Heat Stress and Strain Evaluation Among Aluminum Potroom Employees – Texas

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Health Hazard Evaluation Report
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The employer shall post a copy of this report for a period of 30 calendar days at or near the workplace(s) of affected employees. The employer shall take steps to insure that the posted determinations are not altered, defaced, or covered by other material during such period. [37 FR 23640, November 7, 1972, as amended at 45 FR 2653, January 14, 1980].

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Abbreviations

ACGIH®	American Conference of Governmental Industrial Hygienists
BEI®	Biological Exposure Index
BPM	Beats per minute
BUN	Blood urea nitrogen
CBT	Core body temperature
CDC	Centers for Disease Control and Prevention
CFR	Code of Federal Regulations
°F	Fahrenheit
HR	Heart rate
N	Number of study participants
NAICS	North American Industry Classification System
NIOSH	National Institute for Occupational Safety and Health
OEL	Occupational exposure limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible exposure limit
PPE	Personal protective equipment
REL	Recommended exposure limit
TLV®	Threshold limit value
TWA	Time-weighted average
WBGT	Wet bulb globe temperature
WEEL™	Workplace environmental exposure limit

Highlights of the NIOSH Health Hazard Evaluation

The National Institute for Occupational Safety and Health (NIOSH) received a union request for a health hazard evaluation (HHE) at an aluminum smelter in Texas. The union submitted the HHE request because of concerns about the hot working conditions in the aluminum potroom and possible health problems from working mandatory overtime.

What NIOSH Did

- We evaluated the smelter in August 2006 and again in July 2007.
- We talked with employees, union officials, managers, and medical staff at the facility about the hot working conditions.
- We looked at the company's heat stress program.
- We looked at logs of work-related injuries and illness.
- We reviewed medical records of employees who were reported to have heat-related illness.
- We measured core body temperature and heart rate of employees.
- We measured electrolyte levels of employees.
- We asked employees about their symptoms, medical history, and work history.
- We measured employees' exposure to the heat in the forming department.

What NIOSH Found

- The company had a detailed heat stress management program, but it was not being followed at all times.
- Most of the tasks that we monitored exceeded the limits for working in a hot environment.
- Most employees we monitored had some heat strain.
- Of the employees we monitored, several did not drink enough fluids.

What Managers Can Do

- Reduce the physical demands on employees working in the potrooms.
- Require the use of heat reflective personal protective equipment.
- Install cooling recovery areas in the potrooms.
- Do not use outdoor air to cool employees when it is over 95°F outside.
- Follow the heat stress management program.
- Stop 8-hour overtime shifts during extremely hot weather.

What Employees Can Do

- Use heat reflective personal protective equipment.
- Use the cooling recovery areas when on breaks.
- Take time to work safely.

Summary

NIOSH investigators found that potroom employees were exposed to heat stress in excess of the occupational screening criteria. We recommend reducing physical demands of the work, installing cooling recovery areas, stopping 8-hour overtime shifts during extremely hot weather, and using heat reflective personal protective equipment to reduce the heat stress.

On July 14, 2006, NIOSH received a request from the United Steelworkers to assess employee exposure to heat while working in the potrooms at an aluminum smelter in Texas. The union was concerned about heat-related illnesses during the hot summer months and the health implications of mandatory overtime.

On July 23–27, 2007, we conducted an in-depth heat stress and strain evaluation. We measured potroom employees' HR and CBT throughout the shift. We also measured preshift and postshift serum electrolyte levels and urine specific gravity to assess hydration. After the shift, employees filled out a questionnaire about medical history, work history, and symptoms experienced during the shift on which they were monitored. We measured the WBGT and outdoor weather conditions during the shifts on which employees were monitored.

At the time of our evaluation we found that most monitored tasks exceeded the ACGIH TLV and NIOSH ceiling limit for working in a hot environment. The majority of the employees we evaluated met at least one ACGIH criterion for heat strain. Several employees were not sufficiently hydrated, which could have precipitated the onset and increased the intensity of their heat strain. Lack of acclimatization and lower body mass index could have contributed to heat strain in some employees.

This report includes recommendations to help reduce the potential for heat-related illnesses in potroom employees. These recommendations include reducing physical demands, installing cooling recovery areas, eliminating 8-hour overtime shifts during extremely hot weather, using heat-reflective PPE, and instituting other administrative controls.

NAICS 331314 (Secondary Smelting & Alloying of Aluminum), heat stress, heat strain, hot work environment, aluminum smelting

Introduction

On July 14, 2006, NIOSH received a request from the United Steelworkers to assess employee exposure to heat while working in the potrooms at an aluminum smelter in Texas. The union was concerned about heat-related illnesses during the hot summer months and the health implications of mandatory overtime.

We visited the aluminum smelter on August 16, 2006, and met with employer representatives, union representatives, and medical staff. After touring the potrooms, reviewing the company's health and safety programs and employee medical records, and interviewing employees, we determined that heat stress was a potential health hazard among potroom employees and that further investigation was warranted. Because peak summer temperatures in Texas had already passed, we postponed a follow-up visit until July 23–27, 2007, to conduct an in-depth heat stress and strain evaluation. An interim letter with findings from our first site visit and preliminary recommendations was mailed to the employer and to union representatives on October 16, 2006.

Process Description

This was the largest primary aluminum smelting operation in the United States. It was capable of producing 1.67 million pounds of aluminum per day before closing in October 2008. This facility produced sheet ingots, primary ingots, and aluminum powder. It opened in 1952, and included a lignite mine, power plant, and processing plant. The lignite mine provided 6 million tons of fuel annually for the power plant. The electrode department produced carbon anodes used in the potrooms for aluminum reduction. The six potroom lines consisted of two rooms each.

The aluminum smelter used two pot styles for aluminum production. Each of the older T-51 pots contained 20 carbon anodes while the newer, larger P-100 pots contained 26 carbon anodes each. Each T-51 potroom housed 72 pots, while the P-100 potrooms housed 80 pots per room. Each crew was responsible for 12 T-51 pots or 13 P-100 pots per shift. All pots were approximately 15 by 40 feet in size; the rectangular steel tanks were lined with refractory bricks to resist the heat and the corrosive effects of fluoride metal.

In aluminum smelting, alumina is reduced to nearly pure aluminum at an operating temperature of approximately 1,800°F. Alumina is mixed with molten cryolite, which dissolves up to 20% of alumina and lowers its melting point. Fluorspar is added to lower the melting point of the mixture, and aluminum fluoride is added to increase current efficiency. A crust forms as cryolite solidifies at the surface of the bath mixture and provides a layer of thermal insulation. Because of the high melting point of aluminum oxide, the alumina cannot be smelted by thermal reduction; reduction energy must be supplied. The carbon-lined pots act as the cathode, and the carbon electrodes act as the anode. The passage of direct electrical current reduces alumina to aluminum and oxygen. The resulting molten aluminum metal sinks to the bottom of the pot and is siphoned off periodically into crucibles.

Each carbon anode weighed approximately 300 pounds and had a copper rod inserted through its middle. These anodes were systematically replaced approximately every 18 days as the carbon material was gradually consumed in the aluminum smelting process. Approximately one ton of molten aluminum was removed ("tapped") from each pot every 48 hours.

Approximately 600 employees worked in the potrooms over three shifts. Operations were continuous, with employees working 8-hour shifts and rotating weekly. When a shortage of employees for a given shift occurred, volunteers were solicited from the prior shift to work an additional 8-hour shift. If too few employees volunteered, mandatory overtime was enforced. No employees were allowed to work more than 64 hours per week.

The following jobs were performed by potroom employees:

- Tapper carbon changers removed molten aluminum from the pots and removed spent carbon anodes. Fresh anodes were placed into the pots using an overhead crane.
- Pot tenders periodically broke the insulating crust that formed at the surface of the bath mixture, added aluminum ore, and aligned the anodes. They used wooden probes to break up air gaps in the molten material.
- Overhead crane operators removed spent rods from the pots, positioned new carbon anodes, transported and added alumina via portable bins, and moved all pot tapping equipment.
- Potroom helpers added ore and other materials to the pots, and performed miscellaneous tasks.
- Heat stress carbon setters were additional members on the potroom crews during the warmer summer months. They performed the same duties as the tapper carbon changers, pot tenders, and potroom helpers.

Initial Site Visit

On August 16, 2006, we held an opening conference with union and employer representatives, walked through the plant, reviewed the OSHA Form 300 Log of Work-Related Injuries and Illnesses, and reviewed medical records of employees reported by the union or medical staff to have had heat-related illness. We also interviewed several potroom employees privately and reviewed the current heat stress management program.

Second Site Visit

On July 23–27, 2007, we recruited employees identified by the employer and the union as working in the hottest jobs. We assumed that the hottest jobs occurred during the day shifts, so we selected participants from the first (8 a.m. to 4 p.m.) and second (4 p.m. to 12 a.m.) shifts each day over a 5-day period. Participation was voluntary, and we obtained written informed consent from all participants.

Participants completed a questionnaire about their medical history, work history, and symptoms experienced during the shift on which they were monitored. Symptoms of interest included muscle cramps, headache, lightheadedness or dizziness, nausea or vomiting, racing heartbeat or palpitations, unsteady walk, and confusion or disorientation. Participants were considered unacclimatized if they had been off work or worked completely outside the potrooms for four or more consecutive days in the past 2 weeks.

Continuous CBT and HR were measured throughout a work shift. The HR monitors were attached to participants before their shift and removed after their shift. Before their shift, participants swallowed a VitalSense™ temperature sensor pill, and we attached a data logger to the participant's waist belt. At the end of shift, data loggers were removed, and heat strain information was downloaded. The sensor pills passed naturally through the participant's gastrointestinal tract.

Urine specific gravity and blood electrolytes were measured before and after each participant's shift. All participants were told their electrolyte results at the end of their shift.

WBGTs were monitored at several locations throughout the potrooms, simulating the locations where employees normally worked. Outdoor weather conditions were monitored with a

Assessment (continued)

weather station near the main gate. WBGT and outdoor weather data were collected to assess potential for heat stress during the shifts when heat strain monitoring was performed.

Additional details of the methods used for heat strain and stress can be found in Appendix B. Appendix C contains heat strain and stress evaluation criteria used for this evaluation.

Results

Initial Site Visit

We interviewed 21 employees. One was reported by the union as having been treated for heat-related symptoms, two asked to be interviewed, and the others were serially selected from the employee roster. Three employees reported they had not experienced symptoms of heat strain. The other employees reported symptoms of heat strain occurring during the summer months, mostly muscle cramps and lightheadedness. Ten employees had visited the medical department during the summer, and one employee had been sent to the emergency room to receive intravenous fluids. Two of the ten who sought medical care for heat-related symptoms noted that they preferred to sit outside and felt that cooling off too quickly worsened their muscle cramps. They verified that they were allowed to cool off outside or inside; however, the medical staff did not necessarily recommend one or the other. The other eight had remained indoors while in the medical department. The 2006 corporate heat stress protocol recommended that employees suspected of having heat cramps, heat syncope, heat exhaustion, or heat stress “should be allowed to rest in a cool (e.g., air-conditioned) environment.” All interviewed employees reported satisfaction with the medical care received.

One employee reported falling asleep while driving home after a 16-hour shift. Medical staff thought fatigue from overtime contributed to employees being given a written diagnosis of “hot and tired.” The interviewed employees also reported that when they were required to work overtime, the jobs they worked during the second shift did not always involve a lighter task than during the first shift, as required in the heat stress protocol. For example, it was common to work as a pot tender or carbon setter for two shifts in a row.

We reviewed medical records of nine employees who had entries on the OSHA Logs for heat-related illness, or were reported by coworkers, themselves, or the union to have been treated for heat-related illness. Six employees were diagnosed by the emergency room physician with heat exhaustion, two employees were sent to the emergency room for cardiac problems, and one employee was sent to the emergency room for an extremely elevated blood glucose (sugar) level. We noted a belief among employees that when an employee was sent to the emergency room it was because of heat stress. Our review of medical records did not support that belief.

According to the medical department logs, 158 episodes of heat disorders (mostly "hot and tired" or muscle cramps) and three episodes of employees with heat-related illness had occurred since March 8, 2006. Only employee diagnoses of heat-related illness were documented on the OSHA Logs. Six cases of heat-related illnesses occurred in 2002, three in 2003, and four each in 2004 and 2005.

Second Site Visit

The daily outdoor weather conditions are summarized in Table A1. Mean temperature for July from 1971–2000 was 85°F [NOAA 2004]. The mean temperature for the 5 days of our evaluation was 78°F.

We collected 31 WBGT measurements on July 23 and July 24, 2007, in areas where employees performed routine job tasks. These included a T-51 and a P-100 pot, a pot with side covers removed, a tapping crucible next to a T-51 and a P-100 pot, an aisle with no spent anodes and one with spent anodes, and the operator's enclosure on the overhead crane. Protective clothing worn by employees in the potrooms included a fire retardant long-sleeve shirt and pants, long-sleeve cotton t-shirt, steel toe boots, and a hardhat.

The WBGT data collected in the potrooms are presented in Table A2. The WBGT measurements ranged from 83°F to 120°F, with dry bulb air temperatures reaching 134°F and radiant temperatures reaching 188°F. The highest WBGT measurement in the potroom was collected between a T-51 pot and a tapping crucible during tapping. The second highest WBGT measurement was collected on the center of the catwalk between pots with one side open. This measurement was probably lower than the actual temperature because the WBGT monitor was not fully equilibrated because the high radiant heat load was starting to melt the monitor's tripod.

Radiant heat (globe bulb temperature) measured at all except one location inside the potrooms equaled or exceeded 96°F. At these temperatures, employees absorb rather than radiate heat unless proper shielding is provided. The highest globe bulb temperature was measured on the catwalk in the center of two pots with the side shields removed on one pot. The second highest globe bulb temperature was measured between a T-51 pot and a crucible during tapping.

A clothing adjustment factor was estimated at 5°F for the clothing worn by employees in the potrooms. Metabolic rates for employees in the potrooms were estimated to be in the moderate to light category, ranging from 115 to 360 watts. When compared to the WBGT measurements collected in the potrooms, portions of all tasks, except for the crane operator, exceeded the ACGIH TLV and NIOSH ceiling limit for working in a hot environment.

Of an estimated total population of 600 potroom employees, 61 participated in the heat stress evaluation. One employee completed the questionnaire but was excluded from analysis because that individual only worked 30 minutes. Personal characteristics of the participants are summarized in Table A3. Participants were predominantly male. The average body mass index, a measure of body fat on the basis of height and weight, was 30.5. Values between 25 and 29.9 fall in the overweight category, and values 30 or greater fall in the obese category. However, muscular individuals may have an increased body mass index due to high muscle mass rather than body fat.

The distribution of job titles during the first 8-hour shift is shown in Table A4. Six of the 60 study participants worked an overtime shift. We observed three participants perform equally hot job duties during their overtime shift as during their regular shift, which is prohibited according to the company heat stress management program. Two worked as a tapper carbon changer (considered one of the hottest jobs) for two 8-hour shifts in a row, and one worked as a head tapper carbon changer during the first shift and then as a tapper carbon changer/crane operator for 2 overtime hours.

The prevalence of symptoms reported during the work shift is shown in Table A5. The most common symptoms were racing heartbeat or palpitations, headache, muscle cramps, and lightheadedness or dizziness.

Study participants' preshift and postshift changes in blood and urine measurements are shown in Table A6. Postshift blood bicarbonate, BUN, creatinine, and urine specific gravity increased significantly. The BUN to creatinine ratio and potassium level decreased significantly over the shift. These changes suggest volume depletion. Volume depletion is different from pure dehydration, and occurs when loss of both water and salt/sodium results in a reduced circulatory blood volume [Mange 1997]. Sweat contains water and salt, and excessive sweating can cause volume depletion.

Three participants had a marked increase in preshift to postshift creatinine values, which indicates acute kidney injury. Their preshift and postshift BUN to creatinine ratios were 14.0/1.1 to 20.0/2.3, 11.0/1.3 to 13.0/2.4, and 12.0/1.0 to 15.0/2.6. These participants were advised to drink plenty of fluids and to have their blood creatinine level rechecked the following day either by us or medical staff from the facility. One of these participants returned the following day, and his creatinine had dropped from 2.3 to 1.4 milligrams per deciliter. This drop in creatinine suggests that the acute kidney injury was reversed.

The average amount of fluids consumed during the shift was 180 ounces. The three participants with a marked increase in preshift to postshift creatinine values had a higher mean fluid intake (191 ounces) than the rest of the study participants (180 ounces). Medi-lyte® packets, provided by the employer to replace electrolytes lost from excessive sweating, contain 40 milligrams potassium chloride, 18 milligrams calcium phosphate, and 9 milligrams magnesium carbonate. Among those reporting consumption of Medi-lyte packets during their shifts (20%), the average number of packets used was 3.1. Participants who reported drinking alcoholic beverages during the 24 hours prior to starting work (18%) consumed an average of 3.5 alcoholic beverages.

The number of participants meeting the ACGIH criteria for heat strain is shown in Table A7. Most participants (54%) met at least one ACGIH criterion for heat strain, and 17 participants (29%) exceeded the CBT criterion for their acclimatization status. Participants who exceeded the CBT for their acclimatization status and/or exceeded the sustained peak HR criterion had a significantly lower average body mass index than those who did not exceed those ACGIH criteria. Among unacclimatized participants, 88% exceeded their ACGIH heat strain criterion for CBT compared to 20% of acclimatized participants ($P < 0.01$).

Comparisons of the differences in preshift and postshift laboratory values for participants who did and did not meet ACGIH criteria for heat strain are shown in Tables A8 and A9. Participants who exceeded any of the ACGIH heat strain criteria had, on average, a significantly greater decrease in their BUN to creatinine ratio than those who did not. Participants who exceeded the CBT for their acclimatization status also had, on average, a significantly higher increase in blood creatinine.

Results (continued)

Unacclimatized participants were significantly more likely to exceed the ACGIH heat strain criteria for CBT, as shown in Table A10. Among participants who exceeded ACGIH CBT criteria, the average percentage of the time period monitored above criteria was 22% for unacclimatized employees and 9% for acclimatized employees. Unacclimatized potroom participants had a significantly higher average HR than the acclimatized participants.

A comparison of CBT and HR values based on symptom presentation is shown in Table A11. The only participant who reported nausea or vomiting had the highest peak CBT value of 102.83°F.

Discussion

Many participants were not sufficiently hydrated. The average preshift urine specific gravity for the participants was 1.023, indicating that most were significantly volume depleted or dehydrated before starting their work shift [Casa et al. 2000]. The significant increase in preshift to postshift urine specific gravity indicates that participants did not drink enough fluids to keep up with the amount of water and salt lost through excessive sweating.

Several participants had laboratory evidence of acute kidney injury. Volume depletion may have played a role, causing decreased blood flow to the kidneys and acute injury. However, subclinical rhabdomyolysis, a syndrome characterized by the breakdown of muscle cells due to injury, can occur as a result of excess heat stress exposure or extreme physical activity. Acute kidney injury due to volume depletion or rhabdomyolysis is a reversible condition, and generally responds well to appropriate rehydration.

Discrepancies between the written heat stress management program and actual practice created the potential for increased heat stress and strain. For example, employees working overtime performed similar and not the less strenuous tasks required by the heat stress management program during their overtime shift. We also observed that crews were not all fully staffed with a heat stress carbon setter, so people could not rotate away from hot tasks. Other work crews compressed their job tasks and did not take the required breaks in order to have a longer break at the end of the shift.

Employee interviews and workplace observations during our initial visit in 2006 indicated that the facility had a reduced workforce. As a result, the company policy was to require rather than voluntarily offer overtime to ensure uninterrupted production. Because of

Discussion (continued)

this policy, many employees we interviewed worked consecutive 8-hour shifts, which potentially placed them at increased risk of heat-related illnesses because of the additional heat stress exposure. For example, employees who worked an 8-hour overtime shift (a total of 16 consecutive hours) had just 8 hours to drive home, eat, and sleep before reporting back to work the next day. Sleep deprivation reduces reaction time and increases perceptual and cognitive distortions and changes in mood [Pilcher 1996; Ferrara 2001]. Employees and managers need to be aware of the effects of cumulative fatigue and sleep deprivation associated with excessive overtime work.

We were unable to compare differences in physiologic markers for heat stress and strain in potroom employees working 8-hour shifts and those working an additional overtime shift because of the small number of employees who worked overtime during our evaluation. Additionally, outdoor environmental conditions significantly differed between the time of the initial health hazard evaluation request and the days that we performed physiologic monitoring. The outdoor temperatures on the days of monitoring were cooler than expected during the summertime in Texas, and the heat strain and symptom data may have underestimated what potroom employees might experience during extreme heat. Finally, although the CBTs and HR data were gathered in real time, the data were not analyzed until later. As such, we were not able to provide direct intervention on the basis of physiologic data. Instead, the goal of this evaluation was to use the data to provide future recommendations for the prevention of heat-related illnesses.

Conclusions

The majority of the employees we studied met at least one ACGIH criterion for heat strain. All jobs except the crane operator exceeded the ACGIH TLV and NIOSH ceiling limit for working in a hot environment. Several employees were not sufficiently hydrated, which could have precipitated the onset and increased the intensity of their heat strain. Lack of acclimatization and lower body mass index were also important factors in the level of heat strain experienced by some employees.

Recommendations

On the basis of our findings, we recommend the actions listed below to create a more healthful workplace for workplaces similar to the one we evaluated. We encourage employers to use a labor-management health and safety committee or working group to discuss the recommendations in this report and develop an action plan. Those involved in the work can best set priorities and assess the feasibility of our recommendations for their specific situation. Our recommendations are based on the hierarchy of controls approach (Appendix C: Occupational Exposure Limits and Health Effects). This approach groups actions by their likely effectiveness in reducing or removing hazards. In most cases, the preferred approach is to eliminate hazardous materials or processes and install engineering controls to reduce exposure or shield employees. Until such controls are in place, or if they are not effective or feasible, administrative measures and/or personal protective equipment may be needed.

Engineering Controls

Engineering controls reduce exposures to employees by removing the hazard from the process or by placing a barrier between the hazard and the employee. Engineering controls are very effective at protecting employees without placing primary responsibility of implementation on the employee.

1. Reduce the physical demands for employees working in the potrooms through process automation and/or by increasing the number of employees on each crew.
2. Install cooling recovery areas along the curtain walls in the potrooms where employees typically sit [AIHA 1975; ASHRAE 2007]. Cooling recovery areas should be easily accessible to encourage employee use. They should reduce the radiant and convective heat loads while increasing the evaporative cooling of the employees.

Administrative Controls

Administrative controls are employer-dictated work practices and policies to reduce or prevent exposures to workplace hazards. The effectiveness of administrative changes in work practices for controlling workplace hazards is dependent on management commitment and employee acceptance. Regular monitoring and reinforcement are necessary to ensure that control policies and procedures are not circumvented in the name of convenience or production.

1. Do not use outdoor air to cool employees when the ambient outdoor air temperatures exceed 95°F.

2. Implement and enforce the company heat stress program, with special attention to the following:
    a. When employees are performing overtime work, their jobs during the second shift should involve a lighter task (section 3.4.4 of the company's heat stress program).
    b. Maintain full crews during period of extreme heat.
    c. Reacclimate employees returning from a period of 3 days or more away from the potrooms.
3. Eliminate 8-hour overtime shifts (voluntary or mandatory) during periods of extreme heat. An alternative to 8-hour overtime shifts is to split up the overtime shifts into two 4-hour overtime shifts and assign call duties to a rotating number of employees. Call duty means that an employee may be asked to stay for a 4-hour overtime shift or called in 4 hours earlier to start a shift. They are notified ahead of time regarding their call duty schedule and may be called in to work on assigned dates if there are not enough employees for a given work task.
4. Employees should take the time to work safely. They should be discouraged from compressing work tasks in order to have a longer rest period at the end of shift.

Personal Protective Equipment

PPE is the least effective means for controlling employee exposures. Proper use of PPE requires a comprehensive program, and calls for a high level of employee involvement and commitment to be effective. The use of PPE requires the choice of the appropriate equipment to reduce the hazard and the development of supporting programs such as training, change-out schedules, and medical assessment if needed. PPE should not be relied upon as the sole method for limiting employee exposures. Rather, PPE should be used until engineering and administrative controls can be demonstrated to be effective in limiting exposures to acceptable levels.

1. Require employees to wear lightweight heat-reflective aprons when working around pots, or when tapping. The reflective aluminum-foil surface should be facing away from the employee and be kept clean to maintain its effectiveness. To aid evaporative cooling, reflective aprons should not be worn when employees are in the cooling recovery areas or break rooms.

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Appendix A: Tables

Table A1. Outside weather conditions during the evaluation*

Date	Temperature (°F)†	Relative Humidity (%)†	Wind Speed (miles per hour)†
July 23, 2008	75–90	53–94	0–6
July 24, 2008	72–87	56–93	0–5
July 25, 2008	70–85	62–67	0–10
July 26, 2008	70–85	68–96	0–8
July 27, 2008	72–86	67–98	0–6

*over a 24-hour period
†minimum–maximum

Table A2. Wet bulb globe temperature measurements

Equipment	Monitor Location	Wet Bulb (°F)	Dry Bulb (°F)	Globe Bulb (°F)	WBGT* (°F)
T-51 Pot	Edge of pot	81	95	105	88
	Center of pots on catwalk	87	121	154	107
	Curtain wall	78	91	95	83
	Courtyard (outside)	78	91	95	83
Tapping Crucible at T-51 Pot	Next to crucible	82	93	140	99
	Between pot and crucible	92	127	186	120
	Curtain wall	80	91	110	89
	Courtyard (outside)	80	92	112	89
P-100 Pot	Edge of pot	82	95	112	91
	Center of pots on catwalk	91	134	141	106
	Curtain wall	80	93	98	86
	Courtyard (outside)	79	90	93	83
Tapping Crucible at a P-100 Pot	Next to crucible	83	91	114	93
	Between pot and crucible	86	107	146	104
	Curtain wall	81	97	100	87
	Courtyard (outside)	76	81	88	79
Open pots	Edge of pot	82	93	109	90
	Center of pots on catwalk	89	134	188	119
	Curtain wall	79	87	96	84
	Courtyard (outside)	77	83	92	81
Aisle without spent carbon anodes	Edge of pot	80	90	96	85
	Curtain wall	80	90	96	85
	Edge of pot	81	93	107	89
	Curtain wall	81	93	99	87
	Courtyard (outside)	76	83	92	80
Aisle with spent carbon anodes	Edge of pot	85	118	137	101
	Curtain wall	81	99	118	92
	Edge of pot	85	109	136	100
	Curtain wall	83	101	123	95
	Courtyard (outside)	76	87	97	81
Crane	Behind operator seat in cabin	82	104	108	90

*No clothing adjustment factor has been applied to reported values. An adjustment of plus 5°F is required for the work clothing worn in the potrooms.

Table A3. Personal characteristics of study participants*

Average age (range)	32 (19–50)
Male, number (%)	57 (95)
Average years working in a potroom at the facility, (range)	1.2 (0.1–6.0)
Average body mass index, (range)†	30.5 (19.4–47.3)
Average hours slept before starting work, (range)	6.6 (3.0–10.0)
Unacclimatized, number (%)	8 (13)
History of, number (%)	
Diabetes	1 (2)
Heart Disease	0
High blood pressure	3 (5)
Kidney disease	0
Thyroid disease	1 (2)
Other‡	4 (7)

*N = 57–60
†Body mass index was calculated using self reported height and weight.
‡Arthritis, asthma, depression, and sarcoidoisis

Table A4. Distribution of job titles during the first 8-hour shift*

Job Title	Number (%)
Tapper carbon changer	22 (37)
Pot tender	14 (23)
Head tapper carbon changer	10 (17)
Tapper carbon changer/crane operator	4 (7)
Roving head tapper carbon changer	3 (5)
Roving pot tender	2 (3)
Roving tapper carbon changer	1 (2)
Pot tender sampler	1 (2)
Crane operator	1 (2)
Potroom helper	1 (2)
Trainer (new hire orientation)	1 (2)

*N = 60

Table A5. Prevalence of symptoms reported during the shift*

Symptom	Number (%)
Racing heart beat or palpitations	18 (30)
Headache	12 (20)
Muscle cramps	8 (13)
Lightheadedness or dizziness	8 (13)
Confusion or disorientation	5 (8)
Unsteady walk	3 (5)
Nausea or vomiting	1 (2)

*N = 60

Table A6. Comparison of mean pre- and post-shift laboratory values

	Preshift N = 59–60	Postshift N = 60	*P* value
Blood			
Sodium (corrected)*	138.01	138.37	0.26
Potassium	4.45	4.28	0.03
Chloride	108.67	108.23	0.21
Bicarbonate	23.03	23.52	0.02
BUN	14.47	16.23	<0.01
Creatinine	1.06	1.34	<0.01
BUN/ creatinine ratio	14.04	12.61	<0.01
Glucose	110.20	107.12	0.43
Osmolality	287.31	288.48	0.07
Urine			
Specific gravity	1.023	1.028	<0.01

*Sodium is corrected for participants with glucose concentrations > 200 using the formula: corrected sodium = measured sodium + 0.016 (glucose – 100).

Table A7. Participants meeting ACGIH heat strain criteria*

ACGIH heat strain criteria	Number (%)
Core body temperature greater than criterion†	17 (29)
Sustained‡ heart rate greater than (180–age)	24 (43)
Average heart rate greater than115	11 (20)
Number of ACGIH Heat Strain Criteria met:	
0	26 (46)
1	12 (21)
2	15 (27)
3	3 (5)

*N = 56–58
†ACGIH Heat Strain Criteria: CBT greater than 101.3ºF for acclimatized employees or greater than 100.4ºF for unacclimatized employees.
‡Values sustained for greater than or equal to 5 continuous minutes.

Table A8. Differences in preshift and postshift lab values of participants by ACGIH CBT criteria

	Core Body Temperature Greater Than Criterion*				
	Yes N = 17		No N = 41		
	Pre-mean	Post-mean	Pre-mean	Post-mean	*P* value
Blood					
Sodium (corrected)†	137.82	137.82	138.09	138.56	0.34
Potassium	4.49	4.36	4.42	4.22	0.76
Chloride	108.82	108.18	108.56	108.24	0.66
CO_2	22.41	22.65	23.27	23.78	0.66
BUN	15.35	16.29	14.15	16.32	0.11
Creatinine	0.95	1.28	1.11	1.37	<0.05‡
BUN/Creatinine	16.65	13.44	12.91	12.35	<0.01‡
Glucose	112.76	106.65	107.29	107.37	0.46
Osmolality	287.39	287.39	287.19	288.91	0.23
Urine					
Specific gravity	1.023	1.026	1.023§	1.029	0.59

*ACGIH Heat Strain Criteria: CBT greater than 101.3ºF for acclimatized employees or greater than 100.4ºF for unacclimatized employees.
†Sodium is corrected for participants with glucose concentrations > 200 using the formula: corrected sodium = measured sodium + 0.016 (glucose – 100).
‡A *P* value ≤0.05 was considered statistically significant.
§N = 40

Table A9. Differences in preshift and postshift lab values of participants by ACGIH HR criterion

	Sustained* Heart Rate Greater Than (180 – age)					Average Heart Rate Greater than 115				
	Yes N = 24		No N = 32			Yes N = 11		No N = 45		
	Pre-mean	Post-mean	Pre-mean	Post-mean	*P* value	Pre-mean	Post-mean	Pre-mean	Post-mean	*P* value
Blood										
Sodium (corrected) †	137.98	137.33	137.91	139.06	<0.01‡	138.36	138.45	137.84	138.29	0.66
Potassium	4.45	4.22	4.42	4.29	0.51	4.56	4.36	4.40	4.24	0.94
Chloride	109.00	107.92	108.25	108.50	0.07	109.00	109.00	108.47	108.07	0.92
CO_2	22.67	22.71	23.28	24.00	0.17	23.09	22.64	23.00	23.64	0.07
BUN	15.13	16.88	14.16	16.03	0.95	17.00	18.73	13.98	15.82	0.66
Creatinine	0.99	1.32	1.11	1.32	0.24	1.04	1.44	1.06	1.29	0.07
BUN/Creatinine	15.62	13.52	13.01	12.32	0.03‡	16.56	13.96	13.53	12.56	0.04‡
Glucose	113.96	112.17	105.53	102.66	0.90	106.00	103.73	109.91	107.47	0.99
Osmolality	287.70	286.92	286.73	289.55	<0.01‡	288.69	289.36	286.77	288.20	0.66
Urine										
Specific gravity	1.022	1.026	1.024§	1.029	0.93	1.026	1.031	1.022¶	1.027	0.82

*Values sustained for greater than or equal to 5 continuous minutes.
†Sodium is corrected for participants with glucose concentrations > 200 using the formula: corrected sodium = measured sodium + 0.016 (glucose – 100).
‡A *P* value ≤0.05 was considered statistically significant.
§N = 31
¶N = 44

Table A10. Heat strain measurements in acclimatized and unacclimatized employees

	Acclimatized	Unacclimatized	*P* value
Number	48–50	8	
CBT, average	99.6ºF	99.7ºF	0.68
Peak CBT, average (range)	100.7 (99.0–102.8)ºF	101.0 (99.5–102.4)ºF	0.34
HR, average (range)	107 (84–127) BPM	118 (105–134) BPM	<0.01
CBT > Criterion,* number (%)	10 (20%)	7 (88%)	<0.01
Minutes above criterion, median (range)	28 (6–112)	46 (11–597)	
Period monitored above criterion, average (%)	9%	22%	
Sustained† HR > (180 – age), number (%)	19 (40%)	5 (63%)	0.27
Minutes above criterion, average	53	53	
Period monitored above criterion, average (%)	13%	12%	
Average HR > 115, number (%)	8 (17%)	3 (38%)	0.18

*ACGIH Heat Strain Criteria: CBT greater than 101.3ºF for acclimatized employees or greater than 100.4ºF for unacclimatized employees.
†Values sustained for greater than or equal to 5 continuous minutes.

Table A11. Comparison of CBT and HR values based on symptom presentation

Symptom presentation	N*	Mean CBT (ºF)	*P* value	Mean Peak CBT (ºF)	*P* value	Mean HR (BPM)	*P* value
Racing heart beat or palpitations							
Yes	16–17	99.7	0.39	100.9	0.45	111.9	0.11
No	40–41	99.6		100.7		107.1	
Headache							
Yes	10–12	99.6	0.75	101.0	0.25	109.6	0.69
No	46	99.6		100.7		108.2	
Muscle cramps							
Yes	7–8	99.6	0.85	100.9	0.73	109.0	0.88
No	49–50	99.6		100.8		108.4	
Lightheadedness or dizziness							
Yes	8	99.6	0.69	101.0	0.39	109.3	0.82
No	48–50	99.6		100.8		108.4	
Confusion or disorientation							
Yes	5	99.8	0.44	100.9	0.70	108.4	0.99
No	51–53	99.6		100.8		108.5	
Unsteady walk							
Yes	3	99.6	0.92	101.0	0.57	104.6	0.50
No	53–55	99.6		100.8		108.7	
Nausea or vomiting							
Yes	1	99.8	†	102.8	†	109.3	†
No	55–57	99.6		100.8		108.5	

*Number of participants with or without a specified symptom.
†Statistical testing was not performed because N = 1 in one of the groups.

Appendix B: Methods

Biological Monitoring

We used the i-STAT® 1 handheld analyzer and i-STAT® 8+ cartridges (Abbott Point of Care, Inc., East Windsor, New Jersey) to measure serum electrolytes. Approximately 2–3 drops of whole blood was collected via finger prick and placed in the well of the cartridge prior to inserting the cartridge into the analyzer. Blood was collected following the standard precautions for working with blood and blood products specified by CDC and OSHA [CDC 1998; 29 CFR 1910.1000].

The Atago Uricon-Ne Refractometer® (Atago USA, Inc., Bellevue, Washington) was used to measure urine specific gravity. The refractometer measures specific gravity from 1.000 to 1.050 and is accurate to within 0.001.

Physiologic Monitoring

We used the VitalSense™ (Mini-Mitter Company, Inc., Bend, Oregon) physiological monitoring system to continuously measure CBT to within ± 0.2°F. As the temperature sensor pill travels through the gastrointestinal tract it transmits CBT data to a receiver where it is stored to memory. Once swallowed the normal passage time of the temperature sensor pill is 1–5 days. The Mini-Mitter ActiHeart® HR monitor recorded data at 15-second intervals.

Wet Bulb Globe Temperature

We measured the WBGT (calculated using wet, dry, and globe bulb temperatures) and wind speed using QUESTemp °36 and QUESTemp °34 instruments (Quest Technologies, Inc., Oconomowoc, Wisconsin). These instruments measure temperatures of 23°F–212°F and are accurate to within ± 0.9°F. These instruments were allowed to equilibrate for a minimum of 15 minutes before data were collected unless otherwise noted in the report.

Weather Conditions

We measured weather conditions including temperature, relative humidity, and wind speed at the plant using a HOBO® weather station (Onset Computer Corporation, Bourne, Massachusetts). The weather station was set up near the entrance to the plant and allowed to continually monitor throughout the survey.

Statistical Analysis

Statistical analysis was carried out with SAS version 9.1.3 software (SAS Institute, Cary, North Carolina). A P value ≤ 0.05 was considered statistically significant. Paired t-tests were used to compare preshift and postshift blood and urine laboratory means. When the data were normally distributed, the t-test was used to compare body mass index and changes in preshift and postshift lab values between employees who did and did not meet ACGIH criteria for heat strain. In cases where the data were not normally distributed, the nonparametric Wilcoxon test was used to compare differences in preshift and postshift lab values between employees who did and did not meet ACGIH criteria for heat strain. The t-test was also used to compare average CBT, peak CBT, and average HR between employees who were and were not acclimatized. Fisher's exact test was used to compare differences in the percentages of employees meeting each ACGIH criterion in employees who were and were not acclimatized. T-tests or Wilcoxon tests were used to compare average CBT, peak CBT, and average HR between employees with and without work-related symptoms.

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Appendix C: Occupational Exposure Limits and Health Effects

In evaluating the hazards posed by workplace exposures, NIOSH investigators use both mandatory (legally enforceable) and recommended OELs for chemical, physical, and biological agents as a guide for making recommendations. OELs have been developed by federal agencies and safety and health organizations to prevent the occurrence of adverse health effects from workplace exposures. Generally, OELs suggest levels of exposure that most employees may be exposed to for up to 10 hours per day, 40 hours per week, for a working lifetime, without experiencing adverse health effects. However, not all employees will be protected from adverse health effects even if their exposures are maintained below these levels. A small percentage may experience adverse health effects because of individual susceptibility, a preexisting medical condition, and/or a hypersensitivity (allergy). In addition, some hazardous substances may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the employee to produce adverse health effects even if the occupational exposures are controlled at the level set by the exposure limit. Also, some substances can be absorbed by direct contact with the skin and mucous membranes in addition to being inhaled, which contributes to the individual's overall exposure.

Most OELs are expressed as a TWA exposure. A TWA refers to the average exposure during a normal 8- to 10-hour workday. Some chemical substances and physical agents have recommended short term exposure limit or ceiling values where adverse health effects are caused by exposures over a short period. Unless otherwise noted, the short term exposure limit is a 15-minute TWA exposure that should not be exceeded at any time during a workday, and the ceiling limit is an exposure that should not be exceeded at any time.

In the United States, OELs have been established by federal agencies, professional organizations, state and local governments, and other entities. Some OELs are legally enforceable limits, while others are recommendations. The U.S. Department of Labor OSHA PELs (29 CFR 1910 [general industry]; 29 CFR 1926 [construction industry]; and 29 CFR 1917 [maritime industry]) are legal limits enforceable in workplaces covered under the Occupational Safety and Health Act of 1970. NIOSH RELs are recommendations based on a critical review of the scientific and technical information available on a given hazard and the adequacy of methods to identify and control the hazard. NIOSH RELs can be found in the *NIOSH Pocket Guide to Chemical Hazards* [NIOSH 2010]. NIOSH also recommends different types of risk management practices (e.g., engineering controls, safe work practices, employee education/training, personal protective equipment, and exposure and medical monitoring) to minimize the risk of exposure and adverse health effects from these hazards. Other OELs that are commonly used and cited in the United States include the TLVs recommended by ACGIH, a professional organization, and the WEELs recommended by the American Industrial Hygiene Association, another professional organization. The TLVs and WEELs are developed by committee members of these associations from a review of the published, peer-reviewed literature. They are not consensus standards. ACGIH TLVs are considered voluntary exposure guidelines for use by industrial hygienists and others trained in this discipline "to assist in the control of health hazards" [ACGIH 2011a]. WEELs have been established for some chemicals "when no other legal or authoritative limits exist" [AIHA 2010].

Outside the United States, OELs have been established by various agencies and organizations and include both legal and recommended limits. The Institut für Arbeitsschutz der Deutschen Gesetzlichen Unfallversicherung (IFA, Institute for Occupational Safety and Health of the German Social Accident Insurance) maintains a database of international OELs from European Union member states, Canada (Québec), Japan, Switzerland, and the United States. The database, available at http://www.dguv.de/ifa/en/gestis/limit_values/index.jsp, contains international limits for over 1,500 hazardous substances and is updated periodically.

Employers should understand that not all hazardous chemicals have specific OSHA PELs, and for some agents the legally enforceable and recommended limits may not reflect current health-based information. However, an employer is still required by OSHA to protect its employees from hazards even in the absence of a specific OSHA PEL. OSHA requires an employer to furnish employees a place of employment free from recognized hazards that cause 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))]. Thus, NIOSH investigators encourage employers to make use of other OELs when making risk assessments and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminate or minimize identified workplace hazards. This includes, in order of preference, the use of (1) substitution or elimination of the hazardous agent, (2) engineering controls (e.g., local exhaust ventilation, process enclosure, dilution ventilation), (3) administrative controls (e.g., limiting time of exposure, employee training, work practice changes, medical surveillance), and (4) personal protective equipment (e.g., respiratory protection, gloves, eye protection, hearing protection). Control banding, a qualitative risk assessment and risk management tool, is a complementary approach to protecting employee health that focuses resources on exposure controls by describing how a risk needs to be managed. Information on control banding is available at http://www.cdc.gov/niosh/topics/ctrlbanding/. This approach can be applied in situations where OELs have not been established or can be used to supplement the OELs, when available.

Heat Stress

NIOSH defines heat stress exposure 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, 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 (acclimatize) 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. Increases in unsafe behavior, which may lead to accidents, are also seen as the level of physical work of the job increases [NIOSH 1986].

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 100.4°F or for oral temperature to exceed 99.5°F in prolonged daily exposure to heavy work and/or heat" [WHO 1969]. According to NIOSH, a CBT of 102.2°F should be considered reason to terminate exposure even when CBT is being monitored. This does not mean that an employee with a CBT exceeding those levels will necessarily experience adverse health effects; however, the number of unsafe acts increases as does the risk of developing heat stress illnesses [NIOSH 1986].

NIOSH recommends controlling total heat exposure so that unprotected healthy employees are not exposed to metabolic and environmental heat combinations that exceed the applicable NIOSH criteria. These criteria state that most healthy employees who work in hot environments and are exposed to combinations of environmental and metabolic heat less than the NIOSH recommended action limit for non-acclimatized employees or the NIOSH REL for acclimatized employees 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 that exceed applicable ceiling limits without being provided with and properly using appropriate and adequate heat-protective clothing and equipment [NIOSH 1986].

ACGIH guidelines require the use of a decision-making process that provides step-by-step situation-dependent instructions that factor in clothing insulation values and physiological evaluation of heat strain [ACGIH 2011b]. ACGIH WBGT screening criteria factor in the ability of the body to cool itself (clothing insulation value, humidity, and 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 employees may be repeatedly exposed without adverse health effects. Clothing insulation values and the appropriate WBGT adjustments, as well as descriptors of the other decision-making process components can be found in ACGIH's "Documentation of the Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices" [ACGIH 2011b]. The ACGIH TLV for heat stress provides a framework for the control of heat-related illnesses only. Although accidents and injuries can increase with increasing levels of heat stress, it is important to note that the TLVs are not directed toward controlling these [ACGIH 2011b].

NIOSH and ACGIH criteria can only be used when WBGT data for the immediate work area are available and must not be used when employees wear encapsulating suits or garments that are impermeable or highly resistant to water vapor or air movement. 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. While NIOSH and ACGIH guidelines distinguish between safe and dangerous levels, professional judgment must be used in administering a heat stress management program to ensure adequate protection. The OSHA technical manual's section on heat stress refers to the ACGIH document for guidelines to evaluate employee heat stress and how to investigate the workplace [OSHA 1999].

Heat Strain

The body's response to heat stress is called heat strain. Operations involving high air temperatures, radiant heat sources, high humidity, direct physical contact with hot objects, and strenuous physical activities have a high potential for inducing heat strain in employees. Heat strain is highly individual and cannot be predicted on the basis of environmental heat stress measurements. 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 required sweat rate index) shows excess heat stress.

ACGIH considers one indicator of physiological strain, sustained peak HR, to be the best sign of acute, high-level exposure to heat stress. Sustained peak HR, defined by ACGIH as 180 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 [ACGIH 2011b].

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

- Sustained (over several minutes) HR exceeds 180 BPM minus the individual's age in years, (180 BPM – age) for those with normal cardiac performance
- CBT is greater than 100.4°F for unselected, unacclimatized personnel and greater than 101.3°F for medically fit, heat-acclimatized personnel
- Recovery HR at 1 minute after a peak work effort exceeds 110 BPM
- Presence of 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
- Weight loss over a shift is greater than 1.5% of body weight
- 24-hour urinary sodium excretion is less than 55 millimoles

Acclimatization

When employees are first exposed to a hot environment, they show signs of distress and discomfort, experience increased CBTs and HRs, and may have headaches and/or nausea. On repeated exposure marked adaptation to the hot environment known as acclimatization occurs.

The loss of acclimatization begins when the activity under those heat stress conditions is discontinued, and a noticeable loss occurs after 4 days. This loss is usually rapidly made up so that by Tuesday, employees who were off on the weekend are as well acclimatized as they were on the preceding Friday. Chronic illness, an acute episode of mild illness (e.g., gastroenteritis), the use or misuse of pharmacologic agents, a sleep deficit, a suboptimal nutritional state, or a disturbed water and electrolyte balance may reduce an employee's capacity to acclimatize [ACGIH 2011b].

Volume Depletion

When working in hot environments, it is often difficult to completely replace lost fluids as the day's work proceeds. Sweat contains water and salt, and excessive sweating can cause volume depletion and electrolyte imbalances. Volume depletion is different from pure dehydration, and occurs when loss of both water and salt/sodium results in a reduced circulatory blood volume [Mange 1997]. Some studies have shown that even small deficits adversely affect performance. Volume depletion also negates the advantage granted by high levels of aerobic fitness and heat acclimatization.

Several studies have shown that volume depletion or dehydration increases CBT during exercise in temperate and hot environments. 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. Disorders of water regulation result in hyponatremia or hypernatremia. Most individuals with acute exercise-induced heat disorder are volume depleted with normal to mildly increased serum sodium and serum osmolality (hypernatremia). Increased water intake before and during activities in hot environments is highly emphasized to prevent volume depletion and heat illness. However, drinking too much water can lead to decreased serum sodium concentrations (water toxicity or hyponatremia). Many people with hyponatremia due to water overload have increased their total body water by about 1 gallon to achieve such low serum sodium values.

The most significant clinical signs 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.

Fluid Replacement

Palatability of any fluid replacement solution is important to ensure adequate rehydration. Evidence shows 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 [Rolls 1990]. However, employees should be cautioned to avoid drinking large amounts of sugar-laden beverages in hot climates as this causes an osmotic diuresis (increased urine production) that increases fluid loss through urination. Caffeinated beverages and alcohol intake also increase urinary fluid loss and should be avoided. The temperature of the drink also influences consumption of fluids. Ideally, fluids should be ingested at temperatures of 50°F–60°F, in small quantities (5–7 ounces), and at frequent intervals (every 15–20 minutes).

Average Americans consume adequate, if not excessive, amounts of sodium in their usual diet such that for mild volume depletion, only water replacement is needed. However, in moderate volume depletion or when involved in events resulting in prolonged sweating, electrolyte (i.e., sodium) replacement is indicated. Many oral electrolyte replacement formulas such as Gatorade® are available. Salt tablets are not recommended as they can irritate the stomach, leading to vomiting, which can exacerbate fluid losses and do not address water replacement needs. Those with nausea and vomiting from heat stress may require intravenous saline administration to replace their water and sodium.

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Acknowledgments and Availability of Report

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 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.

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Copies of this report have been sent to employee and management representatives at the aluminum smelter, the state health department, and the Occupational Safety and Health Administration Regional Office. This report is not copyrighted and may be freely reproduced. The report may be viewed and printed at http://www.cdc.gov/niosh/hhe/. Copies may be purchased from the National Technical Information Service at 5825 Port Royal Road, Springfield, Virginia 22161.

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