Keep cool and stay fresh longer

A hot topic: Heat stress in protective suits

Under normal conditions, the human body has a perfectly tuned climate-control system. Inside a chemical protective suit this system is put under pressure – and in the worst case the protective shell itself can become a risk. What can we do to reduce the stress for the wearer?

A tropical rainforest is nothing in comparison

Temperatures well above 30 degrees and a humidity that does not provide cooling, but instead lingers on the skin like an additional warm envelope. This is what it feels like to be inside a protective suit without a cooling system, even after a very short period time, an industry worker describes his experience in an internet forum.

In Germany, the directive DGUV-BGR 189 on the use of protective clothing stipulates that an insulated chemical protective suit (CPS) should not be worn for more than 30 minutes at a time. After that, the wearer must take off the CPS and take a break from any physical labour for up to 90 minutes. Even where light work is performed the suit should not be used more than twice per shift. The US-American Occupational Safety and Health Administration (OSHA) even recommends a reduction of the time spent working in a protective suit to 20 minutes followed by a 40-minute break where medium-heavy physical work is carried out at temperatures of 26 °C or more[1]. Equally strict rules apply worldwide[2] – the main reason being the stress caused by the ambient atmosphere.

Several guidelines provide upper limits for the body temperature of persons while working. According to the World Health Organisation (WHO) <39 °C Trectal should not be exceeded; the American Conference of Governmental Industrial Hygienists defines ~38 °C Trectal as the upper limit.[3]

Twenty minutes can be a very long time when performing strenuous tasks such as cleaning a tank whilst wearing a protection equipment that weighs up to 30 kilograms. However, twenty minutes are not much when complex maintenance or cleaning work must be carried out. In practical application shorter deployment times are an enormous challenge for planners and safety officers who have to time the individual work steps exactly to comply with the defined rest periods. It is therefore very important in terms of organisational and economic aspects how we can ease the stress of wearing protective suits and increase deployment times at the same time.

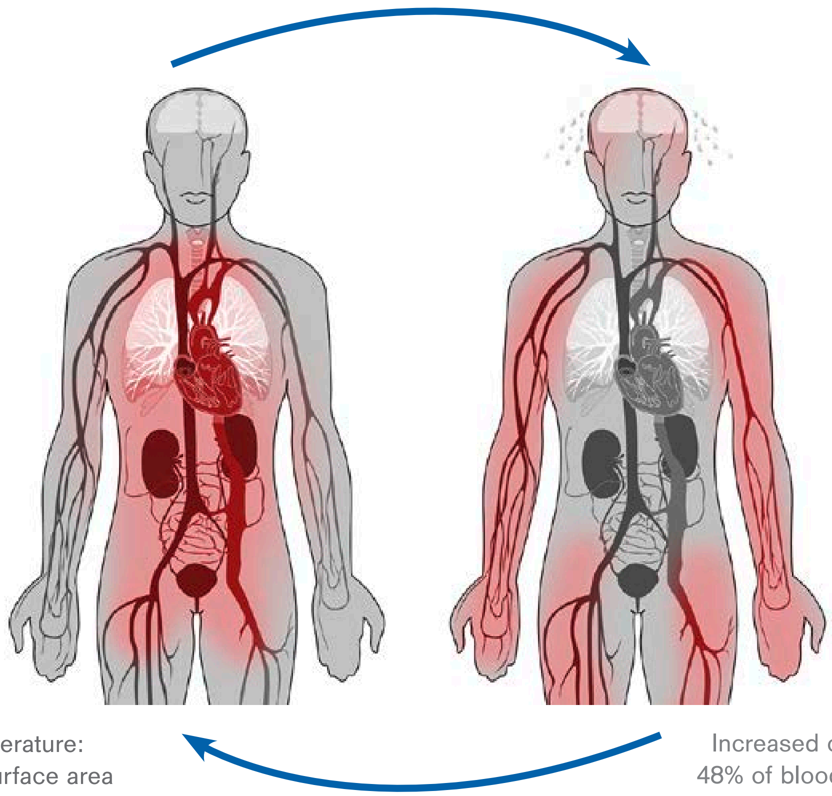
A natural thermal power plant

The operating temperature of the human body is 37 °Celsius and a complex regulatory circuit is responsible for keeping the core of the body stable. The core of the body are the internal organs in the head and torso, like the heart, liver, kidneys, etc. The core temperature is influenced both by external factors such as ambient temperature or radiation heat and internal factors. The latter, apart from fever as the body's reaction to inflammation, mainly includes internal heating. Internal heating is normally caused simply by muscle movement – e.g. during exercise or the body burns food to provide the required energy. On average however, the human body spends only about 20 percent of this energy – the remaining 80 percent are converted into heat and released into the ambient atmosphere.

The resting temperature of the head and torso is considerably higher than that of the extremities. This is where the core temperature of the body is measured. Cooling measures to bring down the body temperature work best on the head and back.

THERMOREGULATION OF THE BODY

1. Heat sensors report a temperature increase to the brain.
2. The hypothalamus receives information from the core of the body and the periphery.
3. The hypothalamus sends signals to the cardiovascular system and the perspiratory glands.
4. The blood flow through the capillaries under the skin increases, transporting heat from the interior of the body to the surface. This causes the skin to redden.
5. More than 2 million sweat glands transport water to the surface of the skin creating cooling from evaporation.



Source: Dräger

The hypothalamus in the brain is the control centre for thermoregulation. This is where the information from the entire body is received and processed and where signals for creating heat (for example through involuntary muscle work = shivering) or providing cooling (for example through sweating) are sent. When the core temperature rises, the body transports the warmth from inside the body to the surface. This occurs through the blood. The fine vessels inside the skin (the capillaries) are opened and blood circulation increases to eight to twelve times the normal circulation level. This can be recognised from the fact that the skin reddens and the temperature in the arms and legs increases.

Less sweat – more heat

There are several ways the human body can release heat into the atmosphere:

Radiation

If the surface temperature of the body is higher than the surrounding atmosphere, the difference can be compensated by radiation, among other things. In reverse, the body absorbs heat radiation if the temperature of the surrounding walls is higher than 37 °C, which can be the case in workplaces in the metalworking industry. At a minimum ambient temperature of 16 °C a person of average height with a body surface of two m^2 creates a heat flow of 120 Watts while resting. During periods of physical activity this value can increase to 300 W and more.

Convection

About a third of the body heat is released through natural air circulation (convection). Warm air rises and cold air sinks – this mechanism alone is responsible for a natural airflow around the body. This airflow can be increased by technical means, for example ventilation. Convection is also the reason we feel the cold more when it is windy.

Evaporation (Sweating)

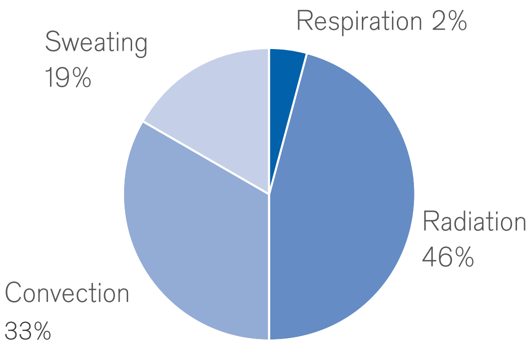
More than two million sweat glands are distributed all over the body. Most of them are on the head protecting the brain, which is particularly sensitive to temperature. When we sweat, the heat is transported to the surface of the body where it diffuses through the skin. It evaporates on the surface and provides very effective cooling: A sweat rate of one litre of water per hour equals a cooling capacity of 674W. The higher the temperature of the skin and the lower the water content of the ambient air, the greater the cooling effect. If the ambient humidity is very high, which is the case in uncooled chemical protective suits, this cooling principle will not work.

Respiration

Inside the lungs, the dry and cool air that is breathed in is humidified and warms up. Breathing out, heat is emitted. However, the cooling effect is very limited.

Almost half the heat is dissipated through radiation

Heat dissipation of the body at an ambient temperature of 20 °C while resting



Source: Dräger

If the ambient temperature exceeds 37 °C, the heat can no longer be released by radiation and convection but only by sweating. In very windy conditions the proportion of convection increases and during periods of physical activity we sweat more.

THERMAL COMFORT: AN INDIVIDUAL MATTER

Our performance and well-being are closely linked to a balanced heat production and heat dissipation ratio, a factor that – both subjectively and depending on the situation – can differ greatly. The body for example, is very good at dealing with major physical stress in terms of thermal factors. A total of five factors affect our thermal balance[4]:

1. Convection, depending on air temperature and air movement (ventilation)
2. Radiation, depending on skin temperature (unclothed or surface temperature of the clothing worn on the body)
3. Evaporation, depending on humidity of the immediate surrounding area
4. Clothing of the wearer (heat insulation, evaporation ability)
5. Metabolic heat generated by physical activity.

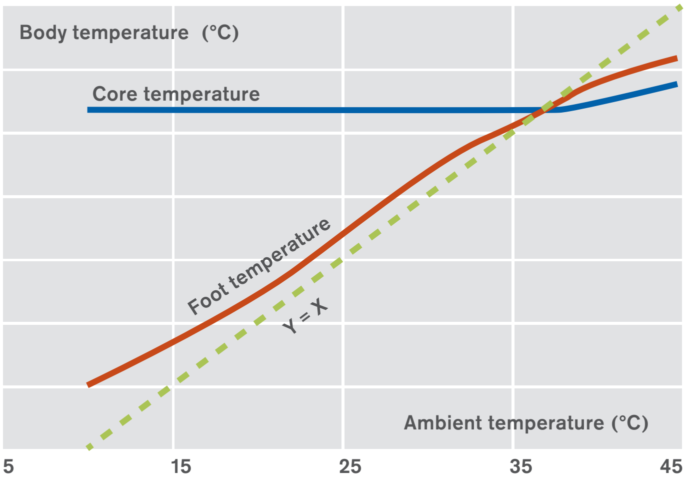
The US-American Occupational Safety & Health Administration (OSHA) defines >Heat Stress< as the net heat stress resulting from the combination of metabolic heat, environmental factors and clothing that a worker is subjected to.[5]

If heat production and heat dissipation become unbalanced for a longer period of time and the body is not able to release enough heat, the core body temperature rises, a process known as hyperthermia. In industries and occupations where great heat stress is part of the everyday working life, hyperthermia is a serious problem. Almost every second fatal work accident during firefighting operations can be attributed to heart failure caused by physiological stress and exhaustion[6].

Also in the areas of mining, heavy industry and the military many studies concern themselves with the effects of heat stress. There is a proven negative correlation between ambient temperature and mental performance. Job performance is measurably reduced starting at temperatures as low as 22 °C. From 34° C onward mental performance goes down by 25 percent.

Stable temperatures in the core of the body

As the ambient temperature increases, the temperature in the periphery of the body rises first. When approx. 37 °C are reached – here measured at the foot – the core temperature of the body reacts as well.



Source: Dräger

When is this really dangerous?

As the core temperature rises, muscular performance decreases. This also applies to the heart's pumping capacity. The body tries to compensate this by increasing the heart rate. In addition, sweat production is increased.

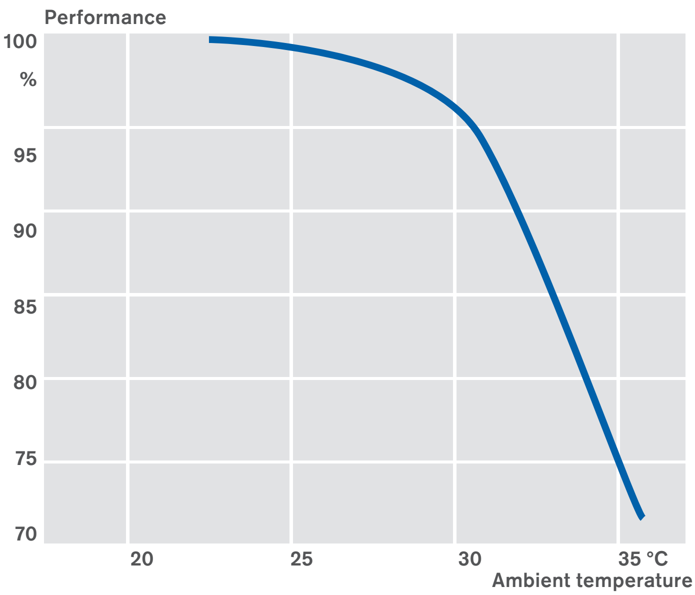
The body dehydrates and loses electrolytes. An increase of the core body temperature by just one degree Celsius will impair mental functions and cause disorientation, delirium or unconsciousness. Hearing performance is reduced measurably. From 37.9 °C motor skills and motor control will deteriorate significantly and the ability to react is diminished. From 38.3 °C mental functions are noticeably affected. Temperatures above 39.5 – 40 °C cause severe stress to the cardiovascular system. If the body is unable to cool down and the temperature reaches 42 °C the body's proteins start to dissolve.[7]

When the body is no longer able to limit temperatures itself, things get dangerous. Heat stress can lead to serious diseases or even cause sudden heath-induced death.

In protective suits, the strict limitations on how long the suit may be worn normally ensure that risks such as heat stroke, heat collapse or heat cramps are avoided. Depending on climatic conditions, the person's physical condition and the intake of fluids, however, these risks must not be disregarded. A factor workers have to face in many operations involving chemical protective suits is heat exhaustion (prostration). The extent to which this occurs depends on the individual condition of the wearer.

Heat reduces mental performance

As ambient temperatures rise, reaction times and sensomotoric coordination become significantly impaired.



Quelle: Dräger

Thus not only regular physiological exercise to maintain a high level of fitness but also learning how to assess one's own individual thermal situation are very important for workers to be able to recognise possible stress limits in time.

Heat exhaustion

A lack of fluids and electrolytes thickens the blood and impairs the body's ability to transport heat to the outside atmosphere. In addition, less and less fluid is available to provide cooling from evaporation. Heat exhaustion can quickly turn into a heat stroke. This is why it is very important to react at the first sign of symptoms!

Symptoms:

Pale, cool and damp skin, increased body temperature, headache, dizziness, quick pulse, low blood pressure, quick, shallow breathing, nausea and dysfunction of the central nervous system.

Heat stroke

A core body temperature above 40 °C for a longer period of time paired with a significant loss of water and electrolytes can cause severe brain malfunction. Only people in very good physical condition, like marathon runners, are able to cope with higher core body temperatures over limited periods of time.

Symptoms:

Severely reddened and dry skin, core body temperature above 40 °C, rapid heartbeat, headache, dizziness, confusion, and unconsciousness.

Heat collapse

Reduction of blood volume due to heat-related lack of electrolytes and dehydration.

Symptoms:

Core body temperature between 38 and 39 °C, low blood pressure, dizziness or fainting.

Heat cramps

Muscles develop cramps due to large amounts of liquid consumed during great heat without compensation for the loss of salts, particularly magnesium.

Symptoms:

Painful muscle cramps in extremities and stomach, damp cool skin, loss of appetite and nausea

First Aid

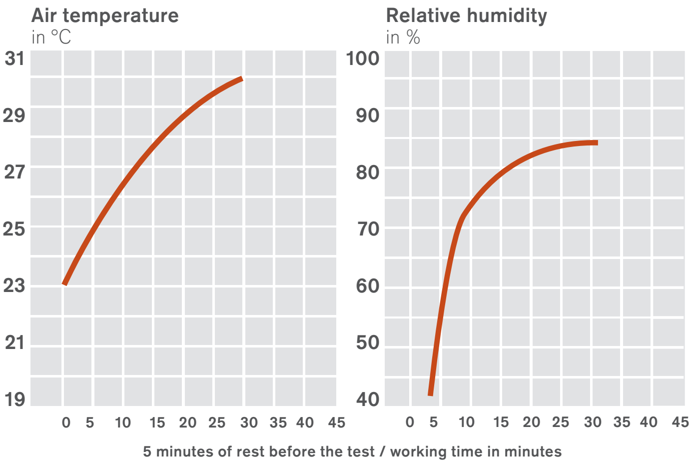
The first response to all heat-related illnesses should be to place the affected person in the shade or a cooler environment and provide fluids (cold water). Fanning air and applying cool compresses help speed up the cooling process. In the event of heat exhaustion or if there are signs of heat stroke medical assistance is essential!

Danger in a suit

What makes operations in protective suits so tricky? First of all, they are heavy: The full equipment consisting of suit, head piece, boots, gloves and breathing apparatus can burden its wearer with a weight of up to 30 kilograms. During strenuous operations like this the metabolic rate increases to a point where the body produces large amounts of heat. Another reason is the humid and hot climate inside the suit. The temperature inside the suit rises rapidly and the wearer starts sweating, increasing the humidity in the suit.

Protective suits quickly develop an uncomfortable, warm and humid climate

During tests, test persons walked on a treadmill wearing a chemical protective suit. The test persons simulated moderate labour at a speed of 3.5 km/h and on an incline of 1.75%. During the test, continuous measurements of the temperature and humidity inside the CPS were taken.



Source: Dräger

The insulation function of the chemical protective suit intensifies the effect. A type 1 suit – depending on the degree of protection – remains tightly sealed for up to 480 minutes and protects the wearer from hazardous gases, vapours, fluids, and particles. Materials especially developed for this purpose, such as Symex, Tychem®F, Umex, Zytron®500 or D-Mex TM® make sure that nothing gets inside the suit – but this also means that nothing can get out. Heat can no longer be released by radiation or convection and the cooling that is provided through the evaporation of sweat also becomes increasingly reduced due to the rising humidity inside the suit.

In an experiment, Jeffrey M. Paull and Frank S. Rosental were able to show just how much: The two American scientists measured the heart rates of two groups of workers at a landfill – one without protective suits, the other one equipped with hooded PVC-Tyvec® suits including rubber boots, gloves and full respiratory protection with two compressed air cylinders (SCBAs). The result: The group wearing the chemical protective suits showed significantly higher values. On average, the stress measured in this group was so high that it would correspond to a WBGT index[8] increase of the environment of 6 – 11 degrees.[9]

This is why the maximum duration a protective suit may be worn is usually strictly limited. In Germany, for example, work carried out wearing a type 1 chemical protective suit must not exceed 30 minutes. The regulations normally also include precise rules regarding breaks and recovery times as well as the number of assignments per shift. Improving the suit's ability to release heat by means of technical cooling concepts thus not only results in a more comfortable working environment but also reduces health risks, helps increase performance and may even increase the length of individual assignments. Aside from the health and safety aspects, these are thus also obvious economical arguments for providing effective cooling!

Providing a comfortable climate

Technical cooling is provided with the goal of supporting the heat release capabilities. At the same time, it must be guaranteed that the suit's safety is not impaired and the mobility of the wearer is affected as little as possible. One of the most important factors is the weight of the additionally required equipment.

More comfort through cooling – what are the options?

Pre-cooled elements

The suit or a vest that is worn under the suit is fitted with cooling elements that take up heat energy as they melt, the most basic version uses ice packs with frozen salt water. Alternative cooling elements are filled with a gel that has a particularly high heat storage coefficient. However, they must also be cooled beforehand in a fridge or chest freezer.

In order to be effective, the cooling elements must be placed as close to the body as possible (radiation) or supported by an additional ventilation technique (convection). The duration and intensity of the cooling effect depend on the amount of packs used. However, it should be noted that the cooling packs make the equipment even heavier. In addition, pre-frozen cooling elements have an immediate cooling effect. At the start of work contact with these elements may feel unpleasant and even carry a risk of hypothermia and frostbite. Experts therefore recommend wearing a suitable additional absorbent layer under the suit.

The phase-change principle

Cooling elements can also be filled with so-called phase change materials (PCM). These are special salts or paraffins with a low melting point. PCM elements are able to absorb large amounts of heat even when the temperature in the suit is relatively low. At a skin temperature of 28 °C the elements begin absorbing heat and the material liquidises. This can lower the temperature in the protective suit by 3 to 4 °C. However, the cooling effect begins prior to the assignment and becomes less effective after a while. Stored at 22 °C, the PCM elements solidify and are ready for use again after 30 minutes to max. four hours (depending on manufacturer).

Ventilation

This is the most effective, albeit technically complex solution: A mobile or stationary air supply from compressed air cylinders, a compressor or a stationary compressed-air line provides air to the suit and the ventilation supports the convection and evaporation cooling of the body by means of increased condensation.

In practice, the principle of ventilation is realised by means of several different concepts:

1. Ventilation of the whole suit

Integrated hoses provide an airflow to the arms and legs. The wearer breathes directly from the suit. The air is supplied from a stationary external supply or carried in compressed air cylinders. A control valve is used to guide breathing air from an external source (e.g. air line equipment or self-contained breathing apparatus) into the chemical protective suit. An integrated internal hose system distributes the airflow. The correct position of the hoses is secured by clips. The compressed air of the SCBA or air line equipment can then be used to ventilate the arms, legs and torso of the wearer. In addition, the moist, warm air can flow out of the suit through valves, transporting heat to the outside and providing additional relief.

Aside from fully ventilated suits there are also vests that are worn under the suit and concentrate the cooling effect where it is most efficient: on the back. Providing additional ventilation along the extremities would result in a negligible increase of the cooling effect but in a significant increase of the technical effort compared to the vest.

2. Ventilation using a vest independent from the breathing air supply

A vest that is supplied with air through a hose is worn under the suit. The cooling air is released into the suit. The respiratory protection device is not connected and must be accessed by opening an additional breathing air intake line when needed.

3. Ventilation using a vest with integrated breathing air supply

Similar to solution 2, a vest supplied with air through a hose is worn under the suit. Air is released from the inner side of the vest toward the body to cool the torso. In addition, the air is provided directly from the vest as breathing air as well. The advantage here is that no extra face piece is needed.

To increase the cooling effect of the ventilation, other systems guide the air inside the suit past a cooling reservoir. The storage elements are cooled in the chest freezer first and then attached to the body directly under the suit. A battery-powered blower unit circulates the air in the suit so that is passes the cooling reservoir and then guides it into the head region. Here, it cools the wearer and reduces fogging of the visor. Some of these solutions do not require an external air supply and work with just the internal blower unit. There are, however, disadvantages besides the necessary power supply. One of them is comfort: The solid boxes of the cooling reservoirs must be worn directly on the chest and present a one-side load.

In all ventilation solutions the airflow produces a continuous background noise. It is thus advisable to select a model with the lowest possible noise level.

Circulation of cooling agents

The cooled liquid is pumped through a hose system, absorbs heat and transports it away from the body. The liquid is then cooled down again inside a cooler and can repeat the circuit. Disadvantage: This is a very large system that cannot be worn underneath normal protective suits. It is therefore usually not used during missions, but instead afterwards to cool the body down again.

Evaporation of water

The underclothes, usually a vest or trousers, are moistened, or loaded with moisture, prior to use. During the operation the moisture evaporates. The water however, increases the weight of the equipment. This principle is only recommended for breathable suits because otherwise the moisture would be trapped inside the suit.

Conclusion: Which is the right principle for which type of application?

Every cooling system has its advantages and disadvantages due to the fact that the intended use, risk potential and general conditions carry a different weight. The question of >How< can therefore not be answered with a general recommendation. The >If<, however, is a different matter: Every improvement of the cooling in protective suits significantly reduces the stress the wearer has to endure. And this is not just a question of safety and comfort but there are also clear economic advantages.

Even though the time a protective suit can be worn during an operation is limited by regulations it is also true that a wearer who is less affected by exhaustion might be able to work longer and be deployed longer and in more efficient ways. Another factor is the time required before and after the deployment. When evaluating a system, positive features include easy handling of the suit when donning and doffing it, a high-quality processing, etc. The safety management and/or service technicians will also take into account the effort required for maintenance and care of the suit including the cooling system. All this must be considered when buying a protective suit. Dräger expert Dr. Joachim Koch recommends: »Even experts struggle when selecting the ideal system for a specific application. This is why I would recommend a detailed consultation before making the final decision. We have noticed that heat stress is often still underestimated in practical application. The greatest challenge safety management staff face today is not just the use of better cooling techniques but also motivating employees to follow a more effective individual thermo-management.«

Reducing heat stress: practical rules

Aside from selecting the ideal cooling system there are a number of other measures that can be employed to reduce heat stress and that will help reduce health risks.

1. Deploy only perfectly healthy and physically capable employees in insulated chemical protective suits

Most countries require a mandatory basic fitness test for the potential wearers of a CPS that is combined with respiratory protection equipment.[10]

2. Select protective equipment that provides the right combination of safety and comfort

When preparing PPE for a specific application each piece of equipment, from head piece to boots, should be checked to find out whether it will increase heat stress and whether it might be replaced by a lighter, less insulating model without compromising safety.

3. Prepare employees for difficult missions

The higher the employee's body mass index, the higher the physiological and thermal stress. Provide advice and support to more heavy-set employees on how they can improve their fitness. Many health insurance providers and Employers' Liability Insurance Associations offer corresponding health programmes.

4. Train employees well and on a regular basis

Every employee should be well aware of the functions and – more importantly – signs for possible failure of each piece of equipment. Apart from technical aspects, the training should teach workers to pay attention to their own well-being. Open communication is the key: supervisors and staff responsible for missions should encourage employees to report every problem and every irregularity immediately. This includes the following:

- Residues or damage to the material of the protective clothing
- Uncomfortable equipment
- Unexpected breathing resistance
- Impaired view (visor) and errors of the communication unit
- Restricted motor functions due to the protective suit
- Physical complaints such as nausea, skin irritation or fast pulse

5. Raise employee awareness for individual reactions to temperature

Employees who often perform missions in protective suits should be made aware of factors that increase heat sensitivity and educated on how to better deal with this stress:

- Avoid agents that amplify heat stress symptoms, such as caffeine, alcohol and nicotine, but also tranquillisers, blood pressure medication or muscle relaxants.
- Keep hydrated and drink lots of fluids! Particularly in protective suits with ventilation systems there can be a higher risk of dehydration. A paradox that occurs when the wearer feels so comfortable inside the cool dry suit is that he forgets to replenish his fluids.
- Sleep enough
- Ensure good cardiovascular health
- Inform your supervisor if there is any sign of an infection or fever

SOURCES:

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7 2013 W.L. Gore & Associates, Inc., http://www.goreprotectivefabrics.com/remote/Satellite/Structural-Fire-Fighting-Turnout-Gear/Heat-Stress-Management (12.02.2015)

8 The so-called wet-bulb globe temperature (WBGT) index was developed in the 50s by the United States Marine Corps for measuring heat stress. The index takes into account the effect of temperature, air humidity, wind speed and visible infrared radiation – usually sunlight – on human beings. (Today, the WBGT index is also used in the fields of occupational health and safety and competitive sports.)

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10 cf. e.g. Germany: DGUV-R 112-189 and DGUV-R 112-190; USA: OSHA Technical Manual (OTM) Section III: Chapter 4: Heat Stress (source: https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html)

More information:
Heat Stress. OSHA Technical Manual (OTM) Section III: Chapter 4 (https://www.osha.gov/dts/osta/otm/otm_iii/otm_iii_4.html , Dez. 2014)

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