A New Generation of Health and Safety Protocols for Working in Heat

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Summary

The existing safety and health management protocols for the management of heat stress in the Enterprise mine are those that currently apply to the other Isa mines. These date to the 1960s when the last full review into working in heat was undertaken, and are based on experimental work conducted by the military in England and Singapore during and shortly after WW2, although the concept of the "six hour shift" dates to 1942 where it came to Isa from the Broken Hill mines. In turn, the short shift came to Broken Hill in the 1920s, probably from Europe, although this origin has been lost in time. The Isa and Broken Hill protocols have formed the basis for much of the existing working-in-heat protocols in Australia and are therefore quite dated. The main body of work done in an occupational setting since WW2 has been undertaken in South Africa, where labour-intensive mining methods, employment practices and education levels are very different to the more capital-intensive and productive Australian mines and the much better educated Australian workforce. Even in Australia, since the mid 1960s, mining methods, personal protective equipment requirements, and statutory and societal attitudes towards health and safety have changed. It is now possible to draw on a vast amount of work that has been done over the past 20 years in the area of sports physiology, in terms of exercise-related heat disorders. Moreover, solid state technology, miniaturisation of electronic components and development of such technology as Erasable Programmable Read Only Memory (EPROM or "firmware") have provided the means to have much better and sophisticated measurement of environmental conditions and the resulting heat stress on workers. Finally, much better monitoring of occupational diseases including heat illness and monitoring of environmental conditions in the workplace have greatly improved the understanding of both the cause and effect of heat illness.

This Paper focuses on the Health and Safety Medical Protocols adopted in the Enterprise Mine to deal with working in heat. Extensive monitoring of heat-related illness and environmental conditions at Isa has shown that existing protocols do not adequately protect the workforce from heat related illness. A comprehensive, integrated approach to managing working-in-heat is presented.

Introduction

The Enterprise mine is located at Mount Isa and is wholly owned by Mount Isa Mines Limited (MIM). It is being developed, at a cost of $331 million, from about 1000 m below surface to almost 2000 m below surface. Expected completion for the construction program is late calender 1999 with the mine producing at 3.5 Mtpa from about 2002 to 2015. The effects of high surface ambient temperatures in summer, combined with "autocompression"[1] in the intake airways, high virgin rock temperatures[2] and heavy use of diesel equipment, results in heat stress in the working place that, without intervention, would exceed the levels that human physiology can withstand. It would also result in significant decreases in productivity and high accident rates even where work is possible.

Enterprise Mine recognises that working in heat potentially affects health, safety, productivity and morale. It also recognises that a "systems approach" must be used to effectively tackle such a complicated issue. This involves setting limits of thermal stress for workers, understanding productivity decrements when working in heat, establishing productive and healthy environmental targets, developing engineering

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1 Autocompression is a term which denotes the fact that the air going underground heats up merely by virtue of the conversion of the "potential" energy of the air at surface into heat when the air moves closer to the centre of the earth. In Mount Isa conditions, the Enterprise Mine is below the "critical depth", which is defined as the depth at which the air itself, once sent underground, is hotter than the acceptable average environmental conditions at the workplace. At Mount Isa, the critical depth is about 1 100 metres below surface.

2 Freshly broken rock surfaces in the Enterprise mine are up to 65 ^{0} C, about the hottest in the world in a mine.

solutions to meet these targets, creating a well-educated workforce with respect to working in heat and then developing health protocols to ensure worker's health is protected.

Refrigeration must be added to the mine to provide acceptable and productive conditions underground. At full production, Enterprise mine will have an installed refrigeration capacity of almost 40 MW. Some of this is provided by way of surface bulk air cooling, some by way of underground air cooling and some by way of chilled service water used in the operation of equipment. A detailed review of the engineering issues involved in the working in heat protocols are given elsewhere[i].

These developments when taken together have provided both the need for a complete review of the safety and health management protocols for working in heat and the ability to come up with new solutions to many of these problems.

Human Physiology, Heat and Underground Mines

The human body has several mechanisms for rejecting heat and remaining cool. However, once the air temperature exceeds about 34 degrees Celsius, the only effective mechanism is by evaporation of sweat from the skin.

In this scenario, heat generated in the deep body organs and muscles is picked up by the blood and pumped to the skin. The skin is cooled by evaporation of sweat. The system operates similarly to a car, with the heart being similar to the water pump, the blood similar to the car's coolant, and the skin operating as the radiator.

The ability of the body to dissipate heat is a function of many factors. The key ones are:

- *Cardiovascular fitness*: a strong, fit, heart (the pump, including provision of essential oxygen from the lungs to operate the pump) and good circulation are essential.
- *Obesity*: this effectively insulates the body reducing heat loss.
- *Acclimatisation*: this is the sum total of all the adaptations the body has to extended exposure to heat.
- *Hydration levels*: the body has to remain well hydrated when working in heat. Even small degrees of dehydration cause significant decrements in the ability to work in heat.
- *Clothing and Personal Protective Equipment requirements*: the more clothing and PPE that is worn, the greater the insulation effect, the greater the loss of evaporative ability and the more difficult it is to stay cool. In most underground mines, there is no direct exposure to radiant heat (except at newly blasted rock faces or when working in or on very hot equipment), so there is little gain from using clothing to reduce radiation heat loads.
- *Environmental conditions*: evaporation is affected by several environmental factors. However, the two most significant in an underground mine are humidity and air speed over the skin. Obviously, at zero humidity it is very easy for water (sweat) to evaporate from the skin into the air. When the air is saturated (100% humidity), it is impossible for any evaporation to occur. At intermediate points, the difficulty in evaporation increases as humidity increases, which is why "hot, humid" air is much more stressful than "hot, dry" air. Air speed over the skin improves the rate of evaporation under all circumstances (except at 100% humidity or very high wet bulb[3] temperatures) and therefore facilitates work in heat[ii].

Of equal significance is the amount of heat that the body needs to reject. Obviously this is primarily a function of the work rate. The maximum efficiency of the human body is about 20%, but it is rare to be this high. The harder the body works, the greater is the metabolic heat generation rate.

The System

The control of hazards[4] related to in working in heat were reviewed under three categories:

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[3] The Dry Bulb temperature is the temperature in common use and referred to in weather reports, etc. The Wet Bulb temperature is the temperature at which water evaporates into the air (at a particular dry bulb temperature). It is very much more important than the dry bulb temperature to physiologists as the moisture vapour holds much of the heat (enthalpy above 0 deg C) in air. Moreover, the evaporation of sweat is related to the partial pressure of water vapour in the air (in effect, the humidity). Knowing any two of dry bulb temperature, wet bulb temperature or humidity will allow calculation of the third.

[4] This is consistent with the more normal "hierarchy of risk control" which sets out the following priorities for risk reduction: elimination, substitution, engineering controls, procedural controls and personal protective equipment.

Figure 1 Enterprise Mine - Working Safely with Heat

- *Engineering the Environment*

We choose airflows, the amount of refrigeration and other engineering solutions to bring the heat to acceptable levels

- *Job Design*

We use air-conditioned cabins, labor-saving devices and other ways to improve the local environment or reduce the physical effort required for work

- *Ventilation & Refrigeration Standards*

We develop standards for the way we install and operate equipment, or go about our work, so that our engineering solutions will be effective

- *Health & Safety Medical Protocols*

We provide health procedures and medical tests to ensure that heat illness is avoided or picked up at a very early stage and treated

- *Education*

We educate our workforce so they understand what happens when they work in heat and can do so safely and without damaging their health

- *Emergency Response*

We provide a means of ensuring that anyone who develops a heat illness can get effective, immediate treatment.

- *Engineering*: what engineering solutions can be put in place to reduce and maintain the risks at acceptable levels
- *Procedures*: what procedures are required to ensure the risks can be managed at acceptable levels
- *Competency*: what level of education, training and competence is required by all persons in the system to ensure the risks are sustained at an acceptably low level

Hazard management was reviewed in three respects:

- *Prevention*: removing or reducing the risks from heat hazards
- *Monitoring*: monitoring the level of risk created by the hazards
- *Contingency*: developing contingency plans that minimise harm if the risk from the hazard rises to a dangerous level

Enterprise Mine then developed a series of statements (Figure 1) that embodies this philosophy in terms which management and the workforce could relate to.

Heat Illness

Prolonged moderate elevations of core temperature can cause *Heat Exhaustion*[iii]. This is characterised by: weakness or extreme fatigue, faintness, nausea, vomiting, headache and restlessness. Replacement of lost water, together with rest in a cool environment, will cure heat exhaustion in a short time.

When the body's capacity to lose heat is exceeded *and* the core temperature rises above 39^0 Celcius, the risk of serious heat illness increases rapidly.

Heat Stroke is a state of thermoregulatory failure: a condition in which an uncontrolled rise in core temperature occurs and the body's tissues start to break down. It occurs when the body core temperature is above 41^0 Celcius[iv]. Symptoms include: confusion, staggering, delirium, coma and, often, the absence of sweating. Death is imminent. Permanent tissue damage usually occurs, although the longer-term health impact depends on which tissues are damaged and the severity of the damage.

About 1 in 5 cases of heat stroke is fatal in underground mines in South Africa[v], even with hospitalisation. Medical treatment requires the most rapid cooling of the body.

The Isa mines have never had a case of heat stroke, let alone a fatal case of heat stroke, despite working at least ten million manshifts in hot conditions (more than 28^0 WB) over the past 30 years. However Isa continues to have many cases of lesser forms of heat illness, with over 100 cases during summer 97/98, and many cases still believed to be unreported. A continuing campaign to improve workforce education about heat illness and its symptoms, is resulting in many of these previously unreported incidents now being reported.

Obesity and poor cardiovascular fitness are risk factors for heat stroke. Hence the need for obesity (Body Mass Index or BMI[5]) and aerobic fitness (oxygen uptake[6] or $VO_{2\,max}$) testing for persons working in heat. Due to the need to drink large volumes of fluids and concentrate the urine when working in heat, persons with poor kidney function should not work in heat. People who are diabetic or anaemic are more

5 BMI is defined as weight in kg divided by height in metres squared, i.e. wt/(ht^2).

6 Measured as milllilitres of oxygen consumed per kg of body weight per minute.

susceptible to heat as are those with circulatory problems, atherosclerosis, previous head injuries, some skin diseases, thyroid disease or blood pressure problems. Depending on the severity of these conditions, some individuals with these conditions may not be able to work safely in heat.

People can also develop an intolerance to heat following recovery from a severe heat illness[vi] although this is very rare in the occupational setting. Irreparable damage to the body's heat-dissipating mechanisms has been noted in many of these cases.

Other heat illnesses include: heat collapse (heat syncope or fainting), heat cramps, heat rash (prickly heat), heat oedema (swelling of the limbs) and chronic heat fatigue.

Safety, Shift Length and Rosters when working in heat

This is a large topic in itself and will not be discussed here except to make a few observations:

- A large number of safety injuries and incidents where persons work in heat "may be caused by mental and physical decrements as a consequence of poor hydration; however, the primary cause (dehydration) is misdiagnosed"[vii].
- A key issue is whether the work is "paced" or "self-paced". In self-paced work, the worker recognises, for example, that he is over-heating or concentration is being affected (cognitive decay) and adjusts accordingly. Any job underground that is not self-paced needs special attention. "Paced" work can include persons working in "teams", persons working to deadlines (including self-imposed ones) or persons working under "contract" or "piece-work" rates.
- In terms of health and safety, more significant factors than the length of the shift appear to be the choice of roster (some rosters provide better recovery between shifts than others do).
- "Moon-lighting" (taking a second job) is a problem that can affect safety especially when working 12 hour shifts in heat. However, the moon-lighting needs to be in work similar to the "normal" work to be a problem (e.g. if a manual worker moonlights doing clerical work this is much less of a problem than a manual worker moon-lighting as a manual worker).
- The length and number of meal breaks appears to be a factor in fatigue on long shifts, i.e. more frequent and smaller meal breaks (snacks) are better than one long break with one large meal which causes significant cardio-vascular shunting to the stomach which, along with hot conditions, results in lethargy and tiredness.
- People should not be engaging in strenuous physical exercise, including sport, immediately before or after their shift.
- Lack of sleep is also a factor in the ability to cope with heat. Good recovery between shifts is essential for working long, hot shifts.
- Drinking water, especially in large quantities, when trying to "catch up" on a "back log" of dehydration, is believed to be a factor in producing cramping.
- Persons should drink sufficient water to urinate every four hours: summer or winter, whether working in heat or not.
- A personal water bottle has been made part of the "standard personal protective equipment (PPE)" for all non-supervisory persons exposed to heat stress.
- Diet cordial is provided on free issue by MIM to workers in heat. It has been found that if the water is made more palatable, then people drink more of it. The composition of cordial for salt and sugar should be checked as these, if taken in excess, will have other detrimental health implications. However small amounts of glucose and salt in the drinking water are advantageous, especially on 12 hour shifts, as an isotonic drink reduces the impact on the body from losses of salt and maintains higher blood sugar levels.
- Properly showering (removing grease, grime, sweat) and drying off is important in assisting prevention of heat rash or "prickly heat" (blockage or inflammation of the sweat glands).
- Psychological stress also adds to the effects of physical stress on the job. Such psychological stress is associated with: the rapid changes required to job descriptions, new and more technically complicated plant to be operated and new skills therefore required, organisation changes in companies and job insecurity. Stress arising from personal circumstances also adds to the load (marriage, children, finances, etc).

- Women do respond differently to men when working in heat. Their smaller body size, higher fat contents and lower aerobic capacity reduce their ability to dissipate heat. In addition, their core temperature is higher than males and varies throughout their monthly cycle[7]. The 1996 ACGIH standard on Heat Stress under "Adverse Health Effects", states:

  "If during the first trimester of pregnancy, a female worker's core temperature exceeds 39^0 C for extended periods, there is an increased risk of malformation to the unborn foetus. Additionally, core temperatures above 38^0 C may be associated with temporary infertility in both females and males".

  Therefore MIM does not currently allow women of child-bearing capacity to work in very thermally stressful situations.

- It is recognised that cell division rates in male sperm decrease in heat. It is also recognised that males wearing nylon underwear when working in heat produce malformed sperm. Male workers are educated to wear only cotton underwear when working in heat.

<u>Health and Safety Medical Protocols</u>

<u>Dehydration Test and Heat Illness Protocol</u>

The MIM Dehydration and Heat Illness Protocol has two basic objectives:

- dehydration testing at the end of each working shift of all persons exposed to moderate thermal stress. This includes re-testing and paid rehydration time (if necessary) before such persons are allowed back into hot environments.
- medical assessment and treatment of all persons who develop any symptoms of heat illness. This includes blood tests for all persons with more severe symptoms.

The MIM Medical Centre is currently monitoring heat illness in the Isa workforce in line with the introduction of the new Dehydration and Heat Illness Protocols. For "fit", healthy adults, dehydration is responsible for almost all of the deleterious effects of working in heat.

Heavy (stressful) physical exertion in heat will result in sweat rates of about 1 litre per hour.

Very stressful environmental conditions will result in sweat rates of about 1.5 litre per hour.

Sweat rates up to 2.2 litres per hour have been recorded and are sustainable over periods of one to two hours in fit, healthy individuals with access to plenty of water.

The limit of the stomach and gut to absorb water is about 1.6 to 1.8 litres per hour on a continuous basis, providing the individual is not dehydrated.

Sweat starts to drip off the body when the body is about 50% fully wet. Sweat rates about 70% above the evaporation rate are required to attain and sustain 100% skin surface wetting.

The sweat glands do fatigue over a period of hours when sweat rate is close to the maximum. When the skin is wet for a period of hours, swelling of the duct opening in the skin can occur, which occludes the sweat gland, a condition called *hydromeiosis*. These conditions are temporary but will affect sweat rate and therefore the ability to work at high sweat rates for long periods in heat[viii]. Allowing a break in which the body can cool down (preferably in an air-conditioned lunch room) and sweating can cease allows the sweat glands to recover.

Some studies have shown [xi]:

- Dehydration of 1 to 2% of body weight results in a 6 to 7% reduction in physical work rate.
- Dehydration of 3 to 4% of body weight results in a 22% to 50% reduction in work rate, for "moderate" and "hot" environments respectively.
- Mental performance (mental function, visuomotor skills and arithmetic tests) begins to decrease at 2% dehydration and thereafter is proportional to the degree of further dehydration. Hence the inference by numerous competent authors that working in heat, *when accompanied by dehydration*, affects safety performance either directly or indirectly. Certainly the experience at Isa is that LTIFR increases over summer, and medical treatments of all sorts are much more numerous in summer than in winter.

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7 Normal circadian rhythm results in a core temperature which fluctuates by 1 deg each 24 hours, and lifts core temperatures in menstruating women by a further 0.1 to 0.4 deg. Average resting core temperature variation within the population is 0.5 deg, all other factors being equal. Oral temperatures are, on average, 0.5 deg lower than core (rectal) temperatures.

The education campaign about dehydration and drinking when working in heat has been so effective that most workers now maintain or even improve their hydration state when working in heat. However, a large number (almost 50%) are coming to work dehydrated, especially after their roster break, and an education focus on this aspect is required for next summer.

For workers with no symptoms of heat illness, oral rehydration (using diet cordial) has been found to take no longer than two hours, with the median being one hour.

Dehydration is affected by any diuretic, including alcohol and beverages containing caffeine (coffee, tea, colas). Some miners, who have developed repeat cases of heat illness, have been found to drink six litres or more of Coke per day on their days off (and nothing else). This will result in dehydration, even while the individual continues to urinate regularly.

Many over-the-counter cold and flu remedies contain codeine (hence the warning on some medications that the substance can cause drowsiness and should not be taken if "driving"). Most contain either a sedative or a stimulant and some contain drugs that cause vaso-constriction, which is a serious problem if working in heat.

There are many prescription drugs that also affect the ability to work in heat. Examples include "beta-blockers" which are often prescribed for high blood pressure. These restrict the maximum heart rate and can also "clamp down" the blood vessels. Persons on such medication probably should not be working in heat. Diuretic medications will affect the ability of a worker to maintain hydration levels.

There are many herbal remedies which also affect the ability to work in heat.

For these reasons, Mount Isa Mines requires:

- Persons to not take cold and flu remedies before or during work.
- Persons who are prescribed medication by doctors other than the MIM Occupational Physicians, or who change their medication, check with the MIM Occupational Physicians before commencing work.
- Persons to ensure any herbal remedies are screened by a competent person prior to being taken.

The workplace temperatures and airflow are measured for all persons who develop a heat illness.

Acclimatisation

Acclimatisation is very real and the sum total of all the ways the body has to adapt to working in heat.

In an early and seminal clinical study[ix], the following results were obtained during acclimatisation:

- reduction in heart rate when working in heat from 153 to 127 beats per minute,
- core temperature when working in heat reduced from 38.8^0 C to 38.1^0 C,
- sweat becomes more dilute, with sodium concentration down by 29%,
- more rapid onset of sweating, up by 15%,
- blood volume increased by 21%.

It is recognised that acclimatisation also results in the sweat glands becoming much more resistant to hydromeiosis and sweat gland "fatigue".

Most of the effects of acclimatisation are developed within 7 days, but continue to 14 days and beyond.

Acclimatisation has a major impact on the ability to work in heat (both cognitive abilities and physical abilities)

Less is known on the time required to lose acclimatisation, but 7 to 21 days is a consensus. For Isa, loss of acclimatisation is considered to occur after 14 days. Therefore MIM considers any person who is a new starter (from outside the Tropics), or has been on leave or sick or otherwise away from work for 14 days (unless within the Tropics) to be unacclimatised.

Persons acclimatise to the level of heat stress they experience. Acclimatisation is therefore not an "on or off" state. Care needs to be taken when a person in one job with one degree of acclimatisation is exposed to work requiring a higher level of acclimatisation.

Formal acclimatisation programs in South Africa typically involve persons working in a controlled environment at a set work rate and needing to be able to keep their core temperature below a threshold. Some workers can do this on their first shift, most in about three shifts, and "heat intolerant" persons (3%) are rejected after five days.

Acclimatisation is being required in an increasing number of codes, e.g. ISO7933[x]. For example, the ACGIH code[iv] now states:

"Acclimatisation and Fitness

> *Acclimatisation to heat involves a series of physiological and psychological adjustments that occur in an individual during the first week of exposure to hot environmental conditions. The recommended TLVs are valid for acclimatised workers who are physically fit. Extra caution must be employed when unacclimatised or physically unfit workers must be exposed to heat stress conditions".*

In reality, "acclimatisation" runs in parallel with two other important adaptations:

- an improvement in aerobic capacity due to physical exercise (especially true for previously sedentary workers), and
- the process of "work hardening" (especially muscle hypertrophy but also blisters/calluses, boot rub and rashes). Work hardening is the adaptive or training effect of physical work and has a major effect on reducing overuse injuries.

Work hardening is very important for workers that have heavy physical demands on certain muscle groups. Many workers in traditional "blue collar" jobs would have relatively "low fitness" in the aerobic sense; however, their work hardening means they could do the work their muscles are adapted for long after an endurance athlete had been forced to retire in the same circumstances.

Work hardening is therefore an issue if it is decided to "job share" some work, or use one type of worker as a "back-up" for another type of worker. For example, to use a forklift driver used to low physical activity in an air-conditioned cabin as the back-up for a bricklayer would result in a high probability of "work hardening" injuries for the forklift driver on those occasions when he is required to lay bricks at "bricklayers intensity". Similarly, the forklift driver may be fully acclimatised to the level of heat stress regularly experienced in his job, but insufficiently acclimatised for the job with higher heat stress. Heat illness is likely to result if this person is required to work alongside a team of workers acclimatised to more heat stress.

A simple, easily administered protocol has been developed 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. This occurs at the supervisor level and is for new starters and persons returning to work when the last 14 days of their absence has been spent outside the tropics.
- Unacclimatised persons must not work alone in temperatures exceeding 27.5 ^{0} wet bulb.
- Unacclimatised persons are not to work in "short shift" conditions [see below].
- 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. The card identifies when their acclimatisation protocol starts and when it is completed. The card also contains "special" precautions for unacclimatised persons, such as increasing the salt intake during the acclimatisation period, not working alone, not working in short shift conditions, hydration etc.
- 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).

Note that the positive effects of acclimatisation are almost entirely lost if the worker is dehydrated.

Short Shift ("6 hour job" or "hot job") Protocol and Temperature and Airflow limits

Mount Isa Mines currently has a "short shift" ["hot job"] protocol, which reduces the working shift length to six hours where workers have worked in thermally stressful situations for more than two hours. Workers are paid for the full shift (8, 10 or 12 hours as the case may be). The concept of a "short shift" came to Mount Isa in 1942 when it was introduced from Broken Hill where it was introduced in the 1920s and is believed to ultimately have originated in Europe. This protocol has been thoroughly reviewed and significant changes are expected to the protocols in 1998 as it is now recognised that the work/rest "cycling" required when working in heat is very much less than 6 hours on and 2 hours off and that heat illness can and does develop in as little as ten to 30 minutes of exposure. The new protocols not only build on the much better understanding MIM now has of the health and safety effects of working in heat, but also build on the new technology now available for measuring environmental conditions (thermal stress) and predicting the impacts on human physiology (thermal strain)[xi]. The new protocols cover the whole range of relevant issues (dehydration, acclimatisation, clothing, pacing, etc) but in terms of environmental (thermal) stress will establish four limits:

- no restrictions
- acclimatised persons only
- action or reporting required limit (AREL)
- withdrawal limit

All limits will be expressed in terms of Air Cooling Power (ACP) which is the cooling power of the air on a sweating person, measured in watts per square meter of body surface area.

The AREL is effectively a “buffer zone”. Work can be done safely in the AREL region but will not be allowed unless the ventilation on the job is up to standard, and must be reported to the Manager within 24 hours.

The AREL and withdrawal limits will be significantly reduced from (i.e. more conservative than) the existing “six hour job” and “stop job” limits and the design of the limits will drive the underground mines towards higher airflows on the job, as low air speed on the job (less than 0.5 m/s) has been found to occur in 75% of all workplaces where symptoms of heat illness commenced. Substantial use of “air movers” (compressed-air venturi fans) will be required in future.

With much reduced temperature limits, current six hour environmental conditions will effectively become “withdrawal” (i.e. stop job) limits in future. A major program of measuring deep body core temperatures and fatigue levels in underground workers most exposed to heat stress shows that heart rates, work rates, core temperatures and fatigue levels on 12 hour shifts in these new limits are within acceptable parameters.

There is a strong correlation between heat illness and surface and underground workplace wet bulb temperatures. However, it is important to understand that focussing on *a temperature protocol alone* will not eliminate heat illness, unless workplace temperatures can be brought down to “office conditions”. For example at Isa, there were about 100 cases of heat illness from underground operations in summer 97/98, but only 6 of these occurred in persons who were granted a “hot job” [i.e. who were “caught” in the formal temperature/time protocol, which has been designed to protect workers from heat illness]. Conversely, there have been over 1000 “hot jobs” granted this past summer, but only 4 of these resulted in heat illness. At Isa, there has been no correlation between the incidence of heat illness and the incidence of short shifts granted, although many workplaces where heat illnesses started were in hot job conditions, but workers did not qualify because they failed to be there for more than two hours.

Clothing and Personal Protective Equipment (PPE)

Clothing has a major impact on the ability of the body to cool itself via sweating as the following Air Cooling Power (ability of the air to cool the body) calculations[xii] shows:

Environmental conditions: 28^0 C wet bulb air temperature, air speed 1 m/s:

ACP for unclothed body .... 313 W/m^2

ACP for lightly clothed body .... 168 W/m^2

ACP for heavily clothed body .... 127 W/m^2

Key issues for clothing include: fabric vapour permeability and conductivity, clothing design (ventilation, e.g. “bagginess”), amount of clothing and personal protective equipment and type of PPE, e.g. wearing leather boots is better than impermeable rubber boots.

Pre-Employment, Pre-Transfer and Periodic Health Assessments

The purpose of health assessments is to ensure persons who cannot work healthily and safely in heat are excluded from working in the Enterprise Mine under MIM’s Duty of Care. These assessments are generally in line with *Guidelines for Safe Mining*[xiii].

It does this by excluding those with known risk factors for heat illness from working in the Enterprise Mine.

Periodic health assessments are every 2 years but managers can refer an individual for medical review at any time if they have concerns.

The two key tests, based on ability to work in heat, which would exclude work are:

- if the BMI is greater than 35 ("morbidly obese")[8]
- if the aerobic capacity ($VO_{2\ max}$) is less than 30 ml/kg/min ("poor aerobic fitness")

Note that a 5'10" male in the "ideal" weight range would weigh no more than 80 kg (BMI of 25). At a BMI of 35 (the MIM exclusion point), he weighs 110 kg (i.e. is carrying a surplus 30 kg constantly) and at a BMI of 45, he weighs 142 kg (i.e. is constantly carrying a surplus 62 kg).

Contrary to popular opinion, physical work rates of underground miners in Australia are relatively low and heavy musculature does not produce high BMIs. Even the burliest of forwards in the Brisbane Broncos does not exceed a BMI of 30.

About 3% of blue-collar workers fail the BMI requirement to be under 35, and about 12% fail the aerobic requirement to be over 30 ml oxygen per kg per minute. The average BMI of Isa blue-collar workers is 26 and the average aerobic capacity is 39 ml/kg/min. Financial assistance (dietary counseling, membership of a local gym, attendance at "Gutbusters"™) is offered to employees who fail their health screen on these tests.

For all new employees, or transferees from other MIM mines, the specific health requirements for the Enterprise Mine are written in to their letter of offer and contract of employment, i.e. BMI, $VO_{2\ max}$, etc and a medical must be passed, even for "internal transfers".

Education is provided for the workforce and also, optionally, for the spouses. Given a largely male workforce, it is the wives who prepare most of the meals for workers underground.

Permit to Work In Hot Locations

Sometimes, work in very hot conditions is unavoidable, e.g. to fix the ventilation itself, or for operating or other emergencies. To ensure proper precautions are taken when persons work in very hot conditions, a Permit to Work in Hot Locations has been introduced. The key components of this system are:

1. No person is allowed to work alone under this permit.
2. No unacclimatised person can work under this permit.
3. No woman of child-bearing capacity can work under this permit.
4. Expected water consumption, work-rest cycles, maximum working time are to be provided before the work commences, except in emergency (e.g. rescuing another worker).
5. Sufficient water must be kept on the job at all times.
6. A supervisor or other competent person must be on the job at all times.
7. Ready access must exist to emergency services (e.g. phone or radio on the job).
8. Each person covered under this Permit must have a dehydration test at the end of the shift.

Emergency Egress (Escape) and Entrapment Procedures

The depth and heat levels within the Enterprise mine add a number of quite serious complicating factors to emergency escape and entrapment procedures. Survival times both with and without access to drinking water have been identified. This impacts on the sizing, location and specification of emergency refuge bays and the selection of self-rescuers. Procedures in the event of power failures, which will bring the volume of ventilating air to a standstill within about three hours in mid summer conditions, when Natural Ventilating Pressure is at its lowest, have also been reviewed.

Visitors Health Screening Protocol

Until recently, there were no medical restrictions on any private or "official" visitors to the Enterprise mine, although some warnings were provided. This was inconsistent with MIM's Duty of Care to all persons and has been rectified by getting each visitor to fill in a health assessment in the form of a self-assessed medical questionnaire. This questionnaire is now:

- included in MIM's Standard Conditions of Contract (in clauses relating to visitor access),

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[8] The Commonwealth Department of Health, the National Nutritional Foundation and many other authorities agree that the following BMI values are useful indications of body fat.

BMI < 20	Underweight
BMI 20 to 25	Ideal weight
BMI 25 to 30	Overweight
BMI 30 to 35	Obese
BMI > 35	Morbidly obese

- sent to any re-sellers of the MIM Underground Tours, plus
- included with any agreement sent out to persons wishing to have a technical or private visit underground.

Chronic Heat Fatigue

In cold climates such as Canada, a common ailment that was historically and colloquially known as "cabin fever", has now been called the SAD syndrome: *Seasonal Affective Disorder*. A related phenomenon, in effect a longer-acting form of Heat Fatigue, has been recognised in the Mount Isa community for many years, and is locally and colloquially known as "Mango Madness"[9]. It is noticeable in the occupational context by an increase in work related incidents over the hot summer months. It is described as resulting in longer term impairment in work performance and social behaviour. A lack of motivation, alcoholic overindulgence and an inability to concentrate are symptoms[xiv]. As for the SAD syndrome, a number of factors working together create the setting for "mango madness".

- Problems for persons on night shift trying to sleep in a hot house during the day
- Problems for persons on night shift trying to sleep with children home on holidays
- Problems for everyone with tropical heat affecting sleep, even in the evenings
- Problems with grog/parties: fatigue, alcohol, etc
- Problems with the post-Christmas "blues" (*didn't* see the relatives over Christmas or *did* see the relatives over Christmas, Christmas didn't work out the way we wanted, etc)
- Problems with being preoccupied with pre-holiday planning/dreaming and/or post-holiday "blues" [mind not on the job]
- Problems with the long daylight hours enticing persons to work or play longer and sleep less
- Problems with many staff being away leading to being short-handed in the work environment and/or persons acting in jobs they don't usually do

The best way to combat "mango madness" is to educate managers, supervisors and workers alike.

Conclusions

The Enterprise Mine will be Australia's deepest underground mining operation and will be among the hottest underground mines in the world. It will employ several hundred workers for at least fifteen years. With high virgin rock temperatures and the adverse Mount Isa surface summer conditions, the workforce will be exposed on a continual basis to adverse thermal conditions. Mount Isa Mines has developed a comprehensive series of health protocols to dovetail with a complete system of engineering and other solutions to managing the risks associated with working in heat. These have been developed from first principles but have been extensively validated by on-site studies.

i Brake, D and Nixon, T. 1998. The Development of Ventilation and Refrigeration Systems and Engineering Controls for the Enterprise Mine. Proc 1998 Annual Conf of AUSIMM. p 187-197.

ii The Thermal Environment. 1990. Brit Occ Hyg Soc. Technical Guide # 8.

iii Hygge, S, 1992. Heat and Performance in *Handbook of Human Performance* (Ed: Smith & Jones). Chapter 4, pp 79-104. Academic Press.

iv ACGIH, 1991. Heat Stress in *Documentation of the Threshold Limit Values For Physical Agents in the Work Environment*.

v Howes, M and Nixon, C, 1997. Development of Procedures for Safe Working in Hot Conditions, paper presented to the 6th International Mine Ventilation Congress. Pittsburg.

vi Shapiro, Y, Magazanik, A, Udassin, Pl, Ben-Baruch, G, Shvartz, E and Shoenfeld, Y, 1979. Heat intolerance in former heat stroke patients. *Annals Inter Med.* 90: 913-916.

9 The fruit from mango trees, which are prolific in Mount Isa, ripens in early December each year.

[vii] Bates, G. The Industrial Worker: a Different Breed of Athlete, 1997. Record of Sports Science Exchange Roundtable. Gatorade Sports Science Institute. Vol 8:2.

[viii] Stewart, J, 1989. Fundamentals of Human Heat Stress in *Environmental Engineering in South African Mines*. Chp 20, page 503. The Mine Ventilation Society of South Africa.

[ix] Lee, D H (ed), Falk, H L (ed) and Murphy, S D (ed), 1988. Handbook of Physiology – Environmental Physiology, American Physiological Society. pp 204-205.

[x] ISO7933. Hot Environments-Analytical determination and interpretation of thermal stress using calculation of required sweat rate. 1989. Int Org for Standardization. Geneva.

[xi] Bates, G. & Matthew, B, 1996. A New Approach to Measuring Heat Stress in the Workplace, paper presented to The Aust Inst of Occ Hyg 15th Ann Conf. Perth. 30 Nov to 4 Dec.

[xii] McPherson, M J, 1992. The Generalisation of Air Cooling Power, paper presented to the 5th International Mine Ventilation Congress. Johannesburg.

[xiii] Guidelines for Safe Mining. 1996. Hygiene and Health Facilities. Chp 4, p 85-86. NSW Department of Mineral Resources.

[xiv] Stewart, J, 1989. Practical Aspects of Human Heat Stress in *Environmental Engineering in South African Mines*. Chp 21, page 539. The Mine Ventilation Society of South Africa.