

Heat Stress in Mining

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ABSTRACT

Heat stress in the mining industry has been a cause for concern for most of this century. Many of the issues affecting work in hot environments which were first addressed in South Africa in the 1920's are still unresolved. Much of the research has been prompted by the serious and sometimes fatal consequences of heat stroke. Problems also exist with the less serious heat disorders, as these can have a deleterious effect on productivity. There are many techniques for measuring heat stress as each climatic condition needs to be assessed and monitored in the manner which best describes the hot working conditions. The identification of heat tolerant individuals is important in maintaining a healthy workforce and acclimatisation has long been used as a method of assisting the body to cope with heat stress. The type of clothing worn is an important factor in controlling heat exposure. This fact applies particularly to the members of mines rescue teams. In order to successfully control heat stress mining companies must develop overall heat stress management plans designed to control the specific conditions present at the mine site.

Heat Stress

Heat stress is the sum of all the internal and external heat factors which cause the body to become fatigued and distressed. In extremely hot environments there is a significant decrease in productivity and a high rate of accidents as well as the risk of workers suffering heat disorders. Internal factors that determine the level of heat stress on the body include core body temperature, acclimatisation, natural heat tolerance and metabolic heat generated by the workload. External factors include ambient air temperature, radiant heat, air velocity and humidity (Lahey, 1984: 60).

Nielsen (1994) has suggested that a high core temperature is the ultimate cause of fatigue due to heat stress by virtue of the fact that the high core temperature affects the function of motor centres and thus decreases the 'motivation' for muscular activity. The subsequent response of the body to heat stress is known as heat strain and is measured by means of biochemical, physiological and psychological parameters. The magnitude of these responses reflects the degree of heat stress to which the body is subjected (Misaqi et al, 1976: 6).

Mechanisms of heat dissipation

Heat is dissipated from the body by means of conduction, convection, radiation and evaporation.

- Heat lost by means of conduction is generally very small because of the fact that a large proportion of the skin is in contact with clothing that precludes effective conduction of heat from the skin to the air. The air must be cooler than the skin and in contact with it for heat dissipation to occur by this means.
- Heat exchange due to convection occurs when air is circulated by means of fans, breezes, etc.
- Radiative heat exchange involves the loss of heat to cooler areas that are not in contact with the body.
- Evaporation allows heat loss by means of:
 - Sweat evaporation through almost two million sweat glands in the skin;
 - Saturation of the inhaled air in the lungs with water vapour;

Invisible loss of water through the skin without involvement of the sweat glands (Strang and Mackenzie-Wood, 1990: 360).

The two most significant environmental factors that affect evaporation in an underground mine are humidity and air speed (Brake et al, 1998: 2). At humidity levels less than 100%, air speed over the skin improves the rate of evaporation, thus reducing the risk of heat stress. However, if the air vapour is saturated (100% humidity), evaporation ceases. Conduction, convection and radiation may result in a heat loss or gain from the body, depending on the surrounding environment. On the other hand, evaporation always causes dissipation of heat from the body (Lahey, 1984: 63).

Heat balance

When the body is at rest in a hot environment, convection and radiation account for three quarters of the heat dissipated, while evaporation accounts for only one quarter. In order to maintain a thermal balance during excessive physical activity the mechanisms of dissipation must work harder to rid the body of the excess heat. Convective and radiative heat losses remain almost constant regardless of the amount of heat produced. Therefore, with increasing heat stress, if a thermal balance is to be maintained, the evaporation rate must increase (Misaqi et al, 1976: 2).

In a steady state condition where the body is not suffering from heat strain the amount of heat generated is balanced by the amount of heat lost (Misaqi et al, 1976: 4). Under conditions of heavy physical work in a relatively cool and dry environment, heat balance may be represented by the equation $M \pm R \pm C - E = 0$, where:

M = heat generated by metabolism

R = radiative heat exchange

C = convective heat exchange

E = evaporative heat loss

With increasing heat stress, heat dissipated through evaporation eventually reaches a ceiling due to sweat gland fatigue (Misaqi et al, 1976: 5). The consequent reduction in sweat production causes a heat buildup which is stored in the body and is reflected by a rise in rectal temperature. It is generally accepted that rectal temperature provides an accurate representation of core body temperature. Under conditions of normal activity core temperature ranges from 36°C to 38°C. In extremely hot conditions, the core temperature may rise to 40°C, at which stage the person is in danger of succumbing to heat stroke.

Heat disorders

Heat disorders attributable to hot environments range from irritations, such as prickly heat, to fatal conditions (Misaqi et al, 1976: 10). The most common conditions in the mining industry are:

- Heat cramps, which usually occur after heavy sweating and are associated with the subsequent excessive loss of salt from the body. (Lahey 1984: 60)
- Heat exhaustion is characterised by profuse sweating, weakness, rapid pulse, dizziness, headache and nausea. (Lahey 1984: 60)
- Heat stroke is a preventable condition and is characterised by a core temperature above 40°C. Strang and Mackenzie-Wood, (1990: 362), report that heat stroke is sometimes complicated by dehydration, loss of electrolytes and low blood sugar, and may be recognised by the absence of sweat on the skin. As the core temperature continues to rise the blood vessels near the skin dilate and reduce the return of blood to the heart. Heat stroke occurs when the flow of blood back to the heart becomes negligible. Medical help should be sought immediately while attempts are made to cool the body. The elevated core temperature must be controlled by cooling with any

safe liquid on the bare skin and by fanning the body. Liquids should not be given to drink. It is important the heat stroke be treated promptly and correctly as it may otherwise prove fatal (Lahey, 1984: 60). Wyndham (1965: 170) found that the two main factors common to the occurrence of heat stroke in South African gold mines were the levels of wet-bulb temperature in working places and the high rates of work in certain job categories. Other factors found to have a bearing on the occurrence of heat stroke were acclimatisation, season of the year, period during the contract, period during the shift, tribal factor and human factors. Brake et al (1998: 3) highlighted obesity and poor cardiovascular fitness as risk factors for heat stroke. Wyndham (1965: 175) cited statistics showing that 75% of the 47 fatal and 179 non-fatal cases of heat stroke during the period 1956-1961 occurred in the summer months.

- Chronic Heat Fatigue, commonly known as 'Mango Madness' is a form of Heat Fatigue which has been recognised in the Mount Isa community for many years. It displays similar characteristics to a syndrome known as Seasonal Affective Disorder and is noticeable in the occupational context by an increase in work related incidents over the hot summer months. It is known to cause long term impairment in work performance and social behaviour. A lack of motivation, alcoholic overindulgence and an inability to concentrate are symptoms. It has been found that the best way to combat 'Mango Madness' is to educate managers, supervisors and workers alike (Brake et al, 1998: 9).

Other effects of heat strain

Poor motor control function has been associated with work in hot environments both in dry and humid conditions. Hancock, in Kielblock and Schutte (1993: 280), observed that heat stress degrades mental performance well in advance of any deterioration of physical performance. Conversely, it has been suggested that an escalation in thermal load would lead to a fall in productivity and an increase in accident frequency rate. These observations are supported by Misaqi et al (1976: 8), who identified dexterity and coordination, ability to observe irregular, faint optical signs, ability to remain alert during lengthy and monotonous tasks, and the ability to make quick decisions as attributes adversely affected by heat strain. General safety may also be compromised by adverse effects such as irritation, anger and other emotions as these may lead to rash acts by workers in hazardous situations.

Measurement of heat stress

Scientists have been searching for the ideal heat stress index since early this century. This research has focussed on the use of various types of thermometers and anemometers combined with statistical data. While rectal temperature and heart rate are both good indicators of the heat strain being experienced by the individual, use of these parameters is not practical at the mine face. Common heat stress indices relate to statistical probabilities of the risk of heat disorders and effect on productivity in a given hot environment rather than to the level of personal comfort. Thus, it is convenient to measure the environment rather than the individual. Air temperature, radiant heat exchange, air movement and the partial pressure of water vapour are the four environmental factors most commonly incorporated into the measurement of heat stress (Lahey, 1984: 60). It is important that the information derived from this index is applicable to the particular mine site. Measurements and calculations should be simple and should relate to the physiological stress experienced in these conditions (Lahey, 1984: 60).

A number of heat stress indices have been developed e.g. Effective Temperature (ET) in 1923; Corrected Effective Temperature (CET) in 1946; Predicted Four-Hour Sweat Rate (P4SR) in 1947; Heat Stress Index (HSI) in 1955; Wet-Bulb Globe Temperature (WBGT) in 1957.

Effective Temperature (ET) was first used in South Africa and uses the dry-bulb temperature, wet-bulb temperature and air velocity to provide an indication of thermal comfort. As a result, it is useful in productivity assessments. (Kielblock and Schutte, 1993: 282 and Misaqi et al, 1976: 16).

Corrected Effective Temperature (CET), unlike the ET, makes provision for radiant heat by substituting the globe temperature for the dry-bulb temperature. This method uses two scales - 'Normal' for lightly clothed persons and 'Basic' for men stripped to the waist (Kielblock and Schutte, 1993: 282).

Predicted Four-Hour Sweat Rate Index (P4SR) was designed to evaluate the stress associated with the amount of sweat produced over a four-hour period. It is used as an adjunct to determining water requirements for workers. (Kielblock and Schutte, 1993: 283 and Misaqi et al, 1976: 17).

Heat Stress Index (HSI) is a more complicated measure of heat stress and is represented on a scale from 0 to 100, where 0 represents no thermal strain and 100 is the maximum strain tolerable for an 8-hour shift by fit, acclimatised young men (Misaqi et al, 1976: 17).

Wet Bulb Globe Temperature (WBGT) was originally devised to monitor heat stress levels during outdoor training activities of U.S. Marine Corps recruits, and is based on measurements of temperature alone. Modern heat stress monitors or analysers are capable of providing a digital readout of WBGT in three minutes or less. One instrument, known as a thermal comfort meter predicts values that represent certain levels of comfort and takes into account variables such as clothing, activity and humidity.

For outdoor evaluation of heat stress (with solar load)
 $WBGT = 0.7 NWB + 0.2 GT + 0.1 DB$

For indoor evaluation of heat stress (or outdoor with no solar load)

$$WBGT = 0.7 NWB + 0.3 GT$$

Where NWB = Natural Wet-Bulb Temperature

GT = Globe temperature

DB = Dry-Bulb Temperature

Instruments commonly used for the calibration of heat stress indices

- Wet-bulb thermometer - the natural wet-bulb temperature is obtained by wetted sensor which is exposed to natural air movement and unshielded from radiation.
- Globe thermometer - a thin-walled, blackened copper sphere 15 centimetres in diameter with a temperature sensor at its centre. The globe thermometer depends upon the transfer of radiant energy between the thermometer and the surrounding surfaces.
- Dry-bulb thermometer - used to obtain air temperature. It should be shielded from radiation without restricting airflow around the bulb.
- Sling psychrometer - used to determine both wet and dry bulb temperatures and relative humidity with accuracy sufficient for all but the most exacting tests.
- Wet kata thermometers are used to measure the cooling power of air.
- The Coretemp Thermometer is a 'tablet' sized disposable temperature sensor that is swallowed by the subject being monitored. This 'tablet' responds to body temperature changes from both work rate variations and external changes in the environment.

Industry Standards - Setting limits

Setting limits for work in hot environments is usually approached in two ways: setting limits for physiological parameters and setting limits for the environment itself. Limit values should take into account both the strenuousness of the activity and the type of ambient climate present (Piekarski, 1995: 26). Gillies (1991: 3) noted that it is commonly accepted that core body temperature may be correlated to a measure of heat stress on the basis of statistical probability. In South Africa, if the risk of developing heat stroke exceeds 10-6, the combination of metabolic rate, exposure time and wet-bulb temperature is regarded as unacceptable. Use of this heat stress index is recommended by the American Conference of Governmental Industrial Hygienists (ACGIH) for its simplicity of measurement equipment and its application.

The EC is used as an indication of heat stress in some Australian mines and limits have been set for work at an ET of 29.40C and a minimum air movement of 15.2metres per minute. The Mines Inspection Branch of the New South Wales Department of Mineral Resources recommends the use of the WGBT and the SCP for monitoring heat stress. Limits are set for work both above ground and below ground.

In Germany, Regulations are based on dry-bulb temperatures and Basic Effective Temperatures, and working time is limited to six hours if more than three hours of the day is spent working at dry-bulb temperatures of over 280C (Piekarski, 1995: 27). Time limits are enforced when temperatures exceed those recommended.

Mount Isa Mines have based their heat stress limits on wet-bulb temperatures incorporating air velocity measurements. They have introduced the "short shift" protocol which reduces the working shift length to six hours where workers have worked in thermally stressful situations (>31.50C wet-bulb temperature) for more than two hours. Once a wet-bulb temperature in excess of 32.50C is reached the job is stopped (Brake & Nixon, 1998: 8). For the Enterprise Mine Project, the optimum (maximum design) temperature at the work place is 27.50C WB @ 0.75 m/s airflow (180 W/m² cooling power). Hence 66% of jobs should lie between 25.50C and 29.50 C; 95% of jobs should lie between 23.50C and 31.50C and 99 % of jobs should lie between 21.50C and 33.50C.

What contributes to overall heat in mines?

Opencut mines

Radiant heat from the sun and rock face accounts for a large proportion of the heat affecting miners working in opencut mining operations. Mines located in tropical areas have the additional burden of high humidity to add to the heat load. Working in confined conditions or in close proximity to hot machinery increases heat stress, particularly if this work requires the wearing of vapour or water impermeable protective clothing (Gillies, 1991: 1). The physiological workload of the individual and factors such as acclimatisation, physical fitness, obesity and general health play the major part in controlling heat stress in these situations.

In a heat stress survey conducted by Gillies (1991: 5), concerns with heat stress were noted by four opencut operations, and one mine which employed both opencut and underground methods. From this information, Gillies (1991: 5) surmised that heat stress problems in opencut mines are more closely linked to the extreme climatic conditions than to specific problems in deep underground operations. Both Ranger Uranium Mines Pty Ltd and Callide Coalfields Pty Ltd recognised the benefits of acclimatisation techniques and the potential for heat stress problems in several 'exposed' occupations. All five companies employed operational strategies such as air conditioning of vehicles, plant, crib rooms and control rooms, as well as water coolers, work rescheduling and safety training.

Underground mines

By far the greatest problems of heat stress have been traditionally associated with underground operations. Factors such as the rock and ground water temperature plus the air temperature of the available ventilation have been identified by Ramsey et al (1986: 215) as the main determinants of temperature at a given stope in an underground mine. Heat from sources such as electrical units and the heat released when stone and coal are broken away also contribute markedly to the thermal load of the mine atmosphere (Piekarski, 1995: 24). Water required for dust control collects in the workings and has a detrimental effect on the mine atmosphere by increasing the level of humidity. Where feasible, through ventilation is used to reduce heat stress, although the air velocity must be kept below specified limits to avoid problems with mine dusts. Cooling systems may be installed instead of or in addition to through ventilation.

Coalmining in Germany this century has followed the carboniferous Ruhr seams which slope downwards to a great depth. Work takes place at depths as low as 1400m where the environment is subject to an average temperature increase of approximately 3k per 100m depth. It has been found in the Ruhr and Saar coalfields of Germany that 'the use of air conditioning in pit ventilation systems has now become an indispensable aid to climate control' (Piekarski, 1995: 24).

The Enterprise Mine at Mount Isa is expected to reach a depth of almost 2000m below the surface. Brake et al (1998: 1) state that the 'effects of high surface ambient temperatures in summer, combined with "autocompression" in the intake airways and high virgin rock temperatures results in heat stress in the working place that, without intervention, would exceed the levels that human physiology can withstand.' Refrigeration, by means of surface bulk air cooling, underground air cooling and chilled service water, will play a major part in providing an acceptable working environment. This is in contrast with the technique of "flooding" the mine with air to remove heat, which is employed at the other Isa underground mines.

Acclimatisation

Acclimatisation is the body's improved ability to withstand heat stress after repeated exposures to hot environments. It improves the ability to work in heat, reduces the strain felt and lessens the risk of heat disorders. Nielsen (1994: 53) suggested that an increase in the sweat rate that occurs during acclimatisation is brought about by an increased sensitivity of the sweat mechanism and a lower threshold for the onset of sweating. The increased sweating lowers the skin temperature, which reduces the need of blood flow to the skin for heat transfer, and consequently lowers the core temperature. Lee, in Brake et al (1998: 6), obtained the following results from a clinical study of acclimatisation:

- reduction in heart rate when working in heat from 153 to 127 beats per minute,
- core temperature when working in heat reduced from 38.80 C to 38.10 C,
- sweat becomes more dilute, with sodium concentration down by 29%,
- more rapid onset of sweating, up by 15%,
- blood volume increased by 21%.

Acclimatisation was first introduced in 1925 in South African gold mines in an effort to combat the high death rate from heat stroke. The Village Deep Mine placed new recruits on light work in hot areas underground for a period of ten days, while workers with previous experience performed the same work for five days. No allowance was made for individual factors such as ill health or injury and the protocol failed to reduce the high death rate (Wyndham, 1965: 166). New methods of acclimatisation were introduced in the early 1930's which were conducted at the hot stopes. These procedures, combined with the investigations of Dreosti (in Wyndham, 1965: 167) into

heat tolerances of labourers and improved ventilation, were successful in reducing the high death rate due to heat stroke. These methods were once again reviewed in 1965 and relocated to air-conditioned climatic rooms on the surface of the mines. The new protocols reduced the time required for acclimatisation from 12 to 9 days. They involved a controlled, steady work rate, a wet-bulb temperature of 91°F (32.8°C), a four-hour period of work daily and new methods of cooling workers e.g. sitting at rest inside the climatic room. It was found that physical conditioning using a high work rate was an important factor in improving the rate and degree of acclimatisation (Wyndham and Strydom, 1969: 62).

In more recent times, Kielblock et al (1993: 289) reported that these acclimatisation procedures were no longer acceptable from an ergonomic point of view and had become too costly in terms of wasted production shifts. They have been replaced by a new approach which involves a short screening test for heat tolerance and a period of natural on-the-job heat acclimatisation. Fully acclimatised people are able to cope with work rates far greater than non-acclimatised people. Following the screening test, heat tolerant workers are allowed to acclimatise naturally over a 12-shift period in the normal workplace.

In the United States acclimatisation procedures suggested by NIOSH are commonly employed in hot mines i.e. mines where the WBGT exceeds 26.1°C for men and 24.4°C for women. The acclimatisation process involves new employees beginning with 50% of the total workload and time exposure for the first day. This is followed by a daily 10% increment until 100% total exposure is reached on the sixth day. Acclimatised workers returning to work after nine or more consecutive days of leave must undergo a four-day acclimatisation schedule. This commences with the same 50% loading but increases daily by 20% increments until 100% total exposure is reached on the fourth day (Misaqi et al, 1976: 46)

Brake et al (1998: 6) cites the use of acclimatisation at the Enterprise Mine at Mt Isa as a means of increasing the ability to work safely in heat (both cognitive and physical abilities). He also recommends it for two other important adaptations: an improvement in aerobic capacity due to physical exercise and the process of 'work hardening' which has a major effect on reducing overuse injuries. A simple, easily administered protocol has been developed at the Enterprise Mine to ensure only acclimatised persons work in heat. The major components of this protocol are:

- A trigger to ensure non-acclimatised persons become subject to the acclimatisation protocol.
- Unacclimatised persons must not work alone in temperatures exceeding 27.5 °C wet bulb.
- Unacclimatised persons are not to work in "short shift" conditions where shift times are reduced to six hours if workers have worked in thermally stressful situations for more than two hours (Brake et al, 1998: 7).
- Unacclimatised persons are given a "card" which will require them to undergo a dehydration test at the end of every work shift during their first seven days back in the tropics. This is over and above any requirements of the dehydration protocol
- Their supervisor must check and initial their acclimatisation card at least once during each shift.
- The card also includes some advice about the issues of "work hardening" (blisters, boot rub, rashes, muscle atrophy/hypertrophy).

Factors influencing acclimatisation

Age - After the age of 40 the sweating mechanism does not work as efficiently and effectively as at a younger age and cardiovascular fitness is generally reduced. Of

course, this varies with the individual, so, while age should be considered when assessing likely heat tolerance, older people should be assessed individually.

Sex - The sweating mechanism in women operates at a higher threshold than for men and does not allow women to withstand hot environments as well as men.

Race - The question of race is a contentious issue, but it is likely that races with certain physical characteristics, such as large body surface to mass ratio, may have a greater natural heat tolerance than others (Lavenne and Brouwers, 1983: 1016).

Dehydration - It should be noted that the positive effects of acclimatisation are almost entirely lost if the worker is dehydrated (Brake et al, 1998: 7). Brake suggests that for 'fit', healthy adults, dehydration is responsible for almost all of the deleterious effects of working in the heat.

Heavy physical exertion in heat will result in sweat rates of about 1 litre per hour. Sweat rates of up to 2.2 litres per hour are sustainable over periods of one to two hours in fit, healthy individuals with plenty of access to water. However, the limit of the stomach and gut to absorb water is about 1.6 to 1.8 litres per hour on a continuous bases, so sweat rates in the order of 2.2 litres would be extremely dangerous to the individual's health if allowed to continue for the duration of the shift. Dehydration of 3 to 4% of body weight may result in as much as a 50 % reduction in the work rate in hot environments, while dehydration of only 2% in the same environment will cause retardation of mental performance. Thus, working in heat, when accompanied by dehydration affects safety performance either directly or indirectly. Any diuretic, including alcohol and beverages containing caffeine is likely to adversely affect dehydration levels (Brake et al, 1998: 5).

The ability to work in heat may also be affected by drugs that restrict maximum heart rate or cause vaso-constriction.

Prior fitness - While not as effective as exposure to hot environments, intensive training in normal environmental conditions favours acclimatisation.

Natural heat tolerance - The first studies of heat tolerance in mine recruits was conducted by Dreosti in South Africa. Using a particularly severe testing procedure he showed that 15% of the men were 'heat intolerant', 25% were 'heat tolerant' and the remaining 60% were 'normal'. His observations were based on oral temperatures ranging from 950F (350C) to in excess of 1020F (390C) (Wyndham, 1965: 167).

Currently, the approach in South African mines is to conduct a short screening test which consists of a 30-minute bench-stepping exercise with an external work rate of 80W in a controlled environment (wet-bulb: 28.00C; dry-bulb: 29.50C; air velocity: 0.4 m/s). An oral temperature of 37.60C, a rectal temperature of 38.90C or a heart rate of 160 beats/min are upper limits for heat tolerance of an individual, and anyone exceeding these limits during the screening test would be deemed heat intolerant. Kielblock and Schutte (1993: 281) have suggested that heat tolerance could be compromised following heat stroke and that the afflicted worker thus rendered permanently unfit for work in hot environments.

Clothing

As previously described, effective thermoregulation of the body is achieved in large part by evaporation. The cooling effect of sweat relies on adequate air circulation close to the surface of the skin. If the worker wears clothing which impedes air flow and limits effective evaporation of sweat, then the thermal load on the body is greatly increased, even though the environment may be within the normal acceptable limits set by heat stress indices (Gillies, 1991: 3).

Loose fitting clothing, which allows a ready movement of the air, should be worn in hot, humid environments. The amount of skin exposed to radiant heat should be minimal, while specially insulated, reflective clothing should be worn in extreme radiant and convective heat environments. Such conditions commonly exist during mines rescue operations and other fire fighting situations.

Mechanically cooled suits operated by forcing cool air through a vortex have been developed for the purpose of microclimate cooling of the individual rather than the environment (Lahey, 1984: 64). These have been met with mixed reception, and while they work effectively to reduce the core temperature of the individual, they also reduce the mobility of the worker.

The effectiveness of garments containing pockets filled with air or water has been investigated by Quigley (1978, 1980, and 1982) and Constable (1994). Water-cooled jackets provided substantial convective and conductive cooling which reduced skin temperature. Sweat rates were reduced and core temperatures lowered. The air-cooled jackets provided a similar cooling effect, but in , allowed a relatively greater rate of evaporation by the passage of air directly over the skin (Quigley, 1978: 18). The jacket proposed by Wyndham, in Lavenne & Brouwers (1983: 1017), contained 4.5l of water distributed among 28 ice pockets, and has become established as a practical working garment.

Constable et al, (1994: 277) investigated the effectiveness of intermittent microclimate cooling during periods of rest. They found that the perceived cooling effect was appreciable for all subjects.

The wearing of safety helmets also contributes to the overall heat load of the body. The extent of this additional heat load varies from one brand of helmet to the next. Liu and Holmér (1995: 135), in their investigations of the evaporative heat transfer characteristics of industrial safety helmets, concluded that the five helmets studied showed statistically significant differences in evaporative heat transfer under experimental conditions.

After comparing the performance of four different clothing systems, Murray-Smith (1987: 38) concluded that the wearing of clothing with poor heat transfer characteristics negated the desired benefits of cooling installations. He found no significant difference between the rectal temperatures of men wearing cotton T-shirt, shorts, socks, boots and hard hats and the rectal temperatures of men wearing shorts, socks, boots and hard hats. Once the T-shirt became totally saturated with sweat and clung to the skin, its insulating effect became negligible and evaporation was able to take place in the usual manner. However, water impermeable garments would not allow this process to occur and would result in steadily increasing rectal temperatures.

Wyndham (1965: 171) cited three fatal cases of heat stroke that occurred at wet bulb temperatures of less than 26°C. These were all attributed to the fact that the men were wearing water and vapour impermeable garments which prevented the evaporation of sweat.

Heat stress in mines rescue operations

Mines rescue operations are commonly conducted in the face of hot conditions not normally acceptable for daily production work. Heat stress is markedly increased, as the conditions are usually very hot and humid. In these hot environments, the wearing of personal protective equipment and self-contained breathing apparatus creates conditions that are generally acceptable for a period of two hours only. This is despite the fact that the breathing apparatus normally used can last for up to four hours (Piekarski, 1995: 28).

As mines rescue team members are generally part-time volunteers, acclimatisation would not serve the usual purpose with regards to improving heat tolerance. Therefore, greater importance must be placed on the identification of heat tolerant volunteers. To that end, Quigley (1988: 25) trialled a 15 minute predictive test for heat tolerance which was conducted under conditions of 40°C and 100% relative humidity. However, results showed that the prediction of the level of heat tolerance by this means was inconsistent with other predictive methods. Despite these limitations, it was thought that the 15-minute predictive test, in combination with subjective feelings, could be reliably used to identify heat intolerant workers.

During a rescue mission the environment must be constantly monitored to indicate the severity of heat stress on the bodies of the men taking part. Throughout the mines rescue operation, the team captain should measure wet- and dry-bulb temperatures and constantly relay them to the fresh air base. If any team member shows signs of a heat stress disorder the whole team should be withdrawn to this base (Strang & Mackenzie-Wood, 1990: 363).

In extreme heat conditions often encountered by rescue workers, the clothing worn must be carefully selected. It is important that this clothing be specific for the local conditions and should not impede sweating. It should provide protection from radiant heat, particularly in the case of fires, by covering as much of the body as possible. Where fire is not a consideration, cooling may be provided by means of microclimate cooling.

Heat Stress Management

To ensure that the risk of heat disorders, in particular, heat stroke, is properly controlled, overall organisation and co-ordination, incorporating a system of regular review are essential.

The following strategies should be considered in the overall management of heat stress:

- Screening tests - Pre-employment, pre-transfer and periodic health assessments are conducted at Mt Isa Mines (Brake et al, 1998:8). These are based on Body Mass Index (BMI) and aerobic capacity and are designed to exclude people with known risk factors for heat stroke from working in the Enterprise Mine.
- Work-rest cycles - These have been shown to improve productivity as well as being an adjunct to reducing heat stress. Formal supervision is essential, though, as the cut-off from 100% productivity to nil productivity is relatively sharp in any given environmental climate (Brake and Nixon, 1998: 8).
- Mandatory water breaks - These are recommended by Kielblock and Schutte, (1993: 291) and should coincide with work-rest cycles. Water is generally considered to be the best liquid for fluid replacement as loss of salt is not usually severe in normal healthy individuals. It is now common practice to provide workers with personal water bottles at the start of each shift.
- Work breaks - Many countries have adopted this strategy in recent years. To ensure that the core body temperature does not exceed 38°C limits should be set using heat stress indices such as WBGT. Appropriate work breaks should be designed around these limits to reduce the level of heat stress Lavenne and Brouwers, (1993:1017)
- Job rotation - This strategy ensures adequate recovery time between shifts after work in very hot environments.
- Engineering controls - Kielblock and Schutte (1993: 279) recommend that engineering strategies should be based on improving mechanisation to minimise high metabolic rates. Robotics and job redesign are also suggested by Lahey (1984: 64) to counter heat over-exposure. Kielblock and Schutte (1993: 279) also recommend the use of shielding, refrigeration and increased airflow.

- Acclimatisation - This process, as previously discussed has been used for many years as an important method of reducing the risk of heat caused illnesses. Varying protocols have been adopted by mining operations for this purpose, and the current trend of screening workers for physiological risk parameters followed by on-the-job acclimatisation has been adopted by Mount Isa Mines.
- Personal protective equipment - It is important that protective clothing does not become a health hazard by forming a barrier to the natural cooling effect of sweat on the body. Selection of appropriate clothing should be monitored and instruction provided for the correct wearing of this apparel.
- Heat stress index - The question of which heat stress index to use should be based on local conditions and made applicable to the particular heat stress management program in place (Kielblock and Schutte, 1993: 283).
- Education - It is important to educate the workforce so that they understand what happens to their bodies when they work in heat and how they can work safely without endangering their health.
- Health and safety medical protocols - These should be conducted at regular intervals to ensure that heat illness is avoided or picked up at a very early stage and treated.

The review of heat stress management protocols undertaken by Brake et al (1998) is extensive and includes many of the issues above. They firmly believe that a successful heat management program will have a major impact on the ongoing success of the Enterprise mine.

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