# REDUCTION OF HEAT STRESS IN CHEMICAL PROTECTIVE! SUITS

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## INTRODUCTION

Wearing chemical protective suits (CPSs) involves the danger of heat stress. At normal protection levels, CPSs combining water vapor and air permeability with NBC-filter characteristics (permeable CPSs = PCPSs) may be able to reduce heat stress. At high protection levels, impermeable chemical protective suits (ICPSs) that lead to a high heat stress are indispensable.

In order to improve heat flow from the body to the environment, new permeable materials have been developed (Table 1), and for impermeable suits, technical aids are available (Table 2). Current research in our laboratory for clothing physiology will be presented for the materials and methods marked (*) in Tables 1 and 2 and the consequences for a possible future development will be discussed.

**Table 1.** Materials for PCPSs to diminish heat stress .

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| • charcoal impregnated foam * |
| • spherical adsorbers * |
| • carbonized knitted fabrics * |

**Table 2.** Diminution of heat stress in ICPSs by technical aids

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| • stationary cooling system (not for mobile use) |
| • ventilation with air fiom a self-contained breathing apparatus (SCBA) * |
| • ventilation with ambient air supplied by a portable battery ventilator * |
| • ice-cooled vest |
| • liquid-cooled undergarment |
| • portable cooling system (refrigerator unit as rucksack) * |

## MATERIALS AND METHODS

To investigate different materials for PCPSs, 9 male volunteers worked on a treadmill (45 min, 4 $km \cdot h^{-1}$, 0% incline) in a climatic chamber (28°C dry bulb ($t_{db}$), 50% relative humidity(RH) 0.2 $m \cdot s^{-1}$ air velocity) after informed consent had been obtained, The subjects wore 5 different PCPSs made fiom new materials (charcoal impregnated foam, 3 x spherical adsorbers, carbonized knitted fabrics) and 1 conventional standard **PCPS** (charcoal impregnated foam) in random sequence. Undemeath, they wore work clothes (underwear with short sleeves and legs, shirt, trousers, socks and boots; **ICL = 0.7** clo). Work clothes only were used as control. Heart rate **(ECG)** and mean skin temperature (1) were measured. Sweat volume was obtained by weighing. The volunteers' self-perceived stress, heat and sweat sensations were ascertained.

Three examples of technical aids for **ICPSs** were studied

**Air (5** $L \cdot min^{-1}$) from a **SCBA** was used to ventilate an overall **ICPS** combined with a **SCBA.** Eight male volunteers worked with and without this ventilation on a treadmill **(4** $km \cdot h^{-1}$**, 3%** incline) in a climatic chamber at **18°C** tdb and **50%** RH **(30** min stay, **15** min walk) after informed consent had been obtained. Heart rate, mean skin temperature were recorded, and sweat volume was obtained. The volunteers' self-perceived stress, heat and sweat sensations were ascertained.

The possible benefits of a higher ventilation with filtered ambient air **(80** $l \cdot min^{-1}$) supplied by a portable battery ventilator were investigated with a 2-piece **ICPS.** Four male volunteers walked on a treadmill (5 $km \cdot h^{-1}$**, 0%** incline) in a climatic chamber **(35°C** tdb, 20-40% RH, 150 $kJ \cdot m^{-2} \cdot h^{-1}$ heat radiation) after informed consent had been obtained. Every subject worked with and without ventilation **of** the ICPS in random sequence. Heart rate, rectal and mean skin temperatures were measured, and sweat volume was obtained. The volunteers' self-perceived stress, heat and sweat sensations were ascertained.

In addition, first orientating examinations using a portable cooling system (refrigerator unit) as rucksack, which blows cooled ambient air into a 2-piece **ICPS,** were carried out.

## RESULTS AND DISCUSSION

The following results were obtained by the examination of the different materials for **PCPSs:**

The differences in between the **PCPSs** made out of 5 different new materials were only of marginal biological or statistical importance. However, all of them showed an improvement in comparison with the standard **PCPS.** Heart rates (mean ± SD) rose from **114.3** ± 9.1 bpm to **117.2** ± **11.5** bpm (new materials), to **128.7** ± **10.3** bpm (standard) and to **102.0** ± 12.9 bpm (work clothes) at the end of work. Mean skin temperatures were **36.1** ± 0.12°C to **36.3** ± **0.33°C** (new materials), **36.7** ± 0.21°C (standard) and **35.4** ± **0.51°C** (work clothes) while sweat losses were **358** ± 202 g to **444** ± **75** g (new materials), **536** ± **144** g (standard) and **337** ± **63** g (work clothes). The results were also reflected in the volunteers' self-perceived sensations of stress, heat and sweat. With the new **PCPSs,** they were lower than with the standard **PCPS,** though higher than with the work clothes only. Extrapolating the linear increase of heart rate (Fig. **1**) observed during the climatic stress up to a limit **of 130** bpm showed a prolonged tolerance time with the new **PCPSs** (80 min; standard **54** min).

Thus all new materials for **PCPSs** show better qualities to reduce the wearers heat stress than the suit with spherical adsorber of a former investigation

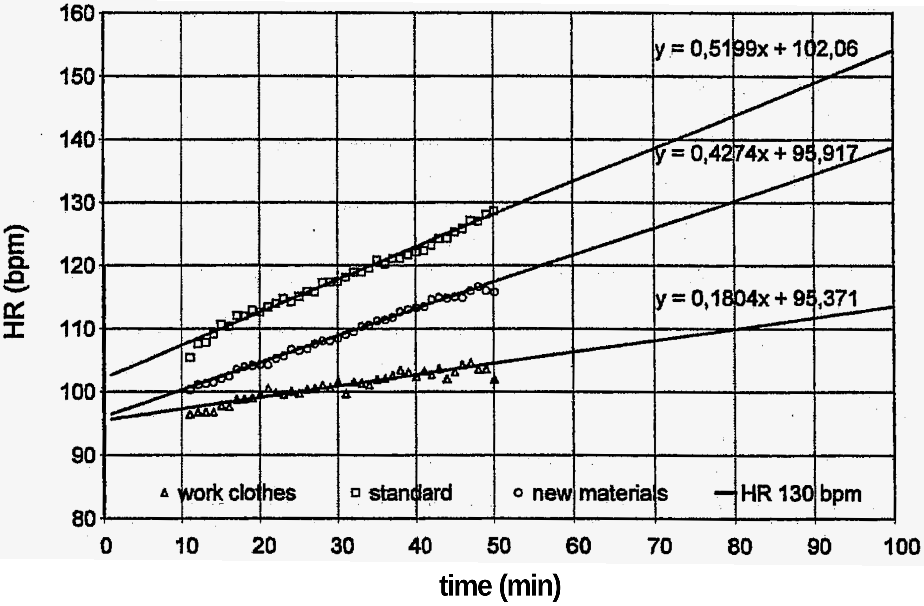


**Figure 1.** Extrapolation of the heart rate observed during the climatic stress, indicating the prolonged tolerance with the new materials.

reported on ICEE 6 (2) The examination of technical aids for ICPSs revealed the following results:

During work with the overall ICPS, mean skin temperature rose to 36.2 ± 0.6°C and sweat loss was 229 ± 83 g·30-min$^{-1}$. Ventilation with air fiom the SCBA gave no relief for the volunteers' physiology nor for their self-perceived sensations of stress, heat and sweat. To reach effective sweat evaporation the ventilation should have been approximately 90 times higher. Due to the restricted air stock of the SCBA, a higher ventilation rate isn't possible. Therefore this method seems not to be meaningful for future development.

In the 2-piece ICPS, heart rate rose to 130 bpm after 12.5 ± 3.0 min, maximum rectal temperature was 38.1 ± 0.29°C, maximum mean **skin** temperature was 38.03 ± 0.36°C and the subjects lost 612 ± 170 g sweat. They had to stop after 21.25 ± 7.8 min because of exhaustion. When 80 l·min$^{-1}$ filtered ambient air was blown into the suit by a portable battery ventilator, tolerance time (23.75 ± 10.9 min) was only insignificantly longer while maximum rectal temperature (38.2 ± 0.52°C), maximum mean skin temperature (37.87 ± 0.45°C) and sweat loss (755 ± 308 g) showed no relief. Only time to reach HR 130 bpm was prolonged (16.0 ± 4.7 min). Differences in the subjects' self-perceived sensations of stress, heat and sweat were not observed. Thus the use of 80 l·min$^{-1}$ ambient filtered air to dissipate heat fiom the ICPS was not successful probably because of the small volume and an uneven distribution (3). Furthermore the system will be less effective at high ambient temperatures and humidities.

If supplied by a stationary cooling system, a wearer of an ICPS doesn't have to carry the weight of the cooling unit and its energy source. However the system is only for limited use, because a working man cannot move freely and problems like damage or knots of the tubing umbilical may occur.

The effectiveness of ice-cooled vests and liquid-cooled undergarments has been verified frequently in the literature. We count this, however, a provisional solution since sweat evaporation as the most important mechanism of heat dissipation of a worker is not supported. Local cooling might cause cutaneous vasoconstriction.

It is our long-term aim to support human heat dissipation by dry, moderately chilled air. Thereby sweat evaporation can be augmented without reducing dry heat dissipation by vasoconstriction.

At the moment, such technical systems are not available. Instead we collected experiences with a portable cooling system (refrigerator unit) as rucksack, which blows cooled ambient air into a two-piece ICPS. The benefits weren't promising because the additional weight (primarily the energy source) causes an additional metabolic heat production.

## CONCLUSIONS

New materials for PCPSs offer a better possibility to reduce the wearers heat stress. Effective work time, however, is still significantly reduced.

It is our long-term aim to support human heat dissipation fiom ICPCs by dry, moderately chilled air. Suitable technical aids are still not available. The development of a lightweight energy source for portable use is especially unpredictable.

## REFERENCES


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