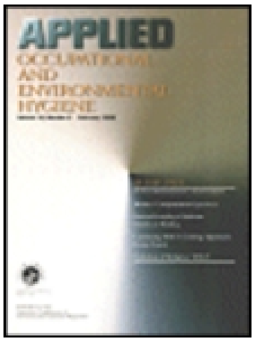

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John B. Moran Column Editor , J.-L. Bélard & R. L. Stanevich

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Construction

Overview of Heat Stress Among Waste Abatement Workers

John B. Moran, Column Editor

Reported by J.-L. Bélard and R.L. Stanevich

Introduction

Occupational heat stress remains a well-known and continuing problem in industrial occupations.(1,2) One might assume, given the sophisticated nature of current technologies for controlling environmental parameters in enclosed spaces, that occupational heat stress would not be, at least in developed countries, a major concern. According to a 1984 survey conducted in France, almost one-fifth of the total active occupational population complained about thermal conditions in the workplace, specifically addressing potential heat stress problems.(3)

A major contributing factor to heat stress is protective clothing.(4–6) A great number of workers must wear such protection during occupational activities. Within the U.S. construction industry, waste abatement constitutes one of these occupational groups. The population of waste abatement workers was estimated by the Occupational Safety and Health Administration to be between 150,000 and 200,000.(7) This figure was confirmed by the Laborers' National Health and Safety Fund. Waste abatement workers perform their tasks in environments that pose a high potential for exposure to hazardous materials. Thus, protecting themselves by wearing totally encapsulating chemical protective clothing is imperative.

The vapor barrier properties of these ensembles are a major factor contributing to heat stress among waste abatement workers. To obtain maximum protection against harmful liquids, gases, fumes, or vapors, chemical protective clothing must be impermeable. When wearing chemical protective clothing, sweating (evaporative heat loss) and convection become ineffective, suppressing the body's ability to shed heat through transpiration. Sweat cannot properly evaporate in the air space saturated with moisture trapped inside the suit; the body's heat storage consequently increases, along with the subject's heart rate.

The maintenance of body temperature within physiological limits is critical to the optimal execution of a given task; protective clothing used by waste abatement workers acts as a barrier to the proper evacuation of metabolic heat produced by high levels of energy expenditure. In addition, the need to use a self-contained breathing apparatus (SCBA) increases the physiological burden. Because of the specific aspects of their work activity, this occupational group is at risk for several heat-related syndromes.

This article examines the current status of the problem, suggests additional research, and addresses technological solutions which could help prevent the occurrence of heat stress in this specific population.

Heat Stress Among Waste Abatement Workers

In everyday activities, sufficient heat transfer can be achieved by allowing sweat to evaporate, by wearing light or minimal clothing, by adapting the work load to the ambient temperature, by drinking water or fluids often, and by resting frequently in a shaded, cool area.(8,9) Hazardous waste abatement work is far removed from these ideal conditions, and clearly the risk of heat stress is increased by the unique features of this specific occupation.(10,11) These features include the following:

- Waste abatement workers generally work outside and are exposed to high ambient temperature and solar radiation, which combine to increase the environmental thermal load.
- Their task requires a high level of energy expenditure, between 350 and 500 W.(8) These levels are considered heavy work by the American Conference of Governmental Industrial Hygienists.(12)
- Because they handle toxic waste, waste abatement workers must be properly protected by vapor barrier chemical suits, which greatly restrict heat transfer. In addition, the weight of the SCBA used for respiratory protection increases the physiological work load.

The acquisition of accurate and quantified information on the interactions between ambient thermal conditions, energy expenditure, and body temperature is essential. Much still needs to be learned about the physical and physiological aspects of thermal exchange in protective clothing systems.(13) Given the seriousness of certain heat-related conditions, relying on current unquantified safety procedures like the "buddy system" or the control of temperature or heart rate only during the resting period is clearly inadequate.

Waste abatement workers are part of the construction industry, which is divided into three major activities according to their standard industrial classification (SIC): (1) general building is SIC 15; (2) heavy construction is SIC 16; and (3) special trades are part of SIC 17. Waste abatement work is generally performed by laborers or operating engineers, and to a lesser extent by carpenters, pipefitters, or painters. This specific occupation can therefore be found in all three major activities.

The data supporting heat stress injuries among construction workers are very limited. Robinson *et al.*(14) have reviewed the construction workers' illness compensation cases occurring between 1977 and 1985; depending on the type of activity—general building, heavy construction, or special trades—they have sorted the 20 most common conditions in this population. Heat stroke, the only heat-related illness reported in workers' compensation claims, ranks in the top ten. Heat exhaustion is not recognized as a classified illness in construction workers' compensation.

Consequently, no data on the occurrence of heat exhaustion among construction workers are available. However, it is possible to estimate the number of heat exhaustion cases using data obtained from the Office of the Surgeon General, U.S. Army, Preventive Medicine Division.[15] Even though the military population is younger on average than the waste abatement population, military data are useful in developing estimates of heat stress. Such data may be used, bearing in mind that the aging process results in a decreased tolerance to heat due to less effective control of body temperature.[16] Therefore, the figures obtained from the military should be considered conservative.

The Division of Preventive Medicine collects all information on heat-related conditions occurring in the military population in the continental United States. For calendar years 1985 through 1989, the data show that for each case of heat stroke, at least ten cases of heat exhaustion required medical attention; additional informal contacts with other emergency physicians suggest that the number of heat exhaustion cases could be two to three times higher because the majority of these cases never go to the hospital and are simply treated by removing the subject from the workplace and allowing him or her to recover in a cool area for the rest of the day.

If this 1:10 ratio were applied, heat exhaustion would constitute the leading cause of worker claims in heavy construction, second in special trades, and third in general building construction.

Heat Stress Overview

The Nature of Heat Stress

Heat stress occurs when the combination of environmental heat load and metabolic heat production exceeds the body's capacity to maintain normal functions without excessive strain.[16]

Much of the energy from metabolism is dissipated as heat. To ensure proper functioning, the body must maintain a core temperature within the acceptable range of 37° ± 1°C. This regulation of core temperature is achieved by a two-way heat exchange between the body and the environment in accordance with the heat balance equation:

$$\pm S = (M - W) - E \pm R \pm C$$

where:

S = heat storage
(M − W) = total metabolism − mechanical work
E = evaporative heat loss
R = radiative heat transfer
C = convective heat transfer

The ideal situation occurs when the S value is null, since it shows a perfect equilibrium between production of heat and dissipation, mainly through radiation and evaporation. This latter parameter is the only one which can play a positive role in lowering heat stress in a hot environment, along with convection, if there is wind.

Conditions of Heat Stress Occurrence

Heat stress is likely to occur when the thermal balance equation shows a positive value for S, which means that the body is gaining heat. A review of the equation's different elements indicates that a potential risk of heat stress may exist when an important energy expenditure level is associated with the following:

- high ambient air temperature
- high air humidity
- high radiative heat (such as full sun)
- absence of air movement

The first three parameters characterize the environment: determining the environmental heat in the area where workers are exposed is very important. Several techniques have been proposed to assess environmental heat,[16] but the wet bulb globe thermometer (WBGT) has been accepted as the standard method[17] and is now widely used as a predictor of heat strain.[18,19]

Physiological Response to Heat

Even when resting in a hot environment, body temperature may rise and reach a value which triggers heat-dissipating responses. Among these thermoregulatory responses are the transfer through blood of heat from the core to the shell, and the dissipation of part of that heat in the ambient air through vasodilation (provided that air temperature is cooler than skin temperature). The increase in superficial vessels' diameter expands the exchange surface between the body and its environment, thus allowing heat loss.[10] When working in a neutral environment, there is a great demand for blood from exercising muscles.[8] When working in the heat, the competition for blood between the skin and the exercising muscles creates a deficit in blood supply to the gastrointestinal and central nervous systems.[20–23] This oxygen deficiency explains the onset of symptoms such as orthostatic dizziness, vertigo, nausea, or hypotension when heat begins to take a toll on the body.

The blood volume is also reduced through sweating, which creates hypohydration. When occurring during physical activity in the heat, hypohydration and electrolyte imbalance become threats to thermal homeostasis.[24] Additionally, hypohydration reduces the core temperature that can be tolerated, even for heat-acclimated individuals.[25,26]

As a consequence of this competition for blood between several systems, heart rate increases. It is an excellent predictor of heat stress, and it is considered a reliable indicator of overall work tolerance in the field.[27] When body temperature and heart rate are not properly controlled, and the level of hydration is also subject to reduction, the risk exists for developing a heat condition which can range from a simple and benign heat rash to a life-threatening heat stroke.

Consequences at Work

Health-related disorders due to environmental heat exposure are exceptionally common in persons who perform hard work in hot climates.[28,29] Studies conducted at the National Institute for Occupational Safety and Health (NIOSH) by White and Hodous show that significant stresses are involved with wearing protective ensembles.[30] In addition to the demanding physical load of the task itself, the personal protective equipment places an additional burden on the user.[31] Human performance decrement has been assessed by various authors.[1,16,32–37] Additional adverse effects, such as reduced work time due to more frequent and longer breaks, have been described by Jensen,[38] along with an increased occurrence of heat-induced illnesses, a decrease in productivity,[39] and significant deterioration of mental functions when body dehydration is over 2 percent.[40] It is important to insist on the positive role of heat acclimation in the prevention of such incidents,[41] and on heat stress prevention through education.[11]

Current Safety Procedures

As indicated in the Environmental Protection Agency Standard Operating Safety Guides, a heat stress monitoring program should be implemented when employees are wearing chemical protective clothing in ambient temperatures above 70°F (21°C).[11]

Safe work practice recommendations suggest that the site safety officer or medical technician closely observe workers for signs and symptoms of heat illness. Parameters such as heart rate and temperature at the beginning of the resting period should be monitored. These recommendations also address proper hydration before and during work shifts, along with salt replacement strategies. The authors mention, however, that the implementation of these measures is not always possible on the job site. Heart rate should be measured by the radial pulse as early as possible in the resting period, but as discussed in the same article, it may take 5 minutes for workers to go through the decontamination line before their vital signs can actually be controlled. A 50 percent work/50 percent rest schedule is recommended. It can be adjusted up or down depending on worker monitoring, environmental conditions, and the written approval of the medical technician and/or the site safety officer.

These recommendations are difficult to implement, and an adequate mechanism for health surveillance of hazardous waste workers has yet to be established.[7] Much remains to be done, and it is now imperative to develop useful, practical guidance and methodology for field application,[31] especially since the Department of Labor has listed high temperatures as a health hazard in its Construction Industry Safety and Health Standards.[42] Better analysis of thermal work conditions is still needed.[43] As the NIOSH-proposed National Strategies for the Prevention of Leading Work-Related Injuries indicates, assessment of workers' stress indicators to improve safe job performance is also necessary.[44]

Current Research Findings

The Division of Safety Research, NIOSH, conducted investigations into the prevention of heat stress in waste abatement workers. The purpose of the study was to help design work/rest recommendations based on laboratory physiological evaluations. Seven workers, aged 28 to 40, exercised on a treadmill in three different environments while wearing level A protection. This protection included totally encapsulating, impermeable, chemical-protective clothing and a SCBA. The weight of clothing and SCBA was approximately 30 lbs.

The time to reach a threshold core temperature (TCT), threshold heart rate, or fatigue was measured. When a TCT was reached, the time to return to pretest core temperature was also measured. Times to reach a TCT and to return to pretest temperature were needed to design scientific work/rest recommendations.

It was found that:

- When performing a 75-W moderate exercise in a 90°F environment, most subjects reached a TCT in 45 minutes. At the same work load in lower environments (80° and 70°F), most subjects stopped exercising in less than 1 hour due to fatigue.
- Core temperature continued to rise after completion of the exercise, even though resting took place in a much cooler environment after removing the suit.
- There was a large variation among subjects in the time to reach TCT, since the longest time was twice as long as the shortest.
- The average time to return to pretest core temperature was greater than the time to reach TCT.

These results are difficult to compare with those obtained in recently published similar studies. Ohnaka *et al.*[45] tested young subjects (mean age = 19.1 ± 0.6) with a mean maximum oxygen uptake (VO_2 max) of 3.5 L/min. Bishop *et al.*[46] used slightly older subjects (mean age = 24.7 ± 4.1) with a mean VO_2 max of 3.7 L/min. Recently, Dessureault *et al.*[47] evaluated heat stress on volunteers who were all cyclists and who had just completed heavy physical training. It is important to note that all these evaluations were performed on subjects who wore a Tyvek-type suit, which is a light, disposable, semipermeable coverall.

The NIOSH subjects were waste abatement workers, generally overweight, with a history of past or present smoking. Older subjects might be more sensitive to heat stress.[16,48,49] In addition, subjects participating in the NIOSH study exercised in totally impermeable chemical protective clothing. These factors might explain their limited performance in the amount of time to reach a TCT, threshold heart rate, or fatigue while exercising in the heat.

Existing work/rest cycle charts are either too vague[50] or underestimate work tolerance in specific situations. Experimental evidence indicates that even relatively mild ambient temperature may induce heat stress when wearing chemical protective clothing. Bishop *et al.*[46] showed that during the performance of heavy exercise in temperate conditions (21°C ambient air temperature), one subject's body core temperatures rose to 39°C in only 33 minutes.

Research Needs

When addressing the thermal environment of hazardous waste abatement workers, the microenvironment existing inside the impermeable protective clothing has not been extensively assessed. Sullivan and Mekjiavec[51] have shown that relative humidity is much higher under the overgarment than outside. A more precise microenvironment characterization may be feasible near term, provided that miniaturization allows a complete WBGT station to be placed under the protective clothing.

Engineering controls are already available to warn users about impending heat stress. These devices are generally attached to the worker's belt and provide visual and pulsating auditive signals when body temperature, collected through an ear canal probe, reaches a danger zone. These engineering controls are not designed for use by workers whose job requires wearing chemical protective clothing, since the clothing would cover the warning light. Such dedicated warning devices must be specifically designed to be used while wearing encapsulating chemical protection.

Although White *et al.*[52] suggest that the use of cooling systems may not be beneficial above certain critical temperatures and work rates, Glen *et al.*[53] confirmed that cooling vests reduce the physiological strain induced by exercise in hot environments. Other authors suggested that the cooling process could be limited to a single body area. Cadarette *et al.*[54] have shown that head cooling is not advisable due to the occurrence of headaches. The simple hand immersion technique induces a significant reduction of body temperature and allows an extension of a heavy work period by 15 minutes.[55] The benefit of using existing microcooling systems during waste abatement work should be further evaluated for effectiveness.

Conclusions

The necessity of using vapor barrier protective clothing and respiratory protection while performing strenuous physical activities in hot environments clearly puts waste abatement workers at risk for heat illnesses. Very limited data suggest that this issue has been overlooked. Additional research must focus on a scientific assessment of the situation, especially regarding the variation of core temperature as a function of time, work load, and environmental conditions. Key parameters such as core temperature and heart rate must be monitored not only during work periods, but also during resting phases. The design of engineering controls must take into account the visual field reduction of workers wearing respiratory protection, and microcooling systems should be improved to lessen the added weight burden and consequently decrease metabolic heat production.

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