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**Physiological assessment of non-airfed suits in
the nuclear industry – Interim report**

Phase 1: Literature search summary

PE/14/05

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External Report

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SUMMARY

This interim report summarises the findings of the literature search carried out in Phase 1 of HSL's work on physiological assessment of non-airfed suits as used in the nuclear industry.

Available published data on the wearing of permeable, semi-permeable and fully impermeable non-airfed suits is sparse. Additionally, it is difficult to draw conclusions about tolerance times when in different environmental conditions and at different levels of physical activity because of the different methodologies employed in the published studies. There is some tolerance time data from studies linked to WBGT; however this data may overestimate the tolerance times as no respirator and hood were worn.

These findings will be used to inform the development of the experimental protocol and tests to be used in subsequent phases of this study.

1 INTRODUCTION

Nuclear operational and decommissioning workers may wear a non airfed suit ensemble consisting of a semi- or fully-impermeable coverall, gloves, boots and negative pressure respirator. The ensemble totally encapsulates the worker reducing the main avenues for heat loss from the body (conduction, convection, radiation, and evaporation of sweat from the skin and water from the lungs). The reduction of these heat loss mechanisms will increase core temperature and dehydration levels of the body. These increases will be exacerbated if the worker is performing tasks that demand a high level of physical activity, such as climbing stairs or lifting and loading weights.

As their core temperature and their level of dehydration increase, the worker's ability to perform their mental and physical tasks efficiently, correctly and safely is reduced. If these levels continue to increase then the worker will suffer heat illness which could lead to their collapse within the containment area or after they have left it.

The aim of Phase 1 of this work is to gain an understanding from published applied thermo-physiological research literature of the working times and thermo-physiological effects of wearing fully encapsulating suits made of semi- and fully-impermeable materials at different levels of physical activity and environmental conditions. This will allow the environmental conditions and physical activity of nuclear non-airfed suit workers (Phase 2) to be placed in a more general industrial context and will guide our experimental design (Phase 3) in evaluating tolerance times.

2 METHODOLOGY

The review was designed to identify papers that would provide data on the tolerance times of individuals wearing semi- and fully-impermeable protective suits in different environments. A search of English language peer reviewed publications over the last 10 years for human subject trials was performed by the HSE Information Services Search Team.

The following background information was provided to the HSE search team:

‘Review of the applied research on the thermophysiological effects (hot and cold) of humans wearing either impermeable or moisture permeable clothing. These suits are worn in the nuclear industry; however the search needs to be wider to include any industrial or military chemical protective clothing which is impermeable or moisture permeable. We are interested in the physiological impact of wearing these types of suits or personal protective equipment (PPE) in both the heat and the cold (though in the search hot environments should have a higher priority than cold). We are also interested in the suits themselves and any information on the clothing microclimate (humidity and temperature) when worn in different climates. Any generic information on the measurements of moisture permeability and thermal insulation of these thin chemical protective suits would also be useful.’

A search of English language peer reviewed publications covering the health, sports, physiological and medical literature. The key word searches were as follows:

- Thermal stress; cold stress; heat stress; heat strain; hyperthermia combined WITH nuclear; chemical protective; asbestos; protective clothing; suit; coverall; personal protective clothing; personal protective equipment.
- Clothing microclimate combined WITH impermeable; semipermeable; moisture permeable; water vapour permeable; moisture vapour permeable (MVP); thermal insulation.

In addition, key references cited in reviews and papers were also reviewed. The data bases used were: Ergonomic Abstracts, Oshrom, Oshupdate, Proquest, Thomson Reuters Web of Knowledge and the internet. It should be noted that this was not a systematic review of the literature.

3 RESULTS AND DISCUSSION

A total of seventy two papers were selected from the search results after a review of the abstracts. The most relevant data on tolerance times, core temperature, type of clothing and level of metabolic activity have been extracted from fifteen of these papers. The data has been divided into two sets; Table 1 where the environmental temperature of the experiment is expressed as dry bulb and Table 2 where the environmental temperature of the experiment is expressed as WBGT (wet bulb globe temperature). It is however important to note that there is very little literature which directly relates to the wearing of non-airfed suits in a nuclear environment. The experimental data concerns the use of protective suits in military environments and for general chemical protection.

Ideally we would have liked to have taken the summarised data and been able to draw conclusions about tolerance times while wearing permeable, semi-permeable or impermeable protective clothing in order to form a basis for the experimental design. However, it is very difficult to form a cohesive picture from the literature of tolerance times when wearing nominally permeable, semi-permeable or impermeable protective clothing, because of the following inconsistencies:

- The clothing worn under the protective coveralls (e.g. underwear to full workwear) and the additional PPE worn with the coveralls (e.g. gloves and boots) differs from study to study.
- Not all experiments include the effects of wearing a respirator.
- The design of the coveralls varies, for example some have hoods and others cover just the torso and limbs.
- Though the clothing has been split into three types of materials permeable, semi-permeable and impermeable, within the permeable and semi-permeable categories there is a wide range of moisture vapour permeabilities which may affect the physiological response to wearing the garment.
- The subjects undertake various types of physical activity e.g. walking, cycling or job specific tasks. Some of the experiments have continuous work cycles and other have work/rest routines. In some of the experiments metabolic rate is measured and in others estimated.
- Different methods of measuring and recording deep body temperature have been used e.g. aural, rectal, intra-abdominal.
- Some of the experiments are limited by time and others by varying levels of deep body temperature.
- Subjects are from varying populations (eg ranges of ages and fitness), some studies do not specify the gender of the test subjects and some studies group male and female data.

However, one of the most important issues is that most of the increases in deep body temperature in many of the experimental studies are small, indicating that the levels of heat strain induced were low. This may be because either the experimental duration was too short or the combination of the environmental temperature and the physical activity were not enough to induce any appreciable level of heat stress. This means that the 'effective forcing function' was too low and so there was little physiological stress and consequently little or no discrimination between the data.

Table 2 gives a greater clarity on the link between environmental temperature (WBGT), work rate and the clothing worn. This may be because fewer papers have been reviewed so the data is derived from a more consistent methodology. This data does suggest that the tolerance time for individuals exposed to a WBGT of 20°C undertaking a moderate level of physical activity will be about two hours when wearing either a semi- or fully-impermeable protective coverall. However, one of the issues with the data from this set of papers is that the majority of the data is for coveralls only with no hood or respirator. As the hood and respirator will have a profound effect on the level of heat stress, the physiological burden, comfort and the ability of the wearer to conduct different tasks, it is difficult to apply the data to the nuclear non-airfed suit scenario.

Fully impermeable							
Environmental temperature (°C)	Humidity %	Deep body temperature reached (°C)	Time (min)	Clothing worn	Respirator	Metabolic rate Resting/Low/moderate /high	Reference
18.40	50	37.50	220#	Impermeable	No	Low	Winterhalter et al (2012)
20.90	70	38.40	45	Impermeable	Yes	High	Hostler et al (2009)
24.90	47	37.70	50	Impermeable	No	Very low	Holmer et al (1992)
25.50	85	38.37	60	Impermeable	Yes	Moderate	Raven et al (1979)
29.20	51	37.95	220#	Impermeable	No	Low	Winterhalter et al (2012)
29.40	85	38.55	60	Impermeable	Yes	Moderate	Raven et al (1979)
33.30	85	38.67	60	Impermeable	Yes	Moderate	Raven et al (1979)
35.00	30	38.00	165#	Impermeable	No	High	Epstein et al (2013)
35.00	50	38.43	67	Impermeable	No	Moderate	Semeniuk et al (2005)
35.70	26	37.50	50	Impermeable	No	Very low	Holmer et al (1992)
37.00	–	38.50	20	Impermeable	Yes	Moderate	Havenith (1999)
40.00	30	38.00	30	Impermeable	No	Moderate	Marszalek et al (2009)
40.00	30	38.00	30	Impermeable	No	Moderate	Bartkowiak et al (2013)

Table 1: Summary of the data from thirteen relevant papers giving the deep body temperature reached for different levels of physical activity at varying environmental temperatures (dry bulb temperature) for subjects wearing three different types of clothing; permeable, semi-permeable and fully impermeable.

The shaded rows band similar environmental temperatures together. # after the time signifies surprisingly long tolerance time taking into account the environmental temperature and metabolic rate.

The metabolic rates have been divided into three groups low, moderate and high from either the metabolic rate or estimated from the type of exercise given in the paper. As follows;

Low metabolic rate: 100-180 W/m ² eg light mechanical work, machining with power tools, casual walking up to 2.5km/hour
Moderate metabolic rate: 165-295 W/m ² eg intermittent handling of moderately heavy materials, walking between 2.5 and 5.5 km/hour
High metabolic rate: 230 -415 W/m ² eg carrying heavy material, pushing /pulling heavily loaded carts, shovelling, walking between 5.5. and 7 km/hour

Table 2: Summary of the data from two relevant papers giving the deep body temperature reached for different levels of physical activity (levels given in Table 1) at varying environmental temperatures (WBGT) for subjects wearing three nominally different types of clothing; permeable, semi-permeable and fully impermeable as classified by the authors.

WBGT (°C)	Deep body temperature reached (°C)	Time (min)	Clothing worn	Respirator	Metabolic rate Resting/Low/moderate /high	Reference
Permeable						
36.00	38.50	78	Permeable	No	Moderate	Bernard and Ashley (2009)
36.80	38.50	61	Permeable	No	Moderate	Bernard and Ashley (2009)
38.20	38.50	55	Permeable	No	Moderate	Bernard and Ashley (2009)
40.10	38.50	38	Permeable	No	Moderate	Bernard and Ashley (2009)
43.80	38.50	26	Permeable	No	Moderate	Bernard and Ashley (2009)
Semi-permeable						
23.00	37.60	223	Semi permeable	Yes	Moderate	Bishop et al (2007)
33.10	38.50	77	Semi-permeable	No	Moderate	Bernard and Ashley (2009)
33.90	38.50	97	Semi-permeable	No	Moderate	Bernard and Ashley (2009)
36.00	38.50	49	Semi-permeable	No	Moderate	Bernard and Ashley (2009)
37.80	38.50	40	Semi-permeable	No	Moderate	Bernard and Ashley (2009)
41.10	38.50	28	Semi-permeable	No	Moderate	Bernard and Ashley (2009)
Fully impermeable						
23.00	38.10	117	Impermeable	Yes	Moderate	Bishop et al (2007)
29.50	38.50	77	Impermeable	No	Moderate	Bernard and Ashley (2009)
30.30	38.50	62	Impermeable	No	Moderate	Bernard and Ashley (2009)
32.00	38.50	56	Impermeable	No	Moderate	Bernard and Ashley (2009)
33.70	38.50	47	Impermeable	No	Moderate	Bernard and Ashley (2009)
37.80	38.50	33	Impermeable	No	Moderate	Bernard and Ashley (2009)

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