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MARINER SAFETY RESEARCH INITIATIVE

Heat Stress

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INTRODUCTION

The principle concern for the thermal interaction between people and their work environment is the movement of heat to and from the person and the body's ability to respond appropriately to heat stress. When there is good balance in the heat flow with little physiological adjustment, the environment is generally considered comfortable and may enhance performance and reduce negative health consequences. When the balance is disturbed so that there is a significant physiological involvement, discomfort, health effects, and performance decrements may be more likely.

> Heat Stress is any combination of air temperature, thermal radiation, humidity, airflow, and workload that may stress the body as it attempts to regulate body temperature

Heat stress can add to the burden on the heart to increase the likelihood of fatigue, and it may lead to a heat-related disorder. In addition, increasing levels of heat stress may lead to increased frequency of accidents and overexertion injuries and decreases in quality and productivity (Chengalur *et al*., 2004). Operations with high air temperatures, radiant heat sources, high humidity, and direct physical contact with hot objects that require strenuous physical activities have a high potential for inducing heat stress in employees engaged in such operations. Also, operations conducted in hot conditions, especially those that require workers to wear some types of clothing or personal protective equipment, are more likely to cause heat stress among exposed personnel.

High temperature and humidity levels can lead to heat stress conditions that may have significant impacts on safety and productivity aboard ships and offshore installations. Many ships and offshore installations spaces contain environments with high heat and humidity. These include engineering spaces, galleys, sculleries, laundries, and weather decks in hot climates, etc. The level of heat stress may result in high levels of heat strain especially during periods of high physical workloads and depending on a crewmember's personal risk factors affecting their ability to tolerate heat stress and acclimatize to it.

Heat stress can lead to a number of illnesses, disabilities, and even death. Exposure to continued high temperatures leading to heat stress conditions can reduce work performance and morale and impair mental awareness, increasing the risk of workplace accidents, and ultimately compromising the readiness of the ship or offshore installation. Moreover, heat stress may directly impact manpower requirements aboard ships or offshore installations when heat exposures are high enough to require work/rest rotations.

TERMS/DEFINITIONS

Acclimatization: A gradual physiological adaptation that improves an individual's ability to tolerate heat stress, and requires physical activity under heat-stress conditions similar to those anticipated for the work.

Basal Metabolism: The smallest amount of energy needed to support the base or vital functions of an organism at complete rest.

Conduction: A direct contact between the person and a solid surface in the workplace, contact may occur through some clothing; conductive heat gain or loss that affects the whole body. The direction and magnitude of the heat transfer depends on the temperature difference between the skin and the solid surface.

Convection: The net flow of heat between the skin and air, some of which may occur through clothing. The direction of the heat flow (gain or loss to the body) depends on the air temperature with respect to skin temperature. If air temperature is higher, it is a gain; conversely, if air temperature is lower, it is a heat loss.

Dry bulb (DB) temperature: A measure of a thermal sensor, such as an ordinary mercury-in-glass thermometer, that is shielded from direct radiant energy sources.

Environmental Risk Factors for Heat Illness: Working conditions that create the possibility that heat illness might occur.

Evaporative cooling: The loss of heat due to the evaporation of sweat from the skin, this is always a negative value. Evaporative cooling may be affected by certain factors; higher humidity will lower the evaporative cooling effect, while increased air speed will aid evaporative cooling up to a certain point. Air speed less than 3 m/sec and air temperature less than 40°C will aid the evaporative cooling effect.

Globe temperature: The temperature inside a blackened, hollow, thin copper globe.

Heat Related Illness: A serious medical condition resulting from the body's inability to cope with a particular heat load, and includes heat cramps, heat exhaustion, heat syncope and heat stroke.

Heat stress: Any combination of air temperature, thermal radiation, humidity, airflow, and workload that may stress the body as it attempts to regulate body temperature.

Metabolic heat: A by-product of the body's activity, or heat produced due to metabolic function.

Metabolic rate: Largely driven by the amount of external work performed. The greater the oxygen consumption associated with the effort, the greater the rate of metabolic heat generation.

Personal Risk Factors for Heat Illness: Risk factors such as an individual's age, degree of acclimatization, health, water consumption, alcohol consumption, caffeine consumption, and use of prescription medications that affect the body's water retention or other physiological responses to heat.

Radiation: The net rate of heat flow between the person and the solid surroundings caused by infrared radiation. The greater the difference, the higher the rate of heat transfer. Clothing insulation will reduce the rate of heat transfer.
Resting Metabolism: The metabolism of a person who is at complete rest, whether in the standing or sitting position.

Storage rate: The cumulative effect of the indicator of risk for hyperthermia (positive value) during heat stress or hypothermia (negative value) during cold stress and other factors. When the storage rate is near zero, there is thermal equilibrium and the risk of excessive heat or cold stress is low.

Wet bulb (WB) temperature: A temperature measured by exposing a wet sensor, such as a wet cotton wick fitted over the bulb of a thermometer, to the effects of evaporation and convection.

Work metabolism any metabolic requirements above resting metabolism.

DISCUSSION

How the Body Handles Heat

The potential for heat related illness and decreased crew performance from work in hot/humid environments depend not only on the environment, but also on physiological factors that lead to a range of susceptibilities depending on the crewmember's level of acclimatization. Therefore, professional judgment is of particular importance in assessing the level of heat stress (environmental risk factors) and physiological heat strain (personal risk factors) to adequately provide guidance for protecting healthy workers. Due consideration of personal risk factors, environmental risk factors, and the type of work required (occupational risk factors) should be given to facilitate crewmembers successfully completing their job (ACGIH, 2009). Assessment of heat stress and strain can be used for evaluating the risk to worker safety, health, and performance.

Maintaining the core body temperature close to 37°C (98.6°F) (average normal human body temperature) is the primary task of the human thermoregulatory system, in hot (or cold) environments. Increases in core temperature of 1°C (1.8°F) can affect personnel comfort, increases in core temperature of 2°C (3.6°F) can severely affect body functions and task performance, while increases of 4°C (7.2°F) can cause bodily damage and potentially be lethal (Kroemer *et al.*, 2001, Talty, 1988).

At the skin, the human temperature-regulation system should keep temperatures below the 40°C (104°F) in its outer layers, but there are major differences from region to region. For example, the toes may be at 25°C (77°F), the legs and upper arms at 31°C (87.8°F), and the forehead at 34°C (93.2°F). Combined, these *approximate* temperatures provide for human comfort (Youle, 1990).

Thermal stress can be viewed from a whole body or local skin surface perspective (Chengalur *et al.*, 2004). Whole body thermal stress is typically measured and attributed to potential adverse whole body health risk and decreased performance. Local skin thermal stress focuses on local tissue temperature. This Module will focus primarily on whole body thermal stress.

Considering whole body heat exchange, normal human body functions generate heat. These functions include basal and resting metabolism which support basic life functions and the added metabolic (work metabolism) activity of the muscles performing work. Therefore, heat stress is largely the physiologic challenge of removing the heat from the body. Heat balance, exchange, and the amount of heat stored (S) by the human body (core temperature) is predominately dependent on:

- Metabolic rate (M)
- Convection (C)
- Conduction (K)
- Radiation (R)
- Evaporation (E)

The heat balance equation is commonly expressed as: $S = M \pm C \pm K \pm R - E$

SAFETY CONSIDERATIONS

Heat strain becomes excessive when the body's ability to adjust to the heat stress is over-taxed, resulting in increased core body temperature. This condition can produce fatigue, rash, cramps (particularly in the extremities and abdomen), profuse sweating, dehydration, tingling in the extremities, rapid heartbeat, severe headache, nausea, vomiting, fainting, and poor physical and mental performance in affected crewmembers. As body temperature continues to rise (due to prolonged exposure), heat related illnesses (e.g., heat exhaustion or heat stroke) may occur resulting in severe impairment of the body's temperature regulating ability and possible death. Recognizing personnel heat strain symptoms and obtaining prompt medical attention for affected persons should be considered primary concern.

Certain safety problems are common to hot environments. Heat tends to promote accidents due to the slippery palms, dizziness, the fogging of safety glasses, etc. Wherever there are hot surfaces, steam, and so on, the possibility of contact burns also exists (NIOSH, 1986).

Aside from these clear dangers, the frequency of accidents in general seems to be higher in hot environments compare to more moderate conditions. One reason is likely that working in hot environments lowers mental attentiveness and physical routine of an individual. Increased body temperature and discomfort can also promote irritability, anger, and other emotional states that sometimes cause people to overlook procedures, or to divert attention from hazardous tasks (NIOSH, 1986).

Heat Stress Factors

The following factors may affect the level of heat stress:

- Temperature
- Humidity
- Air speed
- Workload
- Clothing
- Radiant heat

For specific recommendations for the above occupational factors, please refer to ANSI (1995), ASHRAE (1997), Chengalur *et al*. (2004), ABS HAB (2013, 2012, and 2012).

Heat stress can lead to heat strain and is a function of the working environment, the type of work being performed, and the personnel performing the work. The heat strain susceptibility of offshore personnel depends on a number of individual risk factors including, but not limited to (Ramphal, 1996):

- Level of acclimatization
- Age
- Clothing and personal protective equipment
- The presence of chronic illness (e.g. Diabetes or Hypertension)
- Dehydration
- Obesity
- Degree of physical fitness
- Drug/alcohol use
- A history of previously documented heat-related illness
- The use of certain medications (e.g. Diuretics)

Measurement of the Thermal Environment

To accurately predict the level of heat stress onboard ships and offshore installations, the thermal environment should be measured, monitored, and controlled.

HEAT STRESS MANAGEMENT

The effects of heat exposure are sometimes regarded as an only transient discomfort, and that is considered low on the list of issues to be tackled by designers. Significant heat exposures, however, can increase fatigue, decrease comfort, reduce productivity and efficiency, and reduce the morale of workers. Heat stress conditions can extensively impact mental attentiveness, even before the ability to perform job tasks is impaired. More significantly, uncontrolled heat exposure may lead to serious medical conditions and less than optimal performance.

Work-rest routines, based on job activity, ambient temperature, humidity, and radiant energy are accessible to protect people while working in hot environments. These limits are published in OPNAVINST 5100.19 series, Chapter B2, Heat Stress Program (Naval Safety Center, 2001), and are protective for healthy workers with adequate rest and hydration. Work periods may need to be shortened for people wearing protective clothing, while using respirators, with some medical conditions, or when taking certain medications. Other similar sources are available as well (ACGIH, 2009, Chengular, *et al.*, 2004, Bernard, 2002)

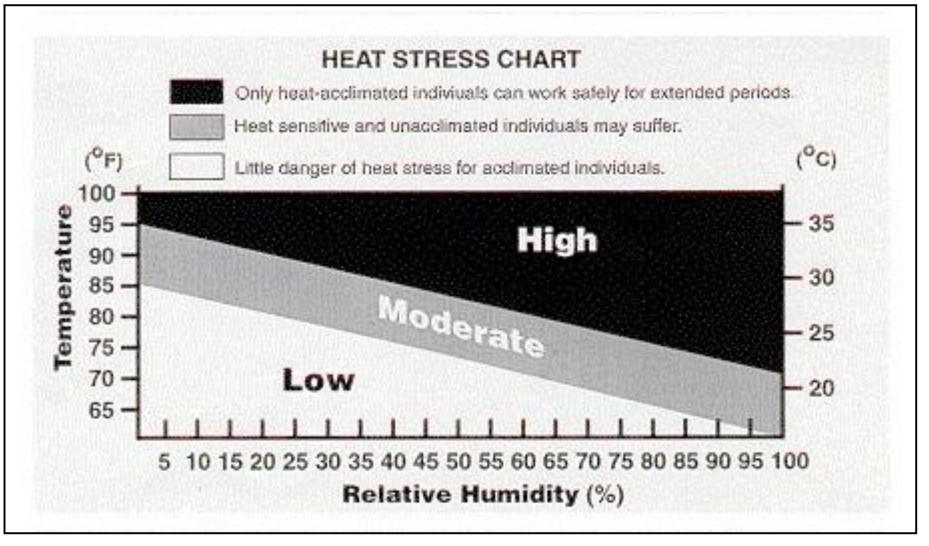
Because heat stress is very common in many workplaces and a common experience among employees and supervisors, the risks of work under conditions of heat stress are often underappreciated. Heat stress is present when the combination of environment, personal risk factors, work demands, and clothing requirements exceeds the effective Wet Bulb-Globe temperature (WBGT) and Apparent Temperature values (in other words, in the potential health risk zone). While there is no statutory requirement, as there is for noise, a heat stress management program should be instituted for those working in the potential health risk zone as a prudent course of action. Guidance for establishing heat stress management programs can be found in most textbooks on ergonomics, industrial hygiene, and in the ACGIH (2001, 2009) publication for heat stress and strain documentation.

Preparing for the Heat

One of the best ways to reduce heat stress on workers is to reduce heat in the workplace. There are, however, some work environments where heat is difficult to control, such as where furnaces or sources of steam or hot water are present, or where the workplace itself is out of door in hot climates.

Humans are somewhat able to adjust to ambient heat (acclimatization). This adjustment, under normal circumstances, usually takes about 5 to 7 days during which time the body undergoes a series of physical changes that renders continued exposure to heat to be more endurable.

On initial exposure to work in a hot environment, body temperature, pulse rate, and general discomfort will be higher. With successive daily exposure, these responses gradually decrease, while sweat rate will increase and the salt content of sweat decreases. When the body becomes acclimated to heat, people find it possible to perform work with reduced strain and distress.



Gradual exposure to heat provides the body time to acclimate to higher temperatures. Heat disorders in general are more likely to occur among people who have not been given time to acclimate to working in heat or among people who have been away from hot environments and have become accustomed to lower temperatures. Hot weather conditions of the summer are likely to affect people that are not acclimated to heat. Likewise, workers who return to work after a being off schedule, on vacation, or after being off for an extended injury/illness may be affected by the heat in the work environment. Whenever such circumstances occur, the crewmember should be gradually reacclimatized to the hot environment (NIOSH, 1986). This is shown in the table, below and right, you can see that as the temperature goes up the chance of an individual who has not been acclimatized being injured due to heat stress increases. Showing that in extremely hot environments or in high humidity it is only safe for heat acclimatized individuals to work for prolonged periods of time.

General Controls

When work takes place in the hot/humid environment or compartment, there is a set of measures that should be implemented independent of the specific exposure conditions (Bernard 2002, ACGIH 2009). These are general controls and include heat stress training, heat stress hygiene practices, surveillance, and medical management. As with any other workplace hazard, crewmembers working in those locations should have an adequate amount of training to understand the hazards and what to do to protect themselves and others. The training should be part of the vessel/offshore installation health and safety training.

Design

Inspections conducted aboard various vessels and offshore installations may identify problems that may cause a heat stress environment. Vessel/offshore installation heat stress conditions, in general, are associated with the following:

- Engine, machinery, and other engineering spaces
- Ventilation system deficiencies, including poorly maintained ventilation systems and unauthorized alterations to existing ventilation systems
- Lack of ventilation maintenance, such as missing or mutilated ductwork, clogged exhaust screens, closed or partially closed dampers, dirty ventilation ducting and inoperative fan motors and controllers
- Steam, water, and hot air leaks
- Boiler air casing leaks (e.g. access panels)
- Missing or damaged insulation on steam piping, valves, and machinery
- Laundry rooms, galleys, sculleries

Initial acquisition cost, weight, and space constraints may result in shipboard and offshore installation ventilation system designs to be based on the highest temperature limit recommended, rather than optimal comfort levels. When a physical environment is not designed for suitable thermal control, creating a heat stress condition for vessel/offshore installation personnel, a suitable work-rest cycle can be implemented (though not ensuring favorable performance or increased morale).

Heat stress conditions that are sufficiently high to require work-rest rotation can impact staffing requirements on vessels/offshore installations. If these high heat stress levels are not addressed by increased staffing, then performance, safety, and morale may suffer.

In engineering spaces, temperatures can be in the range of 33°C (92°F) to 49°C (120°F), with 60% to 90% relative humidity. Based on heat related illness prevention guidance, at the higher temperatures, recommended exposure times in these spaces may be limited to about half an hour with an hour's recovery for each exposure period (ACGIH, 2009). This effectively requires additional manpower. Engine and equipment rooms generate so much heat that it is neither practical nor feasible to fully control temperatures within the entire space. Therefore, high performing ventilation systems should be designed into the vessel or offshore installation and portable (and personal) cooling systems should be considered. Excessive moisture is also encountered in these rooms. Steam and water leaks are frequent sources of increased water vapor, and should be quickly repaired.

Ventilation may be a problem due to the cooking and cleaning processes in galleys, sculleries, and laundries aboard vessels/offshore installations. Poorly designed or maintained ventilation systems can result in exposure to hot and humid air, inadequate fresh air supply, and inadequate exhaust of hot, humid air.

Vessel/offshore installation personnel on weather decks generally do not have protective cover from sunlight and high temperatures. On weather decks, ambient temperatures combined with radiant solar heat and high humidity levels can reduce exposure times, again resulting in the need for additional manpower.

EFFECTS OF HEAT STRESS

Heat stress is the total heat load on the body arising externally from exposure to heat in the workplace, and internally from metabolic heat production associated with physical activity. Crewmembers who perform demanding work, who work in hot environments or who wear protective clothing may be at risk for heat-related illnesses.

Heat-related illnesses include prickly heat, heat syncope, heat cramps, heat exhaustion and heat stroke. They are physiologic disturbances that may result when employees perform high levels of exertion, particularly in hot, humid environments or when the body's thermoregulatory mechanism has been disrupted. The body's thermoregulatory mechanism controls body temperature through evaporative cooling increased cardiac output and blood flow to the skin, and increased respiration.

A range of symptoms of varying severity are associated with heat stress. As with many medical effects, risk varies with a range of personal and environmental factors. These include individual tolerance, personal acclimatization, fatigue, and prior activities that affect water balance.

Potential Medical Effects

Heat Stroke - Heat stroke is the most serious of health problems associated with working in hot environments. It occurs, possibly with little warning, when the body's temperature regulatory system fails and sweating becomes inadequate. A heat stroke victim's skin is hot, usually dry, red or spotted. Body temperature may reach 105˚F or higher, and the victim is mentally confused, delirious, perhaps in convulsions, or unconscious. Unless the victim receives quick and appropriate first aid treatment and immediate hospitalization, death can occur.

Any person with signs or symptoms of heat stroke requires immediate hospitalization. However, first aid should be immediately administered. This includes removing the victim to a cool area, thoroughly soaking the clothing with water, and vigorously fanning the body to increase cooling. Further treatment at a medical facility should be directed to the continuation of the cooling process and the monitoring of complications which often accompany the heat stroke. Early treatment of heat stroke offer means of preventing permanent brain damage or death.

Heat Exhaustion - Heat exhaustion is caused by the extensive loss of fluid from sweating, sometimes with a large loss of salt. A person suffering from heat exhaustion still continues to sweat, and experiences weakness or fatigue, giddiness, nausea, or headache. Vomiting or loss of consciousness can also occur. The skin can feel clammy and moist; the sufferer's complexion can appear pale or flushed, while the body temperature is normal or slightly elevated.

Treatment involves having the crewmember rest in a cool place and drinks plenty of fluids, and mild cases of heat exhaustion usually recover quickly. With severe cases may require several days of extended care. There are no known permanent effects of heat exhaustion.

Heat Cramps - These are painful and severe cramps, affecting muscles of the arms, legs, or abdomen, but tired muscles (those used in performing the work) are usually the ones most susceptible to cramps. Cramps may occur during or after work hours. Heat cramps are typically caused when performing physical labor in a hot environment. Cramps are attributed to an electrolyte imbalance caused by sweating. Cramps can be caused by either too much, or too little, salt (Kroemer *et al*., 2001). Thirst alone should not be relied on as a gauge to the need for water, and water should be taken every 15 to 20 minutes in hot environments. Commercially available carbohydrate-electrolyte replacement liquids may also be considered for rehydration, though caloric and sugar intake should be considered.

Heat Collapse (fainting) - A crewmember who is not accustomed to hot environments (un-acclimatized) and who stands erect and relatively immobile in the heat may faint. Enlarged blood vessels in the skin and in the lower part of the body (the body's attempts to control internal temperature) allow blood to pool there, rather than return to the heart to be pumped to the brain. The onset of heat collapse is rapid and unpredictable. Upon lying down, the worker should soon recover. By moving around, and thereby preventing blood from pooling, the crewmember may prevent further fainting.

Heat Rash - Heat rash (also known as prickly heat) comes about in hot, humid environments where sweat is not readily removed from the surface of the skin by evaporation, and the skin remains wet most of the time. When that happens, sweat ducts become plugged, and a skin rash can soon appear. When the rash is extensive, or when it is complicated by infection, heat rash can be quite uncomfortable, reduce a worker's performance, and in some cases, lead to more serious medical conditions. Generally, heat rash dissipates when the affected person returns to a cool environment. Hygiene, clothing, and treatment can influence the presence and severity of heat rash.

Heat Fatigue - Transient heat fatigue is a temporary state of discomfort and mental strain arising from prolonged heat exposure. People unaccustomed to the heat are predominantly susceptible and can suffer a decline in task performance, coordination, alertness, and vigilance. It is important to note, that de-acclimatization of people can occur during times they are off schedule, since de-acclimatization can occur over a period of a couple weeks if the crewmember is not working in hot environments when they are off schedule. The severity of transient heat fatigue can be lessened by a period of gradual adjustment to the hot environment.

Increased cardiac output to perform the same amount of work in hot environments due to additional blood flow shunted to skin for cooling, resulting in reduced physical work capacity of the crewmember. This is more pronounced in un-acclimatized individuals.

CAUTION: Persons with heart problems have other medical conditions, or those on a low sodium diet who work in hot environments should consult a physician about what to do under these conditions. Also, these recommendations are to be considered a minimal overview of heat related stress, strain, and illness.

SUMMARY

Heat stress conditions have significant impacts on safety and productivity aboard vessels and offshore installations. Heat stress can lead to heat-related illnesses, disabilities, and even death. Sustained high temperatures leading to heat stress conditions can lower work performance and morale and impair mental alertness, increasing the risk of workplace accidents, and ultimately compromising the operation of the vessel/offshore installation. Moreover, heat stress may directly impact manpower requirements aboard ship when heat exposures are high enough to require work-rest rotations.

Designing for proper temperature control and utilizing better technology to avoid or reduce heat stress conditions aboard ship or offshore installation may result in crewmembers performing their duties in a comfortable and efficient manner. Designs that control or eliminate heat stress conditions will reduce the need for additional manpower (thereby reducing costs) and may improve shipboard safety, productivity, and quality of life.

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