PRACTICAL RADIATION TECHNICAL MANUAL

PERSONAL PROTECTIVE EQUIPMENT

IAEA
International Atomic Energy Agency

PERSONAL PROTECTIVE EQUIPMENT

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2004

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IAEA-PRTM-5

Printed by the IAEA in Vienna
April 2004

FOREWORD

Occupational exposure to ionizing radiation can occur in a range of industries, such as mining and milling; medical institutions; educational and research establishments; and nuclear fuel facilities. Adequate radiation protection of workers is essential for the safe and acceptable use of radiation, radioactive materials and nuclear energy.

Guidance on meeting the requirements for occupational protection in accordance with the Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (IAEA Safety Series No. 115) is provided in three interrelated Safety Guides (IAEA Safety Standards Series No. RS-G-1.1, 1.2 and 1.3) covering the general aspects of occupational radiation protection as well as the assessment of occupational exposure. These Safety Guides are in turn supplemented by Safety Reports providing practical information and technical details for a wide range of purposes, from methods for assessing intakes of radionuclides to optimization of radiation protection in the control of occupational exposure.

Occupationally exposed workers need to have a basic awareness and understanding of the risks posed by exposure to radiation and the measures for managing these risks. To address this need, two series of publications, the Practical Radiation Safety Manuals (PRSMs) and the Practical Radiation Technical Manuals (PRTMs) were initiated in the 1990s. The PRSMs cover different fields of application and are aimed primarily at persons handling radiation sources on a daily basis. The PRTMs complement this series and describe a method or an issue related to different fields of application, primarily aiming at assisting persons who have a responsibility to provide the necessary education and training locally in the workplace.

The value of these two series of publications was confirmed by a group of experts, including representatives of the International Labour Organization, in 2000. The need for training the workers, to enable them to take part in decisions and their implementation in the workplace, was emphasized by the International Conference on Occupational Radiation Protection, held in Geneva, Switzerland in 2002.

This Practical Radiation Technical Manual was developed following recommendations of a Technical Committee meeting held in Vienna, Austria, in

November 1994 on the development, management and operation of a personal protective equipment system for use in radioactively contaminated environments. Major contributions to this PRTM were made by R. Wheelton, United Kingdom.

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PERSONAL PROTECTIVE EQUIPMENT

This Practical Radiation Technical Manual is one of a series that has been designed to provide guidance on radiological protection for employers, radiation protection officers, managers and other technically competent persons who have responsibility for ensuring the safety of employees working with ionizing radiation. The Manual may be used with the appropriate IAEA Practical Radiation Safety Manuals to provide training, instruction and information for all employees engaged in work with ionizing radiation.

Introduction

Personal protective equipment (PPE) includes clothing or other special equipment that is issued to individual workers to provide protection against actual or potential exposure to ionizing radiations. It is used to protect each worker against the prevailing risk of external or internal exposure in circumstances in which it is not reasonably practicable to provide complete protection by means of engineering controls or administrative methods. Adequate personal protection depends on PPE being correctly selected, fitted and maintained. Appropriate training for the users and arrangements to monitor usage are also necessary to ensure that PPE provides the intended degree of protection effectively.

This Manual explains the principal types of PPE, including protective clothing and respiratory protective equipment (RPE). Examples of working procedures are also described to indicate how PPE should be used within a safe system of work.

The Manual will be of most benefit if it forms part of a more comprehensive training programme or is supplemented by the advice of a qualified expert in radiation protection. Some of the RPE described in this Manual should be used under the guidance of a qualified expert.

1. RESTRICTION OF EXPOSURE

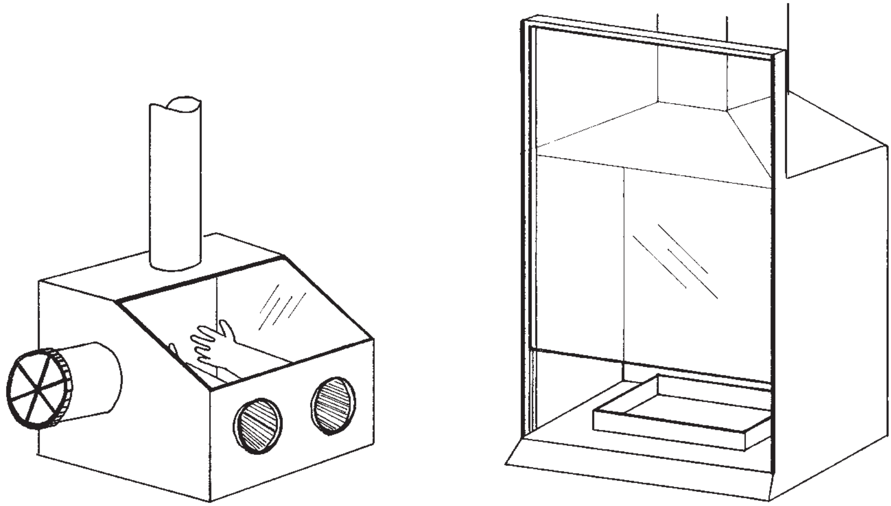
Workers can be protected against ionizing radiations by using either one or a combination of the following means:

(A) Engineering controls
(B) Administrative methods
(C) Personal protective equipment (PPE).

Whenever it is reasonably practicable, protection should be provided 'at the source'. This may involve selecting a radioactive substance of the most appropriate activity and form for a specific application, such as using a source of the minimum activity necessary and in a physical form that is least likely to spill. The term also implies that priority should be given to using engineering controls as a barrier around the source, automatically protecting workers in the vicinity against external and/or internal exposure. The practice should preferably be inherently safe by design.

Protection against external exposure may be achieved by using a combination of shielding and distance. Effective devices and warnings are needed to ensure that the source remains shielded and/or that the correct distance is maintained between the source and those who may potentially be exposed to the radiation hazards. Protection against internal exposure is achieved by containing radioactive substances and/or preventing their dispersal, to avoid causing contamination. Containment can be supplemented, if necessary, by further engineering controls such as extraction ventilation from a point (or points) close to where any dispersion is likely to occur. High efficiency particulate air (HEPA) filters incorporated into the ventilation system will remove radioactive particulates from the extracted air.

Administrative methods are less satisfactory than engineering controls because their effectiveness relies on the co-operation and awareness of individual workers to restrict exposures. For example, exposures might be restricted by limits on who may enter or on how long workers may remain inside controlled and supervised areas.



Engineering controls to contain radioactive material.

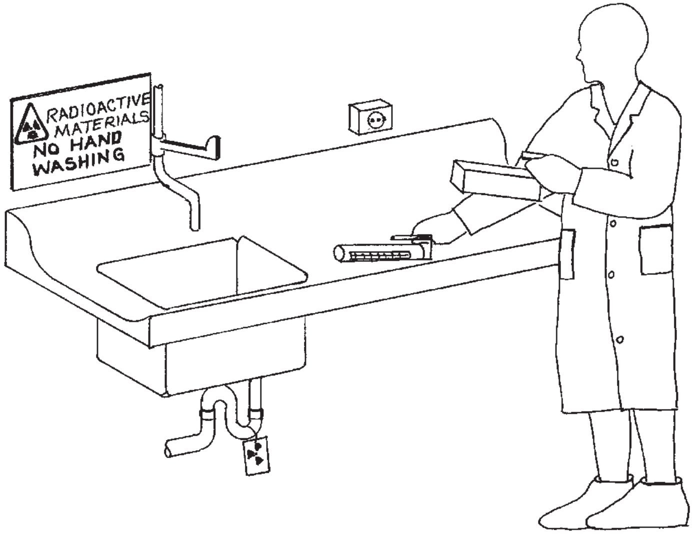
A tray is used to provide simple containment for minor spills and drips. A fume hood is necessary to adequately contain vapours from volatile radioactive substances. The fume hood must draw a sufficient draught of air to provide adequate engineering control. A glovebox is necessary to provide total containment during the manipulation of very hazardous materials such as fine powdered alpha emitters.

2. USE OF PERSONAL PROTECTIVE EQUIPMENT

As an administrative method to restrict exposure or, as a last line of defence, where neither engineering controls nor administrative methods are reasonably practicable, workers should use PPE. The use of PPE may be the only means of controlling the exposure of workers involved in emergency operations. PPE includes clothing or other special equipment that is issued to protect each exposed worker. It is essential that all persons involved in the management and use of PPE are aware of its capabilities and limitations, in order to ensure that an adequate, reliable and planned degree of personal protection is provided.

Different PPE may be used to protect against external and internal exposures. Protective clothing may be designed to shield large areas of the wearer's body or individual organs, such as the eyes, against external irradiation. However, protective clothing and equipment is more frequently used to prevent radioactive substances either making direct contact with or entering the body and delivering internal exposures.

Respiratory protective equipment (RPE) is intended to prevent the inhalation of radioactive substances which would result in radiation doses to the lungs and other organs into which the substance(s) might ultimately pass or which might be irradiated by them.



Administrative controls and PPE in support of engineering controls.

Engineering controls: The bench profile is designed to contain a spill and the location of the integral sink and the electrical socket minimizes the buildup of radioactive contamination.

Administrative controls: The warning notice and a tag on the drainpipe to prevent unauthorized workers entering a contaminated pipe provide administrative controls.

Personal protective equipment is used as a last line of defence.

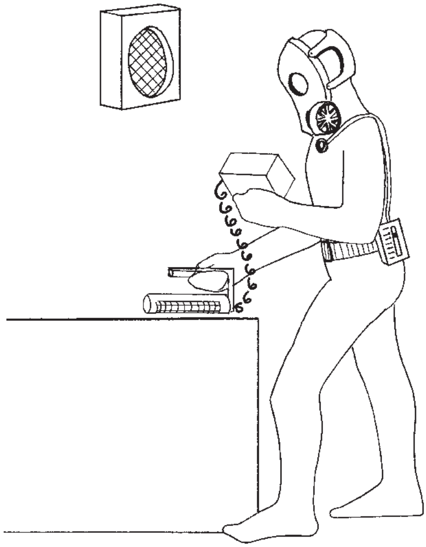
3. THE SELECTION OF PERSONAL PROTECTIVE EQUIPMENT

Three essential items of information are necessary before selecting PPE:

(A) *The nature of the exposure.* Both qualitative and quantitative information is needed about conditions in the workplace. Surveys, as described in the Manual on Workplace Monitoring for Radiation and Contamination (IAEA-PRTM-1), can be performed to determine the radionuclide(s) present, the type of potential exposure(s) and magnitude of possible doses, the physical form of the radiation source(s), and the nature and concentration(s) of any contamination. The radiological risks need to be considered together with other hazards to appreciate the difficulties of accomplishing the work wearing PPE.

(B) *Performance data for PPE.* Data are needed to assess the ability of available and/or approved PPE to reduce the particular exposure(s). This information will usually be available from the manufacturers, who will have carried out tests under controlled conditions as specified in international or national regulations and standards.

(C) *The acceptable level of exposure.* PPE should aim to minimize or even to eliminate exposure. In practice a decision will be made, preferably by a qualified expert, on whether the PPE could in theory provide adequate protection below internationally agreed dose limits or other constraints.



The nature of any potential exposure in the workplace is assessed.

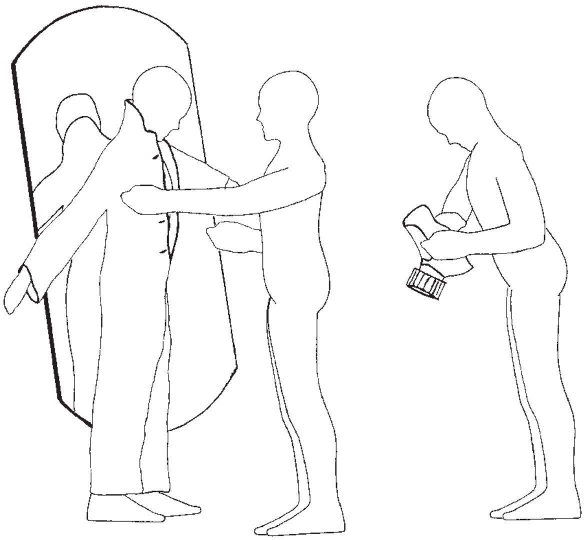
Measurements are made using personal air samplers (belt mounted) and surface and airborne contamination monitors to assess working conditions. Any contaminants present need to be analysed to provide information necessary to select suitable PPE.

4. FITTING, USING AND MAINTAINING PERSONAL PROTECTIVE EQUIPMENT

Maximum protection will only be obtained in practice if the PPE is fitted, used and maintained to the standards specified for the manufacturer's tests.

PPE are manufactured in limited ranges of size for workers of average build, often of a single gender group only. It may be necessary to try different products of a similar specification to find PPE that is comfortable and a good fit and that provides the necessary protection. The workers' training must emphasize the need to fit and use the personal protection correctly each time.

PPE needs to be routinely cleaned, checked and maintained in accordance with the manufacturer's recommendations. The users can be relied upon to carry out or to arrange for cleaning but appropriate arrangements must be in place. For example, either there must be a central system for cleaning or suitable materials must be supplied, both to encourage the action and to ensure that unsuitable cleaning methods or agents are not used. A central system for cleaning facilitates the carrying out of checks, maintenance and repairs. This maintains the level of protection and helps to prolong the life of the PPE. The use of disposable PPE reduces the need for maintenance, but it will still be necessary, for example, to maintain dispensers and to dispose of contaminated clothing.



PPE must be fitted, used and maintained properly.

PPE should be selected to fit individual workers. The training of workers should emphasize the need to use PPE correctly and equipment should be checked and maintained regularly.

5. INFORMATION, INSTRUCTION AND TRAINING

The various individuals and groups normally involved in a system in which PPE is used should all receive adequate information, instruction or training. Their needs differ but may include the following, for example:

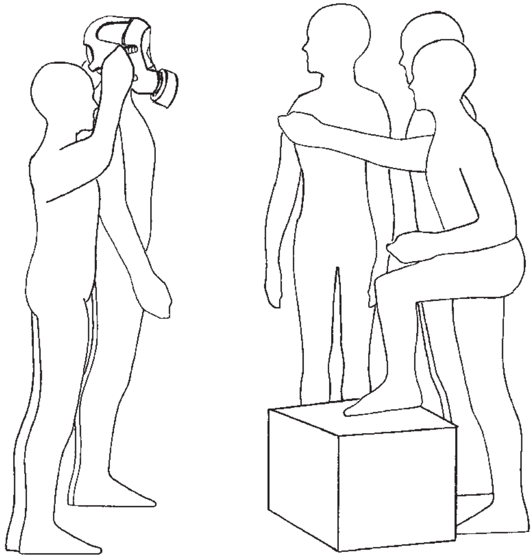
– The manager responsible for the system needs information on appropriate surveys, on the selection of suitable equipment and literature from the manufacturer of the equipment. Management skills are necessary to set up an appropriate system and to maintain its effectiveness in practice.

– Workers need instruction on the specific hazards of the workplace and the consequences of unprotected exposure. Their training should include where, when and how protective equipment is obtained, fitted, used and cleaned. They will also need to recognize faulty equipment and hazards which may arise from use of the equipment.

– Storekeepers need to know how to store and issue the correct equipment properly.

– Maintenance and cleaning staff need to be trained in how to clean equipment properly, how to assess damage and wear, and how to ensure effective repair or replacement. The potential exposure of cleaning staff must be taken into account.

– Supervisors need all of the above and clear instructions which define their responsibilities. They need to provide for refresher training and to ensure that recruits to the system receive appropriate and adequate initial information, instruction and training.



Workers should be trained to use PPE.

Managers, users, storekeepers, maintenance staff and supervisors will have specific requirements for appropriate information, instruction and training.

6. MANAGEMENT OF A SYSTEM OF PERSONAL PROTECTIVE EQUIPMENT

The effectiveness of PPE depends on good management, supervision and monitoring of the system. The system needs to be defined in written procedures with the full support and commitment of senior management. PPE may make work more difficult or more demanding and may not be popular with all workers. Managers and supervisors need to recognize this and to set an example by using personal protection whenever, and for however short a time, they enter areas in which the system is in place.

Supervisors need to monitor whether the protective equipment is being used correctly and consistently; whether it is being cleaned and maintained; and whether provisions for training are being utilized and are adequate. They also need to be alert to possible problems, such as changes in conditions that might render the PPE inadequate, or hazards which the PPE might create or exacerbate (see Section 29).

Supervisors and workers need to keep managers informed of changes in the workplace or processes and changes or improvements in available PPE. There must be clear guidelines for any disciplinary action(s) that would be taken against workers who do not comply with obligations under the system.

A system of work involving PPE has to be properly managed.

To ensure that it provides the intended protection, a system of work has to be set down in writing and everyone involved in it has to comply with the requirements. The system has to be adapted to meet changes as they arise.

7. DESIGNATED AREAS

Whenever there is a potential for occupational exposure to ionizing radiation, a prior evaluation of the radiological risks is necessary in order to consider the need for classifying the working area. Workplaces are designated as controlled areas if specific protective measures or safety provisions are or could be required for:

(A) Controlling exposures or preventing the spread of contamination in normal working conditions, and

(B) Preventing or limiting the extent of potential exposures.

Although specific protection measures and safety provisions are not normally necessary, the working area is classified as a supervised area if it is not already designated as a controlled area but if the conditions of occupational exposure need to be kept under review.

The system of work for a designated area should include the use of PPE if its use would be reasonably practicable, and if it would potentially either reduce the doses to those who work in the area or prevent the dispersal of contamination from the designated area. If the protective equipment is essential, access to the area must be restricted and the PPE should be specified as a condition of entry, such as on a written permit to work in the area. Under these circumstances barrier discipline is essential.

Routine and task related monitoring should be performed as described in the Manual on Workplace Monitoring for Radiation and Contamination (IAEA-PRTM-1). The Manual on Individual Monitoring (IAEA-PRTM-2) describes methods to verify the effectiveness of the practices for control of radiation.

The validity of using PPE and the possibility of replacing it with more suitable engineering controls or redesigned processes should be considered in regular assessments.

Specific protective measures or safety provisions apply in controlled areas.

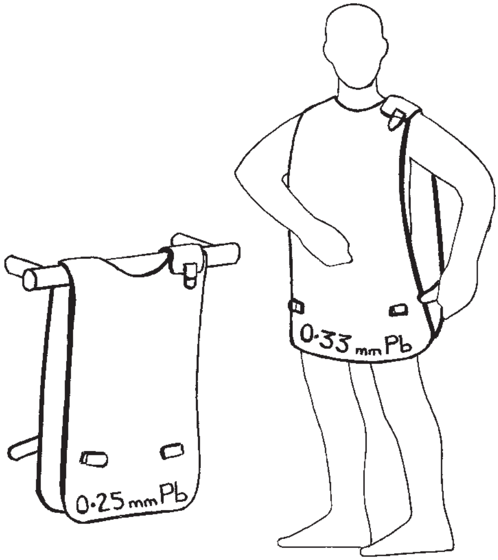
The extent of controlled areas should be clearly defined. Where practicable, the boundaries coincide with fixed barriers, such as the walls and doors of a room. Notices are posted to display appropriate warnings and to prohibit unauthorized access.

8. APRONS TO PROTECT AGAINST PENETRATING RADIATIONS

Flexible aprons with a thickness up to the equivalent of 1/3 mm of lead (written as 0.33 mmPb) are available to shield the upper torso. Double sided aprons shield the chest and the back against radiations scattered behind the body. The aprons attenuate, by about 90%, low energy radiations such as scattered X rays (of tens of keV). However, these aprons are ineffective against the more penetrating primary X rays and gamma radiations (above 100 keV) used more widely in nuclear medicine, radiotherapy and industry.

Wearing an apron for prolonged periods is tiring, which is why garments do not incorporate more substantial shielding. The aprons are cumbersome and may slow down work and thus result in higher personal doses if they do not provide adequate protection.

Aprons must be stored flat or on rounded hangers. Folding or creasing causes cracks or wear in the shielding. Such damage, although minor, may lead to repeated exposure of the same area of the body. An outer fabric cover may need to be removed to inspect the shielding visually. More thorough examinations, including radiographic or fluoroscopic tests, should be carried out periodically (annually). Damaged aprons should be discarded or clearly labelled as being only for uses other than as a body radiation shield. The outer cover can usually be wiped clean with water and mild detergent.



Protective aprons in use and storage.

Aprons provide insignificant protection against the more penetrating radiations. Inappropriate use of aprons can increase personal exposures. Storage conditions and checks are essential to avoid using damaged aprons.

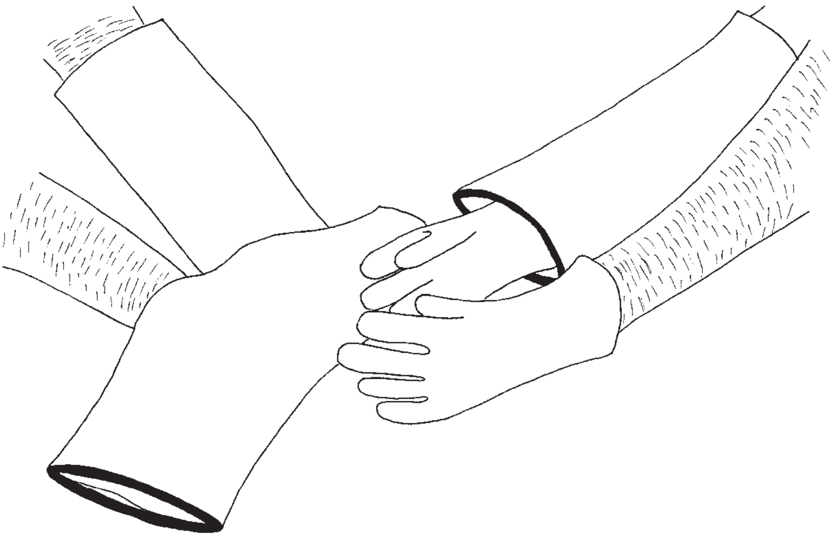
9. GLOVES AND OTHER SHIELDS AGAINST PENETRATING RADIATIONS

Shielding gloves and sleeves containing up to 0.33 mmPb are manufactured. Like aprons, they are ineffective shields against most radiations other than electrons (beta particles) and low energy scattered X rays.

Wearing the gloves reduces dexterity and consequently, if used inappropriately, will result in significant hand doses and greater body doses by prolonging the exposure.

The sleeves are flexible and, when used as local shielding, provide good cover for the extremities. The double thickness provides better protection against external exposure and leaves the fingers free to accomplish the task in the minimum time and with the minimum dose.

Gloves and sleeves must be stored flat. Folding or creasing causes cracks or wear in the shielding. These may be minor but may reduce the level of protection. An outer fabric cover may need to be removed to inspect the shielding visually. More thorough examinations, including radiographic or fluoroscopic tests, should be carried out periodically (annually). The outer cover can be wiped clean with water and mild detergent but severe contamination is problematic.



Protective gloves and sleeves in use.

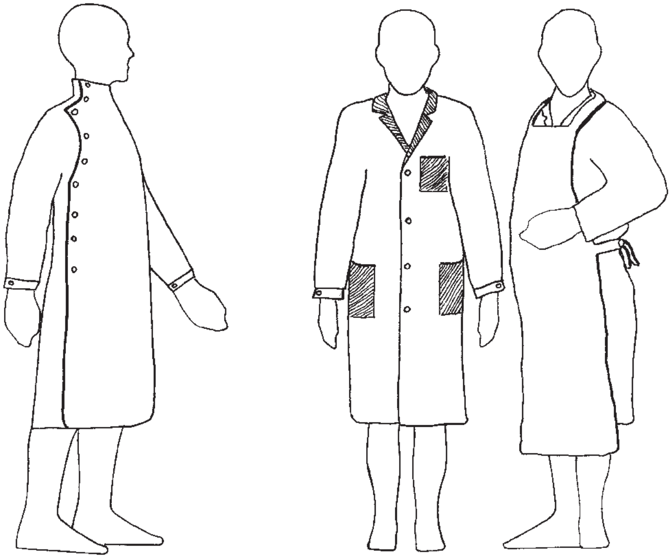
Gloves and sleeves give poor protection against the more penetrating radiations. Sleeves used as local shielding provide better protection. Wearing gloves reduces dexterity. Storage conditions and checks are essential to avoid using damaged shielding.

10. LABORATORY COATS TO PROTECT AGAINST RADIOACTIVE CONTAMINATION

Laboratory coats (labcoats) made of cotton or synthetic fibres are commonly used in research laboratories and hospital departments where there is a risk of minor radioactive contamination. The conditions of the work, such as whether flammability needs to be considered, are a factor in the selection of the fabric. Short jackets and smocks do not protect the lower body. Full length coats need to be fully fastened to ensure that spills or splashes of radioactive substances do not contaminate personal clothing underneath. Labcoats that fasten along one shoulder and the side of the body provide better coverage. Strip fasteners (such as 'Velcro'), instead of buttons, allow the garment to be removed more easily following a spill. Additional protection can be obtained by wearing a disposable plastic bib apron over a labcoat when there is an increased risk of contamination.

Labcoats protect the wearer but also serve to contain any contamination inside the designated area. Labcoats should always be monitored after working with radioactive substances. Barrier discipline dictates that labcoats should not be worn outside the designated areas. Storage lockers or hangers should be provided inside the designated areas.

Labcoats should always be monitored for contamination before being laundered. A coloured collar or pocket covers can help to identify garments that are subject to this routine. Seriously contaminated garments need to be decontaminated, perhaps by soaking or allowing a period of time for radioactive decay, before being sent to the laundry. Seams in particular should be carefully checked before reuse to ensure that persistent contamination will not continue to irradiate the body surface underneath.



Labcoats and aprons protect against radioactive contamination.

Protective clothing needs to cover the parts of the body likely to be exposed to contamination. Clothing is not worn outside the designated area(s) and is monitored and decontaminated as necessary.

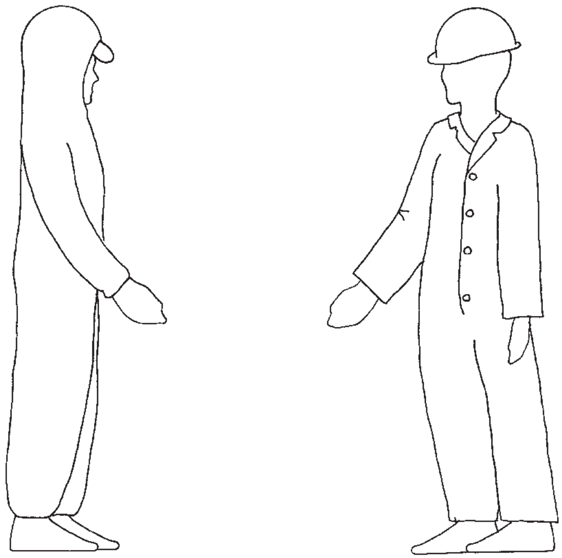
11. INDUSTRIAL SUITS TO PROTECT AGAINST RADIOACTIVE CONTAMINATION

One piece suits, coveralls, overalls or 'slicker suits' are used at industrial workplaces to protect against radioactive contamination the parts of the body covered by the clothing.

Suits are available with or without integrated head cover or hood to allow use with different types of RPE (see later sections). Elasticated hoods and arm and leg cuffs give more comfort and ensure that body surfaces remain covered.

Permeable suits are most comfortable for long term wear. Woven garments retain contamination, minimizing resuspension. For more severe conditions, impermeable suits made of rubber or plastic coated or non-woven fabrics are available. Products vary in durability, in their resistance to chemicals, flames and heat, in comfort, in cost, and so on. They also tend to cause and retain perspiration. Some products are more comfortable and flexible, although they may have lower protection factors. Suits are ventilated through sleeves, seams, valves, filters or sometimes several small holes, possibly concealed. Fully encapsulating, impermeable, pressurized suits (see Section 28) provide the highest level of protection.

The suits can be decontaminated before removal, if this is practicable without further hazard, to avoid transferring or resuspending contamination when removing them. Alternatively, they might be sprayed with a fixative, removed and retained inside a designated area pending specialist decontamination. Seams in particular should be checked carefully to ensure that they are decontaminated. Minor damage to suits should be repaired, as appropriate, in accordance with the manufacturer's instructions.



Industrial suits protect against radioactive contamination.

Industrial suits are available in different materials and styles. Permeable suits are most comfortable; impermeable suits are used in more severe conditions. Suits are monitored and decontaminated as necessary.

12. GUIDE FOR CHOOSING PROTECTIVE SUITS

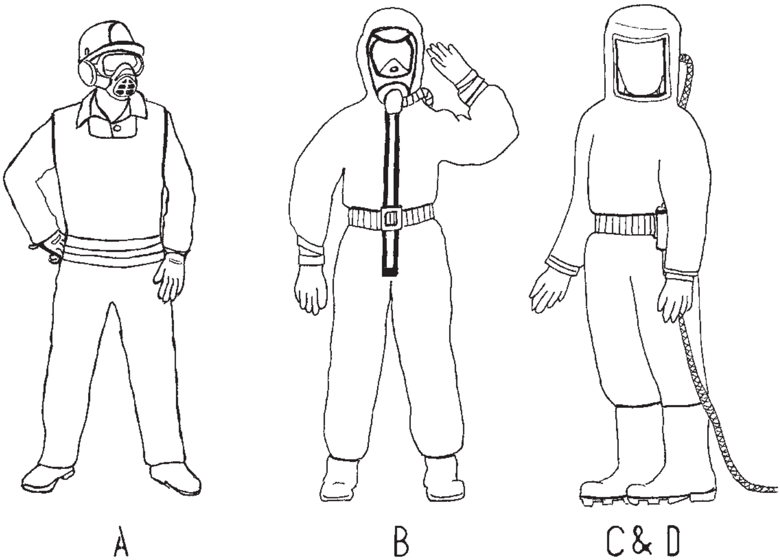
Protective clothing normally displays or is labelled with a trademark or other means of identifying the manufacturer, the product type and the intended purpose. The latter may be in the form of a pictogram or symbol with an indication of the suit's intended level of performance. Manufacturers also typically supply information relating to the care and use of the PPE, and may be willing to discuss the tests applied and performance data. A list of performance levels, preferably in a table of performance, helps in choosing the most appropriate suit for the intended work. Table I is not specific to any particular manufacturer or recognized standard, and is intended only as general guidance for choosing protective suits.

TABLE I. PERFORMANCE LEVELS

Suit type	Expected surface contamination				Expected airborne contamination			
	Solid		Liquid		Aerosol		Gas	
	Low	High	Low	High	Weak	High	Weak	High
A. Non-ventilated, non-pressurized, permeable fabric or non-woven	✓ + R				✓ + R			
B. Non-ventilated, non-pressurized, impermeable	✓ + R	✓ + R	✓ + R	✓ + R	✓ + R		✓ + R	
C. Ventilated, impermeable	✓	✓	✓	✓	✓	✓		
D. Ventilated, impermeable	✓	✓	✓	✓	✓	✓	✓	✓

Notes

✓ = Type of garment is suitable.
+ R = Use together with appropriate RPE depending on specific conditions.
Type C = Air escapes freely through sleeves and seams.
Type D = Exhaust devices such as valves or filters are fitted; pressurized.



Industrial suits of different types provide varying degrees of protection.

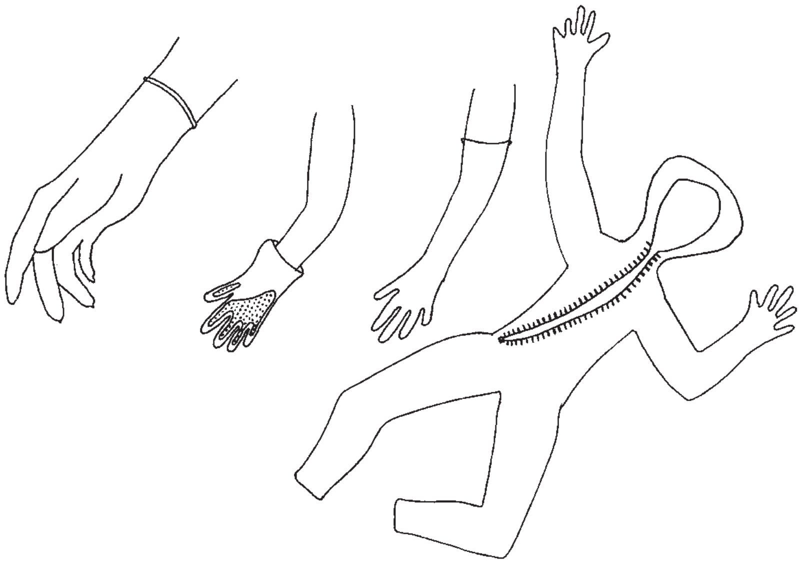
Type A suits are unventilated and are made of permeable fabric or of non-woven material. Type B suits are unventilated but impermeable. Types C and D suits are ventilated and impermeable.

13. GLOVES FOR PROTECTION AGAINST RADIOACTIVE CONTAMINATION

Protective gloves range from lightweight disposable polythene gloves to gloves made of other synthetic materials, various fabrics and elastomers, leather, mineral fibres, glass fibre and so on, or from a mixture of materials. They may be available in different sizes or as stretch to fit; as long gauntlets extending above the elbows or small handpads and mitts covering just the fingers and thumbs; or as separate items, or a fixed or detachable part of a protective suit.

Gloves should be selected to provide the necessary protection while allowing sufficient dexterity. A lightweight polyvinyl chloride (PVC) or thin natural rubber latex (NRL) surgeon's glove may be suitable for laboratory use where maximum sensitivity and flexibility and a good grip are necessary for accurate work. Heavyweight PVC gloves are more appropriate in a harsh industrial environment. They need to form a barrier against contamination as well as protect against any other harmful agents present such as solvents, chemicals, physical hazards and severe climate. Some users of NRL products suffer allergic reaction after contact with either the glove or the glove powder. Symptoms may range from localized skin and eye irritations to asthmatic reactions and, in extreme cases, systemic shock. Using a different powder or cream or wearing gloves of a different material under the protective gloves can help.

Elasticated sleeves pulled down over the gloves or tape around the cuffs prevent the wrists from being exposed to contamination. Gloves that become contaminated or damaged should be discarded. This is not feasible when the glove is an integral part of a suit, which is an advantage for gloves that mechanically lock onto the suit. Gloves that are not disposable may need to be properly decontaminated in special facilities.



Gloves of different types for protection against radioactive contamination.

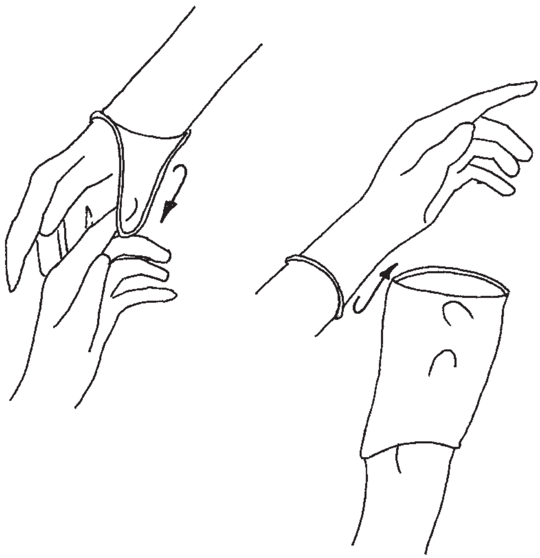
Gloves are available in a wide range of fits and materials to suit different working conditions.

14. PROCEDURE FOR REMOVING CONTAMINATED GLOVES

Gloves are likely to become contaminated more easily than other protective clothing. Procedures should be practised to deal with problems that can arise without spreading the contamination to unaffected surfaces or areas.

Contamination may not be easily removable from the gloves, but having paper tissues or paper towels ready to hand will enable tools, monitoring instruments, gas and power controls, handles, communication aids and other essential items to be manipulated through the clean paper.

At an appropriate time and place, gloves should be removed without allowing the contaminated external surfaces of the gloves to make contact with an unprotected hand. This is normally achieved by gripping the outside of the cuff of one glove and pulling the glove inside out but without fully removing it. The fingers inside the turned out glove can then grip the other glove and pull it inside out and off. The partially removed glove is then fully removed turning it fully inside out. The contamination is safely contained on the inside of the turned out gloves.



Procedure for removing contaminated lightweight gloves.

Gloves are the most likely form of PPE to become contaminated. Gloves are removed by a special technique to avoid transferring contamination to other surfaces.

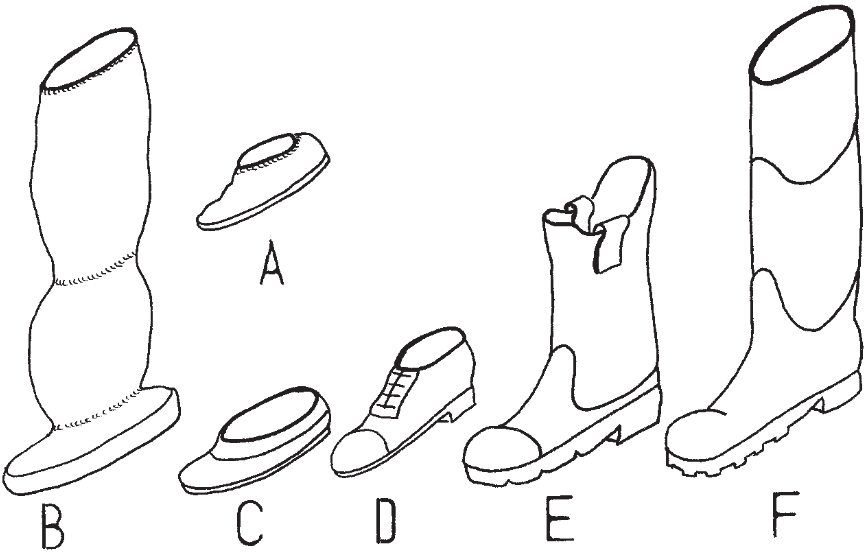
15. FOOTWEAR FOR PROTECTION AGAINST RADIOACTIVE CONTAMINATION

Protective footwear includes overshoes, ‘booties’, shoes and boots.

Overshoes allow personal footwear to be worn in areas where there is a risk of a minor spill or drips contaminating the floor. In their simplest form, overshoes are disposable, single size, foot shaped plastic bags with elasticated openings. More expensive and durable but possibly less effective are outsized plastic shoes (C). These do not fully cover the personal footwear and may not provide a tight fit over it, especially over heels. Fabric overshoes (A) with hard soles and booties (B) and fabric overshoes with legging supported at the knee by elastic or drawstrings provide further inexpensive options.

In an industrial environment, where safety shoes (D) or ‘rigger’ boots (E) with steel toecaps are needed, colour coded footwear of the type is often issued for entry to designated areas. Rubber, rather than leather, safety boots (F) may be preferred to facilitate decontamination or to carry out wet work. Trouser cuffs, preferably elasticated, should be pulled down over the bootleg to complete the protection. Fully encapsulating, impermeable suits (see Section 28) incorporate appropriate footwear.

Fabric overshoes can be decontaminated by allowing a period for radioactive decay and soaking and/or laundering before reuse. Boots and shoes may need deodorizing and hard brushing or grinding to remove impacted contamination.



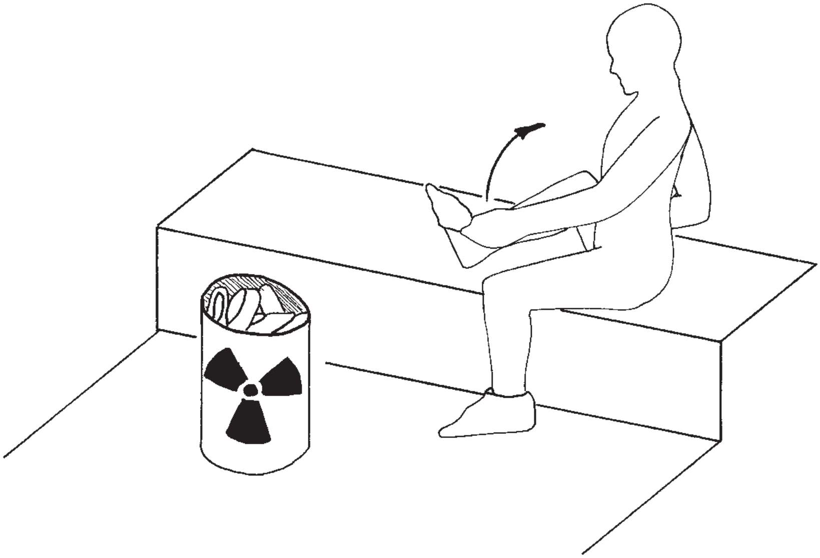
Footwear of different types provides protection against radioactive contamination.

Overshoes and safety shoes are worn in potentially contaminated areas. Shoes are monitored and cleaned or disposed of as appropriate.

16. BARRIER PROCEDURES FOR PROTECTIVE FOOTWEAR

The reason for using protective footwear is primarily to contain any floor or ground contamination within the designated area. In this respect protective footwear differs from other PPE which has a more direct effect in reducing doses to the worker. Ordinary, personal footwear could be worn where there is only a small risk of potential contamination, but the inconvenience of having to decontaminate or confiscate footwear may be unacceptable.

Barrier discipline is imperative to the effectiveness of protective footwear. A physical barrier should be set up between clean areas and the designated 'dirty' area. After placing personal footwear in appropriate storage in the clean area, clean overshoes may be donned before stepping over the barrier. On return, after removing other protective garments, the worker approaches and sits on the barrier. The worker removes one overshoe before immediately swinging the shoeless foot over the barrier. The other foot may then be lifted to remove the second overshoe and again swinging the leg over the barrier without the shoeless foot touching the dirty area floor. Dirty overshoes may not leave the dirty area.



Procedure for removing contaminated footwear.

A disciplined shoe change procedure at the barrier is essential to contain contamination in the designated area.

17. TYPES OF RESPIRATORY PROTECTIVE EQUIPMENT

There are two categories of RPE with several subdivisions in each category (see Sections 19–28):

(i) *Respirators* purify the air by filtering out particulate materials such as dust or low concentrations of gas or vapour. The most common types are:
(A) filtering face piece respirators;
(B) half mask respirators;
(C) full face mask respirators; and
(D) powered respirators fitted with a fan and filter(s) to supply air to a half mask, full face mask, visor, hood or helmet, blouse, half suit or full suit.

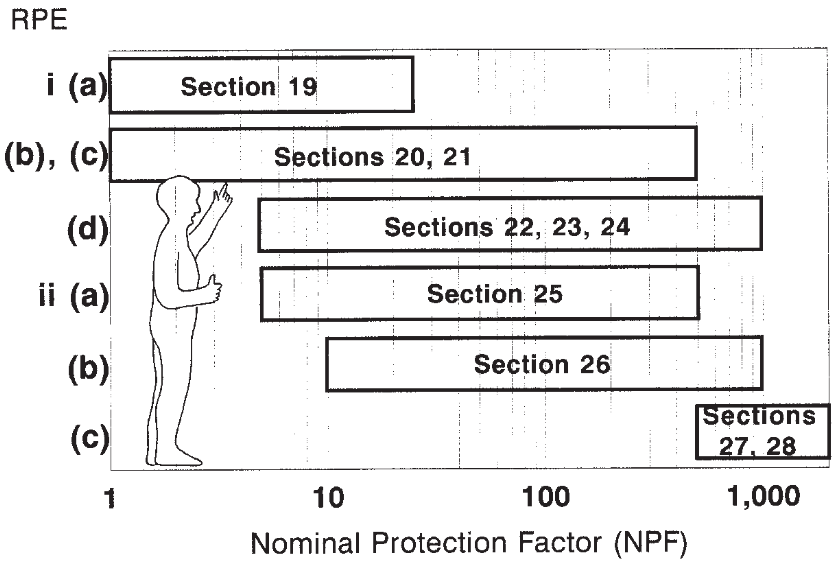
(i) *Breathing equipment* provides clean air or oxygen from an independent, uncontaminated source. The most common types are:
(A) fresh air hose equipment,
(B) constant flow compressed air equipment, and
(C) breathing apparatus which includes full face masks and full suits supplied either from compressed air lines or self-contained cylinders of compressed air.

RPE and some other types of PPE can have an assigned protection factor (APF) defined by national standards and referred to in national regulations. In a typical system, RPE is performance tested to determine the inward leakage (IL) as the ratio of the concentration of the test particles inside the RPE (or PPE) to the challenge concentration of test particles in the test chamber. This is expressed as a percentage, the challenge concentration corresponding to 100%. The manufacturer may quote the inverse (100:IL), called the nominal protection factor (NPF), which is the expected ratio of the concentration of contaminant in the ambient atmosphere to the concentration of the contaminant inside the RPE (or PPE).

The effectiveness of a respirator in minimizing inward leakage depends on two parameters:

(i) the integrity of the face seal
(ii) the filtration capability of the selected canister or filter medium (see Section 20).

Changing either or both of these factors can have a significant effect on the degree of protection actually achieved.



Ranges of nominal protection factors for different RPE.

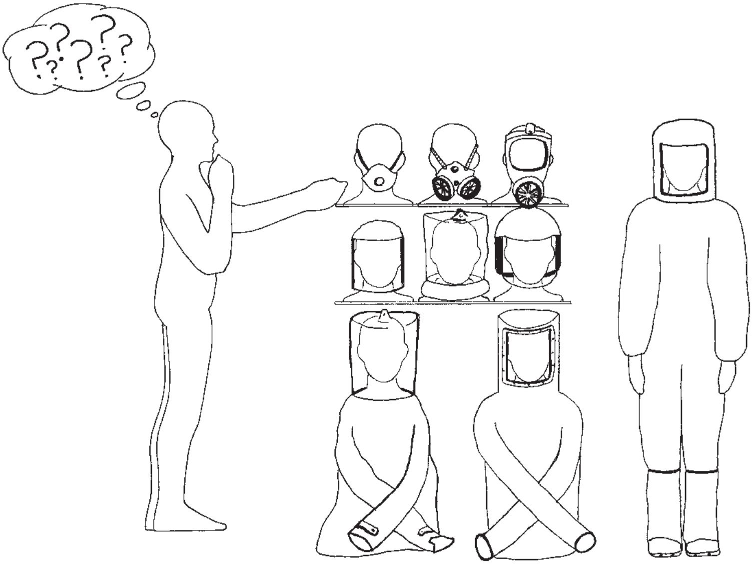
The two main types of respiratory protective equipment (RPE) are (i) respirators and (ii) breathing equipment. Subdivisions of these types of RPE are described in later sections of this manual.

18. SELECTION OF RESPIRATORY PROTECTIVE EQUIPMENT

Several types of RPE might have the necessary APF/NPF to conform with the predicted contamination and/or measurements (see Section 7) taken to determine the physical form and concentration of contamination in the workplace. The choice could include all types of RPE to protect against low concentrations of a particulate contamination. Radioactive vapours and gases would restrict the choice to certain types of respirator or breathing equipment or, for adequate protection against contaminants at high concentrations in the ambient atmosphere, breathing equipment may be the only possibility. Tritium gas has a high diffusivity and necessitates special considerations to prevent its inhalation, ingestion or absorption through the skin.

The APF/NPF indicates the theoretical best protection that can be achieved. If, in addition to RPE, protective clothing is to be used, then the total ensemble has to provide the necessary protection factor. The specified protection factor might not be achieved in practice for various reasons. For example, if equipment that relies on a face seal does not fit the size and shape of a worker's face, the necessary seal will not be possible. Facial hair, even growth over the working day, will lift some masks, possibly by enough to allow inward leakage of contaminated air. In these circumstances, or perhaps to permit prescription spectacles to be worn, RPE such as hoods, visors, blouses or suits would be a better alternative. The problem of facial hair also may be addressed by means of administrative requirements for all potential male users of RPE to be clean shaven.

Although APF and NPF are used interchangeably in this document, there can be significant differences depending on national regulations and standards. In using the system described (in Section 17), for example, a regulatory authority may specify and enforce the use of RPE with an NPF of 3 for work in situations of low hazards, but may require the use of RPE with a higher factor of at least 100 for continuous use as a standard general purpose respirator for work with radioactive substances.



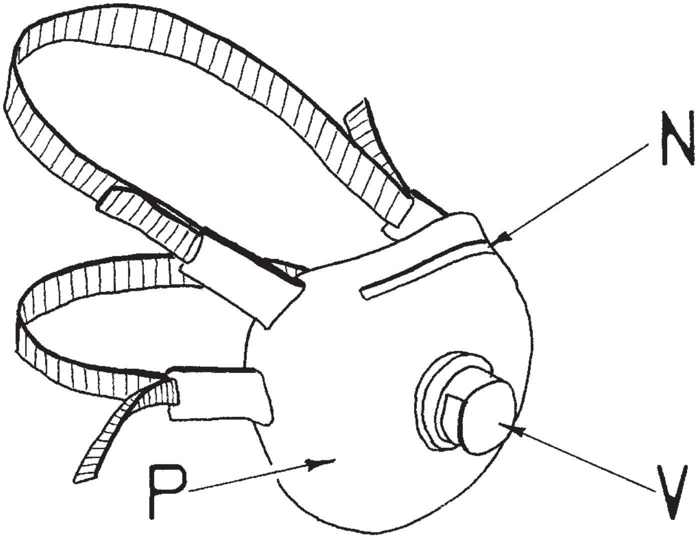
Selection of suitable respiratory protective equipment.

An adequate APF/NPF has to be combined with meeting other conditions. The APF/NPF is the best theoretical protection that the RPE can provide, but this might probably not be achieved in practice. RPE must be used properly to give the best protection.

19. FILTERING FACE PIECE RESPIRATORS

Filtering face piece (FFP) respirators are made wholly or substantially of filter material (P) which covers the nose and mouth. The face piece is held in place by straps and a nose clip (N), which helps to complete the seal. Air is drawn through the material by underpressure when the wearer inhales. Some models incorporate an exhalation valve (V). FFP respirators are mainly used for protection against low to moderately hazardous particles. They should not be confused with nuisance dust masks which only filter larger, low hazard dust particles. Some models are capable of filtering malodorous (but not toxic) gases and vapours.

The nominal protection factor of FFP respirators is relatively low, but the highest retention efficiency filters, class FFP3, provide adequate protection for either low risk and limited risk areas or for short exposures within the specified limits. Their use helps to keep contaminated gloves away from the mouth area but they provide no protection for the eyes and should not be used where skin contamination is a hazard. FFP respirators are easy to use and relatively inexpensive. They are usually described as disposable, for a single shift or single use only, and they should not be reused. They may retain contamination that can be monitored as an aid to assessing working conditions.



A filtering face piece respirator (FFP).

A FFP provides minimal protection for use in low hazard situations. They should not be reused.

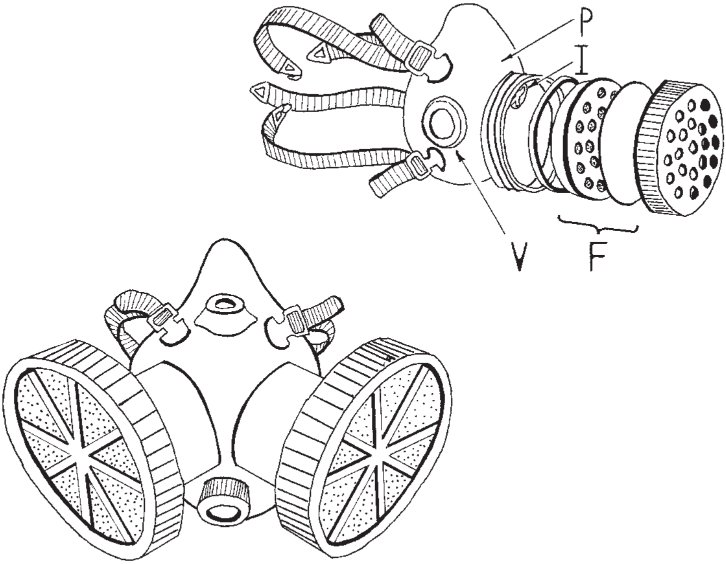
20. HALF MASK RESPIRATORS

The elastomer half mask or orinasal respirator is a face piece (P) of rubber or plastic moulded to cover the nose and mouth and is held in place by adjustable straps. Air is drawn through one or more filters (F) and, where fitted, an inhalation valve (I). The filters are contained in one or more cartridges (canisters). Exhaled air is discharged to atmosphere through an exhalation valve (V) in the face piece.

Replaceable filters are available for particulate contaminants, gases and vapours. Their NPFs are usually much higher than for disposable FFP respirators but their real advantage is that the filter cartridges have a higher absorption capacity for gases and vapours and provide safe containment for subsequent disposal of the contaminant.

Specified gases and vapours are usually absorbed in a bed of activated carbon (charcoal) which may be impregnated with suitable chemicals to enhance the capacity to absorb or react with certain classes of chemicals such as acidic gases. If the contaminant is in the form of an aerosol, both particles and gases and/or vapours may be present in the workplace air and a combination of particulate and activated charcoal filters has to be used.

Half mask respirators provide no protection for the eyes and should not be used where skin contamination is a hazard.



Half mask respirators with single and multiple cartridges.

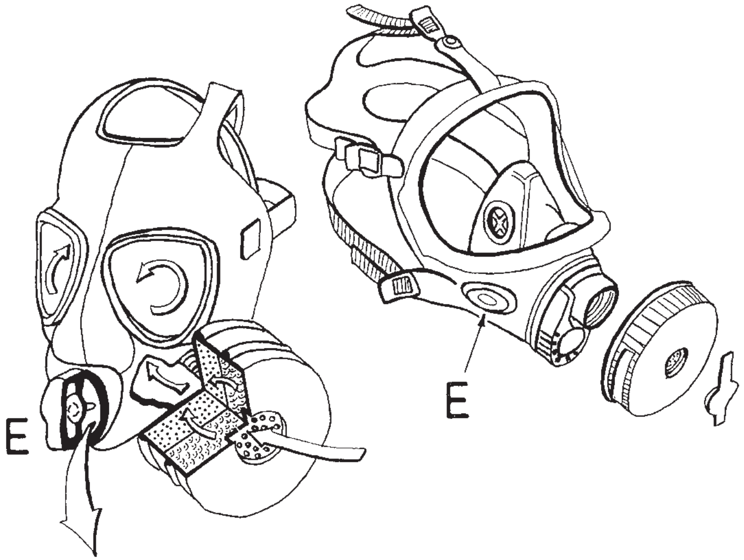
Different cartridges are designed to filter particulate materials, vapours and gases from the air before it is inhaled. Contaminants are safely contained within the filter cartridge.

21. FULL FACE MASK RESPIRATORS

A moulded face mask of rubber or plastic covers the entire face from just below the hairline to beneath the chin and is held in place with an adjustable head harness. Air is drawn through one or more filters and, where fitted, inhalation valves. Exhaled air is discharged through an exhalation valve (E) in the mask. Various models are manufactured, with either a single panoramic visor or individual eyepieces. The inner nose cup mask minimizes the possibility of misting ('fogging') and prevents the buildup of carbon dioxide. To prevent fogging due to moisture in exhaled air, antifogging compounds should be applied to the inside of the visor or the full face mask. The face mask can incorporate a speech diaphragm or microphone and provision for prescription corrective lenses.

The range of available filters is described in Section 20. The larger or multiple cartridges (canisters) can be used, with more comfort than is provided by the half mask, to extend the duration of use. The low inward leakage at the face seal enables the use of high efficiency particulate air (HEPA) filters, which would be over specified for filtering half masks.

Particulate filters indicate the end of their useful lifetime by the increase in resistance to breathing. A noticeable loss of resistance may indicate a hole or leak in the filter, face seal or cartridge (canister) gasket. Carbon (charcoal) filters cannot be tested and there is no feasible method to establish the residual capacity of a filter when it has once been used. The NPF offered against particles by a properly fitted full face mask respirator could be high. The wearer has to monitor the apparent protection being provided by RPE and has to leave the designated area if there is any noticeable deterioration.



Full face mask respirators with visor or individual eyepieces.

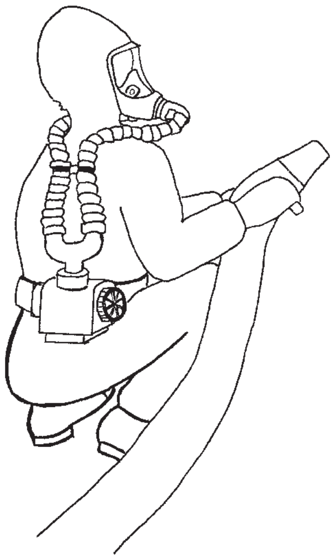
Usually a seal has to be removed before a cartridge is used for the first time. Larger and/or multiple cartridge masks extend the period over which the respirator may be used. Full face masks provide protection for the eyes against radioactive contamination.

22. POWERED AIR PURIFYING RESPIRATORS WITH MASKS

Powered air purifying respirators provide a continuous flow of air into the mask in order to minimize inward leakage of contaminated air around an incomplete face seal. Ideally, the NPFs are then only determined by the filter characteristics and are higher than the NPFs of non-powered respirators.

Contaminated air is drawn through one or more filters by a battery powered fan and the filtered air is delivered to the mask. The ventilator is usually mounted on a belt but it may be incorporated into the mask. Half masks or full masks may be used but the latter are preferred. Exhaled air is discharged to atmosphere through valves of various designs in the mask. Filters are available for particulate contaminants, gases and vapours. These respirators use approximately three times as many filters as their non-powered counterparts because of the increased airflow.

Powered air purifying respirators are desirable under conditions of increased workload because they make breathing easier. If the ventilator fails, the face mask gives the wearer enough time to escape a contaminated area.



Powered respirator with full face mask.

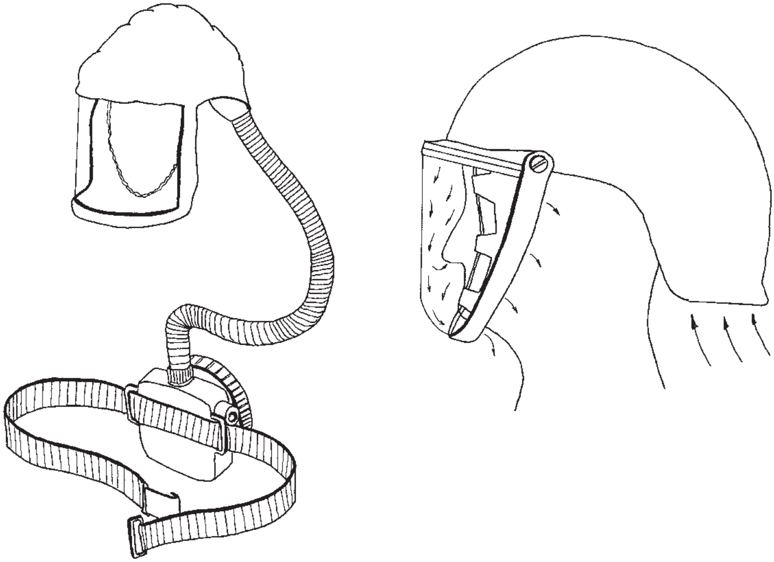
Filtered air is pumped into the mask. Positive pressure inside the mask improves the NPF and makes breathing easier for demanding work. The filters are likely to need to be replaced more frequently because of the increased air flow through them.

23. VENTILATED VISORS AND HELMETS

Powered ventilated visors and helmets normally comprise a head covering, which may be a soft hood or a helmet to provide physical protection. A clear visor covers the face and an elasticated 'skirt' may enclose the area between the bottom of the visor and the neck or face.

Contaminated air is drawn through one or more filters by a battery powered fan and the filtered air is directed downwards over the face. The ventilator, incorporating the fan and filter(s), may be mounted on a belt or fitted inside the helmet between the head harness and the helmet shell. The equipment is less dependent on a face seal to achieve the NPF and provides a high degree of comfort for the wearer. In some situations metal helmets may be more suitable because they provide better protection against beta irradiation resulting from surface contamination.

The protection factors depend significantly on the type and circumstances of the task. Such equipment is normally used for protection against dust and other particulates but some models are available for protection against gases and vapours. Ventilated visors can offer high NPFs but some helmets offer quite low protection. If the ventilator fails there is a possibility of exposure as a result of the drastically reduced protection. They are therefore best for use in low hazard situations or where prompt egress from a contaminated area is possible.



Ventilated visor and helmet.

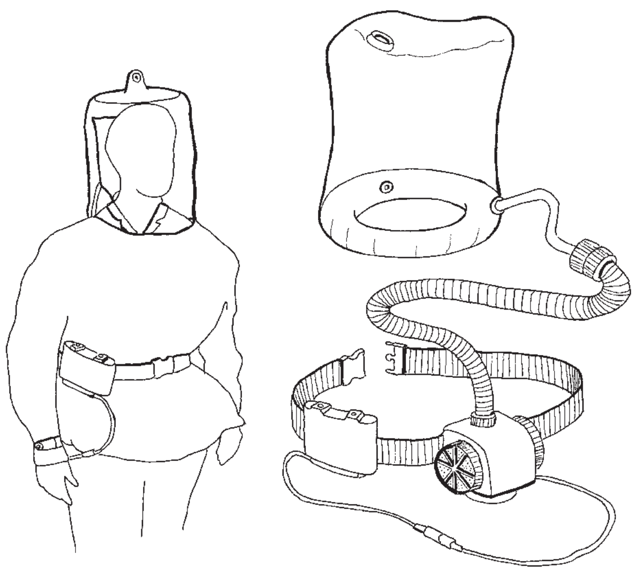
Ventilated visors and helmets provide greater comfort than masks. Visors have high APF/NPF values but those for helmets are likely to be much lower. Helmets can protect against physical hazards and external exposure. Failure of the ventilator may cause a serious hazard.

24. POWERED HOODS, BLOUSES AND SUITS

Powered hoods completely cover the head and are made partially or totally of transparent material that offers minimum distortion or interruption of the wearer's vision. Blouses cover the upper half of the body and seal at the wrists and waist. Suits cover the whole body and may incorporate boots and/or gloves.

Contaminated air is drawn through one or more filters by a battery powered fan and the filtered air is fed directly into the hood, blouse or suit and is exhausted usually by leakage from the protective clothing or through exhaust valves. The ventilator is usually mounted on a belt. Filters, as described in Section 20, are available for dusts, gases and vapours. The shelf life of the filter canisters is limited but, provided that the seal is not broken, they can remain effective for years.

Workers will need more extensive practical training to use hoods, blouses and suits than is necessary for the RPE previously described. They should be prepared for being dependent on the equipment to provide an air supply. They may need assistance to don and remove the RPE. The inner surfaces of the equipment must be disinfected hygienically and the outer surfaces monitored and, if necessary, decontaminated before reuse.

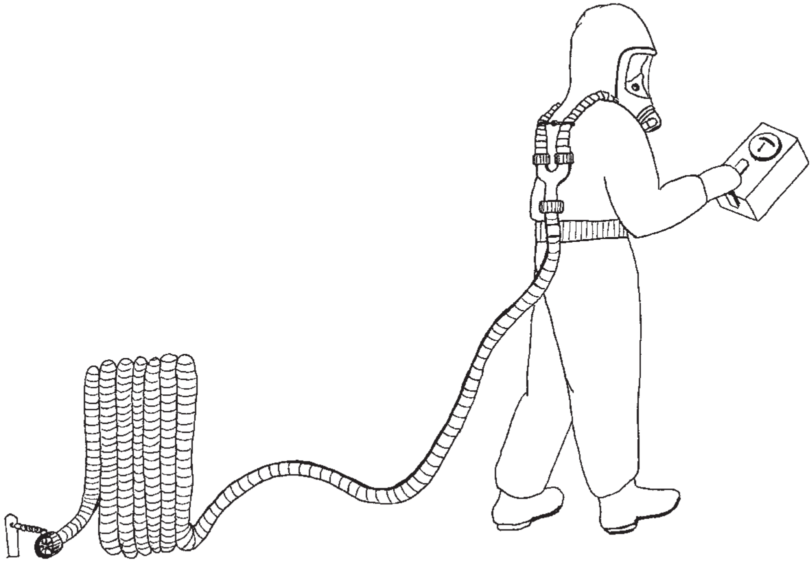


Powered hood and blouses.

Filtered air is pumped into the clothing. Wearers will need extensive training and full technical support.

25. FRESH AIR HOSE BREATHING EQUIPMENT

Fresh air hose breathing equipment comprises either a half or full face mask. The inlet of the hose contains a strainer and is secured by a spike or other means outside the contaminated atmosphere. Air is supplied by either normal breathing (unassisted ventilation), manually operated bellows (forced ventilation) or a powered fan unit (powered ventilation). A large diameter air hose is necessary which, for unassisted ventilation, should not be longer than about 9 metres. Such equipment is vulnerable, heavy and more cumbersome to use than compressed air line equipment (see Section 26). It is not suitable for use in nuclear facilities.



Fresh air hose supplying a full face mask.

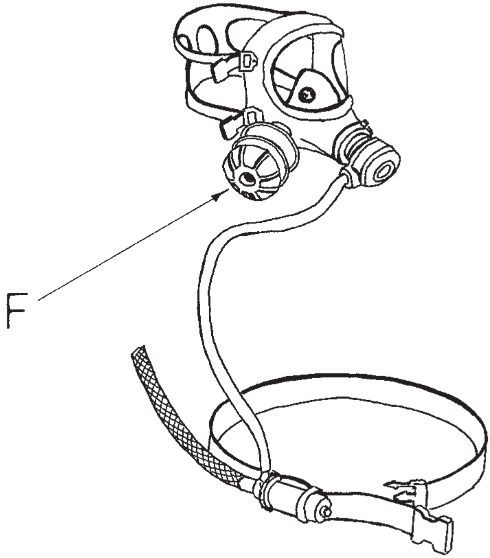
Large diameter hose must not be too long. The hose is cumbersome and vulnerable. Air intake is fixed in a non-contaminated area. A strainer but no filter is used to minimize resistance to air intake.

26. BREATHING EQUIPMENT WITH A COMPRESSED AIR LINE

A compressed air line may be used to supply a face mask, a hood or a blouse. The air may be supplied from a compressor or from compressed air cylinders that are outside the contaminated area. In using compressors, the air intake needs to be properly located to prevent the contaminant becoming entrained in the air supply. In-line filters and traps to remove oil, dust, condensate and odour from compressed gases should be provided as necessary to yield breathable air of an acceptable quality. Large compressors or cylinders are necessary, which may affect measures for atmospheric control in some locations such as vented rooms at subatmospheric pressure.

A face mask is connected through a belt mounted flow control valve to the compressed air line. To save air, especially when using compressed air cylinders, the flow control valve may be replaced by a lung demand valve, preferably of the positive pressure type, which provides a higher protection factor. It can reduce the air flow requirements by a factor of three, which also improves the quality of voice communication. High airflows cause noise and wearer discomfort (cooling or dehydration). With an adequate airflow, an effective positive pressure can be maintained in the mask to provide a high NPF. Some masks are also provided with a filter (F) for emergency escapes and to allow the worker movement through air locks.

A hood or blouse is connected to the compressed air line attached to a belt and may incorporate a valve by which the wearer can increase the flow rate of air supplied above the necessary minimum. The wearer’s comfort is relatively high in combination with moderately high protection. An auxiliary respiratory protection system, for example a filter, may also need to be worn if the wearer has to disconnect the air line to pass through air locks.



Full face mask with compressed air line and auxiliary filter.

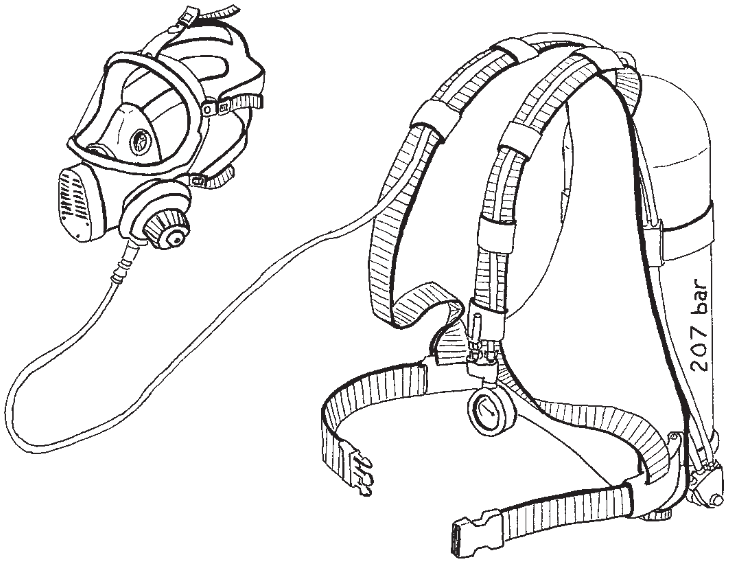
A suitable compressor may supply several workers. Air supply may affect atmospheric control measures. Some equipment allows a degree of control over the air supply by the user.

27. SELF-CONTAINED BREATHING APPARATUS

A self-contained breathing apparatus (SCBA) consists of a full face mask supplied with air or oxygen from compressed gas cylinders carried by the worker. Air is supplied to the mask through a positive pressure demand valve. Alternatively, oxygen is supplied at a constant low flow rate (4 litres per minute) to replace the oxygen consumed. This is achieved in a closed system that collects the exhaled gases, routes them through a soda lime cartridge to remove the carbon dioxide, and then adds oxygen to make up the fresh gas. Both types can be obtained with positive pressure regulators.

An SCBA provides mobility but is bulky and heavy. Compressed air apparatus protects for up to 45 minutes and oxygen apparatus for up to four hours. Extensive training is necessary for the wearers and for those who maintain the equipment. An SCBA is difficult to decontaminate and should be worn under a protective suit when used in contaminated areas.

A type of SCBA that generates oxygen chemically can be used in emergency situations for up to one hour. It is less bulky than compressed oxygen cylinders and has a long shelf life. Oxygen is generated from sodium chlorate or potassium superoxide. The latter is more expensive but has the advantage of releasing oxygen in amounts equal to the exhaled carbon dioxide absorbed.



Self contained breathing apparatus (SCBA) with a demand valve.

Open SCBA systems supply from a cylinder and vent to the atmosphere. Closed systems process the exhaled gases and replace the used oxygen. SCBAs provide mobility and high APF/NPF but are bulky and heavy. Extensive training is necessary. SCBAs should be protected against radioactive contamination.

28. COMPRESSED AIR LINE WITH FULL SUIT

A ventilated pressurized suit enclosing the whole body (arms and legs) may be in one or two parts. Halved suits are sealed together at the waist. Full suits may have a gas tight zipper. The hood has at least the front section transparent, offering minimum distortion or interruption to the wearer's vision. The compressed air supply hose is attached to a belt to withstand the stresses of being dragged. A valve may be attached to the belt to allow the wearer to control the air supply, either to the whole suit or to the hood, according to the design. Exhaust gases are discharged through exhaust valves in the suit body. Part of the air supply may cool the suit.

Full suits offer among the highest NPFs of all PPE. Higher air flow rates provide cooling if necessary and, if no face mask is incorporated, exhaled carbon dioxide needs to be flushed out to maintain its concentration in inhaled air below acceptable levels (less than 1 Vol% carbon dioxide). High overpressures of the suit cannot be achieved. Some substances can permeate or diffuse through the material, making the NPF dependent on the properties of the material and the flushing rate of the suit. An additional respirator should be worn under the suit if it is likely that a suit may become damaged.

There are usually sufficient reserves of air in a suit to allow the worker to egress through air locks after disconnection of the air supply, but for lengthy decontamination procedures breathing equipment may be necessary. Some suits are provided with an emergency breathing device to be used for escape purposes in the event of failure of the primary air supply.

A full suit supplied by compressed air line.

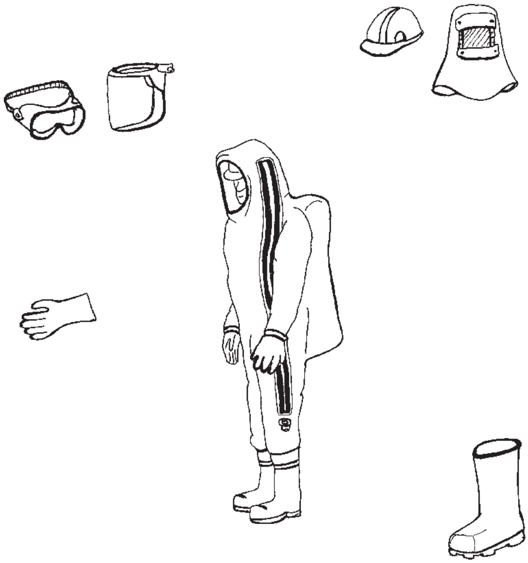
The full protective suit supplied with compressed air will provide an APF/NPF among the highest. The system may be used with an auxiliary RPE in very hazardous areas.

29. OTHER HAZARDS

In addition to radiological risks, there may be other hazards in the area(s) in which PPE is used. PPE can also create other problems and exacerbate hazards. For example, a worker's field of vision may be reduced while wearing respiratory protection, vocal communication may be severely restricted or a hood may impair hearing. Such conditions increase the worker's vulnerability to normal hazards and necessitate increased awareness and care.

Several types of PPE may be necessary to work safely. To protect against physical injury, head, eye and toe protection may be necessary. A safety helmet ('bump cap') may be worn when wearing enclosed suits or hoods. Safety goggles may be worn inside ventilated suits. It is an advantage if the one PPE used incorporates all necessary protection, such as the ventilated helmet (see Section 23); if a respirator has eyepieces made from polycarbonate; or if integral boots have protective toecaps. Use of an eye shield with a respirator will severely limit the already restricted vision. Welding in a radioactive environment necessitates specially modified PPE, with the hoods of ventilated garments fitted with a welder's mask, eye protection and an outer protective apron to protect against hot debris.

Suits made from aluminized fire resistant materials are available to protect against extreme radiant heat and, in hot environments, a cooled suit (see Section 28) should be used. Suits resistant to attack by specific chemicals should be assessed before use in respect of their contamination control.



Full suit with additional eye, ear, head, hand and foot protection.

Personal protective equipment can increase the wearer's vulnerability to other hazards. PPE may be designed to protect against several hazards.

30. WARNING SIGNS AND NOTICES

The designated areas in which PPE needs to be worn must be identified, clearly demarcated and described in written procedures with details of the PPE to be used.

As a reminder to workers who are familiar with the conditions for the use of PPE, and as a warning to visitors, suitable notices in the local language to deny unauthorized access should be posted at the barriers around the designated areas. It is preferable for the notices to display signs and symbols, which do not depend on the observer's literacy. A system of signs using distinctive and meaningful shapes, colours and idealized symbols has been developed. A trefoil symbol on a yellow background within a black triangle indicates the potential presence of ionizing radiation. It could be accompanied by the words 'Radioactive Contamination'. A sign with a person in silhouette on a white background within a red circle and a diagonal red bar prohibits unauthorized entry. Other signs with a blue background may display a symbol indicating the type of PPE that has to be worn by those about to enter the area. A head wearing a full face mask respirator indicates that RPE has to be worn by those about to enter the area and a symbol depicting boots indicates that the footwear used has to have protective toecaps.

Signs and symbols.

Appropriate signs are placed at the barrier on the edge of the designated area. The shape and colour of the signs and symbols may be coded to indicate 'danger', 'must do' and 'do not'. The triangle containing a trefoil symbol warns that there is a potential hazard of ionizing radiations present. A circle with a symbol of a person in silhouette and a diagonal bar prohibits entry. Circular signs containing symbols depicting a head or mask, boots or ear defenders, for example, demand the use of PPE in the areas in which the signs are displayed.

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A qualified expert, a librarian or the IAEA can recommend further reading on the topic of personal protective equipment.