Health and Safety Executive

Physiological safety of airfed suit use during nuclear decommissioning

Literature Review

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Physiological safety of airfed suit use during nuclear decommissioning

Literature Review

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The amount of decommissioning work being carried out in the Nuclear Industry has increased substantially over recent years and is likely to continue increasing. Whilst such work may sometimes be conducted using remotely operated mechanical handling equipment, in many situations this is not a reasonably practical solution. Most decommissioning operations require work to be done by employees working in potentially hazardous environments. Operatives conducting this work are required to wear Airfed suits (AFS) to minimise risks from radioactive particulate hazards.

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EXECUTIVE SUMMARY

Objectives

To review the existing legislation, guidance and standards applicable to Airfed Suit (AFS) use in nuclear decommissioning work, with respect to the physiological safety of the wearer, and to review the published research work in this field.

Main Findings

Whilst there is no specific HSE guidance for AFS wearers, Health and Safety Regulations stipulate that the ergonomic requirements of all PPE wearers should be taken into account. HSE guidance explains the ergonomic risk factors which should be considered and there is general workplace advice and information on how to assess and control some physiological risks (including noise, vibration and manual handling). However, there is a lack of acknowledgement within HSE documentation of the risk of heat stress to PPE wearers and consequently no practical advice or information on how to assess or control the risk. The absence of knowledge of the extent of the risk may result in an underestimation. Workplace attitudes and practices may be increasing the physiological risk to the health and safety of AFS workers.

PPE product standards define minimum standards for product performance. Emphasis is on the ability of the PPE to provide adequate protection. A subjective ergonomic assessment may be required by some standards, but the test methods require significantly less wearer effort than nuclear decommissioning work.

Industry guidance and standards provide limited practical guidance on controlling physiological risks during nuclear decommissioning work.

Research suggests that the risk of physiological stress should be a significant concern for AFS wearers during nuclear decommissioning work. The use of Vortex tubes to cool the air supplied is well documented as a practical method of helping to prevent heat stress of AFS wearers. The air supply flow rate, temperature and distribution within the suit may be critical to preventing heat stress. The temperature of the air as it exhausts from the suit may be a good indicator of the thermal state of the AFS wearer.

Recommendations

HSE should commission on-site assessment of actual nuclear decommissioning operations in order to establish whether there is a significant physiological risk to the AFS wearer. As many sites as possible should be included in order to cover the diversity of equipment, workplace situations and practices.

Objective measurements and subjective assessments should be used to assess the physiological stress on the wearer. Representatives, including AFS wearers, from all sites should be involved in observation and assessment of work tasks and practices at each site, working with specialist scientists (ergonomics and psychology) to share and promote good practice and positive attitudes.

If the physiological risk is found to be significant, HSE should develop industry specific guidance on how to assess and control the physiological risks to the AFS wearer. This would require laboratory testing of the range of variables which may be encountered at sites such as suit design, ambient conditions, air supply parameters and additional PPE. The temperature of the air as it leaves the suit should be measured during such testing as it may prove to be a simple objective assessment of the thermal state of the AFS wearer.

1 INTRODUCTION

The amount of decommissioning work being carried out in the Nuclear Industry has increased substantially over recent years and is likely to continue increasing. Whilst such work may sometimes be conducted using remotely operated mechanical handling equipment, in many situations this is not a reasonably practical solution. Most decommissioning work is carried out by direct manual labour. Operatives conducting this work are required to wear Airfed suits (AFS) to protect them from radioactive particulate hazard.

1.1 AIRFED SUIT WORKING

An AFS is a type of personal protective equipment (PPE) which encloses the head and body with only the hands (and sometimes the feet) not enclosed. The hands are protected by several layers of gloves, to which the AFS is sealed. The AFS is usually made from a transparent/translucent synthetic material (often PVC). It is supplied with breathable air (BS EN 12021:1998) from a remote source (an on site compressor) via several metres of hose. The AFS is designed to protect the wearer from the risk of inhalation of hazardous substances and from skin contamination. As such it is a form of Respiratory Protective Equipment (RPE) as well as PPE. In nuclear decommissioning the hazard being controlled by the AFS is radioactive particulate material. At one nuclear site the number of separate occasions on which AFSs are worn is of the order of 6 000 per year and is predicted to rise possibly to 10 000 per year. A similar situation exists at other sites.

As with all PPE, whilst the AFS is designed to protect the wearer it is not infallible. Operations must follow carefully considered documented procedures and are heavily dependent on team work. Several personnel are involved in each use of an AFS. These persons must be trained and competent in their contribution to the operation, in order to minimise the health and safety risks.

Working in an AFS imposes a physiological burden on the wearer. The wearer is contained within an inflated AFS which restricts their manoeuvrability and the several layers of gloves inhibit dexterity and tactile feedback. The contained environment prevents the body’s temperature regulation mechanisms from being as effective as in a normal environment which may result in heat stress.

1.2 ADDITIONAL PPE AND WORK ACTIVITY

It is often necessary for AFS operatives to wear additional PPE. Lead aprons may be deployed when there is a need for protection against penetrating radiation. These are heavy items which may be worn either under or over the AFS.

Mechanical and heat protective PPE is required for some operations. The need to use power tools and plasma cutting equipment present hazards to the wearer, both directly and indirectly (in the event of the AFS being accidentally damaged). Welding type protective clothing may be worn over the AFS to reduce the risks.

Fall restraint/arrest equipment may be deployed when working at height, and safety footwear and mechanical protective gloves for handling heavy and/or sharp objects.

Additional PPE, some work task requirements and heavy work activity all place an extra physiological burden on the AFS wearer. The weight of PPE and heavy work activity increase the load on joints and muscles and the possibility of heat stress. Specialized protective gloves can further reduce dexterity, grip and tactile feedback, and additional PPE may further inhibit manoeuvrability.

1.3 EFFECTS OF PHYSIOLOGICAL BURDEN

Increasing the physiological burden on the wearer can have short and long term consequences. Heat stress can affect ability to concentrate, cause weakness, giddiness, vertigo and fainting. The possible consequences are an increased risk of AFS wearer error leading to physical accidents and possible radioactive contamination. Reduced concentration may result in an inability to follow procedures as trained (e.g. correct doffing, or following of emergency procedures). As well as the increased risk to the AFS wearer there is an increased risk to colleagues in the support team who may be affected by errors of the AFS wearer. For example the support workers may be at increased risk of contamination when the AFS is removed. Severe heat stress can lead to mental confusion, convulsions, unconsciousness and death. Loss of manoeuvrability, grip and dexterity may lead to accidents. Inappropriate posture being adopted may result in musculo-skeletal injury and there may be an increased likelihood of objects being accidentally dropped, possibly resulting in injury.

In the long term the AFS wearer may suffer from the effects of physical exhaustion (burnout) and musculo-skeletal injury affecting their quality of life and their ability to continue working.

1.4 ASSESSING RISK OF PHYSIOLOGICAL STRESS

HSE Nuclear Inspectors have raised concerns that the Risk of Physiological stress to AFS operatives may not be adequately controlled. Similar concerns have been expressed by Industry (Thompson and Haggarty , 2006; Bunker et al, 2006). Lack of guidance on assessing such risks has been cited as resulting in a ‘guess work’ approach. Typically AFS operatives themselves decide when they need to stop working, but if they are suffering from the effects of heat stress they may not be able to judge correctly. Additionally, HSE Inspectors fear that a ‘macho’ culture may exist, with AFS operatives working as long and hard as they can, until exhausted. The number of incidents occurring with AFS operations is an ongoing cause for concern.

HSE and Industry recognise that there exist a diversity of approaches to decommissioning work. This may be partly due to the diversity of the work tasks involved. Industry has expressed support for sharing good practice and the development of guidance documents (Thompson and Haggarty , 2006; Bunker et al, 2006).

1.5 OBJECTIVES OF THIS WORK

HSL PPE team were asked to review the existing legislation, guidance and standards applicable to AFS use in nuclear decommissioning work, with respect to the physiological safety of the wearer, and to review the published research work in this field.

2 LEGISLATION

The Health and Safety at Work Act came into force in 1974. Subsequently this Act of Parliament has been supported by the introduction of specific regulations laid down as Statutory Instruments. Many of these regulations have subsequently been presented by HSE in their ‘L’ series documents, which include Approved Codes of Practice (ACoPs) and guidance relating to each regulation. The regulations which are most relevant to physiological risks during AFS working are discussed below. As far as possible the discussion is based on the appropriate ‘L’ series document and summarises the relevance of information contained in the text.

2.1 THE CONTROL OF SUBSTANCES HAZARDOUS TO HEALTH REGULATIONS 2002 (AS AMENDED)

HSE document L5: Control of Substances Hazardous to Health regulations 2002, as amended (HSE, 2005 a)

The use of PPE to adequately control exposure to hazardous substances is permitted by Regulation 7 (3) (c). Regulation 7 (9) requires that such PPE comply with the PPE regulations (SI 2002/1144, 2002), be adequate (capable of providing the required protection) and suitable (for the work task, environment and wearer). The ACoP discusses consideration of suitability of PPE for the work task, taking into account the physical effort required, the time to do the work, compatibility with other PPE and ‘wearer comfort’. No mention is made of the potential for heat stress affecting the wearer.

PPE should be used properly (Regulation 8), the ACoP considers that the correct use of PPE, should be in accordance with manufacturer’s instruction.

Regulation 9 requires that PPE be maintained, kept clean and in good working order. In addition RPE should be examined and tested at suitable intervals. The ACoP requires RPE to be examined at least every month, unless it is used only occasionally.

2.2 IONISING RADIATION REGULATIONS 1999

HSE document L121: Work with Ionising Radiation (HSE, 2000)

Regulation 8(2)(c) permits the use of PPE in the control of risk of exposure to ionising radiation provided that it is adequate and suitable. However, the regulation refers to the possibility of the PPE being inappropriate for the work or circumstances. This is expressed in the guidance as the PPE use presenting other risks which are greater than the risk from the ionising radiation. The guidance suggests that in such a situation it might not be appropriate to use PPE. Lead aprons are given as an example, the suggestion being that they may prove too heavy for the work. The possibility of controlling those ‘other risks’ which are presented by wearing the PPE is not mentioned.

PPE must conform to the PPE regulations 1992 (Regulation 9). The guidance suggests considering consulting the radiation protection adviser and safety representative about the suitability of PPE for the wearer. Similarly to COSHH requirements, correct use and maintenance of PPE is required (regulations 8 and 10).

2.3 PERSONAL PROTECTIVE EQUIPMENT REGULATIONS 2002

These regulations are laid down in the European Community Directive 89/686/EEC and relate to the design and manufacture of PPE. The European Commission has issued guidance (European Commission, 2006) on the application of these regulations.

Annex II of the directive covers the basic health and safety requirements. Considering ergonomics, the PPE must allow for performance of the work task. Impediment to user movement, posture and sensory perception must be minimised and the lightness and strength of the PPE balanced; protection from the hazard against the possible adverse physiological effect of weight.

PPE which encloses the body must have sufficient ventilation to allow for sweat evaporation or provision for sweat to be absorbed. Guidance expects sufficient information to be supplied to allow the employer to determine the maximum physiologically acceptable duration of use of the PPE.

2.4 PERSONAL PROTECTIVE EQUIPMENT AT WORK REGULATIONS

HSE document L25: Personal Protective Equipment at Work (HSE, 2005 b)

These regulations are based on European Community Directive 89/656/EEC, requiring similar basic laws throughout the community on the use of PPE in the workplace. HSE document L25 part 1 states the regulations and provides guidance on implementing them.

PPE must be suitable (Regulation 4). It must take into account the ergonomic requirements, health and workstation of the wearer. The guidance advises that heavy or bulky suits can cause or worsen musculo-skeletal problems and cause 'thermal comfort' problems. The employer should choose PPE for maximum protection but minimum discomfort, in consultation with the wearer.

Different items of PPE must be compatible (regulation 5) such that they provide the intended protection. Regulations 6 to 11 require that all PPE must be suitably selected, maintained and stored, and employees must be given information and training, and correctly use the PPE.

Part 2 of L25 provides basic guidance on selection, use and maintenance of PPE. It describes different types of PPE, some of the hazards which it can protect against, and the key points which should be considered. The possibility of the use of PPE posing physiological strain on the wearer is not mentioned in this section e.g. there are a number of key points regarding glove use but no mention of the loss of manual dexterity and tactile feedback.

2.5 PROVISION AND USE OF WORK EQUIPMENT REGULATIONS 1998 (PUWER)

HSE document L22 Safe use of Work equipment (HSE, 1998)

Work equipment must be suitable for the purpose, regulation 4 (1) and (2). The employer must consider the working conditions and additional risk posed by use of the equipment. The ACoP specifically refers to ergonomic risks and the guidance expands on these requiring the operation of equipment not to place undue strain on the user. Regulation 9 requires training of equipment users, including training in the methods of using work equipment.

2.6 MANUAL HANDLING OPERATIONS REGULATIONS 1992.

HSE document L23: Manual handling (HSE, 2004)

Regulation 4 places duties on employers to assess all manual handling operations taking into account specific factors. These include the task, load, working environment, individual capability and other factors. ‘Other factors’ questions the hindrance to posture and movement which PPE may impose, and the ‘working environment’ includes extremes of temperature and humidity.

The guidance on regulation 4 covers all of these specific factors in more detail. Of particular relevance are the sections on work routine, thermal environment and ventilation, and PPE. ‘Work routine’ advises that consideration should be given to task frequency and physical effort, and rest or recovery periods in order to reduce fatigue and risk of injury. The section on ‘thermal environment and ventilation’ mentions the increased risk of injury in extreme thermal conditions. The section on PPE advises of the need to recognise the restrictions which it can impose on movement.

2.7 THE CONTROL OF VIBRATION AT WORK REGULATIONS 2005

New regulations introduced in 2005 are presented in HSE document L141, Hand-arm Vibration (HSE, 2005 c)

This is a comprehensive document which gives extensive guidance on the employer’s responsibilities and how to assess and control vibration risks. It is as applicable to the use of power tools in nuclear decommissioning work, as to many other work environments.

2.8 THE CONTROL OF NOISE AT WORK REGULATIONS 2005

HSE document L108, Controlling noise at work (HSE, 2005 d)

These regulations are based on European Community Directive 2003/10/EC, requiring similar basic laws throughout the community. They replace the Noise at Work Regulations 1989. The HSE document L108, (Controlling noise at work) presents the regulations and gives extensive guidance on how to assess and control noise risks.

3 HSE GUIDANCE AND ADVICE

Guidance documents can provide greater understanding and more useful information on how the requirements of regulations can be put into practice. The format of a guidance document is generally more user friendly and easier to follow than the legal documents from which they are derived. Guidance is designed to help employers to put into practice the requirements of the law. The following HSE guidance and advice documents are particularly relevant to AFS work in the Nuclear Decommissioning industry.

3.1 RESPIRATORY PROTECTIVE EQUIPMENT AT WORK – A PRACTICAL GUIDE HSG 53 (HSE, 2005 E)

As its title suggests this document is designed to give practical guidance to the RPE user. Suitability of RPE for the work task and wearer are discussed within the section on RPE selection. 'Task related factors' mentions the increase in sweating and breathing rate which higher work rates can realise. Reference is made to abnormal temperature and humidity increasing discomfort, sweating and heat stress. It suggests using compressed air devices in such circumstances and mentions vortex tubes as an additional cooling device. Warnings are given regarding the use of power tools with regard to the possible detrimental effect on the protection afforded by the RPE. There is no mention of additional physiological burden which the use of such tools might place on the RPE wearer.

Appendix 1 (Special guidance relating to radioactive substances) concentrates on providing adequate protection against airborne radioactive particles and gases. AFSs are suggested as a means of providing respiratory, skin and clothing protection, but there is no warning of the possibility of physiological strain being placed on the wearer.

3.2 UPPER LIMB DISORDERS IN THE WORKPLACE HSG 60 (HSE, 2002)

This guidance document describes how managers and employees can co-operate to reduce the risk of upper limb disorders in the workplace. Whilst the whole document may be useful, the sections on 'creating the right organisational environment' and 'reducing the risks' may be particularly helpful towards managing the risk of musculo-skeletal disorders in nuclear decommissioning AFS work. There is a strong emphasis on worker involvement and education.

3.3 MANUAL HANDLING ASSESSMENT (MAC) TOOL (HSE, 2003)

An HSE leaflet providing practical information on how to assess manual handling risks associated with lifting, carrying and team handling operations. It uses a traffic light scoring system covering several risk factors to give an overall assessment of risk associated with these tasks. It is applicable to all workplace situations including nuclear decommissioning.

3.4 ACSNI HUMAN FACTORS STUDY GROUP THIRD REPORT: ORGANISING FOR SAFETY

The Advisory Committee on the Safety of Nuclear Installations (ACSNI, 1993) produced this report which discusses many human factors concepts which may affect safety in any workplace. The importance of safety culture is central to the discussions.

The entire document is relevant to AFS working. Of particular note is Chapter 7 'The role of risk perceptions and attitudes'. Problems such as familiarity leading to over confidence and the dangers of 'macho' attitudes and making 'snap judgements' are discussed. There is also mention of greater weight being given to risks about which information is readily or recently available. This would suggest that if knowledge of a particular risk were not readily available a lesser weight might be given to its importance.

4 INDUSTRY GUIDANCE

In addition to HSE guidance there are other guidance documents which have been written in support of good practice in the use of PPE in the nuclear industry.

4.1 PRACTICAL RADIATION TECHNICAL MANUAL, PERSONAL PROTECTIVE EQUIPMENT (IAEA, 2004)

This is a fairly basic document which outlines the management requirements which should be considered before PPE is used in the nuclear industry. It describes a range of PPE types (including AFSs), which are commonly used to protect against radiological hazards. The emphasis is on radiological and particulate protection considerations but the reader's attention is drawn to the drawbacks of wearing PPE. The loss of dexterity which the wearing of gloves imposes and the tiring of the wearer of a heavy lead apron are mentioned. The need to consider additional PPE requirements for other workplace hazards, and the consideration of wearer comfort are referred to.

The general nature of this document gives a useful introduction to PPE against radiological hazards. Although it points out that increasing the airflow to the AFS may provide cooling it is not specific enough to deal with issues such as assessment of physiological risk.

4.2 THE ROLE OF PERSONAL PROTECTIVE EQUIPMENT FOR RADIOLOGICAL DOSE CONTROL (BAIN T, 2003)

This is another document which outlines PPE management in the Nuclear Industry but which goes on to identify and discuss five types of PPE which are commonly required. The section on selection of PPE identifies the need to consider the physiological load on the wearer, and to ensure their well-being. It suggests restricting working time during warm, humid weather.

5 BRITISH STANDARDS

There are a number of British Standards which are relevant to this work which can broadly be categorised as either PPE product standards or Ergonomics Standards.

5.1 PPE PRODUCT STANDARDS

The British Standards which lay down the requirements of manufacture and performance of PPE are also European Standards. Compliance with the relevant standard will result in the product being 'CE' marked, permitting it to be used in the UK workplace as a PPE control measure.

5.1.1 Protective clothing – general requirements

BS EN 340:2003 sets out the general requirements applicable to protective clothing and is called upon as a requirement in more specific standards including the standards for AFSs (BS EN 1073-1:1998) and welding type protective clothing (BS EN 470-1:1995). Ergonomic requirements cover design, which should allow movement and adoption of postures necessary for the work activity, and compatibility with other protective clothing which must be worn to provide overall protection. Test methods are contained in the specific PPE type standards. Warnings should accompany any clothing which poses a significant ergonomic burden (such as heat stress) in the intended application, and specific advice given on duration of use.

5.1.2 Airfed Suits

BS EN 1073-1:1998 (Protective clothing against radioactive contamination - Part 1) is the product standard for AFSs. The standard describes the tests which the AFS should be subjected to and the acceptance level of the results.

References to ergonomics, heat stress and noise emission are included in the requirements. Noise should be measured objectively according to BS EN 270:1995. A 20-minute subjective practical performance test is described as the method of assessing the AFS for usability. The wearer is questioned with regard to comfort and design usability of the AFS, but no objective measurements are required of the physiological stress imposed on the wearer. The product must comply with BS EN 340, which is discussed in section 5.1.1.

5.1.3 Breathable Air

The quality of breathable air to be supplied to the AFS is specified in BS EN 12021:1998. Of significance to the thermal state of the wearer, the maximum permissible water content is specified. There is no specification on the temperature at which the air should be delivered to the AFS.

5.1.4 Protective gloves

There are several standards which are applicable to the types of gloves which could be used by AFS wearers, depending upon the workplace hazards present.

BS EN 420:2003 describes the general requirements and test methods for protective gloves, when the specific standard calls for them. A dexterity test is specified which is based upon the ability of the trained glove wearer to pick-up pins of a range of diameters from a flat surface. This test is required for protective gloves for welders (BS EN 12477:2001), but it is not a mandatory requirement for protective gloves against mechanical risks, thermal risks, ionising radiation or chemicals.

5.1.5 Protective Footwear

BS EN ISO 20344:2004 specifies the test methods for footwear. One of the tests is a subjective assessment of its ergonomic features. The test subjects are asked to don suitable size footwear and perform three tasks: walk for 5 minutes at 6km/h, climb and descend stairs for 1minute, and crouching/kneeling. They are then questioned as to the comfort and performance of the footwear.

Positive responses to all of the questions in the test are required for some footwear, including safety footwear (BS EN ISO 20345:2004) and protective footwear (BS EN ISO 20346:2004)

5.1.6 Fall arrest /restraint

There are several standards which apply to devices designed to prevent or arrest falls from height. Their major concern is the adequate functioning and strength of the device mechanisms and harnesses.

BS EN 363:2002 (Personal protective equipment against falls from height – Fall arrest systems) defines requirements with respect to ergonomics. In addition to the general requirements of the PPE regulations these relate to the performance of the device in the event of a fall.

BS EN 358:2000 specifies the requirements for belts for work positioning restraints and lanyards.

5.1.7 Protective clothing for welding

The specification for BS EN 470-1:1995 concentrates on the ability of the clothing to protect against welding type hazards including heat, flame and molten metal spatter. The general requirements of EN 340 are called upon as explained in section 5.1.1 of this report.

5.1.8 Lead Aprons

The only standard for lead aprons is BS 3783:1964, which was written for aprons which are designed to provide protection against medical diagnostic X-rays. The specification is to ensure that the patient or operator is adequately protected against X-rays. The apron material is required to be at least 0.25mm lead equivalent and there is a minimum size given. There is an option to include shoulder pads, if the purchaser requests them.

5.2 ERGONOMICS STANDARDS

There are several British Standards which address Ergonomics. Some of these specifically relate to the use of PPE.

5.2.1 BS EN ISO 9886:2004 Ergonomics – Evaluation of thermal strain by physiological measurements

This standard describes a number of methods which may be used to evaluate thermal strain. The principals of the methods and how the results should be interpreted are explained. The document is for the professional to use and refer to, in order to support consistency in measurement.

5.2.2 BS EN 7963:2000 Ergonomics of the thermal environment – Guide to the assessment of heat strain in workers wearing PPE

This standard describes how to take measurements and estimate the effects of PPE on the wearer. It is a complex document written by professional ergonomists for their use. It refers to a range of PPE and work environments but AFSs are not discussed.

5.2.3 BS EN 13921:2007 Personal protective equipment – Ergonomic principles

A standard written for PPE standards writers to assist with specifying requirements for the PPE with respect to ergonomic constraints.

5.2.4 BS 8469:2007 Personal protective equipment for firefighters – Assessment of ergonomic performance and compatibility – Requirements and test methods

This standard, although specifically addressing the assessment of ensembles of PPE for firefighters, provides a toolkit of objective and subjective tests which could be used to assess other combinations of separate PPE items. Objective and subjective methods for assessing physiological strain, dexterity, compatibility and ergonomics of the equipment are given. While not specifically addressing AFS use, some of these techniques may be applicable, particularly when evaluating the increased burden of additional PPE items on AFS users.

6 INDUSTRY STANDARDS

These are documents which have been generated by the collaboration of end users, pooling their knowledge and expertise for mutual benefit. The most recent document which has been acquired was published in 1984.

6.1 SAFETY IN THE USE OF PRESSURIZED SUITS: AECP 14 (AUTHORITY STANDARDISATION COMMITTEE, 1984)

Representatives from throughout the Nuclear Industry including employees of UKAEA, BNF and MOD prepared this ‘Atomic Energy Code of Practice’, for their own use. The 28 pages give guidance on a range of areas which need to be considered when undertaking AFS work. This document is known in the industry where it has been used as the basis for the more recent development of individual site policies and procedures.

The emphasis is on protecting operatives from the risk of radiological particle contamination. Physiological strain on the AFS wearer is not mentioned as such, however there are some recommendations which appear to reflect consideration of this. It recommends limiting the work duration to 3 hours and reducing this where operations involve vigorous effort. Recommendations concerning the Breathing Air supply are also given. The flow rate is specified as 5cfm (135 l/min). The stated temperature at which the air should be supplied to the suit is between 15 and 20^0C and the relative humidity 85%.

A number of documents are referred to as being relevant to this Code of Practice, they include the following two.

6.2 THE STANDARDISATION OF PRESSURISED SUITS: (AUTHORITY STANDARDISATION COMMITTEE, 1967)

This is another document which was put together by representatives from across the nuclear industry. It includes the deliberations and decisions of the working party towards the development of a standard AFS, and describes the resulting AFS.

Reference is made to the work of Rowlands (described in section 6.3) with respect to the thermal situation inside the AFS. This work was largely responsible for the specification on air supply flow rate to the AFS of between 5 and 10 cubic feet/min (135-270 l/min). The air is distributed to the headpiece first and removed from the extremities via four ducts which exhaust at the back of the suit, thus ensuring air is circulated throughout the AFS. The working party considered it highly desirable to incorporate ventilation into the AFS, on the grounds of comfort.

Consideration of the thickness of PVC to be used for the suit recognised the need for resistance to snagging. Tests had concluded that a thicker material gave no significant advantage, therefore a 0.012 inch thickness was specified rather than 0.020 inch. There is no mention of consideration of possible physiological advantage for the wearer of a thinner AFS.

From the descriptions and photographs in this document and the diagrams in the code of practice (section 6.1) the standard suit is the one featured in the 1984 code of practice.

6.3 PHYSIOLOGICALLY SAFE WORKING CONDITIONS FOR MEN WEARING PRESSURISED SUITS (ROWLANDS, 1966)

This is an account of work conducted to measure the physiological response of one test subject AFS wearer during tests conducted at AWRE, Aldermaston. Measurement of the rectal temperature, heart rate and sweat loss of the AFS wearer were taken during the tests. Rowlands used the results to develop a series of charts which could be used to manage AFS operations, in order to minimise the risk of the AFS wearer being exposed to thermal stress.

The emphasis is on adjusting the air flow rate to mitigate the ambient conditions and considering work task and rest pauses. Rowlands found that the air supply flow rate could be varied in response to ambient conditions and workrate in order to aid prevention of thermal stress. However, he found that increasing the air-flow rate above 10cfm (270 l/min) had little additional benefit. He predicted that by cooling the incoming air the thermal stress on the AFS wearer could be significantly reduced.

Rowlands' charts predict that it should be possible to conduct moderate work at temperatures up to 25^0C without cooling of the breathing air. The predictions assume that the suit is well ventilated with good air distribution. However, the possibility of additional PPE being worn with the AFS was not considered.

7 RESEARCH

A literature search was requested through the HSE Information Service, searching for the following keywords:

- Ventilated protective clothing
- Airline suits
- Airfed suits
- Pressurised suits
- Pbas

The search returned references to guidance, industry standards and research. The guidance and industry standards are discussed in sections 4 and 6. The majority of the documents which resulted from the search were reports of research work concentrating on the heat stress imposed on the wearer of an AFS, or protective clothing. This would tend to indicate that heat stress is a major concern.

The hazard protection afforded by an AFS is the basis of only a few pieces of work, looking particularly at protection against tritium.

Many of the references are quite old (1960 - 1980), but some refer to work which has been carried out quite recently.

7.1 SUMMARY OF RESEARCH WORK PRE 1980

7.1.1 Stresses involved in wearing PVC supplied–air suits: a review (Raven et al, 1979)

This review was aimed at making recommendations for standardized testing of AFSs with respect to the physiological burden they place on the wearer. The significant physiological burden of working whilst wearing an AFS is discussed. Research tests conducted by several different individuals are drawn upon. Particular significance is attributed to the work of Rowlands. The tests documented rely on physiological measurements including heart rate, rectal and skin temperatures and sweat loss, to assess heat stress.

Emphasis is placed on the importance of sufficient airflow to the AFS, especially during heavy work and even at normal ambient temperatures, in controlling heat stress. There is strong support for using Vortex tubes to cool the air supplied to the AFS when ambient temperature and work rates are high. The significant beneficial effect of this air-cooling on the wearer's physiological state is demonstrated by reference to a number of test reports.

The authors recommend that AFSs should be tested to evaluate their performance at a range of work rates, ambient temperatures and air supply flow rates and vortex cooling and that the manufacturer should outline the performance of the suit in terms of thermal properties.

7.2 AFS COOLING

7.2.1 The physiological effects of cooling (Webb 1969)

In this discussion document on the benefits of cooling of the AFS wearer, Webb asserts that cooling systems can act either to reduce external heat load, or to remove metabolic heat, or both. If there is increasing heat storage in the body, then the conditions are too severe to be maintained long term, and a heat tolerance limit must be observed. Failure to observe the heat tolerance limit will result in unconsciousness. At rest, a skin temperature of 33-35 °C is comfortable. At higher work rates, a lower skin temperature is required. Air cooling and water cooling can both be used; water cooling has the advantage that most people can be cooled in such a way as to render them comfortable with only minimal sweating (<100 g/hour), even at high work rates.

7.3 VORTEX TUBES FOR AIR COOLING

In addition to the work referred to in section 7.1.1 others have documented the use of Vortex tubes to cool air as it enters the AFSs or protective clothing. Vortex tubes are simple devices to which an airflow is applied which is separated into a cold airflow from one outlet, and a hot airflow from another outlet. The cold airflow is supplied to the AFS and the hot airflow is exhausted to atmosphere.

7.3.1 A feasibility study of the use of PVC Pressurised suits in workplaces at temperatures of 40 to 50^{0}C (Rowlands, 1970)

This is a theoretical account based on previous tests (Rowlands, 1966) of how it should be possible to allow AFS working at temperatures of 40^{0}C to 50^{0}C. Calculations are based on an air inlet temperature of 5^{0}C. Rowlands asserts that such a temperature is easily achievable by the use of Vortex tubes with an air supply of 20cfm (540 l/min) at 60 psi (4.1 bar) being required to supply 10cfm (270 l/min) of cooled air to the AFS.

7.3.2 Development and use of an air-cooled suit for work in nuclear reactors (Featherstone, 1988)

This AFS was designed to insulate from very high ambient temperatures, as well as protect against the particulate radiological hazard. The air is supplied to the AFS via a 50-60m length of hose. The temperature of that air can be virtually ambient (55^{0}C) by the time it reaches the AFS. Featherstone used a double vortex tube to reduce the temperature of the air supplied to the AFS to a comfortable level.

7.3.3 Cooling individual workers at a large atomic energy installation. Proceedings of the Symposium on Individual Cooling. (Croley, 1969)

Workers in a nuclear facility wore airfed suits for protection against radioactive and chemical hazards, in very warm environments (up to 43 °C). This severely restricted safe working periods, and so vortex tubes were used to cool the supplied air just before it entered the suit. Air supplied at a rate of 700 l/min and a pressure of 5.5-7 bar was found to produce cooling of 10-15 °C. The system is simple, lightweight and inexpensive. However, the vortex exhaust tube can become very hot and must be insulated. Also, considerable noise is produced, and this must be muffled for the comfort of the wearer.

7.3.4 Effectiveness of a Vortex Tube microclimate cooling System. (Pimental et al, 1987)

This is an account of a study which demonstrated effective reduction in heat stress to wearers of protective suits. A vortex tube cooled vest worn under the suit proved much more effective at maintaining heart rate and rectal temperature at an acceptable level, compared to the same suit worn without a cooling vest. Advantages of the cooling system were given as extremely low weight and cost, reliability and ease of operation, compared to other types of cooling vests. The only disadvantage was given as the need to be tethered to an airline.

7.3.5 Respiratory Protective Equipment at a large nuclear facility. (Zippler et al, 1976)

This report presented at a conference, includes a description of the use of Vortex tubes to provide cool air to AFSs in warm weather and hot environments to control heat strain. To provide 15cfm (405 l/min) of cool air to the AFS, the vortex tube required 20 cfm (540 l/min) of air at 80 psi (5.5 bar).

7.4 MICROCLIMATE COOLING SYSTEMS

Microclimate cooling systems are garments worn close to the torso (effectively vests) which are capable of extracting heat from the body and can be worn under outer clothing. They function in a number of ways. For example, passive systems use ice or frozen gel material, active systems circulate cooling liquid to remove the heat. The results of performance testing of these types of device are summarised in the following documents:

7.4.1 A review, evaluations of microclimate cooling systems. (Teal & Pimental, 1995)

Eleven studies conducted by the US Navy are reviewed in this document. Typically testing was carried out with the test subjects wearing standard navy uniform or chemical protective suits. Physiological measurements were taken and from the resulting data it was concluded that such systems are effective in reducing heat stress. Logistical problems associated with their use, including the need to replace ice packs and charge and replace batteries, are noted. The ILC Dover 1905 cool vest is concluded as the most effective in reducing heat strain.

7.4.2 Evaluation of Three Commercial Microclimate Cooling Systems (Cadarette et al, 1990)

The systems selected for testing included the ILC Dover Model 19 cool vest, which performed the most effectively in controlling body temperature. The test subjects wore permeable or semi permeable chemical protective clothing over the vest. Detail of the test procedure makes it clear that the ice needed to be replaced every hour, and the battery every two hours. The total weight of the system is given as 7.4 kg.

7.4.3 Endurance time in the self-contained toxic environment protective outfit (STEPO) with personal ice-cooled microclimate cooling system (PICS) in three environments. (Levine, May 2003).

The STEPO is an impermeable suit used with a closed-circuit rebreather. The PICS is a long sleeved top that uses water cooling from a small ice pack. When the ice pack was changed every 30 minutes, acceptable time limits for wearing the suit were 2.5 hours at 35 °C; 4 hours at 24 °C and 15.5 °C.

7.5 AIR CIRCULATION/DISTRIBUTION WITHIN THE AFS

The work described in section 6.3 (Rowlands, 1966) was carried out using a specific AFS, which was designed to provide good air circulation throughout. Rowlands appears to have assumed that good ventilation and air distribution is a basic requirement of AFS design in the interests of minimising heat strain. Others have quantitatively considered the effect of air distribution within the AFS design on heat strain.

7.5.1 Individual protection equipment and ergonomics associated with dismantling operations in a hostile environment (Teunckens et al, 2001)

This study looked at the effect of a newly adapted combined breathing and cooling air supply on AFSs used in nuclear decommissioning work. Physiological measurements (heart rate and rectal temperature) of suit wearers indicated that compared to the AFS equipment used previously there was a 20% improvement with respect to heat stress limits. AFS wearers achieved 100% recuperation during their lunch break.

7.5.2 Decontamination of Hot Cells K-I, K-3, M-1, and A-1, M-Wing, Building 200: Project Final report Argonne National Laboratory – East. (Cheever and Rose , 1996)

Within this report of a decommissioning project, Section 9.1 is entitled ‘Lessons learned’ in which a number of points are noted. Of significance to physiological strain control is the need for AFS wearers to utilise the air-distribution harnesses to distribute air throughout the AFS. This is to ‘provide effective cooling and to reduce sweat moisture’. No further details are given.

7.5.3 Assessment of the efficiency of personal protective equipment for use in radioactive contaminated Environment. (Bruhl et al 1996)

The work of IPSN (France) in this area of PPE is summarised in this conference document. There is a section on ‘Improvement of Physiological comfort’. Their tests have shown that direct skin ventilation, especially in hot environments, can increase work duration times by 50%. This is achieved by wearing underwear only under the suit and not the traditional clothing.

7.6 SIGNIFICANCE OF AIR TEMPERATURE INSIDE THE AFS

7.6.1 Work tolerance and physiological responses to thermal environment wearing protective NBC clothing. (Cortili et al, 1996):

This is an account of laboratory testing conducted whilst test subjects wore a head-ventilated impermeable NBC protective suit with a separate respirator sealed to the suit. Ventilation of the clothing was provided by filtered ambient air, pumped into the suit at up to 200 l/min. A range of test temperatures, relative humidity and two different ambient air flow rates were used during 32 tests. Test subjects were six healthy young male university students. No indication is given of any previous protective suit wearing experience. Physiological measurements (heart rate, rectal temperature and skin temperature) were taken whilst they conducted ‘medium intensity’ work. Oxygen uptake and the temperature within the suit were also measured.

The study concluded that when the air temperature inside the suit rose to 30^0C, wearing the suit even for moderate working imposed significant physiological stress. This applied to all tests but was particularly significant if the air humidity was high. All tests conducted at an ambient temperature above 20^0C had to be terminated early, before the end of the planned test time of two hours.

7.6.2 Heat and Mass transfer in Air-fed Pressurised Suits. (Tesch et al, 2007)

This is a report of recent work which attempts to predict the temperature of air exhausting from the suit using computational fluid dynamic software. The aim of the work is to enable scientific specification of optimum suit design and operating procedures for the physiological benefit of the wearer. The authors consider that the temperature of the air leaving the AFS is an important indication of thermal balance although the reason for this assumption is not given.

8 DISCUSSION

The use of AFSs for nuclear decommissioning work is subject to a number of regulations, which include the requirement placed on the employer to take account of the ergonomic needs of the wearer. COSHH and IRR require compliance with the PPE regulations and PPE at work regulations, both of which state that ergonomics must be considered. The HSE guidance which supports these regulations provides information on the ergonomic factors which should be considered. The suggestion that perhaps PPE should not be used if it presents a greater additional risk than ionising radiation, might warrant clarification as possible ways of controlling the additional risk perhaps ought to be considered first. HSG 53 uses the term heat 'stress', but all other guidance uses the term 'comfort', a word which has less of an implication of adverse effect on the wearer. Most of the HSE documents do not inform the reader of how to assess and control physiological risks. However, some of the newer documents published in 2005 on vibration and noise (section 2.7 and 2.8), and the manual handling assessment (MAC) tool (section3.3) give guidance on how to assess and control these particular risks in the workplace.

Lack of knowledge of what the physiological risk is, is likely to result in lesser weight being given to its importance (see ACSNI document, section 3.4). The significance of attitudes towards risk and the problems which uninformed and inappropriate attitudes can create in exacerbating risks are also discussed. The importance of creating a positive safety culture and involving and educating workers are central to the ACSNI document and HSG 60 (section 3.2).

Industry guidance documents and standards do give some advice relating to the physiological well-being of the wearer, whether stated as such or not. Limiting work time and specification of breathable air temperature and minimum flow rate is for the physiological benefit of the wearer. One document suggests restricting working time during warm, humid weather, but does not define 'warm' and or what working time restriction is necessary. Quantification of these ambient parameters and the working time restriction required would be more helpful.

Only one document came to light during the course of this literature review which could be used to assess and control the risk of heat stress whilst wearing a particular AFS. Laboratory testing and interpretation of the results (section 6.3, Rowlands, 1966) resulted in the production of several charts which could be utilised for such risk control. However this was only one piece of work, on one design of AFS, and one test subject, with good air distribution throughout the AFS and no additional PPE being worn. Wearer and AFS variability and the need to wear additional PPE and use power tools, all factors which apply to nuclear decommissioning work, were not investigated by Rowlands.

British Standards are concerned with maintaining a minimum standard in the provision of PPE. Whilst practical performance is assessed, it is a short (20 minute) subjective test. Objective testing over a period of time such as might be typical of an AFS wearer's shift, is not required. The standard for breathable air is concerned with quality and the absence of hazardous substances. Although the breathable air should be of low humidity there is no specification as to its temperature. Dexterity tests are only mandatory for one type of glove. Even if such dexterity test results are available for a given glove, the effect of using multiple glove layers will severely affect performance in this area. The ergonomics standards are technically complex and very much for the professional ergonomist to make use of, to ensure consistency of measurement and test methods.

The proportion of research documents which address the subject of heat stress prevention indicates that this is a significant concern for AFS wearers and body enclosing PPE wearers.

Wearer cooling is beneficial in controlling heat stress and trials of cooling devices have been documented. The most suitable for the AFS wearer appears to be the vortex tube, due to its lightness and low-maintenance reliability. The only disadvantage stated by one study into military chemical protective suits, was the need to be tethered to a compressor via an airline. An airline is of course essential for an AFS but the large amount of air consumed by the vortex tube is a disadvantage. In addition, the hot air exhausted to atmosphere from the vortex tube will add to the temperature of the working environment; this may be counter-productive if the suit is being used in a restricted space. Microclimate cooling vests have been demonstrated as being effective for PPE wearers, but the need to frequently recharge or change components makes them impractical for AFS wearers who are required to remain enclosed in their AFS for significantly longer than the recharge time. Another disadvantage is that the additional bulk and weight of the cooling vest device will add to the physiological burden on the wearer.

The importance of airflow and distribution throughout the suit and the significant improvement it can bring in reducing physiological strain has been highlighted by more recent research. The significance of the temperature of the air within the suit in indicating the thermal state of the suit wearer has been demonstrated by one laboratory study. Another researcher has assumed that the temperature of the air as it leaves the suit is a significant indicator.

9 CONCLUSIONS

Whilst there is no specific HSE guidance for AFS wearers, Health and Safety Regulations stipulate that the ergonomic requirements of all PPE wearers should be taken into account. HSE guidance explains the ergonomic risk factors which should be considered and there is general workplace advice and information on how to assess and control some physiological risks (including noise, vibration and manual handling). However, there is a lack of acknowledgement within HSE documentation of the risk of heat stress to PPE wearers and consequently no practical advice or information on how to assess or control the risk. The absence of knowledge of the extent of the risk may result in an underestimation. Workplace attitudes and practices may be increasing the physiological risk to the health and safety of AFS workers.

PPE product standards define minimum standards for product performance. Emphasis is on the ability of the PPE to provide adequate protection. A subjective ergonomic assessment may be required by some standards, but the test methods require significantly less wearer effort than nuclear decommissioning work.

Industry guidance and standards provide limited practical guidance on controlling physiological risks during nuclear decommissioning work.

Research suggests that the risk of physiological stress should be a significant concern for AFS wearers during nuclear decommissioning work. The use of Vortex tubes to cool the air supplied is well documented as a practical method of helping to prevent heat stress of AFS wearers. The air supply flow rate, temperature and distribution within the suit may be critical to preventing heat stress. The temperature of the air as it exhausts from the suit may be a good indicator of the thermal state of the AFS wearer.

10 RECOMMENDATIONS

HSE should commission on-site assessment of actual nuclear decommissioning operations in order to establish whether there is a significant physiological risk to the AFS wearer. As many sites as possible should be included in order to cover the diversity of equipment, workplace situations and practices.

Objective measurements and subjective assessments should be used to assess the physiological stress on the wearer. Representatives, including AFS wearers, from all sites should be involved in observation and assessment of work tasks and practices at each site, working with specialist scientists (ergonomics and psychology) to share and promote good practice and positive attitudes.

If the physiological risk is found to be significant, HSE should develop industry specific guidance on how to assess and control the physiological risks to the AFS wearer. This would require laboratory testing of the range of variables which may be encountered at sites such as suit design, ambient conditions, air supply parameters and additional PPE. The temperature of the air as it leaves the suit should be measured during such testing as it may prove to be a simple objective assessment of the thermal state of the AFS wearer.

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Physiological safety of airfed suit use during nuclear decommissioning

Literature Review

The amount of decommissioning work being carried out in the Nuclear Industry has increased substantially over recent years and is likely to continue increasing. Whilst such work may sometimes be conducted using remotely operated mechanical handling equipment, in many situations this is not a reasonably practical solution. Most decommissioning operations require work to be done by employees working in potentially hazardous environments. Operatives conducting this work are required to wear Airfed suits (AFS) to minimise risks from radioactive particulate hazards.

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