Heat Stress in Mining

U. S. Department of Labor
Mine Safety and Health Administration
National Mine Health and Safety Academy

Safety Manual Series
SM 6

Revised 2012

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PREFACE

This is one of a series of manuals prepared by the Mine Safety and Health Administration (MSHA) to acquaint the reader with a specific area of mining. This manual defines "hot" work sites, heat stress, heat strain, and the natural coping mechanisms of the human body. Also explained are heat-related injuries and disorders, an overview of treatments, and control methods used in the mines.

Other manuals available in this series are listed on the inside back cover. Multiple copies of Safety Manuals may be ordered for $2.00 each and single copies may be obtained free of charge from:

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What is a "hot" work site?

The following factors help define a "hot" work site:

- high air temperatures
- high surface temperatures
- high humidity
- relatively low air movement

A "hot" work site is any combination of air temperature, humidity, radiation, and wind speed that exceeds a wet bulb globe temperature (WBGT) of 79°F (26°C).
(See Appendix A for explanation of WBGT device)

A surface area where excavation, construction, and related operations are conducted outdoors in hot weather can be a "hot" work site.

Indoor facilities such as smelters, furnaces, and kilns at mines are "hot" work sites.

Deep underground mines are "hot" work sites because of the heat from the rock itself. Ground water flowing through hot rock formations becomes hot and adds to the air temperature.

Activities like drilling, blasting, and welding add to the heat load put on miners, on the surface and underground.

Powered equipment -- engines, motors, compressors, and some lighting -- also increase the amount of heat found in all these work areas.

Human bodies generate a significant amount of heat, especially when strenuous movement is involved.

Generally, the higher the amount of moisture in the air -- *humidity* -- the more uncomfortable and dangerous the area becomes.

What is heat strain?
Heat strain refers to adjustments made by the individual in response to heat. These adjustments include biochemical, physiological, and psychological processes. Heat strain can show itself in the form of irritation, anger, and other emotions that can lead to rash, unsafe acts.

What is heat stress?
Heat stress refers to the total heat-related load on the individual from all natural and man-made sources. If this heat load is not reduced or eliminated, workers can suffer from mild to dangerous heat-related disorders and illnesses.

When the body is shielded or prevented from normal circulation of air, perspiration does not evaporate, thus eliminating the body's main mechanism for cooling. A cool towel on the back of the neck will effectively cause the hypothalamus (the body's thermostat) to reduce the body's temperature immediately by 2 to 4 degrees in a heat stress situation.

Does heat contribute to high accident rates?
Studies have shown that workers in hot, humid environments have difficulty concentrating and some-

times take dangerous shortcuts. Dexterity and coordination, the ability to remain alert during lengthy and monotonous tasks, and the ability to make quick decisions are adversely affected by the heat. Lowest accident rates have been related to miners working at temperatures below 70°F (21°C); highest accident rates are connected with temperatures above 80°F (27°C). When humidity is a factor, heat stress can occur at lower temperatures.
(See Appendix B Temperature-Humidity Index)

How does the human body cope with heat?
As warm-blooded beings, we function normally in almost all types of weather and climate because we can internally regulate and maintain our body temperature within a narrow range. Fats, carbohydrates, and proteins in our food provide energy for our daily activities. But the human body is not 100 percent efficient. At best, only 25 percent of the energy we generate through metabolism is converted into mechanical work. Thus, at least 75 percent of the energy produced by metabolism is converted into heat which, in turn, is needed to support the metabolic process. However, heat stress interferes with our metabolism, causing health problems such as heatstroke, fainting, exhaustion, cramps, and dehydration.

If you can think of the human body as having a *shell* surrounding a *core*, it may be easier to understand how your body controls heat. The *shell* consists of skin, tissues forming the skin base, muscles that lie close to the skin, and hands and feet.

The *core* contains the deep muscles and tissues, including the heart, lungs, abdominal organs, and brain. The *core* can release its heat only through the *shell*.

When you are at rest, your core temperature remains fairly uniform. Under extreme conditions -- from sleeping in a cold environment to doing hard work in a hot work site -- your core temperature can vary from a low of 95°F to a high of 104°F (35°C to 40°C).

The core cannot store an excessive amount of heat without upsetting its delicate thermal balance. Your ability to cope with heat, both at rest and during work, depends upon the stability of your core body temperature. If the core temperature can be stabilized at a high of 100°F (38°C), you will probably be safe.

How does the body release heat?

The harder you work the more heat your body produces. Blood transports this heat from the core to the shell where it reaches the tiny capillaries in your skin. The capillaries dilate (expand) and cause a rise in skin temperature. If there is nothing between your skin and the air, this heat is thrown off. Two conditions lower the effectiveness of this method --

1. Clothing, which can trap heat or slow its rate of release.
2. The level of warmth in the surrounding air. Air must be cooler than your skin in order for your body to release the heat.

Moving air -- circulated by means of fans, breezes, etc. -- helps remove the heat from your body. Contact with cooler objects also helps.

Sweating, which is the release of fluid through sweat glands in the skin, helps release heat, but it must evaporate in order to cool you.

Your lungs also work to release heat by exhaling water vapor.

Are some persons affected by heat more than others?
There is evidence that older persons have a lower tolerance for heat. They start to sweat later than do younger individuals. It takes longer for their body temperatures to return to normal levels. In one study, the majority of all the individuals who fell victim to heatstroke were over 60 years of age. People 65 years old or older (as a rule) do not sense or easily respond to changes in temperature.

Persons who were born with no sweat glands or have damaged glands due to illness or injury have lost an important mechanism that helps cope with heat stress.

Persons who are overweight may be at higher risk because of their tendency to retain more body heat.

Pre-existing conditions, such as high blood pressure, depression, or poor circulation, interfere with your coping mechanisms. Certain medications, for example, a *diuretic* taken to cause dehydration, can make you more susceptible to heat disorders.

What are heat disorders, their symptoms, and treatments?
Healthy and physically fit persons are able to work under heat strain as long as sweat evaporation takes place. The first sign of heat strain is an increase in

the sweat rate. A steady rise of the sweat rate causes an excessive wetting of the skin. Extended exposure to heat will cause a decline in sweat rate; that is, sweat glands become fatigued and stop functioning properly. **In all cases, remove the victim to a cooler area.** Heat-related illnesses, each of which can occur alone or in combination with others, are generally classified and treated as follows:

- **Heat Rash** (also known as prickly heat) is in the form of tiny red blisters in the affected skin area, usually on the neck and upper chest, in the groin, under the breasts, and in elbow creases. This condition is related to the maceration (wasting away) of skin by the continuous presence of unevaporated sweat.
  Treatment -- Regularly washing and drying the skin are both the prevention and most of the treatment for this rash. Since the rash can develop where clothing is most restrictive, loosen clothing in these sensitive areas. Apply powders to keep the skin dry. Avoid ointments and creams that keep the skin warm and moist -- they may make the condition worse. If blisters form, take care not to burst them; this can allow infection to set in.

- **Sunburn** damages the skin, sometimes far below the top layer, causing the skin to redden and feel feverish. In more severe cases, fluid-filled blisters form that can become infected. Repeated burns have been linked to forms of skin cancer.
  Treatment -- Apply cold compresses to the sunburned areas. The victim can be immersed in cool

water. Stay away from using salves, ointments, or butter that prevents heat from escaping the skin. Some moisturizing lotions help. If blisters form, avoid breaking them; infections can set in to the broken skin.

• **<u>Heat fatigue</u>** usually indicates a lack of acclimatization; that is, becoming accustomed to the environment. Signs of heat fatigue include impaired performance in jobs that require skill and adeptness in motor activities as well as good judgment and vigilance. **In all cases, remove the victim to a cooler area.**
Treatment -- Since this condition is the first indication of heat stress, removing the victim to a cooler area and allowing time for recovery will normally be enough.

• **<u>Heat cramps</u>** are muscle pains or spasms -- commonly those in the abdomen, arms, or legs. They can be caused by both too much and too little salt. Cramps often affect people who sweat a lot during strenuous activity. Sweating depletes the body's salt and moisture; low salt level in muscles cause painful cramps.
Treatment -- All activity, once in a cooler area, must stop. Give the victim lightly salted water (1/4 tablespoon of table salt per quart of water) or a beverage that replaces lost electrolytes. If the cramps don't subside in about one hour or the worker is on a low-sodium diet or has a history of

heart problems, seek professional medical attention without delay. If the cramps do let up within an hour, the victim must still remain inactive for a few more hours while drinking proper fluids. Returning to work too quickly can lead to heat exhaustion or heat stroke.

• **Heat syncope** (heat collapse or heat fainting) occurs when the blood moves from the central organs to vessels in the lower part of the body and to the skin. When blood pools in these extremities, rather than returning to the heart to be pumped to the brain, conditions from light-headedness to fainting occur.

Treatment -- Fainting leaves the victim prone and helps the blood that's pooled in the lower body to circulate back to the brain. As in all cases of fainting, waiting for normal color to return to the victim's face is a good indicator of recovery. Have the victim drink water (or a clear juice or sports beverage) slowly. After the victim feels like standing up, allow some walking to ensure that a return to work is safe.

• **Heat exhaustion** (dehydration) or "water-deficiency heat exhaustion" occurs when workers fail to replenish enough fluids and minerals (*electrolyte balance*) lost during excessive sweating. Symptoms include headache, nausea, vertigo, weakness, thirst, profuse sweating, rapid pulse, dizziness, paleness, muscle cramps, and giddiness. The victim's skin is clammy and moist; the complexion pale or flushed. Left untreated, heat exhaustion can lead to heat stroke.

Treatment -- It is vital that the victim drink lots of lightly salted water (1/4 tablespoon of table salt per quart of water) or a beverage that replaces electrolytes. Plenty of rest away from heat is important. The victim needs treatment from a medical professional as well.

• **Heat stroke** (sunstroke) is the most serious heat-induced illness. It's caused by a failure of the body to sweat which results in an accelerating rise in core temperature. Symptoms include confusion, hallucinations, chills, throbbing headache, loss of consciousness, convulsions, slurred speech, and coma. The skin is hot and dry, the pulse is rapid, and blood pressure falls. Body temperature can soar to 106°F (41°C) or more. Heat stroke can cause irreversible damage and is life threatening.

Treatment -- This condition can be fatal unless rapid and adequate treatment is obtained! After removing the victim to a cooler area, immediately begin cooling the skin -- for example: loosen clothing, spray with cool water and a fan, or immerse in chilled water coupled with vigorously massaging the skin. Seek treatment from a medical professional without delay while attempting to cool down the victim.

How can heat problems be reduced in mines?

The objective of controls in a hot work site is to keep workers' body core temperature from rising above 100°F (38°C). Excessive heat gained by the human body must be offset by adequate periods of heat loss. The methods of reducing heat fall into these three categories:

- Engineering Controls
- Administrative Controls and Work Practices
- Personal protective clothing and equipment

Engineering Controls

Mine planning, ventilation, and air conditioning may reduce heat to acceptable levels. Proper planning will provide for conveniently available cool rest areas and allow workers rest time to cool off. When natural cooler air is not available, air conditioning becomes necessary.

Heat from the sun can be reduced by using canopies in many cases. Radiant heat from dryers and kilns can be controlled with shielding. Since heat gain in a worker's body is partially lost through evaporation, dry air moving past the body is helpful.

Automation and remote controls are effective measures where metabolic heat is a problem, especially in crowded areas. From 50 to 100 percent of the energy set free in blasting shows up in the form of heat. Skillful blasting procedures can reduce the amount of excessive heat.

In underground areas, ventilation is the best method of combating the effect of rock temperature.

The problem of hot ground water heating up underground mine air can be controlled by using covered ditches or insulated piping for a speedy transfer of hot water to the surface.

Administrative Controls and Work Practices

There can be a point, however, when engineering controls fail to prevent workers from suffering from heat stress. A combination of engineering controls and proper work practices is possibly the best solution.

Follow these work practices to help prevent heat stress:

- Increase workers' heat tolerance by increasing their physical fitness.
- Provide a work-rest regimen - frequent breaks and reasonably short work periods.
- Pace a task.
- Perform heavy tasks in cooler areas or at cooler times.
- Rotate personnel on hot jobs.
- Provide readily accessible cooler rest areas -- 50 to 60°F (10 to 15°C).
- Provide cool drinking water 50 to 60°F (10 to 15°C) near the workers.
- Encourage all workers to drink a cup of water every 15 to 20 minutes (some authorities recommend "mandatory" water breaks).
- Use extra salt at meals (not for persons on a

restricted salt diet by physician's orders).

- Avoid drinks with caffeine, alcohol, and large amounts of sugar.
- Drink lightly salted water (1 level tablespoon of salt per 15 quarts of water for general use). See treatments for certain disorders for alternate mix of salt and water.
- Caution against drinking extreme amounts of water; generally no more than 12 quarts over a 24-hour period.
- Wear sunblockers and proper protective clothing when working in the sun.

Clothing and Personal Protective Equipment

Ideally, clothing worn in hot environments should be loose fitting. At a mining site, however, loose clothing exposes the wearer to the hazard of being caught on or pulled into machinery, conveyors, and other moving parts.

Fabrics that allow some air movement through the weave and those that "wick" wetness away from the body are recommended. If perspiration remains in contact with the skin, it has a better chance of evaporating and cooling the body surface. If perspiration is allowed to run off the body quickly, less evaporation occurs.

Reflective clothing, which can vary from aprons and jackets to full body suits, can stop the skin from absorbing radiant heat. However, since most reflective clothing does not allow air exchange through the garment, the reduction of radiant heat must more than offset the corresponding loss in evaporative cooling. For this reason, reflective clothing should be worn as loosely as possible.

In situations where radiant heat is high, auxiliary cooling systems can be used under the reflective clothing.

Commercially available ice vests, though heavy, may accommodate as many as 72 ice packets, which are usually filled with water. Carbon dioxide (dry ice) can also be used as a coolant. The cooling offered by ice packets lasts only 2 to 4 hours at moderate to heavy heat loads, and frequent replacement is necessary. However, ice vests do not encumber the worker and thus permit maximum mobility. Cooling with ice is also relatively inexpensive. Studies showed that the wearer also experienced lower heart rate, lower core temperature, and reduced sweat loss when the vest was replenished regularly and used with regular rest periods.

Wetted clothing is another simple and inexpensive personal cooling technique. It is effective when reflective or other impermeable protective clothing is worn. The clothing may be wetted terry cloth coveralls or wetted two-piece, whole-body cotton suits. This approach to auxiliary cooling can be quite effective under conditions of high temperature and low humidity, where evaporation from the wetted garment is not restricted.

Water-cooled garments range from a hood, which cools only the head, to vests and “long johns,” which offer partial or complete body cooling. Use of this equipment requires a battery-driven circulating pump, liquid-ice coolant, and a container.

Although this system has the advantage of allowing wearer mobility, the weight of the components limits the amount of ice that can be carried and thus reduces the effective use time. The heat transfer rate in liquid cooling systems may limit their use to low-activity jobs; even in such jobs, their service time is only about 20 minutes per pound of cooling ice. To keep outside heat from melting the ice, an outer insulating jacket should be an integral part of these systems.

Circulating air is the most highly effective, as well as the most complicated, personal cooling system. By directing compressed air around the body from a supplied air system, both evaporative and convective cooling are improved. The greatest advantage occurs when circulating air is used with impermeable garments or double cotton overalls.

One type, used when respiratory protection is also necessary, forces exhaust air from a supplied-air hood ("bubble hood") around the neck and down inside an impermeable suit. The air then escapes through openings in the suit. There are three ways in which air can also be supplied directly to the suit without using a hood:

1. by a single inlet,
2. by a distribution tree, or
3. by a perforated vest.

In addition, a vortex tube can be used to reduce the temperature of circulating air. The cooled air from this tube can be introduced either under the clothing or into a bubble hood. The use of a vortex tube separates the air stream into a hot and cold stream;

these tubes can also be used to supply heat in cold climates.

Circulating air, however, is noisy and requires a constant source of compressed air supplied through an attached air hose.

One problem with this system is the limited mobility of workers whose suits are attached to an air hose. Another is that of getting air to the work area itself. These systems should therefore be used in work areas where workers are not required to move around much or to climb. Another concern with these systems is that they can lead to dehydration. The cool, dry air feels comfortable and the worker may not realize that it is important to drink liquids frequently.

Researchers have found significant differences in evaporative heat release among hard hats. At least one study has concluded that wearing personal protective equipment and self-contained breathing apparatus, under mine rescue operations, should be limited to no more than two hours.

Are there other recommended measures?
Other than the controls just described, management should consider:

- Acclimatization
- Education
- Medical surveillance

Acclimatization
Acclimatization is a long-term adjustment of an individual to a stress. Repeated exposure to heat stress can increase many workers' tolerance to heat. This is especially practical with underground miners.

Miners should be given enough time for adjustment to a hot work site where the WBGT exceeds 79°F (26°C). A recommended six-day acclimatization schedule calls for the miner to work in the hot work site for 50 percent of the time on the first work day, and an additional 10 percent of the time on each succeeding day.

Not all persons will become acclimatized on this schedule; there are remarkably heat-tolerant workers and others who require more time.

Day	Percent Exposure
1	50
2	60
3	70
4	80
5	90
6	100

Already acclimatized workers who return after nine or more consecutive calendar days away from work should undergo a similar, but less gradual, schedule:

Day	Percent Exposure
1	50
2	60
3	90
4	100

(See Appendix C "Heat Stress Guidelines for Work Limits.")

Education

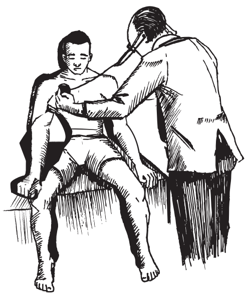
All workers, and supervisors in particular, need education in recognizing the conditions of a "hot" job, and should be provided heat stress training that includes information about:

- Worker risk
- Prevention
- Symptoms
- The importance of monitoring yourself and coworkers for symptoms
- Treatment
- Personal protective equipment

Key workers also must have training in first aid and treatment of heat-related illnesses. Acclimatization and education of new employees to heat stress should be conducted at the same time. During the initial stages of acclimatization, new miners should be warned against trying to keep up with active already-acclimatized miners.

Medical Surveillance

A program of medical surveillance can be set up for miners working in hot work sites. This entails medical examinations by a physician for all personnel who are to be assigned to hot jobs for the first time. The physician will examine the condition of the heart, blood vessels, kidneys, liver, glands of internal secretion, respiratory system, and the skin.



From these examinations, the physician can help select individuals able to work in hot jobs, or recommend that certain persons not be put in these conditions.

For instance, persons with no (or severely damaged) sweat glands should not work in extremely hot jobs.

The mining industry in South Africa, where many deep coal and diamond mines are found, has made a good deal of progress in reducing the incidence of severe heat stress through medical selection and acclimatization of miners.

An Australian mine requires unacclimatized workers to undergo a dehydration test (comparing body weight to determine loss of fluid) at the end of every work shift during their first seven days.

Reports and Records

The incidence of any heat-stress illness or injury must be reported. Such records are also useful for future heat stress studies.

APPENDIX A

The wet bulb globe temperature (WBGT) is measured with the help of a cluster of thermometers adapted to measure various work site temps:

- A dry bulb thermometer is used to measure the temperature of mine air to get an estimate of convective heat exchange in the mine work area.
- A wet bulb thermometer reading and its comparison with the dry-bulb thermometer reading is used as an estimate of evaporative heat exchange.
- A globe thermometer reading indicates the radiative heat coming from the surfaces around the work site.

The temperatures indicated by these three thermometers are used in a formula which produces the WBGT. If the WBGT exceeds 79°F (26°C), a work site is "hot."

APPENDIX B

Heat Index

% Relative Environmental Temperature in °Fahrenheit

Humidity	70	75	80	85	90	95	100	105	110	115	120
0%	64	69	73	78	83	87	91	95	99	103	107
10%	65	70	75	80	85	90	95	100	105	111	116
20%	66	72	77	82	87	93	99	105	112	120	130
30%	67	73	78	84	90	96	104	113	123	135	148
40%	68	74	79	86	93	101	110	123	137	151	
50%	69	75	81	88	96	107	120	135	150		
60%	70	76	82	90	100	114	132	149			
70%	71	77	85	93	106	124	144				
80%	71	78	86	97	113	136					
90%	71	79	88	102	122						
100%	72	80	91	108							

For example: ***A temperature of 90°F combined with a humidity reading of 90 percent can yield a heat index reading of 122°F. If full sun exposure is added to the temperature/humidity mix, the heat index can rise even higher.***

NOTE: Keep in mind the following cautionary guidelines for heat indexes:

94° to 104°F — Heat cramps or heat exhaustion is possible.
105° to 130°F — Heat cramps or heat exhaustion is likely; heat stroke is possible.
131°F or higher - Heat stroke is highly likely.

APPENDIX C

Heat Stress Guidelines for Work Limits

Discontinue Work If Any of the Following Occur

Heart Rate	• Sustained heart rate minus the individual's age is above 180 beats per minute. (Heart Rate - Age > 180) • Recovery heart rate at one minute after a peak work effort is greater than 100 beats per minute.
Body Core Temperature	• Greater than 101.3°F (38.5°C) for medically selected and acclimated workers. • Greater than 100.4°F (38.0°C) in unselected, unacclimatized workers.
Symptoms	• Sudden and severe fatigue, nausea, dizziness, or lightheadedness. • Profuse sweating is sustained over a couple of hours. • Workers appear disoriented or confused, or suffer inexplicable irritability, malaise, or flu-like symptoms. • Sweating stops and skin becomes hot and dry. Seek immediate emergency care with hospitalization. • Weight loss over a shift is greater than 1.5% of body weight.

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NOTES

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