RESPIRATORY PROTECTIVE EQUIPMENT

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This article is intended to outline the role of respiratory protective equipment (RPE) in a risk control programme and to provide advice on the steps in setting up and implementing an effective RPE programme so that occupational physicians can check the effectiveness of any such programmes they may encounter.

Although the details of such a programme may depend on the requirements of national legislation, the general principles to be applied should be independent of local legislation. In this article the details of the programme are described in terms of UK legislation and guidance.

It should be noted that although all duties in the UK to prevent or control exposures to hazardous substances are to the limit of "reasonably practicable", the corresponding duties under the European Directives, on which the UK legislation is nominally based, are to the limit of "technically feasible" and that the English Civil Court has judged that an employee can have a valid case against the UK government where he/she would have been protected by duties to the limit of "technically feasible" but not by the limit of "reasonably practicable". It is therefore considered that it would be prudent for a reasonable employer to work to "technically feasible" rather than "reasonably practicable" where possible as action to "technically feasible" could be a valid defence in civil litigation.

Respiratory protective equipment is widely used to protect wearers against hazardous aerosols, gases, or vapours because it is perceived to provide effective and relatively inexpensive protection whereas preferred techniques, such as total enclosure, cannot be applied or are perceived to be expensive.

The major limitation of RPE is that the anticipated protection is achieved only if the equipment is worn correctly. In addition, RPE performance in the workplace is generally much poorer than suggested by standards or manufacturers' literature. RPE should therefore be used only as one component of an overall prevention and control programme. Airborne hazards should be controlled by substitution of hazardous substances by safer substances, total enclosure, etc rather than by RPE. In any situation, the "control hierarchy" of prevention, control, and personal protection should be applied. The control hierarchy is enshrined in both European and UK legislation; for example, Article 2(h) of the European "Framework" Directive requires that the employer gives "collective protective measures priority over individual protective measures",[1] and is reiterated in Regulation 7 of the Control of Substances Hazardous to Health Regulations 2002. However, there will be situations where preventing or controlling risks is not technically possible and RPE use is unavoidable; for example, during incidents, between recognising risk and implementing control, or to supplement inadequate control.

When used, RPE must provide adequate protection without imposing unacceptable discomfort on the wearer as uncomfortable equipment may be worn incorrectly to minimise discomfort. RPE must therefore match each individual wearer's personal characteristics, job, and working environment, and any other items of personal protective equipment (PPE), which may have to be worn simultaneously with the RPE.

SETTING UP AN EFFECTIVE RPE PROGRAMME

An effective RPE programme should include the following steps.

Assess risks and identify where control is required
The essential first step is an assessment to identify any likely occupational hazards and to quantify any risks. The assessment should identify all unacceptable risks and the individuals at risk and provide the information needed for preventing or controlling such risks and for selecting adequate and suitable RPE.

Substitute the hazardous by less hazardous if technically possible
Determine if it is possible to use a less hazardous substance or the same substance in a less hazardous form; for example, replace a fine powder by a solution or a coarse powder.

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Abbreviations

- ▶ APF: assigned protection factor
- ▶ BA: breathing apparatus
- ▶ COSHH: Control of Substances Hazardous to Health Regulations 2002
- ▶ HSC: Health and Safety Commission
- ▶ HSE: Health and Safety Executive
- ▶ MEL: maximum exposure limit
- ▶ NPF: nominal protection factor
- ▶ OEL: occupational exposure limit
- ▶ OES: occupational exposure standard
- ▶ PF: protection factor
- ▶ PPE: personal protective equipment
- ▶ RPE: respiratory protective equipment

Implement all technically possible controls

If hazardous substances or processes must be used, all technically possible means of reduction of risk at source should be considered before adopting RPE; for example, to enclose any process involving hazardous substances or to apply local exhaust ventilation to such processes. It may also be necessary to minimise the number of persons who may be exposed and/or to reduce the duration of exposure.

Identify who needs residual protection

From the assessment of likely risks and of the effectiveness of the measures applied to prevent or reduce these risks, all persons still potentially at risk should be identified and the level of residual protection still required should be quantified.

Inform wearers of consequences of exposure

To ensure that all employees fully utilise all control measures, they should be made fully aware of the risks to their health and safety in the workplace and the potential consequences if these risks are not adequately controlled. If the correct use of control measures involves inconvenience or reduction in productivity, particularly for those on piecework, control measures may not be correctly used unless those at risk perceive some benefit to themselves. Since many types of RPE are inherently uncomfortable, some exposed persons may refuse to wear such equipment unless convinced that the imposed discomfort can be justified in terms of reduced risk to themselves. To ensure that wearers are aware of the benefit of wearing the RPE provided, it is important to ensure that all persons exposed to risk in the workplace have a perception of the risk(s) to which they may be exposed.

Select RPE adequate to control residual exposure

RPE should be selected which reduces any risks to acceptable levels. Given the general reduction in OEL and the increasing number of substances assigned a maximum exposure limit (MEL) rather than an occupational exposure standard (OES), it is considered prudent to limit personal exposures to <OEL. In the case of a substance assigned an OES, it is considered prudent to reduce personal exposure to <25% of the OES or in the case of a substance assigned an MEL or a control limit, to <10% of the MEL or control limit. RPE should be selected on the basis of demonstrated workplace performance. If a manufacturer cannot supply workplace data or written assurance as to the level of performance which can realistically be achieved in the workplace, his RPE should not be used.

Involve wearers in the RPE selection process

Many types of RPE impose some level of discomfort on the wearer and since the level of discomfort may reflect the degree to which the RPE and the wearer's face have to mutually deform to achieve adequate fit, wearers should be fully involved in the selection process to minimise the imposed discomfort. Involving wearers in the selection procedure and in all aspects of the RPE programme gives them a stake in ensuring the programme's overall effectiveness. The importance of such involvement is recognised in Article 8 of the "Use" Directive, Commission of the European Communities,[1] which requires the "consultation and participation of workers and/or their representatives".

Match RPE to each wearer

RPE wearers can vary substantially in size and facial characteristics so that a piece of equipment which fits one person may not fit another. RPE must therefore be selected to fit each individual wearer.

Carry out fit tests

Current UK guidance requires that fit tests should be used to ensure that each wearer is provided with a facepiece which fits his/her face. Details on carrying out such tests is provided in HSE (2004).[2] However, it should be appreciated that such tests identify gross misfits only and should not be used to infer likely performance in the workplace. However, fit tests are an extremely valuable training aid and can illustrate the consequences of incorrect fitting or facial hair.

Ensure that RPE does not create risks

Full facepieces can reduce downward vision so that descending steps can be dangerous, particularly in poor lighting conditions. If RPE is worn together with chemical protective clothing, the clothing can reduce the body's ability to lose metabolic heat, so causing heat strain. In addition, sweating can reduce the protection afforded by RPE.[3] Facepieces should be selected which are suitable for the intended use. Any potential for heat strain must be very carefully addressed and avoided; for example, by providing personal cooling and/or by limiting wear periods.

Ensure RPE are mutually compatible

Wearers often have to wear more than one type of PPE; for example, RPE may need to be worn with a safety helmet and/or protective clothing etc. If not selected with care, the different types of PPE can interact to reduce the protection provided by one or both items or generate a new risk for the wearer. For example, when safety helmets are worn with full-facepiece RPE, the front head-harness buckle may reduce the space between forehead and helmet, so that an impact on the front of the helmet can force the buckle into the forehead. If the helmet is struck on the brim, the helmet can be forced downwards onto the facepiece and cause it to be displaced. It is therefore essential that each item of PPE provides the required level of protection without affecting the effectiveness of any other item of PPE. Care must therefore be taken to ensure that all items of PPE which may have to be worn together are mutually compatible. It should also be appreciated that a combination of two or more "comfortable" items of PPE may be uncomfortable when worn simultaneously.

Train wearers in the correct use of their PPE

Wearers and supervisors should be trained in how to fit the RPE correctly, how to assess that it is correctly fitted, how to inspect the RPE to ensure it has been correctly manufactured and is complete, and, if relevant, has been adequately cleaned and maintained. Wearers should be aware that any hair which lies between the facepiece and the face may cause leakage. Male RPE wearers should be instructed to shave prior to any RPE wear period. RPE wearers should be informed that RPE is the first equipment fitted when wearing ensembles of two or more different types of PPE and that the head harness straps and facepiece must be worn below any clothing. If the clothing becomes contaminated, for example with asbestos, the facepiece must not be removed before the clothing otherwise the wearer may inhale fibres released off the contaminated clothing. Figure 1 shows an incorrectly worn ensemble with the facepiece and the head harness straps worn over the hood of the protective clothing. The hood will interfere with the seal between the face and the facepiece and the facepiece must be removed before the contaminated clothing can be removed. Figure 2 shows a correctly worn ensemble. Personnel servicing reusable RPE must be trained how to clean, service, and inspect the equipment and how to ensure that they are not put at risk by any contamination on uncleaned or inadequately cleaned RPE.

Supervise wearers to ensure the correct use of RPE

The overall effectiveness of any RPE programme can be critically dependent on the actions of supervisors who should actively enforce correct usage of RPE. Supervisors should ensure that all RPE wearers are clean-shaven, wear their RPE correctly when required, and that the equipment is clean and properly maintained. Unshaven wearers should be instructed to shave or be excluded from the job. Note that employees have a duty under the Health and Safety at Work etc Act 1974 to cooperate with the employer in ensuring health and safety and also have a duty to ensure their own and others' health and safety.

Minimise wear periods

Many types of RPE are inherently uncomfortable. Acceptability of a given level of discomfort can decrease with increasing wear time; for example, wearing shoes two sizes too small is bearable for a short time but not for a long walk. Wear times should therefore be reduced as far as possible. If most exposure occurs during a short period, it may be possible to achieve adequate exposure reduction by wearing RPE only during such processes. However, care must be taken to ensure that contamination of the wearer, RPE, or other PPE does not constitute a significant exposure source if the RPE is removed.

Maintain RPE in efficient and hygienic condition

Reusable RPE will need to be cleaned, serviced, and maintained. Such cleaning, servicing, and maintenance should be extended to any so-called ''low maintenance'' equipment. RPE maintenance is the legal responsibility of the employer, not the employee. Wearers may be unwilling to wear obviously dirty or faulty equipment. The persons responsible should ask themselves ''would *I* be prepared to wear the RPE provided?''.

Inspect RPE to ensure it is correctly maintained

Regular inspection and testing of serviced RPE is required by UK regulations, such as the COSHH Regulations, to ensure that the equipment is maintained in good condition.

Monitor programme to ensure continuing effectiveness

The RPE programme should be continually monitored to ensure its ongoing effectiveness. If any shortcomings are observed, additional training of wearers and/or supervisors and/or maintenance personnel may be required.

Audit programme to ensure continuing effectiveness

The RPE programme should be regularly audited to ensure its ongoing effectiveness. Such auditing should preferably be carried out by an independent person who is not involved in the day-to-day running of the programme.

CLASSES OF RPE

There are two main classes of RPE: breathing apparatus and filter devices. Breathing apparatus (BA) supplies the wearer with breathing gas independent of the wearer's immediate environment. Breathing gas may be supplied from cylinders worn by the wearer, fed from a remote location by an umbilical, or generated chemically on the wearer. The simplest form of BA is a facepiece fitted with a hose whose distant end is located in clean air. BA can be worn in conditions of potential oxygen deficiency. Filter devices use filters to remove contaminants from air in the wearer's immediate environment. Filter devices may be fitted with particulate, gas, and vapour, or combined gas and vapour and particulate filters. Filter devices do not supply oxygen and

Figure 1 Incorrectly worn ensemble.

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Figure 2 Correctly worn ensemble.

must never be worn in conditions of potential oxygen deficiency. Table 1 shows the different types of filters available and the relevant markings and filter canister colours.

Combined particulate and gas and vapour filters carry both particulate and gas and vapour markings; for example, an ''A3P3'' is a high capacity ''A'' filter fitted with a ''P3'' particulate filter.

Combination filters are available; for example, an ABEK2P3 filter combines the performance of the A, B, E, and K filters and is fitted with a P3 filter.

Combination filters are marked with the relevant colours for each filter element; for example, an ABEK2P3 filter is marked with brown, grey, yellow, green, and white stripes.

Full references to the relevant European Standards is given in BSI (2001).[4]

Most contamination inside correctly functioning BA and filter devices is from leakage between the wearer's face or body and the RPE. To minimise such leakage, the breathing gas may be blown into the facepiece. The breathing gas supply can be continuous or controlled by a demand valve so that gas is supplied only on inhalation. *Positive pressure demand* devices maintain gas pressure higher inside the facepiece than outside. Such devices provide the highest performance

of any RPE type. Both BA and filter devices are available with continuous flow and positive pressure demand breathing gas supply.

Quantification of RPE performance

There is much debate about the how to define the RPE performance which can realistically be achieved in real workplaces. RPE performance is quantified by the protection factor (PF), which is the ratio between the contaminant concentration outside the facepiece to that inside the facepiece—that is, a device with a PF of 50 maintains the in-facepiece concentration a factor of 50 lower than the outside concentration.

RPE is tested in the laboratory to demonstrate compliance with European Standards such as BS EN 136, which covers full face masks.[5] These tests include inward leakage measurement. The minimum PF required to meet the standard for a given class of RPE is called the nominal protection factor (NPF); for example, power assisted filter devices fitted with facepieces and P3 filters have an NPF of 2000.

Until recently, RPE in the UK was assumed to achieve the NPF in the workplace. This assumption is still made in most European countries. However, there is extensive evidence that workplace performance is substantially lower than the

Table 1 RPE filter types

Substances	Filter type; comment	Casing
Particulate	P1 Low efficiency P2 Medium efficiency P3 High efficiency	White
Organic gases with boiling points >65°C as specified by manufacturer	A1, A2, A3*	Brown
Inorganic gases and vapours as specified by manufacturer, excluding carbon monoxide	B1, B2, B3*	Grey
Sulphur dioxide and other acid gases and vapours as specified by manufacturer	E1, E2, E3*	Yellow
Ammonia and organic ammonia derivatives as specified by manufacturer	K1, K2, K3*	Green
Mercury	Must incorporate a P3 filter	Red–white
Oxides of nitrogen	NO must incorporate a P3 filter, single use only	Blue–white
Organic gases with boiling points <65°C as specified by manufacturer	AX	Brown
Filters against specific substances as specified by manufacturer	SX, marked with name of chemical	Violet

*Gas and vapour filters are available with three capacities: 1, lowest; 3, highest.

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Table 2 Assigned protection factors

APF	Device
4	½ masks with P1 filters, FFP1, FFGasP1, FMP1
10	½ masks with P2 filters, FFP2, FFGasP2, FFGasP3, FFGas, FMP2, FMGP3, FMGas ½ masks with gas and combined filters Full masks with gas and vapour and combined filters Powered hoods or masks TH1 or TM1 ½ mask fresh air hose BA Light duty airline LDH1 BA
20	½ masks with P3 filters, FFP3, FMP3 Full mask P3 and combined P3 Powered hoods or masks TH2 or TM2 Light duty airline mask or hoods LDM1, LDM2, LDH2 BA ½ mask continuous flow airline BA
40	Full masks with P3 filters Powered hoods, blouses, or masks TH3 or TM3 Full masks or hoods, fresh air hose BA Light duty airline hoods LDH3 BA Constant flow airline hoods, blasting helmets, or full masks BA Negative pressure demand full mask BA
200	Air fed suit BA
2,000	Positive pressure demand full mask BA

For details on devices see BSI[4] or HSE.[6]

NPF; for example, Howie et al reported workplace protection factors of 42 for power assisted P3 devices as against the NPF of 2000.[3] Although the reduction in PF from 2000 to 42 is large, most devices achieve laboratory PF substantially higher than the NPF. For the devices tested by Howie et al, the laboratory PF was >100 000. That is, the workplace performance was about a factor of 2000 lower than in the laboratory.

Given the reality of workplace performance, RPE assumed performance in the UK is now quantified using assigned protection factors (APF) derived from measured performance in real workplaces. APF is defined as that ''level of respiratory protection that can realistically be achieved in the workplace by 95% of adequately trained and supervised wearers using a properly functioning and correctly fitted respiratory protective device''.[4]

The APF assigned to the different classes of RPE are given in BS 4275.[1] Table 2 summarises the APF for BA and filter devices.

The three major difficulties of testing RPE in real workplaces are cost, availability of suitable test sites, and lack of standardised test methods. To some extent the first two problems can be addressed by carrying out simulated workplace protection factor studies; for example, in the UK, HSE has recently funded three such studies, for example, Johnston et al,[7] and in the USA such a study was reported by Cohen et al.[8] The validity of such simulated studies can be assessed from table 3 which compares the available results of real and simulated workplace studies. The very much higher PF in simulated studies suggests to this author that such studies do not provide a safe basis for predicting RPE performance in real workplaces.

RPE SELECTION

RPE selection procedures should address all the following aspects.

Legal requirements

Only EC marked RPE may be used in the workplace to achieve compliance with health and safety regulations. Such equipment has either been shown to comply with the

Table 3 Comparison of PF from real and simulated workplace studies

Device	Real WPF	Simulated WPF	Ratio simulated:real
Full-mask powered			
R2*	55†	11000‡	200
R3*	49†	22500‡	459
R4*	8.4†	998‡	119
Air fed blasting helmet	2870§	>40000§	>14

* Respirators as identified in Howie et al.[3]
†Howie et al.[3]
‡Johnston et al.[7]
§Parker et al.[9]

relevant harmonised standard or with the essential health and safety requirements of the PPE ''Product'' Directive.

Selecting BA or a filter device

Filters devices must never be worn unless there is clear evidence that oxygen deficiency is very unlikely.

Gas and vapour filters are effective against specified gases or vapours only; for example, filters for use against solvents provide no protection against carbon monoxide. Unless it is known that no gaseous contaminants are likely to be present or that the given filter will provide protection against all likely gaseous contaminants, BA should be selected.

Filter selection

The capacity of gas and vapour filters can vary with contaminant concentration and wearers' breathing rates and can be reduced in high humidities. In multiple gaseous challenges, retention of a strongly absorbed substance can cause release of a less strongly absorbed substance previously retained. It is therefore difficult to predict gas and vapour filter lifetimes in many workplaces. Manufacturers should be provided with comprehensive information about the intended use and asked for recommendations regarding the most suitable filter type and likely filter lifetimes.

Summary

▶ RPE should be only one component of a comprehensive programme to prevent and reduce risks to health, unless in emergency or minimal risk situations.

▶ If RPE must be used, the assumed protection should be based on information derived from tests in real workplaces only.

▶ Those planning RPE programmes should ask themselves "would *I* wear that RPE doing the job they are doing for the time they are doing it?".

▶ The reality of RPE is best summed up by a comment in the 1988 draft *Approved Code of Practice for Carcinogenic Substances*: "but PPE, particularly RPE, depends for its effectiveness on the wearer's willingness to wear it".[10]

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Key point

▶ For routine ongoing exposures to airborne hazardous substances, RPE should be used *only* after all technically possible means of prevention and/or control have been applied.

RPE selection

The APF can be regarded as the maximum multiple of the acceptable exposure concentration of any airborne contaminant is which a given class of RPE may nominally provide adequate protection and are used to identify RPE nominally adequate to provide adequate protection in any given situation. For example, select adequate RPE for a situation where a worker may be exposed to 0.6 fibres/ml of amosite asbestos fibres.

The UK control limit assigned to respirable amosite fibres is 0.2 fibres/ml. For a control limit of 0.2 fibres/ml, it is prudent to limit in-facepiece concentrations to 10% of the control limit—that is, 0.02 fibres/ml. The minimum required APF is therefore given by 0.6/0.02 = 30.

As there is no likelihood oxygen deficiency a filter device may be used.

From table 2 either a full mask unpowered or powered particulate filter device would provide an APF of 40. However, unpowered devices provide less secure protection than powered devices and impose greater breathing resistance to breathing. A powered device should always be selected when wear periods are likely to be longer than a few minutes. If safety factors >10 are considered prudent, positive pressure demand equipment should be used.

Competing interests: none declared

REFERENCES

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QUESTIONS (SEE ANSWERS ON P 362)

(1) Identify the main class(es) of respiratory protective equipment:
  (a) Breathing apparatus
  (b) Filtering facepiece devices
  (c) Filter devices
  (d) Power assisted devices

(2) Identify the type of respiratory protective equipment that can be used in oxygen deficient atmospheres:
  (a) Full mask gas filter devices
  (b) Breathing apparatus
  (c) Power assisted filter devices
  (d) Full facepiece fitted with carbon monoxide filter

(3) What is the performance index currently used in the UK for selecting respiratory protective equipment?
  (a) Nominal protection factor
  (b) Protection factor
  (c) Workplace protection factor
  (d) Assigned protection factor

(4) What type of respiratory protective equipment gives the highest performance?
  (a) Full mask power assisted devices
  (b) Fresh air hose devices
  (c) Positive pressure demand devices
  (d) Blasting helmets

(5) What is the correct function of quantitative fit testing in the selection of respiratory protective equipment?
  (a) To predict likely performance in the workplace
  (b) To determine if a given device can fit the wearer
  (c) To quantify the effect of facial hair on fit
  (d) To identify gross misfits only