NIOSH HEALTH HAZARD EVALUATION REPORT:

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U.S. Department of the Interior
Grand Canyon National Park
Grand Canyon, Arizona

April 2002

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

PREFACE

The Hazard Evaluations and Technical Assistance Branch (HETAB) of the National Institute for Occupational Safety and Health (NIOSH) conducts field investigations of possible health hazards in the workplace. These investigations are conducted under the authority of Section 20(a)(6) of the Occupational Safety and Health (OSHA) Act of 1970, 29 U.S.C. 669(a)(6) which authorizes the Secretary of Health and Human Services, following a written request from any employer or authorized representative of employees, to determine whether any substance normally found in the place of employment has potentially toxic effects in such concentrations as used or found.

HETAB also provides, upon request, technical and consultative assistance to Federal, State, and local agencies; labor; industry; and other groups or individuals to control occupational health hazards and to prevent related trauma and disease. Mention of company names or products does not constitute endorsement by NIOSH.

ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by Ann Krake, Joel McCullough, and Brad King of HETAB, Division of Surveillance, Hazard Evaluations and Field Studies (DSHEFS). Field assistance was provided by Loren Tapp. Desktop publishing was performed by David Butler. Review and preparation for printing were performed by Penny Arthur.

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For the purpose of informing affected employees, copies of this report shall be posted by the employer in a prominent place accessible to the employees for a period of 30 calendar days.

Highlights of the NIOSH Health Hazard Evaluation

Evaluation of Heat Stress in Grand Canyon Park Rangers

In Sept. 1999, and June/July 2000, NIOSH representatives conducted health hazard evaluations at Grand Canyon National Park. We looked into management and employee concerns about park rangers' exposures to high temperatures while patrolling and hiking into and out of the canyon.

What NIOSH Did

- We measured the outdoor temperatures in the canyon and on the rim. We also measured how much work (work load) the rangers did.
- We weighed the rangers before and after their hikes to test for dehydration (not enough water in their bodies). We took blood to look for signs of hyponatremia (not enough sodium in the blood).
- We measured the heart rates and body temperatures of the rangers while they hiked in and out of the canyon and patrolled the inner canyon and the South Rim.
- We talked to the rangers about their jobs and asked them to tell us their health concerns.

What NIOSH Found

- Inner-canyon and south rim temperatures and ranger work loads caused rangers to be exposed to excess heat stress and increased their risk of getting heat sickness.
- None of the rangers were acclimatized (used to working in the hot weather) and many were not used to working so hard.
- Every ranger had heat strain, which means that their heart rates, and/or body temperatures were so high during parts of their work shifts that they were in danger of becoming seriously ill.
- Most rangers were mildly dehydrated before and during their hikes, but none got sick.
- There were not enough rangers to work at inner-canyon stations when other rangers needed to rest or get used to the heat.
- There is no formal heat stress management program at the park.

What Park Managers Can Do

- Decrease the work load of those hiking out by using mules or helicopter transportation.
- Create a heat stress program that will:
  - assess employees for medical fitness before they begin hard work and especially during the hot season;
  - allow employees to get used to the heat (acclimate) before they work in it full time;
  - train employees to know the dangers of and protect themselves from working in extreme heat;
  - encourage employees to report any heat stress symptoms and signs;
  - keep systematic records of employee reports of heat stress illnesses;
  - teach employees to monitor their own and others' heat stress and strain signs.
- Install outdoor showers and/or use ice vests to prevent employee heat stress and strain.

What Park Employees Can Do

- Take more time to complete hard work, such as hiking out, by taking longer breaks more often.
- Wait to do hard work until it's cooler.
- Soak your body and clothes in the shower or the creek during hot weather before you leave the station for rescues or patrol.
- Learn to monitor yourselves and co-workers for heat stress, and heed the warning signs of heat stress by taking breaks and rehydrating when needed.
- Take care of personal needs before those of victims for safer, more effective rescues.
- Report and record any heat-related illnesses and other concerns.

CDC Workplace Safety and Health

What To Do For More Information:
We encourage you to read the full report. If you would like a copy, either ask your health and safety representative to make you a copy or call 1-513/841-4252 and ask for HETA Report # 99-0321-2873

National Institute for Occupational Safety and Health NIOSH

Health Hazard Evaluation Report 99-0321-2873

U.S. Department of the Interior Grand Canyon National Park
Grand Canyon, Arizona
April 2002

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SUMMARY

The National Institute for Occupational Safety and Health (NIOSH) received a health hazard evaluation (HHE) request from the management of the Grand Canyon National Park in Arizona. The request indicated that many employees, especially park rangers assigned to the park's inner canyon and wilderness areas, are at high risk for heat stress illness because duties requiring moderate to extreme physical exertion are conducted in outdoor temperatures that usually exceed 100°F during spring and summer. The requesters asked NIOSH to evaluate heat stress in the work environment and make recommendations to prevent heat illness among the employees.

The first of two investigations was conducted September 5–12, 1999. Core body temperatures (CBTs), physiological hydration measurements, and self-reported heat strain indicators, were collected from patrolling corridor rangers and trail crew personnel rebuilding an inner-canyon section of the North Kaibab trail. The second evaluation took place June 26–July 5, 2000; CBT, heart rate, blood electrolytes, and pre- and post-activity body weights were measured on wilderness and corridor rangers, preventative search and rescue rangers (PSARs), and maintenance rangers. Individual and task-specific metabolic rates were estimated, and wet bulb globe temperatures (WBGTs) were measured during both evaluations. Monitored activities included hiking into and out of the canyon between the South Rim and Phantom Ranch, patrolling the inner canyon, and patrolling the South Rim. Most activities included trail-dependent elevation changes of up to 4,900 feet (ft).

The results were compared to the NIOSH recommended action limits and recommended exposure limits (RALs/RELs) and the American Conference of Governmental Industrial Hygienists (ACGIH) Threshold Limit Values (TLVs®). NIOSH and ACGIH assess heat stress using sliding scale limits based on environmental and metabolic heat loads. In addition, ACGIH provides physiological heat strain limits in situations of excess heat stress. For individuals with normal cardiac performance, sustained (over several minutes) heart rate should remain below 180 beats per minute (bpm) minus age (in years), maximum CBT should remain below 100.4°F for unselected, unacclimatized personnel (101.3°F for medically selected, acclimatized personnel), recovery heart rate at one minute after a peak work effort should be below 110 bpm, and there should be no symptoms of sudden and severe fatigue, nausea, dizziness, or lightheadedness.

Results of both surveys indicated that most trail crew members and rangers were exposed to heat stress in excess of the screening criteria. During the 2000 survey, daily high WBGTs at Phantom Ranch averaged 92°F with a one-day peak of 98.8°F, and none of the participants could be considered fully acclimatized (used to working in the extreme heat.) All participants experienced heat strain to some degree, i.e., some or all of their measured physiologic parameters exceeded at least one of the evaluation criteria during each activity. Five of six participants hiking out of the canyon exceeded a CBT of 100.4°F an average of 43% of their activities, and two participants exceeded 101.3°F about 20% of the time. One ranger exceeded a CBT of 102.2°F for 14% of the activity, a level that calls for immediate termination of exposure even when the individual is being monitored. All of those hiking out also exceeded the heart rate criterion. All monitored participants hiking into the canyon exceeded the heart rate and CBT criteria, as did five of six PSAR participants patrolling the south rim, and all three employees conducting inner-canyon patrol. All but one of the measured participants developed mild dehydration (body weight loss of 1.5% or less) during their activities in the heat, but their electrolytes remained within normal limits. One case of hypernatremia (attributed to dehydration) occurred. The baseline osmolality (a measure of serum solute concentration) was elevated in approximately 50% of the participants, which indicates some degree of dehydration prior to activities. During both surveys, the majority of employees reported that they had a history of heat-related symptoms or illnesses while working in the park but had never reported them.

Health hazards exist from excessive heat and overwork for employees assigned to the corridor trails and inner canyon of Grand Canyon National Park. Every participant was exposed to combinations of environmental and metabolic heat in excess of occupational criteria, and every participant with heart rate and core body temperature measurements exceeded one or both of the criteria for at least part of the sampling period. The majority of participants reported a history of heat-related symptoms or illnesses while working at the park, however, the park does not have a formal heat stress program for its employees or a system for reporting heat-related illnesses. Recommendations are made regarding reductions in workload and the establishment of work monitoring, heat stress training, and medical surveillance programs.

Keywords: SIC 7999 (Amusement and Recreation Services, Not Elsewhere Classified) and SIC 9512 (Land, Mineral, Wildlife, and Forest Conservation). Heat stress, heat strain, heat-related illness, heat disorders, core body temperature, metabolic rates, WBGT, wet-bulb globe temperature, park rangers, hyponatremia, hypernatremia, dehydration, serum electrolytes, sodium, osmolality.

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INTRODUCTION

On August 18, 1999, the National Institute for Occupational Safety and Health (NIOSH) received a health hazard evaluation (HHE) request from the management of the Grand Canyon National Park, Grand Canyon, Arizona. The request indicated that many employees, especially park rangers assigned to the park's inner canyon and wilderness areas, were believed to be at high risk for heat stress and strain because their duties require moderate to extreme physical exertion and are conducted in outdoor temperatures that usually exceed 100°F during spring and summer months. The requesters asked NIOSH to evaluate heat stress risk in the work environment and make recommendations to prevent heat strain and illness among the employees.

Two investigations were conducted by NIOSH occupational health and medical officers. During September 5–11, 1999, a preliminary investigation was completed which indicated that park rangers on inner-canyon patrol and trail crew personnel rebuilding an inner-canyon section of the North Kaibab trail were exposed to combinations of environmental and metabolic heat in excess of NIOSH and the American Conference of Governmental Industrial Hygienists (ACGIH) screening criteria. As a result, a sampling strategy was developed for a more extensive heat stress and strain evaluation during peak hot weather season.

During the last week of June and the first week of July 2000, all categories of park rangers, except river patrol, were evaluated for heat stress and strain while hiking into and out of the canyon and conducting other duties. The work environment was assessed with wet bulb globe temperature (WBGT) monitors and by calculating the estimated metabolic heat load of each work task. The heat strain evaluation included monitoring core body temperature (CBT), ear temperature, skin temperature, heart rate, activity levels, pre- and post-activity body weights, serum electrolyte analysis, and self-reported heat strain indicators. On August 16, 2000, individual serum analytical results were mailed to participants of that portion of the study.

BACKGROUND

The Grand Canyon National Park in Grand Canyon, Arizona, is one of almost 400 national land areas managed by the U.S. Department of the Interior's National Park Service. The park includes the South Rim, which draws 90% of the visitors, the North Rim, and the canyon, with the Colorado River flowing through it. The park is 277 river-miles long, an average of 10 miles wide, about 1 mile in depth, and encompasses 1.8 million acres (1,904 square miles). About 5 million visitors a year to the canyon stay an average of 4 hours.

Access to the inner canyon, Phantom Ranch Lodge, and the river, 2,400 feet (ft) in elevation (elev.), is via the corridor trail system, the primary work area of concern. The system includes two trails that start at the south rim of the canyon and go to the river, the Bright Angel (BA) trail, about 10 miles long, elev. 6,860 ft, and the South Kaibab (SK) trail, about 7 miles long, elev. 7,260 ft. A third trail, the North Kaibab (NK), starts from the canyon's north rim, (elev. 8,800 ft), and is about 14 miles long. Each of the three trails has a change in elevation of about 1 mile from beginning to end. Total "rim to rim" mileage (from the south rim down to the river and up to the north rim) is about 25 miles, depending upon which trails are hiked. Park facilities at Phantom Ranch include a ranger station, bunkhouse, wastewater treatment plant, and campground. A similar facility, Indian Garden, is located on the BA trail between Phantom Ranch and the south rim, and another, Cottonwood Camp, is on the NK trail between Phantom Ranch and the north rim. There are no such facilities on the SK trail. Summer temperatures on the south rim range from 50–80°F, while north rim temperatures are generally 10°F cooler. Inner canyon temperatures run about 30°F higher than south rim temperatures and have been recorded at 120°F and above.

Approximately 400 rangers are employed throughout the park during the summer. They serve in one or more of four major job categories—corridor patrol, wilderness patrol, river patrol, and interpretation. Corridor, wilderness, and river rangers are responsible for providing rescue and emergency medical services and law enforcement, and many are trained and certified emergency medical technicians and law enforcement officials. Much of their time is spent patrolling the main corridor trails and campgrounds (corridor rangers), smaller trails and back country campgrounds (wilderness rangers), and the river and river trails (river patrol rangers). Interpretation rangers are responsible for guiding nature hikes and providing interpretive and educational programs to visitors. There are also rangers who operate and maintain the wastewater treatment plants throughout the park and who remain at their stations while on duty. A fifth category, preventive search and rescue rangers (PSARs), are mostly volunteers who work part-time shifts and patrol much of the rim area and upper 3 to 5 miles of the BA and SK trails.

Rangers who work the inner-canyon trails stay as residents of Phantom Ranch, Indian Garden, or Cottonwood Camp ranger station for about eight days while they conduct their duties. The first and last days of each shift are for hiking into and out of the canyon. During the summer, there are nine ranger positions that rotate between these three inner-canyon locations. However, currently and in the past several years, only six rangers have been available to cover them—two rangers rotate through Indian Garden and four through Phantom Ranch. There were no rangers assigned to Cottonwood Camp at the time of the NIOSH survey. Two maintenance rangers rotate through Indian Garden and Phantom Ranch, and one is stationed at Roaring Springs on the NK trail.

Park employees conduct over 2,000 visitor rescues per year, most of which involve heat-related illnesses. About 400–500 of these are documented search and rescue operations, and usually involve helicopter evacuation from the canyon, mostly from Phantom Ranch. Other rescues include hiker assists and minor medical treatment and are not documented. These rescues and other duties often require heavy physical exertion and from spring to fall are conducted in temperatures of 100°F and higher. Fatigue, weight loss, dehydration, and hyponatremia (water toxicity due to a loss of blood electrolytes) have been reported among rangers. Rangers also reported experiencing and observing co-workers with a lack of coordination, impaired judgement (for example, the inability to make simple drug-dosage calculations), and loss of composure during rescue situations in elevated temperatures.

METHODS

Environmental

During both evaluations, wet bulb globe temperature measurements (WBGTs) were collected using two RSS-214 WiBGeT® instruments (Imaging & Sensing Technology, Horseheads, New York). These monitors are capable of measuring temperatures of 32–150°F and are accurate to within ±0.5°F. The WBGT index accounts for air velocity, temperature, humidity, and radiant heat and is a useful index of the environmental contribution to heat stress. It is a function of dry bulb temperature (a standard measure of air temperature taken with a thermometer), a natural wet bulb temperature (simulates the effects of evaporative cooling), and a black globe temperature, which estimates radiant (infrared) heat load. During the 1999 evaluation, environmental conditions on the NK trail were monitored, and for the 2000 evaluation, one WBGT monitor was placed on the south rim near the ranger headquarters building while the other was placed outside the Phantom Ranch ranger station. WBGTs were measured at one-minute intervals from morning to late afternoon.

Individual metabolic rates were estimated using the NIOSH table, "Estimated metabolic heat production rates by task analysis" (Appendix A). This method allows for specific rate estimation because it breaks the job down into three categories that account for body position and movement, type of work, and basal metabolism. Metabolic rates for those on rim and canyon patrol were estimated by assuming that participants spent approximately two-thirds of the total activity ascending the trail and one-third descending or walking on the flat. Each employee's body weight and estimated pack weight were added together and used to calculate a correction factor for the standard weight of 154 pounds (lbs) used in the NIOSH table. Estimated pack weights are as follows: Law enforcement and life support rangers (from all categories), 40 lbs; life support rangers, 30 lbs; maintenance employees, 20 lbs; and PSARs, 15 lbs. Appendix A includes sample metabolic rate calculations for rangers who hiked out of and into the canyon, calculations '1' and '2', respectively.

Metabolic rates for many uphill hikes in the Grand Canyon were estimated for various completion times using the same formula as for individuals. Sample calculation '3' in Appendix A provides an example of estimating metabolic rates for hiking out of the canyon on the SK trail in 4 hours and 5½ hours, respectively. The information provided is for guidance purposes only, and it is important to note that individual results will vary depending on age, sex, fitness level, current health status, pack weight, body weight, etc.

During both evaluations, heat strain was assessed using the CorTemp™ Wireless Core Body Temperature Monitoring System (HTI Technologies, Inc., Palmetto, Florida). The CorTemp Temperature Sensor, a 0.9 x 0.4 inch silicon-coated electronic device, is swallowed and provides continuous monitoring of CBT to within ±0.2°F. The sensor is passed through the gastrointestinal tract and exits the body at participants' normal transit time, an average of approximately 72 hours. The sensor, intended for one-time use only, runs on a non-rechargeable silver-oxide battery for a week or longer and utilizes a temperature sensitive crystal which vibrates in direct proportion to the temperature of the substance surrounding it. This vibration creates an electromagnetic flux (frequency = 262.144 kilohertz) which continuously transmits through the surrounding substance. A recorder, the CT2000, receives this signal and translates it into digital temperature information, which is then displayed on the unit and stored to memory. The CT2000 Recorder monitors temperatures of 50–122°F. The recorder operates on one standard 9-volt alkaline battery, weighs about 7 ounces, and attaches to the user's belt. The rangers' CBTs were recorded at 1-minute intervals during each work activity.

During the 2000 evaluation, heat strain was also assessed using a Mini-Mitter Mini-Logger® Series 2000 (Mini-Mitter Company, Inc., Bend, Oregon). Heart rate, gross motor activity, skin temperature, and ear temperature, all of which directly impact or are a function of the body's metabolic rate, were monitored at 1-minute intervals.[a] The participants were asked to wear an aural (ear) temperature probe, a skin temperature probe, Polar® chest band heart rate monitor, and an activity sensor on the dominant ankle. The Mini-Logger's ear and skin temperature readings are accurate to within ±0.18°F and have a range of 86–108°F. The Polar chest band heart rate monitor counts up to 250 beats per minute (bpm) and is accurate to within ±1 heart beat. The activity monitor, which works by counting the number of movements per collection interval, is accurate to within ±1 millisecond and counts up to 65,353 movements per interval. The logger weighs about 4 ounces and is worn on the user's belt.

Medical

For both surveys, the medical evaluation consisted of a self-administered questionnaire and a dehydration assessment. The questionnaire asked participants to describe methods used to self-monitor health in the heat, history of heat-related illnesses, and usual work practices. Before and after each activity, participants were asked to record information including date, time, base ranger station, activity, activity completion

[a] The ear and skin temperature and activity measurements are not included in this report. No evaluation criteria exist for any of these measurements, and ear and skin temperatures are influenced by environmental conditions thereby decreasing their accuracy. Rather, these measurements will be compared to the CBT, heart rate, and WBGT measurements, which do have established criteria. Grand Canyon management and employees will be provided with the results of any future analyses of these measurements.

time, type and amount of fluid and food consumed, pre- and post-activity weights, and any symptoms they experienced during the activity. Degree of dehydration was determined by measuring pre- and post-activity body weights. Weight loss (or gain) over a few hours is a reflection of change in extracellular fluid volume and occurs when water is lost from sweating and through the respiratory tract. Body weight loss of 1.5% or less is indicative of mild dehydration, whereas a loss of greater than 1.5% of body weight indicates greater risk of heat strain. Seca Travelite™ digital scales, accurate to within ±0.1 lb with a range of up to 330 lbs, were used. All weights were obtained with participants wearing their uniforms but not shoes, equipment, or packs.

During the second survey, changes in blood chemistries that occurred during the participants' job activities were also determined. Blood chemistries, including sodium, potassium, chloride, blood urea nitrogen (BUN), and glucose were measured to determine if levels were maintained within normal limits during work activities. Dehydration results in an increase in certain blood chemistries, and hyperhydration (fluid overload) results in a decrease. Euhydration, the normal hydration state, results in little change. Blood chemistry levels were measured before participants began their duties and again afterward, and were determined using the i-STAT handheld analyzer and the i-STAT $^{EC}8+$ cartridges. (The i-STAT system has been shown to be accurate for the blood chemistries it measures, is simple to operate,[1] and has been used successfully to study hyponatremia among back-country hikers at the Grand Canyon National Park.[2]) Whole blood (65–95 micro liters [µL]) was placed in the well of the cartridge prior to inserting the cartridge into the analyzer. Serum osmolality (dissolved particle concentration in blood) is measured in milliosmols per liter (mosm/L) and was calculated from the blood chemistries using the following formula:[3]

$$\text{Osmolality} = (1.86 \times \text{serum sodium}) + (\text{serum glucose} \div 18) + (\text{BUN} \div 2.8)$$

For analysis of the second survey results, corridor patrol rangers, wilderness rangers, and interpretation rangers were combined into one group called "park rangers," PSARs and all other volunteers were combined into the "volunteer" group, and inner-canyon maintenance workers, Park Service management, and others assisting with patrolling activities were combined into the "other employees" group. The activity "hike out of the canyon" included hikes from Phantom Ranch to the south rim using either the SK or BA trail, "hiking into the canyon" included hikes from the south rim to Phantom Ranch on either the SK or BA trail, and "patrols" generally included 1.5 to 5-mile hikes of the inner canyon and rim areas.

Methods Limitations

Because of mechanical problems, south rim WBGT data are missing for all but two days of the study period. The dry bulb data are hourly averaged temperatures recorded by the Park Service for June 29-July 4, 2000, so peak temperatures are not included. The NIOSH monitors collected WBGTs from mid-morning to early evening, and included the highest daily temperature but not the lowest.

Treadmill studies have shown that descents involve about 25% less energy than walking on the level; however, on very steep, slow descents, energy expenditure may be considerably higher than when walking on the level.[4] No specific descent adjustment factors exist, however, nor do any of the available methods for calculating metabolic energy expenditure include such a provision.[5] Therefore, although calculations for uphill climbs in this study factor in an additional 0.8 kcal/min per meter risen (Appendix A), the estimated metabolic rates for those who descended do not include any metabolic rate adjustment and are likely underestimated.

When estimating the metabolic rate for a person completing a certain task, ideally every move would be recorded and rates and times would be combined to provide a time-weighted average. The logistics of this study were such that participants could not be monitored in this way, and so the metabolic rate results may either over- or underestimate the actual energy expenditure of each participant. Also, in part because of individual variability, errors in estimating metabolic rates may vary by ± 10–15%.[10]

Some of the baseline blood samples, although ideally collected just before the participants begin their activities, had to be collected hours or even the night before the activity. Thus the change in concentration of the analytes may underestimate the actual changes that occurred during the activity. Also, many participants wore clothing that was soaked with sweat during post-activity weigh-ins, likely resulting in an overestimation of body weight and subsequent underestimation of the actual change in body weight.

EVALUATION CRITERIA

To assess the hazards posed by workplace exposures, NIOSH investigators use a variety of environmental evaluation criteria for the assessment of chemical and physical agents. These criteria are intended to suggest levels at which most workers may be exposed for a working lifetime without experiencing adverse health effects. However, wide variations in individual susceptibility may cause a small percentage of workers to experience illness even if exposures are maintained below these levels. The criteria do not account for individual sensitivity, pre-existing medical conditions, medications, or possible interactions with other workplace agents.

The primary sources of environmental evaluation criteria for the workplace are NIOSH Recommended Exposure Limits (RELs),[6] the American Conference of Governmental Industrial Hygienists' (ACGIH) Threshold Limit Values (TLVs),[7] and the U.S. Department of Labor, Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs).[8] Employers are encouraged to follow the OSHA limits, the NIOSH RELs, and the ACGIH TLVs, or whichever are the more protective criteria. OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm (Occupational Safety and Health Act of 1970, Public Law 91-596, sec. 5(a)(1)). Employers should also understand that not all hazardous exposures, including heat stress, have specific OSHA PELs or short-term exposure limits (STELs); however, even in the absence of a PEL or STEL, an employer is still required by OSHA to protect employees from these hazards.

Heat Stress

Total heat stress is defined by NIOSH as the sum of the heat generated in the body (metabolic heat) plus the heat gained from the environment (environmental heat) minus the heat lost from the body to the environment, which is primarily through evaporation. Many bodily responses to heat stress are desirable and beneficial because they help regulate internal temperature and, in situations of appropriate repeated exposure, help the body adapt (acclimate) to the work environment. However, at some stage of heat stress, the body's compensatory measures cannot maintain internal body temperature at the level required for normal functioning. As a result, the risk of heat-induced illnesses, disorders, and accidents substantially increases.[10] Increases in unsafe behavior are also seen as the level of physical work of the job increases.[10]

Many heat stress guidelines have been developed to protect people against heat-related illnesses. The objective of any heat stress index is to prevent a person's CBT from rising excessively. The World Health Organization concluded that "it is inadvisable for CBT to exceed 38°C (100.4°F) or for oral temperature to exceed 37.5°C (99.5°F) in prolonged daily exposure to heavy work and/or heat."[9] According to NIOSH, a deep body temperature of 39°C (102.2°F) should be considered reason to terminate exposure even when deep body temperature is being monitored.[10] This does not mean that a worker with a CBT exceeding those levels will necessarily experience adverse health effects; however, the number of accidents increases as does the risk of developing heat stress illness.[10]

NIOSH recommends that total heat exposure be controlled so that unprotected healthy workers who are medically and physically fit for their required level of activity and are wearing, at most, long-sleeved work shirts and trousers or equivalent, are not exposed to metabolic and environmental heat combinations exceeding the applicable NIOSH criteria, as follows: Almost all healthy employees, working in hot environments and exposed to combinations of environmental and metabolic heat less than the NIOSH Recommended Action Limits (RAL's) for *non-acclimatized* workers (Appendix B, Figure 1) or the NIOSH Recommended Exposure Limits (REL's) for *acclimatized* workers (Appendix B, Figure 2), should be able to tolerate total heat stress without substantially increasing their risk of incurring acute adverse health effects. Also, no employee should be exposed to metabolic and environmental heat combinations exceeding the applicable Ceiling Limits (C) of Figures 1 or 2 without being provided with and properly using appropriate and adequate heat-protective clothing and equipment.[10]

ACGIH guidelines require the use of a decision-making process which provides step-by-step situation-dependent instructions that factor in clothing insulation values and physiological evaluation of heat strain (see *Evaluation Scheme for Heat Stress*, Appendix C). ACGIH WBGT screening criteria (Appendix D) factor in the ability of the body to cool itself (clothing insulation value, humidity, wind), and, like the NIOSH criteria, can be used to develop work/rest regimens for acclimatized and unacclimatized employees. The ACGIH WBGT-based heat exposure assessment was developed for a traditional work uniform of long-sleeved shirt and pants, and represents conditions under which it is believed that nearly all adequately hydrated, unmedicated, healthy workers may be repeatedly exposed without adverse health effects. Clothing insulation values and the appropriate WBGT adjustments, as well descriptors of the other decision-making process components can be found in ACGIH's *Threshold Limit Values (TLVs®) for Chemical Substances and Physical Agents and Biological Exposure Indicies.*[7] The ACGIH TLV for heat stress provides a framework for the control of heat-related disorders only. Although accidents and injuries can increase with increasing levels of heat stress, it's important to note that the TLVs are not directed toward controlling these.[14]

NIOSH and ACGIH criteria can only be used when WBGT data for the immediate work area are available and must not be used when encapsulating suits or garments that are impermeable or highly resistant to water vapor or air movement are worn. Further assumptions regarding work demands include an 8-hour work day, 5-day work week, two 15-minute breaks, and a 30-minute lunch break, with rest area temperatures the same as, or less than, those in work areas, and "at least some air movement." It must be stressed that NIOSH and ACGIH guidelines do not establish a fine line between safe and dangerous levels but require professional judgement and a heat stress management program to ensure protection in each situation.

OSHA does not have a specific heat stress standard, however, acceptable exposure to heat stress is enforced by the Secretary of Labor under the General Duty Clause [section 5(a)(1)].[11] The OSHA technical manual, Section III, Chapter 4,[13] provides investigation guidelines that approximate those found in ACGIH's 1992-1993 *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices*.

Heat Strain

The body's response to total heat stress is called heat strain.[10] Operations involving high air temperatures, radiant heat sources, high humidity, direct physical contact with hot objects, and strenuous physical activities all have a high potential for inducing heat strain in employees. Physiological monitoring for heat strain becomes necessary when impermeable clothing is worn, when heat stress screening criteria are exceeded, or when data from a detailed analysis (such as the International Standards Organization [ISO] required sweat rate [SR_{req}]) shows excess heat stress.[14]

One indicator of physiological strain, sustained peak heart rate, is considered by ACGIH to be the best sign of acute, high-level exposure to heat stress. Sustained peak heart rate, defined by ACGIH as 180 beats per minute (bpm) minus an individual's age, is a leading indicator that thermal regulatory control may not be adequate and that increases in CBTs have, or will soon, occur. Sustained peak heart rate represents an equivalent cardiovascular demand of about 75% of maximum aerobic capacity. During an 8-hour work shift, although sustained peak demands may not occur, there may still be excessive demand placed on the cardiovascular system. These 'chronic' demands can be measured by calculating the average heart rate over the shift. Decreases in physical job performance have been observed when the average heart rate exceeds 115 bpm over the entire shift. This level is equivalent to working at roughly 35% of maximum aerobic capacity, a level sustainable for 8 hours.[14]

According to ACGIH, an individual's heat stress exposure should be discontinued when *any* of the following excessive heat strain indicators occur:

- Sustained (over several minutes) heart rate is in excess of 180 bpm minus the individual's age in years, (180 bpm - age) for those with normal cardiac performance;
- Core body temperature is greater than 38.0°C (100.4°F) for unselected, unacclimatized personnel and greater than 38.5°C (101.3°F) for medically fit, heat-acclimatized personnel;
- Recovery heart rate at 1 minute after a peak work effort exceeds 110 bpm; or
- There are symptoms of sudden and severe fatigue, nausea, dizziness, or lightheadedness.

An individual may be at greater risk of heat strain if:

- Profuse sweating is sustained over several hours; or
- Weight loss over a shift is greater than 1.5% of body weight; or
- 24-hour urinary sodium excretion is less than 55 millimoles.

Health Effects of Exposure to Hot Environments

Heat disorders and health effects of individuals exposed to hot working environments include (in increasing order of severity) skin disorders (heat rash, hives, etc.), heat syncope (fainting), heat cramps, heat exhaustion, and heat stroke. Heat syncope (fainting) results from blood flow being directed to the skin for cooling, resulting in decreased supply to the brain, and most often strikes workers who stand in place for extended periods in hot environments. Heat cramps, caused by sodium depletion due to sweating, typically occur in the muscles employed in strenuous work. Heat cramps and syncope often accompany heat exhaustion, or weakness, fatigue, confusion, nausea, and other symptoms that generally prevent a return to work for at least 24 hours. The dehydration, sodium loss, and elevated CBT (above 100.4°F) of heat exhaustion are usually due to individuals performing strenuous work in hot conditions with inadequate water and electrolyte intake. Heat exhaustion may lead to heat stroke if the patient is not quickly cooled and re-hydrated.

While heat exhaustion victims continue to sweat as their bodies struggle to stay cool, heat stroke victims cease to sweat as their bodies fail to maintain an appropriate core temperature. Heat stroke occurs when hard work, hot environment, and dehydration overload the body's capacity to cool itself. This thermal regulatory failure (heat stroke) is a life-threatening emergency requiring immediate medical attention. Signs and symptoms include irritability, confusion, nausea, convulsions or unconsciousness, hot dry skin, and a CBT above 106°F. Death can result from damage to the brain, heart, liver, or kidneys.[12]

Prolonged increases in CBT and chronic exposures to high levels of heat stress are associated with disorders such as temporary infertility (male and female), elevated heart rate, sleep disturbance, fatigue, and irritability. During the first trimester of pregnancy, a sustained CBT greater than 102.2°F may endanger the fetus.[7] In addition, one or more occurrences of heat-induced illness in a person predisposes him/her to subsequent injuries and can result in temporary or permanent loss of that person's ability to tolerate heat stress.[10, 13]

The level of heat stress at which excessive heat strain will result is highly individual and depends upon the heat tolerance capabilities of each individual. Age, weight, degree of physical fitness, degree of acclimatization, metabolism, use of alcohol or drugs, and a variety of medical conditions, such as hypertension and diabetes, all affect a person's sensitivity to heat. At greatest risk are unacclimatized workers, people performing physically strenuous work, those with previous heat illnesses, the elderly, people with cardiovascular or circulatory disorders (diabetes, atherosclerotic vascular disease), those taking medications that impair the body's cooling mechanisms,[b] people who use alcohol or are recovering from recent use, people in poor physical condition, and those recovering from illness. A core body temperature increase of only 1.8°F above normal encroaches on the brain's ability to function.[14]

Acclimatization

Acclimatization is a low-cost, highly effective way to improve the safety and comfort of employees in heat stress situations.[14] Acclimatization allows the employee to withstand heat stress with a reduction in heat strain by a series of physiological adaptations. Acclimatized individuals are able to perspire more abundantly and more uniformly over their body surface and they also start to sweat earlier than non-acclimatized individuals. This results in lower heat storage (lower CBT) and lower cardiovascular strain (lower heart rate). In addition, acclimatized individuals lose less salt through sweating and are therefore able to withstand greater water loss.[15]

Working at even a moderate rate in a heat stress situation brings about physiological changes that substantially improve comfort and safety for those who are in general good health. Exposure to heat only, however, will not bring about acclimatization—an elevated metabolic rate, such as happens during work activities, is required. The ability of a worker to tolerate heat stress requires integrity of cardiac, pulmonary, and renal function, the sweating mechanism, the body's fluid and electrolyte balances, and the central nervous system's heat-regulatory mechanism. Impairment or diminution of any of these functions may interfere with the worker's capacity to acclimatize to the heat or to perform strenuous work in the heat once acclimatized.[10] Acclimatization at a certain temperature is effective only at that temperature—a person exposed to higher levels of heat stress will not be fully acclimatized at that level, only the lower one.[14] Empirical data suggest that fewer than 5% of workers cannot adequately acclimatize to heat stress.[10]

There are three phases of heat acclimatization. Initially, consecutive exposures to heat in the first few days, with the requisite rise in metabolic rate for 2 hours (e.g. doing work, exercising), cause the body to reach 33% of optimum acclimatization by the fourth day of exposure. The intermediate phase is marked by cardiovascular stability, and surface and internal body temperatures are lower, reaching 44% of optimum by day 8. During the third phase, a decrease in sweat and urine osmolality and other compensations to conserve body fluids and restore electrolyte balances are seen, and 65% of optimum is reached by day 10, 93% by day 18, and 99% by day 21.[14]

Although heat acclimatization for most individuals begins early in a period of working in the heat, it is also quickly lost if the exposure is discontinued. The loss of acclimatization begins when the activity under those heat stress conditions is discontinued, and a noticeable loss occurs after four days. This loss is usually rapidly made up so that by Tuesday workers who were off on the weekend are as well acclimatized as they were on the preceding Friday. However, if there is no exposure for a week or two, full acclimatization can require up to three weeks of continued physical activity under heat stress conditions similar to those anticipated for the work.[14] Chronic illness, the use or misuse of pharmacologic agents, a sleep deficit, a suboptimal nutritional state, or a disturbed water and electrolyte

[b] β–adrenergic receptor blockers and calcium-channel blockers, used to treat hypertension, limit maximal cardiac output and alter normal vascular distribution of blood flow in response to heat exposure. Diuretics, such as caffeine, can limit cardiac output and affect heat tolerance and sweating, and antihistamines, phenothiazines, and cyclic antidepressants impair sweating.[10]

balance may reduce the worker's capacity to acclimatize. In addition, an acute episode of mild illness, especially if it entails fever, vomiting, respiratory impairment, or diarrhea, may cause abrupt transient loss of acclimatization.[10]

Workload Assessment

Muscular activity is divided into dynamic exercise (walking, bicycling, etc.) and isometric (static) exercise, which involves lifting some form of weight. Dynamic exercise causes greater energy expenditure, while static movements readily induce muscular fatigue.[16] Whole body fatigue occurs when the metabolic demands of dynamic and static activity exceed a worker's maximum aerobic capacity (MAC), or VO_2 max.[17] VO_2 max varies widely among workers according to age, sex, physical fitness, etc.,[17] and work capacity is directly associated with the number or size of the muscles available to do the work.[18] A very fit individual can sustain higher workloads, averaging about 50% of MAC during an 8-hour shift, however, few industrial workers meet these fitness levels, so a value of 33% is found to be a more appropriate upper limit for them.[19] Also, studies show that healthy workers will choose a level of work that produces an average heart rate of 112 bpm, which is equivalent to 33% of MAC.[16] Because worker populations, VO_2 max values, and job conditions vary widely, it is important to know the VO_2 max of individuals or groups of individuals and to avoid prolonged work at levels greater than 50% of VO_2 max in order to avoid fatigue.[17]

Except for lifting tasks,[20] no specific workload standards exist. However, metabolic research findings can provide rough guidelines for establishing appropriate limits for specific worker populations. Oxygen consumption, metabolic energy expenditure rate, and heart rate are the physiological measurements which have been suggested for determining the maximum work intensity that can be continuously performed without accumulating excessive physical fatigue.[16] Average VO_2 max values, assessed using treadmill procedures, have been reported for 20-year-old conditioned male workers to be as high as 20 kilocalories per minute (kcal/min) and as low as 7.3 kcal/min for 55-year-old female workers; in general, older workers have a lower capacity than younger workers, and female workers have a lower capacity than male workers.[17] With reference to a normal, healthy, 35-year-old working man, three limitations in physical work capacity as a function of working time were proposed by NIOSH in 1981:[16] 1) an upper energy work limit of 16 kcal/min for 4 minutes; 2) an 8-hour continuous work limit of 5.2 kcal/min (33% of 16 kcal/min); and 3) a 24-hour performance limit of 2.85 kcal/min, with a female equivalent equal to 70% (of the values for men). For a general comparison, estimated hourly metabolic rates for Grand Canyon study participants were divided by 60 minutes.

Fluid and Electrolyte Balance

Because water is the most abundant constituent in the body, comprising approximately 60% of the body weight in men and 50% in women, maintaining enough water improves the body's overall function. Total body water is distributed in two major compartments: 55–75% is intracellular fluid (ICF), and 25–45% is extracellular fluid (ECF).[21] The solute, or dissolved particle concentration of a fluid, is known as its osmolality (expressed as milliosmoles per liter [mosmol/L]). The major ECF component is sodium (Na^+); therefore, ECF volume is a reflection of total body Na^+ content. Normal regulatory mechanisms ensure that Na^+ loss balances Na^+ gain.

Normal plasma osmolality ranges from 275–290 mosmol/L and is kept within a narrow range by mechanisms capable of sensing a 1–2% change in plasma concentration. Most people have an obligate water loss consisting of urine, stool, and evaporation from the skin and respiratory tract, and to maintain a steady state, water intake must equal water excretion. Disorders of water regulation result in hypo- or hypernatremia. Changes in urine and plasma osmolality are better suited for diagnosing hydration status than changes in hematocrit, serum proteins, and blood urea nitrogen (BUN), which are more dependent on factors other than hydration.[3] The primary stimulus for water ingestion is thirst, mediated by either an increase in effective osmolality or a decrease in ECF volume or blood pressure. Osmoreceptors in the hypothalamus are stimulated by a rise in serum concentration. The average osmotic threshold for thirst is approximately 295 mosmol/kg and varies among individuals. Under normal circumstances, daily water intake exceeds physiological requirements.[22]

Hyponatremia

Sweat is a hypotonic fluid that contains 10–90 milli-equivalents per liter (mEq/L) of sodium, equal amounts of chloride, and 3–5 mEq/L of potassium. Sustained sweat volumes of 1–2 liters per hour (L/hr) are common during strenuous exercise in the heat.[23] A sweat loss of 1.5 L/hr for 8 hours, with 50 mEq/L of sodium, results in a loss of 600 mEq (26 grams) of sodium. A 154 lb person has extracellular sodium stores of 5,880 mEq (264 grams). With no sodium intake, the loss of 26 grams of sodium (over 8 hours) would lower the serum sodium to 125 mEq/L. Further dilution could occur if there was excess intake of water.

Hyponatremia develops when serum sodium levels drop below 135 mEq/L and is a condition that has been recognized as a potential health consequence of endurance activities conducted in hot environments. Most individuals with acute exercise-induced heat illness are dehydrated with normal to mildly increased serum sodium and serum osmolality.[24] However, decreased concentration of sodium in the serum (hyponatremia) has been recognized as an increasing problem among hikers in Grand Canyon National Park.[25]

Most cases of hyponatremia result from the inability of the kidneys to excrete an appropriately dilute urine. The most significant clinical symptoms of hyponatremia involve the central nervous system, and symptoms vary from subtle changes in one's ability to think, to decreases in energy levels, to severe alterations, such as coma or seizure. Symptoms generally parallel the rate of development and degree of hyponatremia.[26]

Hyponatremia may occur with hypo-, hyper-, or normal hydration status.[27] Symptomatic hyponatremia can occur when blood sodium concentrations decrease to less than 130 mEq/L and is generally caused by hypervolemia (water overload) secondary to extensive over-drinking. Many people with hyponatremia have increased their total body water by about 1 gallon to achieve such low serum sodium values.[28]

The pathophysiology is complex and probably involves fluid, electrolyte, and plasma protein imbalances between intra- and extracellular compartments.[29] Circulating factors that may be elevated during exercise in the heat include aldosterone, arginine vasopressin (also known as antidiuretic hormone [ADH]), and atrial natriuretic peptide; these have been implicated in the pathophysiology of hyponatremia and volume overload. Since elevation of ADH occurs with exercise and possibly with the initial plasma expansion that also occurs during exercise, some have ascribed the fluid overload to the 'syndrome of inappropriate secretion of ADH,' or SIADH; however, other forms of SIADH require several days to develop, whereas this syndrome occurs in several hours.[30]

Dehydration and Fluid Replacement

When working in hot environments it is often difficult to completely replace lost fluids as the day's work proceeds. High sweat rates with excessive loss of body fluids may result in dehydration and electrolyte imbalances.[31] Some studies have shown that even small deficits have adverse effects on performance.[32] During the process of dehydration, water is lost from the plasma more rapidly than from other compartments.[33] During more severe dehydration, both the intracellular and extracellular compartments may be depleted. Changes in both compartments are associated with thirst and drinking. Dehydration also negates the advantage granted by high levels of aerobic fitness and heat acclimatization.[34]

Several studies have shown that dehydration increases CBT during exercise in temperate and hot environments; a deficit of only 1% of body weight increases CBT during exercise. As the magnitude of the water deficit increases, there is an accompanying elevation in CBT when exercising in the heat. The magnitude of this elevation ranges from 0.2–0.4°F (0.1–0.23°C) for every 1% body weight loss.[35] A 2%

loss of body weight is generally accepted as the threshold for thirst stimulation.[36] A 3% decrease in body weight causes an increase in heart rate, depressed sweating sensitivity, and a substantial decrease in physical work capacity.[37] Some investigators have reported that a 4% to 6% water deficit has been associated with anorexia, impatience, and headache, while a 6% to 10% deficit is associated with vertigo, shortness of breath, cyanosis, and spasticity. With a 12% water deficit, an individual will be unable to swallow and will need assistance with rehydration. Lethal dehydration levels are estimated to occur at 15% to 25% lost body weight.[38]

Palatability of any fluid replacement solution is important to ensure adequate rehydration. There is evidence that adding sweeteners to drinks leads to increased consumption. Glucose-electrolyte solutions have been shown to facilitate sodium and water absorption. Also, the glucose in these solutions provides energy for muscular activity in endurance events that require vigorous exercise.[39] The temperature of the drink will also influence consumption of fluids. Ideally, fluids should be ingested at 50–60°F in small quantities (5–7 ounces) and at frequent intervals (every 15–20 minutes).

RESULTS

During the 1999 survey, estimated individual metabolic rates ranged from 300 kilocalories per hour (kcal/hr) to over 500 kcal/hr, and inner-canyon WBGTs averaged 83°F, with a one-day peak of 98°F. These results indicate that most trail crew members and rangers were exposed to excessive heat stress. While all participants had small to moderate rises in core temperature, none exceeded the CBT criterion. The median percent body weight loss of trail crew members was 1.5%. One employee lost 6 pounds (3.0% of body weight).

Two park rangers, five trail crew members, and one maintenance employee had confidential interviews with the NIOSH medical officer, and all reported at least one incident in which they had suffered a heat-related symptom. Each thought the most common heat-related health problem was the dehydration they said usually occurs during strenuous duties, especially victim rescues. The rangers described rescue situations where they found themselves in isolated areas with insufficient water and other supplies. They reported that hiking to and from the rim, sometimes several times a week, was another activity that often results in dehydration and heat strain. Most mentioned they drank water and glucose-electrolyte replacement fluids to replace sweat loss. Several trail crew members described incidents in which former trail crew leaders required employees to continue with their work, even as they were observed to be developing visible signs of heat strain. NIOSH investigators noted there were current park management policies to help mitigate potential heat strain among trail crew members, including performing trail work in the canyon only during cooler months (with the crews working at or near the rim in summer) and adjusting the crews' work schedules to early morning and late afternoon/early evening hours.

Workload and Task Assessments

June and July are usually the hottest months at the Grand Canyon, and the temperatures that were measured at Phantom Ranch and on the south rim were typical for that time of year. Daily high WBGTs at Phantom Ranch averaged 92°F with a one-day peak of 98.8°F, and for two days of the study, south rim WBGTs averaged 78°F (Table 1). Participants wore the uniform of the U.S. Park Service, which includes short-sleeve cotton-blend tan-colored shirts and dark-green shorts, hiking boots, and hats; the PSARs wore shirts that were dark green and of a thicker cotton-blend material. Therefore, no ACGIH WBGT clothing corrections were necessary.

The activities of the participants were also typical, except that no rescues were conducted. About 60% of participants' estimated metabolic rates were between 250 kcal/hr and 400 kcal/hr, while the rest were in the range of 500–750 kcal/hr. Due to the nature of the job, none of the participants remained in one location and, during their hiking activities, most underwent considerable changes of elevation within short periods of time. As a result, they experienced significant air temperature changes, which for practical and logistical reasons could not be recorded, therefore making heat-stress screening difficult for many Grand Canyon tasks.

Metabolic rates for a variety of uphill hikes in the Grand Canyon were estimated for various completion times using the same formula as for individuals, but without the correction factor (Table 2). Most of the estimated rates fell between 300 kcal/hr and 500 kcal/hr (for 154 lb hiker), depending upon elevation change and completion time, and are therefore considered moderate to heavy workloads (Appendix D). Table 2 also illustrates that irrespective of environmental temperatures, elevation changes and hiking rates can have marked effects on metabolic rate and subsequent heat stress risk and the development of heat illness.

Individual and task metabolic rate estimates indicated that physical requirements for many Grand Canyon activities exceeded the criteria. At the time of the study, none of the participants had been medically evaluated for fitness of duty in a hot environment, and many, including all of the PSARs, had not been medically evaluated for physically challenging work. The estimated metabolic rates for male and female study participants ranged from 7.6–12.2 kcal/min for those hiking out, from 4.2–6.6 kcal/min for those hiking in, from 4.6–7.3 kcal/min for those on rim patrol, and from 5.1–7.1 kcal/min for those on inner canyon patrol.

Physiological (Heat Strain) Monitoring

The number of participants and the acclimatization status of the rangers differed in the 2000 NIOSH survey because of a hiring freeze. The freeze made it necessary for the Park Service to provide Phantom Ranch with relief rangers, many of whom were recruited from south rim automobile patrols and were not used to working in the hot environment at the bottom of the canyon. These relief rangers were neither medically selected nor required to acclimatize to their new work environment and had the highest CBTs and heart rates over the greatest percentages of their activities when compared to the results of those who regularly work in the canyon.

There were 15 participants in the environmental component of the study including 8 park employees 6 park volunteers, and 1 visitor. In all, 21 sets of data were collected as some rangers completed multiple tasks. The work schedule for Phantom Ranch, Indian Garden, and Cottonwood Camp employees is about 8 days of work followed by about 6 days of leave in a significantly cooler climate. When work activity in hot environments is discontinued, a noticeable loss of acclimatization occurs after just 4 days; if there is no exposure for a week or two, full acclimatization can require up to three weeks of continued physical activity under heat stress conditions similar to those in the work environment.[14] Phantom ranch "regulars," therefore, are likely never fully acclimatized to conditions in the canyon, but are at various stages of acclimatization. Therefore, according to the criteria, none of the participants were considered acclimatized for the purposes of this study.

The results, divided by activity in Tables 3–6, indicate that every monitored participant experienced heat strain to some degree, i.e., the rangers' measured parameters exceeded at least one of the heat strain criteria during each activity. The trails the participants hiked are listed because of their differences. The SK trail, although approximately 3 miles shorter than the BA trail, is considered very strenuous and difficult by most rangers because of its steepness, complete lack of water, and little to no shade. The BA trail is about 10 miles long and less steep, with an elevation change of about 400 feet less than the SK trail. The BA trail also has three park-maintained water facilities and at least two creeks, and parts of it are shaded.

Only one ranger and four PSARs completed activities that lasted approximately 8 hours, while the rest of the participants finished their activities in 3–5 hours. Therefore, only the results for PSARs J, K, M, O, and ranger B, are 'full-shift' time-weighted averages. The full-shift averages for the rest of the participants would likely have been lower but would depend upon the activities of each participant during the rest of the shift.

The results for those hiking out of the canyon are listed in Table 3. Five of six participants completing seven activities exceeded the HR criteria of 180 bpm minus age, ranging from 11–92% of their activities (one HR monitor failed). Five of the six participants also exceeded 100.4°F CBT, ranging from 13–70% of their activities. Two of those rangers, both used to working on the south rim, exceeded 101.3°F CBT (the criterion for acclimatized workers) for about 20% of their activities, and one had a CBT of 102.2°F for 35 continuous minutes, which is reason to terminate exposure even when the employee is being monitored.[10] The only ranger who did not exceed 100.4°F CBT is a Phantom Ranch "regular" who hiked out on the BA trail.

Table 4 lists the results for participants who hiked into the canyon except that three of five HR monitors failed as did one CBT monitor. Two participants exceeded the HR criterion from 6.6–15% of their activities. Four participants exceeded 100.4°F CBT from 2.6–68% of their activities, and one ranger exceeded 101.3°F CBT for about 2% of the time. It should be noted that ranger C3 was returning to Phantom Ranch after having hiked out earlier that day (see C1, Table 3), which could contribute to increased CBT and HR results.

Results for participants patrolling the outer canyon/rim area are listed in Table 5. Five of six participants exceeded the HR criterion 3.5–47% of their activities, and two of six had HR averages in excess of 115 bpm for their entire 9½ hour shifts. All six participants exceeded 100.4°F CBT, and one exceeded 101.3°F CBT.

Table 6 lists the results for rangers conducting inner-canyon patrol. Two of three heart rate monitors failed, but the working monitor indicated that one ranger exceeded the HR criterion for 20% of the activity. Another ranger exceeded 100.4°F CBT for 36% of the activity and also exceeded 101.3°F CBT for a short time (1.6%).

Medical

Twenty-two employees and volunteers, including a visitor, a park manager, and seven PSARs, completed questionnaires, were weighed, and/or had blood drawn for electrolyte analysis. Two workers completed the questionnaire but did not have their blood drawn or a body weight measurement. Seventeen workers were monitored for one activity, and three workers were monitored for more than one activity.

The median age of the park rangers was 35 years, the PSARs, 27 years, and the other employees, 44 years. The rangers had worked in Grand Canyon National Park a median of 3.5 years, the PSARs, 0.4 years, and the other employees a median of 4.5 years. Among the eight rangers, four (50%) were women; of nine participating PSARs, six (67%) were women; and all five participants in the others category were male.

Seventeen (77%) of the questionnaire respondents reported monitoring their hydration status while exposed to work in hot environments. The monitoring methods they used included drinking fluids when thirsty, monitoring sweat output, monitoring the color of their urine, and weighing themselves before and after working in the heat. However, only four individuals (18%), all using personal heart rate monitors, reported monitoring themselves for working too hard in the heat. Twenty-two individuals (81%) reported that they had, in the past, experienced at least one heat-related symptom while on duty, while fifteen (55%) reported two or more heat-related symptoms. Of those reporting single symptoms, the most common was fatigue (15%). Thirty percent reported that they drank caffeinated or alcoholic beverages while off duty and exposed to hot environments.

Twenty participants, some completing more than one activity, were monitored for weight change and pre- and post-shift blood chemistry changes. The activities included 4 hikes into the canyon, 7 hikes out of the canyon, and 12 patrols. Most serum electrolyte concentrations were within normal limits. Five individuals experienced a decrease, while six had an increase, in post-activity sodium levels compared to baseline levels of 135–145 mEq/L. Only two individuals had post-activity sodium out of the normal range; one had a level of 135 mEq/L or lower, and another had a level of 145 mEq/L or greater. Individual weight change results ranged from no change (0%) to -

2.6%. Individual weight change and blood test results for participants are listed in Tables 3–6.

For the three participant groups, the amount of weight change did not differ (Figure 1). The median percent decrease in body weight for park rangers was 1.3% (range of 0.0–1.9%), 1.2% for the volunteers (range of -0.9–2.3%), and 1.1% for other employees (range of 0.3–2.6%). The median serum sodium levels were also similar among the groups, but the park ranger group had much less variability than the other two groups (Figure 2). A similar finding occurred in the calculated serum osmolality. Most individuals in the groups did not experience physiologically significant changes from baseline values in the measured blood chemistries (Table 7).

For most activities, the median percent weight loss was similar (Figure 3), and for all activities, the median percent loss in body weight was 1.0% or greater. Hiking out of the canyon was associated with the greatest median weight loss (1.3%) and also caused the greatest changes in serum sodium concentrations (Figure 4). When grouped by activity, the differences in individual serum sodium concentrations and osmolality changed little between baseline and post-activity values (Table 8). In 10 participants (45%), the baseline calculated osmolality was greater than 290 mosmol/L (normal range is 275–290 mosmol/L). There were no significant changes in glucose, potassium, or chloride between the different activities.

Interview and Questionnaire Results

A few participants monitored their exertion levels using heart rate monitors, which is one of the best methods to determine individual heat strain. Most participants reported monitoring their hydration status when exposed to hot environments, however, many individuals said they used thirst as a gauge to their state of dehydration. Thirst is a poor indicator of hydration status because significant dehydration has already taken place when the thirst sensation occurs. And, some were unaware that alcohol- and caffeine-containing beverages may result in dehydration because of greater fluid loss through increased urine production.

During both surveys, participants expressed concern about the potential for impaired judgement reportedly brought on not only by heat stress, but also by regularly-occurring sleep deficits. They mentioned a hiring freeze that has reportedly reduced staff numbers by 40% throughout the park. As a result, inner-canyon employees reported that they have no one to replace them when they need rest after being up all night, are heat strained, or are becoming acclimatized. Others were concerned about the lack of an official supervisor at Phantom Ranch, lack of enforcement of employee policies, and poor communication between employees and management. Also mentioned was a general lack of support for their efforts in establishing heat stress health and safety guidelines for park employees. Several rangers also mentioned that the "rescue mentality," common to many helping professions and including the ranger/rescue/law enforcement culture, keeps rangers from taking care of their own needs before those of the victim in an emergency. The potential for skin cancer was also a concern, and most of the rangers said they regularly wear hats and sunglasses, but less than half regularly use sun block.

The Park Service has no formal policy regarding acclimatization, and all employees and volunteers are expected to complete their duties regardless of their states of acclimatization. Workers are also not screened by health care providers to determine if they are at increased risk for heat-related illness. And, while most participants reported that they had experienced at least one occupationally-related heat illness, there is no surveillance system in place, and the incidents went unreported.

DISCUSSION

The results of the study confirm that participants working the corridor trail system, including the south rim and inner-canyon areas, experienced heat stress exposure resulting from high air temperatures and high physical workloads. And, though no one developed heat illness during the study, all participants experienced heat strain at levels that should have triggered a cessation of activity followed by rest and rehydration until their CBTs, heart rates, and body fluids had returned to safe levels.[10,14] Many of the participants were not sufficiently hydrated or rested prior to beginning their activities, which could have precipitated the onset and intensity of the heat strain.

Lack of acclimatization also was likely an important factor in the heat strain experienced by participants. Corridor and wilderness rangers are never sufficiently acclimatized because of their work schedules and off-work living conditions in cooler temperatures. The mostly voluntary PSARs conduct physically demanding patrols that are scheduled to reflect peak visitor hours, which often occur during the hottest parts of the day. The patrols require descents on the trails into hot environments where the PSAR may remain for a few hours but not long enough to become acclimatized.

Other factors that likely contributed to participant heat strain included poor work habits, lack of training, and no fit-for-duty evaluations for work in hot and physically strenuous work environments. For example, during the hottest parts of the day, rangers were seen conducting non-essential activities requiring high metabolic rates, such as hiking out of the canyon for leave, lengthy non-essential patrols, and post-hole digging. Rangers and PSARs reported that they were not trained to understand and respond to heat stress and strain situations in which they found themselves. Study results indicated that personal monitoring will be especially important for employees working the corridor trail system conducting activities that involve changes in elevation or other areas where WBGT data are not available. Heat stress screening, and thus the determination of work/rest regimens, were not found to be practical for all employees, but could be useful for those who stay in the Phantom Ranch and Indian Garden areas, such as the maintenance rangers, because both these locations have WBGT monitors. And, given the metabolic rate results, the physical demands of the job, and the wide variety of participant fitness levels, individual VO_2 max testing would likely provide important data for the medical evaluation of current and prospective Grand Canyon employees and volunteers.

Visitor Rescues

Rescue services, while not obligatory, are routinely performed regardless of staffing levels. Most of the more than 2000 rescues per year are for victims of (preventable) heat-related illness. Rescues may involve long hikes to reach victims, often during the hottest part of the day, sometimes on steep and dangerous terrain, sometimes in the dark, and reportedly many times without adequate food, water, or sleep. According to the participants, park visitors have unlimited access to the corridor trail system and are not aware of heat stress dangers.

Reducing the number of rescues would reduce heat stress incidents among the rangers. One way of achieving this is to require more visitor education prior to starting down the trail. Currently, back-country hikers are required to view an educational video prior to obtaining their permits, however some rangers felt that the video does not provide sufficient guidance on heat stress issues. The rangers also believe that *all* park visitors should receive heat stress education before they begin their hikes, not just those requiring permits. Heat stress warnings and recommendations, in English only, were seen at trail heads, infrequently on the trails, on tent cards in at least two cafeterias, and in the park's newspaper, *The Guide*. Park administration is in the process of developing and implementing a restricted-access system where visitors are brought in by train. This would provide an opportunity to educate visitors on the dangers of hiking the corridor trails and could also be used to limit corridor trail access to those visitors who are sufficiently educated and prepared.

Reducing the number of rescues may involve improving trail facilities. Hikers on the Bright Angel trail have access to at least three drinking water sources and there are likely to be PSARs and rangers available to help. But, because the South Kaibab trail is 3 miles shorter, many hikers choose this route instead, believing it to be easier. Hikers using the South Kaibab trail, however, do not have access to drinking water or shade, and there are generally no PSARs or rangers available. On several different days, a NIOSH investigator encountered hikers on the South Kaibab trail believed to be in significant heat distress. The NIOSH investigator provided water and sought out rangers to provide assistance.

Heat stress rescues may also be reduced by educating visitors on the dehydrating effects of alcoholic and caffeinated beverages. Guests of Phantom Ranch Lodge and other concessions (not part of the Park Service) are served caffeinated tea and coffee with breakfast and dinner and can purchase alcoholic beverages, as well. There are no verbal or posted warnings to visitors about the dehydrating effects of these beverages.

Study Observations

A specific assessment of the physical impact of the workload on study participants was not conducted. However, it was observed that those working the corridor trail system may be at increased risk of developing degenerative joint diseases because of their heavy physical workloads and repetitive work activities. One such joint disease is osteoarthritis (OA), a painful, disabling condition of the joints caused by a gradual deterioration of the cartilage between the joints. Continuous stress on joints can cause premature breakdown of the cartilage, thus increasing the likelihood of developing OA. The changes which occur in OA are currently viewed as an adaptive response of joints to a variety of genetic, constitutional, or biomechanical insults.[40] Studies have shown that workers whose jobs involve physical labor have high rates of knee OA.[41,42,43] When jobs with heavy physical labor were examined, those requiring kneeling or squatting along with heavy lifting were associated with especially high rates of both knee and hip OA. Forces across the knee increase in the crouching or squatting position, and lifting loads from such a position further increases loading. Because much of OA may be attributed to modifiable environmental risk factors, namely occupation, physical activity, quadriceps strength, joint injury, obesity, and diet, identification of these factors provides an opportunity to modify or prevent disease.

Although most of the rangers demonstrated significant knowledge of heat stress and strain issues, few seemed to follow the guidelines they are helping to develop. For instance, few rangers ever soak themselves with water before going out on patrol or on a rescue. Many reported that doing so takes too much time, especially in the case of a rescue. Also in rescue situations, many admitted to being stranded with the victim without adequate food or water because of poor planning and preparation prior to leaving the station. During the survey, most rangers expressed surprise at how their bodies responded to even the simplest activity as they checked their CBT monitors. For example, one ranger reported noticing a big difference upon soaking down with water—both CBT and heart rate were decreased, and there was increased comfort while hiking.

It was evident to us from the physiological results and interviews that there are not enough personnel to provide relief to those working at Indian Garden, Phantom Ranch, and Cottonwood Camp. Employees' heat exposures need to be limited and sufficient rest breaks provided. Employees may become impaired as 8-hour shifts are extended, especially in hot work environments where an increase in CBT of only 1.8°F above normal encroaches on the brain's ability to function.[14] The rangers reported having to work long hours, sometimes greater than 24 consecutive hours, without sufficient time to sleep or rest. Some researchers have found that sleep deprivation may result in decreased reaction time and an increase in perceptual and cognitive distortions and changes in mood.[44] Slower rates of recovery from effort and higher resting heart rate levels are also associated with fatigue caused by sleep loss.[45]

There are few laws or regulations governing work hours in the U.S. However, one example of a state regulation limiting hours of workers, specifically physicians in training (residents) in New York, is discussed in the Bell Commission report.[46] The Bell Commission mandates that residents must work no more than 24 consecutive hours, must have no less than 8 non-working hours between shifts, and must not work more than 80 hours per week. The federal government has placed a 10-hour limit on the length of time a long-haul trucker can drive each day, and there are also federal regulations governing flight and rest times for commercial airline pilots. Research has suggested that work schedules can be improved, and a well-designed work schedule can lead to increased health and safety, worker satisfaction, and productivity.[47]

CONCLUSIONS

Environmental temperature measurements and work load assessments confirmed that there are significant health risks to Grand Canyon employees and volunteers, especially those working the corridor trail system during the summer. Also, although relatively few of the participants had major changes in their fluid and electrolyte measurements, based upon the physiological measurements, significant heat strain was evident. These results justify including employees in a formal heat stress management program. The fact that few symptoms were reported indicates that participants may not have been aware of their heat strain, indicating a specific need for a physiological self-monitoring program.

RECOMMENDATIONS

An effective heat stress management program is essential to ensuring adequate protection for employees against heat stress and strain. The following recommendations are provided to help park management and employees work together to create a heat stress management program that will reduce the incidence of heat stress and strain among Grand Canyon National Park employees.

Communication

✔ To facilitate communication, park management and employees, especially those who work in the canyon and may be under-represented at policy-setting and other meetings, should create health and safety committees to discuss specific Phantom Ranch/corridor trail work-related health issues. One way to begin is to discuss how to reduce the number of events requiring rescue. Other topics could include establishing acclimitization schedules, developing educational programs such as for skin cancer screening and sun block use, and evaluating the effectiveness and acceptability of ice vests and other cooling garments.

Administrative Controls Regarding Employees

✔ Reduce the physical demands of the work. Consider alternatives such as mule or helicopter transportation, especially for employees leaving the canyon.

✔ Develop and implement a formalized plan to limit work hours. Employee representatives and management should improve the current work/rest schedule for those working both inner- and outer-canyon areas. This may involve maintaining a staff of two or three mostly-acclimatized workers at the station at all times, one available for nighttime medical emergencies, one for relief of any unacclimatized ranger who has worked in the heat as much as s/he should for the day, and possibly another for injured or ill employees.

✔ Institute pre-placement and periodic medical examinations of persons applying for work in hot and/or physically demanding environments. Because aerobic capacities (VO_2 max values) in the working population vary greatly, persons being considered for jobs requiring high metabolic demands should be specifically tested. Only through routine aerobic capacity testing can objective decisions be made about what job is "too difficult for certain susceptible groups of people and for specific individuals."[16] The examination should be performed by a health care provider with knowledge of the health effects associated with work in these environments. The examinations should be performed to assess the physical, mental, and medical qualifications of the individuals and to exclude those with low heat tolerance and/or physical fitness. The health care provider should also update the information periodically for people working in these environments.

✔ Develop a heat-related illness surveillance program, which includes establishing and maintaining accurate records of any heat-related illness events and noting the environmental and work conditions at the time of the illness. Such events may include repeated accidents, episodes of heat-related disorders, or frequent health-related absences. Job-specific clustering of specific events or illnesses should be followed up by environmental and personal monitoring and medical evaluations. A successful program will encourage employee and park volunteer participation, and each must understand the reasons for using new, or changing old, work practices for maximum participation.

✔ Develop continuing education programs to ensure that all employees and volunteers potentially exposed to hot environments and physically demanding job activities stay current on heat stress and heat-stress prevention information. Include at least the following components for a good heat stress training program:

- knowledge of the hazards of heat stress;
- recognition of predisposing factors, danger signs, and symptoms;
- awareness of signs and symptoms of heat-related illness and first-aid procedures for treatment;
- employee responsibilities in avoiding heat stress;
- dangers in using drugs, including therapeutic ones, and alcohol in hot and physically demanding work environments;
- use of protective clothing and equipment and the potential for increased heat stress risk;
- purpose and coverage of environmental and medical surveillance programs and the advantages of worker participation in them.

✔ Establish a heat-acclimatization program. One that is properly designed and applied will dramatically increase the safety of workers in hot and physically demanding jobs and will decrease the risk of heat-related illnesses and unsafe acts. Such a program involves having employees work in hot environments for progressively longer periods. NIOSH recommends that workers who have had previous experience in jobs where heat levels are high enough to produce heat stress (CBT and heart rate increase but do not exceed recommended levels) should work in the environment 50% of the shift on day one, 60% on day two, 80% on day three, and 100% on day four. New workers who will be similarly exposed should start with 20% on day one, with a 20% increase in exposure each additional day.[10] Because employees who have worked at Phantom Ranch, Indian Garden, and Cottonwood Camp regularly for many months would likely fall somewhere between the two schedules, the program should permit self-limitation of exposures.[10, 16] Being able to work 100% of the shift does not mean that workers will be fully acclimated after 5 days, but that they could work their entire shift in the work environment in which they were acclimatized. The body's acclimatization will continue to improve each day in that environment for up to 3 weeks. Figure 5 illustrates the acclimatization schedule for both types of workers.

✔ Because Grand Canyon rangers, PSARs, and others will be exposed to WBGTs and/or physically demanding work rates which exceed recommended levels, they should be instructed on personal monitoring techniques. Personal monitoring is used in addition to environmental and metabolic monitoring, and involves checking the heart rate, oral temperature, extent of body weight loss, and/or recovery heart rate (see Appendix E). Measurements should be taken at appropriate intervals covering a full 2-hour period during the hottest parts of the day, and again at the end of the workday to ensure a return to baseline.[10] Use of any of these techniques should always include the determination of baseline values for deciding whether individuals are fit to continue work that day.

✔ Install an outside shower at each station for rangers to soak themselves and their clothing prior to outdoor activities. In conditions of high temperature and low humidity, where evaporation from garments is not restricted, wetting clothing is a very simple and inexpensive personal cooling technique and should be mandatory prior to any activities in the heat.

✔ Provide accurate scales at each work station to enable employees to monitor their body weight, and thus hydration status, prior to and after work that is physically demanding and/or conducted in a hot environment.

✔ Assign the PSARs shirts that are lighter in color/more reflective than their dark green ones.

✔ Consider the use of commercially available ice vests. Ice vests may be appropriate for many Grand Canyon job activities. They accommodate as many as 72 small ice packs and cooling lasts 2–4 hours at moderate to heavy heat loads. Cooling with ice is relatively inexpensive, and the vest is generally not cumbersome and permits high mobility. However the weight of the vest and ice must be added to the employee's pack weight for the correction factor when metabolic rates are estimated prior to outside activities.

✔ Encourage all employees to carry cool (50–60°F) water or any cool liquid (except alcohol and caffeinated beverages) and to drink small amounts frequently, e.g., one cup every 20 minutes.

Administrative Controls Regarding Visitors

✔ Educate visitors prior to their hiking activities to protect them from heat illness and reduce the need for rescue services. Such education might include stationing a ranger or volunteer at each trail head to assess the status of hikers who attempt access and/or having a mandatory video viewing at the trail head.

✔ Translate all warnings and recommendations into languages that reflect the diversity of the park's visitors.

✔ Consider adding water stations or maintaining water caches on the South Kaibab trail. More water stations overall, but especially on the SK trail, should reduce the need for rescues and help rangers in heat distress, as well.

✔ Consider placing emergency radios at appropriate intervals along all trails for earlier reports of visitors in distress.

Employee Practices and Heat Strain Monitoring

✔ Take more time to complete activities that have uphill climbs associated with them by taking longer and more frequent breaks.

✔ Schedule physically demanding jobs for the cooler part of the day, and schedule routine maintenance and repair work in hot areas during cooler seasons of the year. When temperatures are highest, restrict patrol to immediate areas (e.g. the campground). Delay response to minor mishaps, if status is known, until temperatures have cooled.

✔ Use the attached metabolic rate chart (Table 2) prior to heading out to choose trails and completion times that suit your individual needs and anticipated environmental conditions. Begin by calculating your individual weight correction factor to get your estimated metabolic rate (see Appendix A, sample calculation 1 for an example). The estimated rates in Table 2 must be multiplied by your correction factor for a more accurate metabolic rate estimate for that hike. For example, if your body and pack weight combined are less than 154 lbs, the estimated metabolic rate will be less than that listed in Table 2, and if your combined weight is greater than 154 lbs, the estimated metabolic rate will be higher. WBGTs (if known) should be used to assess heat stress risk prior to beginning any of the hikes.

✔ If you will be working in a fixed location, i.e., Phantom Ranch or Indian Garden, check the WBGT monitor every 45 minutes or so noting any temperature changes. Use your calculated metabolic rate and the WBGTs for comparison to either the NIOSH or ACGIH figures (Appendices B and D) to see how frequently you should take breaks. If your calculated metabolic rate and/or the WBGTs are too high to register on the charts, wait until temperatures have cooled, or increase the amount of time you take to complete the activity, and see Appendix E for personal monitoring instructions.

✔ Carefully monitor your coworkers for signs of heat illness and for adequate supplies when leaving for rescues or other emergencies. Creating a 'buddy' system among rangers in the canyon will help to ensure that each of the rangers has enough water and food and has soaked down prior to leaving. If a co-worker shows signs of heat intolerance (weakness, unsteady gait, irritability, disorientation, confusion, changes in skin color, flu-like symptoms, or general malaise) the worker should rest in a cool location with rapidly circulating air and be kept under skilled observation. Immediate emergency care may be necessary. If sweating stops and the skin becomes hot and dry, immediate emergency care with hospitalization is essential.[7]

✔ Some of the first symptoms of heat strain are lack of judgement and ability to think critically and these symptoms usually go unnoticed by the person inflicted. Ensuring that you are well-hydrated, nourished, prepared, and not sleep-deprived or working too hard are some of the best ways to avoid heat strain, unsafe behavior, and poor job performance. Most of the study participants prepared emergency rescue packs ahead of time that contained food, water, and medical supplies, and they should continue to do so. Also take the time to properly prepare for patrols that may last longer than originally planned and always take the time to soak your clothes and body prior to heading out into a hot environment.

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Table 1: WBGT Environmental Temperature Data
Grand Canyon National Park, HETA 99-0321-2873

Date	WBGT Range Phantom Ranch	Sampling Times (Time of Highest Temp.)	WBGT Range South Rim	Sampling Times (Time of Highest Temp.)
6/27/00	65.8-90.9°F	08:50 - 17:19 (15:15)	62.8-76.1°F	11:34 - 20:03 (13:11)
6/28/00	73.8-93.2°F	11:25 - 19:54 (16:42)	61.2-79.2°F	11:12 - 19:41 (14:45)
6/29/00	75.7-92.5°F	12:24 - 20:53 (14:59)	$^{\Delta}$	$^{\Delta}$
6/30/00	70.9-92.3°F	11:14 - 19:43 (16:48)	$^{\Delta}$	$^{\Delta}$
7/01/00	69.8-93.0°F	11:58 - 20:27 (16:44)	$^{\Delta}$	$^{\Delta}$
7/02/00	68.5-88.3°F	11:47 - 20:16 (17:37)	$^{\Delta}$	$^{\Delta}$
7/03/00	62.4-86.9°F	10:24 - 18:53 (17:54)	$^{\Delta}$	$^{\Delta}$
7/04/00	70.0-98.8°F	13:56 - 20:53 (16:42)	$^{\Delta}$	$^{\Delta}$

$^{\Delta}$ Data not available because of equipment failure.

Date	Dry-Bulb Range Phantom Ranch	Sampling Times (Time of Highest Temp.)	Dry-Bulb Range South Rim	Sampling Times (Time of Highest Temp.)
6/27/00	74.3-111.2°F	08:50 - 17:19 (17:11)	72.7-88.5°F	11:34 - 20:03 (18:29)
6/28/00	69.4-114.8°F	11:25 - 19:54 (16:42)	70.7-93.0°F	11:12 - 19:41 (14:64)
6/29/00	90.9-108.9°F	12:24 - 20:53 (14:46)	$^{\epsilon}$60.3-77.0°F	00:00 - 23:00 (11:00)
6/30/00	83.1-109.9°F	11:14 - 19:43 (16:48)	$^{\epsilon}$60.8-78.3°F	00:00 - 23:00 (17:00)
7/01/00	83.5-114.4°F	11:58 - 20:27 (18:29)	$^{\epsilon}$59.2-82.2°F	00:00 - 23:00 (14:00)
7/02/00	82.6-111.7°F	11:47 - 20:16 (17:36)	$^{\epsilon}$55.8-79.5°F	00:00 - 23:00 (14:00)
7/03/00	72.9-110.5°F	10:24 - 18:53 (17:52)	$^{\epsilon}$55.8-79.7°F	00:00 - 23:00 (14:00)
7/04/00	92.3-122.5°F	13:56 - 20:53 (16:41)	$^{\epsilon}$51.8-79.7°F	00:00 - 23:00 (14:00)

$^{\epsilon}$ These measurements were collected by Grand Canyon National Park temperature monitors.

Table 2: Estimated Metabolic Rates for Various Completion Times (kilocalories per hour [kcal/hr]), without Correction Factors,* for Uphill Hiking Activities Grand Canyon National Park, HETA 99-0321-2873

Trail	Start Location-Finish Location	Mileage**	Elev. Change**	30 minutes	1 hour	1½ hours	2 hours	2½ hours	3 hours	3½ hours	4 hours	4½ hours	5 hours	5½ hours	6 hours	6½ hours	7 hours	7½ hours	8 hours	8½ hours	9 hours
Bright Angel	Colorado River-South Rim	10	1359				784	675	602	551	512	481	457	437	421	407	395	385	376		
Bright Angel	Colorado River-Pipe Creek Rest House	1.5	49	318	279	266	260	256	253												
Bright Angel	Colorado River-Devil's Corkscrew	3	114	422	331	301	286	277	270												
Bright Angel	Colorado River-Indian Garden	4.5	450			480	420	384	360	343	330	320	312								
Bright Angel	Indian Garden-South Rim	4.5	933				613	538	489	453	427	406	389	376	364	355					
Bright Angel	3-Mile House-South Rim	3	644		755	584	498	446	412	387	369	354	343	334							
Bright Angel	1½-Mile House-South Rim	1.5	345	792	516	424	378	350	332	319	309										
South Kaibab	Colorado River-South Rim	7	1481				832	714	635	579	536	503	477	456	438	422	409	398	388		
South Kaibab	Colorado River-Little Panorama	0.75	232	611	426	364	333	314	302	293											
South Kaibab	Colorado River-Panorama Point	1.5	372	835	538	438	389	359	339	325	314	306									
South Kaibab	Colorado River-Skeleton Point	4	860			698	584	515	469	437	412	393	378	365	355						
South Kaibab	Colorado River-Cedar Ridge	5.5	1119				688	598	538	496	464	439	419	403	389	378	368				
South Kaibab	Skeleton Point-South Rim	3	622		738	572	489	439	406	382	365	351	340	331							
South Kaibab	Cedar Ridge-South Rim	1.5	347	795	518	425	379	351	333	319	309										
South Kaibab	Ooh-Aah Point-South Rim	0.75	238	621	430	367	335	316	303	294											
North Kaibab	Phantom Ranch-North Rim	14	1911					852	750	677	622	580	546	518	495	475	458	444	431	420	410
North Kaibab	Phtm Ranch-mouth of Phantom Creek	2	82	371	306	284	273	266													
North Kaibab	Phantom Ranch-Cottonwood Camp	7.3	448		598	479	419	383	360	342	330	320	312	305	300						
North Kaibab	Phantom Ranch-Roaring Spring	9.5	814		674	566	501	457	426	403	385	370	358	349	340	333					
North Kaibab	Cottonwood Camp-Supai Bridge	4	610		565	484	435	403	379	362	348	338									
Misc.	Phantom Ranch-Sumner Wash	2	381	850	545	443	392	362	342	327	316	308									
Misc.	Phantom Ranch-Clear Creek Trail end	9.2	521		657	518	448	407	379	359	344	333	323								
Misc.	Phantom Ranch-Utah Flats	1	405	888	564	456	402	370	348	333	321	312									

* These metabolic rates (MRs) have NOT been corrected for body and pack weight. Use the formula below to calculate an individual correction factor (CF) then multiply the CF by the MR on this table that corresponds to your trail and estimated completion time.

1. $\frac{\text{body weight (lbs)} + \text{pack weight (lbs)}}{154 \text{ lbs}} = CF$

2. CF x metabolic rate on table = *your* est. MR

3. If your estimated MR is greater than 500 kcal/hr, wait until cooler weather to hike. Or, take longer to complete the hike by slowing your pace, and increase the frequency and/or length of breaks.

** Approximate one-way distance (in miles) is from Phantom Ranch Ranger Stn. For SK and BA trails, approximate elevation changes (in meters) are from the lowest elevation in the canyon, the river bank.

Table 3: Physiological Measurement Results—collected while participants hiked from Phantom Ranch up to the South Rim Grand Canyon National Park, HETA 99-0321-2873

Ranger	Date	Sampling period (total activity minutes)	Estimated metabolic rate (kcal/hour)	Heart rate in excess of 180 bpm minus age[α] (percent of activity)	Average heart rate (beats per minute)	CBT in excess of 100.4°F[α] (percent of activity)	CBT in excess of 101.3°F[α] (percent of activity)	Average CBT	Change in body weight	Change in sodium (mEq/L)	Change in BUN (mEq/L)	Change in osmolality (mosmol/L)
A	6/26	16:15-20:36 (262)	661	19:43-20:34 **(20%)**	122	18:48-20:36 **(41%)**	19:45-20:36 **(20%)**	100.2°F	**-1.9%**	0.0	4.0	1.0
B	6/27	05:34-12:30 (417)	457	[Δ]	[Δ]	07:32-07:54; 08:16-08:41 **(13%)**	Did not exceed	100.0°F	-0.8%	-4.0	8.0	-6.9
C1	6/27	11:16-15:05 (230)	713	11:48-13:35; 13:46-14:57 **(77%)**	148	14:08-15:05 **(25%)**[Δ]	Did not exceed[Δ]	100.0°F[Δ]	**-1.7%**	-3.0	1.0	6.2
D[γ]	6/28	05:03-09:17 (255)	734	07:35-08:27; 08:37-09:17 **(37%)**	136	06:44-07:08; 07:41-09:17 **(47%)**	07:46-08:35 **(19%)**	**100.5°F**	-1.1%	-1.0	3.0	-1.1
C2	6/30	08:46-13:58 (313)	611	09:29-10:02 **(11%)**[Δ]	134[Δ]	13:05-13:58 **(17%)**	Did not exceed	100.0°F	-1.5%	0.0	3.0	1.0
E[γ℘]	7/04	04:03-08:36 (274)	605	04:40-04:50; 05:26-05:45; 06:53-07:24 **(23%)**	120	Did not exceed	Did not exceed	98.8°F	-1.1%	-2.0	2.0	-1.8
F1	7/04	02:36-07:20 (285)	585	05:45-06:17; 06:26-07:12 **(28%)**	123	03:36-05:15; 05:42-07:20 **(70%)**	Did not exceed	100.4°F	-1.3%	1.0	11.0	3.5

[α] These are the main criteria used to evaluate heat strain. CBT = core body temperature.
[Δ] Not all data available because of equipment failure or failure to wear equipment, which can over- or underestimate the participant's results.
[γ] Indicates this participant hiked the Bright Angel trail; all others hiked the South Kaibab trail.
[℘] Indicates maintenance and Park Service employees and others assisting with patrolling activities.
Numbers in bold indicate the participant exceeded the recommended NIOSH or ACGIH limits.

Table 4: Physiological Measurement Results—collected while participants hiked from the South Rim down to Phantom Ranch Grand Canyon National Park, HETA 99-0321-2873

Ranger	Date	Sampling period (total activity minutes)	Estimated metabolic rate (kcal/hour)	Heart rate in excess of 180 bpm minus age[α] (percent of activity)	Average heart rate (beats per minute)	CBT in excess of 100.4°F[α] (percent of activity)	CBT in excess of 101.3°F[α] (percent of activity)	Average CBT	Change in body weight	Change in sodium (mEq/L)	Change in BUN (mEq/L)	Change in osmolality (mosmol/L)
C3	6/27	18:30-21:16 (167)	313	[Δ]	[Δ]	19:24-21:16 **(68%)**	Did not exceed	100.2°F	[δ]	[δ]	[δ]	[δ]
F2	6/27	06:58-11:02 (245)	289	[Δ]	[Δ]	10:38-10:55 **(7.3%)**[Δ]	Did not exceed[Δ]	99.0°F[Δ]	-1.3%	2.0	1.0	3.4
G1[∈]	6/27	04:40-08:58 (259)	253	07:15-07:24; 08:31-08:58 **(15%)**	116	[Δ]	[Δ]	[Δ]	-1.1%	7.0	7.0	16.4
H[℘]	7/04	07:12-10:12 (181)	394	[Δ]	[Δ]	09:30-09:37; 09:42-10:07 **(16%)**	09:56-09:59 **(2.2%)**	99.9°F	-1.2%	8.0	8.0	17.5
I1	7/04	06:54-10:40 (227)	302	09:59-10:09; 10:33-10:38 **(6.6%)**	126	10:07-10:13 **(2.6%)**	Did not exceed	99.5°F	-1.2%	-1.0	1.0	1.83

[α] These are the main criteria used to determine heat strain. CBT = core body temperature.
[Δ] Not all data available because of equipment failure or failure to wear equipment, which can over- or underestimate the participant's results.
[∈] Indicates a volunteer ranger.
[℘] Indicates maintenance and Park Service employees and others assisting with patrolling activities.
[δ] This parameter not measured.
Numbers in bold indicate the participant exceeded the recommended NIOSH or ACGIH limits.

Table 5: Physiological measurement results—collected while participants patrolled the South Rim and from 1-4.5 miles into the canyon Grand Canyon National Park, HETA 99-0321-2873

PSAR	Date	Sampling period (total activity minutes)	Estimated metabolic rate (kcal/hour)[∇]	Heart rate in excess of 180 bpm minus age[α] (percent of activity)	Average heart rate (beats per minute)	CBT in excess of 100.4°F[α] (percent of activity)	CBT in excess of 101.3°F[α] (percent of activity)	Average CBT	Change in body weight	Change in sodium (mEq/L)	Change in BUN (mEq/L)	Change in osmolality (mosmol/L)
J[∊]	6/27	10:53-19:19 (507)	352	16:27-16:34; 17:28-17:53; 18:24-18:40 **(10%)**	113	17:50-17:52 **(0.6%)**[Δ]	Did not exceed[Δ]	99.3°F[Δ]	**-1.7%**	-2.0	4.0	-0.4
K[∊]	6/28	07:46-15:54 (489)	281	10:37-10:53 **(3.5%)**	105	10:40-11:09; 11:17-11:30; 15:24-15:54 **(15%)**	Did not exceed	99.8°F	-0.3%	2.0	0.0	4.4
L[∊γ]	6/28	07:39-13:28 (350)	276	Did not exceed	85	10:57-11:21 **(7.1%)**	Did not exceed	99.4°F	-1.1%	2.0	-1.0	4.0
M[∊]	6/28	10:24-19:35 (552)	352	10:26-10:46; 10:55-11:21; 11:40-12:12; 12:41-13:59; 16:18-16:32; 17:34-17:45; 18:20-18:39; 19:17-19:35 **(41%)**[Δ]	**145**[Δ]	12:07-12:17; 12:45-13:48; 14:07-14:44; 16:34-17:22; 18:27-19:31 **(42%)**[Δ]	13:01-13:47; **(8.5%)**[Δ]	100.3°F[Δ]	-1.2%	-7.0	6.0	13.0
N[℘]	6/29	11:12-16:48 (337)	438	14:00-14:24 **(7.4%)**	97	16:26-16:31 **(1.8%)**[Δ]	Did not exceed[Δ]	99.0°F[Δ]	-0.8%	-3.0	-2.0	-6.9
O[∊]	6/29	11:00-20:14 (555)	334	11:41-11:46; 12:12-13:55; 15:01-15:11; 15:29-15:41; 15:57-16:09; 18:06-20:00 **(47%)**[Δ]	**159**[Δ]	19:21-20:04 **(8.6%)**[Δ]	Did not exceed[Δ]	99.3°F[Δ]	-0.6%	1.0	9.0	4.3

[α] These are the main criteria used to evaluate heat strain. CBT = core body temperature.
[∇] These results were calculated by assuming the participant spent 2/3 of the activity ascending and 1/3 of the activity descending or walking on the flat.
[∊] Indicates a volunteer ranger.
[Δ] Not all data available because of equipment failure or failure to wear equipment, which can over- or underestimate the participant's results.
[γ] This PSAR patrolled the South Kaibab trail; all others patrolled the Bright Angel trail.
[℘] Indicates maintenance and Park Service employees and others assisting with patrolling activities.
Numbers in bold indicate the participant exceeded the recommended NIOSH or ACGIH limits.

Table 6: Physiological Measurement Results—collected while participants conducted inner-canyon patrol Grand Canyon National Park, HETA 99-0321-2873

Ranger	Date	Sampling period (total activity minutes)	Patrolled trail	Estimated metabolic rate (kcal/hour)[∇]	Heart rate in excess of 180 bpm minus age [α] (percent of activity)	Average heart rate (beats per minute)	CBT in excess of 100.4°F [α] (percent of activity)	CBT in excess of 101.3°F [α] (percent of activity)	Average CBT	Change in body weight	Change in sodium (mEq/L)	Change in BUN (mEq/L)	Change in osmolality (mosmol/L)
G2[∈]	6/28	09:36-13:50 (255)	Clear Creek	304	[Δ]	151[Δ]	Did not exceed	Did not exceed	98.7°F	**-2.3%**	5.0	5.0	14.1
F3	7/02	11:30-14:20 (171)	Utah Flats	426	11:43-11:51; 12:00-12:02; 12:13-12:35 **(20%)**	119	11:48-11:51 **(2.3%)**[Δ]	Did not exceed[Δ]	99.0°F[Δ]	0%	0.0	5.0	0.7
I2	7/04	13:42-17:56 (255)	B.A. to Pipeline Creek	297	[Δ]	[Δ]	14:25-15:12; 16:29-16:32; 16:39-16:46; 16:54-17:25 **(36%)**	14:49-14:52 **(1.6%)**	100.3°F	[δ]	[δ]	[δ]	[δ]

[α] These are the main criteria used to determine heat strain. CBT = core body temperature.
[∇] These results were calculated by assuming the participant spent 2/3 of the activity ascending and 1/3 of the activity descending or walking on the flat.
[∈] Indicates a volunteer ranger.
[Δ] Not all data available because of equipment failure or failure to wear equipment, which can over- or underestimate the participant's results.
[δ] This parameter was not measured.
B.A. is Bright Angel trail.
Numbers in bold indicate the participant exceeded the recommended NIOSH or ACGIH limits.

Table 7: Median Blood Analyte Results by Job Title
Grand Canyon National Park, HETA 99-0321-2873

Job Title	Analyte (normal values)	Baseline	Post Activity	Change (Range)[℧]
Park Rangers	Sodium (135-145 mEq/L)	140 mEq/L	140 mEq/L	0 (-4 to 3) mEq/L
	Blood Urea Nitrogen (12-20 mg/dl)	14 mg/dl	18 mg/dl	4 (9 to 22) mg/dl
	Osmolality (275-290 mosmol/L)	290.4 mosmol/L	290.7 mosmol/L	1.1 (-6.9 to 6.2) mosmol/L
Volunteers	Sodium (135-145 mEq/L)	140 mEq/L	142 mEq/L	1.5 (-7.0 to 7.0) mEq/L
	Blood Urea Nitrogen (12-20 mg/dl)	11 mg/dl	16 mg/dl	4.5 (-1 to 9) mg/dl
	Osmolality (275-290 mosmol/L)	286.9 mosmol/L	291.3 mosmol/L	4.2 (-13.0 to 16.7) mosmol/L
Other Employees	Sodium (135-145 mEq/L)	141 mEq/L	143 mEq/L	0 (-3 to 8) mEq/L
	Blood Urea Nitrogen (12-20 mg/dl)	20 mg/dl	22 mg/dl	2 (-2 to 12) mg/dl
	Osmolality (275-290 mosmol/L)	293.2 mosmol/L	298.2 mosmol/L	1.2 (-6.8 to 18.8) mosmol/L

[℧] Each group's change in analyte levels is noted here, with the ranges of all the individual analyte changes in parentheses.

Table 8: Median Blood Analyte Results by Activity Performed
Grand Canyon National Park, HETA 99-0321-2873

Activity	Analyte (normal values)	Baseline	Post Activity	Change (Range)[℧]
Hike into Canyon	Sodium (135-145 mEq/L)	138 mEq/L	142 mEq/L	4.5 (-1 to 8) mEq/L
	Blood Urea Nitrogen (12-20 mg/dl)	13 mg/dl	17 mg/dl	4.0 (1 to 8) mg/dl
	Osmolality (275-290 mosmol/L)	285.7 mosmol/L	295.5 mosmol/L	10.1 (-6 to 17.5) mosmol/L
Hike out of Canyon	Sodium (135-145 mEq/L)	142 mEq/L	142 mEq/L	0 (-4 to 7) mEq/L
	Blood Urea Nitrogen (12-20 mg/dl)	15 mg/dl	21 mg/dl	4(2 to 12) mg/dl
	Osmolality (275-290 mosmol/L)	293.9 mosmol/L	296.5 mosmol/L	1.1 (6.9 to 18.8) mosmol/L
Patrol	Sodium (135-145 mEq/L)	140 mEq/L	140 mEq/L	0 (-7 to 5) mEq/L
	Blood Urea Nitrogen (12-20 mg/dl)	14 mg/dl	16 mg/dl	2 (-2 to 9) mg/dl
	Osmolality (275-290 mosmol/L)	289.2 mosmol/L	290.0 mosmol/L	0.1 (-13.0 to 14.1) mosmol/L

[℧] Each group's change in analyte levels is noted here, with the ranges of all the individual analyte changes in parentheses.

***Figure 1: Percent Decrease in Body Weight by Job Title**
Grand Canyon National Park, HETA 99-0321-2873

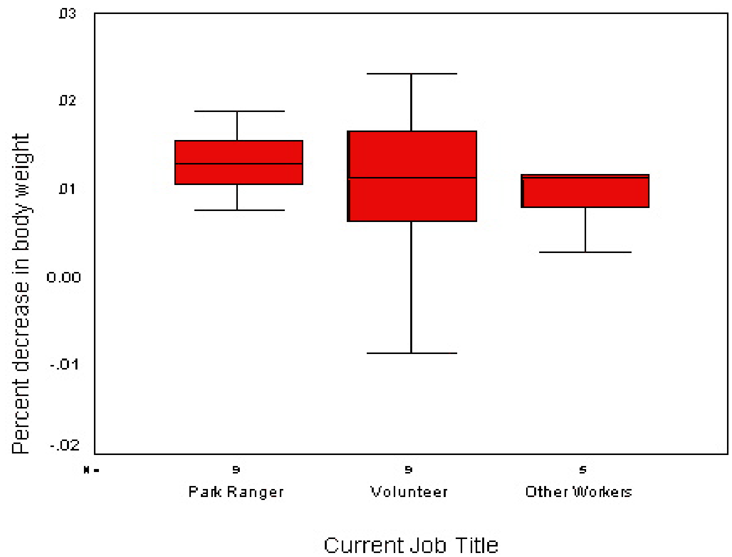
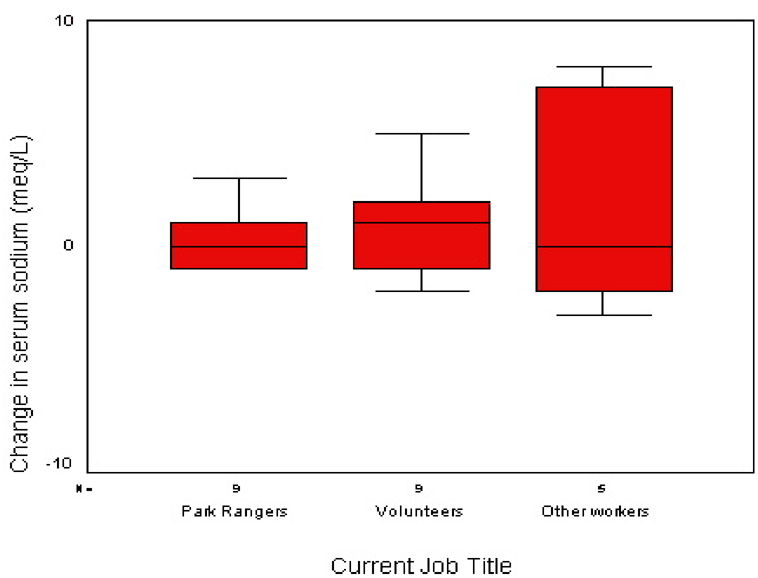


***Figure 2: Change in Serum Sodium Concentration by Job Title**
Grand Canyon National Park, HETA 99-0321-2873



*The boxplot shows the median (the horizontal line within the shaded area), interquartile range (shaded area), and extreme values for each group.

***Figure 3: Percent Decrease in Body Weight by Activity Performed**
Grand Canyon National Park, HETA 99-0321-2873

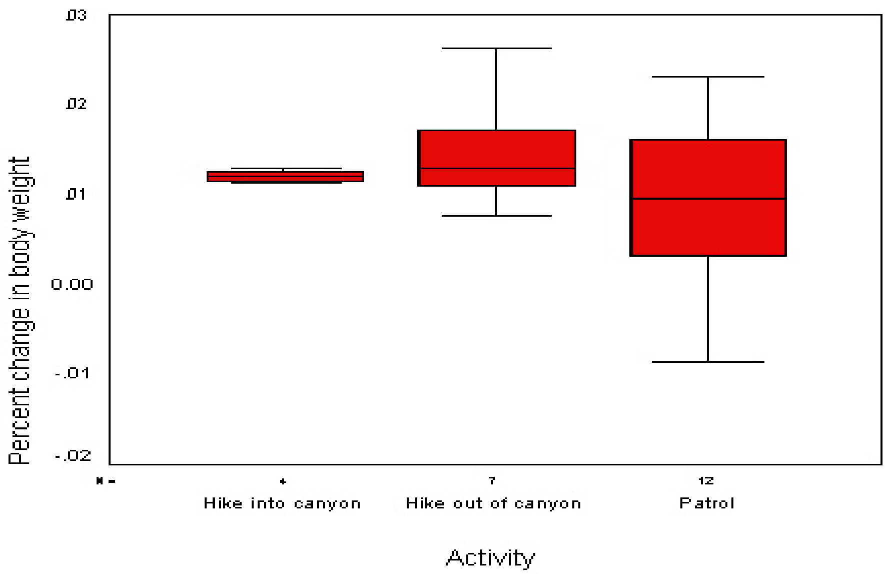
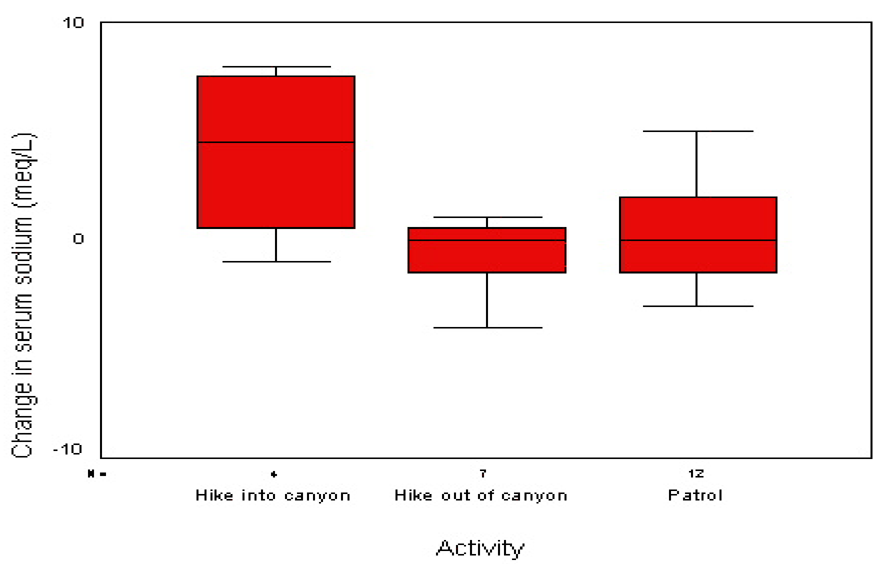
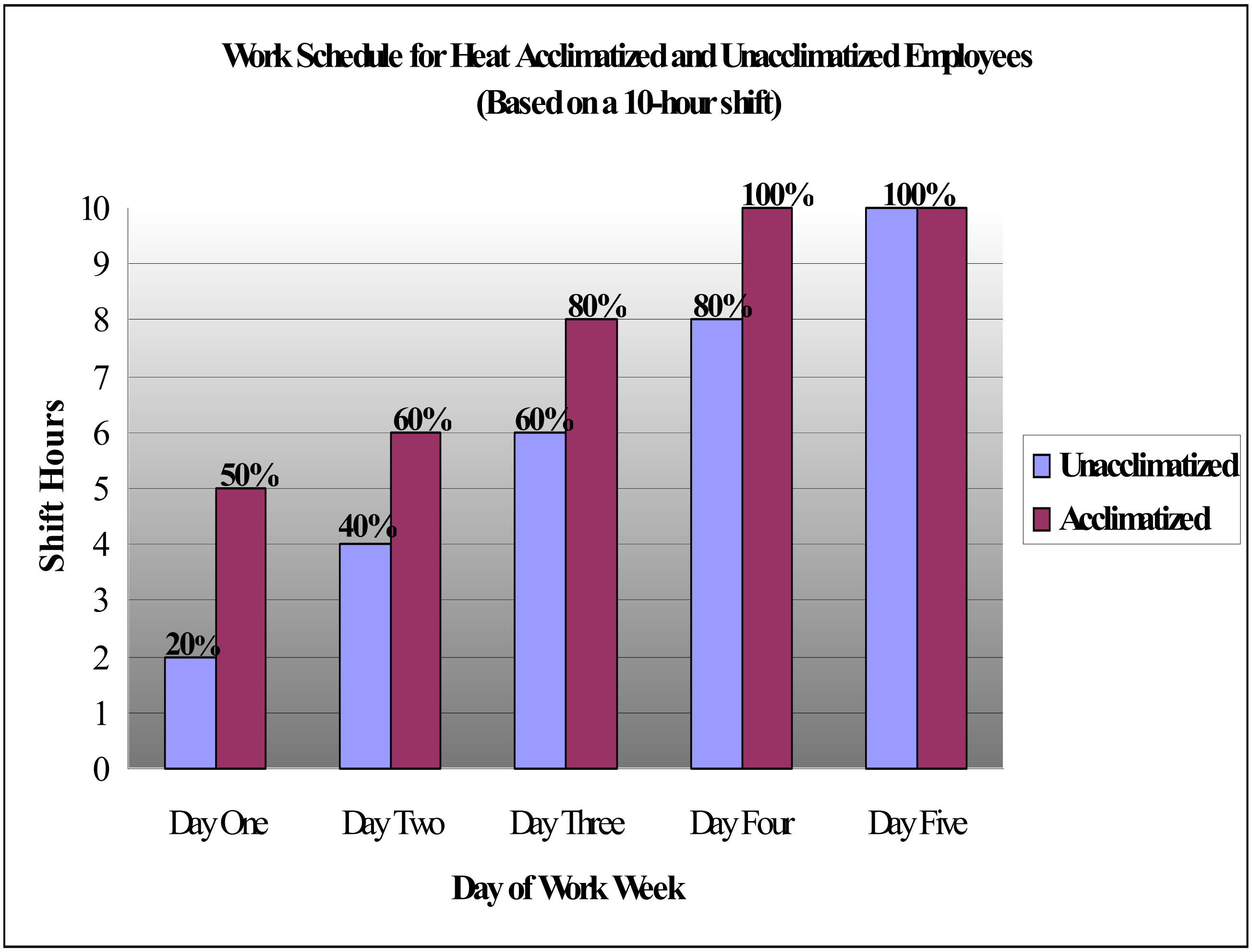


***Figure 4: Change in Serum Sodium Concentration By Activity Performed**
Grand Canyon National Park, HETA 99-0321-2873



* The boxplot shows the median (the horizontal line within the shaded area), interquartile range (shaded area), and extreme values for each group.

Figure 5: Acclimatization schedules[c]
Grand Canyon National Park, HETA 99-0321-2873



[c] This illustration was created for this report from information in NIOSH [1986]. Criteria for a recommended standard: occupational exposure to hot environments, rev. Cincinnati, OH: U.S. Dept. of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, DHHS (NIOSH) Publication No. 86-113.

Appendix A: Assessment of Work
Estimated Metabolic Heat Production Rates by Task Analysis[10]

A. Body Position and Movement	kcal/min*	
Sitting	0.3	
Standing	0.6	
Walking (uphill)	2.0 - 3.0 (add 0.8 kcal/meter rise in elevation)	
B. Type of Work	**Average (kcal/min)**	**Range (kcal/min)**
Hand work:		
light	0.4	0.2 - 1.2
heavy	0.9	
Work, one arm:		
light	1.0	0.7 - 2.5
heavy	1.8	
Work, both arms:		
light	1.5	1.0 - 3.5
heavy	2.5	
Work, whole body:		
light	3.5	2.5 - 9.0
moderate	5.0	
heavy	7.0	
very heavy	9.0	
C. Basal Metabolism	1.0	1.0
Sum of A, B, and C equals estimated metabolic production per task		

*For a standard male worker of 70 kg (154 lbs) body weight and 1.8 m^2 (19.4 ft^2) body surface.

1. Sample calculation for hiking out of the Grand Canyon on SK trail (ranger A):

Task	kcal/min
A. Walking -	3.0 kcal/min
- walking uphill, add 0.8 kcal per meter risen -	4.5 kcal/min†
B. 'Type of Work' -	0 kcal/min
C. Basal metabolism -	1.0 kcal/min
Metabolic Rate Total -	8.5 kcal/min x 60 min/hour = 510 kcal/hour
D. Multiply by the weight correction factor -	510 kcal/hour x 1.29‡

Total estimated metabolic rate = 661 kcal/hour

† Ranger A hiked out in 262 minutes. The change in elevation from Phantom Ranch to the South Rim via the South Kaibab trail is 1,481 meters. Therefore, ranger A's estimated average metabolic rate only for hiking uphill was 1,481 meters ÷ 262 minutes = 5.7 meters/min x 0.8 kcal/meter = 4.5 kcal/min.

‡ The weight correction factor is used when an employee plus his/her pack or load weigh other than 154 lbs. The factor is calculated by dividing the sum of the employee's current body weight (BW) and the pack weight (PW) by 154 lbs or ([BW + PW] ÷ 154 lbs = weight correction factor). Ranger A's correction factor on the day of the study was calculated as: (159 lbs + 40 lbs) ÷ 154 lbs = 1.29.

Appendix A: Assessment of Work (continued)
Estimated Metabolic Heat Production Rates by Task Analysis[10]

2. Sample calculation for hiking into the Grand Canyon on SK trail (ranger C3):

Task	kcal/min
A. Walking -	3.0 kcal/min
- walking downhill -	0 kcal/min†
B. 'Type of Work' -	0 kcal/min
C. Basal metabolism -	1.0 kcal/min
Metabolic Rate Total -	4.0 kcal/min x 60 min/hour = 240 kcal/hour
D. Multiply by the weight correction factor -	240 kcal/hour x 1.31‡

Total estimated metabolic rate = 313 kcal/hour

† Ranger C3's descent took 167 minutes. No metabolic cost is added for hiking downhill.

‡ The weight correction factor is used when an employee plus his/her pack or load weigh other than 154 lbs. The factor is calculated by using the equation: (BW + PW) ÷ 154 lbs = weight correction factor. Ranger C3's correction factor on the day of the study was calculated as: (161 lbs + 40 lbs) ÷ 154 lbs = 1.31.

---

3. Sample calculation for hiking out of the Grand Canyon on SK trail in 4 hours versus 5½ hours:†

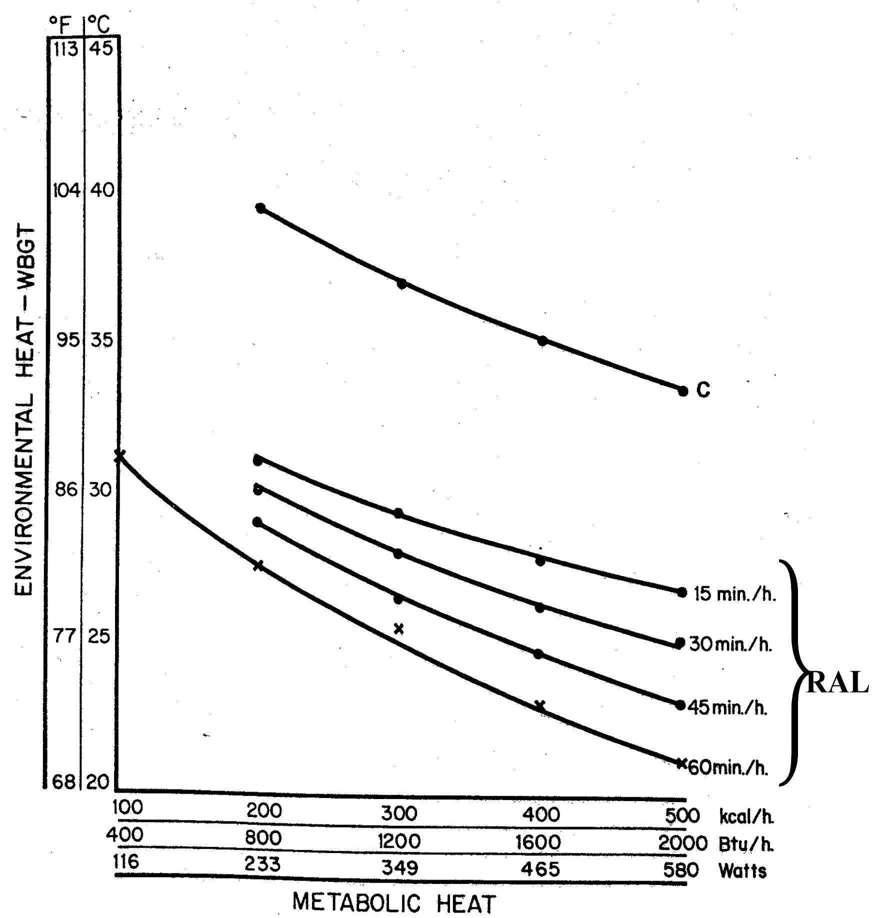
Task	4 hours	5½ hours
A. Walking -	3.0 kcal/min	3.0 kcal/min
- walking uphill, add 0.8 kcal per meter risen	4.9 kcal/min	3.6 kcal/min
B. 'Type of Work' -	0 kcal/min	0 kcal/min
C. Basal metabolism -	1.0 kcal/min	1.0 kcal/min
Metabolic rate total	8.9 kcal/min x 60 min/hour	7.6 kcal/min x 60 min/hr

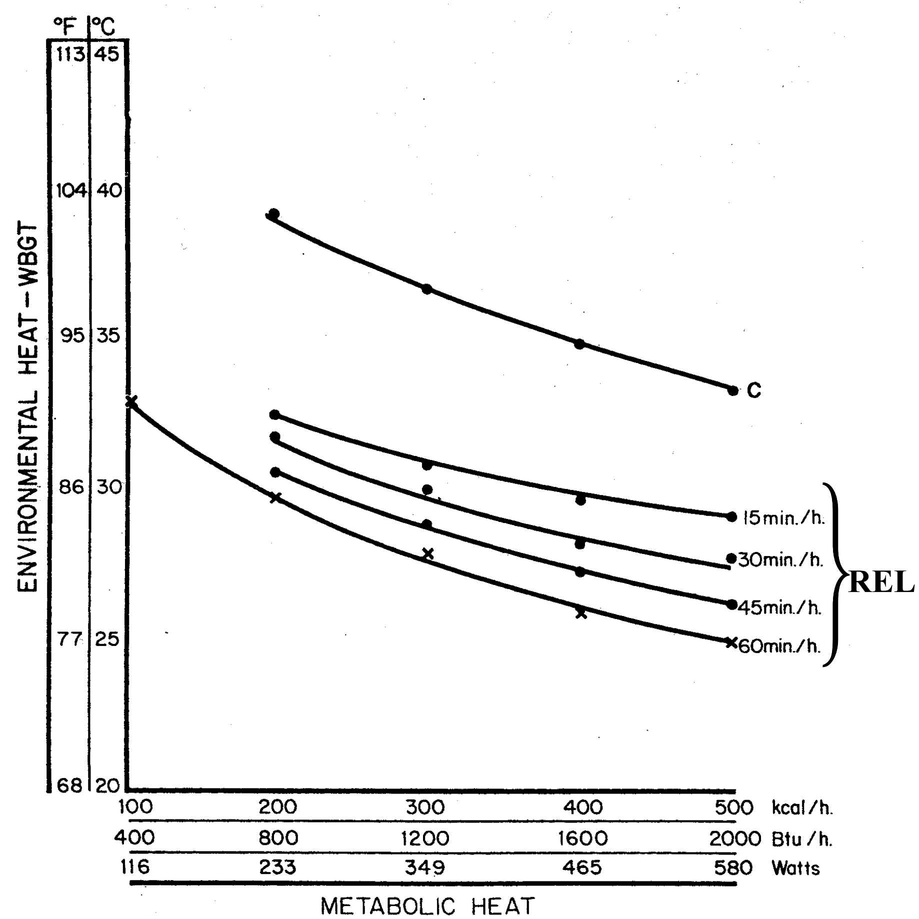
Total estimated metabolic rate = 536 kcal/hour* versus 456 kcal/hour*

† Lengthening the average time of ascent by 90 minutes reduces the estimated metabolic rate by 80 kcal/hr and brings the rate within the NIOSH REL/RAL levels of 100-500 kcal/hr.

* These rates do not include a weight correction factor.

Appendix B: NIOSH Recommended Heat-Stress Alert and Heat-Stress Exposure Limits[10, d]



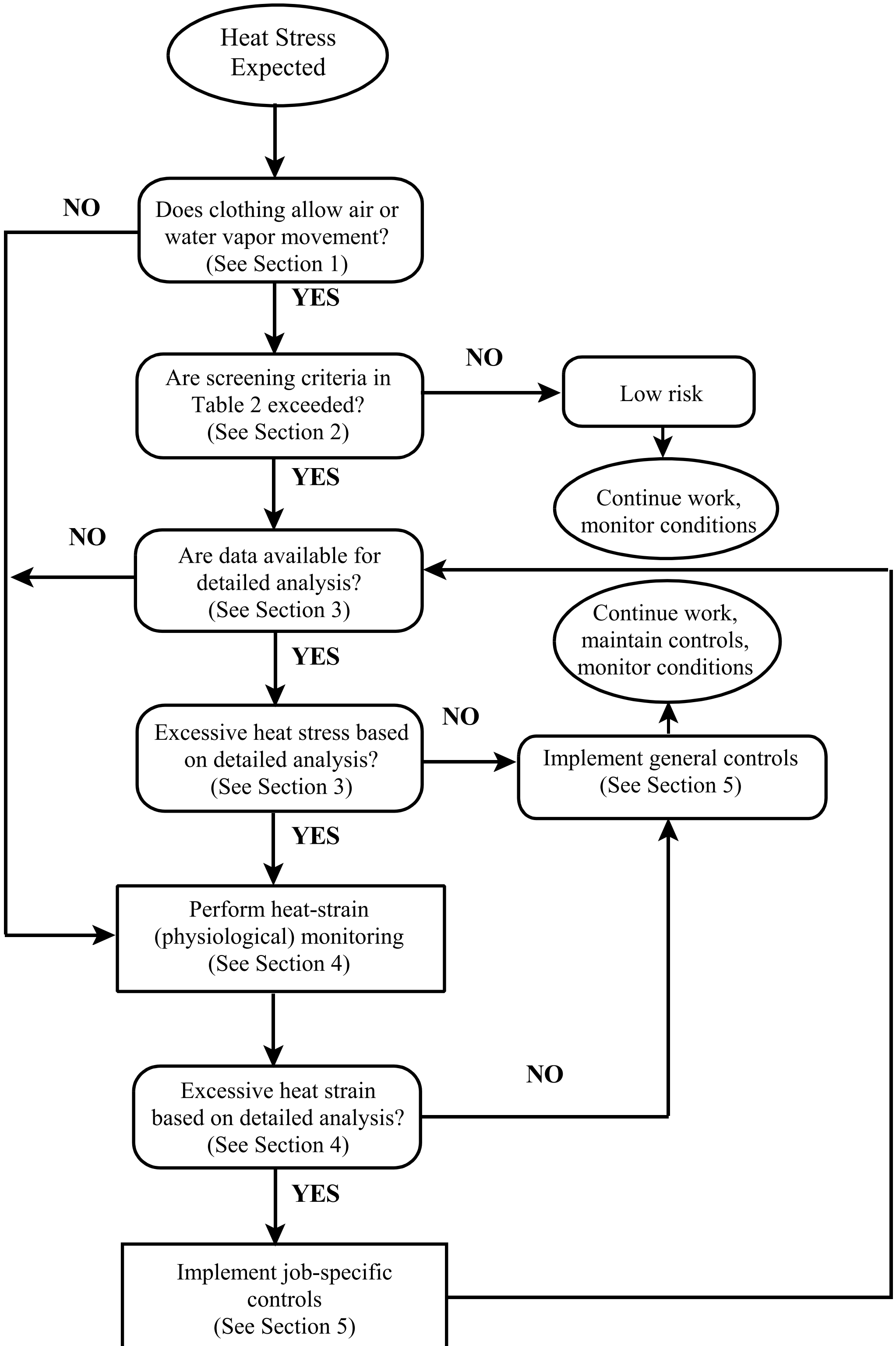


[d] The figures' curves indicate recommended work/rest regimens for a combination of external heat (measured as wet-bulb globe temperatures) and internal (metabolic) heat. The 'C' curve is the Ceiling Limit, indicating that workers should not be exposed to such conditions without adequate heat-protective clothing and equipment.[10]

Figure 1. Recommended Heat-Stress Alert Limits (Unacclimatized Workers)

Figure 2. Recommended Heat-Stress Exposure Limits (Acclimatized Workers)

Appendix C: ACGIH Evaluation Scheme for Heat Stress*



* From American Conference of Governmental Industrial Hygienists (ACGIH®), *2001 TLV® and BEI® Documentation* and *2000 Supplement: Heat stress and strain: Documentation of TLVs® and BEIs®, 6th Edition*. Copyright 2000 and 2001, respectively. Reprinted with permission

Appendix D: ACGIH Screening Criteria for Heat Stress Exposure*

	Acclimatized (WBGT values in °F)				Unacclimatized (WBGT values in °F)			
Work Demands	**Light**	**Moderate**	**Heavy**	**Very Heavy**	**Light**	**Moderate**	**Heavy**	**Very Heavy**
100% Work	85.1	81.5	78.8		81.5	77.0	72.5	
75% Work; 25% Rest	86.9	83.3	81.5		84.2	79.7	76.1	
50% Work; 50% Rest	88.7	85.1	83.3	81.5	86.0	82.4	79.7	77.0
25% Work; 75% Rest	90.5	87.8	86.0	85.1	87.8	84.2	82.4	79.7

Notes:
- See work demand categories table below.
- WBGT values represent thresholds near the upper limit of the metabolic rate category.
- If work and rest environments are different, hourly time-weighted averages (TWA) should be calculated and used. TWAs for work rates should also be used when the work demands vary within the hour.
- Values in the table assume 8-hour workdays in a 5-day workweek with conventional breaks as discussed in the Evaluation Criteria section of this report.
- Because of the physiological strain associated with Very Heavy work among less fit workers regardless of WBGT, criteria values are not provided for continuous work and for up to 25% rest in an hour. The screening criteria are not recommended, and a detailed analysis and/or physiological monitoring should be used.

The following work load categories, descriptions of work, and estimated energy expenditures help to estimate a conservative WBGT heat exposure limit for workers conducting these or similar jobs:

Work Categories	Example Activities
Resting	Sitting quietly; Sitting with moderate arm movements
Light (<200 kcal/hr)	Sitting with moderate arm and leg movements; Standing with light work at machine or bench while using mostly arms
Moderate (200-350 kcal/hr)	Scrubbing in a standing position; Walking about with moderate lifting or pushing; Walking on level at 3.7 mph while carrying a 6.6 pound load
Heavy (350-500 kcal/hr)	Carpenter sawing by hand; Shoveling dry sand; Heavy assembly work on a noncontinuous basis; Intermittent heavy lifting with pushing or pulling (e.g. pick-and-shovel work)
Very Heavy (>500 kcal/hr)	Shoveling wet sand

* From American Conference of Governmental Industrial Hygienists (ACGIH®), *2001 TLV® and BEI® Documentation* and *2000 Supplement: Heat stress and strain: Documentation of TLVs® and BEIs®, 6th Edition*. Copyright 2000 and 2001, respectively. Reprinted with permission.

Appendix E: Use of Personal Monitoring Methods to Reduce Heat-Related Illnesses[10]

Periodic monitoring of the heart rate, oral temperature, extent of body weight loss, and/or recovery heart rate should always include the determination of baseline values for deciding whether individuals are fit to continue work that day.

✔**Heart rate:** Calculate your heart rate limit by subtracting your age from 180. Your heart rate at peak work effort should not exceed this number for more than 3 or 4 minutes. If it does, stop work immediately, find some shade, drink, and rest until your heart rate returns to a more normal pace. Repeat as necessary.

✔ **Oral Temperature:**[10] Use a clinical thermometer right after stopping work but before drinking anything. Try to avoid open-mouth breathing prior to inserting the thermometer, as well. If the oral temperature taken under the tongue exceeds 99.7°F, shorten the next work cycle by one-third and maintain the same rest period. An oral temperature of 100.4°F (deep body temperature of 102.2°F) should be considered reason to terminate exposure even when temperature is being monitored.

✔ **Body Weight:** Monitor hydration status on a regular basis. Thirst is a poor indicator of hydration because significant dehydration has already taken place when the thirst sensation occurs. Workers should be familiar with their weight when they are fully hydrated and should strive to maintain this weight. Weight loss should not exceed 1.5% of total body weight in a work day. If it does, fluid and food intake should increase. (Alcohol and caffeinated beverages should always be avoided when working under heat stress conditions.) Workers should attempt to re-hydrate themselves until they achieve their baseline weight. For this purpose, accurate scales should be made available at every work station. Body water loss can be measured by weighing the worker at the beginning and end of each work day and by using this equation:

(pre-activity weight - post-activity weight) ÷ pre-activity weight × 100 = % body weight lost

✔ **Recovery Heart Rate:**[10] Following a normal work cycle, compare a pulse rate taken at 3 minutes of seated rest, $\mathbf{P_3}$, with the pulse rate taken at 1 minute of rest, $\mathbf{P_1}$. Interpret the results using the following table:

Heart Rate Recovery Pattern	P_3		P_1 minus P_3
Excessive heat strain:	≥90 bpm	and	≤10 bpm
Moderate strain:	≥90 bpm	and	≥10 bpm
Sufficient recovery:	<90 bpm	and	>10 bpm

DEPARTMENT OF HEALTH AND HUMAN SERVICES
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health
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