# HEAT STRESS MANAGEMENT IN HOT MINES

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## Introduction

Occupational heat stress is a recognized health and safety hazard in South African mines. The consequences of high occupational heat loads can be expressed in terms of impaired work capacity, errors of judgment with obvious implications for safety, and the occurrence of heat disorders, especially heat stroke which is often fatal.

Engineering strategies to counter occupational heat stress usually involve reducing the environmental heat load (through shielding, refrigeration and increased air flow) to facilitate heat dissipation from the human body, and/or improved mechanization to minimize high metabolic rates. In the South African mining industry, technological and economic constraints often preclude a purely engineering-based approach. Personal protection and administrative controls, such as heat acclimatization and heat stress management, for example, then become the only viable alternatives.

The serious consequences of excessive levels of occupational heat stress were recognized by the South African gold mining industry when the first death from heat stroke occurred in 1924 (1). Steps to combat the heat stress hazard were taken almost immediately and the first form of heat acclimatization was introduced in 1925 (2). This rudimentary method of heat acclimatization was followed by a research program aimed both at obtaining a better understanding of human heat tolerance and at developing improved heat acclimatization procedures.

Research conducted as part of this program since the 1930s has culminated in the development of scientifically based heat acclimatization procedures, heat tolerance test procedures and the Heat Stress Management Programme currently used in the South African mining industry.

In South African mines, work environments having a wet-bulb temperature in excess of 27.4 °C are considered to be ‘hot’ and necessitate the introduction of practices to safeguard miners. This is the heat stress limit for unacclimatized men and is based on an analysis of heat stroke accidents which have occurred in the South African gold mining industry (3).

## Formal Heat Acclimatization

Formal acclimatization of miners to work in hot underground environments was a widespread practice at South African gold and platinum mines for the greater part of the previous century.

### *Underground Acclimatization*

Prior to 1953 the method used to acclimatize miners was known as ‘underground acclimatization’ (2). This method consisted of allocating miners to work in a hot production area underground, but under supervision, for 14 days. During the 14-day period the miners’ work rate was gradually increased to that undertaken by acclimatized men. This method was not very successful as it was difficult to control the work rate of the miners as well as the thermal conditions of the areas in which they worked.

Recognition of the above problems led to the development of the ‘two-stage acclimatization’ procedure, which took 12 days. The first six days served to condition the miners to physical work in relatively mild heat stress (29.5 to 30.5 ºC wet-bulb) while the last six days adapted the miners to the most severe levels of the stress that they were likely to encounter subsequently (31.7 to 33.9 ºC wet-bulb). The acclimatization procedure was closely supervised: body temperatures were recorded and miners developing high levels of heat strain were identified and treated. While ‘two-stage acclimatization’ was simple in principle, it was difficult to maintain the required thermal conditions always.

Both of the above procedures resulted in the partial acclimatization of miners and a concomitant high heat stroke risk when they were transferred to normal production teams.

### *Climatic Room Acclimatization*

The difficulties encountered in the application of acclimatization procedures underground, particularly in regard to obtaining the right combinations of thermal conditions and work rate, led to the development of climatic room acclimatization procedures.

These procedures were introduced in 1965 and the period of acclimatisation was reduced from 12 to eight days (4). During this period miners worked continuously for four hours a day in a climatic room controlled at 31.7 ºC wet-bulb, with an air speed of 0.4 m/s. A block-stepping routine was used to obtain the required work rate, which was increased progressively from 35 W (external component) on the first day to 70 W on the eighth day. Hourly measurements of body temperature and daily checks of body mass were made, and any abnormal mass response or high body temperatures were given appropriate treatments. The body temperature profile of a miner was used to determine whether he was acclimatized or not.

The most significant breakthrough in heat acclimatization occurred with the discovery that miners respond more favourably to heat when supplemented with ascorbic acid (Vitamin C). Vitamin C supplementation reduced the acclimatization period from eight to five days, in general, and from eight to four days for previously acclimatized miners (5). A further advantage of the Vitamin C supplementation was the decrease in the number of miners who did not respond to the acclimatization routine from five percent to less than one percent (6).

## Heat Tolerance Testing

Selection procedures based on heat tolerance were first applied in the South African mining industry by Dreosti in 1935 (7). Dreosti’s heat tolerance test was based on the body temperature responses of miners shovelling rock for 60 minutes in a saturated environment of 35 ºC. Miners whose oral temperatures were below 38 ºC on completion of the test were classified as “heat tolerant” while those with oral temperatures of above 39 ºC were regarded as “heat intolerant”. Miners with oral temperatures of between these two values were classed as “normal”. In a sample of 20 000 men 25 percent were judged “heat tolerant” and 15 percent “heat intolerant”. Eighty-three percent of the “heat intolerants” could be acclimatized to exhibit heat tolerant responses.

During experiments aimed at the refining of Vitamin C-supplemented acclimatization in the 1970s two important observations were made that paved the way for the development of a test procedure to identify individuals with a high natural tolerance to heat. Firstly, the results showed that, for any given individual, there is an optimum period of acclimatization to heat in which a satisfactory level of adaptation is reached; and, secondly, there are wide individual differences with respect to the optimum period required.

The heat tolerance test that was devised in 1977 (8) involved a block-stepping routine for four hours in a climatic room. Work rate was fixed at 54 W (oxygen consumption of approximately 1.25 l/min) and the thermal conditions used for the test were 29, 30, 31 and 31.7 ºC, depending on the temperature of the underground workplaces miners were required to work at on successful completion of the test. Oral temperatures were recorded hourly during the test and miners with temperatures not exceeding 37.5 ºC were classified as “hyper-heat-tolerant”. These “hyper-heat-tolerant” miners had been shown not to benefit any further from formal acclimatization and could be posted immediately to normal underground work. The percentage of miners classified as “hyper-heat-tolerant” depended on the severity of the heat stress applied: at the recommended test temperatures of 29, 30, 31, and 31.7 ºC the pass rates were 85, 75, 50 and 35 percent, respectively.

In 1991 a new approach to heat tolerance testing was adopted with the introduction of Heat Tolerance Screening (HTS) (9). The primary objective of HTS was to identify gross or inherent heat intolerance (i.e. individuals with an unacceptable risk of developing excessively high levels of hyperthermia during work in heat).

The HTS used in the South African mining industry consists of bench-stepping for 30 minutes in a climatic chamber at an external work rate of approximately 80 W (positive component), in an environment with a dry-bulb temperature of 29.5 °C and a wet-bulb temperature of 28.0 °C (10). The assessment of relative heat tolerance is based on the body temperature recorded at the end of the 30-minute bench-stepping exercise. Any person whose body temperature does not exceed a given value at the end of the test is classified as "potentially heat tolerant". This implies that that person is fit to undertake physically demanding work in a 'hot' environment (with wet-bulb temperatures of greater than 27.5 ºC) and that he will be able to acclimatize successfully with regular exposure. Individuals with body temperatures of above the given value on completion of the test are considered to be "heat intolerant" and will not be allocated to work in 'hot' areas.

## Heat Stress Management

Heat Stress Management (HSM) is a multi-faceted approach to promoting health, safety and work performance through minimizing human heat strain and the incidence of heat disorders. It is essentially a risk management approach for reducing risk by removing high-risk individuals from the underground mining population and, through the implementation of countermeasures, striving to minimize the risk of developing heat disorders during work in heat.

HSM consists of two essential elements: the assessment of overall fitness to work in heat, and a natural progression towards heat acclimatization on the basis of safe work practices. These two elements are to a large extent based on the aetiology of heat stroke: the overall fitness for hot environments is measured against an individual employee risk profile and the causal factors in the development of heat stroke in the mining industry are translated into safe work practices.

### *Overall Fitness for Physical Work in Heat*

It is obvious that although most individuals would, in a qualitative sense, exhibit similar responses to heat, the actual response pattern for any given individual is a function of a variety of factors. These determinants can be broadly divided into two categories: *inherent* determinants, i.e. those over which the individual has no control, and *external* determinants, i.e. those over which the individual has some control or which he voluntarily accepts. In the latter category, the most important are nutrition and hydration, whereas the former includes factors such as maximum work capacity, age, gender and body dimensions.

In the present context, overall fitness for work in heat will depend on the outcome of a purpose-designed medical examination, with special emphasis on features that would rule out physical work or exertion in heat (11), and an assessment of heat tolerance by means of HTS (10) in a climatic chamber.

### *Risk Profile*

One of the cornerstones of HSM is the introduction of an individual employee risk profile against which his overall fitness for work in hot environments is measured (12). On the basis of the outcome of the medical examination and HTS, it is quite feasible to develop a 'risk profile' for any employee destined to enter 'hot' working environments in the execution of his duties and responsibilities.

The risk profile consists of the following elements:

- medical contraindications, i.e. a particular condition, treatment or even a medical history likely to lead to a critical job-related reduction in heat tolerance
- age (≥ 50 years), in concert with full-shift exposures to 'strenuous' work in heat
- obesity (Body Mass Index ≥ 30)
- heat intolerance, i.e. inability to successfully complete HTS
- strenuous work *per se*
- a history of heat disorders.

In developing an employee risk profile on the basis of the above elements a threefold approach is recommended, namely:

- a risk profile that features only one of the above elements, especially where it can be controlled or brought under control, should be regarded as 'acceptable'

- the presence of any two elements should be viewed with concern and should not be condoned unless the situation can be ameliorated, for example through specially developed safe work practices
- a profile containing more than two undesirable elements will constitute an unacceptable risk.

***Safe Work Practices***

Within the context of HSM no form of formal heat acclimatization will have preceded the allocation of employees to 'hot' areas of work. Workers will have been screened only for gross heat intolerance and will be expected to commence duties without the advantage of acclimatization. For this reason, special precautions are indicated, the rationale for which is based on the major causes of heat stroke in mining.

A review of the occurrence of heat stroke over a ten-year period indicates that the origin of heat stroke is multi-factorial (13). The main causal factors are interactions between strenuous work, suspect heat tolerance, excessively hot environments, and concurrent dehydration. On the basis of this analysis, a basic framework with the following elements can be derived for work practices in 'hot' environments:

- monitoring work-place wet- and dry-bulb temperatures on a basis designed to ensure that safe limits are not exceeded and to detect the development of possible trends

- ensuring that acceptable work rates are maintained in order to avoid the early onset of fatigue (achieved through work-rest cycles: 10 to 15 minutes of rest in every hour) where work is of necessity strenuous and ongoing (e.g. drilling) or by instilling, through constant reminders, a sense of self-pacing
- ensuring that fluid-replacement beverages (preferably only water or hypotonic fluids) are available at the place of work and that a fluid replacement regimen of at least 2 x 250 – 300 ml per hour is observed
- detecting early signs and symptoms of heat disorders and instituting proper remedial action, depending on the precise set of signs and symptoms
- ensuring that emergency treatment and communication facilities are available and fully functional on a daily basis
- setting into motion purpose-developed emergency action plans in the event of sudden escalations in environmental temperatures

## Measures of Success

Heat has been a constant health hazard in South African gold (and more recently platinum) mines for more than 90 years; the problem cannot be resolved overnight and is likely to remain a potential hazard for some years to come. Measured against its objective, namely, the promotion of the health, well-being and safety of all employees exposed to working conditions potentially conducive to heat disorders, HSM proved to be very successful. If statistics on the incidence of reportable heat disorders (heat stroke and heat exhaustion) are considered, the implementation of HSM has contributed to a decline in heat disorders from 83 cases (21 heat strokes and 62 heat exhaustions) in the three-year period before the general implementation of HSM in 1991 to 33 cases (five heat strokes and 28 heat exhaustions) for the period 2005 to 2007. This reduction is achieved through the elements that form the backbone of HSM: the detection of gross or permanent heat intolerance (approximately three percent of the population assessed) and the control of the progression.

## Future Research

One of the major objectives of the South African mining industry is to provide the safest work environment possible for miners, especially in view of the changing demographics of the mining population.

In order to achieve the above objective it is important to assess the physiological strain experienced by miners, especially where physical work is performed in hot environments. Very little information is available on the actual physiological strain (the combined strain reflected by the thermoregulatory and cardiovascular systems) associated with mining tasks, especially when these tasks are performed by females or older males. Where information is available, it has been based on the physiological responses of healthy young males.

In the South African context, with its milestones for the employment of female miners, there is a definite need to establish the role of gender with regard to the physiological strain experienced by miners during typical mining activities. In view of their smaller physical work capacity (aerobic capacity) and physical strength, female mineworkers may experience undue physiological strain when performing “prolonged and strenuous” physically demanding tasks as is the case in mining. The current difficulties experienced with the placement of female miners in underground occupations highlight the need for such research.

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