THE ROLE OF PERSONAL PROTECTIVE EQUIPMENT FOR RADIOLOGICAL DOSE CONTROL

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Arnhem October 2003

INTRODUCTION

The increasing complexity of processes and activities in the nuclear field and the growing awareness of the potential hazards associated with these processes have led to an increased dependence on the use of Personal Protective Equipment (PPE) in routine operations, and increasingly in the decommissioning of redundant facilities.

The main emphasis in personnel protection should always be directed towards preventing, eliminating or controlling the hazard by engineering or administrative methods, but there will be situations which require the use of PPE to protect the individual either from actual or potential hazards.

PPE in recent years has become more sophisticated and specialized, requiring careful selection, wearer training and effective maintenance. This has made the work more complex for employers and licensees responsible for the selection, use, maintenance and training of PPE.

In situations where engineering controls and techniques are not practicable or cannot guarantee the elimination of radiological hazards then in these circumstances PPE represents the most reasonable option or last barrier to protect the wearer.

It is essential that all persons involved in the management and use of PPE are aware of the capabilities and limitations of PPE to ensure the delivery of effective personnel protection.

Information about the workplace in which the PPE is to be used, the capability of the equipment and any limitations imposed on the wearer is required to allow rational PPE selection and optimum use to minimize risk to the wearer.

OBJECTIVES

The objective of this paper is to provide information on the basis of experience gained by BNFL in the use and management of personal protective equipment in meeting the challenges of protecting personnel from ionising radiation.

The paper discusses the practicalities of developing and implementing an effective PPE management system to protect personnel exposed to ionizing radiation in field areas such as, nuclear power plants, fuel recycling plants, and redundant facilities.

Lastly the paper attempts to highlight challenges of meeting new PPE standards and applying regulatory guidance to existing PPE systems.

DISCUSSION

1 Safety Standards

Today there is a wide range of protective equipment available in the marketplace. Generally the PPE employed by the nuclear industry that is manufactured and sold today is subject to many British, European and International Standards relating to the design and performance of the equipment. For example all PPE should carry the CE mark and be tested to the relevant European Norm (EN) where such tests exist.
The paper does not discuss the detail or requirements of Standards. However within the text there are examples of situations where PPE selection and standards have been adopted to comply with relevant statutory requirements or best practice from relevant guidance.

2 Policy

BNFL understands that radiological exposure responsibilities require policy, procedures and arrangements for personnel protection with priority given to engineered design and technical measures for controlling radiological hazards.
An objective of the text is to provide guidance on the development, management and use of PPE and to provide a generic practical guide for facilities and bodies responsible for radiological protection.

In relation to PPE employers / licensees should ensure as a minimum that their policy provides:

(a) Workers with suitable PPE which meets relevant standards and specifications
(b) Workers with adequate instruction in the proper use of personal protective equipment
(c) Suitable PPE to workers who are physically fit and capable of wearing the equipment safely
(d) Arrangements for PPE to be maintained in proper condition and if appropriate testing at regular intervals
(e) A suitable and sufficient assessment of non-radiological risks to ensure the suitability of the PPE
(f) Suitable PPE for an unplanned event or an emergency situation.

There are a number of additional requirements which impact on the effective use of PPE including:

(a) Delineation and control of areas
(b) Safety assessment
(c) PPE design requirements
(d) The monitoring of worker exposure
(e) Adequate record keeping
(f) System audit and review

3 Developing a PPE System

The primary objective of any PPE system is to assist in minimising risk of injury or harm to personnel. It is also essential to establish the operational requirements, needs and capabilities of the facility in order to develop the most effective system. The PPE system should therefore be based on a holistic approach of meeting the protection requirements of personnel and the organisation.

This section of the paper outlines further essential requirements of a management system with the objective of highlighting the main aspects of hazard identification, assessment, selection and use of PPE.

An effective PPE System should

- Take stock and understand site operations – through task analysis
- Identify and assess the potential hazards likely to be encountered
- Recognise who is at risk and requires protection
- Understand what level of protection is required
- Identify and select suitable and acceptable equipment
- Understand the capability of the equipment
- Introduce policy as required
- Provide suitable procedures and training
- Provide suitable facilities
- Review and audit the system for compliance and ongoing suitability

4 Hazard Identification

A fundamental element in defining any PPE system is the systematic and structured identification (**Recognition**) of existing and potential hazards in the work environment and the assessment (**Evaluation**) of the risks and the type of PPE required to provide satisfactory safe working conditions (**Control**).

Recognition	**Evaluation**	**Control**
Workplace Hazard Assessment	> Protection Requirements	> PPE Requirements

The first step in any assessment is to identify the hazard types the following are examples of common hazards:

Radiation exposure	*Toxic chemicals/dusts*	*Mechanical impact*
Heat / steam, hot liquids	*Toxic atmospheres*	*Low oxygen atmospheres*
Work in confined spaces	*Work at height*	*Noise and vibration*

Hazard analysis will require a comprehensive listing of activities during routine and potential abnormal conditions. The extent of the analysis should be in proportion to the scale of the operation and the extent and severity of the hazards.

Hazard can change with time and it is important that hazards and PPE suitability are reviewed periodically to take account of experience and changing operational conditions.

Identification and evaluation of the hazards should be a joint exercise between operators and safety personnel. Where practicable assessment should be part of a formalised risk assessment system with suitable forms and check lists. Where conditions are unknown or unpredictable it is recommended that a structured approach to hazard analysis be carried out to minimize the possibility of a hazard being overlooked.
It is the intention of this paper to concentrate on the radiological hazard. It is important however to recognize that PPE should protect against **all** hazards present as far as reasonably practicable. The selection of PPE commonly can be a compromise with the main protection focussed on the most severe hazard, which may not always be radiological.

The aim of the assessment process should be to identify and, where appropriate, quantify risks from the radiological, chemical, physical and biological hazards. The nature and relative severity of the hazards will determine the level, of protection required and the types of PPE to be considered.

Radiological Hazards

External Exposure
Radioactive material can expose persons to ionizing radiation by external exposure from sources in the work place or from contaminated clothing where there has been a transfer of contamination to protective clothing or skin causing direct exposure. Possible routes of external exposure can be direct radiation from an external source liquid, solid, vapour or gas that may expose all or parts of the body.

Internal exposure
Radioactive material can be deposited inside the body from various routes; by inhalation of radioactive airborne materials, absorption through skin directly, via cuts and punctures, and by ingestion.
Airborne activity is a significant potential direct source of internal exposure via inhalation. Surface contamination can generate airborne activity by re-suspension when work activities are carried out on the surface.

The principal indications of the degree of severity of radiological risks present will depend on:

a) The type, nature and quantity of the source
b) The operations to be carried out
c) The duration of the operations
d) Airborne activity concentration - Derived Airborne Concentration or Bq /m3
e) Surface contamination - usually stated as the activity per unit area Bq/cm^2
f) Radiation levels - expressed as dose rates in the work areas

Non Radiological Hazards

Chemical hazards can be segregated into irritants, corrosives, sensitisers ,carcinogens and toxins. Specific chemical effects should always be identified as part of the hazard assessment and considered in the PPE selection process.

Physical hazards must not be overlooked in the PPE selection process. Care must be exercised so that these safety hazards are given careful consideration since many of them can be seriously injurious e.g. working at height.

Biological hazards may arise in biological laboratories where pathogens and toxins are handled or for example in reactor cooling towers where Legionnella bacteria may be present in significant concentrations.

Human factors can generate additional hazards to the existing work place hazards such as allergic reactions, increased physiological stress, and excessive breathing resistance from some filtering respirator types.

Environmental factors such as temperature and humidity should also be considered at an early stage as these adverse types of conditions could exclude certain types of PPE.

For normal operations it will be possible to predict the type, nature, extent and significance of additional non-radiological hazards present to employ suitable engineered barriers and then assess any residual risks in order to select the most effective PPE.

5 Types of PPE

This section considers the general types and characteristics of PPE that is widely used and available. The generic types of PPE can be divided into the following groups:

1. Respiratory protection equipment (RPE)
2. Protective suits and garments
3. Gloves
4. Footwear
5. Other equipment

Respiratory Protective Equipment (RPE)

The level of protection offered by a respirator is commonly referred to as the protection factor. The protection factor is generally defined as the ratio of the contaminant concentration in workplace air to that of inhalable air inside the respiratory protective device.

Manufacturers and test houses use standardized test methods under controlled laboratory conditions to obtain a Nominal Protection Factor (NPF).

In British HSE guidance (HSG 53 The selection,use and maintenance of Respiratory Protective Equipment) the NPF has been replaced by the Assigned Protection Factor (APF). For a given respirator type, or category, a device has been given a specific APF.

The APF is considerably lower than the NPF and will vary significantly for different respirator devices. RPE such as breathing apparatus (BA) provides continuous positive pressure and offers higher effective workplace protection factors than a filtering device.

The APF is a guide not a hard and fast rule for identifying or selecting equipment. Protection levels can fall below the APF when RPE is unsuitable for the task and is not suited to the wearer and the environment.

However, where an effective RPE management system is in place it is possible to achieve protection at or above the APF value. The actual or real protection factor achieved under operational conditions is dependent on a number of design, environmental and human factors.

There are two distinct methods of providing personal respiratory protection in contaminated atmospheres:

- By purifying contaminated air before it is inhaled by using a filtering air purifying respirator
- By supplying uncontaminated air or oxygen from an independent source

For respiratory protection the physical form of the radiological hazard must be known to permit proper selection:

a) For particulate hazard most types of RPE provide protection to different degrees
b) Radioactive vapours require specialized respirators and the correct canister must be selected.
c) Radioactive gases can only be controlled by independent supplied air equipment.

Filtering RPE are tight fitting devices that depend entirely on the seal between the mask and the wearer`s face. This method of protection against particulate matter, gases and vapours used in respirators, is based upon filtering the contaminated atmosphere before inhalation occurs by the respirator wearer. Respirator fit testing is mandatory at all BNFL nuclear facilities.

Respirators may be two types:

a) Negative pressure respirators where the wearer's lungs are used to draw air through the filter
b) Powered devices with a battery-driven fan to draw air through the filters and deliver it to the wearer

Respirators are fitted with filters designed to remove particulate matter, gases or vapours from the atmosphere.

In general, particle filters will be equally effective against any particulate matter. Gas and vapour filters based on activated charcoal will only absorb a small range of chemical substances for which they are specifically designed.

If the contamination is in the form of an aerosol with particles and gases / vapours present in the workplace air then combination particulate and charcoal filters must be used.

Protective Garments and Clothing

Protective clothing in the form of suits, boots, hoods and gloves, provide a barrier between the wearer and the workplace hazard. The degree of protection provided by the clothing is dependent on matching a suitable protective material with the physical / chemical nature of the contaminant as well as the item`s design and construction.

BNFL employ air-fed suits, non-ventilated re-usable suits and limited use disposable types .
The protective suits are generally employed to provide skin protection from radioactive contamination, powders and chemicals with a radiological component.
The type of suit selected for a given task will depend on the contaminant challenge as well as the environmental and physical robustness requirements of the task.

The level of protection provided by protective garments, gloves and footwear from chemical exposure is determined by standardized tests for penetration and permeation. Specific test results for a large variety of barrier materials are available from the manufacturer of the protective clothing item.
The results from these tests must be used carefully because they are normally tested in the laboratory on the suit material, not the whole garment, using a single challenge chemical. If direct contact of toxic materials with protective garments, gloves or footwear is expected and there is no available penetration or permeation data, then laboratory tests should be carried out on potential manufacturers` products to provide data. This data can then be used to select the most appropriate PPE.

Protective suits are available with or without integrated head cover or hood for application in radiological environments. The relatively new standard EN 1073/2:Protective clothing against radioactive contamination, recommends that all protective suit ensembles should be able to pass the test criteria as stipulated.
Due to the rigorous inward leakage test in the standard some suits will be unable to attain the pass criteria and would therefore, in theory, be excluded from selection and use for radiological contamination protection.
This standard is now being widely acknowledged throughout the UK as the relevant standard for radiological protective suits. Compliance with this standard will require a full review of how we use suits and coveralls in the future.

The selection of the appropriate protective clothing is however limited by what is commercially available and the number of garments successfully tested to the standard.
There are now examples of suits being carefully tailored to pass the test and not suitable for practical use.
To some extent PPE suit functionality can be compromised through manufacturers successfully meeting test house performance criteria.

Gloves

When selecting the range of gloves for use in a facility, care must be taken to ensure that the appropriate types are specified and overall suitability for the operational use. The material should provide the protection required whilst ensuring enough dexterity.
Further consideration should be given to whether the gloves are integral, taped or worn “loose” to ensure compatibility with existing protective suits and to provide a suitably safe interface between glove and suit to maximise protective performance.
Glove s for radiological protection can be captured in three broad categories:

- Rubber (latex) gloves for hand contamination protection
- Chemical protection gloves to protect against corrosive rubber permeable chemicals
- Mechanical gloves rubber coated to protect against cuts and punctures

Footwear

Apart from providing barrier protection, the appropriate range of footwear should also be selected with an aim to prevent the spread of activity. Footwear can be categorized as overshoes, conventional work shoes or boots.
For work in areas with the likelihood of contamination conventional work shoes are appropriate. Overshoes made of light fabric or cotton provide low protection and are used only in areas of low contamination. Boots are used in wet areas or when a suit is worn. Shoes and boots can be decontaminated and reused.

Other PPE

This can include a diverse range of protective equipment such as:

- (i) Suits incorporating a cooling system (ice vests) for working in high temperature environments
- (ii) Modified equipment for welding incorporating a welder’s mask, eye protection shield
- (iii) Suits resistant to specific chemical attack made from specialist materials and coatings.
- (iii) Modified over garments to protect air-fed suits from plasma size reduction techniques
- (iv) Body apron, often leather or lead impregnated

6 Selection of PPE

The basic aim in the use of PPE for all types of hazards is to provide a barrier between the environment and the wearer. The type of barrier can range from a pair of gloves to a totally encapsulating suit depending on the nature and severity of the hazard. A wide range of PPE is available to reduce exposure to radiological hazards..
The fact that the protection factors provided by different PPE are variable, depending on the type of activity and the environmental factors necessitates a careful matching of PPE to task. The PPE will have to be suitable to meet the challenge of the expected and occasionally unexpected circumstances.
The factors affecting the selection of equipment include:

- a) The type of equipment available;
- b) The results of the hazard assessment
- c) The subsequent level of protection required
- d) The environment conditions in which the PPE is to be used
- e) The availability of support systems to test and maintain the PPE
- f) The frequency and type of use
- g) The user acceptability (comfort, hygiene, freedom of movement)
- h) The cost of purchase, delivery, storage, maintenance requirements and facilities
- i) The need for disposal, decontamination and recycling
- j) The compatibility with other equipment being worn.

For protective suits and clothing the degree of protection required will be determined largely by levels of surface contamination present or likely to be encountered and the type and extent of airborne contamination. It is important that the requirements for protective clothing and respiratory protection be considered together.
The protection factor achievable by providing personal protective equipment should be balanced in relation to the cost and estimated hazard reduction. In regions of high contamination and high radiation fields it is the ability to work quickly and reduce working time, which may be a more critical factor in dose reduction.

Specialist protective equipment and PPE combinations will need to be considered when radiological and other conventional hazards are present together. For example:
Head protection: Safety helmets may be used generally for protection if worn outside suits
Eye protection: Safety goggles may be worn inside ventilated garments.
Heat: Cool vests where prolonged exposure in hot environments is expected
Welding: Outer protective apron to protect against hot debris.
Chemical: Suits resistant to specific chemical attack

Factors Effecting Selection of PPE

Human Factors
All forms of PPE can impose restrictions on the wearer to some extent, for instance, decreasing mobility, increasing resistance to breathing, reducing the field of vision. The selection procedure should ensure that the equipment has the minimum detrimental effect on the wearer and his ability to do his job.
All forms of PPE generate some discomfort due to the very nature of providing protection. It should be recognized that personal, environmental and task factors all contribute to the level of discomfort, and human performance. Attention should be focussed when operators wear multiple items of PPE to ensure that protection of the overall combination plus the individual items provides the expected and required protection.

PPE Design Factors Affecting Selection

The design of PPE should aim to use materials that will not cause irritation or allergic reactions. The mass of garments should be as low as practicable and of a material that does not seriously impair movement or impair visibility.

Individual Factors Affecting Selection

The availability of different sizes of the PPE to accommodate different wearers, e.g. male and female are important factors influencing the selection of PPE. Other equally important considerations concern the expected physiological load on the user for the types of work envisaged. The tasks requiring PPE should only be assigned to those individuals medically capable of safely sustaining the extra effort required to wear the PPE.

The effect of working in PPE can be demanding and the need to regularly check physiological well being of the wearer should be considered. When wearing PPE the working time may need to be restricted particularly in warm, humid weather or at high work rates.

7 Management Requirements

The implementation of a PPE system and its incorporation into facilities operations requires an effective management system to ensure that basic safety objectives are met.

The facility processes and tasks will be well known in the case of existing plant but may be conceptual for a facility being decommissioned. In both cases it is important that the hazards are identified and then eliminated or minimized by engineered means wherever reasonably practicable.

After the application of engineered hazard reduction methods then consideration should be given to the provision of PPE to manage any residual risk. The provision of suitable and adequate PPE within the framework of an established personnel protection system should be the final means of worker protection.

The PPE arrangements must cover both normal use and protective requirements during abnormal or emergency situations.

The management system should define responsibilities and document any requirements for PPE selection, use, training, testing, storage, inspection and maintenance. In addition an audit plan should verify that the activities are being carried out in accordance with management objectives. It is important that management systems are developed to produce a continuous improvement in cost effectiveness and safety deliverables.

Support Arrangements

The effective and safe use of PPE requires suitable facilities and procedures to ensure that the PPE can be used to achieve its purpose. Support arrangements must cover any residual activities as part of an overall radiological protection programme to ensure effective control of contamination and radiation exposure.

The nature and extent of support facilities will vary according to the degree and nature of the hazard, the PPE to be worn and the frequency and duration of work to be carried out.

Training

It is essential that training and education be provided to enable wearers to be fully competent and confident in the effective use of PPE. Personnel must be made aware of why PPE is needed, how to wear it, how it protects them and what to do if the unexpected happens.

Training should aim to include both theoretical and practical aspects and the content should match the complexity and degree of reliance placed on the equipment. Basic theoretical and practical training will depend on the type and use of the PPE and how frequently it is used.

Theoretical training should include:

a) An explanation of the risks due to exposure to radiation and contamination
b) the operation, capabilities and the limitations of the chosen equipment
c) the factors which can degrade the protection provided by the PPE
d) the physiological effects and limitations of the use of PPE e.g. heat stress

Practical training should include:

a) Dressing and undressing for PPE items
b) Practice in the inspection and testing of equipment before use

c) Rehearsing emergency procedures

RPE training should emphasize the basic operating principles and the need for achieving a satisfactory seal with respirators and the limitations on where certain types can be worn.
Practical training for relatively simple respirators may take little time, whereas more complex equipment may require extended training. Refresher training will be required for more complex equipment or for equipment where use is sporadic or non-routine.
Adequate records of training must be maintained to identify each individual's requirement and achievements.

Maintenance

The aim of maintenance is to ensure that PPE is capable of achieving its specified performance and can provide the required degree of protection when worn.
The extent and frequency of maintenance is usually recommended by the equipment manufacturer. The manufacturer can perform the maintenance. However, relatively few manufacturers have the capability to provide specialist service arrangements for a large radiological PPE Maintenance is carried out at BNFL by a dedicated internal department.
Where PPE is to be re-used it may be convenient for equipment to be collected at a central point at the end of each work period for cleaning and inspection. Items with faults should be discarded or repaired.
RPE should be stored in dust free containers away from sunlight, heat, extreme cold or excessive moisture. They are normally kept in labeled and dated sealed plastic bags at designated points. RPE should be packed or stored such that the rubber face piece does not receive excessive pressures that could distort the rubber face piece.
Suits made from PVC can be laundered and recycled successfully. After cleaning, suits must be re-monitored to confirm that cross contamination has not occurred during the cleaning process and inspected to identify any physical damage. Care should be taken to follow manufacturer's instructions for storage of PVC suits to maintain integrity.

Inspection and Testing

The objective of testing is to verify that the condition, functionality and safety of the equipment conforms to established levels and standards. Inspection and testing forms an important Quality Assurance element of any PPE programme. The key elements are:

i. To verify the quality of purchased equipment
ii. To check that equipment is ready and fit for use
iii. To examine integrity and safety after use
iv. To regularly inspect and maintain equipment

PPE must be kept in a good condition to perform properly even if it is new. A suitably qualified and experienced person must perform the control and maintenance operations to ensure that the tests are done properly.

Quality Assurance & Auditing

The PPE system should be part of an overall Quality System of the organization. The Quality System encompasses the structure, responsibility, processes and resources for implementing quality management.
The overall objectives are:

a) To define and achieve the quality of the product or service;
b) To provide evidence and confidence that the required quality is being achieved.
h) To provide procedures to ensure that training, tests, inspections are being carried out regularly
i) To provide procedures for a reporting system on the use of PPE
j) To carry out periodic audits to confirm that procedures are being followed
k) To investigate reported failures with the aim of further improving PPE systems

The Quality arrangements will include regular reviews of the process and procedures, and demonstration that the procedures are being followed in practice. The information can then be used to update or upgrade the PPE system. In particular, changes in process should be identified rapidly to ensure that the PPE remains adequate and suitable.

CONCLUSION & SUMMARY

The application of PPE is an essential component of radiological dose reduction programme has been proven over many years at BNFL. The reliance on PPE systems to protect will continue as a means of practical personnel protection.

The dangers of over reliance on PPE without an effective PPE Management System can not be over emphasised. Without the essential support and infrastructure described earlier then adequate protection levels may not be achieved.

The paper attempts to illustrate the potential for dose reduction in an effective PPE management system. It highlights some of the limitations and potential non-radiological hazards that can arise in other conventional safety areas through employing inappropriate PPE systems.

There is always a compromise of basic personal comfort, safety and human performance whenever any item of PPE is worn. The extent of the compromise is usually directly proportional to the amount, complexity and duration of the PPE worn.

PPE should however always be considered as the “Last Resort” for the good reason that if an item fails it generally fails to an unsafe condition.

The principles of ALARA / ALARP have driven us to an increasing use of PPE in our industry in an attempt sometimes to remove the smallest residual risk.

There are of course moral and legislative drivers for greater dose reduction achievements. The use of PPE should only be one part of a holistic approach in which we provide protection. An over dependence on PPE should be avoided.

BNFL try to match the residual hazard with the appropriate type of PPE. We also make every attempt to anticipate the potential for unforeseen events or accident to further eliminate a source of potential radiological exposure.

For much of the time in Radiological or in Occupational protection we wear our PPE much as you would wear a car seat belt, you drive your vehicle daily but you do not expect to require the protection from your seat belt ,but it is there just in case.