	**High air velocity (300 fpm or above)**
Light (Level 2) (200 kcal/hr or below)....	86	90
Moderate (Level 3) (201 to 300 kcal/hr)	82	87
Heavy (Level 4) (Above 300 kcal/hr)	79	84

*From Reference 2

B. Category 2

This includes any employee whose job requires exposure to extreme heat. The level is such that even a brief exposure will result in excessive strain unless special protection is provided. Work practices required for extreme heat exposure are listed in reference 2.

PRE-PLACEMENT EXAMINATION FOR NEW EMPLOYEES (CATEGORIES 1 and 2)

A. Adaptability to Heat Stress

1. A history of recurrent episodes of heat related disorders (occupational or non-occupational) is disqualifying for new employment on hot jobs.

2. By the same token, a history of successful adaptation to heat stress in previous or present employment is an important criterion for predicting successful performance on the proposed assignment.

B. Sex

1. Female applicants for employment, who have no history of heat intolerance and are currently in good health, are acceptable for category 1.

2. The thresholds of heat exposure for initiating work practices for female employees will be 3°F lower than those for male employees, as shown in Table 1.

3. Female employees are ineligible for jobs in Category 2. This is based on studies that have shown that, at moderate levels of heat stress, women adapt, or can perform very well, but they are not as tolerant to extreme heat as the male.

C. Age

An applicant 45 years of age or older who has had no previous occupational experience on hot jobs is unqualified for new employment on such jobs.

D. Obesity

1. New applicants whose body weights exceed their standard weights by 15% or more are unqualified for hot jobs.

2. An applicant, if obese but otherwise qualified, will be advised to reduce his or her weight to meet job qualifications.

E. Physical Fitness

1. An important criterion for successful job performance under heat stress is the employee's level of physical fitness.

2. For any work level, the upper limit of the prescriptive zone (ULPZ) is lower for the physically unfit. By the same token, deep body temperature in the permissible zone (PZ) is higher for the physically unfit individual than for the physically fit co-worker performing at the same work level. In other words, the level of deep body temperature reached in the metabolically regulated zone (PZ) is proportional to the ratio of metabolic expenditure during a given level of work and the individual $\dot{V}O_2$ max.

2. For the same level of acclimatization, the physically fit employee possesses greater heat tolerance than a co-worker who is not as physically fit.

3. It is recommended, therefore, that the pre-placement examination include a simple submaximal exercise test for estimating physical fitness. For example, this could be an exercise test at a work load of 125 watts on a bicycle ergometer at room temperature with measurement of final heart rate, which reaches a plateau in 5 minutes or less (4). From heart rate the examiner can estimate the applicant's $\dot{V}O_2$ max. An estimated $\dot{V}O_2$ max below an acceptable minimum would be disqualifying (e.g., 33 ml/kg min. or less).

4. A stepping exercise test at room temperature but at lower energy output and longer duration (40 watts for 15 minutes) with measurement of final heart rate and body temperature, provides a higher correlation with heat tolerance in young test subjects than estimated $\dot{V}O_2$ max alone (5).

F. Review of Systems

1. Cardiovascular System — Physiological strains from heat stress are manifested largely in the cardiovascular system. Therefore, medical evaluation of applicants for hot jobs requires the examiner to place primary emphasis on functional capacities of the heart and circulatory system. This applies both in taking a medical and occupational history as well as in the examiner's physical examination and in the evaluation of laboratory findings. Laboratory tests include the 12 lead EKG, the 14 x 17 inch chest X-ray, and other components, such as routine blood counts and urinalysis.

Organic diseases of the heart or vascular system of significant degree preclude assignment of an applicant to a hot job. As examples, valvular heart disease, myocardial disease, cornary artery disease, renal vascular disease, cerebral vascular disease, or disease of other peripheral arteries are disqualifying.

Applicants with essential hypertension that is uncontrolled or under treatment with a low salt diet and diuretics, or with therapeutic agents acting directly or indirectly on the heart or vascular system, are not qualified for jobs under heat stress. In case of minor functional disorders, e.g., benign arrhythmias, the examiner must decide whether or not heat exposure will constitute a significant added risk to the employee. I would like to emphasize that these recommendations are all for new employment. If the individual was simply up for a periodic examination we would recognize that the worker had successfully performed on the job; this would be an important criterion for continued employment.

Minor organic vascular disorders (e.g., varicose veins), which can be treated, are not disqualifying.

2. Respiratory system — Chronic obstructive pulmonary disease of more than minor degree is disqualifying. Restrictive disorders (e.g., from pulmonary fibrosis) will require careful evaluation regarding etiology and degree of pulmonary impairment, as well as the disease status (stable or progressive). Both restrictive and obstructive diseases result in impaired pulmonary circulation, which leads eventually to cor pulmonale.

An active lung disease, e.g., tuberculosis, is disqualifying. Findings would be reported to the applicant's personal physician, or to the public health physician. Following treatment, the applicant might be eligible to reapply.

Other chronic or recurrent acute respiratory disease in an applicant requires the examining physician to determine on clinical grounds whether or not the applicant is acceptable for assignment to a job requiring heat exposure.

3. Skin — The presence or history of skin disease of a recurrent and generalized nature, which would be aggravated by heat exposure or which would impair the secretory function of the sweat glands, will be disqualifying.

Recent acute injury to the skin and sweat glands (e.g., extensive and severe sunburn) might temporarily disqualify the applicant. Not until normal sweat gland function had returned or the examiner was satisfied that chronic impairment of sweat gland function was not a possible sequela, would the applicant be considered eligible for employment on hot jobs.

4. Other systems (liver and biliary; renal and urinary; endocrine and metabolic; digestive) — In taking the medical history

and in performing the physical examination, the examiner should inquire into and examine the systems listed under this heading, with particular attention to possible chronic impairments.

Diseases of these systems are considered disqualifying only if the applicant is not under treatment by a personal physician.

Clinical judgment of the examining physician, however, must be used in deciding whether the applicant would tolerate heat and work stresses. If, in the examiner's judgment, the impairment would jeopardize safe performance on the job, or if heat stress would aggravate the impairment, the applicant should be rejected.

G. Drugs

1. An applicant using prescription or nonprescription medications that impair thermoregulatory responses to heat stress will require clinical evaluation of his medical qualifications for work under heat stress.
2. Drug abuse, including alcoholism, would be disqualifying.
3. Medications affecting behavior and mood, such as sedatives, tranquilizers, antidepressants, antihistaminics, muscle relaxants, and amphetamines, might be disqualifying if treatment were to continue indefinitely.

H. Other Qualifications

1. These will depend on statutory or other medical requirements not specifically related to heat exposure. Examples are vehicle operators, cranemen, radiation workers, etc. Fitness for these jobs may require special laboratory or other examining procedures.
2. The examiner must recognize, moreover, that heat exposure on the job may increase the hazard of toxic industrial agents (e.g., CO) or increase the employee's susceptibility to other physical stresses, such as work at high or low barometric pressure. Dehydration from uncompensted loss of water and electrolytes in the sweat also may impair the body's tolerance for toxic agents.

PERIODIC MEDICAL EXAMINATION

A. Employees below the age of 45 will undergo a periodic examination every 2 or 3 years.

B. Employees below age 45 who had been accepted with health impairments not considered disqualifying will be examined periodically at shorter intervals, at the discretion of the medical examiner.

C. On attaining age 45, employees previously selected for hot jobs would receive periodic examination on an annual basis.

D. Physiological monitoring of employees on the job can provide important information to the medical examiner regarding heat tolerance of the new employee, or those previously employed, who have returned from sick leave.

DISCUSSION

In the main, the proposed categories of employees for whom both preplacement and periodic medical evaluations would be mandatory follow the recommendations of the Standards Advisory Committee on Heat Stress (2).

This committee proposed that work practices be initiated for employees (Category 1) performing at three specified work levels for two hours or more in duration, if ambient heat stress at the work site equalled or exceeded two specified limits for each work level, depending on whether air velocity was above or below 300 fpm. Special work practices, in addition to one or more of those advocated for employees in Category 1, would apply for employees exposed to extreme heat (Category 2). Pre-employment (or preplacement) and periodic medical examinations are important components of these work practices.

To insure that the work practices as a whole provide adequate protection to employees on hot jobs, the medical examiner will utilize the periodic examination and interval history to note any significant events during the interval since the employee's previous examination, such as repeated accidental injury on the job, episodes of heat-related disorders, or frequent sick absences. Such events may lead the physician to suspect possible heat intolerance of the employee, or the possibility of an aggravating stress in combination with heat, such as exposure to hazardous chemicals or physical agents.

In assessing the employee's capacity to continue on the same job, the medical examiner might request physiological monitoring of the employee on the job, with emphasis on recovery heart rates and oral temperatures. Where work practices are judged as adequate in protecting the majority of employees working at comparable levels of heat stress, evidence of heat intolerance in a susceptible employee may lead the physician to recommend a transfer to another job.

Predictive tests of work capacity prior to assigning employees to jobs with exposure to heat stress might help to identify the applicant who is intolerant to heat or at risk because of low physical fitness. Eliminating the applicant before his or her assignment to work under heat stress avoids an unnecessary risk to a susceptible individual.

Submaximal exercise at 125 watts for 5 minutes on a bicycle ergometer, in comfortable ambient temperatures, was useful in predicting physiological strain, measured as mean heart rate during the shift, in second helpers in the open hearth department of a Pittsburgh Steel Mill (4). These were individuals well acclimatized to their jobs. The shortest time on the job was fourteen years among the individuals tested, so that we knew they were qualified from the standpoint of heat tolerance and physical fitness. But within those individuals we could still predict which one would perform better on the job in terms of a lower mean heart rate.

More recently, Shvartz, et al. (5) found that heart rate and rectal temperatures measured in 51 test subjects at the end of a 15-minute stepping exercise at 80 watts in a comfortable environment are highly correlated ($r = 0.94$) with these measurements of physiological strain when the same subjects performed 3 hours of bench stepping at 40 watts in the heat (39.3°C DB, 30.3°C WB). Those with the highest heart rates and rectal temperatures (i.e., low scores) in the 15-minute test showed evidence of heat intolerance while working in the heat, whereas well acclimatized subjects with high heat tolerance had the lowest heart rates and body temperatures (i.e., high scores) in the 15-minute test at room temperature. These authors found that the heart rate alone on submaximal exercise or the $\dot{V}O_2$ max alone correlated less well with performance in the heat.

It is recommended that the preplacement medical evaluation include an exercise test of an applicant's work performance with measurement of heart rate and body temperature. Those who perform poorly should not be assigned to jobs requiring vigorous physical exertion in the heat.

Further research is needed to determine work test parameters for optimal predictive value.

REFERENCES

1. Criteria for a Recommended Standard — Occupational Exposure to Hot Environments. U.S. Department of Health, Education and Welfare, National Institute for Occupational Safety and Health, U.S. Government Printing Office, Washington, D. C. 1972.

2. Ramsey, J. D., Standards Advisory Committee on Heat Stress — Recommended Standard for Work in Hot Environments. Appendix C in Standards for Occupational Exposure to Hot Environments. Proceedings of a Symposium, Horvath, S. M. and R. C. Jensen (Ed.) pp. 191-204, Cincinnati, Ohio, USDHEW, CDC, NIOSH Jan. 1976.
3. Minard, D. Effective Temperature Scale and its Modifications, Naval Med. Res. Inst. Report No. 6, Mar. 12, 1964.
4. Minard, D., R. Goldsmith, P. H. Farrier, Jr., and B. J. Lambiotte, Jr., Physiological evaluation of industrial heat stress. Am. Ind. Hyg. Assoc. J. *32*:17-28, 1971.
5. Shvartz, E., S. Shibolet, A. Meroz, A. Magazanik, and Y. Shapiro. Prediction of heat tolerance from heart rate and rectal temperature in a temperate environment. J. Appl. Physiol. *43*:684-688, 1977.

QUESTIONS, ANSWERS, AND COMMENTARY

DR. SHVARTZ: I think there is no question that hypertension would be one problem in the ability to work in heat. But what about hypotension, or low blood pressure? During exposure to heat, blood pressure is usually lower because of blood pooling, especially in standing jobs. People who tend to have resting low blood pressure tend to be heat intolerant.

DR. MINARD: This is very interesting. I am sure we would all be interested in knowing if there were some data on this point. I would go along with you and assume that an individual with a low normal or low blood pressure would be more susceptible to heat effects and might be more likely to develop heat syncope. But, it is hard to say whether the same person would be more likely to develop one of the more serious heat illnesses.

DR. RAMSEY: Dr. Minard, you asked for some clarification on the recommendations from the OSHA Advisory Committee. First, heavy work is defined as greater than 300 kilocalories. Second, an extreme heat exposure category is a short duration high intensity activity. Preplacement medical examinations are recommended for those situations.

DR. MINARD: Employees working at or above the exposure levels on your table would require the preplacement and periodic examinations, regardless of work level?

DR. RAMSEY: This was a distinction between the blanket preplacement exams and those where the metabolic work was indicated to be heavier. This was the way it was intended. The documentation has a large number of alternatives and votes, and some of the points do not represent a concensus. One must consider that it reflects different levels of agreement.

DR. DUKES-DOBOS: In your presentation, did you mention the atropine type of medications that are often used?

DR. MINARD: Cholinergic?

DR. DUKES-DOBOS: Cholinergic, anticholinergic drugs.

DR. MINARD: I did not go into detail, but I did say medications that would adversely affect thermoregulation.

DESIGN OF WORK-REST SCHEDULE FOR HOT JOBS

Eliezer Kamon, Ph.D.

ABSTRACT

Work-rest periods were designed for the following work levels:

(1) Walking at 40% $\dot{V}O_2$ max,

(2) Walking at 60% $\dot{V}O_2$ max, and

(3) Combined walking and carrying at 30% and 75% $\dot{V}O_2$ max, respectively.

Each of the three work levels was performed under each of the following ambient conditions:

(1) Neutral — T_{db} 23°C, T_{pwb} 16°C,

(2) Warm-humid — T_{db} 36° C, T_{pwb} 31° C, and

(3) Hot-dry — T_{db} 50°C, T_{pwb} 25°C.

The rest after each work level was either under the same warm or hot conditions as that for work or under the neutral conditions. The work periods were predetermined on the basis of the expected cumulative strain of the muscular work and the heat as reflected by increments in heart rate (HR). The total sum of the HR was treated in terms of its equivalent to % $\dot{V}O_2$ max based on the linear relationship between them. The resting periods were designed on the basis of an efficient rotation between workers. Judged by the rise and the leveling off in HR and the measured rectal temperature (setting the average to 38°C), the procedure was adequate for the hot-dry conditions irrespective of the location assigned for resting, and for the warm-humid conditions only if the resting was under the neutral ambient conditions.

This discussion is based on some recent observations that my colleagues and I have made on the physiological responses to cyclic work under warm-humid and under hot-dry ambient conditions. The cycles of the work periods were predesigned according to the expected cardiovascular strain as represented by the heart rate.

Under heat stress, the cardiovascular system is called to support two basic needs:

(1) The O_2 demand of the working muscles, and

(2) The transfer of metabolic heat from core to surface.

These two functions can therefore be combined for the design of the work periods. The capacity of the cardiovascular system to meet the O_2 demand of muscles limits physical work. Consequently, cardiac strain correlates best with O_2 demand as a fraction of the maximal aerobic capacity ($\dot{V}O_2$ max). Since maximal HR, and thus the limits to work, are also a function of age, the correlation between HR and muscle O_2 demands in terms of % $\dot{V}O_2$ max and between HR_{max} and $\dot{V}O_2$ max are age dependent. A schematic of these relationships is shown in Figure 1.

Heat stress increases HR to the extent that the increments above the work specific HR reduce the reserve capacity of the heart in proportion to its proximity to HR_{max}. The cumulative strain of work and heat could then be treated in terms of the approach toward HR_{max}. But the heat induced approach to HR_{max} can also be expressed in terms of reserve capacity to deliver O_2 or the cardiovascular equivalence of % $\dot{V}O_2$ max.

The use of relative $\dot{V}O_2$ for the cardiovascular strain due to work and heat allows for a better design of work periods, because of the relationship between the endurance time and the relative intensity of the work (% $\dot{V}O_2$ max), as shown in Figure 2. A summary of our rationale for the design of the work periods under the two steps of hot ambient conditions is as follows:

a. Assuming no heat stress, the expected relationship between HR and % $\dot{V}O_2$ max is linear, with the average range of 130 bpm at 50% $\dot{V}O_2$ max and HR_{max} at 100% $\dot{V}O_2$ max (Figure 1).

b. Heat induced increments in HR, above the work specific HR, are expected to be about 1 bpm for 1°C above air temperature (T_a) of 25°C under dry heat. Dry conditions are assumed for skin wettedness below 0.6 (see definition below).

c. Under humid ambient conditions the HR increments are due to excessive ambient vapor pressure. Vapor pressure can be considered stressful when skin wettedness is forced above 0.6 (see definition below). Skin wettedness (w) is defined by the ratio of $(M+R+C)$ over E_{max}, where M is the metabolic heat production, R is the radiative, and C the convective heat exchange. E_{max} is the capacity of the air for evaporation. It is worth noting that in this context the strain evaluation for work in hot environments requires the use of both the relative value of M (% $\dot{V}O_2$ max) and the absolute value of M.

The increase in vapor pressure (vp) to where w is above 0.6 is expected to raise HR above the work-specific HR because of the circulatory strain involved in maintaining core temperature (T_c), despite the reduction in E_{max}. The increment in HR due to reduced E_{max} is proportional to the increase in w and involves time factors, i.e., creeping of HR with time. With the high humidity of our experimental design, w was high; thus, heat induced increments of 20-25 bpm within 15 to 30 minutes of work were to be expected. Although such HR increments above the work specific HR could be validated from other studies (Kamon and Belding, 1971; Gonzales, Berglund, and Gagge, 1978), there is a need to better establish the vp/HR relationships.

d. If we use the formula for HR_{max} as adopted by the American Heart Association (1972): $HR_{max} = 220 - \text{Age (years)}$, and use a safety margin HR_{max} of two standard deviations below the mean, the slope of % $\dot{V}O_2$ max on HR can be derived. The following examples demonstrates this approach:

(1) Assume that the age of the workers is between 20-30 years. The maximal $HR_{max} = 220 - 25 = 195$ bpm. One standard deviation from the mean is 7 bpm (e.g., Astrand, 1960). Thus, HR_{max} of 180 bpm is an acceptable safe value. The range between $\dot{V}O_2$ max to 50% $\dot{V}O_2$ max equals HR range of 180 to 130 bpm or a slope (Figure 1) of

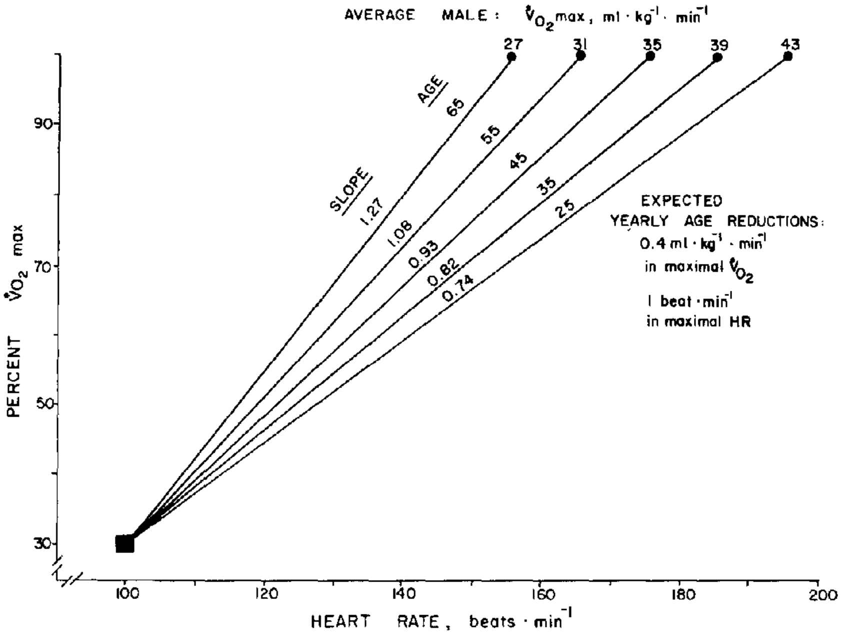

Figure 1. Schematic representation of the expected relationship between heart rate and the relative work load (% $\dot{V}O_2$ max) based on age expected maximal heart rates.

$$\frac{\dot{V}O_2\ \text{max} - 50\%\ \dot{V}O_2\ \text{max}}{180\text{-}130} = \frac{50}{50} = 1\%\ \dot{V}O_2\ \text{max}/1\ \text{bpm}$$

(2) Assume that the workers are in their mid-forties. $HR_{max} = 220 - 45 = 175$; two standard deviations below the mean is a

safe HR_{max} = 160 bpm, using the same ranges

$$\frac{\dot{V}O_2 \text{ max} - 50\% \ \dot{V}O_2 \text{ max}}{160\text{-}130} = \frac{50}{30} = 1.67\% \ \dot{V}O_2 \text{ max}/1 \text{ bpm}$$

The slope of 1.67 could be an overestimation of the expected slope, because at 50% $\dot{V}O_2$ max the HR is expected to be somewhat lower than 130 bpm. Since the age reduction in HR at 50% $\dot{V}O_2$ max is quite small, it could be ignored for the purpose of designing safe working conditions.

e. In equating work induced HR to heat induced increments in HR, let us return to the simple ratio of 1% $\dot{V}O_2$ max per 1 bpm HR that was derived above for young adults in their twenties. If the cause of the increment is dry heat, such as t_a of 45°C, the expected HR will be 20 bpm (45 − 25) above the work specific HR.

The 20 bpm increment can be equated with the slope of 1% $\dot{V}O_2$ max per 1 bpm; which indicates the heat induced increments of 20 bpm could be equivalent to an increase in the work intensity of 20% $\dot{V}O_2$ max. In our design, the work load was adjusted for 40% $\dot{V}O_2$ max and the hot dry ambient conditions were set at 50°C and P_a = 11 Torr. Thus, the expected 25 bpm increments in HR due to heat were equated with 25% $\dot{V}O_2$ max and the work was considered as equivalent to 65% $\dot{V}O_2$ max (40 + 25).

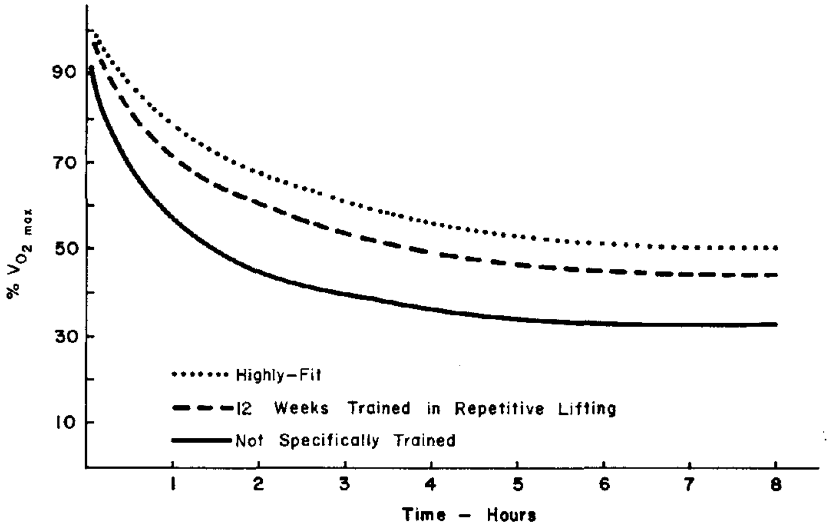

Figure 2. Enrudance to exhaustion as a function of relative and work load (% $\dot{V}O_2$ max) for highly fit individuals (Astrand and Rodahl, 1970), for repetitive lifting (Petrofsky and Lind, 1978) and for untrained individuals (Bonjer, 1971)

Work Endurance. With a rationale for a unit of strain that combines the stresses of work and of heat, we established the work periods based on this rationale. The inverse relationship between the intensity of work in $\% \dot{V}O_2$ max and the time to exhaustion is shown in Figure 2. However, an approach-to-work-design based on work-to-exhaustion is not reasonable. An acceptable work practice calls for a work-rest design that will prevent undue fatigue. Some past observations on intermittent work versus continuous work-to-exhaustion seemed to indicate that for heavy work, dividing the work and rest into proportions of one-third and two-thirds, respectively, allows for prolonged continuance of the work (Astrand, et al., 1960; Simonson, 1971). With no better clue to the best nonfatiguing work-rest ratio, we chose to use the one-third of the time to exhaustion as the best approach to the design of the length of the work period. Using the available data on work intensity to fatigue, which also included repeated lifting (Petrofsky and Lind, 1978), but reducing the work time to one-third the time to fatigue, yielded a simplified formula for the length of the work period in minutes (t) as a function of $\% \dot{V}O_2$ max:

$$t = \frac{4000}{\% \dot{V}O_2 \text{ max}} - 39$$

The relationship of the nonfatiguing working time and work intensity is shown in Figure 3.

Although our rationale for work design is based on cardiovascular responses, the expected rise in core body temperature (T_c) should not be overlooked. Indeed, core body temperature can also serve as an indicator of physiological strain due to work and heat stress. T_c was shown to be linearly related to $\% \dot{V}O_2$ max within certain limits of ambient conditions (Saltin and Hermansen, 1966; Kamon, 1975). However, beyond these limits T_c is expected to rise in proportion to the heat stress imposed either by high air temperatures (Kamon and Belnding, 1971a) or by high humidities (Kamon and Belding, 1971b).

Verification of Work Schedule. This experiment was conducted as described below.

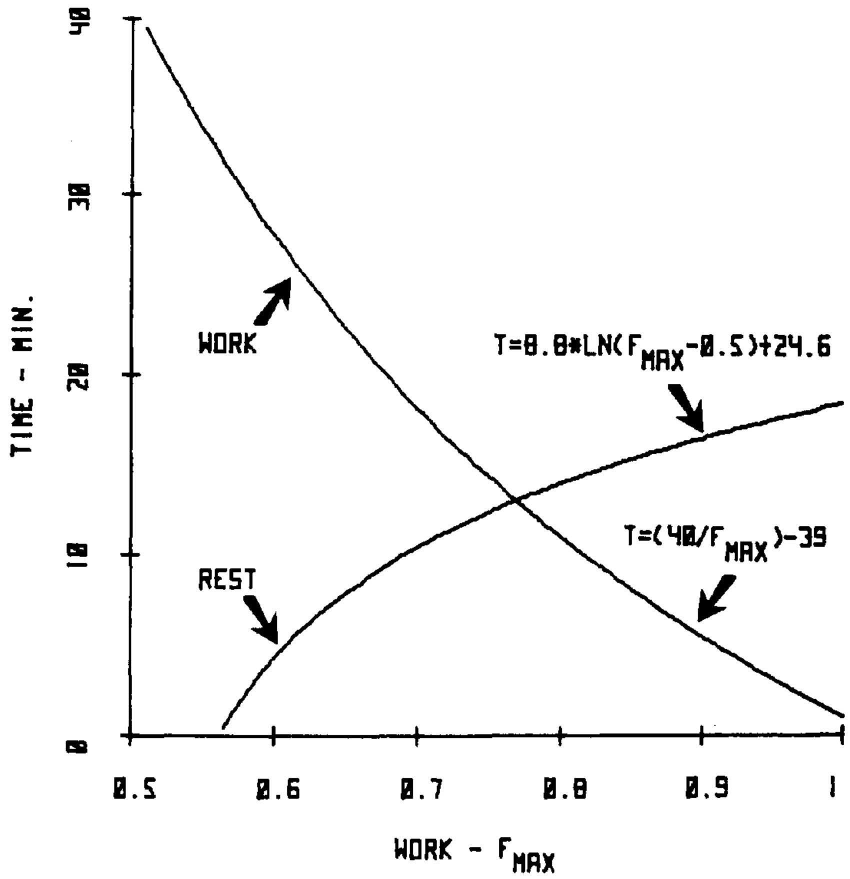

Figure 3. Model for non-fatiguing working period and resting period as a function of relative work load (F=fraction of $\dot{V}O_2$max)

METHODS

Subjects were young adult college students whose physical characteristics are summarized in Table 1.

Ambient conditions were set to be: (1) warm-humid and (2) hot-dry, as shown in Table 2. These combinations of humidity and heat were designed to elicit heat induced increments in HR of about 25 bpm above the work-specific HR. The control test provided work-specific responses only.

Clothing worn consisted of a T-shirt, short underwear, long sleeve cotton shirt, khaki trousers, gym shoes, and socks.

Workload. Two types of work were used (Table 1). In one, the only activity was treadmill walking. In the other, the activity

Table 1

Summary of Physical Characteristics of Subjects
(Mean and Standard Deviation)

N	Age (yr.)	Weight (kg)	Height (cm)	S.A. (m^2)	HRmax* beat·min^{-1}	$\dot{V}O_2$max (L/min^{-1})
Walking Tests						
6	23	64.8	176	1.79	—	3.36
	± 3.2	± 8	± 7.8	±0.15	—	±0.76
Carrying Tests						
Women						
N	21.67	56.1	160.9	1.58	192.7	2.26
3	± 1.53	± 7.6	± 7.3	± .12	± 6.4	± .03
Men						
N	26.0	82.7	182.7	2.04	195.3	4.66
3	± 3.6	±14.6	± 5.8	± .19	±11.7	± .91

*$\dot{V}O_2$ max estimated from submaximal exercise for walking tests. Therefore no HRmax is available.

involved carrying a load while walking on the treadmill. The two work types are described below:

Work Without Load Carrying. The work involved treadmill walking at 40% $\dot{V}O_2$ max and at 60% $\dot{V}O_2$ max. Our formula (see work endurance, above) was used to derive the length of the work period from the HR strain equivalence in terms of % $\dot{V}O_2$ max for the work under the hot ambient conditions. The derived work periods were 22.5 min and 8.1 min for the 65% $\dot{V}O_2$ max and the 85% $\dot{V}O_2$ max, respectively.* Since, in practice, work-rest cycles call for a rotational system, the work and rest periods should not unduly overlap for a given number of workers. Therefore, the derived work periods were rounded to 20 min and 10 min for the strain equivalence of 65% and 85% $\dot{V}O_2$ max, respectively. The rest periods were adjusted to allow rotation between two workers for the 65% $\dot{V}O_2$ max and between three workers for the 85% $\dot{V}O_2$ max. Thus, with work at the 40% $\dot{V}O_2$ max with a strain equivalence of 65% $\dot{V}O_2$ max, the work-rest cycles were equal (20 minutes each); and with work at the 60% $\dot{V}O_2$ max with a strain equivalence of 85% $\dot{V}O_2$ max, the length of the rest periods were twice the work periods (10 min. work and 20 min. rest).

Work With Load Carrying. During a walk at 30% $\dot{V}O_2$ max,

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*In each case the heat strain was equated with 25% $\dot{V}O_2$max; the actual work loads were 40% and 60% $\dot{V}O_2$max.

Table 2

The Mean Dry Bulb (T_{db}) and Wet Bulb (T_{wb}) Temperatures for the Working and Resting Periods

Notation	Description		Ambient Conditions*			
	Ambiance	Period	Work Period		Rest Period	
			T_{db}°C	T_{pwb}°C	T_{db}°C	T_{pwb}°C
WH-1	Warm -Humid	Working	36	31		
	Warm -Humid	Resting			36	31
WH-2	Warm -Humid	Working	36	31		
	Neutral	Resting			23	16
HD-1	Hot-Dry	Working	50	25		
	Hot-Dry	Resting			50	25
HD-2	Hot-Dry	Working	50	25		
	Neutral	Resting			23	16
G	Control	Working	23	16		
		Resting			23	16

*Temperatures were within a standard deviation of 1°C. Mean air movement was 1 m in the heated room and 0.18 m s^{-1} in the cooler resting room.

which preceded the carrying, the treadmill was level with an average speed of 1.34 $m{\cdot}s^{-1}$ (3.0 mph) for women and 1.57 $m{\cdot}s^{-1}$ (3.5 mph) for men. At the onset of the carrying, the inclination of the treadmill was adjusted to raise the individual's oxygen consumption to 75% $\dot{V}O_2$ max, including the cost of load carrying. The uphill grade was 10-14% for the women and 12-15% for the men. The weight carried by the women was 10 kg., while the men carried 12 kg. It was equally distributed in a box 45 x 25 x 23 cm. The box was carried in front, on the hands, with the elbows bent at 90°.

In this case, the work and heat strain equivalent was assumed to be 50-55% and 90-100% $\dot{V}O_2$ max, respectively, for the walking and for the carrying. Since, according to our formula, the carrying could be tolerated for about 3 min, the walking and the carrying were tried at 25 min and 5 min, respectively. Thirty minutes' rest was given to allow rotation between two workers.

Measurements. Rectal temperature (T_{re}) was measured by a thermistor inserted 10 cm beyond the anal sphincter. Mean skin temperature (T_s) was calculated as the unweighted average of six skin temperatures measured with uncovered copper-constantan thermocouples located on the forehead, chest, back, forearm, and both thighs. The temperatures from the thermistor and thermocouples were recorded continuously throughout the test period. Heart rate obtained from an electrocardiogram was taken for 15-30 seconds every five minutes during the walk and rest periods, and once each minute during the carrying. Oxygen uptake ($\dot{V}O_2$) was determined by the open circuit method. Expired air, collected through a low resistance valve into a Douglas bag, was analyzed for O_2 and CO_2 content with a Beckman E2 paramagnetic analyzer and an MSA Lira Infrared Meter, respectively. Volume was measured with a Parkinson Cowan dry gas meter.

Total sweat production (S) was calculated as the change in nude body weight measured prior to and after each experimental session, and corrected for water intake. Evaporation rate (E_v), measured every 30 minutes, was determined by the change in total body weight and water intake. No corrections were made for respiratory evaporation or metabolic gas exchange weight loss.

Heat Acclimation. Prior to the experimental sessions, each subject was heat acclimated by a two-hour daily exposure to T_{db} 50°C, T_{wb} 25°C for four consecutive days, and to T_{db} 36°C, T_{wb} 31°C for two to three days. Exposure included level treadmill walking requiring 30% $\dot{V}O_2$ max. Full acclimation was determined by the reduction and leveling off in T_{re} and HR and by the improved tolerance time.

Heat Exchange. Heat equivalent of sweat was calculated using 0.67 $Whr.g^{-1}$ as latent heat. Dry heat exchange (R + C) was calculated using the equation $(R + C) = h_o\ (T_o - Ts)$, where $H_o = 8\ W{\cdot}m^{-2}{\cdot}\phi\ C$, derived according to Kerslake (1972) for nude men and corrected by a factor of 0.65 for clothing, as suggested by Hertig and Belding (1963). The operative temperature (T_o) was equal to T_{db}, since there was no radiant heat; the measured black globe temperature was within 0.5°C of the T_{db}. The ambient evaporation capacity (E_{max}) was calculated as $E_{max} = h_e (P_s - P_a)$, where $h_e = 12\ W{\cdot}m^{-2}{\cdot}\ Torr\ ^1$, which is a conservative value, from our observation; that is, one standard deviation below the mean value we found for clothed men and women (Kamon, et al., 1978); P_s and P_a are the saturated skin vapor pressure and air vapor pressure, respectively.

Metabolic heat production was derived from the measured oxygen consumption, where a steady state $\dot{V}O_2$ of 1 $L{\cdot}min^{-1}$ was equivalent to 348W. The required evaporation (total heat load), $E_{req} = M + R + C$, was calculated in units of W·m^{-2}.

RESULTS

The control observations (neutral ambient conditions) of HR for the work cycles and T_{re} for the work-rest cycles are shown in Figure 4 for the 40% and 60% $\dot{V}O_2$ max. It can be seen that the T_{re} fluctuates around 37.5°C, with higher values at the end of each work period. Actually, T_{re} is somewhat below the expected work-specific level; this probably is a result of the intermittent nature of the work. The working HR's were at the expected work-specific levels, as shown in Figure 4. Since resting HR's were at the expected values, they are not shown in Figure 4.

The main observation on the responses to cyclic work were conducted with forced air movement at 1 m·s^{-1} in the heated cham-

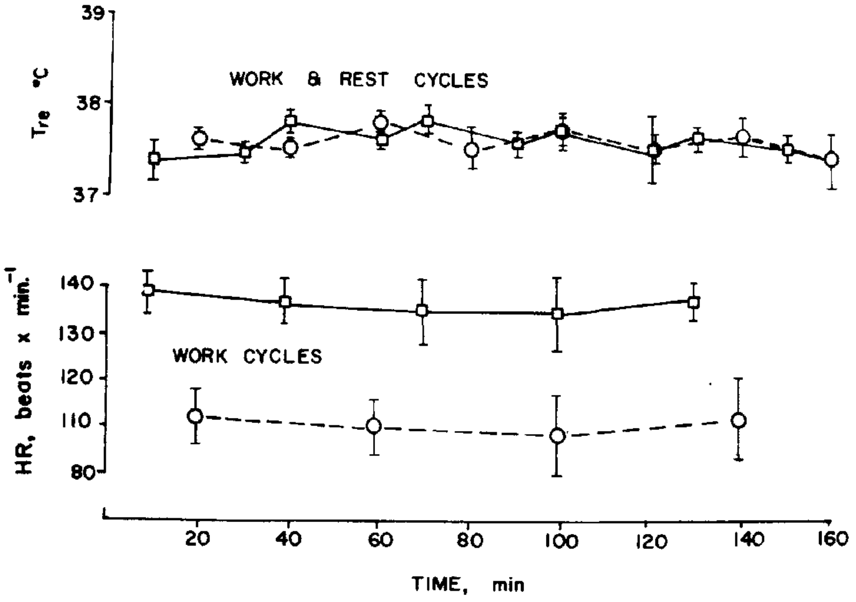

Figure 4. End values of heart rates for the working periods and of rectal temperature for the working and resting periods during the 20 minutes work and 20 minutes rest at 40% $\dot{V}O_2$ max (0), and 10 minutes work and 20 minutes rest at 60% $\dot{V}O_2$ max (....), under neutral ambient conditions

ber. The time course of the rectal temperature (T_{re}) for the combinations of the ambient conditions and the work loads is shown in Figure 5. It can be seen that under the warm-humid conditions, with resting under the same condition as working, (WH-1) T_{re}

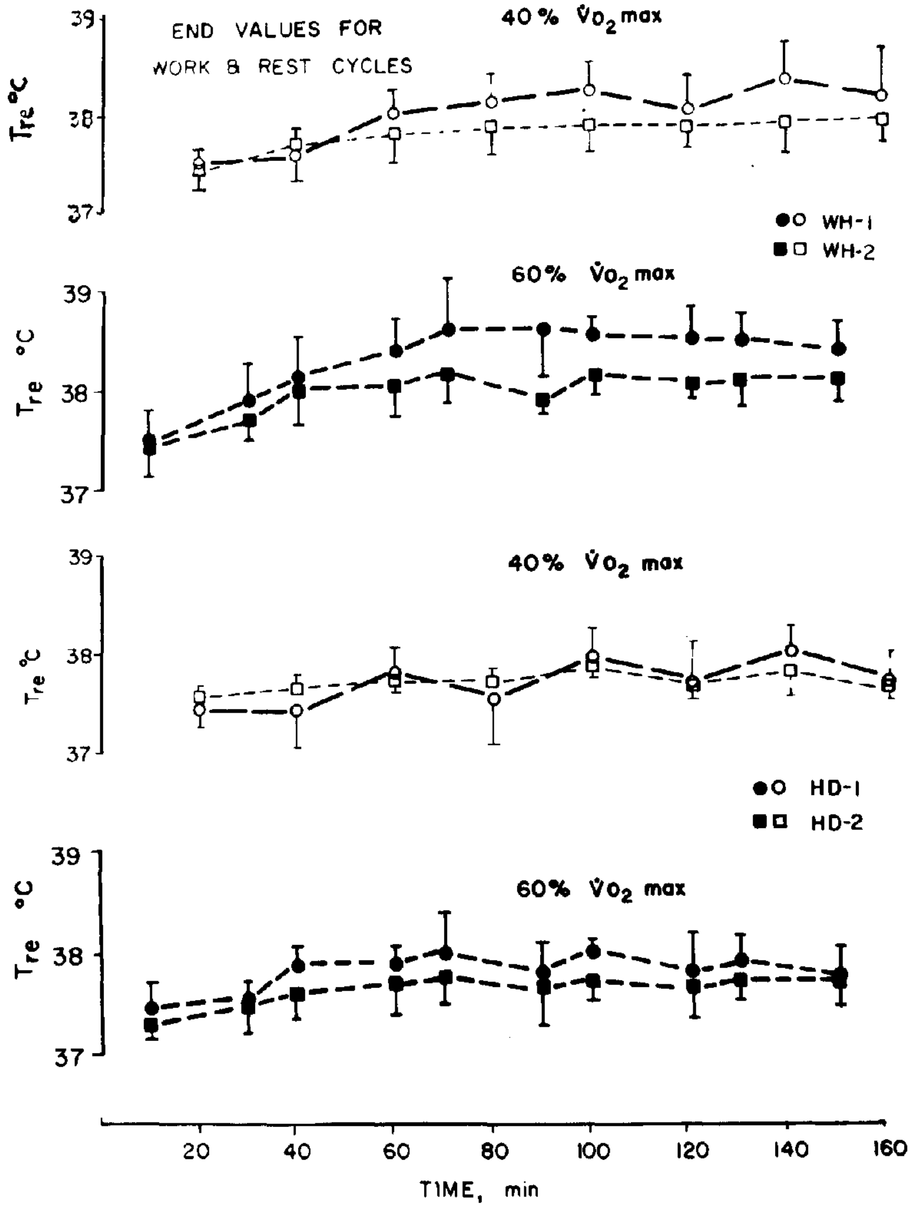

Figure 5. Rectal temperatures for the two work loads under the warm-humid (WH) and hot-dry (HD) ambient conditions. 1 - refers to resting under the same conditions as working; 2 - refers to resting under neutral ambient conditions (see Table 2)

levels off at slightly above 38°C, particularly for work at 60% $\dot{V}O_2$ max. Thus, maintaining these conditions for a prolonged time could be considered undesirable. Resting outside the warm-humid conditions (WH-2) improved the situation by allowing T_{re} to remain below 38°C for the entire 160 minutes of the test. Based on

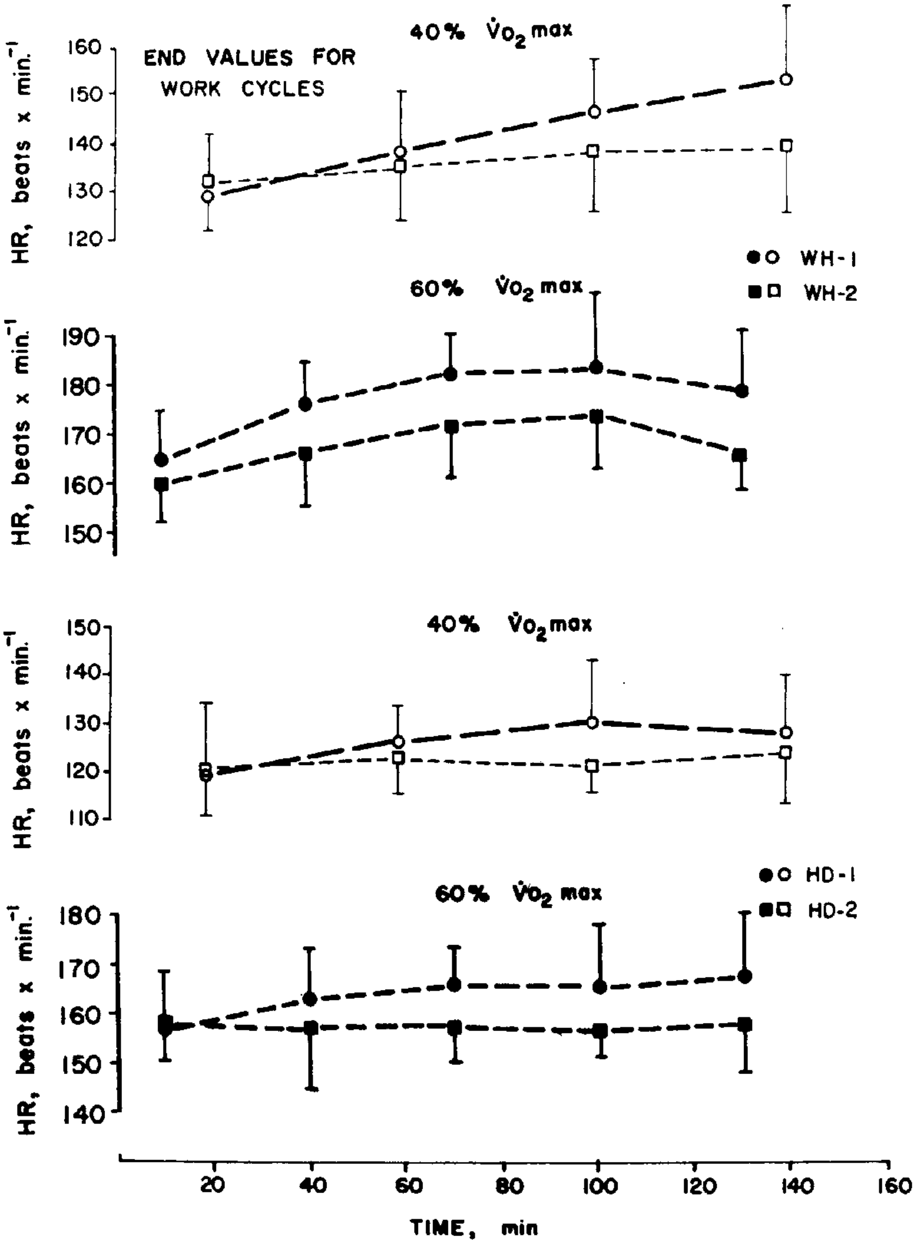

Figure 6. Heart rates for the two work loads under the two ambient conditions (see Figure 7 for details)

the T_{re}, the prescribed cycles of work were effective for the hot-dry conditions (HD-1 and HD-2).

The end values of HR for the working periods are shown in Figure 6. Similar to T_{re}, work and rest under the warm-humid condition (WH-1) resulted in a continuous rise in HR for work at 40% $\dot{V}O_2$ max and leveling off at levels close to the maximal HR for the work at 60% $\dot{V}O_2$ max. Although not shown in Figure 6, the resting HR was rising from cycle to cycle up to 100 bpm, and above 100 bpm, at the end of 160 minutes for the work at 40% $\dot{V}O_2$ max and 60% $\dot{V}O_2$ max, respectively. Again, the hot-dry conditions were more favorable; HR did not rise more than that expected from the work and the heat stresses, and it leveled off for most of the cycles; during rest (not shown in Figure 6), HR dropped very slowly to below 100 bpm, particularly for the rest in the heat, following the work at $\dot{V}O_2$ max (HD-1).

CARRYING CYCLES

It should be noted that in these observations the HR was pushed to maximal levels at the end of the five minutes of load carrying under heat stress. Under the neutral ambient conditions (control study) the T_{re} peaked at the end of each carrying period to 37.8°C, but the following resting period allowed a return of the T_{re} to a pre-work level of 37.2°C.

The values shown in Figures 7 and 8 are for men and women working under the WH and HD conditions, respectively. The inadequacy of the WH-1 (resting in heat) is seen again in the rise in T_{re} during work and the practically no drop during rest (Figure 7). In contrast, the HD-1 conditions were just acceptable (Figure 8). If one considers an average T_{re} of 38°C as acceptable, then the rise above 38°C during work is compensated for by the drop below 38°C during the rest period. As in the previous tests, resting outside the hot areas (WH-2, HD-2) provided enough cooling and recovery to maintain an acceptable T_{re}.

The end values of HR for the walking and carrying phases are shown in Figure 9. The carrying elicited close to maximal or maximal HR during heat exposure. The effect of the heat is seen in the increase of the HR during the walking phases; it was also observed for the resting phases under WH-1 and HD-1. However, the conditions were crucial only for WH-1 and, to a lesser degree, for HD-1.

Sex differences in T_{re} response were noticed. Between the work and rest cycles, the men fluctuated more than the women

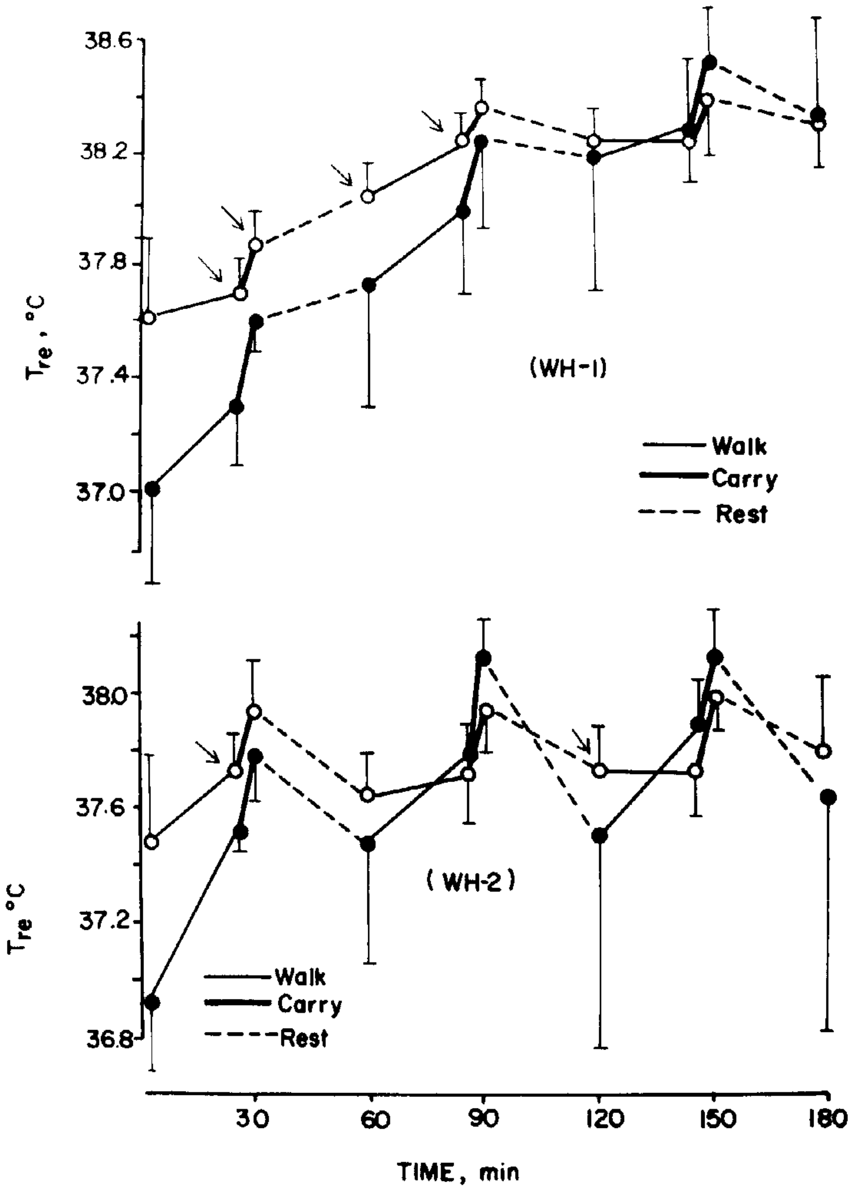

Figure 7. Rectal temperature for the carrying session under the warm-humid ambient conditions; (●) men, (0) women

(Figures 7 and 8). The decrease in T_{re} during rest was markedly more in the men, particularly under the HD-1 conditions, than in the women. During work, the men's T_{re} rose sharply so as to be similar to that of the women.

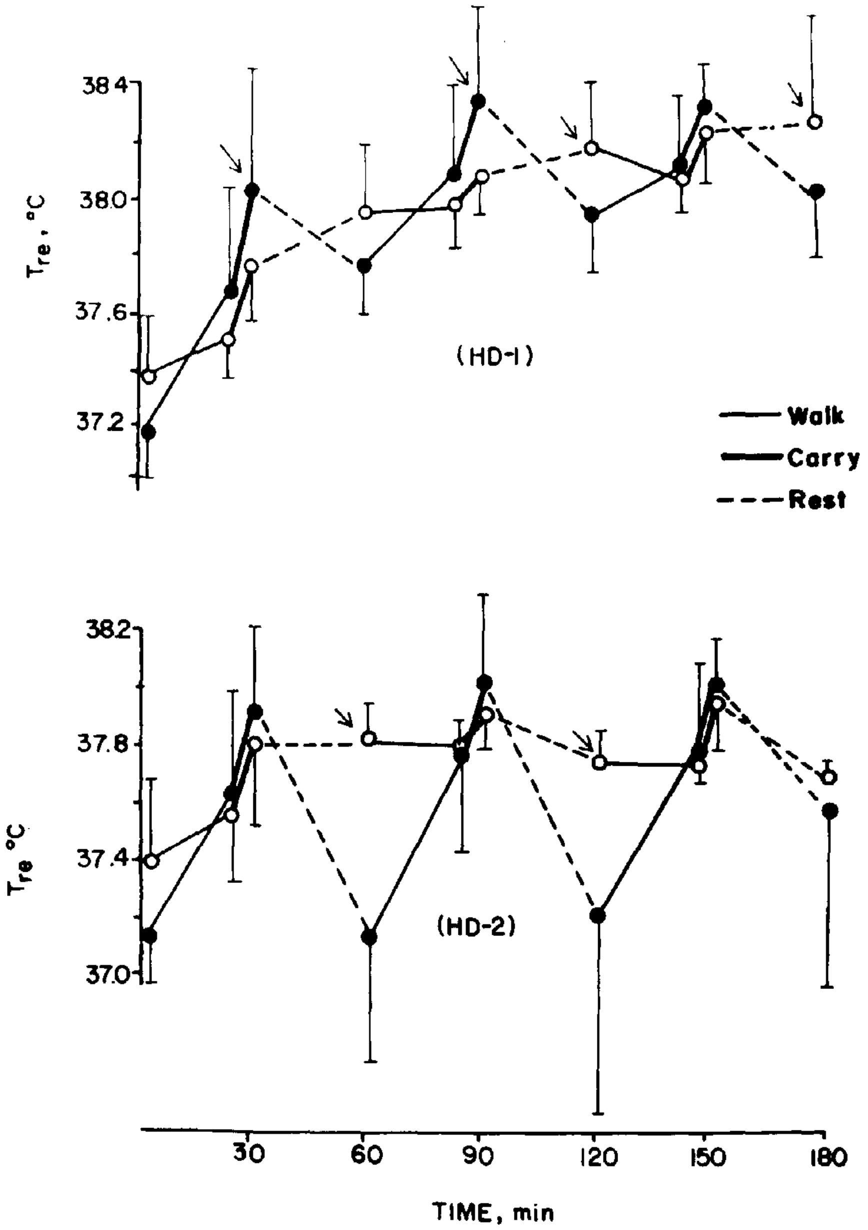

Figure 8. Rectal temperature for the carrying sessions under the hot-dry ambient conditions; (●) men, (0) women

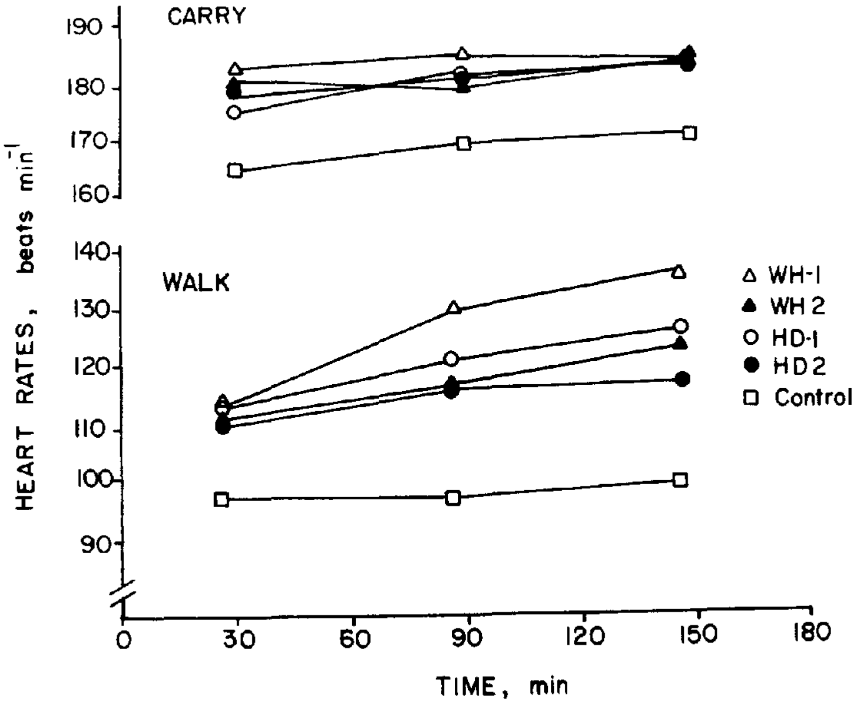

Figure 9. **The end values of heart rates for the walking and carrying periods of the carry session, averaged for the men and the women**

DISCUSSION

In the design of the cyclic work, the rest periods were based more on the work rotation system than on the required physiological recovery. Recovery from rhythmical muscular work can be defined as the time needed for the physiological parameters to return to pre-work levels and to the ability to endure the scheduled work load. A similar recovery to endure given repetitive work, which is common in industry, was studied very little. Not considering hot ambient conditions, there is one study where repetitive elbow flexion and recovery were studied (Yates, 1977). It was found that at 15% maximal voluntary contraction, rhythmical flexion to exhaustion required 20 minutes of recovery to regain 90% of the first endurance of the rhythmical contractions.

If the safe working period should last only to one-third of the time to exhaustion, recovery time will be shorter. Since the amount of research into this problem is limited, the resting period should be based on muscle metabolism (Kamon, 1978). The best use can be made of the most effective metabolic by-product, lactic acid. Lactic acid is considered an important factor in impairing muscle function. The design of rest periods can be based on the following events:

a. The time course of production and elimination of lactic acid in the working muscles, and

b. The rate of elimination of lactic acid from the blood.

The information on lactic acid during exercise is quite well known (Karlsson, 1971). Lactic acid is produced in substantial quantities as work load exceeds 50% $\dot{V}O_2$ max, and its production increases exponentially with the rise in the work load (Saltin and Karlsson, 1971; Petrofsky and Lind, 1978b). Diffusion of lactic acid into the blood and its elimination from the blood occurs at rates that can be measured. The important factor for our purpose is its elimination rate from the blood, which is at about 3 mg % per minute (Stamford, et al., 1978). This rate is constant down to a level of about twice the resting value (20 mg %); thereafter the rate of elimination remains unchanged for a prolonged time (Astrand, et al., 1963).

With this information in hand we derived: a. The expected lactic acid production for the intensity and duration assigned to the work periods; b. The time of elimination of this quantity of lactic acid from the blood, down to a level of twice the resting value; and c. An equation that describes the rest periods: $T = 8.8 \ln (F_{max} - 0.5) + 24.6$, where T is in minutes and F_{max} is a fraction of $\dot{V}O_2$ max. This % $\dot{V}O_2$ max, rest period relationship is described in Figure 3. Such rest periods should be adequate for the work periods derived from the above mentioned equation, for work periods of up to one-third of the time to exhaustion. The curves to design work-rest schedules are shown in Figure 3. Notice that they are adequate for work above 50% $\dot{V}O_2$ max.

Indeed, considering the heat stress induced increments in HR as equivalent strain in terms of $\dot{V}O_2$ max, work at 65% and 85% $\dot{V}O_2$ max require rest of 10 minutes and 15 minutes, respectively. Thus, our design of 20 minutes rest for the walking series was more than adequate if lactic acid production is the only fatigue factor. The results, except for the WH-1 condition, seem to indicate that either extending the work period or reducing the rest period could still be adequate, particularly when rest was under favorable ambient conditions. In other words, our work-rest design based on strain equivalence in terms of $\dot{V}O_2$ max and using Figure 3 is probably practical. Adjustment for appropriate rotation makes the design even better.

HEAT BALANCE AND WBGT

The physiological responses can be explained by the heat balance equation. Put differently, the current knowledge on the expected metabolic heat production and heat exchange between the worker and the environment permits prediction of the physiological responses. This can be demonstrated in the example given below for the walking test, where work level was at 40% and 60% $\dot{V}O_2$ max. This was equivalent to 260 $W \cdot m^{-2}$ (400 $Kcal \cdot hr^{-1}$) and 392 $W \cdot m^{-2}$ (600 $Kcal \cdot hr^{-1}$) of heat production (see $\dot{V}O_2$ max values, Table 1). Resting M was equivalent to 56 $W \cdot m^{-2}$ (100 $Kcal \cdot hr^{-1}$). The mean skin temperatures for both work loads are shown in Table 3. Using these T_{sk} and the appropriate saturated skin vapor pressure, average values for R+C and E_{max} could be calculated. $E_{req} = M+R+C$ and E_{max} are also shown in Table 3.

Table 3

Mean Skin Temperature (°C) and Calculated Ambient Evaporative Capacity (E_{max}), Sum of Metabolic (M), Radiative (R) and Convective (C) Heat Load (E_{req}) and Total Sweating in Watts per m^2 for Two Continuous Work Loads

		WH_1	**WH_2**	**HD_1**	**HD_2**
T_s	work	36.5	35.8	35.1	34.6
	rest	36.4	34.0	35.5	33.5
40% $\dot{V}O_2$ max, $M=260\ W \cdot m^{-2}$					
E_{max}	work	174	150	372	360
	rest	174	125	384	125
	$\bar{x}$	174	137	378	243
E_{req}	work	254	262	379	383
	rest	53	—32	172	—28
	$\bar{x}$	154	115	276	178
Total Sweat		305	233	323	200
60% $\dot{V}O_2$ max, $M=392\ W \cdot min^{-2}$					
E_{max}	work	174	150	372	360
	rest	174	130	384	126
	$\bar{x}$*	174	136	380	202
E_{req}	work	388	394	511	515
	rest	53	—32	172	—28
	$\bar{x}$	165	110	285	153
Total Sweat		553	329	496	343

*Time weighted average.

The heat balance can be viewed in terms of the ratio of E_{req}/E_{max}, which represent the skin wettedness (w), or the Belding and Hatch Heat Stress Index. When the ratio approaches 1, circulatory strain is expected and $w > 1$ indicates heat accumulation. Using the values given in Table 3 for the WH-1 conditions and the walking as 40% and 60% $\dot{V}O_2$ max, the derived mean value of the E_{req}/E_{max} ratio is around 0.92. Resting outside the warm-humid room (WH-2) improved the heat balance to w of about 0.82.

The calculation of heat balance could be misleading unless sweat and evaporation are considered. As expected, the humid conditions and limited evaporation resulted in oversweating. Thus, with the skin fully wet, stepping outside to the air conditioned room (WH-2) allowed evaporative cooling from the sweat cover on the skin. This sweat actually dripped under the WH-1 conditions. Such cooling of sweat cover could explain the T_{re} equilibrium shown in Figure 5, particularly for the WH-2 conditions. This extra cooling is overlooked by the use of the heat balance equation to derive strain.

In fact, the fluctuation in T_{re} seen for the men in the carrying phase (WH-2, HD-2, Figures 7 and 8) could be attributed to the men's excessive wettedness. Table 4 shows that men experienced higher sweat and evaporation rates than women. Thus, it can be concluded that at the onset of the rest period, in particular under the cooler temperature ambient conditions, men had a greater

Table 4

Mean (± Standard Deviation) of Sweating Rates and Evaporation Rates During the Entire Exposures to the Five Ambient Conditions, for the Men and Women who Participated in the Carrying Tests

Ambient Conditions†	**Sweat, $W \cdot m^{-2}$**		**Evaporation, $W \cdot m^{-2}$**	
	Men	**Women**	**Men**	**Women**
HD-1	417.3* ±42.7	296.0 ±22.4	342.5* ±55.0	226.4 ±22.1
HD-2	285.5 ±40.4	209.3 ±17.3	245.3* ±25.1	192.4 ±21.8
WH-1	428.2* ±124.3	257.6 ±26.9	250.0* ±99.7	151.4 ±13.1
WH-2	325.5* ±100.6	182.4 ±27.8	199.7* ±42.6	119.5 ±12.2

†See Table 2 for details.
*Sex difference significant to the 0.05 level.

capacity for cooling than women. The men were probably wetter than the women and may have continued to sweat more as long as the T_{re} did not drop to levels that would inhibit sweating during the rest period. This evaporation cooled the men more than the women. When the work was resumed, the men who worked at levels requiring larger absolute metabolic heat production (since their $\dot{V}O_2$ max was higher) experienced a more rapid rise in T_{re}, ocmpared to the women.

Also, the difference in surface area, and thus in dry heat exchange (R+C), could contribute to the sex difference in the T_{re} fluctuation. On the other hand, the women, whose surface area was smaller than the men's, lost less heat during rest outside the hot room, and, on the other hand, gained less during the work inside the hot room.

The hot-dry ambient conditions were, on the average, more favorable than the warm-humid conditions. However, the difference of resting outside the hot-dry room was not as advantageous as resting outside the warm-humid room. The E_{req}/E_{max} ratio (w) was about 0.74, which definitely explains the well-equilibrated T_{re} and HR seen in Figures 5 and 6.

The design of our experimental ambient conditions was such that in terms of WBGT, the warm-humid (WH) were the same as the hot-dry (HD) conditions (WBGT = 33°C). The values of WBGT for the work and rest ambient conditions and the time weighted average (TWA) of WBGT and of M for each combination of work-rest are given in Table 5.

The WBGT of 33.0°C for WH-1 and HD-1 is above the current threshold suggestion of 27.8°C. In terms of the ratio $E_{req}/E_{max} = w$, the severity of these ambient conditions is indeed in close agreement with the WBGT, but only for the WH-1 conditions. That is, if the ratio is taken from Table 3, WH-1 for the 40% and 60% work levels is about 0.92 (HSI = 92), which, for the average person, is the limit for heat balance. However, for the HD-1 conditions, w = 0.74 (HSI = 74), could be considered acceptable and would not put the average worker at risk, despite the WBGT of 33.0°C. This is borne out in the leveling off of the physiological responses (Figures 5 and 6).

The point to be emphasized in the carrying experiments is the observed sex differences. In absolute terms, the men accumulated more heat than the women. The M of 177 kcal/hr for the women put them in the light work category of the OSHA-suggested threshold values. Therefore, for the WH-2, HD-2 conditions, the TWA, WBGT of 26°C will be considered adequate for women (the threshold is at 29°C). The men, however, will be placed under the category of heavy work where the threshold is 26°C, and thus

Table 5

The Wet Black Globe Temperature (WBGT), the Time Weighted Average (TWA) of WBGT, and of the Metabolism (M) for the Mode of Work and Ambient Conditions Employed

Mode of Work	**WBGT-°C**		**Notation***	**TWA**	
	Work	**Rest**		**WBGT-°C**	**M-Kcal·hr^{-1}**
Work at:					
40% $\dot{V}O_2$ max	33.0	33.0	WH_1, HD_1	33.0	245
60% $\dot{V}O_2$ max					262
Work at:					
40% $\dot{V}O_2$ max	33.0	19.5	WH_2, HD_2	26.0	245
60% $\dot{V}O_2$ max				24.0	262
Work at:					
30% $\dot{V}O_2$ max and carry at 75% $\dot{V}O_2$ max	33.0	33.0	WH_1, HD_1	33.0	177 women 312 men
Work at:					
30% $\dot{V}O_2$ max and carry at 75% $\dot{V}O_2$ max	33.0	19.5	WH_2, HD_2	26.0	177 women 312 men

*See Table 2.

additional work practices would be required. Yet, both sexes were similar in their physiological responses to the work.

While the walking tests were typical laboratory experiments, to verify our hypothesis the carrying test was designed to simulate a practical industrial situation in which a worker is asked to interrupt his regular activities at an acceptable metabolic rate to perform a short, heavy, less acceptable work load. Such a demand will usually be followed by a rest period. The ambient conditions were expected to induce HR increments of 20-25 bpm above the work-specific levels (Kamon and Belding, 1971a and 1971b; Gonzales, et al., 1978). With the rationale of equating such HR with strain induced by higher work load of 20-25% $\dot{V}O_2$ max, the design considered the work accordingly. Except for the warm-humid conditions in which resting was inside, the expected HR was indeed obtained. Since the work load was relative, the HR for the men and the women was similar. They were expected to be 100 and 170 bpm for walking at 30% $\dot{V}O_2$ max, and carrying at 75% $\dot{V}O_2$ max. Indeed, the control tests under the neutral ambient conditions yielded such values. Likewise, HR for 40% and 60% $\dot{V}O_2$ max was close to the expected 120 and 140 bpm, respectively. The heat-induced increments were also as expected, as long as the ambient capacity for evaporation (E_{max}) was adequate, even with w = 0.6 (HSI 60).

The T_{re} responses were also as expected. Equilibrium was expected at 37.9 and 38.4 for 40% and 60% $\dot{V}O_2$ max, respectively (Kamon, 1975; Saltin and Hermansen, 1966). The five minutes of carrying provided the expected transient T_{re}. Because of the intermittent nature of the work, T_{re} did not rise to the work-specific level under neutral ambient conditions. Under heat stress, particularly when rest was not in the cooler room, T_{re} rose to above 38°C. This was not critical for the carrying, since during the rest period the T_{re} dropped below 38°C (except for WH-1 conditions), thus averaging a T_{re} of below 38°C. However, conditions similar to those observed in the walking tests when T_{re} leveled off at above 38°C should be interrupted, particularly if exertion that will further raise T_{re} is anticipated. In our tests, even if T_{re} equilibrated above 38°C under the WH-1 conditions, which could be acceptable on grounds of a leveling-off rather than a rising T_{re}, it is clear that the strain was excessive, because T_{re} was temporarily in equilibrium at the expense of the rising circulatory strain, as indicated by the HR.

In summary, designing the work-rest schedule for work under hot environments on the basis of the cumulative circulatory strain of the stresses of work and heat is possible. The working period can be based on the HR, using heat-induced increments as strain, which is equated with the HR increase due to change in work in terms of % $\dot{V}O_2$ max. The resting period seems to fit a relationship derived from the expected lactic acid production and the work load in terms of % $\dot{V}O_2$ max. Although we have used longer rest periods than that predicted from lactic acid production, the physiological responses seem to indicate that we could do with shorter periods when rest is in a cooled air conditioned room.

REFERENCES

1. American Heart Association, Committee on Exercise, 1972. *Exercise Testing and Training of Apparently Healthy Individuals: A Handbook for Physicians.* (New York: American Heart Association).

2. Astrand, I. Aerobic capacity in men and women with special reference to age. *Acta Physiologica Scandinavica* 49, Suppl 169, 1960.
3. Astrand, I., P. O. Astrand, E. H. Christensen and R. Hedman. Intermittent muscular work. *Acta Physiologica Scandinavica,* 48:448-453, 1960.
4. Astrand, P. O., I. Hallbach, R. Hedman and B. Saltin. Blood lactates after prolonged severe exercise. *J. Appl. Physiol.* 18:619-622, 1963.
5. Astrand, P. O. and K. Rodahl. *A Textbook of Work Physiology.* (London: McGraw-Hill), 1970.
6. Bonjer, F. H. Temporal factor and physiological load. In: *Measurement of Man at Work, an Appraisal of Physiological and Psychological Criteria in Man-Machine System* (W. T. Singleton, J. G. Fox and D. W. Whitfield, edts.) (London: Taylor and Francis), pp. 41-44, 1971.
7. Gonzales, R. R., L. G. Berglund and A. P. Gagge. Indices of thermoregulatory strain for moderate exercise in the heat. *J. Appl. Phyiol. Respirat. Environ. Exercise Physiol.* 44:889-899, 1978.
8. Hertig, B. A. and H. S. Belding. Evaluation and control of heat hazards. In: *Temperature, Its Measurement and Control in Science and Industry.* (J. D. Hardy, ed.) (New York: Reinhold) Vol. 3, part 3, 347-355, 1963.
9. Kamon, E. and H. S. Belding. The physiological cost of carrying loads in temperate and hot environments. *Human Factors* 13, 153-161, 1971a.
10. Kamon, E. and H. S. Belding. Heart rate and rectal temperature relationships during work in hot humid environments. *J. Appl. Physiol.* 31:472-477, 1971b.
11. Kamon, E. Ergonomics of heat and cold. *Texas Reports on Biology and Medicine* 33:145-182, 1975.
12. Kamon, E. Environmental Characteristics. In: *Safety in Manual Materials Handling.* (C. G. Drury, ed.) U.S.D.H.E.W. Public Health Service National Institute of Occupational Safety and Health. Cincinnati, Ohio 155-169, 1978.
13. Kamon, E., B. Avellini and J. T. Krajewski. Physiological and biophysical limits to work in the heat for clothed men and women. *J. Appl. Physiol. Respirat. Environ. Exercise Physiol.* 44:918-925, 1978.
14. Karlsson, J. Muscle ATP, CP and lactate in submaximal and maximal exercise. In: *Muscle Metabolism During Exercise.* (B. Pernow and B. Saltin, eds) (New York: Plenum Press) pp. 383-393, 1971.
15. Kerslake, D. McK. *The Stress of Hot Environments.* (Cambridge: Cambridge University Press), 1972.
16. Petrofsky, J. S. and A. R. Lind. Comparison of metabolic and ventilatory responses of men to various lifting tasks and bicycle ergometry. *J. Appl. Physiol.,* 45:60-63, 1978 a.
17. Petrofsky, J. S. and A. R. Lind. Metabolic, cardiovascular and respiratory factors in the development of fatigue in lifting tasks. *J. Appl. Physiol.* 45:64-68, 1978 b.
18. Saltin, B. and L. Hermansen. Esophageal, rectal and muscle temperature during exercise. *J. Appl. Physiol.* 21:1757-1762, 1966.
19. Saltin, B. and J. Karlsson. Muscle glycogen utilization during work of different intensities. In: *Muscle Metabolism During Exercise.* (B. Pernow and B. Saltin, eds) (New York: Plenum Press), pp. 289-299, 1971.

20. Simonson, E. *Physiology of Work Capacity and Fatigue.* (Springfield, Illinois: Charles Thomas), pp. 440, 1971.
21. Stamford, B. A., R. J. Moffatt, A. Weltman, C. Maldonado and M. Curtis. Blood lactate disappearance after supramaximal one-legged exercise. *J. Appl. Physiol.* 45:244-248, 1978.
22. Yates, J. W. Recovery Pattern of Submaximal Isotonic Muscular Endurance. *M.Sc. Thesis.* University of Kentucky, Lexington, Kentucky, 1977.

QUESTIONS, ANSWERS, AND COMMENTARY

DR. DUKES-DOBOS: I noticed that you had some rectal temperatures of 39°C and above. In the carrying experiment, the standard deviation is less.

DR. KAMON: Yes. Only under those circumstances where it is going up all the time; as in hot humid conditions. But for those cases where it was going up and down, it never went above 38.5°C.

DR. DUKES-DOBOS: Do you accept rectal temperature as high as 39°C and above?

DR. KAMON: No. I emphasized that I can accept prolonged 38°C. If there is a temporary rise above it, and then a drop below it, this seems reasonable. I would not accept it going above 38°C where there is a rapid rise. I think Dr. Minard's suggestion of temporary rise to 39°C would probably be acceptable under these conditions, too.

DR. GONZALEZ: I have two points. First, we confirmed the relationship in terms of the heart rate data and in terms of the esophageal temperature, which is strongly related to heart rate. We find that 37°C + 0.5 times percent $\dot{V}O_2$ max is an ideal statement for esophageal temperature level when exercising, except that it is perturbated by age, so that normally you would have a higher slope.

Second, we have done some studies that lead us to prefer to have the ratio of the sensible heat transfer to the insensible heat transfer, which we call "SI," related to the wettedness. When you relate that to heart rate, you find that there's a discrete zone, regardless of sex, that is also very similar to Lind's criteria. That is, the break off at about 0.5 wettedness.

DR. KAMON: But your sensible and insensible heat transfer will already be nearly maximum.

DR. GONZALEZ: No, the problem is that because females have a higher skin temperature than males, and because they don't sweat as much or they don't evaporate as much sweat, they have more R + C. They have a greater problem with dry heat stress than males do, at least from our data. All this becomes apparent at 25% $\dot{V}O_2$ max, which is unpublished data. Now at 50% $\dot{V}O_2$ max, the males have a higher skin temperature than the females. So what I'm saying is that your data are very good, but they may be complicated by sex. And the sex is complicated by the R+C that females are required to have because of their higher skin temperature and their limited skin blood flow. You have determined that females are different from males. But in terms of 25% to 30% $\dot{V}O_2$ max, we have found that females are no different.

DR. KAMON: So you designed different rests?

DR. GONZALEZ: I'm just saying that the rational effective temperature, which is preferable to the WBGT, seems to be equivalent in both males and females.

PREDICTION OF HEAT STRAIN, REVISITED 1979-1980

R. F. GOLDMAN, Ph.D.

ABSTRACT

The original 1972 Criteria for a Recommended Standard "Occupational Exposure to Hot Environments" is reviewed. The use of two air motion levels for WBGT is questioned and WGT is suggested as a simpler index for routine work site assessment. The use of body core temperature as a basis for recommendation is questioned (unresponsive and unmeasurable), and heart rate based criteria are suggested. Differences in WBGT criteria based on gender, and emphasis placed on age, are questioned; it is suggested that individual fitness, genetically based work capacity, and state of acclimatization are far more relevant, although age and sex trends exist. Acclimatization and hydration recommendations are supported and amplified, but the need for a 4-day reacclimatization after a 9-day break may require further investigation. The emphasis on salt supplementation is seriously challenged. Finally, guidance for work in heat involving the wearing of protective clothing is suggested.

It has been almost ten years since the Occupational Safety and Health Act of 1970 emphasized the need for standards to protect the health of workers exposed to heat. A criteria for a "Recommended Standard Occupational Exposure to Hot Environments" was published by HEW in 1972. The recommendations made at that time included the following:

(1) The WBGT index was specified as the environmental metric of choice, with a value above 79°F defined as a hot environment.

(2) For sedentary jobs where continuous unimpaired mental performance was required, no employee should be exposed to conditions of 30.5°C for more than 4 hours, 31°C for more than 3 hours, 32°C for more than 2 hours, or 33°C for more than 1 hour, with exponentially decrementing exposure times as WBGT increased to 43°C, at which, in theory, some 15 minutes of exposure was permissible.

(3) No employee was to be permitted to work without observation at high heat stress levels; however, "high heat stress levels" were not specifically defined.

(4) Different criteria were established for men (time weighted average WBGT 79°F) and women (76°F) as the threshold for concern.

(5) The upper limit of employee body core temperature was not to exceed 100.4°F.

(6) Unacclimatized employees were to be acclimatized over a period of 6 days, beginning with 50% of the anticipated total work load/time exposure on the first day, followed by 10% daily increments to reach 100% exposure on the sixth day.

(7) A break of nine or more consecutive calendar days of leave required a 4-day reacclimatization, beginning again with 50% of anticipated exposure on the first day, with 20% increments on subsequent days to reach 100% on the fourth day.

(8) Absence for 4 consecutive days of illness required a similar 4-day reacclimatization period, as well as "medical permission" to return to the job.

(9) A minimum of one break every hour was prescribed "for employees to get water and replacement salt." A minimum of 8 quarts of cool, potable 0.1% salted water (or salt tablets) per person per shift were to be provided, with the water supply never further than 200 feet from the work station.

Work practices to distribute load over the entire work day, scheduling hottest jobs for the coolest part of the shift, appropriate work/rest regimens to reduce peaks of strain and improve recovery, appropriate protective clothing, equipment, and the like were also recommended. Warning signs for areas where WBGT exceeded 86°F, and training programs for the work force, were required. Special care was suggested for employees 45 years of age or older. A medical evaluation was specified for personnel who were to be assigned to hot jobs for the first time, with periodic re-examinations every two years for employees under age 45, and every year for employees 45 years or older. Finally, record keeping requirements were imposed, with monitoring requirements specified. This presentation will review work during the past 10 years that provides information relevant to some of the proposals incorporated in the original 1972 document, in some cases reinforcing the original recommendations, and suggesting alternatives in others.

THE ENVIRONMENTAL INDEX — WBGT OR WGT

The choice of the WBGT index has never seriously been questioned, based on its demonstrated utility in reducing heat casualties during military training. However, a few comments seem appropriate about the use of this index. First, the 1974 OSHA recommendation specified different WBGT levels as a function of air motion. Air motion is difficult, at best, to measure in an industrial setting, and there is no theoretical reason why, if WBGT is appropriately measured, there should be any need for a separate assessment of wind speed. The use of the non-psychrometric wet-bulb lies at the very heart of the applicability of WBGT index to the worker since, the argument is, no one is going to swing the worker by the heels with 100% sweat-wetted skin to insure that he receives the same maximum evaporative potential as the conventional "psychrometric," or sling, wet-bulb thermometer.

A second problem with the WBGT is that a number of instruments have appeared on the market for its measurement. Some use the psychrometric wet-bulb. This is inappropriate, but some claim that it is consistent with OSHA requirements. It would appear that OSHA certification of WBGT instrumentation will be required.

Third, the classic WBGT instrumentation is expensive and requires an expensive and hard to find 15.4 cm (6″) black globe. Much of what is commercially available requires calibration. Glass thermometer columns separate or break, requiring replacement. A further problem with the WBGT is that the wet-bulb wick must be kept relatively dust free and clean, since erroneous results will be derived if the wick becomes dirty. Finally, the need to measure 3 different temperatures, to perform a mathematical combination, to rely on electronics, which do the integration, and to maintain calibration, pose additional problems for the worker monitoring the work space stress. Admittedly, for the expert who assesses the factors in order to decide how to reduce heat stress, the ability to differentiate between low air motion, high ambient humidity, or radiant heat load, provided by measurement of the independent parameters, is extremely valuable. However, for the routine monitoring of heat stress at the work place, the need to use 3 separate instruments or 3 separate sensors, and combine them into a single index, is time consuming.

We have recently investigated in detail the Botsford "botsball," a small, wetted, black globe with a metallic stem thermometer indicating "wet globe temperature" (WGT), which we feel offers distinct advantages over the WBGT index. Although allegations have been made that it has not been assessed in an industrial setting or in an outdoor setting, our review of the literature suggests that it has been adequately evaluated indoors. In our study it was extensively evaluated outdoors.

The WGT, like the WBGT appears, perhaps, to have gained wide acceptance in heat stress industries. The WGT will be difficult to keep wet in a hot-dry, high radiant heat load environment.

It provides a different reading than WBGT. It seems clear that the WBGT can be derived by linear translation, if necessary, from the simple equation WBGT = 1.044 WGT − 0.19, with sufficient precision for all practical stress monitoring. Alternatively, we have suggested that for adoption of WGT by the Army, the dial of the WGT thermometer simply be color coded green, yellow, pink, and red, to indicate the varying levels of heat stress concern, using the criteria established for the Armed Forces in TB MED 175. We are concerned that the black cotton cover is not changeable, that it may get dirty, and that it becomes bleached by sunlight.

We have recently field tested this instrument with the 82nd Airborne Division for assessment of its use by individuals unskilled in the measurement of heat stress in the field. The results were favorable. My personal conviction is that the ability to simply glance at a dial and assess whether the indicator is in the green, yellow, pink, or red zone, using an unbreakable and inexpensive instrument, offers so much. This does not deny the importance of assessing the individual parameters when a heat stress situation has been identified in an industrial setting, so that the appropriate corrective measures may be invoked.

THE ALLOWABLE EXPOSURE

Since the curve in the 1972 recommended standard representing the upper limits of exposure for unimpaired mental performance is based on experiments where subjects were not uniformly acclimatized, these limits are hard to justify. Acclimatization, at least from the recommended standards developed by the American Conference of Government Industrial Hygienists, appears to be equivalent to a 2°C offset in WBGT tolerance criteria. This recommendation, too, is not clearly derived from the literature. The more usual recommendation within the military, both in this country and abroad, is that if the "Effective or Corrected Effective Temperature" is 30°C (under hot, wet conditions with low air motion, "Corrected Effective Temperature" roughly corresponds to WBGT at low air motions), then one has a reasonable presumption that there will be a decrement in performance of cognitive tasks, with a hierarchy of effect ranging from such relatively insensitive operations as addition, manual dexterity, and the like, to more easily decremented tasks, such as vigilence and decision making. This conclusion is derived from review of a large number of psychological studies and draws heavily on the earlier review by Wing. Being unaware of any real basis for the specification of time-temperature interaction guidance on continuous unimpaired mental performance, one wonders whether such a simple recommendation as: "in sedentary jobs with unimpaired mental performance, there will be a decrement in performance when employees are exposed to conditions such as WBGT = 30°C. Exposures should not be permitted in conditions above those" is acceptable. Short-term completion of tasks under an emergency situation would be a possible exception. In addition, a WBGT 30°C is specifically defined as a high heat stress level for a civilian work force.

MALE-FEMALE DIFFERENCES

The differences in WBGT for men and women workers were based on a limited number of studies, with subjects of inadequately defined fitness and acclimatization levels. There is no question that an individual with a reduced maximum oxygen uptake will require a greater percentage of his or her available blood flow for work in the heat to serve the working muscles and provide the oxygen needs of the body. Therefore, there will be less cardiac output available to transfer heat to the skin for elimination by sweat evaporation. It is also true that individuals who are unacclimatized will have a delayed sweating response, and will sweat less profusely at a given work/heat stress combination than an acclimatized individual. Indeed, conditioning of the sweat gland is one of the major incidents in heat acclimatization. Finally, there is no question that lighter subjects doing essentially the same task as heavier subjects will produce less metabolic heat and therefore will have a reduced need for evaporative cooling in the same environment.

It appears that it is this combination of factors, i.e., that females are lighter, are less acclimatized, and less fit, that has been interpreted to indicate that females do not tolerate heat stress as well as males. The female is usually less heat acclimatized. I am not arguing that unacclimatized females are usually fit, because they have, at best, a genetically based, lower maximum oxygen uptake than a male of equivalent fitness. They tend to be in a lower physical fitness classification because of our culture rather than any innate need for the average female to be in fair condition while the average male will be in average condition. I am not arguing that the unacclimatized, unfit female is not less tolerant of heat stress than the average, more fit, more acclimatized male. Since physical fitness alone induces roughly the equivalent of the first three days (or over 50%) of the total benefit induced by 6 or 7 days of acclimatization to work in heat, fitness is very important. Neither would I argue that in conditions for heavy work in the heat, the female worker, with her genetically based, lower maximum oxygen uptake, will not be at a disadvantage compared to a male of the same fitness category. However, most industrial work in our society does not demand a high level of sustained hard work.

We have completed a series of studies comparing male and female workers in the heat. A major difference between our studies and those reported in the earlier literature is that the females we selected were of good to above average physical condition, and were carefully heat acclimatized before we compared their responses to those of heat acclimatized males. The results of our studies suggest strongly that under hot-wet conditions, acclimatized females, performing moderately hard work (walking at 3 miles per hour on a level treadmill, which is a level of sustained work unlikely to be exceeded in industry), are not more heat intolerant, and may be slightly more heat tolerant, than male workers. Under hot-dry conditions, the females appear to have a statistically significant, but practically meaningless, disadvantage.

Thus, I would strongly argue that gender is an inappropriate metric for discrimination for heat stress criteria and one which, in our modern American society, is not apt to be accepted by the work force without more justification. A discrimination in criteria for heat stress exposure does exist based on physical fitness and acclimatization to heat. It is recommended that the criterion differentiating males from females be eliminated in favor of a criterion based on fitness and state of heat acclimatization.

THE PHYSIOLOGIC LIMIT — BODY TEMPERATURE OR HEART RATE

The recommendation that the upper limit of employee body core temperature not exceed 100.4°F (38°C) is a troubling one on two counts. First, it is unlikely that employee core body temperature will be measured to insure that it is less than 100.4°F. Second, and even more troubling, is that work physiologists have recognized, since the classic 1938 studies of Nielson, that body core temperature is primarily a function of heat production, rather than environment. As expressed in our prediction model, rectal temperature will increase from 37.1°C for an individual at rest (i.e., heat production at 105 watts) by 0.4°C per 100 watts of incremental heat production. Thus, the specification that the upper limit of employee body core temperature should not exceed 38° C (100.4°F) can also be looked at simply as another way of stating that the heat production of the worker should not be much above 300 watts. While it is true that industrial tasks rarely invoke work levels of 300 watts or more (even a very fit worker would be unable to sustain heat production demands of more than 500 watts for more than 2 or 3 hours), it seems that this specification adds little to the recommended standard. It might be better to revert to the recommendation of the old German school, that heart rate during work should not exceed an increase of 30 beats per minute, or to adopt the recommendations derived from a number of sources that heart rate should not exceed 180 beats per minute for any exposure, 160 beats per minute for 2 hours, 140 beats per minute for 4 hours, or 120 beats per minute for an 8-hour work day.

EFFECTS OF AGE

Heart rate is readily measured. If, instead of using the absolute values of heart rate given above, one references the criterion to the finding that the maximum heart rate of an individual is probably not more than 220 beats per minute minus age in years, it is possible to provide an age adjustment for a recommended upper limit of work/heat demand that could be readily assessed in the field simply by measurement of heart rate by radial pulse. A further advantage would be that workers of low physical fitness, and hence greater susceptibility to heat illness, would automatically be identified by their heart rate during work in the heat. It might be much more difficult to identify them by their core temperature.

EFFECTS OF PROTECTIVE CLOTHING

Additional difficulties with a body core criterion exist for unique work situations where workers are encapsulated in protective clothing. The number of cases where the toxic nature of the environment is severe enough to require encapsulating protective clothing appears to be rising with the increase in nuclear industries and the increased recognition of the toxicity of some of our industrial chemicals. Individuals wearing protective clothing for work in the heat require special precautions. In general, our recommendation is that, as a rule of thumb, the WBGT criterion for individuals so encapsulated be reduced by 10°F for assessing the risk of heat exposure.

If the problem is not the ambient environment, but rather the heat production of the worker, then the ambient environment is much less important than the heat production of the worker in the encapsulated clothing. In this case, the body is unable to eliminate heat by evaporation of sweat on the skin, and therefore skin temperature rises to converge towards rectal temperature. We have reported in our findings that collapse can be imminent when core temperature is at relatively modest levels (38.2°C) as skin temperature converges on core temperature. Although heart rate is not a totally adequte trigger for alerting to this stress, it is certainly preferable. If the conservative criteria recommended above for heart rate were adopted, then heat exhaustion collapse could be more readily avoided in workers wearing essentially impermeable clothing.

ACCLIMATIZATION EFFECTS

The acclimatization recommendation is clearly supported by the extensive studies of heat acclimatization that have been carried out over the last 10 years. Our model predicting the effects of acclimatization, which has been validated in some 15 or 20 different studies over the past years, clearly suggests that full acclimatization can be achieved with 6 to 7 days of work-in-heat exposure. Most of the benefits accrue during the first 3 or 4 days. The last 2 days simply represent convergence towards the ultimate, 100% acclimatized condition where no further improvement is to be anticipated. Dasler's studies suggest that it takes 21 days for this "absolutely fully acclimatized" level to be achieved, but the acclimatization achieved in 6 to 7 days (95%?) is adequate for all practical purposes. The additional 0.1°C change in rectal temperature between the 7th and 21st day hardly seems worth a recommendation that acclimatization be continued beyond 5 or 6 days.

Two points need amplification: first, our studies clearly indicate that a physically fit individual (of above average condition) starts with a cardiovascular conditioning that represents roughly the equivalent of the first 3 days of heat acclimatization. No special criterion recommendation need be made based on physical fitness from this point of view. The second finding is that, even among military personnel, roughly two to three percent are unable to be acclimatized to severe work in heat stress. This may require a recommendation. The presumed reason for this failure to achieve full heat acclimatization is low genetic fitness (i.e., low maximum oxygen uptake), which limits their ability to work for the 100 minute per day sustained period in the heat necessary to fully induce heat acclimatization. It is very likely that a larger percentage of the civilian population will experience difficulty in acclimatization to work in the heat. Thus, some criteria for identifying those individuals with low maximum oxygen uptake should be established as a screen to carefully identify individuals who presumably lack the potential for the development of full acclimatization for severe work in heat stress jobs, even with careful acclimatization exposure. Such individuals should function quite well under conditions of low physical work demands and modest heat stress. However, in heavy jobs with severe heat they represent an undue risk, which apparently will not be adequately compensated for by the heat acclimatization.

LOSS AND REINDUCTION OF HEAT ACCLIMATIZATION

The recommendation that a break of nine or more consecutive calendar days of leave requires a four-day reacclimatization is not consonant with our findings. Our findings suggest that once heat acclimatization is well established in a fit young population, the rate of decay is much slower and reinduction much faster than implied by the original draft requirement. While this may not be equally relevant for the older and less fit work force, I believe this needs additional research before any firm statement is made that will require four days of reduced productivity after a consecutive nine-day leave period.

A similar concern is the basis for the four-day reacclimatization period required after an absence of four consecutive days of illness, particularly with "sick leave" in our civilian work force as liberally interpreted as it is. I would argue that workers returning from "illness" will be able to pace themselves sufficiently and not require a reacclimatization, or that one or two days should suffice. Of course, much depends on the nature of the illness. Perhaps the recommendation should not be for any mandated reacclimatization schedule, but for a mandatory review by the plant or patient's personal physician with a recommendation required in writing.

WATER REQUIREMENTS

The importance of adequate hydration has received increased emphasis over the last 10 years. Our model for the effects of dehydration supports Ladell's assertion that the body has one to two liters of extra fluid that can be lost without any real decrement in performance. A 1-to-2% of body weight dehydration may produce little or no decrement. However, every additional percent dehydration appears to accelerate the rate of rise in body temperature by roughly 6%. For a 70kg man, a body water weight loss of 700 grams induced by heat during the work shift represents a 1% dehydration. Within the feasible limit for functional performance with dehydration, which is about a 5% dehydration, there appears to be no alteration in the ultimate core temperature the body achieves for work in the heat, even though the rate of rise is markedly accelerated by dehydration. Thus, since the body has a sustainable sweat capacity of about 1 liter per hour, the recommendation for a minimum of 8 quarts of cool potable water should receive as much emphasis as possible. Military studies of work in the heat clearly indicate that thirst is an inadequate stimulus to avoid dehydration. It was only when the participants in military maneuvers were weighed during their rest breaks and required to drink back the water lost in the sweat that their performance in desert operations was minimally degraded compared with performance when the troops were given water ad lib. Encouraging water intake by scheduled water (ice tea, etc.) breaks would help alleviate the effects of severe heat stress.

SALT REQUIREMENTS

The recommendation that the potable water be 0.1% salted, or that salt tablets be used, conflicts with more recent research findings. The recommendation for salt is an old one. It arose from the occurrence of heat cramps in some workers during the first few days of heavy physical work in the heat, probably when they were not eating adequately because appetite was reduced. The average

American diet contains an excess of salt. The body's mechanisms for acclimatization include an aldosterone turn-on, which results in the production of a more dilute sweat, and therefore, conservation of body salt. Individuals taking supplemental salt lack this conservation mechanism because there is no need for its induction. In addition, studies by Dasler strongly suggest that development of other facets of heat acclimatization are delayed by supplementary salt ingestion. Since the occurrence of heat cramps is readily and almost instantaneously reversed by administration of salted water at that time, the current military guides do not recommend salt tablets or salted water. It is strongly recommended that this element of the original draft standard be reconsidered.

EFFECTS OF AGE

As indicated above, there is support for the argument that older employees may be more at risk than younger ones, based on the classic, physiological evidence that maximum oxygen uptake and maximum heart rate fall with age. However, using age as a criterion in modern America is minimally socially acceptable. It seems preferable to treat all employees equally and screen for physical fitness and work capability. Recommendations as to placements in hot jobs and reduction of heat stress exposure should be based on the individual's physiological responses, rather than on arbitrary discrimination based on age and sex.

SHUTDOWN VERSUS WORK PRACTICES

In the current political climate of jobs, economics, management, and labor problems, it appears socially unacceptable to mandate shutdowns of industries, or work areas, based on arbitrary assignments of a WBGT index. The work practices recommendations preferred by the American Conference of Government Industrial Hygienists (where work-to-rest ratios are altered from 100% work to 75% work/25% rest, to 50% work/rest and, ultimately, to 25% work/75% rest) would accomplish two things: it would allow the worker to remain on the job and the industry to maintain some productivity for those few days when conditions become excessive. It would also convince industry of the economic advantages of conditioning the environment, based on experience over the work year, rather than impose arbitrary, mandated standards that will cost industry production and worker pay.

SUMMARY

In summary, research on the problems of work in the heat, carried out over the last 10 years, both provides support for some elements of the original draft proposal and questions other elements. It is recommended that the current revision of a Recommended Standard "Occupational Exposure to Hot Environments" consider the points raised above in deriving a new standard for the 1980's. Perhaps it should also consider the advantages of a less mandatory, more rational standard, which does not shut down industry and cost jobs but leads to a recognition, by both management and labor, of the benefit of altering the heat stress in the work space.

QUESTIONS, ANSWERS, AND COMMENTARY

MR. BRUSTEIN: You say that you do not think the application of those permissible exposure limits and shutdown of work would be acceptable, but that the work/rest regimen would presumably be adequately protective. Does that mean you think it would be realistic to require the work/rest regimen, but without a cutoff at the top end?

DR. GOLDMAN: Even if the work/rest regimen has to go to five minutes of exposure; there are conditions that we have people go into that are absolutely intolerable and unsurvivable for more than moments. I don't think that we need an absolute shutdown of everything.

DR. BANKS: Protective clothing is available; not only insulating and reflective clothing, but such items as vortex tubes for positive cooling or the cooling vests cooled with either dry ice or cool circulating water. With these items, a high priority job that requires a short exposure time can be done in very high temperature. The point is that once the worker comes out he must take off the insulated clothing and cool down.

DR. KAMON: To come back to this work/rest issue, consider how the "rest" is designed and how complicated this is for industry when you consider the percentage of maximum. How do you suggest we do that?

DR. GOLDMAN: By heart rate and fitness.

DR. KAMON: Right. So that means you are looking for the fitness of each individual by sex and age.

DR. GOLDMAN: I think Dr. Shvartz's paper covered some of that.

MR. FULLER: Among other things you mentioned, I strongly endorse the use of the WGT, both for OSHA and for the employer, if there is going to be an action level. It is an excellent screening device. With one measurement, you can screen out all of those work environment situations that need further study, where you use the psychrometric wet-bulb, air velocity, and so forth.

DR. GOLDMAN: There are problems with it, however. It is difficult to keep the globe wet in high heat stress. If you leave it out in the sun, as we did for three months, it bleaches, and you want it to be black. There is no calibration once you have a thermometer, there are no glass stems to break, and there is no six-inch globe to obtain. If the wick gets dirty, I do not think it makes any difference. We have not tried getting it greasy, which might change things. The professional needs WBGT, an on-site monitor, or the equivalent measurement.

DR. BANKS: It has another advantage, too. It can be used with a low-priced recording instrument, the kind that you wind up, and it requires no electricity. Eight to 24-hour recordings can be made in the field with such low-cost, rugged equipment. If you have a wide area to screen, just scatter the instruments, and the next day you get the readings to see what to spend more time on. On the other hand, if you are using a NIOSH or Reuter-Stokes instrument, you need a competent technician to read the instruments and record the measurements and the calibration.

DR. DUKES-DOBOS: There is an instrument now available made by RAECO for recording 24 hours WBGT, so that problem alone does not prevent the use of WBGT index. There are other considerations for using the wet bulb globe temperature.

DR. BANKS: One of our problems is cost, which affects a lot of people. It is only after October first that we start on our new budget and can afford to buy something like a Reuter-Stokes, or one of the electronic units, which cost about one thousand dollars apiece. It is a difficult item to suddenly squeeze in. It is a lot easier to scrape up some money for thermometers, especially for small companies or for unions to have equipment that the workers can use to check their own exposure. We see more union industrial hygienists or union safety committeemen taking measurements inside the plant to see how good a job the company is doing. It is highly advantageous to keep the equipment small, rugged, and simple.

DR. GOLDMAN: We produced a technical report on the comparisons that we did outdoors that brought out the effects, because we had all the conventional instrumentation computerized. It included the effects of wind and solar radiation.

DR. SHVARTZ: I forgot to mention a point concerning heart rate levels during work. We have a lot of data showing that if the heart rate while exercising in heat is above 130 beats per minute, and if you remain in a standing rest position, you will faint. You may faint with a relatively low body core temperature. I think we should consider heart rate below 130 beats per minute as a safety factor against fainting, which, in some conditions, could be a serious matter. Most people recover from it, but in certain conditions, such as deep mines, it could be difficult. The problem involves work, heat, and clothing.

DR. BANKS: We found a number of hot, confined-space situations, such as cleaning of kilns, cleaning of furnaces, and entry into certain manholes and vaults. The WBGT may be very high inside a confined space that is difficult to get someone out of. Normally, we think of heat stress as being an open situation, but it often occurs in confined spaces.

DR. HENSCHEL: Dr. Goldman, do you have the physiological parameter measurements with the WGT as well as with the WBGT?

DR. GOLDMAN: They are still being worked up. We ran hot-wet and hot-dry conditions with and without radiant heat, with and without clothing, on male and female subjects.

PERSONAL HEAT STRESS MONITORING

Uwe Reischl, Ph.D.

ABSTRACT

A prototype radio-telemetry based monitoring system capable of measuring heat stress and physiological responses of persons working in occupationally stressful environments is described. Application of this monitoring system to fire fighters and steel workers is illustrated. Examples of data obtained using the personal heat stress monitoring system are presented.

INTRODUCTION

Accurate assessment of occupational exposure to heat stress requires simultaneous information about air temperature, air velocity, humidity, and heat radiation. To determine the impact of heat stress on a worker requires information about body temperature, heart rate and sweat production. To determine the relationship between heat stress and heat strain, one must take into account such factors as a person's fitness, level of acclimatization, water consumption, work performed, and use of protective clothing.

Development of a viable heat stress standard requires not only consideration of data describing the relationships between the thermal environment, clothing, and physiological responses of persons under controlled laboratory conditions, but it also requires a clear understanding of the behavioral options used by workers in managing their heat stress exposure problems in the field.

To evaluate heat stress in actual work settings, instrumentation is needed that is capable of monitoring thermal parameters as well as key physiological responses. Along with fast responding environmental and physiological sensors, continuous real-time data acquisition is desirable. Modern electronic technology now makes personal heat stress monitoring feasible. Field information can be collected that will clarify the relationships between heat stress and heat strain in actual work settings. Personal monitoring will contribute significantly to the development of a viable heat stress standard.

HEAT STRESS MONITOR

A prototype 7-channel radiotelemetry based personal monitoring system has been developed that is capable of measuring heat stress and physiological responses of persons working in occupationally stressful environments (1,2). The parameters measured for assessing heat stress include ambient air temperature and humidity and heat radiation, while physiological responses monitored include body skin temperature, rectal temperature, and heart rate. The monitoring system consists of a backpack unit and a lightweight receiving station capable of being carried to industrial, as well as open field locations. The radiotelemetry system was designed specifically for monitoring fully instrumented subjects in the field, where fixed monitoring installations are impractical. For ruggedness and flexibility, the 7-channel system is equipped with servometers. The visual inspection of meter readings and documentation of data are carried out when environmental and physiological parameters fluctuate relatively slowly. For rapidly fluctuating conditions, however, continuous recording of data on strip charts is employed.

The environmental monitoring system was developed for field research purposes and has been successfully applied in a steel factory (3) and is now being used in wildlands fire fighting research (4). This environmental monitoring system is a prototype and as such, modifications are made periodically to improve its performance.

SYSTEM DESIGN

Standard industrial hygiene methods for monitoring heat stress are relatively slow and cumbersome. Generally, black globe thermometers and dry bulb and wet bulb sensors are used. Measurements are basically limited to station samples. No versatile personal heat stress monitoring system has been made available for industrial hygiene use, although the need for such equipment has long been recognized.

Several investigators have designed and constructed radiotelemetry systems useful for monitoring test animals or human subjects exposed to limited environmental stress settings (5-10); however, they have not been adapted to industrial hygiene use.

It has been shown that a radiotelemetry system using a bridge-type transducer network with pulse width modulation can maintain a high degree of accuracy in transmitting slowly varying parameters (6,11). Also, such a system has a low power drain. The variations in the environmental and physiological parameters encountered in occupational health work are also relatively slow; therefore, needed information can easily be obtained by such a system. The radiofrequency section of the system consists of a multichannel, pulse-width modulated, time-division multiplexed transmitter-receiver system that is produced for the remote control industry by Kraft System, Inc. (12). Pulse time stability for the system is guaranteed to be ± 1% between −15°C and 50°C.

The complete 7-channel Heat Stress Monitoring Telemetry System is diagramatically illustrated in Figure 1. Temperatures are sensed with precision thermistors (13), while humidity is detected with a Xeritron Humidity Sensor (14). Time constants for these transducers are in the order of a few seconds. Heart rate is detected by a pulsimeter (15) attached to an ear lobe of the subject. For the reference channel either a resistor is used in place of a thermistor, or a thermistor is used to telemeter internal transmitter temperature. Any variation in the output level of the reference channel may be correlated to a drift in the electronics for compensation.

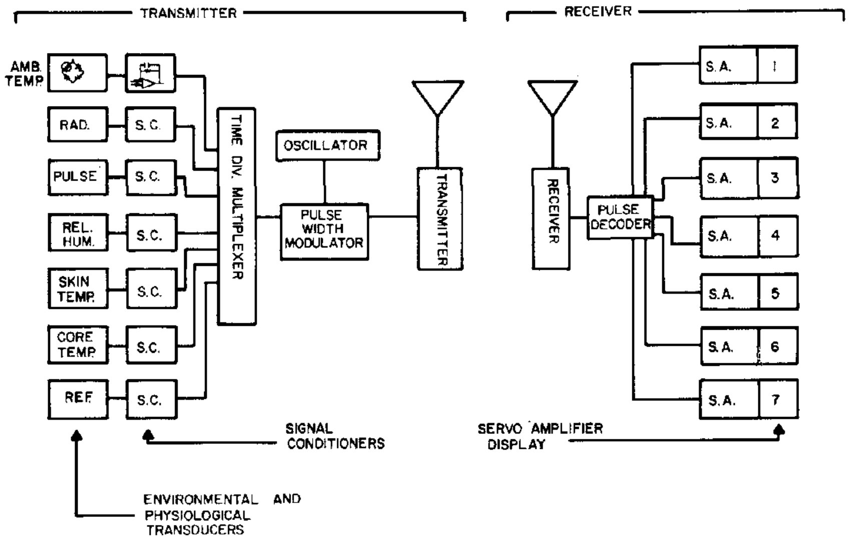

Figure 1. Diagramatic illustration of radiotelemetry system used in monitoring worker heat stress

Transducer bridge networks couple the signals to the signal conditioner. The signal conditioners are low noise, broad band, high-gain differential, integrated circuit amplifiers that provide signals between 0 and 2 volts to the multiplexer. The multiplexer combines the signals from the amplifiers into a time serial stream that modulates the transmitter. Commutation rate is 50 Hz.

The battery powered receiver reshapes and decommutates the pulse train, which in turn branches to the servo amplifiers. The servo amplifiers control a meter of a strip chart interface. The entire receiver package measures 3 cm. x 24 cm. x 5 cm. and weighs 80g.

The transmitter system, multiplexer, signal conditioner, and batteries are mounted into a chassis 15 cm. x 27 cm. x 5 cm. It weighs 1 kg. and has an operating time of 5 hours with a 9.6v, 500-mahr battery pack. To be in compliance with FCC regulations, the power into the final radiofrequency stage is presently limited to 100 mw in the 27 MHz frequency band (16). The package can be conveniently mounted on a backpack or harness with transducer rack. Signal leads from the transducers are connected to the transmitter by a 15-pin connector. Ambient air temperature and humidity are measured within the sensor chassis, ventilated via a small electric fan.

A CB voice communication transceiver that now provides a direct voice link between the receiving station and the test subject has been added to the personal monitoring system. Oftentimes, the test subject is out of the line of sight and must therefore describe his work activities by voice communication.

MONITOR APPLICATIONS

FIRE FIGHTING. Large areas of the U. S. are subjected to grass, brush, and forest fires. It is estimated that approximately 150,000 wildland fires break out each year in the U.S. Local, state, and Federal agencies commit over 75,000 men and women to fight these fires each year. Many of these fires are seasonal, so the fire fighters are often unacclimatized to heat. During the fire season, regular and volunteer fire fighters involved in controlling these fires work under conditions of extreme stress, often racing against time to construct fire lines. Work sometimes continues day and night, with little time for rest or sleep, bringing fire fighters to the point of exhaustion.

Environmental heat stress and excessively heavy protective clothing result in about 5 to 10 heat stress fatalities each year among the fire fighters. The majority of casualties involve new and highly motivated fire fighters during training and fire line construction operations. Furthermore, a lack of understanding of heat stress on the part of fire commanders has often resulted in misapplied safety efforts requiring use of relatively heavy and impermeable protective clothing during wildlands fire fighting operations.

In order to document the thermal conditions that prevail at the fire scene, sophisticated monitoring equipment is needed. In the past, the WBGT monitor, the Botsball, and the sling psychrometer have not been satisfactory, because heat stress conditions fluctuate very rapidly, and these traditional monitoring techniques cannot pick up the fluctuations.

The personal heat stress monitor is now being used for assessing heat stress conditions during training operations and simulated fire attack operations (Figure 2). Eleven training sessions have been monitored to date. These include hill climbing, carrying 18 kg hose packs, and laying 310 m long water lines to the top of a hill. These training activities represent typical work assignments for wildland fire fighters. In all of the training sessions a 125 m high hill with a 40% grade was used. A total of 310 m hiking distance was involved in reaching the top. A midpoint rest station was selected at a 50 m height, which represented half the walking distance (155m) between bottom and top.

The heat stress monitor was always carried by one of three test subjects. The receiving station was located within 1 kilometer of the test site. Voice radio communication between the test subject and the receiving station was maintained at all times. The test subjects were clothed in regulation uniform, including Nomex shirt and pants, leather gloves, boots and helmet.

Physiological and environmental data obtained during the training operations are summarized in Table 1. Hill-climbing could be accomplished three times during one training session before the fire fighters were fatigued. Hose-carrying up and down the hill could be accomplished twice, while hose-laying could be accomplished only once. Hill-climbing training sessions were repeated on separate days, while hose-laying was limited to one session.

A one-minute rest period was provided when the test subjects reached the midpoint on the way up the hill and on the way down. Three minutes of rest were permitted at the top, while 7 to 10 minutes of rest were allowed at the base, after completion of each exercise.

Figure 2. Illustration of personal heat stress monitor carried by wildlands fire fighter during training activities

Table I. Summary of telemetry data obtained during wildlands fire fighting training activities

ACTIVITY	EVENT	SUBJECT	TOTAL TIME (Min.)	BASE			MID-POINT			TOP			MIDPOINT			BASE			ENVIRONMENT		
				Rectal °C	Skin °C	Pulse BPM	Rectal °C	Skin °C	Pulse BPM	Rectal °C	Skin °C	Pulse BPM	Rectal °C	Skin °C	Pulse BPM	Rectal °C	Skin °C	Pulse BPM	Air °C	R.H. o/o	Wind Km/Hr
HILL CLIMBING	1	F	20	36.7	35.0	124	36.3	35.0	176	37.6	36.0	180	37.8	35.1	128	38.0	34.8	168	24	42	0-10
	2	F	20	38.0	35.0	124	38.0	28.0	172	38.2	36.9	188	38.4	35.8	148	38.4	35.3	172			
	3	F	20	38.2	34.3	136	38.3	35.0	148	38.4	35.1	184	38.5	35.0	148	38.5	34.8	172			
HILL CLIMBING	1	Y	18	37.4	34.4	92	37.5	36.6	148	37.6	37.1	148	37.8	35.0	112	37.9	34.8	120	29	15	20-40
	2	Y	20	38.1	34.1	120	38.3	34.5	152	38.3	35.0	164	38.4	34.2	115	38.4	34.0	132			
	3	Y	20	38.4	33.6	112	38.4	34.9	156	38.4	34.4	152	38.5	33.4	120	38.4	32.6	124			
HOSE CARRYING	1	F	16	37.5	31.0	136	37.5	30.8	164	37.6	30.4	188	37.9	33.0	148	38.0	33.8	164	17	84	10-20
	2	F	17	37.8	31.6	120	37.8	31.5	184	38.2	32.6	192	36.2	34.0	136	38.3	34.2	168			
HOSE CARRYING	1	Y	22	37.0	33.2	72	37.0	35.8	148	37.3	36.2	164	37.6	35.4	136	37.5	35.0	148	25	36	10-20
	2	Y	24	37.8	33.0	104	37.7	32.7	168	38.1	35.1	184	38.2	33.6	148	38.3	33.2	178			
HOSE LAYING	1	Y	54	36.9	31.0	64	37.2	33.0	116	38.2	35.8	180	38.4	35.2	124	38.5	35.3	168	18	62	0-10

A maximum rectal temperature increase of 1.8°C was observed during the 60-minute hill-climbing exercises, while a 1.3°C increase was recorded for the hose-carrying exercise, which was accomplished in 46 minutes. A maximum increase of 1.6°C in rectal temperature was observed for the hose-laying exercise, which was completed in 54 minutes.

While maximum rectal temperatures were observed at the end of each exercise period, peak heart rates were observed when the subject reached the top of the hill. A maximum of 188 bpm were observed during the climbing exercise. One hundred and ninety-two bpm were observed during hose-carrying, and 184 bpm were observed during hose-laying operations.

The personal heat stress monitor has also been used successfully to study the effectiveness of water fog-streams in reducing radiant heat exposures for fire fighters during attack operations (Figure 3). In this study, only the environmental factor of radiant heat was studied. Figure 4 illustrates typical radiant heat data obtained during the tests. Ninety-degree fog-patterns proved to be the most effective in reducing radiant heat exposure. This reduction allows for a significant increase in exposure time for fire fighters at a fire scene. This type of information was collected primarily for use in fire fighter tactical training.

Figure 3. Illustration of personal heat stress monitor used in assessing effectiveness of water-fog-stream heat radiation attenuation

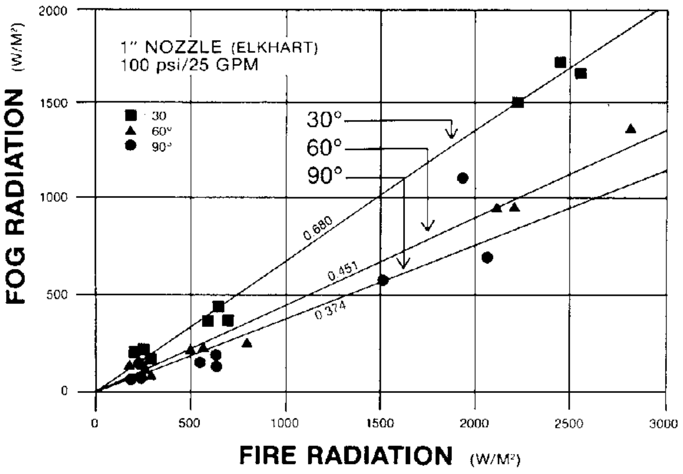

Figure 4. Illustration of radiotelemetry data obtained for fog-stream heat radiation attenuation studies

STEEL FACTORY. Environmental temperature conditions and physiological responses of test subjects working in the hot strip mill of a steel factory were measured using the personal heat stress monitor. The study was divided into two phases. First, the heat stress monitor was mounted on a tripod and placed at various locations in the work area, as shown in Figure 5. Air temperature and humidity, and radiant heat were measured. The receiving station was located 30 m away from the work area. Radiant heat intensities were determined for 10 coil stock types at various distances from the conveyor, as illustrated in Figure 6. Secondly, the heat stress monitor was used as a personal monitor carried on the back of a test subject performing standard work tasks, as shown in Figure 7. Radiant heat, relative humidity, air temperature, heart rate, and rectal and skin temperature were telemetered for 2-hour increments, including two 30-minute work periods and two 30-minute rest periods. Environmental and physiological data were documented at 5-minute intervals during work and at the beginning and end of each rest period. Telemetry transmissions continued throughout the work periods.

Radiant heat measurements in the hot strip mill work area indicate a wide range of conditions, as illustrated in Figure 6. A worker who marks the coil will actually approach the surface of a coil to a 1-meter distance and will experience radiant heat in excess of 2,000 W/m^2. Humidity and air velocity measurements indicated that, on the average for all working conditions, the atmospheric water vapor pressure was 12±1 mm Hg and air velocity was 10±5 m/min.

Physiological parameters, including heart rate, skin temperature, and rectal temperature obtained in the steel factory, are illustrated in Figure 8. Changes in heart rate reflect the work-rest schedule. The average heart rate at check-in was 70 bpm, with

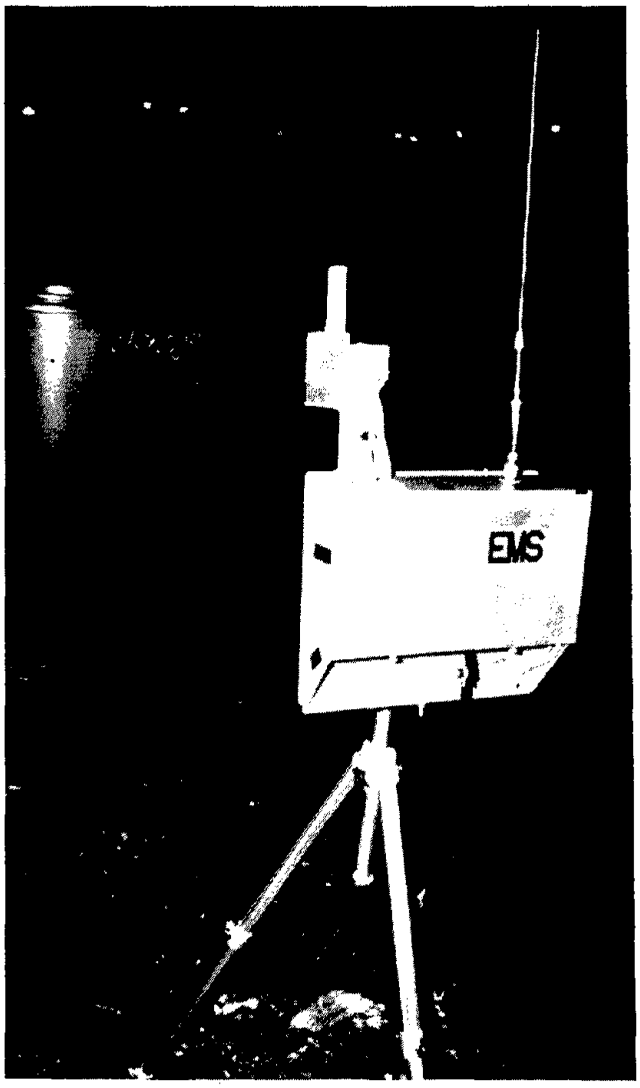

Figure 5. Example of heat stress monitor used in determining heat radiation intensities of various coil stock types in Hot Strip Mill

an average high of 83 bpm at the end of the second work period. Recovery to baseline values can be observed after each rest period. Average skin temperature at check-in was 32.6°C. Relatively large increases can be seen during work periods, where the average high value reached 37.6°C at the end of the second work period. Skin temperature recovery is almost complete at the end of each rest period. However, a gradual increase in average core temperature

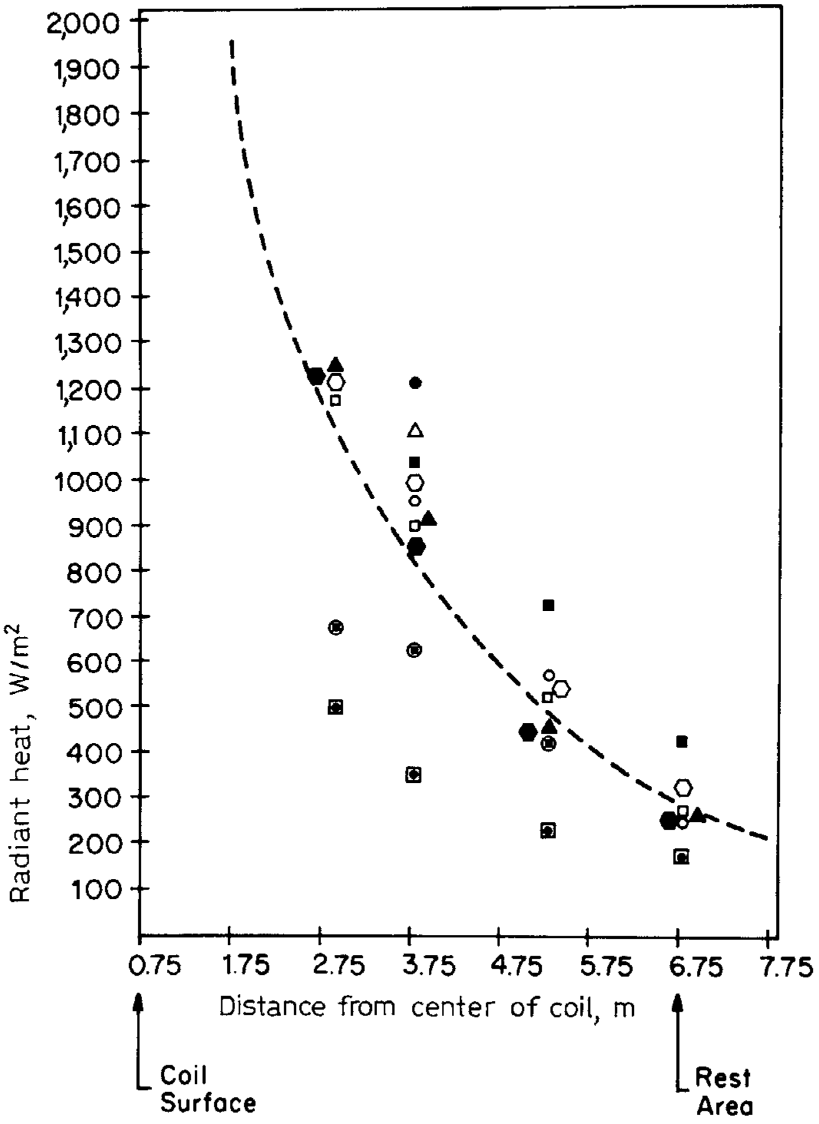

Figure 6. Example of heat radiation data obtained with the personal heat stress monitor

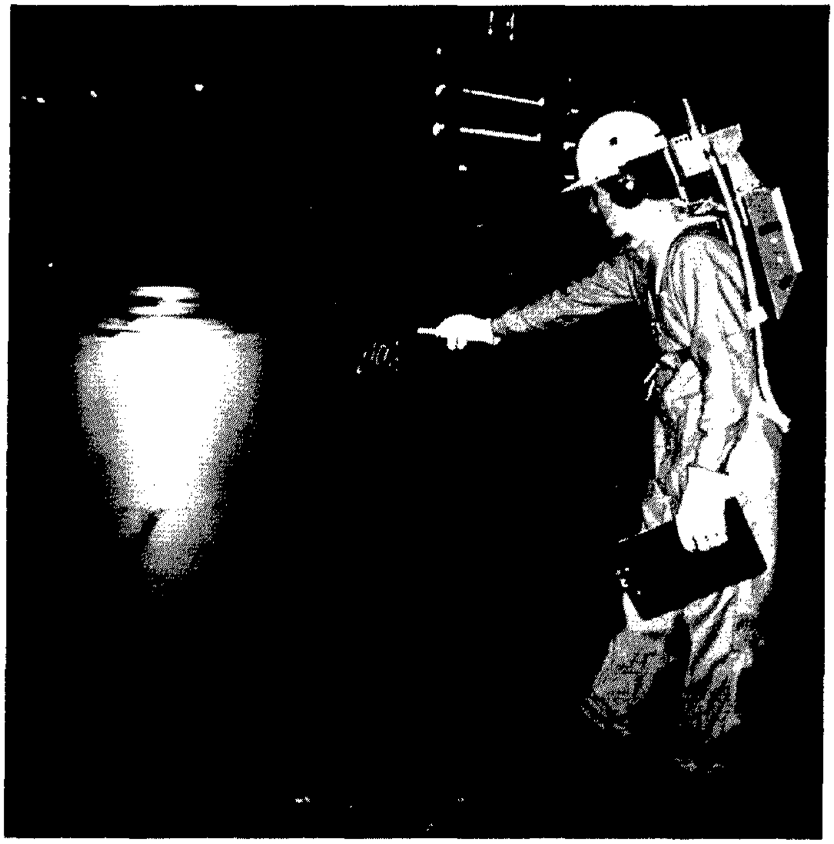

Figure 7. Illustration of a fully instrumented test subject carrying personal heat stress monitor

of 0.3°C can be seen at the end of the 2-hour shift. Work-rest fluctuations are not evident. Recovery to baseline values does not occur with this work-rest regimen.

Fluctuations in air temperature and humidity surrounding the test subject are illustrated in Figure 9. Data points representing the heat stress monitor measurements and rest area measurements obtained by traditional aspirated psychrometers illustrate the differences in temperature and humidity conditions experienced by the test subject in relation to the rest area environment. On several occasions, the ambient temperature surrounding the worker was 10°C higher than in the rest area. Relative humidity conditions were consistently 5-10% higher near the worker than at the rest area. This appears to be due to the body sweat evaporation monitored by the humidity transducer positioned 8cm above the left shoulder. Baseline calibration checks were performed during rest periods, when the worker was not perspiring.

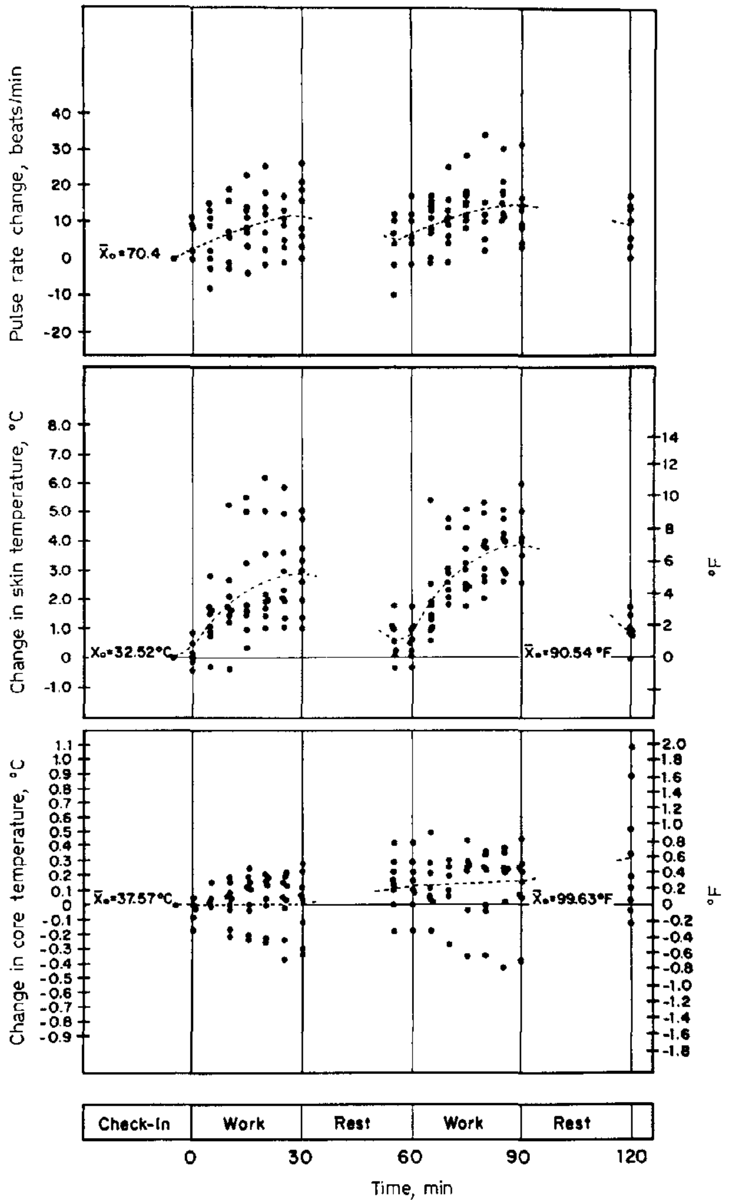

Figure 8. Example of physiological data obtained of test subject performing coil marking operations in a Hot Strip Mill

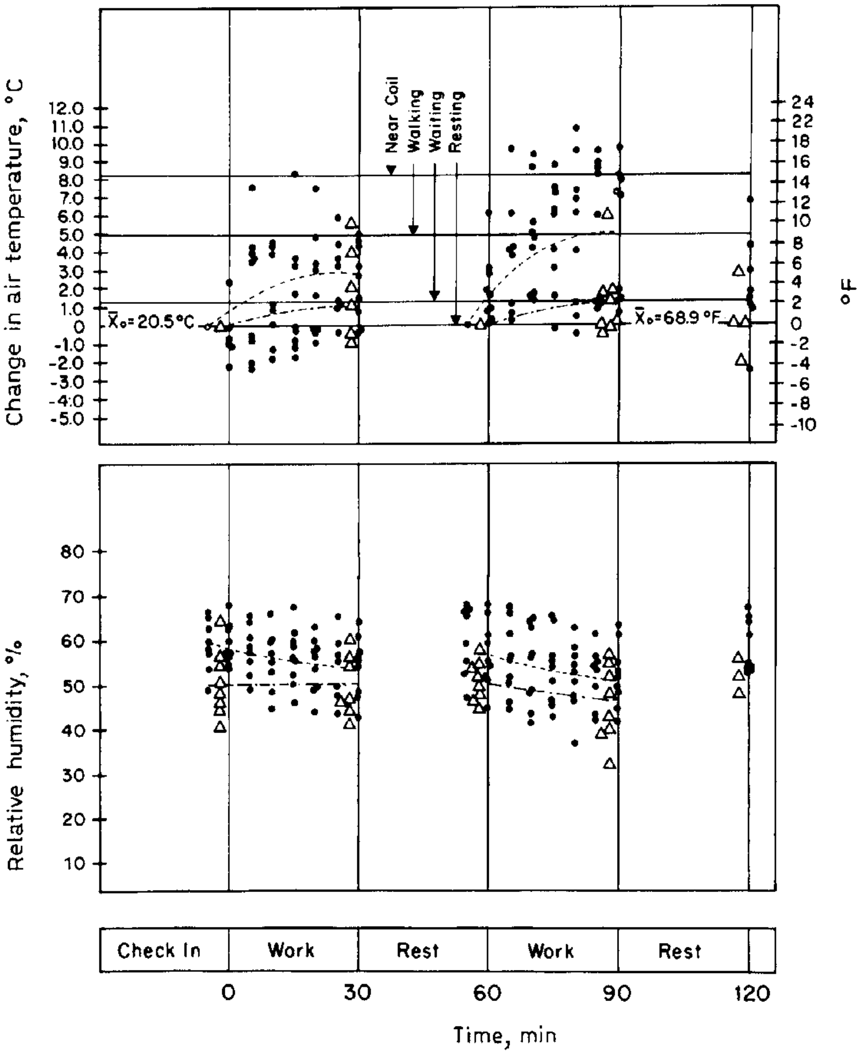

Figure 9. Example of environmental data obtained by the personal heat stress monitor during coil marking operations in a steel factory

SUMMARY AND RECOMMENDATIONS

The personal heat stress monitor has provided much useful, continuous, real-time environmental and physiological data. An advantage of radiotelemetry is that it makes it possible to make observations right away on the data collected. Accurate assessment of short-duration, high-intensity heat stress is now possible. Separate air temperature, humidity, and radiant heat measurements can now be obtained. Response times of the environmental sensors are in the order of seconds rather than minutes, making such a system very useful in evaluating actual work settings. The addition of a CB transceiver has contributed immensely to the usefulness of the system by providing a voice link between the test subject and the researcher. This voice link has proven especially useful under conditions where the test subject could not be observed visually.

External connectors for physiological transducers have made it possible to monitor several test subjects by using only one monitoring system. While the prevailing environmental parameters are being monitored with the backpack carried by one test subject, other test subjects connect their physiological transducers to the backpack at various intervals and their physiological data are then transmitted to the receiving station. Each subject is identified over the CB transceiver whenever a change in transducer hookup is made. It is clear that use of radiotelemetry can be very useful in field investigations, where long cables or connecting wires are impractical. Real-time observations also add a useful dimension when professional interpretations are needed during field tests. In real-time, researchers can direct test subjects to move about the environment to identify and quantify specific environmental stress sources. Also, investigators can terminate experiments when physiological parameters of test subjects exceed predetermined safety levels. Overall, real-time measurements enable investigators to make notes and record general observations directly onto strip charts or data sheets, eliminating the need for costly and time-consuming playback and time-motion matches after data have been obtained.

The heat stress monitor described here is a prototype system developed for research use. The system has been modified and improved to meet specific project needs. Subminiaturization has not been attempted because occasional changes in electronic components are often necessary. Subminiaturization would have limited our access to individual subsystems and components. However, a commercial system based on subminiaturization and constructed on a modular basis could provide much flexibility, and at the same time, reduce overall weight and size of the monitor.

The personal heat stress monitoring system described here uses off-the-shelf transducers and electronic components. Commercial production of low cost personal heat stress monitoring systems is possible. Availability of such systems to industrial hygiene researchers would contribute greatly to the understanding of heat stress and heat strain relationships in actual occupational settings. NIOSH should encourage the commercial development of such personal heat stress monitoring systems.

REFERENCES AND NOTES

1. Reischl, P., and U. Reischl: Radiotelemetry System for Occupational Health and Industrial Hygiene Research. Biotelemetry III, T. B. Fryer, Ed. pp. 29-32, 1976.
2. Reischl, P., and U. Reischl: Pulse Width to Analog Converter for a Portable Radio Telemetry Receiver. *Biotelemetry,* Vol. 4, pp. 9-17, 1977.
3. Reischl, U., D. Marschall, P. Reischl: Radiotelemetry Based Study of Occupational Heat Stress in a Steel Factory. *Biotelemetry,* Vol. 4, No. 3, pp. 115-130, 1977.
4. Reischl, P., and U. Reischl: Radiotelemetry Application for Assessing Environmental Stress and Physiological Strain of Fire Fighters in Training. *Biotelemetry* IV, H. Klewe, Ed., pp. 223-226, 1978.
5. Bergey, G. E., W. C. Sipple, W. A. Hamilton and R. D. Squires, et al.: Personal FM/FM Biotelemetry System. *Aerosp. Med.,* 39:488-492, 1968.
6. Bodenlos, L. H.: Transmitter Back-Pack for Free-Roaming Animals. *Lab. Animal Care,* Vol. 16, No. 5, pp. 454-458, 1966.
7. Cupal, J. J., A. L. Ward et al.: A Repeater Type Biotelemetry System for Use on Wild Big Game Animals, ISA BM 74329, pp. 145-152, 1974.
8. Murray, R. H., A. Marko, A. T. Kissen, and D. W. McGuire: A New Miniaturized, Multichannel, Personal Radiotelemetry System, *J. Appl. Phys.,* Vol. 24, pp. 588-592, 1968.
9. Nagasaka, T., S. Ando et al.: A Radio Telemetering System and the Changes of EKG and Heart Rate of . . . Mountaineering. *Nagoya J. Med. Sc.,* Vol. 29, pp. 93-103, 1966.
10. Watson, N. W., D. L. Franklin, and R. L. Van Citters, et al.: Back-Pack for Free-Ranging Primates, *J. Appl. Phys.,* 24:252-253, 1968.
11. Winget, C. M., E. G. Averkin, et al.: Quantitative Measurement by Telemetry of Ovulation and Oviposition in the Fowl. *Am. J. Physiol.,* 209:853-858, September, 1965.
12. Kraft Systems, Inc., 450 W. California Ave., Vista, California 92083.
13. Precision thermistor ± 0.1°C. interchangeability, YSI #44034; General purpose esophaegeal or rectal temp. probe YSI #401; Attachable surface skin temp. probe, YSI #409; Direct reading/wavelength independent/radiometer probe YSI #6551; Yellow Springs, Ohio, 45387.
14. Model XNAM 10205, Hygometrix, Inc., 285 Fifth St., Oakland, CA 94607.
15. Item No. 015023801 OPT/MOD Ref. 06A00601, Tektronix, Inc., P. O. Box 500, Beaverton, Oregon 97077.
16. Makay, R. S.: Bio-Medical Telemetry, New York, John Wiley, 1970.

QUESTIONS, ANSWERS, AND COMMENTARY

DR. GOLDMAN: I appreciate and recognize your enthusiasm. I work for a group that's been chasing field study data for many years and has spent about two million dollars on such equipment. The problem is not finding the equipment, it is getting the things to work reliably and consistently in the field. The sensors fall off. Calibration drifts are a problem. If one can't see the subjects or the participants, the fact that they're getting into trouble is not very much help. You need to see every man who gets into trouble or may collapse. We've looked at small-scale units using six-to-eight man squads, and we've thought about larger units. If you can hot-wire your measurement rather than use telemetry, you're better off. If you can get access to your subjects by being close to them and monitor them, you're a lot better off. You have a nice idea; its got a lot of promise; but its got a lot of problems.

DR. REISCHL: I agree. However, I think modern technology, or available technology, can come up with a reliable system. Prototype units will always exhibit problems. But I think we need to come up with a system that is able to do the environmental monitoring in the field; only through these types of measurements can we reliably validate the laboratory studies.

DR. GOLDMAN: Time constants of different sensors are very different from the human time constants. The problem has not been hardware, except for the sensor-human interface. We've seen good systems that work beautifully. However, when put on a hot, sweating, working subject, who's trying to fight a fire or trying to fight a war, they don't stay on. There have also been problems with the ear probes. We've hooked them in the ear and implanted them under the skin, and we still had problems.

DR. REISCHL: I think there are environmental situations and work settings where existing hardware and the units that may be built in the future will work. I don't think you can say that none of the systems work reliably. If we do use them to gain experience in the field, the type of data that we are able to collect will be useful.

DR. DUKES-DOBOS: You said you have to monitor the temperature of the sensors. You need thermometers to do this, and they change their temperature, so you would have to have another set of thermometers to monitor the temperature of these control instruments.

DR. REISCHL: What we actually do is monitor the temperature of the transmitter unit. We use the temperature reading that we get from the transducer that measures the temperatures of the equipment, and we correlate this directly with the changes in the other parameters. So it really doesn't matter what happens to that one sensor. We use whatever information we get to correlate and correct the other monitors. So we don't have to monitor the monitor.

DR. DUKES-DOBOS: But usually, when you monitor radiation, you are interested in the mean radiant temperature. Your sensor is directional and that prevents measuring the mean radiant temperature.

DR. REISCHL: The heat sensor that we have now is directional in the forward direction. I think a sensor or a multiple number of sensors would be appropriate. We find that under fire fighting conditions, the radiant heat that is the most intense is the fire, and it is frontal.

DR. ZENZ: I had one of the photo-electric cardiotachometers about 25 years ago, before we could buy transistors. I used it in many studies and it worked pretty well then. I didn't have telemetry at the time. I think you'll do all right.

DR. REISCHL: Our pulse sensor is very clean.

DR. ZENZ: It sounds like you have to tape them on pretty firmly.

DR. REISCHL: We clip them on and, since we have radio communication, we put on a head set. Actually we put an ear set over that ear; it protects the sensor from intense sunlight, which often influences the readings. At this point we've had exceptionally good luck in climbing operations, initial attack, and mop-up operations.

DR. SHVARTZ: For a number of years I have tried to interest fire fighters' organizations in California, on a local level in the San Diego area and San Francisco Bay area, and also on a Federal level, to help fire fighters in two major things. One is to develop a screening test such as I described, to screen out people who cannot be fire fighters because they are heat intolerant. Another area is to develop some body cooling techniques for fire fighters, because many times they work in such high heat stress conditions that it's not possible to acclimatize. But no one seemed to be interested in these things.

DR. REISCHL: There are several reasons for this. One is that the fire service is an independent organization. They do not have one spokesperson or group of spokespersons to convey their needs and interests.

Second, I think fire fighters are not generally exposed to very high heat stress conditions. Certainly, structural-type fire fighting can be intense under some conditions. But I think a major problem now is the effect of heavy protective clothing and the inability of the fire fighters to evaporate sweat sufficiently. The stress levels are not as high if they start taking off some of the protective clothing. Knowing something about the environmental conditions, we can say how much protective clothing they can take off under certain fire fighting conditions. They are not always near a fire. For example, in brush fires, they are often a mile or so in advance of the fire lines. Once the fire line approaches, they must get out of the way. So much of the heat stress is produced because of high work levels and very heavy protective clothing. Once the role of protective clothing and the heat stress problem is understood, much more can be done.

DR. SHVARTZ: But there are still many heat casualties. The conclusion that fire fighters are exposed to high strain and stress, regardless of the conditions, is being ignored. Some inexpensive, individual cooling methods could solve the problem.

DR. HORVATH: I think it is a very good idea, despite the problems that Dr. Goldman spoke of. We have, for example, demonstrated beautifully that you can do this in an environment that is much more severe than the one you are talking about — that is, deep sea diving. We have devices that we have been using in these situations, which include a microprocessing unit that does every bit of the calculation and sends up beautiful data. This unit tells us about the problems divers are having from a thousand feet under the water; and a small television camera tells us exactly what is going on. So do not be discouraged despite all of these comments. Get the money from NIOSH, and then spend it.

COMMENTS ON MATHEMATICAL MODELS FOR THERMOREGULATORY BEHAVIOR

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ABSTRACT

This is an introduction to the use of mathematical models of the human thermoregulatory system. Models are expected to be useful in setting the heat stress standards of the future, in field assessment of hot environments, in design of work situations, and in physiological research. A short summary of the range of existing models is given. This is followed by a discussion regarding their usefulness and by a suggested program of research.

I. *INTRODUCTION*

Attempts to use mathematical models to predict physiological parameters, such as rectal temperature, heart rate, and rate of sweat production, have become of increasing sophistication and interest. It is appropriate to discuss the models of the human thermoregulatory system in a workshop on the heat stress standard. Research towards standards to be set in the future must consider a possible role to be played by these models. The subject of heat stress and heat strain would seem to be a natural subject for mathematical modeling because the physics of heat storage and heat flow is quite well understood. The uncertainties in our understanding of thermoregulatory behavior arise because of the complexity of the human body and of the physiological processes that accompany heat strain and heat flow in the body.

The existing and the chief recommended standards for working in hot environments are all stated in terms of parameters that do not define unique thermodynamic states but are natural averages over many states. One would expect any single such standard to be inadequate under extreme values of particular thermodynamic variables (such as very high relative humidity). Future research should be aimed at setting standards in terms of unique thermodynamic states. It is quite likely that this will best be done in terms of model predictions.

The next section will give a brief overview of the types of models that are being studied. This will be followed by some remarks on the applications of these models and on the research that it is suggested should be carried forward.

II. *DESCRIPTION OF MODELS*

Mathematical models have been developed for a single element of the body (e.g., finger) as well as for the entire human body. We will consider only the whole body models. The types of whole body models are:

1) One-cylinder models
   a) Single zone model — Givoni and Goldman(1)
   b) Two node model — Gagge, Stolwijk, and Nishi(2)
   c) Multilayer model — Wyndham and Atkins(3)
   d) Three part model — Kawashima and Yamomoto(4)
2) Multisegment model
   a) Stolwijk model(5)
   b) Wissler model(6)
   c) An interactive model — Miller and Walters(7)

The listing is representative but not complete. We do not intend to provide here a complete summary and review of any of the models; we shall say just a few words about each, merely to convey their flavor. For a summary and review of the early mathematical models, see the article by Fan, Hsu, and Hwang(8); for the later models until 1977, see the article by Hwang and Konz(9).

The simplest type of models is one that represents the body as one single cylinder. The simplest of the one cylinder models is the one zone model of Givoni and Goldman. In fact, the equations of Givoni and Goldman are really a predictive set of equations; they are a model only insofar as the form of the equations is set by theoretical guides. The predictive equations, or model, of Givoni and Goldman were written on the basis of an extensive experimental program. Guided by theoretical considerations and by laboratory measurement, Givoni and Goldman have listed predictive equations that give the rectal temperature and heart rate as time-dependent output parameters dependent upon the work environment, the physical characteristics of the worker, and the work rate. The model assumes a final skin temperature (e.g., 35°C for naked and 36°C for clothed worker) and then estimates the effects of various heat loss processes in producing elevated rectal temperatures and heart rates. The model is simple enough to be programmed on a hand-held programmable calculator; I have programmed it on a TI 59(10).

The next most complicated model is the two node model developed by Gagge and his associates at Yale University and studied further by Azer at Kansas State University. The cylinder representing the body is divided into a central or core cylinder and a surface layer surrounding the core cylinder. There is an exchange of heat between the core cylinder and the surface and between the surface and the environment. Heat by conduction, radiation, evaporation, and respiration is considered. There are two fundamental coupled equations to predict the core temperature and the surface temperature. These are that the heat gained by the core equals $m_c c_c dT_c/dt$; the heat gained by the surface equals $m_s c_s dT_s/dt$, where m stands for mass, c for specific heat, and T for temeprature, with the subscripts c and s representing core and surface. The model predicts core temperature and surface temperature. The equations are somewhat more complex than those of Givoni and Goldman, but they can also be programmed on a hand-held programmable calculator.

In the Wyndham-Atkins model, the body is considered to consist of a single cylinder divided into four concentric sections (the core, the muscles, the fatty tissue under the skin, and the skin). Heat, generated mostly in the muscles, may be transferred between layers by conduction, or by convection associated with the circulation of blood.

The Kawashima-Yamamoto model is more complex than the Wyndham-Atkins model. The human body is divided into three portions: an inner part (core), and outer part, and a connecting circulatory system. The circulatory system includes the large blood vessels (heart, aorta), small blood vessels, and the cutaneous circulatory system. Heat is produced by metabolism and shivering, and transmitted by conduction and convection. It is dissipated by radiation, convection, and evaporation.

A representative and often used multisegment model is the Stolwijk model. The Stolwijk model divides the body into six segments — the head, central body, and four limbs. Each segment is in turn modeled as a cylinder; each of the six cylinders may be considered to be subdivided into four concentric cylinders (core, muscle, fat, skin). A central blood compartment links the segments together by way of appropriate blood flow between the segments. In a sense, this model combines features of the Wyndham-Atkins model with features of the Kawashima-Yamamoto model, but with a representation of the human body which has greater complexity than either of the other two models.

The Wissler model is in the same spirit as the Stolwijk model. The model described by Miller and Walters is also quite similar and explicitly portrays the human circulatory, thermoregulatory, and energy-exchange systems as an intercoupled set of systems. It is designed to serve as a means of communication between members of an interdisciplinary research team.

The multisegment models are best programmed in Fortran language on a medium memory computer. The Wissler model has been simulated with an analog computer.

III. *APPLICATION OF MODELS*

Because of the large number of factors involved in determining man's physiological response to the environment, a complete and systematic study relying on experiments alone seems unreasonable. An alternative approach is a combination of modeling and experimental verification. Some of the specific applications of this approach can be outlined.

1. It will help to identify different combinations of environmental factors, activity, and clothing that can result in similar feelings of physiological strain. This will aid the designer of the work environment in hot, cold, and office work situations.
2. Work-rest regimens for work in hot industrial environments can be planned. The work environment may be entirely different from the rest environment.
3. Ultimately, a model can be used as a basis to set the work standard in a hot environment. The proposed OSHA standard and the standards being recommended by many workers in the field are not based on unique thermodynamic states. Hence they are expected to be either too restrictive or too lax under different combinations of extreme environmental conditions. An accurate predictive model based on unique thermodynamic variables is an appropriate basis for a work standard.
4. A model can be used for assessment of work conditions at any time by simulation of the environment and of the work situation.
5. A model is useful in strictly physiological studies of man's response to the environment. Application of this type requires one of the more sophisticated models including blood flow characteristics.

The applications of the models come in three levels of sophistication: field assessment, setting standards in complicated work environments (rapid variations in space or time, extreme conditions, etc.), and basic physiological research. For different applications, different models are appropriate. One cannot say that a particular model is "best"; different models are best for different applications. For field assessment studies one might choose a model that can be programmed on a hand-held calculator. Both the single zone model of Givoni and Goldman and the two node model of Gagge, Stolwijk, and Nishi have this feature and would seem to be ideal candidates for field assessment studies. In the design of complicated work environments, more sophisticated models, such as the more complicated one-cylinder models or even the simpler multisegment models, may be appropriate. Models for physiological research need the greatest sophistication.

All the models described, both the one-cylinder models and the multisegment models, have been programmed in Fortran on medium memory size computers. The larger computers have obvious advantages over hand-held calculators — a continuous printed output of the physiological state is possible and the more complicated models can be programmed. The multisegment model of Stolwijk is a very good one for research purposes at this stage of development of the field. It contains details of the head, body, and appendages, including core, muscle, fat, and skin, as well as blood flow. Experiments are not sophisticated enough to use a more complicated model effectively; the Stolwijk model describes in minimum detail the most important parameters that a sophisticated model should describe.

IV. *PROGRAM OF RESEARCH*

One suggested program of research aimed at using a model to set the heat stress standard assumes that the best heat stress standard will eventually be stated in terms of thermodynamic variables that uniquely describe the thermodynamic state of the environment in which the work is being performed (e.g., air temperature, relative humidity, mean radiant temperature, and wind velocity). The heat stress indices being considered at present — WBGT, ET, new ET, Botsball, etc. — all fail in this regard. Hence it is quite likely that different extreme environments will require different standards if one of these indices is used, since none of them describes the environment uniquely.

1. All the representative models should be programmed on the same computer at one central research location. Differences in predictions of the models for different work and rest environments should be determined. The reasons for the differences should be examined and appropriate modifications made. (As an example, I analyze in the last section a difference between the Givoni-Goldman and Gagge-Stolwijk-Nishi models.)

2. An experimental program should be undertaken to challenge and test the programs under critical, extreme, and varying situations. The program predictions and test results should determine future test environments.

3. The models should be expanded to include such modifications as may be necessary to account for physical fitness, sex, and age.

4. A reexamination of workers' tolerance to heat stress should be undertaken to determine what physiological reactions should control the setting of standards. The results can depend on a rather complex variety of parameters. For example, the allowed metabolic rate can be specified as a function of air temperature, relative humidity, mean radiant temperature, and air velocity.

5. The spread in the response of different workers to the same work environment should be studied and incorporated into the models. Thus standards can be set with a built-in and known margin of safety.

6. A predictive model or set of models for use in setting a heat stress standard should be determined. Metabolic rates or physiological parameters should be programmed on a calculator; tolerable environments and work-rest regimens should be determined from the model predictions. Ideas of simplicity of heat stress indices should be adjusted to the reality that sophisticated-looking models are made simple with the use of a calculator. Relatively simple work environments that do not include rapidly varying conditions or extreme values of environmental parameters could still be characterized and auxiliary standards set by the presently commonly used indices such as WBGT or Botsball. Complex situations should have standards that have more complicated dependences on the thermodynamic variables that describe the work environment. But the definitive standards should eventually be stated in terms of the thermodynamic variables that uniquely describe the thermodynamic states of the environment in which the work is being performed. If desired, the usefulness of the presently used indices (e.g., WBGT, Botsball) can also be determined by the model.

V. *THE GIVONI-GOLDMAN MODEL AND THE GAGGE-STOLWIJK-NISHI MODEL*

As an example of what is involved in comparing models, I shall make some remarks regarding the Givoni-Goldman model and the Gagge-Stolwijk-Nishi model. The latter two-node model, as stated by Azer, consists of two basic heat flow equations:

$$m_c C_c \frac{dT_c}{dt} = M - W - E_{res} - KS(T_c - T_s), \tag{1}$$

$$m_s C_s \frac{dT_s}{dt} = KS(T_c - T_s) - (R + C) - E_s. \tag{2}$$

The subscripts c and s stand for core and skin, respectively; m = mass, C = specific heat, T = temperature, t = time, M = total metabolic heat production per unit body surface area, W = external mechanical work, KS = overall skin conductance, E_s = total evaporative energy loss from the skin, R + C = dry energy exchange by radiation and convection, E_{res} = respiratory energy exchange with environment.

At equilibrium, the left-hand sides of equations (1) and (2) vanish and we can subtract the resulting equations to obtain

$$T_c = T_s + \frac{1}{2KS}(M - W) - \frac{1}{2KS}E_{res} + \frac{1}{2KS}(R + C) + \frac{1}{2KS}E_s. \tag{3}$$

Further, the model states

$$R + C = hf_{cl}F_{cl}(T_s - T_o),$$

$$K_s = 12.05 + 42.45(T_c - 36.98) + 8.15(T_c - 35.15)^{.8} \times (T_s - 33.8), \tag{4}$$

where T_o = the ambient operative temperature, h = the combined convective and linear radiation heat exchange coefficient, f_{cl} = ratio of surface area of clothed body to nude body, F_{cl} = thermal efficiency of clothing.

The Givoni-Goldman model predicts the equilibrium core (rectal) temperature to be given by

$$T_c = 36.75 + .004(M - W) + \frac{.025}{\text{clo}^*}(T_o - 36) + .8 \exp\left\{ .0047(E_{req} - E_{max}) \right\}, \tag{5}$$

where clo* is the clo value modified to account for the effective wind velocity, E_{req} = required evaporative cooling, E_{max} = maximum possible evaporative cooling.

A direct comparison between the predictions of the equilibrium core temperature is now possible for the two models (eq. 3 and 4 vs. eq. 5). The Givoni-Goldman model ignores the term involving E_{req} and uses fixed constants for some of the corresponding parameters of the two node model. The two node model gives a complicated expression for E_s, which we shall not reproduce, but which gives a richer possible dependence on E_{req} and E_{max} than that given by the last term of equation (5).

It seems intuitively obvious that the two node model should give a better prediction of the equilibrium rectal temperature than the Givoni-Goldman predictions, simply because of the greater flexibility in the coefficients. The time dependence is more complicated to compare. The Givoni-Goldman time-dependent predictive equations, however, does have built in inertial effects that are guided by experimental determinations. The time dependence of the two node model is given by equations (1) and (2), and the response of the rate of change of core temperature to the environment is immediate. Of course, for a real worker, if the outside temperature is lowered abruptly, the body core cannot cool off immediately because the effect takes a finite time to travel from the outside to the core. The two node model does not permit inertial effects of this type. It seems plausible that a simple model will eventually evolve which combines the equilibrium predictions of the two node model with inertial features such as are contained in the Givoni-Goldman equations. These latter equations probably give reasonable time dependences only for intermediate range time intervals. For example, they certainly do not follow 15-second variations and they almost certainly do not follow accurately a work-rest regimen of two cycles per hour for a period of 6 hours. A new, rationally based, model would seem to be needed for accurate time dependence for field assessment purposes.

REFERENCES

1. B. Givoni and R. F. Goldman, J. Appl. Physiol. 32, 812-822 (1972) and J. Appl. Physiol. 34, 201-204 (1973).

2. A. P. Gagge, J. A. J. Stolwijk, and Y. Nishi, ASHRAE Trans. vol. 77, part I, pp. 247-262, (1971).
   N. Z. Azer, ASHRAE Trans., vol. 85, part I, (1979).
   N. Z. Azer and S. Hsu, ASHRAE Trans., vol. 833, part I, (1977).
3. C. H. Wyndham and A. R. Atkins, Pfluegers Arch, Vol. 303, pp. 14-30 (1968).
4. The Kawashima-Yamomoto Model is reviewed by C. L. Hwang and S. A. Konz, IEEE Trans. on Biomed. Eng., 24, 309-325, (1977).
5. J. A. J. Stolwijk in *Physiological and Behavorial Temperature Regulation* edited by J. D. Hardy, A. P. Gagge, and J. A. J. Stolwijk; Charles C. Thomas, Pub., Springfield, Ill. (1970) Chapter 48, pp. 703-721.
6. E. H. Eissler, Chem. Eng. Prog. Symp. Ser. Vol. 62 (1966).
7. N. C. Miller and R. F. Walters, Simulation 1-13, Jan. 1974.
8. L. T. Fan, F. T. Hsu and C. L. Hwang, IEEE Trans. on Biomed. Eng. 18, 218-239 (1971).
9. C. L. Hwang and S. A. Konz, IEEE Trans. on Biomed. Eng. 24, 309-325, (1977).
10. L. Witten, NIOSH Report, to be published.

QUESTIONS, ANSWERS, AND COMMENTS

DR. GONZALEZ: The Gagge model does predict the heart rate and also has an option for changing the threshold coefficients during the acclimation. Based upon the experimental model and the results we have obtained, you can have a multiple change in both skin blood flow effects and sweating effects.

The second thing that is important is the marriage between the actual results and the models. The prediction in terms of dry heat stress and humid heat stress is very well predicted by the Gagge two node model, as compared in over 111 experiments. I prefer the HP system because, even though the TI system uses algebraic notations, the reverse Polish notation is a little better.

DR. WITTEN: Now that the HP has a bigger memory I would possibly go with it too. Which program are you referring to?

DR. GONZALEZ: This is one I just recently developed for NASA. It gives the time rate of change of rectal temperature, or the rate of body heat storage.

DR. KAMON: The models are very good as long as you can predict what M is in terms of relative heat. Givoni and Goldman wanted to predict absolute metabolism, but if you take a different age group, it would not work as well. Also, all their data are based on young military subjects. When they added their predictor they compared it backwards to the same group of subjects. That is why they got the high correlation. You have to account for different fitness levels, and the M should be the relative value.

DR. GOLDMAN: You are working with an earlier version of the model. We have changed some of the coefficients, in part because of that. We are working on a block to handle the average man, which is not what our model was developed for. It was developed for the military population. The miliary population now includes females, older men, and, occasionally, those who are less fit. We have a block we are working on that will put in age, sex, and physical fitness. Then we will come out from that with a baseline heart rate. We do not specify an initial rectal temperature; it gets modified with the acclimatization.

The one unique thing about our model is that it allows one to deviate from the conventional 0.6 for clothing with different permeabilities. Some of the models can handle ranges of insulation but not ranges of permeability. And no model except ours, that I know of, can handle clothing factors such as weight of material, cut, fit, drape, and insulation and permeability change. Ours covers the full range from shorts up through a heavy multiple layer chemical protective clothing system.

DR. KAMON: You mentioned the need for environmental correlation. I think you are wasting your time, and there is proof for it. Someone in your laboratory wrote a paper in which he tried to compare modeling different systems, and it ended up that the best correlate was with the katathermometer.

DR. WITTEN: A good model would show whether the WBGT or any other index is a good heat stress index and would define its bounds of usefulness.

DR. HORVATH: There is a great deal of difference between predictive equations and modeling. There is a tendency for everybody to use the same terms whether they're talking about predictive equations or modeling.

Also, the model we tried to develop included multiple layers (going down as far as the bone) and multiple segments, plus counter-current exchange of blood, which is even more complex. The main trouble with all of the modeling is that the basic information required to put into the model is so sparse and so inadequate that a model is only good for pointing out that there are certain things we don't know, and that we should go ahead and do something about it.

If we use data for a model, then I think you are talking about something useful. But it you start talking about models with predictive equations, I think you're making a serious mistake.

Dr. WITTEN: The use of a model for setting heat stress standards arises through its pedictive ability. Hence for setting such standards it is not important to distinguish carefully between predictions resulting from a model and from predictive equations. The use of a model in physiological research is largely as a guide telling what should be measured and how. Models have different applications and should be used in different ways for the corresponding different applications. Generally speaking, models used for research will serve as a guide in telling which parameters to measure.

DR. HORVATH: Those are the ones you cannot measure, such as how much blood squeezes out from the muscle to the skin.

Part II

WORKING GROUP REPORTS

WORKING GROUP NO. 1

Chairperson: J. Ramsey

Rapporteur: P. Smith

Members:

F. Dukes-Dobos, B. Hollett, R. James, H. Jones, P. Smith

ASSIGNED TOPIC: Should the heat stress standard recommended by NIOSH remain in a "Work Practices" standard or should it be changed to one limiting heat exposure to permissible limits? What work practices should be mandatory?

Is it necessary to include in the standard upper permissible exposure limits in order to protect workers?

A. If yes:
  1. Could the ACGIH TLV be adopted for this purpose?
  2. Could the set of PEL's developed by Dr. Dasler for the Navy be adopted for this purpose?
  3. Is there another set available which is better than Dasler's?
  4. What future research is needed in this problem area?

B. If no:
  1. How can work practices by themselves (without PEL's) prevent heat illnesses?
     a. Should there be an action level for work practices?
     b. What work practices should be mandatory and when? (NIOSH versus OSHA version)
        What future research is needed in this problem area?

REPORT OF THE CHAIRPERSON

We agreed that a work practices standard should be required under any circumstance. Basically, we considered a threshold limit standard and an upper limit or permissible limit standard. In either one of these, perhaps on a time weighted average heat stress basis, work practices would be required. A third category is a ceiling limit, above which no work would be allowed. We did not pursue this issue.

We also discussed the effects of various factors, such as clothing, physical fitness, sex, and acclimatization. These factors are not addressed independently in the existing recommendations. We felt these were important issues and that they should be considered in any future standard. This topic was covered by Working Group #4.

We looked at the ACGIH TLV in detail and arrived at two conclusions: first, there is a continuous heat-work curve; second, there is a set of curves representing different levels of metabolic work with different ratios of work to rest. The 50-50 work-rest regimen is calculated assuming a half-time rest at a lower metabolic rate, and a half-time work at a higher metabolic rate. In effect, it is a single subset of a wide range of work-rest schedules with variable heat exposure and variable rest temperature exposure. A procedure to calculate time-weighed averages is also assumed. This is comprehensively covered, along with an infinite array of other combinations that might be encountered.

In addressing the TLV permissible limits, we felt it would be necessary to group them into categories of metabolic expenditure: high, medium, and low, as shown below. Working Group #1 also felt that it is possible to identify, in a general metabolic range, a work task that is continued over an extended period of time. Even if it is measured precisely with a detailed time study and detailed physiological estimates of work load, we arrived at a level of about 220 kilocalories per hour for most industrial jobs.

LOW	150	kcal./hr.	
MEDIUM	250	"	"
HIGH	350	"	"

It would be useful to have the information in a simple tabular form indicating low, moderate, and high metabolic work plus the appropriate WBGT limits associated with each category. In the calculation of time-weighed averages, we felt it should be done on the basis of the mid-point of each of these work categories.

We were also asked to consider the upper limit curves, such as those prepared by Dr. Dasler. The permissible heat exposure limits had a time-weighted average metabolic load and a time-weighed average WBGT, with a specific tolerance time indicated. We felt that Dr. Dasler's work was very good, but it represented a specific population in terms of work tasks and in terms of workers. It would be difficult to extrapolate to the general working population. This is one of the areas that deserves more thorough investigation. Our committee did not feel it was appropriate or timely to recommend the inclusion of these data in a TLV type coverage, or to recommend their inclusion as additional upper limit criteria for heat exposure.

In considering the question of mandatory work practices, we very carefully went through some of the previous work in this area. We agreed with the work practices suggested by OSHA's Advisory Committee, with some notable changes in the groupings and in how the groupings are handled. We arrived at three mandatory work practices for a work environment above the threshold limit: available potable water, acclimatization of the worker, and a written policy concerning procedures, scheduling, and definitions.

The written policy is the major change we envisioned. It would define acclimatization policy, prescribe procedures during a sudden increase in climatic temperature, and address the desirability of moving heavy work schedules to cooler parts of the day. A company must also respond to the issue of allowing workers in a hot environment to disrupt work because of extreme discomfort. Previously, these practices were included in a "shopping list," from which industry could select work practices. As written policy, they should be considered mandatory. A company would not be required to shift heavy work to the cooler part of the day, but it must identify its policy on this, as a feasible alternative. The written policy must also define those jobs involving extreme heat exposure. This is a situation where the environmental conditions are so extreme that a brief exposure could result in excessive strain, unless special protection is provided. Examples include patching a hot furnace, fire fighting, or boiler repairing. The acceptable duration of exposure is determined by professionals, based on experience with similar work conditions. The worker should have the option of terminating exposure because of an impending heat disorder. This policy should be explained and made available to employees. It should be kept on file and be available for inspection by the Department of Labor.

Our next issue concerned medical examinations. Fitness of employees should be determined on the basis of a preplacement and periodic medical evaluations. In addition, one or more special practices should be applied. These include engineering controls responsive to basic thermal exchange relationships between the worker and the environment, work-rest procedures, work-rest scheduling, and appropriate protective equipment. We felt that the person responsible for emergency repair jobs should have a more rigorous medical examination than the other workers.

The question was raised: How do you measure the adequacy of a work practice? Is it the engineering controls, or is it the schedule, that is supposed to handle the job? When we apply a work practice or a work-rest regimen, how much do we reduce the TLV?

There are several interpretations of the TLV, as it is now envisioned. The first is that the TLV is the threshold warning point; the point of increased health risk from heat exposure. But it is also considered as an upper limit. If there are engineering controls or a work-rest regimen, they must return conditions to the TLV. The adequacy of the work practice should be judged on physiological demonstration of a return to the appropriate TLV. This is a rigorous criterion.

Another alternative we explored was the interpretation of the TLV as a threshold. At this point, work practices would be initiated for the general population. The management has the tradeoff potential of providing funds for training procedure and subselecting their population to allow for the performance of a stressful task, thus permitting the upper limit to be raised. Or, management can choose to spend no money and comply with the more stringent limits.

The third alternative discussed was physiological monitoring. The criterion is: does the worker's body core temperature exceed 38° C? There were two increased risk alternatives. One is changing the stress criterion from 38° C to a higher value that would be defensible in a scientific community; it would be acknowledged as a higher level of risk. This is a matter of risk tradeoff. The OSHA Advisory Committee recommendations do not specify that the core temperature should never exceed 38° C.

The other increased risk alternative is not requiring that the work practices return the situation to the TLV. If an industry has hot conditions, some work practices need to be initiated. But we are not requiring measurement, monitoring, or technological help to prove compliance.

RECOMMENDATIONS FOR FUTURE RESEARCH

We felt that a better means for field measurement techniques would be desirable and needs further development. This includes core temperature measurement during acclimatization, covering different sub-groups and regional differences. There are still some questions concerning parts of this country that operate at higher temperatures during much of the year.

We also need a personal dosimeter for the environment. It would be helpful if Dr. Reischl's kit were available in a portable size. A personal monitor is needed for physiological strain measurements and to determine the cooling efficiency of low air velocity. There has been work in this area, especially as it relates to WBGT, but this question has not been resolved.

More information is needed on salt intake, since the work that has been done in this area has not resolved the issue. We need to develop improved medical screening procedures for workers in hot conditions, as well as a monitoring system for extremely high temperatures. We need research to develop and evaluate upper exposure limits for percentiles other than the 95th; and we need an assessment of the increased risk incurred by raising core temperature above 38° C.

WORKING GROUP NO. 2

Chairperson: A. Henschel Rapporteur: U. Reischl
Members:
O. Banks, D. Brustein, F. Fuller, E. Kamon, S. Konz

ASSIGNED TOPIC: What heat stress index and measuring techniques should be adopted in the standard? How should the work-rest regimen be determined? When and under what conditions should environmental, metabolic, and medical monitoring be required?

I. Should a single index be specified in the standard?
  A. If yes: Which index should it be?
  B. If no: Which indices should be acceptable?
II. Should environmental and physiological monitoring techniques be specified in the standard?
  A. If yes: What monitoring techniques should be specified?
  B. If no: 1. What alternative procedure should be accepacceptable?
    2. What research is needed in this problem area?
III. Should the standard specify what work-rest ratio is necessary at different levels of heat exposure?
  A. If yes: Should a specific method be specified for estimating the work-rest ratio or should different methods be listed as acceptable?
  B. If no: Should the work-rest ratio be left as it is in the present NIOSH and OSHA recommendations?
  C. What further research is needed in this problem area?

REPORT OF THE CHAIRPERSON

Group No. 2 found it impossible to discuss any index or instrument that would be used without considering the whole problem of heat stress indices and standards. How would the standard be formulated? Would it refer to work practices or would it specify levels of heat stress that should never be exceeded?

We concluded that a single index or equivalent should be specified. The basic index suggested is the wet globe thermometer (WGT) because of its simplicity and ease of use in industry; the primary purpose would be to establish a point at which some other more detailed observations must be made. We considered that as we looked at a possible standard, we saw that we needed an action level index. What we visualized is an action level and a simple instrument that can be used to determine when that action level is reached. Allowing for a WGT or equivalent methods provides the opportunity for use of other instruments, since the specificity of the method is not of major concern. It also would allow an industry that wants to, to employ a more complicated measuring system. A single mercury thermometer would be inadequate. An industry must have a measurement that is at least equivalent to the wet globe thermometer.

The second issue was: should environmental and physiological monitoring techniques be specified in the standard? We determined that environmental monitoring techniques should be specified. For determining the action levels we suggest a single statement: whenever the condition is above the action level, it is necessary for compliance that the industry, by appropriate methods, show that the total heat load does not exceed an E_{req}/E_{max}, or equivalent, of 0.5. It would be management's responsibility to determine that the industry is in compliance.

We considered whether a list of work practices that could be used to achieve this 0.5 level should be recommended; however, we concluded that this would make the standard too complicated. We tried to think of the simplest expression of a standard so that it would be easy to determine compliance, and easy for the industry to achieve compliance. Our concern is the achievement of conditions that will not produce undue heat strain in the individual workers.

We also worked on the complicated issue of environmental monitoring. Industry must know what the levels are under ordinary conditions of the heat load at the particular jobs, and they must be able to categorize jobs as hot, cool, or moderate. Cool jobs would not require monitoring. For hot jobs, the level of heat will change under a variety of conditions. Under certain levels of heat stress, hot jobs should be environmentally monitored periodically; under more severe levels of heat stress, monitoring would be required whenever there are workers exposed.

We suggest that a heat level profile for jobs be established.

Most industries already know which jobs are hot or cool. If they do not know, we suggest wet globe temperature readings. If the WGT is below the action level, no special steps need to be taken. If it is above the action level, monitoring of the actual conditions at the job would be required, and this should be done during the hottest part of the day in the hot seasons. It is the responsibility of management to monitor their hot jobs to be sure they do not exceed the expected level of heat exposure. If it is exceeded, the industry must institute procedures to keep the $E_{req}/_{max}$ at 0.5 or below (an HSI of 50).

We believe that with the development of new equipment, physiological monitoring is not out of the question. Industry can use it as a method of showing compliance, if it wishes. If acceptable heart rate levels are achieved, regardless of the level of heat stress, then the industry is in compliance. Absolute values for acceptable heart rates were not determined. We felt that an eight-hour time-weighted average rectal temperature should not be higher than 38° C. Fluctuations during the day may go up to 39° C without the individual being under undue heat strain.

The next question concerned the work-rest ratio. We decided that there is not enough data on the best work-rest ratios for different levels of heat stress and levels of metabolic stress in terms of length of the rest cycle versus length of the work cycle. A statement recommending 50% work-50% rest or 25% work-75% rest was considered too simplistic. A lot depends on the actual length of work and rest periods and the level of physical work. We suggest using research funds to study the issue, since optimizing the work-rest regimen will be one of the more important methods of reducing the overall heat strain on the individual worker. Ergonomic physiologists could design joint experiments to collect the data to be used in making a determination. For specific levels of physical work and environmental heat stress, one could determine how long the work and rest periods should be to minimize heat strain.

The group did not address the issue of medical monitoring, except to say that it should be put in the hands of medical persons who are experienced in industrial medicine. The group felt that it was not competent to talk about medical monitoring or medical selection.

RECOMMENDATIONS FOR FUTURE RESEARCH

Recommendations for research needs include the development of models to predict work-rest regimen impact upon heat strain.

If good data are available, then a determination can be made about an optimum work-rest regimen for a specific hot job.

We agreed that emphasis should be placed on the development of practical techniques for monitoring physiological parameters. We should be able to measure body temperature during the work period. From the work that has been done in some industries on work heart rate and recovery heart rate, we feel this may be a very useful physiological monitoring technique.

Finally, we want to strongly recommend that people who are doing laboratory work on industrial heat stress should use the type of clothing the workers wear in hot industries.

WORKING GROUP NO. 3

Chairperson: C. Zenz   Rapporteur: R. Ilka
Members:
B. D. Dinman, K. Lacey, D. Minard, E. Shvartz

ASSIGNED TOPIC: What pre-employment selection criteria should be adopted?

I. Should there be a pre-employment selection for work in hot jobs?
  A. If yes: Should there be a specific screening method prescribed in the standard for pre-employment selection or should there be different methods listed as acceptable (which methods)?
  B. If no: Should medical criteria for selection be listed in the standard?
  C. If no: Should selection criteria be left to the physician's discretion?
  D. What further research is needed in this problem area?
II. Should periodical medical examinations be required?
  A. If yes: Should medical criteria be specified?
  B. If yes: What should these criteria be?
  C. What further research is needed?

REPORT OF THE CHAIRPERSON

Working Group No. 3 made a slight change in the question, "Should there be pre-employment selection for work on hot jobs?"

We changed the wording to the more commonly used terminology, namely, preplacement examinations. The question now reads, "Should there be a preplacement medical examination for work on hot jobs?"

The answer is: There should be a preplacement medical selection of employees for work in hot jobs. This examination shall be conducted to evaluate the worker's fitness for heavy workload in heat or for any work in extreme heat exposure. It shall place special emphasis on the cardiovascular system and shall include a review of previous medical history, with special attention to cardiovascular and heat-related disorders or illnesses. For those over age 45, there should be a required periodic medical examination. Medical criteria for these examinations should presently be based on the physician's clinical judgment, and on high standards of medical practice. Actual physiological response to the job should be considered as an important assessment of the individual's heat tolerance.

It may appear to some that these ideas were plagiarized from one of the documents distributed to workshop participants, namely "Appendix C—Standard Advisory Committee on heat Stress—Recommended Standard for Work in Hot Environments." After hours of discussion our thoughts congealed along similar lines. Our constants have not changed, except that we indicated a higher standard of medical practice. I hope we can find that in our society.

RECOMMENDATIONS FOR THE RESEARCH

Another finding from Group #3 was that research is urgently needed to devise a simple exercise test for the prediction and assessment of heat intolerance. Research is also needed on the long-term effects of hot jobs on normal individuals, as well as on categories of people who may be at increased risk, such as hypertensives, diabetics, and pregnant women. Workshops could be conducted on each of these conditions, particularly pregnancy. A critical consideration here is that a woman is often unaware of the fact that she is pregnant during the first three months. Similarly, research is needed on the genetic effects on men, since gonads are also exposed to the environment and are particularly sensitive to high temperatures.

The final point is not a medical one; it relates to nomenclature. With the diversity of terms in this field we would like to recommend either a uniformity of terms, a simplification of terms, or a parenthetical explanation of the terms being used.

WORKING GROUP NO. 4

Chairperson: S. M. Horvath Rapporteur: R. F. Goldman
Members:
R. R. Gonzalez, L. Myhre, R. L. Stephens

ASSIGNED TOPIC: Should there be different considerations given in the standard to workers of different age, sex, state of acclimatization, and physical work capacity?

REPORT OF THE CHAIRPERSON

Physical fitness, not age or sex, is most important to the hot industry worker. The worker should be encouraged to remain fit, since this is one of the most important elements in continuing to work in a hot job. Most of the observations made on physical fitness of industrial workers suggest that they are considerably below the level of fitness noted in most laboratory investigations. Consequently, the transfer of information from laboratory investigations to the worker on the job must be considered in light of the potential difference in physical work capacity. This is a very important difference, since the ordinary worker is troubled by numerous other factors that tend to reduce his capacity to perform work at high level.

We discussed various methods of evaluating physical fitness, and decided that a medical screening committee should determine the best method of evaluating physical fitness.

The second area discussed by the group concerned acclimatization to hot environments. It was concluded that acclimatization to the hot environment was an essential component of the worker's performance capability. We made several comments about the induction of acclimatization in relationship to absence from work, either due to vacations, to extended illnesses, or for other reasons. We strongly recommend that acclimatization procedures be initiated when a worker is absent from the job for a period of two weeks. The acclimatization procedure should be approximately four days in length, and should be designed to ensure that the worker will be working at full potential by the fourth day.

The problem of absence due to illness was difficult to evaluate because of differences in the duration and type of illness. The basic factors may be different in each case. We felt that anyone who has been away from work due to illness be returned to the job only with the full approval and consent of the medical supervision involved at the plant. Acclimatization procedures should be reinstituted for these individuals in the same manner as they would be for employees who are absent for an equivalent period of time.

We want to point out the need for an adequate educational program both for the employee and for the employer. Such an educational program should include: the relationship of the heat load, potential heat problems, the process of acclimatization, and any other factor that would help the worker and the employer understand the potential difficulties facing the worker in a hot environment.

Our third point concerned how fitness was compromised by other factors, including obesity, smoking, drug use, alcohol use, and types of chemical exposure. The group was aware that there are many other factors influencing the ability of a worker to perform at a high heat level. These include emotional, physiological, anatomical, or chemical factors. We feel that all factors that modify the fitness of an individual need to be taken into account in assigning workers to hot environments.

The fourth issue concerned work practices that might improve the ability of individuals to acclimatize to work in the heat and to improve their physical fitness. Three factors were considered: (1) The first work practice issue was water or fluid balance. It is important to understand that thirst is a very poor indicator of fluid balance. The worker should have an adequate intake of fluid, and a sufficient quantity of potable water should be made available to him at all times. (2) Protective clothing was another factor. Heat load may be increased by the amount and type of protective clothing worn by the worker. Employers should be aware of potential problems associated with the use of such clothing, and should take appropriate precaution in situations where protective clothing is worn. Employees should also be cognizant that protective clothing may allow a worker to work effectively for a brief period in a hot environment, without deleterious effect. (3) Finally, we felt that education about the problems occurring in hot environments was important and should be encouraged. Educational programs should be aimed at both the employer and the employee.

RECOMMENDATIONS FOR FUTURE RESEARCH

Research is needed to determine the rate of decay of acclimatization following the return of the individual to a normal type of environment. Information should include data on workers returning from employment in normal environments and from periods of nonemployment. Research efforts should strive to understand time factors related to the reinduction of acclimatization. It is not clear how much re-acclimatization is needed for an individual who has been away from a hot environment for a specified period of time. The research should be conducted on people who are actually working in the environment. We know very little about the processes of acclimatization and its loss in the ordinary worker.

Our second point of emphasis is the need for research on the problem of protective clothing and other devices designed to modify heat loads.

The third identified research need is the issue of decreased productivity due to heat exposure. We had some disagreement among ourselves on the problem of the physiological effects of working under hot conditions. Some of us felt there might be degradation consequences, while others were certain that many individuals would perform better simply because they were in this environment. Unfortunately, we do not know the full answer. Most psycho-physiological observations of people in hot environments have been limited to short periods of exposure. We cannot use experimental subjects for more than one or two hours, whereas the actual worker spends eight hours a day, five days a week, in that environment. His or her response may be entirely different from the response of the short-time-exposed experimental subject.

We agreed that research is needed on psychophysiological degradation as a possible result of chronic heat exposure, and on the adequacy and availability of appropriate training aids and programs.

WORKING GROUP NO. 5

Chairperson: R. Jensen Rapporteur: T. E. Bernard

ASSIGNED TOPIC: Should accident prevention aspects be included in the heat stress standard?

REPORT OF THE CHAIRPERSON

The NIOSH criteria document stressed the importance of unimpaired mental performance in accident prevention. In that document there was a recommendation that sedentary workers (e.g., equipment operators) should not work in environments above a certain WBGT over a specified length of time or if their job requires critical safety components. This provision was subsequently deleted by the OSHA Standards Advisory Committee.

We found that there is significant evidence demonstrating decreased mental performance with increasing environmental heat levels. However, we concluded that an upper limit of permissible exposures, for the purpose of enhancing the employee's safety, cannot be established. There are four major reasons for our conclusion and recommendations. First, there are no distinguishable inflection points in the mental performance data. Second, there are no obvious relationships between laboratory performance measures and industrial applications. Third, we are concerned that the correlation between thermal stress and accident rates has not been established adequately. Fourth, the relative importance of heat stress as a contributing factor in accidents is unknown.

With regard to the first point, laboratory investigations into mental performance suggests that optimal performance is achieved somewhere in the lower region of the comfort zone. Performance decreases steadily with increasing thermal stress. There is no point at which there is a sudden decrease in performance; it is a very gradual change. Furthermore, among laboratory measures of mental performance there is no transcending relationship between performance and environmental conditions. Time of exposure is a factor to be considered.

There are data that suggests that accident rates are minimal at the lower end of the comfort zone and that there is an increase in accident rates with increasing thermal stress. Again, it is not clear that there are any inflection points at which the accident rate increases rapidly due to the increasing thermal stress.

Concerning the second point, the relationship between laboratory performance tests and field applications is complex. Laboratory tests have indicated that decrements in the different performance tests do not change uniformly with environmental heat stress and time. In actual working situations many different mental tasks are integrated into a single job. There is no simple method to extrapolate the laboratory data to most industrial performance requirements. In addition, the safety experience gained from one type of job may not be applicable to all jobs. This would suggest the need for several standards, depending on the critical components of the job in question.

The third reason we are not recommending any special provisions for safety is that research has not established the relationship between thermal stress and accident rates or between thermal stress and behavior that might lead to an accident. Field data show that reported injuries increase as environmental temperatures increase. However, data are not available to establish a quantifiable relationship between thermal stress and accident rates. We think the quantifiable relationship is necessary, if we are to justify exposure limits based on accident prevention consideration.

The final reason for not recommending special provisions based on accident prevention is that the relative importance of heat stress as a contributory factor in accidents is unknown. We do, however, anticipate that the implementation of a work practices standard, such as we have been discussing, would yield a reduction in injury rates. If we reduce the number of workers who experience excessive thermal strain, we should reduce the number of accidents.

In conclusion, there is not enough information available to recommend additions to the heat stress standard to enhance accident prevention. This is due to the questionable appropriateness of extrapolating laboratory performance data to a broad spectrum of industrial jobs, and the inadequate field data on relationships between heat and accidents.

RECOMMENDATIONS FOR FUTURE RESEARCH

Further research should be directed to field evaluation of thermal stress to quantify measures of accident probability or frequency with consistent environmental and job metrics, and to determine the role of heat stress in accidents.

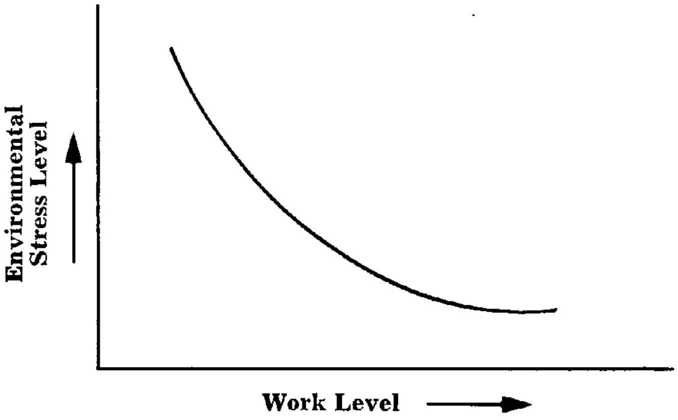
Part III

DISCUSSION OF WORKING GROUP RECOMMENDATIONS

DISCUSSION OF WORKING GROUP RECOMMENDATIONS

Dr. O. Banks, *Moderator*

As a point of departure for the discussions, Dr. Banks put on the board the hypothetical heat stress diagram shown below:



This diagram had the general characteristics of the ACGIH TLV curve for continuous work. However, it had no numerical reference points for either the level of environmental heat stress or the level of physical work. This was accepted by the participants as an approach for discussion. The major issues discussed were: (1) What index or indices should be used to express the level of environmental stress?; (2) What should be the range of physical work included on the abscissa that would realistically reflect industrial jobs?; (3) Should there be a single curve or a family of curves presented?; (4) What should the curve or curves mean in terms of the physiological heat strain and/or the possibility of incurring heat illness at any point above the line or lines? The debate on each of these issues continued until a general agreement seemed to be reached. However, in some cases the debate had to be terminated because an agreement seemed not to be possible.

The first issue, "What index or indices should be designated on the ordinate?," was readily resolved once the group agreed that, for the purposes of the discussion, no numerical values would be assigned. It was agreed that for industrial heat stress monitoring purposes the recommendation of working group No. 2 would be accepted. This recommendation was that for industrial monitoring, the WGT or equivalent should be used. It was also agreed equivalent scales for the WGT, WBGT and ET would be included on the ordinate.

Before this decision was reached a discussion ensued over which ET would be used. Recently a new ET, designated ET,* has been developed which is a rational index, rather than the empirical index that the old familiar ET is. Many of the members of the discussion group did not know of or thoroughly understand the development of the ET* and the theory and data upon which its development was based. A copy of a working paper describing the development and application of the ET* was given to each of the discussants. The background of the ET* was reviewed, its advantages and disadvantages argued, and its applicability to routine industrial heat stress monitoring was discussed. As a heat stress index, it was accepted as scientifically excellent. However, for routine industrial heat stress monitoring it was considered too complex and, at least for the time being, should not be recommended to replace the old ET as an acceptable heat stress monitoring index.

The second issue, "What is the realistic range of levels of physical work that are characteristic of industrial jobs?," was intensively debated, with the introduction, by several, of work level data obtained on industrial workers on the job. It was agreed that the work would be roughly classified as sedentary (light), moderate, and heavy, and that the range of work levels was a continuum rather than discrete points. What each of these classes represents in terms of energy cost raised the point of whether only a midpoint of each class range be designated. Another concept was to take the upper value for each class range. The consensus was that sedentary or light work covered the range of energy expenditures of 100 to 200 kcal/hr with a midpoint of 150; moderate work, 200 to 300 kcal/hr with a 250 kcal midpoint; and heavy work, 300 kcal/hr or above with a midpoint of 350 kcal. Data obtained on workers on the job indicate that rarely do industrial jobs require more than 350-400 kcal/hr energy expenditures except for short periods, and workers cannot and do not work at levels higher than these except for relatively short periods.

These numerical values for the abscissa of the hypothetical chart were accepted. This permits establishing either a continuum of energy levels or discrete points, whichever best serves the purpose of the user.

Another point of discussion on this issue was what units of energy should be used. Should it be kilocalories (kcal), British thermal units (Btu), watts (W) or some other unit? In order to minimize confusion, it was considered logical to designate energy expenditure in units of kilocalories per hour and or British thermal units. These two units are understood by most engineers and health scientists.

Considerable discussion centered around how the energy expenditure would be determined and whether it had to be measured on every worker, on each job, and for each of the tasks that make up each industrial job. There are essentially two ways that energy requirements of a job can be calculated: (1) direct measurement by collecting expired air from the worker while performing all aspects of the job—this includes both work and rest periods; (2) the indirect method of estimating energy expenditure utilizing the existing tables of energy for specific tasks and a determination of the exact amount of time the worker spends on each aspect of each task; from these a time-weighted average energy expenditures can be calculated. Once the energy requirements of each job are established, they need not be repeated unless the job has changed.

Direct measurement is the most accurate and desirable procedure, but because it is very difficult to accomplish under most industrial situations, it was considered impractical for routine industrial use. The indirect method was agreed to be the only acceptable alternative. The recognized wide interindividual differences in physical work capacity, body build and size, work efficiency, and the way the task is performed, all of which influence energy costs of doing the job, argue against the value of a precise measurement of energy cost for an individual performing a specific task.

Another point of discussion on this issue was the period of time to be covered in the time-weighted average (TWA) energy cost calculation. Should it be one hour, two hours, four hours, or a full eight-hour day? Good arguments were made for selecting each of the alternative time periods. This point was not fully resolved, although either the one- or two-hour TWA was preferred. Because most jobs consist of repetitive tasks separated by rest periods, either the one- or the two-hour TWA should reasonably reflect the average for the entire work day. When the situation arises where an individual works continuously without any stopping for one or more hours in the heat and then has a long rest break in a cool environment, a TWA covering the total work and rest time would not be very meaningful physiologically, especially under conditions of high environmental heat load and moderate or heavy work loads. The total heat-work stress during the prolonged work period could overwhelm the capacity of the body to handle the stress, with resulting occurrence of serious heat disorders.

The third issue, "Should there be a single curve or should there be a family of two or more curves?," was extensively discussed but was not fully resolved. The discussion became inextracably intermeshed with issue #4. Efforts to confront issues 3 and 4 as separate and independent entities were not successful. Until the meaning and limits of the line or lines were specifically defined, any serious discussion of the number seemed premature; however, during the course of the discussions several pertinent points were raised. Particularly relevant was the question of whether all workers, regardless of age, sex, physical work capacity, body size and build, level of acclimatization, past history of heat illnesses, or health status, could be considered as a group based on some common denominator; or whether they had to be considered as separate groups with different lines for each category. From the discussion and data presented, it appeared that the factors of age, sex, physical work capacity, body size and build, and level of physical fitness could be combined, with the common denominator being the aerobic work capacity ($\dot{V}O_2$ max). The level of strain would be, therefore, a function of the percentage of the $\dot{V}O_2$ max required on the job. It was also shown that the rate of acquiring heat acclimatization in the physically fit is about twice as fast as in the physically unfit. Even in the physically fit, heat unacclimatized individual, the level of heat strain would be expected to be less for an equal amount of heat stress than it would be for the physically unfit individual. This concept has special significance when establishing acceptable levels of heat stress for heat-acclimatized and heat-unacclimatized workers.

Whether separate lines should be established for workers with a history of heat illnesses, with past or present health problems (such as hypertension, diabetes, etc.), who are on a regimen of therapeutic drugs, with drug or alcohol abuse histories, and others, was considered to be a medical problem. It would be the responsibility of a physician to decide whether the individual required special considerations or whether heat exposure on the job would be prohibited completely. It was also agreed that pre-placement and periodic medical examinations of employees in hot jobs is an important work practice for reducing the risk of heat induced disorders.

The discussion on issue #3, therefore, did not resolve whether there should be one, two, or more lines, but it did, by combining several items, reduce the potential number.

The fourth issue, "What should the curve mean in terms of physiological strain and/or the probability of incurring heat illness?," generated the most discussion and the least agreement.

Several important points emerged. Foremost among them, and the one basic to all other points, was "What is the meaning of the line shown on the diagram?" Is it an action line, a threshold limit value (TLV), a permissible exposure limit (PEL), or a maximum level beyond which no worker should ever be exposed? Without numerical values of environmental heat stress levels on the ordinate of the diagram, it was virtually impossible to coherently discuss the point. An increase or decrease in the numerical values of any point on the ordinate would change the entire concept of the line. This point was debated at some length, but no agreement was reached on what values should be adopted. The numerical values would influence the meaning of the line, and the meaning of the line would influence the acceptable numerical values.

However, agreement was reached that if it were to be an action line, then all points below the line should represent conditions to which essentially 99.5 percent of healthy, heat-*un*acclimatized people could be exposed without risk of heat illness. By definition, then, all points on or above the line would represent some risk of heat illness and would require appropriate preventative action. In effect, the entire area of heat stress-work load combinations could be divided into two categories: (1) no risk of heat illness and (2) risk of heat illness, with the two zones being separated by the action line.

What would constitute "appropriate action" when the action line was reached or exceeded? It was agreed that this would depend on how far the action line was exceeded. Environmental monitoring at least during the hottest hours of the day would be required. Work practices and/or engineering controls would be initiated to ensure that the level of heat strain did not exceed acceptable levels. Acceptable levels of heat strain would be reflected by TWA deep body temperatures not exceeding 38° C, with peak values not to exceed 39° C, and TWA work heart rates of not over 140 beats per minute, with peak values of 160 to 180, and 3-minute recovery heart rates of not over 110 per minute. Environmental monitoring by any of the rational heat stress indices would be required. A Belding-Hatch heat stress index value of 50, which corresponds to those levels of physiological response, should not be exceeded. Physiological monitoring of the workers would be an acceptable alternative method of ensuring that an acceptable level of heat-work stress was not being exceeded. Under high levels of heat stress, work practices and environmental controls would be required to keep the total heat-work stress within acceptable values.

If the above concept of the action line were accepted, then what would the TLV line be? Would it be the same as the action line, or a line with values above the action line? How far above the action line would it be? What percentage of the worker population would it protect? What would be the required work practices and/or engineering controls to ensure compliance?

In the ensuing discussion, it was soon apparent that the action line would have to be below the TLV line, because the concept of the ACGIH TLV line for continuous work was that 95% of the healthy heat-acclimatized worker population would be protected, while the action line assumed almost a 100% protection of unacclimatized workers. If a line for 99.5% was constructed and another one for 95%, then it would seem logical to construct 75%, 50%, and 25% lines also. This would result in a heat-work diagram with a family of curves, each relating to a population with a higher level of heat tolerance. This approach would require preplacement selection to eliminate those with lower heat tolerance from the worker population. Although the concept had some appeal, it was not considered by the majority as a workable instrument for practical industrial use at the present.

The issue of action lines versus TLV lines was not completely resolved. Either or both could be included, provided the users appreciated the exact meaning of each. If this were the case, no confusion should arise; however, conversely, no advantage would accrue from using both. If the action line were the same as the TLV line, then, by definition, only 95% of the healthy heat acclimatized worker population would be protected.

Should a permissible exposure limit (PEL) line be included? The concept of the PEL is that any heat-work exposure above this line would involve imminent danger of the exposed individual incurring heat illness. Thus, exposure to such conditions should not be permitted. Some of the discussants thought having both an action line and a PEL line would be helpful. It was agreed that if this alternative were chosen for the standard, then the area between the two lines would delineate those combinations of heat and work where management must be alert to possible heat induced health effects and where work practices, engineering controls, protective equipment, and physiological and/or medical monitoring must be instituted. Environmental monitoring would also be required.

The concept was discussed, but not resolved, of whether, by the application of work practices and engineering controls, the total heat-work stress would be controlled, so that high heat-work stress situations that approached the PEL would be reduced to lower, less stressful, levels approaching the action line. If this philosophy were accepted, then, by definition, only an action line (protecting an agreed upon percentage of workers) would be needed, such as the present ACGIH TLV. Any measured heat-work stress level that exceeded the action line would require the application of practices and controls that would reduce the stress level to or near the action line.

A maximum heat-work stress level, beyond which no person under any circumstances or for any length of time should be exposed (maximum exposure level), was briefly discussed, but it was not considered relevant to a heat stress standard. Such high levels of heat stress do not occur under general industrial operations, but only in cases of fire, explosions, etc., where immediate evacuation and the use of special emergency protective equipment would be the rule.

Medical preplacement and job assignment examinations and monitoring were considered in the deliberations. With little dissent, the suggestions of Dr. Minard and those of working group #3 were accepted as reasonable, feasible, and adequate.

The application of work practices as a major way of controlling industrial heat stress was accepted by all the discussants. Useful work practices for hot jobs have appeared as lists in many documents and publications; consequently, they were not again individually enumerated and discussed. It was agreed that such a list should be available to management and the workers. But whether a list should be included in the standard itself was not resolved. Because different combinations of work practices, engineering controls, and environmental or physiological monitoring can be used to achieve the same end result of reducing heat strain, it should not be necessary to specify which ones should be applied at different levels of heat stress.

It was agreed that for compliance purpose, management would be required to furnish a written procedure that would be put into practice when a heat stress situation (as set forth in the standard) was reached at the job site. The adequacy of the procedures policy would be judged on the basis of the work practices, engineering controls, and environmental or physiological monitoring that would be put into effect to control the heat stress. Environmental and work level monitoring would be required to alert management when a potential heat stress problem was present. To check compliance, the OSHA inspector would measure the environment with the WGT, WBGT, or ET, estimate the work level, and then decide whether the management procedures would be adequate to control the heat stress and minimize the possibility of heat illness occurring. The standard would specify the goals and effective ways to meet them; industry would be responsible for achieving the goals.

The question of salt replacement and/or supplementation for both heat acclimatized and non-heat acclimatized workers was discussed but a precise statement of the problem or of a recommendation was not reached. Replacement of salt loss in the sweat is necessary. However, the consensus appeared to be that for fully acclimatized individuals who are healthy, the average diet contains sufficient salt to replace that lost in the sweat and that little advantage is gained by salt supplementation. For the unacclimatized individual, salt replacement and supplementation may be desirable during the first few days of heat exposure. The point was raised that excessive salt intakes may induce increased potassium loss. This concept, however, has not as yet been accepted by many heat experts. In addition it was cautioned that persons with heart problems, those on a low sodium diet, and those taking diuretics should not be given salt supplementation except on the advice and orders of a physician.

Part IV

CONCLUSIONS OF THE WORKSHOP

A. RECOMMENDATIONS FOR AN IMPROVED HEAT STRESS STANDARD

Points on which a conclusion was reached are:

1. The time-weighed mean hourly levels of energy expenditure are 150, 250, and 350 kilocalories per hour for work categorized as low, moderate, and heavy in industrial work. The level of work seldom exceeds 350 kcal in an hour.
2. The primary heat stress index to be used for monitoring the industrial environment should be the WGT, with the alternative of using the WBGT, the ET or equivalent.
3. Some type of curve, graph, or table should be used to designate those combinations of work level and environmental heat stress beyond which the presence of heat stress can be expected. What the values of WGT, WBGT, or ET are that would indicate the beginning of heat stress for each work level was not agreed upon. The values would depend on the safety factor included.
4. Except for unusual and rarely occurring situations, industrial heat stress-strain problems can be controlled by application of appropriate work practices, engineering controls, and/or physiological monitoring. These procedures are well documented and readily available in the scientific literature.
5. Preemployment or preplacement medical examination and/or medical monitoring is recommended to identify those individuals who are especially heat intolerant or are likely to become a heat casualty because of any of a wide variety of reasons.
6. Physiological monitoring of heart rate and/or body temperature of the worker during work is feasible. If heart rate and/or body temperature do not exceed an acceptable level, it can be assumed that the worker is not experiencing undue heat strain, regardless of the level of environmental heat.
7. A heat stress standard should be kept as brief, simple, and general as possible, within the needs for clarity and unambiguity.
8. Flexibility in how management could achieve compliance was urged. The standard should establish goals and limits, and industry should be free to use any combination of work practices, engineering controls, physiological monitoring, or medical assignment that best fits its purposes to meet the goals and limits.

9. Each industry which operates hot plants shall put in writing policies and practices they adopted for preventing heat illnesses. This should address as a minimum monitoring methods, acclimatization procedures, the established work-rest regimen, provision of water and salt, use of protective clothing, available engineering controls for cooling the environment, preplacement and periodical medical examinations, emergency procedures during periods of hot spells in the area, and procedures for first aid as well as for taking unscheduled rest if a worker feels exhausted or overheated.

The point that generated a long discussion, but developed no consensus, was whether one or more of an action line, a TLV line, a PEL limit, and/or a maximum exposure limit should be designated. In concept, two lines, such as an action line and a TLV or PEL, received considerable support. However, no agreement was reached on what the environmental stress index values for each should be or what the philosophical basis for each was.

On this note the meeting was adjourned.

B. RESEARCH RECOMMENDATIONS

Each Working Group was charged with the responsibility of recommending areas where research is urgently needed to provide the data base for a scientifically acceptable, reliable, fair, and workable heat stress standard. The working groups agreed that, in spite of the large number of heat stress studies that have been conducted during the past fifty years, there still remain significant gaps in our knowledge that must be filled before a completely uncontroversial heat stress standard can be promulgated.

Similar recommendations expressed in different terms were made in some instances by more than one of the working groups, while some were made by only one of the groups. This summary list of relevant recommendations was extracted from the deliberations of the five working groups.

1. Develop simple, reliable, and practical instrumentation for field monitoring environmental and physiological parameters.
2. Develop a personal environmental heat stress dosimeter relatable to physiological heat strain.
3. Determine the optimum levels of salt intake for acclimatized and unacclimatized workers exposed to moderate and high levels of heat stress.
4. Establish the increased health risk resulting from a rising core temperature above 38° C for short- and long-term exposures.

5. Establish the optimum rest-work regimen for a wide range of heat stress and work intensity combinations. This would include development of models to predict the best rest-work regimen for a specific hot industrial situation.
6. Develop a simple exercise test that can be conducted at comfort temperatures for predicting and assessing a worker's tolerance or intolerance to heat.
7. Establish the rate of decay and the rate of reinduction of heat acclimatization.
8. Establish the effects of short- and long-term heat exposure on health, productivity, and psychophysiological degradation, in normal workers and in special categories of workers, such as hypertensives, diabetics, and pregnant women.
9. Determine the role of heat stress in accident probability and accident rates.
10. Determine the physiological strain imposed on the worker from the use of protective clothing and equipment in hot environments.
11. Prepare educational programs aimed at both the employer and employee, to point up the health effects of heat stress and what each individual can do to minimize the effects.
12. Validate the degree to which heat tolerance can be enhanced by improving physical work capacity.
13. Establish the degree to which other factors (e.g., obesity, smoking, drugs, chemical, emotional factors, etc.) compromise the individual's ability to work in the heat.
14. Determine the genetic effects of heat exposure in men, particularly in relation to spermatogenesis and libido.
15. Establish the prevalence of acute and chronic heat illnesses or occupational origin.

APPENDICES

APPENDIX A

NIOSH WORKSHOP ON THE HEAT STRESS STANDARD

September 17-19, 1979

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APPENDIX B

LIST OF HANDOUTS FOR HEAT STRESS WORKSHOP

1. Dukes-Dobos, F. N., and A. Henschel. Development of Permissible Heat Exposure Limits for Occupational Work. ASHRAE Journal 15:53, 1973.
2. Kuhlemeier, K. W., and J. M. Miller III. Assessment of Deep Body Temperature for Workers in Hot Jobs. DHEW (NIOSH) Publication No. 77-110. August 1976.
3. Jensen, C. and D. A. Heins. Relationships Between Several Prominent Heat Stress Indices. DHEW (NIOSH) Publication No. 77-109. October 1976.
4. Kamon, E., A. Goldfuss, J. L. Hodgson, J. L. Loomis, and F. N. Dukes-Dobos. Cooling Efficiency of Different Air Velocities in Hot Environment. DHEW (NIOSH) Publication No. 79-129. March 1979.
5. Ramsey, J. D. Appendix C — Standards Advisory Committee on Heat Stress — Recommended Standard for Work in Hot Environments. DHEW (NIOSH) Publication No. 76-100. February 1973.
6. NIOSH A Recommended Standard for Occupational Exposure to . . . . Hot Environments. DHEW Publication.
7. Goelzer, B. Evaluation of Heat Stress in the Work Environment. World Health Organization Document No. OCH/77.1. Undated.
8. Shvartz, E., S. Shibolet, A. Meroz, A. Magazanik, and Y. Shapiro. Prediction of Heat Tolerance from Heart Rate and Rectal Temperature Environment. J. Appl. Physiol.: Respirat. Environ. Exercise Physiol. 43(4): 684-688, 1977.
9. Maffly, R. H. Running Out of Water. Emergency Medicine. p. 57-61, June 1979.
10. Kamon E Scheduling Cycles of Work for Hot Ambient Conditions Ergonomics, Vol. 22, No. 4, p. 427-439. 1979.
11. Astrand, I., O. Axelson, U. Eriksson and L. Olander. Heat Stress in Occupational Work. AMBIO, Vol. 4, No. 1, p. 37-42. 1975.
12. Belgian Heat Stress Standard of 1975. Moniteur Belge, May 21, 1975 p. 6307-6312.
13. International Standard Organization Document. No. ISO/TC159/SCS/GTI/44, May 28, 1979. Draft Standard for Hot Environments: Determination of the "Required Sweat" Heat Stress Index.
14. International Standard Organization Document No. ISO/TC159/SCS/GTI/N41. Draft Standard for Hot Environments: Determination of the WBGT Heat Stress Index.

15. Dukes-Dobos, F.N. and R. Jensen. Abstract. Heat Tolerance of an Indigenous Desert Population in the United States of America. Jerusalem Satellite Symposium on Environmental Physiology. May 1974.
16. American Conference of Governmental Industrial Hygienists Booklet. Threshold Limit Values (TLVs) for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1977.

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