NUCLEAR INDUSTRY GUIDANCE

An Aid to the Design of Ventilation of Radioactive Areas

Issue 1

This guide has been endorsed by the nuclear industry Safety Directors Forum

NVF/DG001 January 2009

FOREWORD

This issue of the Nuclear Industry guidance document for the ventilation of radioactive areas was published (for comment) by the Nuclear Ventilation Forum on behalf of the Nuclear Industry Safety Directors Forum (SDF) in October 2008. The document is intended as an aid for designing ventilation for radioactive areas. This document is now formally Issue 1, January 2009.

The Forum recognises that, following use and experience of this guidance, there may well be comments, questions and suggestions on the content. The Forum is committed to maintaining and updating this guidance so that it continues to represent good practice, and welcomes any such comments on the document.

Comments should, in the first instance, be sent to the Nuclear Ventilation Forum at the following address:

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This document is believed to be consistent with all relevant legislation and guidance, and has so far been endorsed by the following organisations:

Safety Directors Forum organisations:

Sellafield Sites Ltd	Magnox South Ltd
GE Healthcare Ltd	Urenco (UK) Ltd
Dounreay Site restoration Ltd	Babcock Marine (Rosyth) Ltd
Magnox North Ltd	Babcock Marine (Devonport) Ltd
AWE Aldermaston	

This aid to designing has been the subject of review and consultation amongst relevant stakeholders. However, as with any such document, publication may lead to a call for further advice, or for other aspects to be considered. The Nuclear Ventilation Forum will itself in future keep this document under review, and strongly encourages users to comment, ask questions or make suggestions on the content of this document. The Forum undertakes to respond to any such comment in an appropriate manner and will revise and re-issue it as necessary.

This document provides the top tier of guidance for nuclear facility ventilation design. It is the NVF's intention to produce supporting documents to address specific issues in more detail. The subjects to be addressed are to be proposed by the NVF (from requests and suggestions received) to be endorsed by the SDF.

NUCLEAR VENTILATION FORUM REPRESENTATION

The support of the following organizations and their nominated individuals in the production and review of this document is gratefully acknowledged:

AWE PLC - Grant Hall

Babcock Marine (Rosyth) Ltd - Steve Martin

Babcock Marine (Devonport) Ltd – Stephen Cooksley

Urenco (UK) Ltd – Keith Simpson

Dounreay Site Restoration Ltd - John Keeton

Environment Agency - Matthew Emptage

GE Healthcare Ltd - Darran Mountjoy

Scott Wilson Ltd - Alan Connell

Magnox North Ltd – Keith Morris

Magnox South Ltd – Martin Stabb

Mott Macdonald - Derek Booth

HSE, Nuclear Installations Inspectorate - Bill Seddon

Sellafield Sites Ltd - Ray Doig

Studsvik Alpha Engineering Ltd – Martin Crouch

Current at Date of issue.

RECORD OF REVISIONS

Document Issue	Revision Date	Changes Made
AECP 1054 Issue 1	June 1979	Issued throughout the Nuclear Industry as an aid to designing ventilation systems for radioactive areas
AECP 1054 Issue 2	April 1989	Document updated and published as a 'Provisional' Code of Practice
NVF/DG001 Issue 1	January 2009	Document updated and issued to the nuclear industry

CONTENTS

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1. GENERAL

1.1 SCOPE

1.1.1 This document covers the design principles for the ventilation of radioactive areas and buildings, from the point where air is drawn in, to where it is discharged to atmosphere.

1.1.2 The document gives guidance to those responsible for designing, commissioning, and maintaining ventilation systems. It outlines good practice for the provision of an acceptable working environment, and supplementary containment by providing protection, for operators and members of the public, from radioactive emissions in both normal and abnormal operating conditions.

1.1.3 Relevant statutory and mandatory requirements are identified, and where appropriate, reference is made to standards which will be helpful to the designer, engineer and operator.

1.1.4 To assist in achieving the objectives advice is given on the following aspects of ventilation systems:

(a) Criteria for the sealing of buildings against air leakage and the means whereby the effectiveness of the ventilation systems can be measured or demonstrated;

(b) Area classification and its relationship to ventilation design;

(c) Detailed principles for the design of ventilation systems for caves, cells, glove boxes and fume cupboards;

(d) The proper use of filters excluding the detailed design of filters and housings;

(e) The electrical supply, control and instrumentation to ventilation systems;

(f) Measures that may be taken to minimise the spread of fire, and aid in ensuring the safety of operators;

(g) The commissioning and periodic testing of the ventilation systems;

(h) The requirements for maintenance, safe access, decontamination and commissioning.

(i) Differing standards for buildings subject to change in use.

1.1.5 It is intended to supplement this guidance with future documents addressing specific technical areas in more detail e.g. Filtration.

1.2 LEGAL FRAME WORK

1.2.1 Nuclear site licensees have a moral and legal obligation to provide a safe working environment for their employees, protect others from risk of harm, and to protect the environment.

1.2.2 The 36 standard License Conditions attached to each Nuclear Site License places specific legal duties and conditions on each Licensee in respect of the design, operation, maintenance, and control of the plant on the licensed site and the nuclear material it may contain.

In addition the Health and Safety at Work Act places specific duties and responsibilities on all employers and employees. In particular, for any task the Management of Health and Safety at Work Regulations (1999) require a risk assessment to be undertaken and this should reveal the hazards and controls necessary for particular facilities and activities.

1.2.3 The Environmental Protection Act requires Best Practical Means (BPM) to be applied to control of radioactive material.

1.2.4 It is important therefore that assessments should be undertaken as soon as possible within any design process to ensure health, safety and environmental objectives are both understood and prioritised within the design.

1.3 KEY DESIGN REQUIREMENTS

1.3.1 The most important aspect of the design of ventilation systems is a clear definition of the functional requirements and objectives of the system. Although this document is primarily concerned with Radiological aspects, the design should also consider:

- Physical and chemical processes
- Environmental conditioning and protection
- Conventional safety
- Building regulations
- Operating principles
- Design life
- Running costs and energy

At each stage of the engineering process it is imperative that the design intent is clearly identified, and is carried through to the final operating system, and finally verified as such by a competent authority.

1.3.2 The ventilation design should be closely integrated with the facility nuclear safety case, design and operational philosophy as this allows the design to be optimised to achieve the specified objectives. Designers should be aware of other legislation and regulations that may affect the design and operation of the new facility, see section 1.4.

Designers should examine the HSE's Safety Assessment Principles (SAP's) as pre-requisites of the design. Its inspectors use the Safety Assessment Principles, together with the supporting Technical Assessment Guides (TAGs), to guide regulatory decision making in the nuclear licensing permisssioning process. Underpinning such decisions is the legal requirement on nuclear site licensees to reduce risks so far as is reasonably practical, and the use of the SAPs should be seen in that context. It is important therefore that designers have

examined their design against such criteria and are able to justify the fault tolerance of their proposed designs in both normal operations and faulted conditions.

1.3.3 Concept design is the most important stage for identifying requirements of a ventilation system. The objectives of the system should be identified at this stage in a clear and concise manner, without excessive detail that can sometimes confuse or distort the requirements. All modes of plant operation and emergency conditions should be considered e.g. power failure.

1.3.4 From early in the design process, account should be taken of the space requirements for ventilation plant and ductwork. Space allocation and coordination (including access and working space for maintenance) should be addressed in conjunction with all other design disciplines involved in the facility design.

It should be recognised that nuclear facility ventilation is primarily concerned with the containment of radioactive material and it is the physical barriers, i.e. containers, process equipment, and the building structure, that provide the actual containment: the ventilation system reinforces that containment by providing depressions and flows which discourage adventitious spread of material. It is therefore important, to achieve an effective containment system, that the ventilation, building layout, and process designs are tightly integrated and not performed in isolation.

1.3.5 Although modifications to existing systems may be constrained by the existing building fabric and layout, the concept design should still clearly identify the objectives. The reasons for the modification should be made clear without being prejudiced by the functionality of the existing system.

1.3.6 One of the first documents to be produced should be an integrated process flow sheet(s) (for both normal operations and fault conditions) showing typically:

- Process flows
- Contamination / radiological burden
- Environmental conditions
- Waste & energy requirements,

The flow sheet should contain enough detail to support the assessment of BPEO, BPM, safety, and business cases. Further details of the health, safety and environmental requirements are given in section 2. Integrating hazard assessments into the design is an important design development process and a typical procedure is shown in figure 1.

1.3.7 More specific requirements for the design of various ventilation components and systems are given in the latter sections of this document. It is important to recognise that this document gives guidance for typical arrangements – these should not be taken as read and need clear assessment to support their use.

1.4 RELATED DOCUMENTS

1.4.1 The following mandatory and advisory documents are pertinent to the design, installation and operation of ventilation systems for nuclear facilities.

This list is not comprehensive and designers must satisfy themselves that they have taken account of all legislative requirements.

Key Legislation:

- Health and Safety at Work Act 1974.
- The Nuclear Installations Act 1965 (as amended 1990).
- Radioactive Substances Act (RSA 1993).
- The Environmental protection Act 1990
- Factories Act 1961.

General Health and Safety Regulations:

- The Management of Health and Safety at Work Regulations (1999)
- Workplace Health Safety and Welfare Regulations (1992).
- Control of Substances Hazardous to Health (COSHH) Regulations (2002).
- Construction Design and Management (CDM) Regulations (2007).
- Ionising Radiations Regulations 1999
- Personal Protective Equipment at Work Regulations 1992
- Provision and Use of Work Equipment Regulations 1998
- Dangerous Substances and Explosive Atmospheres Regulations 2002
- Confined Space regulations 1997
- Energy Performance of Building Regulations (Certificates and Inspections) (England and Wales) (Amendment No. 2) Regulations 2008 (SI 2008/2363)

All the above Regulations have one or more accompanying **Approved Codes of Practice** which provides recommended procedures for compliance with the regulations.

Other Government Documents:

- Command 2919, Radioactive Waste Management 1995.
- HSE Safety Assessment Principles for nuclear facilities 2006

European Documents:

- Basic Safety Standards Directives of the European Community 80/836 EURATOM L246 1980),
- 84/467/EURATOM(L265 1984).
- BS EN 60761 Equipment for continuously monitoring radioactivity in gaseous effluents.

International Documents:

- ISO 17873 Nuclear Facilities – Criteria for the design and operation of ventilation systems for nuclear installations other than nuclear reactors.
- The 2007 Recommendations of the International Commission of Radiological Protection, ICRP Publication 103 (ICRP 103).
- Dose coefficients for intakes of Radio-nuclides by Workers ICRP Publication 68 (ICRP 68).

Advisory Documents and Standards:

- TGN/RSANUC/01 Environment Agency, Technical Guidance Note - Release to air from Nuclear Facilities: Methods of Abatement of Radioactive Discharges.
- TGN/RSANUC/02 Environment Agency, Technical Guidance Note - Release to air from Nuclear Facilities: Methods of assessment of Radioactive Discharges.
- TGN/RSANUC/M11 Environment Agency, Technical Guidance Note – Monitoring of Radioactive Releases to Atmosphere from Nuclear Facilities
- BS 476 Pt 20-23 (1987) Fire tests on building materials and structures.
- BS EN ISO 5167/1 (1997) Measurement of fluid flow by means of pressure differential devices.
- BS 3928 (1969) Method for sodium flame test for air filters (other than for air supply to IC engines and compressors).
- BS 4247 Pt 1 (1981) Surface materials for use in radioactive areas - Methods of measuring and evaluating the decontamination factor.
- BS 5243 (1975) General principles for sampling airborne radioactive materials.
- BS 9999 Fire precautions in the design, construction and use of buildings.
- BS EN 14175 Pts 1-6 (2006) Laboratory fume cupboards
- BS 6399 Pt 2 (1997) Loading for buildings - Code of Practice for wind loads.
- DW 143 Ductwork Leakage Testing – a practical guide (Heating and Ventilating Contractors Association).
- DW 144 Specification for sheet metal ductwork (Heating and Ventilating Contractors Association).
- DW 154 Specification for plastics ductwork (Heating and Ventilating Contractors Association).
- HSE guidelines: Programmable electronic systems in safety related applications:
  Vol. 1 An introductory guide ISBN 01 18839136;
  Vol. 2 General technical guidelines ISBN 01 18839063.
- Safety Directors Forum: Change rooms Design, Operation, and Maintenance Code of Practice, September 2005.

- AECP 8 Design principles for radiological protection instrumentation systems.
- AECP 14 Safety in the use of pressurised suits.
- AECP 59 Shielded and unshielded glove boxes for hands-on operation.
- AECP 1002 The coating of surfaces for use in the Nuclear industry
- AECP 1041 The Selection of Air filters
- AECP 1057 Radioactive Decontamination.
- AECP 1063 Active Area Design.
- AECP 1064 Charcoal traps for radio-iodine in the nuclear industry
- AECP 1072 Sampling and monitoring of airborne radioactive discharges.

Note that some of the AECP documents are no longer maintained and should be used with care whilst taking appropriate advice from qualified persons. Site Licensees may also provide local standards and guidance.

1.5 DEFINITIONS

1.5.1 The following definitions are used in this Document.

Access Area.	An area through which people move to access the operating area and as such it has low levels of radiation and contamination associated with it.
Actinide	Any element of the actinide series, typical heavy metal elements used in nuclear fuels.
Active/Radioactive Area.	An area where it is necessary to control access because of potential risks from ionising radiation.

Active/Radioactive Ventilation. The ventilation of radioactive areas.

ALARP	As Low As Reasonably Practicable
Air Change.	A quantity of air equal to the volume of the room or compartment ventilated.
Axial Flow Fan.	A fan in which the impeller rotates in a cylindrical casing, the air flowing into and from the impeller axially.
Balanced System.	A ventilation system regulated such that input and extract ventilation rates to a space are equal.
Barrier.	Physical element which limits the movement of contamination to adjacent compartments.
BPM	Best Practicable Means.

Care and Maintenance (C+M) The condition into which a building is put following its operating life and prior to decommissioning

Cave. A shielded enclosure within which the processing of radioactive materials takes place, and there is likely to be designed human/mechanical interfaces and access provision (also called cells in some establishments).

Cell. A shielded enclosure within which the processing of radioactive materials takes place and for which there may, or may not be, designed human/mechanical interface and access provision.

Centrifugal Fan. A fan in which the impeller rotates in an involute casing, the air flowing into the impeller axially, turning at right angles within it, prior to radial discharge by centrifugal force.

Changeroom. A change room is accommodation provided to enable personnel working in potentially radioactive contaminated areas, to change into appropriate working clothing on arrival and back at the end of the working period.

Coalescing Filter Filter designed to encourage liquid droplets to coalesce into larger droplets and to remove them from an air or gas flow.

Containment. Those parts of the equipment plant and building structure provided specifically to limit the escape of radio-toxic substances.

Debris Arrestor. A means of preventing solids above a predetermined size being carried along the ducting.

Decommissioning. The action taken at the end of the useful life of a plant in removing from service with adequate regard for health and safety of workers and members of the public.

Decontamination Factor (DF). This indicates the cleanliness achieved in high efficiency filtration systems and is the ratio of the original to the residual contamination.

Depression. A pressure lower than a given reference pressure.

Derived Air Concentration (DAC) If an operator were to be exposed to airborne radioactivity to the maximum level recommended by ICRP for 2,000 hours (in one year) he would receive, from the inhaled contamination, an internal dose equivalent to the annual limit of 20 mSv. These maximum levels of air contamination are referred to as Derived Air Concentrations (DAC) - formerly termed Maximum Permissible Concentrations (MPC).

Derived Limit (discharged) That level of radioactive discharge which if continued for a year would give the most exposed person his permitted annual dose (see AECP 1063).

Diffusion Temperature Difference. The temperature difference between the air to a supply opening and room design temperature.

Discharge Stack. A duct (usually vertical) at the terminal section of a system from which the air is discharged to atmosphere.

Extract System. A ventilation system extracting air from a space.

Fan Room. A room to house ventilation fans, with suitable access for maintenance under active conditions where necessary.

Filter. A device in an air stream for arresting airborne particulate matter.

Filter Room. A room to house and service filters.

Fume Cupboard. An enclosed chamber with a sash or sliding door which is opened for working access. Through this opening a flow of air is induced which has a velocity sufficient to limit the spread of radio-toxic and other substances from the enclosure to the work place.

Glove Box. A total enclosure with facilities for gloved hand entry and in which material may be manipulated in isolation from the operator's environment.

Glove Box Posting Facility. A means of transferring radioactive material in and out of the glove box while maintaining the containment barrier.

HEPA Filter. A High Efficiency Particulate Air Filter to the appropriate standards.

High Pressure Extract (HPE) or **High (Negative) Pressure Extract**. An emergency extract system which is automatically activated when the pressure within a glove box varies from a predetermined level.

Input System. A ventilation system conveying air into a space (the term plenum is sometimes used but is not recommended).

Negative Pressure System. A ventilation system regulated so that the ventilated space is at a negative pressure with respect to an adjoining zone or external ambient pressure.

Operating Area. A working space normally occupied by personnel but where air contamination might occur under abnormal conditions.

Post Operative Clean Out (POCO). The Operations carried out to remove the main hazardous materials from a redundant facility and to clean it up, prior to placing under either Care and Maintenance (C+M) or prior to complete decommissioning.

Postulated Accident. Any variation from normal operating conditions which needs to be considered in the hazard assessment.

Pre-filter. A filter fitted upstream of the main air filters to minimise, by removal of large particles, the dust burden on the latter.

Pressure Drop or Resistance. The depression through a section of ductwork, filter or fitting in the air stream.

Pressurised Suit Area. An area that may only be entered by personnel wearing pressurised suits. It is always a RED area.

Pressurised System (Positive Pressure System). A ventilation system regulated so that the ventilated space is at a positive pressure with respect to an adjoining area or external ambient pressure.

Process Ventilation System.	A ventilation system associated with the major sources of activity which includes the ventilation of gloveboxes, fume cupboards, vessels, caves and cells but excludes the ventilation of access and operating areas.
Process Vessel.	Any container including all its inter-connecting pipework.
Radioactive Fire Zone (RFZ).	Any area which would normally be classified as a AMBER area or RED area in accordance with this document. Equally any area normally classified as a WHITE or GREEN area that could be contaminated, in a fire or explosion inside a building, to levels of radioactivity equal to AMBER or RED area classification should also be considered as an RFZ. Any area which would normally be classified GREEN or cleaner, and where these levels of activity would not be exceeded either during or after a fire or explosion would not be considered an RFZ.
Radio nuclides	Elements that give rise to nuclear radiation.
Spark Arrestor.	A device installed upstream of the filter to protect it from glowing debris and sparks.
Sub-Changeroom.	A room, located within the area served by a main changeroom, which provides for a further change of clothing so that the user can proceed into an area of potentially higher contamination.
Throw.	The distance between a grille and a point in the air stream at which the bulk of the air discharge has fallen to a speed of 0.15 m s-1.
Total Enclosure.	An enclosure (other than a fume cupboard) intended to prevent the escape of any unsealed radioactive substance therein into any work place.
Work Room/Place.	Any place where a person could be working.
VXA	Vortex amplifier: a fluidic device with no moving parts that can change its resistance in response to an upstream pressure variation (often used to induce a breach flow within cells and gloveboxes).

2. RADIOLOGICAL SAFETY

The following text is intended to give a general overview of basic safety considerations pertinent to ventilation systems. Advice and guidance must always be sought from the appropriate Health & Safety professional before any decisions are made that may affect safety.

2.1 BASIC HEALTH PHYSICS

2.1.1 Radioactive materials

Radioactive materials are hazardous to man because of the photons or particles they emit, and some such materials are also chemically poisonous. Those emissions transfer their energy to the atoms and molecules in tissue and thereby damage it by destroying or altering vital parts of its structure.

The best protection for the worker against these materials is to prevent the radiation from them reaching his body by shielding him from penetrating radiation and by preventing all radioactive substances, particularly the alpha emitters like plutonium, from coming into contact with his body tissue, either as skin contamination or by being taken inside the body when he breathes, eats or suffers cuts or abrasions. For plutonium and some other radionuclides, the route of entry through the lungs is of particular importance and air in working areas must at all times be maintained within the permitted levels of contamination.

In general, in areas without excessive air movements particles of, say, ten microns or larger are unlikely to be airborne and will not readily be inhaled as gravitational effects will predominate. Very small sized particles have a low mass and are most likely to coalesce. Thus, the bulk of the activity, of radiological significance as regards inhalation, will be in the range 0.1 to 6.0 μ m.

2.1.2 Control of Discharges

Processes which involve the use of nuclear or radioactive material result in the generation of radioactive waste. Gaseous radioactive waste may be only discharged to the atmosphere from nuclear licensed sites through ventilation systems or discharge stacks, in strict accordance with the limits laid down by the authorisations issued by industry Regulators. These discharges present a potential hazard to workers and members of the public as a result of the radiation the materials emit. Some materials are also chemically hazardous.

The discharge of radioactive wastes is controlled subject to the Radioactive Substances Act 1993. Authorisations to dispose of gaseous waste are granted under this act and include such limitations and conditions as are considered necessary. The powers of this act are exercised by the Environment Agency in England and Wales and by the Scottish Environmental Protection Agency (SEPA) in Scotland. Before granting an authorisation, the appropriate agency is required to consult relevant Government departments, local authorities and other public bodies as appear proper to be consulted and they can consult the general public.

The authorisations granted by the appropriate agencies generally call for the waste producer to use 'Best Practicable Means' (BPM) to reduce the radioactivity in discharges. Auditable records should be maintained in order to demonstrate that BPM is being applied. The waste producer is required to take such samples, measurements, tests and surveys as are

necessary to assess the discharges and the means by which this will be achieved will normally be agreed with the agencies. The waste producer will be required to keep records of the waste discharged from each outlet and provide periodic reports to the agencies. All these conditions are specified in the certificate of authorisation at each site. In addition, the authorisation may contain annual limits on the discharges of specified radionuclides or groups of radionuclides. Recent authorisations have, where appropriate, included 'notification levels'. These levels are set by the appropriate agency below the annual limits and are intended to represent the levels of discharge that the appropriate agency regards as achievable using BPM. If the notification levels are exceeded on a regular basis then the waste producer will be required to provide a justification to the Environment Agency or SEPA.

There is also a requirement to comply, for non-active discharges, with the Integrated Pollution Control (IPC) Regulations of the Environmental Protection Act 1990.

2.2 RADIOLOGICAL PROTECTION

2.2.1 General

Before any attempt is made to specify or design a ventilation system for a radioactive facility, its purpose must be clearly understood. Ventilation systems in radioactive facilities are almost always multifunctional. In the first instance, they perform the conventional non-nuclear role of providing an acceptable working environment. Secondly, they provide operator protection by maintaining the required depressions and flows in various areas of the facility. At the same time, by collecting contaminated air flows they aid control (by filtration and measurement) of airborne activity which could be released from the facility. The ventilation design must be such that required discharge standards are met, and the measurement systems are required to demonstrate that the standards are being met.

2.2.2 Limit to Operators

ICRP 68 recommends limits for the concentration of airborne radioactivity in the workplace. The designer and operator of a ventilation system should understand the basis of the derivation of the recommended limits. The advice of a radiological protection specialist (eg Facility RPA) should be sought on the application of these limits.

2.2.3 Design Implications

Airborne radioactivity in the working environment, other than that from natural background activity, can arise from:

(i) Discrete releases from the operation of facilities;

(ii) Unintentional recycling of discharged air;

(iii) Contaminated working areas (re-suspension).

Experience in active areas has shown that moderately low levels of surface contamination can give rise to 10% DAC due to re-suspension of the radioactive particles by operators carrying out their normal duties. The ventilation system will do little to reduce operator exposure as air flow would need to be impractically high to produce significant improvements. Low levels of airborne activity are best achieved by limiting the levels of surface

contamination by appropriate design features (containment etc.) and operational good housekeeping.

The selection and design of plant and equipment must be made after careful consideration of the materials that may be handled. These considerations must take into account radiological problems, both direct radiation and contamination, and the corrosive nature of the gases in use or arising from the process. Where the equipment is handling high beta/gamma contamination, assessments must be made as to the requirements for shielding during both normal and accident situations. This is particularly applicable to filters, which collect radioactive material over a period of time, but may also be relevant to ductwork or fans. Where this is identified as a potential problem, consideration must be given to the remote handling and disposal of filters and maintainability and decontaminability of fans.

2.2.4 The General Public

The effect of discharges from ventilation systems on members of the public must be addressed in the design of the system. The designer should demonstrate compliance with the ALARP principle and show that BPM has been employed.

2.3 HAZARD ASSESSMENT

2.3.1 Before commencing any ventilation design a hazard assessment should be carried so that design safety and environmental principles, and actual targets can be adequately defined.

All licensees should have arrangements for the development of safety and environment cases to support the installation and modification of ventilation systems.

2.3.2 The hazard assessment process forms part of the safety and environmental assessment procedures covered by the Licensees arrangements. Figure 1 shows an example of how hazard assessment can be integrated into the general design procedure.

Figure 1 shows that hazard assessments can take place at various stages in the project. Soon after a project is started and a rudimentary conceptual design is available, possibly coupled with a preliminary flow sheet, a Preliminary Hazard Assessment should be carried out. This gives a very basic outline of the hazards that are likely to be met. The nature of the assessment is partially qualitative, and where possible some hazards are quantified such as the sources of gamma and neutron activity. In a qualitative manner it may identify possible contributions to airborne contamination, with quantification of the possible upper limits of occasional airborne contamination. The main risk operations may be highlighted, together with possible areas which could give rise to radioactive contamination hazards or containment problems. The standard of containment required, the activity levels of the extract gases prior to cleanup, and the decontamination required will be defined. Potential fire and explosion hazards plus general industrial hazards will be identified where possible.

After completion of the preliminary hazard assessment the Design Safety Principles (DSPs) document is produced and the building/plant is classified into radioactive areas and fire zones. The DSPs describe in outline the design intention to ensure that the hazards noted in the preliminary assessment are dealt with. The DSPs are guidance to designers on safety related matters. As regards active ventilation, guidance may be given on, for example, air flow velocities, filtration, and in-situ filter testing. With respect to the surface contamination, the aim will be to achieve negligible surface contamination. However, where appropriate, the DSPs

will state levels of surface contamination which are allowable. Allowable gaseous discharges to the environment will be defined, and the requirements for fire dampers will be stated.

2.3.3 The designer then develops his conceptual design in gradually increasing detail through to main design.

On some occasions, particularly on innovative designs, there may be some technically difficult areas in the design with strong safety implications. Before progressing too far into the main design stage it may be necessary to carry out an Intermediate Risk Assessment to give confidence that the design arrangement is acceptable from the safety point of view.

2.3.4 Licensees should have arrangements for controlling modifications to designs including appropriate risk assessment to support the changes.

2.3.5 It should be noted that the design needs to be worked up to a reasonable level of detail before a meaningful intermediate risk assessment, hazard analysis (HAZAN) or HAZOP study can be carried out. A HAZOP study only covers the identification of operational hazards in the total risk assessment process. It does not quantify hazards, consequences, and risks.

2.3.6 A risk assessment will produce the radiological criteria necessary for the designer and operator. These should include:

- The permitted levels of air and surface contamination within the building, and the air monitoring requirements;
- The discharge limits from the ventilation plant;
- The clean-up requirements prior to discharge.

Clearly, these affect the containment standards, and ventilation may be a major factor in the containment system.

2.3.7 This concept of risk means that the greater the potential release (and subsequent exposure) the lower the acceptable frequency of occurrence. This leads to two complementary approaches to reducing the risk from a plant or facility:

- The release can be limited still further by additional clean-up units, e.g. additional HEPA filters; or
- Additional engineered safety features, such as increased reliability of safety-related equipment etc., can decrease the estimated frequency of occurrence.

2.3.8 The Nuclear Installations Inspectorate has published safety assessment principles giving a guide to "acceptable" levels and frequencies in Safety Assessment Principles for Nuclear Plants. Numerical evaluation of the consequence and frequency of the potential release allows the use of criteria against which the plant or facility risk can be judged. However, it must not be forgotten that ALARP still applies.

2.4 OTHER ASPECTS

2.4.1 Other factors which should be taken into account by designers of radioactive ventilation systems include the following:

a) There is a need to minimise, as far as is reasonably practicable, the level of naturally occurring airborne alpha activity in the workroom air

b) For environmental protection (and also cost reasons), it is now accepted policy to minimise radioactive waste arisings as far as practicable; in particular, contaminated HEPA filters, being of low density are very expensive to store or dispose of as radioactive waste;

c) By its very nature, an enclosure through which air is exhausted via ductwork, filters, fans and a stack to the outside atmosphere, can give only limited protection against a sudden pressure generated within it;

d) Provision of comfortable working conditions;

2.5 GENERAL SAFETY PRINCIPLES

2.5.1 It arises from the foregoing that certain general safety principles should be followed when designing radioactive ventilation systems, they are:

a) The air flow and air flow patterns in the working environment should, as far as is reasonably practicable, be adequate to give the occupants protection against airborne contamination;

b) The total air flow through the system from inlet to discharge into the atmosphere should be minimised. This will result in the number of filters to be disposed of as radioactive waste also being minimised;

c) Sufficient fresh air must be provided to the spaces which are normally occupied to ensure acceptable industrial hygiene conditions;

d) In designing the ventilation system, consideration should be given to extreme weather conditions, i.e. wind and temperature, and other external hazards;

e) Physical containments (e.g. total enclosures) are the most effective means of minimising the egress of active material. Ventilation provides a supportive role to this physical containment by means of maintaining a negative pressure differential (a depression) within the containment. The system should provide a sufficient inward air velocity through unavoidable or accidental openings in containment barriers, to limit the egress of particulates as far as is reasonably practicable;

f) The air flows should, as far as is reasonably practicable, be adequate for both the normal conditions and the postulated accident conditions.

g) The system should incorporate maximum use of energy efficiency, (e.g. heat reclamation from exhaust air), but this must not compromise the containment and safety requirements.

2.6 CONTAINMENT

2.6.1 In this document, those parts of the plant, building structure and equipment provided specifically to limit the escape of radioactive and toxic substances, whether in the form of gas, dust or fume, will be referred to as the containment. Total enclosures, fume cupboards and the rooms in which these are housed are all examples of containment.

2.6.2 A sealed containment is the most effective way to prevent the escape of particulate and gaseous substances. However, perfect sealing is not possible and since some openings in the containments are necessary to allow access by staff, transfer of materials and equipment, etc., and also since structural cracks will occur, a depression across each containment barrier is usually maintained to create inward flows of air to minimise leakage.

2.6.3 The degree of containment, including the number of barriers required, for the particular plant must be determined by a risk assessment, taking account of the design safety principles for the project. This will take into consideration the severity and likely frequency of potential accidents, including such factors as the quantity of radioactivity present, the isotopic toxicity and potential dispensability (gas, liquid or solid).

In some cases, it will be necessary to provide more than one successive independent containment, in order to prevent the escape of significant quantities of radioactive material to the external environment or work place. This is particularly likely to be true for plants handling significant quantities of High Toxicity radioactive substances.

2.6.4 Where there are multiple barriers, the first will often be that provided by a total enclosure in which the radioactive substance is contained. This may be a cave/cell or glove box. In some cases risk assessment will show that a further barrier is necessary to achieve a sufficient degree of containment. This is often necessary in order to give adequate protection to the workers, particularly where high toxicity substances are involved.

2.6.5 An additional containment may be required to guard against the release of radioactive material to the workplace or environment. This may be an integral part of the structure of the building and should surround totally the inner containment, and must remain effective under postulated accident conditions.

2.6.6 The practicalities of handling radioactive materials in a total enclosure require that it must be opened and entered from time to time for the purposes of maintenance and replacement of equipment. The containment from which entry is made may then become potentially as contaminated as the enclosure itself, and thus the containment barrier may recede from the enclosure face to the next effective barrier. If, under these circumstances, significant quantities of radionuclides are exposed, it may be necessary to provide an additional barrier before the outermost containment barrier. This will create access areas which are normally kept at a low level of radioactivity, but which may on occasion become contaminated to the level of the total enclosure. Access to these areas must be through change facilities.

The barrier of the access area may be a permanent or temporary structure (colloquially called a tent). In the latter case the associated change facility is also temporary.

2.6.7 Differing approaches to the principles of compartmentalisation for both containment and contamination control must be adopted to solve the varied problems which arise from plant to plant, and space does not allow description of all these in this document. However, the foregoing is intended to give the underlying principles on which containment is based. For a particular project, the designer of the ventilation system for radioactive areas should seek to

understand the operational requirements of the various areas to be ventilated, because air flow patterns within them and from the one area to the next are an essential safeguard by which the escape of radioactive substances into occupied workrooms and to the environment is minimised.

2.6.8 The ventilation system for radioactive areas is a vital component for maintaining containment of radioactive materials. Figure 2 illustrates a notional radiological facility.

2.7 CLASSIFICATION OF WORKING AREAS

2.7.1 The Ionising Radiations Regulations (1999) and the associated Approved Code of Practice (L121) introduce the concept of 'supervised' and 'controlled' areas. The overall classification system employed for radioactive areas must comply with the requirements of these Regulations.

2.7.2 It is good practice to classify areas in which work on radioactive materials takes place according to the degree of radioactive hazard potential. The purpose of this is to grade the operational requirements such as, type of protective clothing, monitoring control of access and to specify the design provisions needed to fulfil these requirements; for example, lockers for clothing, power points for monitors and boot change areas to demarcate limits of access. In other words, it is operationally convenient to classify areas and it enables some general statements to be made about equipment and structural provisions which are of assistance to designers. However, there are limits to the general applicability of such classifications; they cannot be all-embracing and variations in usage will be observed at all establishments and from one establishment to another.

Classification may be according to direct radiation, surface contamination or airborne contamination. Direct radiation classification of areas is not normally appropriate to a document on ventilation provisions in radioactive areas and is not included in this document. However, designers, operators and maintenance staff must be cognizant of possible direct radiation dangers arising from plant. Whilst some establishments have separate classifications for surface and airborne contamination, a common classification is used in this document.

2.7.3 The four colour classification used in this document (described later) provides a convenient way by which the broad divisions of areas may be referred to in operational and design documents, but should not be taken as an absolute definition of what must be provided in a particular area since what is provided will depend upon the needs of the process. In a particular case, the designers should use the descriptions of areas as a guide, but should ask the client to specify what additions or omissions are appropriate.

An approximate comparison of the area classifications, against the colour code system used in this guidance, for some of the co-operating organisations of the NVF are shown in Appendix A.

Other licensees may have alternative classifications that must be considered by the designer.

2.8 CONTAINMENT AREA CLASSIFICATION

2.8.1 The classification of working areas described in the following clauses is that which is used in this document, but its use as such does not preclude the application of this guidance to other classifications. Establishments classify areas according to particular needs which differ from site to site. Use of classification in the document implies no criticism of any existing classifications. An approximate comparison of the classification systems used on various sites is shown in Appendix A.

WHITE means a clean area free from radioactive contamination, whether surface or airborne.

GREEN means an area which is substantially clean. Only in exceptional circumstances is airborne contamination such that provisions must be made for its control.

AMBER means an area in which some surface contamination is expected. In some cases there will be a potential for airborne contamination such that provision must be made for its control.

RED means an area in which contamination levels are so high that there is normally no access without appropriate respiratory protection.

Note: Under abnormal (accident) conditions the GREEN and AMBER areas may be at an increased level of contamination as a result of an occurrence. This would be a high consequence, low frequency event (referred to as high potential).

3. THE GENERAL PRINCIPLES OF DESIGN OF NUCLEAR VENTILATION SYSTEMS

3.1 INTRODUCTION

3.1.1 To meet the safety criteria detailed in this document, ventilation systems must be designed, not only on normal industrial principles, but also specific to nuclear facilities. The aim of the designer should be to produce a system that, by reinforcing the basic safety provision of physical containment, minimises the effects of airborne radioactivity on persons and the environment.

3.1.2 The designer must recognise the probable needs to provide for the particular requirements of the various types of radioactive facilities, for example:

- Process plants and the various type of containment structures;
- Laboratories;
- Decontamination centres;
- Waste stores;
- Change rooms, etc.

All of these may be contained within one building and, if so, each may need a separate system, but they must be inter-related within the ventilation system of the whole building.

3.1.3 The main principles and design objectives are as follows:

(a) Provide appropriate air flow patterns within areas such that air movement is towards higher sources or potential sources of contamination;

(b) To reinforce containment by providing the appropriate depressions between areas so that the air always flows into areas of higher contamination at sufficient velocity to control back diffusion of contamination;

(c) Where the physical containment of the radioactive area is breached by openings provide, as required by the hazard assessment, appropriate means to maintain the containment in normal operation, unplanned events or in the accident state;

(d) Provide suitable conditions of temperature and pressure within the containment;

(e) Protect plant operators and the external environment in normal operation, unplanned events and the accident state;

(f) Minimise the throughput of air;

(g) Minimise any airborne effluent arisings;

(h) Minimise any waste arisings associated with the ventilation treatment equipment;

(i) Ensure that suitable facilities are available for the safe monitoring, status indication, and, where necessary, the continued operation of the ventilation equipment and functions during normal and abnormal conditions;

(j) Comply with Statutory Regulations and Site Licensee Policy (including Codes of Practice);

(k) Facilitate effective measurement of radioactive discharges for both statutory and operational purposes.

(l) To ensure that the system incorporates the maximum use of energy efficiency.

3.2 AIRBORNE CONTAMINATION

3.2.1 The concern in designing ventilation systems is with airborne contamination rather than surface contamination, although the two may be associated both in practice and in classification of areas. Surface contamination can exist with varying concentrations of airborne contamination in the atmosphere of a compartment. Increasing surface contamination will give rise to increasing airborne contamination.

3.3 FUNCTIONAL REQUIREMENTS

3.3.1 The main function of the ventilation system is to support the physical containment in controlling and minimising the escape and spread of particulate and gaseous contamination.

3.3.2 In the event of accidental breaches in the structural barriers segregating areas of different levels of contamination, the ventilating systems must be capable of maintaining sufficient air flow, through such adventitious openings, to limit back diffusion of the higher contaminated atmosphere into the lower contaminated atmosphere of the adjoining area.

3.3.3 To achieve this, the various areas must be maintained at different atmospheric pressure levels; areas with the highest atmospheric contamination levels must be maintained at the greatest negative pressures or depressions with respect to the atmospheric depressions in the adjoining areas. The area with the lowest atmospheric contamination level is maintained at the smallest depression. In this latter case, the potential contamination level may be considered to be so low that it is not necessary to hold the area at a depression.

3.4 CONTAINMENT AND AREA CLASSIFICATION

The concept of multiple containment barriers has been discussed in Section 2.6 and the role of the ventilation system in support of the containment is summarised in 3.1.3.

3.4.1 The enclosing structure around a RED area housing a radioactive process will be the first line of containment and will therefore require integrity and leak tightness appropriate to the activity contained. Penetrations will be sealed or fitted with appropriate clean-up devices and the ventilation system will be required to hold the structure at a depression which ensures sufficient velocity of airflow through adventitious openings to control leakage of activity to adjacent areas. For some facilities penetrations may not require sealing, but the design depression must be maintained.

Further containment barriers will be provided by the surrounding area boundary structures (AMBER, GREEN or even WHITE areas) as required by the plant hazard analysis, and the depressions/flows should be at levels, consistent with the defined containment quality.

In some cases, e.g. accident conditions, the levels of depression and in-leakage flows will require to be increased and this will require appropriate ventilation provision (e.g. operation in an extract only mode).

3.5 CHANGE OF AREA CLASSIFICATION

3.5.1 It may be necessary on a short term basis to change the classification of some areas, or portion of areas, due for example to specific operational or maintenance requirements.

In the case of permanent areas such as cave maintenance facilities which are integral with the cave structure, these areas might normally be classified as GREEN or AMBER. When some maintenance activities are being carried out, these areas may need to be classified as RED. Where such areas are identified, the ventilation system must be designed to meet the requirements of the higher classification.

In other applications, temporary tents may be erected. The tents may have portable ventilation systems, or be connected to the main ventilation system at connections previously provided for this purpose. Where such temporary connections are envisaged, the necessary extra capacity should be included in the system design or, if utilising existing systems, the designer is to ensure that the additional capacity can be incorporated without compromising system operation. In such cases it may not always be practicable to achieve all the requirements of the higher classification, and a lower standard may be acceptable subject to a safety assessment.

Figure 2 illustrates one such example to allow access into a glove box. Here, part of the GREEN operating area is temporarily re-classified as AMBER inside the tent.

3.6 VELOCITY TO LIMIT BACK-FLOW

3.6.1 The minimum air velocity at openings to limit back-flow of contaminated particles has generally been taken as 0.5 ms^{-1}. Designers should aim to maintain this minimum velocity through adventitious openings.

3.6.2 Engineered openings should be designed appropriately consistent with the risks in the operational area.

3.6.3 Higher average velocities may be required to overcome instability of the air flow pattern, and when dealing with some gases and volatile liquids. These velocities should be determined after consultation with the responsible safety assessor. It should be noted that higher velocities than 1.0 ms^{-1}, to limit back-flow, can cause eddies and hence loss of protection.

3.6.4 For long narrow openings, such as slots around doors or plugs in shielded facilities, the minimum air velocity to limit back-flow must be determined taking account of the geometry of the opening, and the properties of the substances contained.

3.7 BASIC AIR PATTERNS AND CLEAN-UP (FILTRATION) SYSTEMS

3.7.1 Air should enter the building GREEN area through industrial grade filter (to reduce the build up of dust on extract filters, hence prolonging their life, and also protect against backflow in the event of loss of extract system airflow) and where necessary, in locations having a higher potential level of contamination, through HEPA filters (to ease the discrimination between airborne actinides and the background activity). The air may be treated to maintain the designed environmental conditions.

3.7.2 To prevent freezing of the input filter system and matting in high relative humidity conditions in winter, the filter installation should be preceded by pre-heaters or anti-frost coils. In summer months with high external relative humidity conditions it may be necessary to provide moisture removal equipment. Suitably located access doors or openings should be provided to enable periodic cleaning of air inlet points. The air inlets should also be engineered to facilitate cleaning.

3.7.3 Within the building, air flows should be from areas of lowest potential contamination to those of highest contamination (i.e. from WHITE to GREEN areas and so on). Air velocities through breaches or potential breaches in the containment BARRIERS should be sufficient to prevent unacceptable back diffusion of contaminated aerosols into the lower contaminated atmosphere of the adjoining area. Where shown to be necessary, as a result of hazard assessment, air flow paths should be through HEPA filters between areas of different classification. Consideration should be given to supplying air adjacent to the operator work station, so as to flow past the operator and be extracted near the points where potentially radioactive contamination will be released.

3.7.4 In general, air is extracted from the areas via ductwork to the discharge duct or stack. The number and type of filters in series in the duct systems from the various areas, prior to the discharge point, will be determined as result of hazard assessment.

3.7.5 Containments for RED areas, such as glove boxes, caves, etc., all contain loose radioactive materials, a very small proportion of which is airborne at any time. The activity in the extract from these facilities will be directly proportional to both the airborne contamination concentration and the extract flow rate. In many situations double HEPA filtration will provide the necessary clean up for these extracts.

3.7.6 Other extracted areas are cells, usually incorporating shielding, which house active plant, e.g. solvent extraction, evaporation, effluent treatment. Such items are in high quality primary containment. The extract from these cells will be clean if there has been no containment breach. The clean up requirements are usually dependent upon the accident potential of the system as assessed by hazard assessment, and single or double HEPA filtration may be required. An option on these systems is to keep the clean-up plant on a standby basis, bringing it into use in the event of an accident. This option will have to be justified; it will be necessary to demonstrate that appropriate indication and control functions exist to bring the system into use in sufficient time to control the release to acceptable levels.

3.7.7 There are other nominally contaminated areas which need consideration, such as fume cupboards which are used extensively in laboratories, decontamination facilities and nuclear chemical plants. These contain limited amounts of dispersible activity. Typically they would be subject to single filtration for normal operations. Any additional protection would be identified by hazard assessment and justified on release potential grounds.

3.7.8 Air in AMBER areas is unlikely to be sufficiently contaminated to require more than one stage of HEPA filtration on the discharge. The need for additional treatment on the grounds of potential accident releases will need to be considered as part of the plant hazard assessment. It should be noted, in this context, that the level of activity in relation to operator access is not directly relevant to the need for discharge filtration; this latter requirement arises more from the need to keep discharges ALARP (and BPM).

3.7.9 In most cases, filtration of GREEN area discharges may not be required. The need should be reviewed as part of the plant hazard assessment, taking into account the potential for accident releases and the requirement for all activity discharges to be ALARP (and BPM).

3.7.10 In cases where the ventilation discharge has little accidental discharge risk, clean-up systems are not always justified. To avoid, during normal running, passing large amounts of air through HEPA filters (which are expensive to install, maintain and dispose of after use), standby systems serving a number of areas, could be brought into use for fault conditions.

3.7.11 An illustrative air flow diagram is shown in Figure 3. On installations where a significant hazard exists and the GREEN area is provided to containment standards, there may be a requirement for motorised dampers and a HEPA filter on the input ventilation system. There are many variations of this illustrative diagram to suit differing installations. All, however, should comply with the foregoing Subsections.

3.8 VELOCITIES BETWEEN AREAS

3.8.1 The air flow must always be from areas of low contamination to areas of higher contamination. The air velocity from one area to the next will vary with different designs, e.g. door or other openings, and the operational state, e.g. if a door is open or closed. The following information on air velocities defines minimum requirements:

(a) Where there is no requirement for a containment barrier between WHITE areas and GREEN areas of negligible potential hazard, the direction of airflow must be towards the GREEN area and there is no requirement to maintain minimum air velocities;

(b) Where a containment barrier is provided against potential hazards in the GREEN area, the airflow through penetrations must be consistent with the required containment quality. In the absence of any other specified value, a minimum velocity of 0.5 m/s is recommended;

If the penetration is a door, this air velocity applies when the door is closed. Transiently, with the door open, the direction of bulk air movement should remain from WHITE to GREEN areas;

(c) The airflow through openings between GREEN and AMBER areas should not be less than 0.5 m/s. This criterion applies to all openings except that where two doors are provided in series, and only one door is opened at any time, the criterion then only applies to air paths openings across the closed door; The classification may be desirable where there is a likelihood of airborne contamination.

(d) The airflow through openings into RED areas should not be less than 1.0 m/s. Where two doors are provided in series, and only one door is opened at any time, the criterion then applies only to air paths across the closed door. For single doors, which are open for short periods only, lower velocities may be acceptable subject to safety justification.

3.8.2 To prevent back-flow, non-return devices or HEPA filters should be provided between RED and AMBER (or GREEN) areas.

3.9 AIR CHANGES

3.9.1 The number of air changes will be determined by the conventional ventilation requirements to cater for fresh air, removal of odour, potential asphyxiates, vapours and heat etc. In addition, the air change may be determined by the radiological requirement to maintain correct depression and air flows between areas, and allow efficient air monitoring where this is required.

Table 1 illustrates **typical** air change rates that have been used in the past.

Designers should justify the air change rates they select based on the specific requirements of the plant areas they are ventilating.

TABLE 1 Rough sizing Guide to air changes

This table may be used in the initial design stage, for the purpose of roughly sizing the plant required. **Rates shown should only be used for initial schemes** and a hazard assessment carried out to determine the necessary air change rates.

Compartment	**Typical air changes per hour**	**Area Classification**
Change rooms / Airlocks	4 - 5	WHITE, GREEN or AMBER
Normally clean air corridors	1 - 2	GREEN
Normally non-active rooms	1 - 2	GREEN
Controlled areas of medium potential hazard	2	GREEN
Controlled areas of high potential hazard	5 - 10	GREEN
Maintenance areas to primary containments of low risk process plants	1 - 5	AMBER
Maintenance areas to primary containments of high risk process plants	10	AMBER
Primary containments (gloveboxes / containment enclosure or shielded cell)	1 to 30 depends entirely on process and hazards	RED

NOTE: In establishing the effective volume for air change calculations, in certain instances, only the first 3 or 4 m of height may have to be considered.

3.9.2 WHITE areas, by their definition, are free from contamination and generally do not require special consideration other than to recognise a potential for contamination. This does not preclude the use of ventilation in these areas as determined by the normal building mechanical service requirements.

3.9.3 In those areas which have a potential for airborne activity, increasing the air change rate may not in itself produce a significant reduction in airborne activity levels local to the operator. Also, it should be noted that high flow rates should, where possible, be avoided, since they can cause levitation of contamination and hence increase airborne activity levels. However, increased flow can reduce the average concentration in the area as a whole. Distribution of the air at operator level is important. The air flow rates include air quantities that may be induced into the area from the WHITE area and external volumes. In certain circumstances, subject to hazard assessment, and by agreement with the responsible safety authority, a proportion of the air change may be obtained by re-circulating the air within the area. In areas having a potential for high contamination the air must be filtered to HEPA standards before recirculation.

3.9.4 The air change rate should be the lowest rate possible which fulfils the requirements of the area.

3.10 PRESSURES (DEPRESSIONS)

3.10.1 Depressions between areas are necessary in order to create the required inflow of air through openings of not less than the specified average velocity during normal and abnormal conditions. Depressions are maintained by means of balancing dampers, vortex amplifiers and fan speed regulators, etc. The input and extract systems must be balanced to maintain the required depressions in the areas.

3.10.2 The depressions required to create the recommended velocities (0.5 – 1.0 m/s) are very small and are not easily measurable. Where it is required to measure and/or alarm loss of flow it is usually necessary to enhance these depressions; a value of between 30 and 60 Pa is usually sufficient for this purpose. It should be noted however, that larger depressions may be required for caves, cells, or glove boxes.

3.10.3 In certain circumstances, for example where the effects fo wind loading have to be considered, it may be necessary to enhance depressions.

3.11 FANS AND MOTORISED DAMPERS

3.11.1 When selecting supply or extract fans allowance must be made for the varying resistances of filter systems between clean and dirty conditions, both for normal operating and accident conditions.

3.11.2 Standby fans should be provided, unless a hazard assessment demonstrates this to be unnecessary. They may be provided with automatic changeover devices such that, in the event of failure of the operating fan, the standby fan is automatically started. To achieve the required level of reliability, careful design and maintenance of the relevant systems are necessary.

3.11.3 Dampers should be provided on the upstream and downstream sides of parallel filter banks. Dampers should also be provided on the suction and discharge sides of each duplicate fan. Consideration should be given to having the damper on the discharge side of each duplicate fan, motorised and arranged to open and close on fan start-up and shut-down respectively. The damper on the suction side of the fans would be manually operated and normally left in the open position. A self-operating non-return damper should be considered on the upstream side of the discharge damper as a back-up, in the event of a failure of the motorised damper.

3.11.4 Motorised dampers, operable from a central control area should be considered on the separate air input ductwork system to the AMBER area and also the GREEN area where there is deemed to be a potential hazard.

3.11.5 If the duct is venting from an area that is part of a fire zone, then a fire damper is required where it penetrates the fire barrier. If the ductwork passes right through a fire zone, but has no opening into it, then no damper is required but the ductwork must be fire rated. Fire dampers may be subject to automatic or manually initiated closure.

3.11.6 Where an extract fan is handling high beta/gamma contamination, consideration must be given to shielding, maintenance and decontamination of the fan. Wherever it is practical to do so however, contamination should be treated by filtration upstream of the fan.

3.11.7 Extract fans discharging air to atmosphere via stacks should be located as close as possible to the stack to limit the length of positively pressurised ductwork.

3.11.8 An illustrative air flow diagram is shown in Figure 3. On installations where a significant hazard exists and the GREEN area is provided to containment standards, there may be a requirement for motorised dampers and a HEPA filter on the input ventilation system. There are many variations of this illustrative diagram to suit differing installations. All, however, should comply with the foregoing Subsections.

3.12 INCIDENT CONTROL ROOM

3.12.1 The ventilation systems serving incident control rooms should be designed to continuously maintain comfortable and safe environmental conditions, and to control airborne contamination levels below the set targets. The incident control rooms must remain viable under incident conditions within the plant or elsewhere on the site to allow safe, controlled shutdown of operations. Consideration should be given to the following:

(a) Maintaining the control room at a positive pressure with respect to atmosphere;

(b) Providing the standard of filtration necessary to maintain the required environmental conditions;

(c) Ensuring reliability in the fans and their associated electrical supply

(d) Possible toxic gas concentrations in supply air, and the need for activity monitoring of the supply air to initiate protection systems (e.g. by-pass with filter/adsorber).

3.12.2 In the event of an incident on site, workers may be asked to take shelter inside surrounding buildings. Designers should therefore consider the habitability of such sheltering buildings during an emergency and ensure they are offered appropriate protection and an adequately clean supply of filtered air if necessary.

3.13 INITIAL DESIGN SCHEMES

3.13.1 Figure 4 may be used as an aid in the early conceptual design stage of ventilation systems. The figure gives a simplified picture covering many but not all ventilation sub-system configurations (for example, it does not cover natural ventilation systems, or re-circulated systems). It shows some major items of equipment required, the direction in which some air cascades from one sub-system to another, and typical inlet and extract arrangements.

3.13.2 In practice some air may cascade from one room to another within a ventilation sub-system (this occurs in the example shown in Figure 5).

3.13.3 Use of Figure 4 does not obviate the need for a thorough understanding and application of the principles outlined in this document.

3.13.4 Figure 5 shows a possible application to a process plant of some of the sub-systems shown in Figure 4.

4. PRINCIPLES OF DESIGN FOR THE VENTILATION OF NUCLEAR FACILITY CONTAINMENT SYSTEMS

4.1 GENERAL

4.1.1 The previous sections of the Document have laid down general principles to be adopted in the design of ventilation systems for radioactive areas. This Section develops these philosophies to produce more detailed principles and practices for the design of some of the more frequently encountered active ventilation systems, namely:

(a) Glove boxes;

(b) Caves;

(c) Cells;

(d) Fume cupboards.

Including:

(e) Inert gas systems, and

(f) Vessel ventilation systems.

The construction of and the functions performed by (a), (b) and (c) are different. The design approach to ventilation is however generally the same, although the system requirements and final equipment selected may be varied. Each system must therefore be individually assessed to establish its optimum design, both technically and economically.

4.1.2 Although these systems are generally independent of each other and of the main building ventilation, the interaction between them must be considered and where hazard assessment dictates suitable interlocks provided.

4.2 GLOVE BOXES

4.2.1 The range of uses and activity levels handled in glove boxes is varied. Typically they can be used for the following applications:

(a) Handling of certain alpha radioactive materials, e.g. plutonium;

(b) Handling of certain low energy beta radioactive materials, e.g. tritium;

(c) Handling of non-radioactive toxic materials, e.g. beryllium;

(d) Handling of pyrophoric materials in oxygen-free atmospheres, e.g. finely divided metals in argon gas;

(e) Handling of bio-hazardous material.

AECP 59 provides further information on the design, operation and ventilation of glove boxes. For this reason, only the basic systems are included here to illustrate the principles involved.

4.2.2 Glove boxes handling radioactive materials should be maintained at a suitable depression to create sufficient inflow and hence limit the escape of particulate matter or radioactive gases, through such unavoidable leaks as may exist, for example, around the window seals. This depression should be as small as possible having regard to the process within, glove operability, the reliability of the ventilation system in maintaining it, and the leak tightness of the boxes and the associated pipework. Depressions for normal operations may vary between 150 and 650 Pa, and are typically 375 Pa.

4.2.3 Cases exist where boxes operate above atmospheric pressure, for example, where it is essential to maintain a very pure reducing atmosphere within the box or its equipment. Such instances require special consideration including the need for an additional containment barrier. The overall effect on the ventilation system due to the higher box pressures is not generally significant.

4.2.4 In circumstances where it is necessary to guard against a loss of containment, due to glove failure or other causes, there may be a need to provide an automatic emergency system. The system should be designed to accommodate the maximum emergency flow whilst maintaining the remaining glove boxes in a safe condition.

4.2.5 For dry processes, especially where finely divided material is handled, it is important to minimise the disturbance of the product. Hence, high air or gas flows for normal conditions are undesirable and the atmosphere must enter the box space at low velocity and in the position where it causes minimum disturbance. Static conditions, however, lead to the formation of ozone in the air in the boxes, due to the radiation effects on the oxygen content, and this attacks and results in the breakdown of gloves, flexible connections and seals. A reasonable flow in dry boxes is 1 to 5 changes per hour.

4.2.6 Wet chemical processes release vapours which may condense and cause misting of the panels. Condensation on the panels will be a function of the following:

(a) Nature of substance being evaporated and its surface area;

(b) Amount of evaporation;

(c) Temperature of liquid and movement of gas over it;

(d) Temperature of air inside and outside the enclosure;

(e) The temperature of the clean side of the panel.

A flow of 10 to 15 changes per hour may be required to prevent condensation, and consideration should be given to the use of equipment to remove the vapours.

4.2.7 Corrosive vapours and gases should not be released into the box atmosphere, but should be vented from the process equipment by a separate system using scrubbers, or other appropriate means of removing and/or neutralising them. However, the escape into the box atmosphere of some such vapours or gases may be unavoidable, and flow rates of 30 changes per hour or more may be required in extreme cases to prevent excessive concentrations in the box and in the extract system.

4.2.8 Where local concentrations of gases can arise with undesirable or potentially dangerous results, the position of the air input and extract points must be arranged to prevent this. Sparge pipes, swirl nozzles or recirculation fans may be necessary to achieve the required

dispersion. Care must be taken in the positioning of fans, and motors may need to be flameproof. Designers should also refer to the Dangerous Substances and Explosive Atmospheres Regulations (2002) (DSEAR) for further requirements.

4.2.9 Pressure control, for both normal and emergency conditions, should be arranged in the glove box extract, and this may be achieved by one or more of the following typical systems:

(a) Vortex amplifier, (VXA);

(b) Operation of a control valve, either directly or through a pressure switch;

(c) Low pressure extract system, having sufficient capacity to maintain a nearly constant depression against varying flow conditions. This system is still under development.

4.2.10 The details of each of the foregoing types of control are as follows:

(a) The Vortex amplifier (see figure 6). The Vortex amplifier has the advantage of possessing no moving parts. Control and switching to emergency conditions are effected by using movement within the amplifier. Vortex amplifiers may be used in various modes depending on the system requirements. Only one exit line may be required from the glove box, for both normal and emergency conditions. Air from the control flow inlet ports is admitted to the amplifier box through fixed nozzles to create a vortex. This restricts the air flow from the glove box to maintain design pressure in the box and at normal conditions of flow. A breach of glove box containment is accompanied by an increase in pressure in the extract branch which causes the vortex to collapse and permits a much increased flow from the glove box sufficient to provide the necessary velocity, inwards through the breach. The extract discharges into a High Pressure Extract (HPE) line at a depression of 1.5 kPa. Figure 7 shows a typical simple VXA system and Figure 8 the control system characteristic. The first stage filter in VXA may be in the position shown or immediately downstream of the VXA, providing that the system is designed to cater for the respective filter position.

Design must ensure that system capacity is matched to extract impedance to ensure correct VXA function. This should be reconfirmed during commissioning (typically by working through the ventilation test schedule for the plant.

(b) Pressure switch operating a control valve system and a direct operating emergency valve system (see figure 9). These systems would require separate extract branches for normal and emergency conditions. A small branch should pass sufficient air or gas for normal operation with acceptable accuracy of control. A larger system should have a valve set to open and provide the increased flow required when the emergency depression is reached. It is important that independent pressure sensing lines are taken from the box at each of the normal and emergency valves or switches. Discharge is into the High Pressure Extract (HPE) main duct in which the depression is maintained at 1.5 to 2.25 kPa. Final discharge is through HEPA filters and the HPE fans to the building main extract duct, or if desired, direct to the stack. Where high pressure gases or vacuum source are connected to equipment within a glove box, consideration should be given to the provision of lutes or other devices to protect the integrity of the glove box under fault conditions. It should be noted that the speed of response to a transient is slower than (a) and (c).

(c) Low pressure extract system. The low pressure extract system should have sufficient capacity to maintain constant depression against varying flow conditions and requires

no control valves or vortex amplifiers but has large low resistance branches and a high volume ducting system. Thus, when a breach of containment occurs (for example, a glove removal) the requisite in-flow velocity through this breach will not seriously affect conditions in the rest of the systems; the depression in the extract main should be not more than 0.75 kPa. This system has the advantage that if glove boxes are subjected to full system depression the integrity of the boxes will not be jeopardised.

The foregoing alternatives should have sufficient instrumentation to cover postulated accident conditions in relation to particular application needs as well as the mechanical functioning of the extract equipment.

4.2.11 Section 5 of this document gives general information on the proper use of filters. Filter design and selection is covered in AECP 1041. The following information is particularly useful in connection with glove boxes. A range of suitable filters are available including:

- 0.25 L/s for sensing lines;
- 1.25 L/s for inlet branches;
- 5.00 L/s for inlet and extract branches;
- 25.00 L/s for extract branches.

The inlet and outlet branches to each box must be fitted with HEPA filters to minimise the release of radioactivity through the ventilation system under both operating and static conditions. The filters must be fitted so as to accommodate flows in both directions without loss of integrity. The extract filters must be sized to cater for emergency flows. Special provision is required to deal with wet atmospheres.

The purpose of the inlet filter is to clean the input air and to limit the escape of contamination in the event of loss of depression or actual pressurisation of the glove box. Many filters are now supplied marked with an arrow indicating the required direction of flow.

The extract system should have appropriate treatment as deemed necessary by hazard assessment. This typically includes first stage and final stage HEPA filters - the final stage being required to prevent escape of contamination during changing or in the event of a breakdown of the first stage filter.

Normally, pressure sensing lines to control valves, pressure switches and gauges should be fitted with HEPA filters to minimise the spread of contamination. These should be positioned so that particulate matter cannot settle on them by gravity. Vortex amplifiers in some forms do not use sensing lines.

4.3 CAVES AND CELLS

4.3.1 The operations and processes which are carried out in caves and cells are varied, and a complete understanding of them is necessary since they dictate the ventilation requirements. The following factors must all be considered in designing an acceptable and effective system:

(a) The depression of the cave or cell relative to the adjacent working area;

(b) The leak tightness of the physical barrier;

(c) The heat and moisture gains within the enclosure;

(d) The activity arising and their form under both normal and postulated incident conditions;

(e) The allowable airborne effluent discharge levels;

(f) The long term reliability of the system;

(g) The decontamination and decommissioning facilities and procedures.

4.3.2 Both caves and cells should be operated at depressions with respect to all adjacent areas to protect personnel and the working environment from the effects of contamination migration through engineered or adventitious routes in the physical containment. It may not be necessary to design cave and cell extract systems for emergency breach flows since the normal depression and air flow rate may be sufficient to cater for all credible breaches of containment. If this is not so, consideration should be given to features such as VXAs.

4.3.3 Care should be exercised when selecting a value for the depression since there are conflicting requirements:

(a) It should be measurable and controllable;

(b) It should be sufficient to induce a minimum average velocity of 1 m/s through any engineered inlet system and adventitious opening.

Whilst meeting (a) and (b) it should be optimised to:

(i) Limit the amount of in leakage which requires subsequent treatment.

(ii) Be positive with respect to any enclosed process vessel or vessel vent system.

(iii) Minimise fan energy consumption.

4.3.4 The design depression for caves and cells based on the above criteria is generally at least 125 Pa, but it is dependent on the number of penetrations and on construction standards. Suitable instrumentation will generally be provided to give continuous safety confidence and to alarm on loss of depression. Caves and cells can be operated at depressions less than 125 Pa, dependent on hazard assessment and construction standards.

4.3.5 Caves are often built in suites with large interconnecting shielded doors. Due to potential maintenance access problems, interconnecting shielded doors are generally not sealed, however, the final door to the general access area should be well sealed to prevent activity release during incident conditions and to maintain the design depression with minimum air flow rates.

4.3.6 Where there is a suite of caves, air flows through from areas with the lowest, to areas with the highest contamination level where it is extracted for treatment. This method helps to reduce the spread of contamination, the total air flow and the extract treatment requirements.

4.3.7 Due to the type of operation carried out in caves, viewing is generally through shielded windows. To achieve satisfactory visibility, a high illumination level is required, 3,000 to 6,000 lux being typical, and this gives rise to high internal heat gains. This heat, and any additional process or equipment heat gain, is normally removed by the ventilation system which controls

the internal temperature to an acceptable level. Acceptable temperatures in caves vary depending on the construction and internal equipment limitations, however, few caves operate at temperatures greater than 50 ° C.

4.3.8 In some circumstances, where significant spillages into the cell of highly active liquor are identified as credible fault conditions, a cell to vessel ventilation interlink may be provided so that the cell extract can be closed and the cell air extracted and treated, albeit by a reduced volume flow rate, by the more appropriate vessel ventilation system.

4.3.9 Air extracted from caves and cells may contain radioactive particles. A hazard assessment must be completed to quantify potential activity levels. After comparison with allowable plant discharge levels the required treatment can be determined. Generally, one or more stages of HEPA filters are required for final treatment with appropriate shielding to minimise operator dose uptake. Hazard assessment may also identify a need for a local first stage HEPA filter. See AECP 1041 for special reference to the siting and installation of filtration equipment.

4.3.10 Where an input of air is necessary to a cave or cell a single stage HEPA filter with an isolation/air flow regulating damper is normally provided to control possible back diffusion. This input may be required where infiltration, through the concrete for example, is insufficient to cater for the heat load or process within the containment.

4.4 FUME CUPBOARDS

4.4.1 In areas where odorous or hazardous materials are handled, the provision of a clean working environment is ideally achieved by physical containment. With laboratories, where complete containment is not feasible due to the requirement for operator access, fume cupboards are generally used. The fume cupboard is designed to envelop, as far as possible, the equipment and processes whilst maintaining variable access to the front face.

4.4.2 Each fume cupboard is connected to an extract ventilation system from which the gas, after suitable filtration, is exhausted to atmosphere. The air flow rate is designed to maintain a velocity of typically 0.7 to 1.0 m/s through the fume cupboard face. Velocities in excess of these figures can be undesirable since they may create turbulent and uncontrolled air flow patterns leading to releases of contamination. It is recommended that a flow indication with some form of fail safe visual and audible alarm be provided (see BS 7258).

4.4.3 Consideration should be given to the effects on the space ventilation of the operation of fume cupboards, particularly where there are a number of cupboards in one room. In these cases it is the airflow requirement of the fume cupboards which determine the ventilation of the room itself. The high face velocities involved, and the use of by-pass airflow systems giving constant airflow irrespective of the sash opening, gives rise to a higher number of changes per hour than that recommended in this document. The significance of this is that the air input diffuser velocities must be kept at a level consistent with operator comfort and therefore the input diffuser area has to be considerably increased. In general, installation of fume cupboards means that larger air handling units are required together with larger heater batteries than would be required for normal active area, ventilation. A compromise, between over extraction on space extract, and face velocity on fume cupboards, can be helped by the use of glove plates set into the fume cupboard sash gap.

4.5 INERT GAS SYSTEMS

4.5.1 For some operations, such as the handling of irradiated and non-irradiated reactor components and fuels in the presence of liquid metal coolant (molten sodium 130-150 °C), high quality inert atmospheres suitable for use at elevated temperatures are essential. Thus the cave or facility must be constructed to a high standard of leak tightness.

4.5.2 In order to achieve this, economically closed cycle systems are used and the inert gas is circulated through purification plant as appropriate. Typically a ventilation plant associated with such a facility would consist of:

(a) HEPA filters and charcoal traps (adsorbers);

(b) Fan or blower;

(c) Cooling loop;

(d) Deoxo unit;

(e) Molecular sieve drier.

In the case of a pure argon system, there would be an additional requirement to provide for nitrogen removal by means of a low temperature distillation plant. These systems are complex and design is more the concern of the chemical engineer. The control system requires careful attention and this is facilitated by incorporating a gas holder in the circuit.

4.6 PROCESS VESSELS

4.6.1 The ventilation of process plant vessels and equipment is primarily the concern of the process plant designer rather than the ventilation engineer. Generally the current practice is to discharge vessel ventilations to atmosphere via dedicated clean-up systems and fans, and a segregated extract flue. There are, however, possible interactions with space ventilation in respect to pressure differentials, and in some cases a common discharge stack is used and should in fact be used if it is economically and practically viable to do so. The ventilation designers should therefore appreciate the overall functional characteristics of the vessel ventilation system, and liaise closely with the process plant designer during the design and commissioning stages. Reference should also be made to AECP 1063. The following aspects should be considered:

(a) The vessel ventilation (VV) extract system should maintain all vessels at a depression relative to their surroundings, and at a zero differential relative to each other irrespective of location;

(b) The system must be stable under vessel sparging conditions or inadvertent air admissions;

(c) The system must separate and convey to a safe place any liquor which may be carried into it;

(d) The system should, where applicable, deal with slightly acid gases;

(e) The system should be capable of being washed down to an appropriate point for decontamination purposes;

(f) The system should effectively treat the extracted gas prior to discharge;

(g) Wherever possible the system should have a flow pattern which conveys gases towards the high active section of the plant.

4.6.2 In addition to the above, there are other specialists systems required, within the VV system, to deal with off gases from:

(a) Fuel and residue dissolvers, both irradiated and non-irradiated;

(b) Exhaust from ejectors used for creation of depressions and transfer of active liquids.

In the former case, apart from any specialist plant for removal of possible gaseous radioactive materials, the removal of nitrogen oxides (NOX) is essential both to comply with current emission regulations and also to prevent corrosion in filtration systems and the main ventilation ducting etc.

4.6.3 VV of gases, after treatment, are usually passed through high efficiency filters before discharge into any other ventilation system or direct to atmosphere. As the gases are often moist, especially if liquid scrubbing has been carried out, and can contain entrained active mist due to active liquid transfers, special provision must be made to deal with this.

4.6.4 Treatment systems employed typically include high efficiency electrostatic precipitators and corrosion resistant demisters. HEPA filters can also be used, and in this case dilution and preheating are employed to ensure a moisture level low enough not to impair the HEPA filter medium. Typically the VV system is maintained at a depression of 125 to 500 Pa below that of the surroundings. However a differential pressure of 25 Pa can be quite satisfactory under certain conditions.

4.6.5 Ejectors are frequently intermittent in operation and impose a highly variable load on the exhaust gas system. Further, due to the use of high pressure fluids for ejector operation, off gas rates are high. This requires special attention to sizing of pipework if pressurisation in the exhaust system is to be avoided, This can be a particular problem where a number of ejectors discharge into a common exhaust manifold, particularly if a number of ejectors are used simultaneously.

5. AIR HANDLING AND TREATMENT SYSTEMS

5.1 GENERAL

5.1.1 Section 6 gives an indication of the leak tightness of a building. However, the ventilation system of the building may require an inlet connection and will certainly have an outlet, usually via a vertical stack to the external atmosphere. In order to limit the escape of radioactive matter by these routes, special provisions are necessary so as not to compromise the building leak tightness

5.1.2 Ventilation-air flows to the discharge stack from areas of high contamination will require to be treated to remove the contamination before discharge. In some cases it may be more economic to utilise specialised equipment to deal with particular air borne contaminants at source before they are diluted with flows from less potentially hazardous areas.

5.1.3 The radioactive contaminants to be removed can be grouped as particulate aerosols, volatiles and semi-volatiles such as iodine, including gaseous compounds, and the inert gases. Contaminants arising from chemical processing and similar operations may require particular treatment which is outside the scope of this document.

5.2 HEPA FILTRATION

5.2.1 The High Efficiency Particulate Air (HEPA) Filter is the usual means of achieving effective particulate entrainment. Consideration may be given to the use of a pre-filter (see 5.8.1).

5.2.2 The purchase, handling and disposal of HEPA and other particulate filters is expensive, particularly when significant activity is loaded onto the unit. Hence it is important to maximise the service life by minimising the arisings of active or inactive particulate. The internal surface materials in the whole containment should therefore be carefully considered, and reference made to AECP 1057, which covers radioactive decontamination, and AECP 1002 which advises on the selection of surface materials tested for Decontamination Factor to BS4247 Pt 1.

Generally, HEPA filters for nuclear applications should be type approved. In addition, where performance is claimed in the safety case, for any HEPA filter, then that filter will normally be testable in situ. Type tests are performed on HEPA filters (made using a particular manufacturing route) to ensure they meet the requirements of the relevant Standard Specification. These type tests are normally carried out, on samples of filters, at the start of a running contract. Any subsequent changes in the manufacturing route will require the type test to be repeated.

5.3 IODINE ADSORPTION

5.3.1 A carbon bed adsorber is the most common means of retention of iodine and gaseous iodine compounds. The carbon may be impregnated with potassium iodine (KI) and

triethylenediamine (TEDA) to improve its effectiveness. It should be noted that, in some circumstances, the use of charcoal is not compatible with other contaminants which might be present, for example, nitrogen oxides in chemical plant.

5.3.2 Alternative iodine adsorbers have been developed for chemical plant use. In particular AC 6120, which is a silver containing substance, is very effective. It is, however, very expensive and would only be used in a specially designed facility where the hazard analysis and cost benefit analysis showed it to be necessary. Thus further discussion is outside the scope of this document.

5.3.3 Carbon (charcoal) adsorbers are often utilised in specially designed units which in the past often were shallow (100 mm deep) trays, more commonly now deeper beds are used which have a greater capacity and therefore capability to adsorb the poisonous trace impurities which impair iodine trapping efficiency. Modular iodine traps are now commercially available for use with smaller flow rates. They are sized to be interchangeable with 609 x 609 x 305 mm HEPA filters and may therefore be fitted in standard mountings. Full details of carbon bed traps and trapping can be found in AECP 1064.

5.4 THE INERT GASES

5.4.1 If retention of these gases (e.g. krypton, xenon) is required, specialist treatments which are outside the scope of this Document are needed.

5.5 PARTICULATE FILTRATION DECONTAMINATION FACTORS

5.5.1 Standard HEPA filters are manufactured to a rated penetration of not greater than 0.01% when tested by the Sodium Flame Method, BS 3928 (Bench test). The equivalent efficiency is thus 99.99%. However, it is often, more convenient to refer to the Decontamination Factor (DF) which is defined as the reciprocal of the penetration. Thus standard filters have a DF of (100/0.01) = 10,000. HEPA filters of higher and lower efficiency are also available.

5.5.2 The required DF for a filtration system will be determined by carrying out an analysis of routine and accident conditions (hazard assessment) clean-up requirements to meet the appropriate site safety criteria. When designing a filtration system, the following points should be taken into account so that the required DF can be achieved:

(a) Leakage across the filter seating (gasket leakage);

(b) Decreased efficiency of the unit(s) under extreme (accident) conditions;

(c) Redundancy requirements.

5.5.3 When a guarantee of DF is required, by the Safety Case, for any filter, the installation should be tested (typically biennially) to determine that the required DF is being achieved. This test under normal flow conditions will be done by an approved method which, ideally should utilise particles of the most penetrating size, about 0.2 μ m diameter. Smaller and larger aerosols will be retained with a greater efficiency. This functional test will include any bypassing and gasket leakage.

5.5.4 Since it is not possible to test in-situ filters under extreme (accident) conditions, it is often considered prudent to assume a decreased DF for the purposes of hazard assessment. This reflects the lack of experimental and statistical data on filter performance, particularly of aged (used) units, under unusual conditions.

5.5.5 High DFs can be obtained by filters in series. The overall DF can be taken as the product of the individual DFs. However it may have to be assumed that the first stage filter is not functioning or has been destroyed, particularly in an accident situation.

5.5.6 The in-situ testing of filters is covered in Appendix B.

5.6 INPUT FILTRATION SYSTEM

5.6.1 Input air filtration may be provided for a variety of reasons, and hence differing DFs may be applicable. Industrial grade filtration, such as bag or panel filters, may be adequate to reduce general particulate ingress, and will generally be cost effective in reducing the frequency of building maintenance, decoration, etc. HEPA inlet filtration may be cost effective in some applications as it could reduce the frequency of change and disposal of active extract filters. HEPA filtration may also be required if a hazard assessment shows the possibility of a reverse flow containing radioactive aerosol.

5.7 EXTRACT FILTRATION SYSTEM

5.7.1 The extract system may have one or more stages of filtration to preserve the containment function. Where more than one stage of filtration is used, then the first filter should be positioned as close as possible to the origin of the activity. If this filter is not testable it will not be possible to credit it in calculating the DF, but it serves to limit the spread of activity outside the working volume.

5.7.2 Subsequent filter(s) should be fitted in a filter room, located upstream of the fans so as to maintain them under negative pressure and keep the fans free of significant contamination. This filtration would normally be of HEPA capability (to satisfy the ALARP principle) and provide the main protection against the release of radioactive particulate matter to the environment. The required DF will ensure that the levels of release to the atmosphere are within acceptable limits. The location of these filters in a separate filter room provides some measure of assurance that their integrity will be maintained.

5.7.3 The filter room may become contaminated as a result of filter changing, and should thus have floors and walls free from dust traps and be made of materials which can be easily decontaminated. There must be adequate room to perform the filter change operation, and also to perform decontamination procedures. Every effort should be made to design the filter change facility so that pressurised suit operations are not required.

5.7.4 Where the extract filters may acquire a high radiation level due to their service loading, shielding and remote change facilities may be required. For details of possible filter housing designs the reader should consult AECP 1041.

Where loose contamination is envisaged on filters, provisions should be incorporated to enable fully contained replacement, e.g. by the use of bag change techniques.

5.7.5 The design of a filter installation should, where practicable, be such that when a filter is changed any material which is dislodged will fall on the upstream side of the housing.

5.7.6 Equipment, such as vacuum pumps and compressors, should be carefully selected to limit the potential for oil vapour which could have a detrimental effect on the extract filters.

5.8 PRE-FILTERS, DRIERS, SPARK ARRESTORS AND OTHER PRE-TREATMENT DEVICES

5.8.1 **Pre-filters.** These are not now fitted to many installations as their relative advantage is far outweighed by the cost associated with the handling and disposal of these active items, and they will not necessarily increase significantly the life of the following HEPA filter. However, exceptionally there may be an application where a designer can justify the use of a prefilter.

5.8.2 **De-humidifier.** Free moisture can cause rapid blocking of the filter media, and moisture removing equipment may be necessary on some plants. Although standard HEPA filters are capable of continuously handling air at high relative humidity, it is not good practice. Heaters, or a HEPA filtered air in-bleed may be required to ensure that the relative humidity of the air is such that fine moisture formation does not occur.

5.8.3 **Spark arrestors.** These may be fitted upstream of the plant room filter(s), preferably as close as possible to the source of fire hazard. Cooling sprays within the ductwork are not recommended. Spray cooling externally on the ductwork is acceptable.

5.8.4 **Other devices** that may be used include inertial collectors, cyclones, wet scrubbers, electrostatic precipitators (ESPS) and demisters. Some of the merits and demerits of these items are described in the following clauses.

5.8.5 **Dry inertial collectors and cyclones.** These may be used satisfactorily where there is a high dust load and large particles for example from cutting operations during decommissioning.

5.8.6 **Wet scrubbers.** These can be used for treating vessel ventilation streams. The type required is normally selected by the process engineer since this aspect is part of the chemical treatment. There are many designs of wet scrubber, but they all operate on a similar principle; contaminated air/gas (the effluent stream) is carried into a chamber where the particulate is captured by the liquid. The contaminated liquid is then drained from the chamber, and the treated air passes out of the chamber for further treatment (e.g. demisting, filtration) prior to discharge.

Advantages:

(a) Removes NOx;

(b) Removes iodine;

(c) On warm effluent streams it reduces the specific water content of the airstream (scrubbing liquid is cooled).

Disadvantages:

(a) For a high efficiency they must be run with high pressure drop;

(b) Some of the designs are complex;

(c) Before the treated air is passed through HEPA filters it is necessary to reduce the relative humidity.

5.8.7 **Electrostatic precipitators (ESPs).** These are sometimes used for treating vessel ventilation streams, and also for treating recirculated breathing air. There are many types of ESPs but they all operate on a similar principle; particulate is removed from the contaminated air/gas passing through the unit in which, by the application of an electrical force, the particles are attracted to a collector plate. Although there are a number of methods used for cleaning the collector plates, in the nuclear industry they are normally washed down when the unit is switched off.

Advantages:

(a) Low power demand;

(b) Ease of disposal of contaminated liquid;

(c) Low pressure drop.

Disadvantages:

(a) Loss of services (e.g. electrical supply) means loss of filtration;

(b) If the units are of a type not requiring maintenance they are expensive;

(c) Reliability and relatively low D.F.

5.8.8 **Demisters (coalescers).** These are used principally, for vessel ventilation streams downstream of processes which give rise to airborne droplets (mists). They are used to remove free moisture from the contaminated gas/air stream by impingement of the droplets and subsequent drainage. The most common types used in the nuclear industry are knitted mesh, and packed beds.

5.9 FILTER INSTALLATIONS TESTING AND MONITORING

5.9.1 Some salient points on the housing of filter units are listed below:

(a) The installation should allow quick or easy filter changing so as to minimise contamination and irradiation of personnel;

(b) Proprietary bag change systems which maintain containment are available and are generally preferred;

(c) Remote changing may be necessary and designs are available;

(d) A robust support structure, in a properly engineered housing, is necessary so that a good standard of flatness and squareness of the filter seating is achieved, hence

allowing satisfactory sealing with the filter gasket. Gasket leakage is a major source of inefficient filtration;

(e) For certain designs, the filters can be mounted horizontally ("shelf") or vertically ("ladder"). Downward airflow in shelf systems helps minimise particle loss when changing filters. The filters should be changed from the upstream side, to minimise the spread of contamination to clean areas. Protection of personnel against contamination and ingestion hazards may be required;

(f) Corrosive conditions may require special consideration.

5.9.2 Extract ducting must be provided with sampling positions to allow injection and sampling of the test aerosol used for DF determinations. It should be noted that in some installations it may be necessary to install permanent test features (see Appendix B). In general, the requirements are for:

(a) An upstream port for the injection of the test aerosol;

(b) An upstream sample probe for each bank of filters;

(c) A downstream sample probe after each filter unit to allow identification of individual faulty filters;

(d) A downstream sample probe after each bank of filters;

(e) Ports, for the return of samples to the duct, particularly where activity levels are high;

(f) Appropriate services for operation of the test equipment.

5.9.3 The detailed design of the filter test facilities is of considerable importance if meaningful results are to be obtained. The requirements for filter testing are covered in Appendix B.

5.9.4 Where required for radiological protection, provision should be made for monitoring filter units, especially where these are gamma-shielded, so that radiation levels can be checked prior to removing the filter without having to remove shielding (other than the access plug).

5.9.5 It may also be required to monitor the ductwork. For example, a duct monitor after the first in-cell filter will give information and assurance about the performance of that (un-testable) filter.

5.9.6 Unless otherwise acceptable to the authorising authority, it will be necessary to sample the effluent stream after the last filtration stage, i.e. prior to discharge to the environment. This will require the flow velocity to lie within certain limits, for this and other information on sampling and monitoring of airborne discharges.

5.9.7 The filters in the discharge line from a glove box represent a unique design requirement. They must not be allowed to reach the state where the full emergency flow cannot be accommodated.

5.10 EXHAUST STACKS

5.10.1 The major purpose of using an exhaust stack is to ensure adequate dispersion of the residual contamination. This ensures that the remaining activity in the discharge stream has a much lower concentration when it returns to ground level. Care must also be taken to ensure that the discharge stream is sited away from all ventilation inlets whatever the wind direction.

5.10.2 **Effective stack height.** The acceptable stack height for a given plant will be decided by reference to the anticipated activity discharge, the position of the stack with respect to the source building, the adjacent building heights, the authorised discharge levels and the dispersion model. The dispersion model is site specific and involves factors such as aerial suspension, fall out, uptake by crops and animals, re-suspension, inhalation and ingestion in food. The stack height will normally be decided in conjunction with the site Health Physicist and may involve wind tunnel tests to establish the effect of adjacent buildings, and hence the effective stack height.

The effective stack height may be defined as the physical height of a theoretical stack which if sited on a flat open plain, would give a similar dispersion pattern. In general, for the full stack height to be effective, it must be significantly higher than the tallest building in the immediate vicinity (and local tomography). The height of stacks should be assessed and justified based on the discharge requirements.

5.10.3 **Efflux velocity.** The efflux velocity must be sufficient to project the exhaust air into the atmospheric air-stream. If the efflux velocity is too low, the exhaust air tends to flow down the stack on the lee side and thus to reduce the effective height of the stack. It has been found that efflux velocities of 15 m s-1 give adequate insertion of the plume into the atmospheric air-stream. However, wind tunnel tests may be used to study the effect of increased or decreased velocities.

5.10.4 **Stack diameter.** The diameter of the stack will be determined by the requirements of the velocity pressure drop limitations and strength. Adequate efflux velocities are often achieved by reducing the stack diameter near the exit.

5.10.5 **Construction.** The normal methods of construction are, to use stainless steel flues inside a stainless steel or reinforced concrete windshield. Helical strakes are often fitted to steel stacks to prevent vortices causing resonant vibrations of the stack, and hence possible failure.

5.10.6 **Sampling.** There is normally a need to sample gaseous discharges in order to comply with licensing and statutory requirements. Hence, provision must be made for the installation of an appropriate discharge sampling system. The detailed requirements of such systems are contained in the Environment Agency Technical Guidance Notes.

5.10.7 **Drainage.** Ventilation stacks should incorporate a drain point routed to a suitable discharge.

5.10.8 **Multiple Discharges.** Separate ventilation systems discharging into a common exhaust stack should incorporate non return dampers or motorised isolation dampers interlocked to close on loss of system flow, upstream of the connection to the stack.

6. BUILDING EXTERNAL CONTAINMENT

6.1 GENERAL

6.1.1 This section is concerned with the standard of leak tightness of the building shell exposed to the external environment in circumstances where it is considered to have a radiological containment function (whether this is so will be decided by carrying out hazard assessments of the plant and processes associated with the building).This is not to be confused with permeability that is addressed in part L of the Building Regulations.

6.1.2 The Radiological aspects, part L of the building regulations, and the needs for energy (and Carbon) efficiency, may result in conflicting requirements: in this case the Designer should consider the Building Regulations, part L, as the minimum standard and that other constraints may also apply.

6.2 STANDARD OF LEAK TIGHTNESS

6.2.1 The required standard of leak tightness of a building shell, where this forms a containment barrier, is dependent upon the magnitude of the potential airborne contamination hazard within it. The greater the potential hazard, in accident conditions, the higher the standard of leak tightness required.

6.2.2 The magnitude of the potential hazard will include consideration of the following:

(a) The amount and type of dispersible radioactive materials;

(b) The type of process;

(c) The reliability of the ventilation system;

(d) Whether or not, in the event of an accident, the process can be controlled to limit the release of radioactivity;

(e) Whether the process is contained in a single or double containment.

6.2.3 In general, the standard of leak tightness required of building shells falls into two main categories

- Conventional buildings
- Low leakage buildings

6.3 CONVENTIONAL BUILDINGS

6.3.1 In most Radiological buildings it can be shown that the potential airborne contamination level in the air space immediately adjacent to the building shell does not represent a significant

hazard to the environment. Therefore it is not necessary from a radiological perspective to make the building shell to a very high standard of leak tightness: designers should refer to part L of the Building regulations as a minimum standard.

6.3.2 With the maximum defined steady external wind speed it is acceptable for wind suction to create an outward flow of air to atmosphere through the leak paths in the shell, provided correct internal ventilation airflow patterns are maintained.

6.3.3 Under postulated accident conditions there will not be a requirement to hold the interior of the building shell at an enhanced depression.

6.4 LOW LEAKAGE BUILDINGS

6.4.1 In buildings where the airborne contamination level is high during accident conditions, the building shell must be provided to a high standard of leak tightness; it should be capable of being held at a depression marginally greater than that created by the maximum postulated steady wind speed on its exterior. Standards of leak tightness will be determined by hazard assessment. A particular application here is to some reactor containment buildings. During normal operation, this type of building shell is often maintained at a depression of about 125 Pa relative to atmosphere (with no wind blowing). Entry into the building may need to be via air-locks.

6.5 WIND SPEED

6.5.1 The maximum steady wind speeds are determined from site surveys over a number of years. Siting of the building in relation to other tall buildings in the adjacent areas should be taken into consideration, since their presence can affect the normal air flow patterns and wind speeds.

6.5.2 Designers should consult Site Licensees documentation concerning maximum winds speeds.

6.6 WIND PRESSURE

6.6.1 Investigation into the effect of wind pressure on buildings reveals that local external depressions on a building shell can be equivalent to one velocity head of the wind speed on the walls, with higher depressions at the corners and eaves of the roof, although on the surface as a whole they are unlikely to exceed 0.8 velocity heads.

A typical wind pressure distribution diagram in terms of velocity head factors for an elementary building form is shown in Figure. 10.

Any inherent leak paths in the building shell construction will therefore allow an inward and outward flow of air, the magnitude being related to the wind speed and direction.

6.6.2 To prevent air escaping from the building a depression must be provided within it at least equal to, or greater than, the depression caused by the wind on the external surfaces. It may not be practicable to provide this depression at all times and the design must be optimised in the context of the maximum allowable leak rate determined from a hazard analysis.

6.7 DESIGN FACTORS

6.7.1 To minimise the effect of winds on the escape of air from buildings, the following should be taken into consideration:

(a) Sealing of roofs, special attention being paid to corners and eaves;

(b) Sealing of joints and penetrations in the building shell, the latter being kept to a minimum;

(c) Provision of two successive well-fitting doors or airlocks at all normal entrances to the building;

(d) Holding the building at a depression by the ventilation system.

6.8 LEAK TIGHTNESS OF BUILDING STRUCTURES

6.8.1 The leak rate into or out of a building is a function the pressure of differences across the building structure including positive and negative wind effects.

6.8.2 The leak rate as a percentage of the contained volume decreases as the contained volume increases.

6.8.3 Building leak tightness is affected by the number of entrances into the building, the number of joints and penetration in the building structure and the porosity of the building material.

6.8.4 The determination of the leak tightness of buildings is a complex issue and should be referred to the appropriate specialists. The results of leak tightness tests for three types of building structure are given below as an indication of the order of leakage for these types of building structures.

TABLE 2 Leak tightness of example buildings

	Type of building construction	**Contained Volume m^3**	**Test pressure (Pa)**	**Typical Leakage Rate (m3 / Hr)**
D9867	Brick building with brickwork painted internally with chlorinated rubber paint, no windows, entry through two successive well-fitting doors.	7840	130	5880

PFR	Concrete panel building, no windows, entry through two successive airlock doors.	75,040	1,000	1560
DFR	All-welded metal shell construction, with all welds radio-graphed, entry through engineered airlock doors.	27,400	69,000	0

6.9 PERIODIC TESTING

6.9.1 Where necessary, periodic tests should be carried out to demonstrate the leak tightness qualities of the structure. The means to carry out these tests should be provided in the initial design.

6.10 BUILDINGS HOUSING PLUTONIUM

6.10.1 Special precautions may be necessary to minimise adventitious, unfiltered air in leakage into buildings where plutonium is handled or stored, as the ingress of radon and thoron daughters can effect the monitoring of alpha in-air due to the increase in background level. However, modern instrumentation does much to discriminate between the naturally occurring and process produced alpha activity.

6.11 BUILDING CONTAINMENT STRUCTURE

6.11.1 Where necessary, devices should be provided to prevent over-depressurisation or over-pressurisation of the building containment structure. This is particularly important during transients such as start-up, shutdown, etc.

6.11.2 Where HEPA filters are incorporated within supply systems excessive depressurisation of the building can occur due to loading of filters, thus creating difficulties. In such cases consideration should be given to the incorporation of visual / audible alarms to inform personnel of abnormal conditions.

7. ELECTRICAL SUPPLY, CONTROL AND INSTRUMENTATION

7.1 INTRODUCTION

7.1.1 The purpose of the control and instrumentation is to provide information on the status of the plant, and to be the means of controlling the delivery of the correct quantities of conditioned air to the required locations, and the removal of the same whilst maintaining the designed depressions and flow patterns.

7.1.2 The security, diversity and reliability of the system will be dependent on the processes taking place within the building - as reflected in the hazard assessment and other studies – operational requirements will also need consideration.

7.1.3 Ventilation designers should ensure a clear control philosophy is available to enable specialist Electrical, Control & Instrumentation designers to design an appropriate system in conjunction with Health, Safety and Environmental advice.

7.2 ELECTRICAL SUPPLY PHILOSOPHY

7.2.1 The electrical supply to a nuclear facility ventilation system may need to be duplicated. In such cases each feeder should be sized to carry the total load and, as far as the supply network allows, the two feeds should come from substantially different sources by spatially separate routes.

7.2.2 The hazard assessment should consider the consequences of failure of the normal mains supply, and whether this may be serious enough to warrant one or more standby diesel generators being provided as an independent source of power. Such an assessment would incorporate the assessed reliability of the utility supply, taking account of whether this supply is itself obtained from a duplicated, that is "firm" supply. Furthermore, the effect of any delay between the main electrical supply failing and the diesel supply becoming available should be taken into account. Consideration should also be given to the potential and safe guard required for common mode failures. Consideration should be given to the consequences of the pressure differentials created on reconnection of the supply, and hence the possible need for automatic or manual sequencing of the restart operations.

7.2.3 Where a system consists of several fans and a duplicated mains electrical supply, the design should be such that both supplies are in use with each one supplying a number of fans. The distribution of fans between supplies will need careful consideration and must take account of their duty (e.g. inlet/extract). Note that fan availability may be improved by the use of in-situ off-line motors, either belted or not, or by automatic changeover to the healthy supply. Selection of the most appropriate means must be made with reference to the total system design.

7.2.4 A non-interruptible (battery backed) source of supply may be required for the alarm system and may also be required for essential instruments and some plant items. In identifying essential instruments consideration should be given to the conditions which will exist after a power supply interruption.

7.2.5 All electrical control and distribution equipment should be located in a WHITE area or, if this is not possible, in the least radioactive area. In cases where fans etc. are located some distance from the control gear they should be provided with dust tight push buttons (for stop and start duty only) adjacent to the fan.

7.3 CONTROL PHILOSOPHY

7.3.1 The control system will be determined by the particular ventilation scheme required and must function during the normal and the postulated plant fault conditions. This section is concerned with the control of air movement and depressions within the system. Designers must also account for all required functionality of the system as determined in the Basis of Design and safety assessments, for example temperature and humidity control. Designers should also consider the required managerial control of the system, for example in the event of a fire.

7.3.2 Co-ordination of the control system is essential, and control panels must be located at a point where effective action can be taken, whether routinely carrying out tests of the plant or acting in an incident situation. In the event of an incident, the access to parts of the building may be restricted and consideration should be given to the need for a separately ventilated incident control room, or the need to transmit information to an area incident control room outside the boundaries of the building involved. This could influence the choice of signal transmitters.

7.3.3 Control should always be by direct measurement of air flow or pressure drop etc. For these measurements to be made the proper fluidic conditions must be created in the ducts and this will have a significant effect on the ductwork design. It will be necessary to ensure that, for example:

(a) Tapping points are made available in accessible positions for all types of measurement;

(b) The cross-sectional area of the ducts at the measurement points is such that, with the designed air velocity, a representative signal can be measured;

(c) Sufficient lengths of straight duct be provided both up and down stream of a flow measurement point in accordance with standard flow measurement practice.

7.3.4 Automatic start-up of the standby fans should be considered, to cover failure of the main fan (fan failure or supply failure). The automatic start-up procedure should be initiated by a direct measurement, e.g. detection of loss of flow. If there is a need to start-up emergency standby plant, the system should have a backup measurement, e.g. fan rotation detection (not motor current or contactor status).

7.3.5 It is usual to have a well defined sequence for starting and stopping fans which will form part of the control system. Interlocks should also be provided to safeguard against the failure or mal-operation of any single safety related item of plant, whether damper, valve or fan. If, for example, analysis shows that failure of an extract fan (which is effectively in series with the inlet fan) could cause hazardous overpressure in part of the system, an interlock between the input and extract fans must be provided to prevent this occurring.

7.3.6 Normal control should be designed to keep the extract ventilation running at all times, with manual override facility to allow the operator, in the event of an incident, to decide which items of equipment to keep running or to shut down.

7.3.7 Means of isolating electrical equipment and of monitoring fire control features should be readily accessible in a safe area.

7.3.8 The significance of fire dampers in the overall control scheme must be fully considered. The dampers should be capable of regular testing and resetting from a suitable control point (preferably associated with the main ventilation control centre) and their status should be indicated. As these dampers, when closed, will cause loss of flow signals their status may need to be incorporated into any automatic changeover systems for fans etc., and the ability to be able to selectively reset them, in the event of an incident, will determine to what extent the ventilation system can be manually controlled. The panel controls should be easily comprehensible and should provide a simple shut down operation.

7.3.9 The importance at the construction stage of proper testing and commissioning of the plant to a written test schedule must be stressed. The design should also allow periodic testing of standby plant (when provided), to demonstrate its state of readiness.

7.3.10 Periodic testing of the running plant may also be required in order to meet the reliability deemed necessary. If this is the case the design must make provision for such testing and the reasons, methods etc. must be recorded in the operating manual or other suitable documents.

7.4 INSTRUMENTATION

7.4.1 Designers should consider the functionality of the system in determining the parameters that are to be monitored and what the information gained may be used for.

7.4.2 Process plants to which this document applies range from highly active contained volumes, normally unmanned (e.g. process cells), to large, manned, low activity areas. These differences will affect the emphasis and interpretation which must be given to some of the following recommendations. On most systems, a mixture of flow, temperature, pressure, humidity and position measurements will be needed. Of these some will be associated with controllers and others will be informative. For operational and other reasons, there is a trend to using centralised control which, depending upon the size of the system, may incorporate computer control rather than discrete elements. If any part of the system relies upon the correct operation of a programmable electronic system (PES) to maintain safety, then the control system designer should ensure that the HSE Guidelines on PESs in safety related applications have been observed.

7.4.3 In addition to addressing the effect of the measurement and control in the overall design of the ventilation system, consideration must also be given to proprietary plant items which often contain their own controls that must be specified, or selected, at the time of ordering to be compatible with the total instrumentation design concept and realisation.

7.4.4 Amongst the measurements or facilities that should be provided are the following:

(a) Duct flow measurements;

(b) The current state of dampers, valves and fans (running and standby);

(c) Indication of the condition of all filters by the pressure drop across each filter bank;

(d) In designs containing RED areas, direct evidence to the operator, by means of a pressure gauge or flow indicator, that the negative pressure difference is being held between any RED area and the operating face;

(e) Means to correctly measure filter efficiency: this is of considerable importance, since the safety justification for the function of the facility will be based on the actual measured efficiency of the correction for the inherent, and usually optimistic, errors which filter testing invokes. The problem is that of ensuring adequate test aerosol mixing, and hence of uniform challenge or representative sampling.

Refer to Appendix B for filter test requirements.

(f) Fire detection and the status of fire dampers;

(g) Instrumentation to measure the build-up of the activity in the duct or on certain filters.

(h) Discharge activity monitoring.

The above points relate directly to the ventilation services. There will be additional Health Physics monitoring of the activity in the environmental air.

7.4.5 Alarm states should be announced by both audible and visual alarms. In large complex areas the key systems status information should be relayed to a point where the overall picture of the operating condition can be assessed, and if necessary controlled. In self-contained areas this centralisation of control may not be necessary.

7.4.6 For plants handling significant activity there are advantages in replacing control dampers with fluidic control elements such as Vortex amplifiers. A vortex amplifier, when acting as a controlled damper, maintains a predetermined depression over a wide range of flow rates. It has the advantage of being a no-moving-part device that is maintenance free, with the control action being derived by the momentum interaction of fluids - air in this case. Various 'standard' applications of these devices have been designed. These designs also identify the positions of filters and measurements associated with them, and reference should be made to these applications for guidance.

7.5 PROCESS AND INSTRUMENTATION DIAGRAMS (P&IDS)

7.5.1 All control and Instrumentation requirements for ventilation systems must be demonstrated on P&IDs. P&IDs must be produced in accordance with the relevant standards.

P&IDs shall indicate all components of control loops. Multiple inputs and outputs into a common controller/PLC are not permitted. If control functions are performed by a PLC, the control logic must be demonstrated by showing the individual control loops on the P&ID.

7.6 ACTIVITY MONITORING

7.6.1 It is a legal requirement that internal and external exposure of radiation workers must be evaluated (IRRs) and that discharges to the environment are monitored. The health physics aspects of activity monitoring are not part of this document, but its objectives places demands on ventilation system design. For this reason it is necessary to consider this topic as part of the document.

The effect of these requirements on ventilation design will vary widely depending upon the type of facility. It is most exacting in the case of facilities handling plutonium and actinides, but is much less of a problem on facilities such as reactor plant, where significant levels of alpha emitting nuclides are unusual.

7.6.2 The design of the monitoring scheme should take into account both the normal and abnormal or postulated incident conditions. Where a closed cycle system is not proposed, all gases extracted from all areas of the plant will eventually be discharged by the ventilation system to the atmosphere through the discharge stack. The ventilation system design must ensure that effective monitoring for radioactive contamination can be carried out, in conditions mentioned above, in order to control emissions within the prescribed safety limits established by comprehensive hazard assessments.

7.6.3 Airborne activity levels will normally have to be measured in all occupied GREEN and AMBER areas of buildings. This may require the installation of sampling equipment for air contamination measurements. For facilities such as reactor plant, where significant levels of alpha emitting nuclides are unusual, air sampling with retrospective assessment will probably suffice. For facilities with significant levels of alpha activity, typically Pu installations, alarm air activity monitoring instruments are usually required. Where specified by Health Physics advisers, the fixed air monitoring systems are backed up by Personal Air Samplers to assist in dose assessment.

7.6.4 The ventilation system must be designed to allow effective monitoring to take place in order that it can be demonstrated that the plant complies with the legal safety and operational requirements, Typical examples being:

(a) To ensure that areas in the plant can be monitored for occupational exposure at the level set for the plant, within the prescribed limits;

(b) To allow air monitoring to discriminate against background activity, such as radon and thoron daughters products, when monitoring for alpha activity;

(c) To enable adequate assessment of routine discharges to the environment in order to demonstrate compliance with the Discharge Authorisation;

(d) To allow effective measurement of discharges to the environment in identified accident conditions.

7.6.5 In order to meet the requirements set out above, consideration should be given to the following typical interactions between the monitoring and ventilation designs:

(a) The positioning of the air samplers/monitors with respect to work stations and ventilation flow patterns. This may require careful thought in positioning space ventilation inlet and outlet grilles and perhaps some internal partitioning. This must

be done in connection with Health Physics staff. In the case of some Pu facilities this may require some mock-up work to be carried out;

(b) Where stack discharge is to be monitored the effect of diluting a sensitive flow with a large mainly inactive flow may require a separate duct measurement in order to achieve the desired measurement accuracy;

(c) Where stack sampling is to be used and there are multiple inputs to a single flue stack, adequate provisions must be made at the design stage for effective mixing of the flows, so that a homogeneous and representative sample can be taken at a reasonable position within the stack, and at an acceptable distance from the stack and at an acceptable distance from the instrument. Alternatively each separate ducted input to the stack may be individually sampled;

(d) Air monitoring, as part of a permanent ventilation scheme which may involve sampling from ducts and stacks, where activity is high, and presenting the sample to instrumentation for assessment. Special care must be taken in the design to ensure that activity from the sampling system cannot appear in working areas as a result of operational or maintenance malpractices.

7.6.6 This document deals only with the basic principles of the subject, and reference should be made to relevant British (BS), European (EN) and International (ISO / IEC) Standards and Environment Agency Technical guidance notes.

8. FIRE SAFETY

8.1 GENERAL

8.1.1 The design and operation of the ventilation system plays an important part in the control of the consequence of a fire. Designers will need to determine a philosophy that addresses both fire regulations requirements and containment philosophy. Detailed consideration of the design philosophies, engineering considerations etc. is outside the scope of this document.

8.1.2 There are no ideal solutions to the problems created by the accident situation involving fire. A satisfactory compromise can only be reached by the fullest consideration from an early stage in the design by all the interested parties, including a fire safety engineer, the hazard analyst, the operator, the architects and design engineers.

8.1.3 The potential for a fire must be considered at the start of the design of a building or facility as it will affect many design decisions, and the ventilation engineer must be involved as ductwork etc. provides potentially serious breaches of fire zones. A preliminary hazard assessment, carried out early in the project, will indicate the depth of fire precautions and protection needed. This will give a basis for measures likely to be required to achieve a standard of fire safety which is acceptable in relation to the amount and form of the radioactive inventory involved.

8.1.4 The basic outline to fire and smoke control given under the enabling regulations of the Health and Safety at Work etc. Act 1974, e.g. Building Regulations or Buildings Standards (Scotland) Regulations should apply. However, a range of conflicting requirements may well arise, for example, in the contradiction between the need to vent smoke, and the requirements to maintain radioactive containment. The best practicable solutions to these sometimes divergent and incompatible facets will vary according to actual and potential radioactive inventories, area zoning etc. Thus it is vital that intended design and operating philosophies be established at an early stage in the project.

8.2 FIRE BARRIERS AND FIRE DAMPERS

8.2.1 The building will usually be divided into Radioactive Fire Zones, and may be subdivided, by nominated fire resistant walls and floors (designated one hour, two hours or exceptionally four hours rating to BS 476 or other appropriate standard). The system should be designed to keep the size and number of all penetrations in these fire barriers to a minimum.

8.2.2 Where a ventilation duct penetrates a nominated fire barrier, a fire damper should normally be fitted which has the same level of fire resistance as that required by the barrier through which it passes. One exception which could be considered is, for example, where a duct passes through a number of fire barriers, to fire rate the duct to the level of the barriers through which it passes.

8.2.3 Fire dampers and barriers should be tested and certified by an approved authority in accordance with a nationally recognised standard, e.g. BS 476. The designers should ensure that the fire damper is installed in the manner in which it was tested. For situations where a

higher standard of performance than that required by BS 476 is necessary, consideration should be given to the use of insulated (blade and casing) fire dampers.

8.2.4 Additional fire dampers may be required in locations other than in fire compartment barriers, e.g. for containment of active material. The actual location and number of fire dampers will be dependent on design philosophy and constructional details. Each project must be considered on its merits and the advice of a fire safety engineer must be sought.

8.2.5 The materials of construction of a fire damper should be suitable for the likely environment within the duct. Care needs to be taken in the presence of acid vapours, which may cause long-term corrosion. Intumescent fire dampers are not normally recommended owing to their comparatively high initiation temperature (~250°C).

8.2.6 It is necessary to be able to test the correct operation of the damper by closing and opening it, either at the damper or from a control point. A positive indication of successful operation should be included, possibly by the use of switches. Dampers should be re-settable without having to gain access into the duct. If it is not permissible to stop the ventilation by fully closing the damper, partial testing may be achieved by closing the damper to say 30°, thus demonstrating that the damper is not stuck in the open position.

8.2.7 Depending on individual circumstances, some or all of the fire dampers may need to be re-settable from a safe location, e.g. control room. The need for this capability will be dependent on factors like ease of access to damper location, likely local environment in the fire area, and the importance of the damper in the overall fire control philosophy.

8.2.8 Automatically initiated closure of fire dampers within certain ductwork systems may not be acceptable. This is particularly relevant to those within potentially contaminated extract systems. In such cases manually initiated closure and reopening as required from a safe location is preferable.

8.3 DUCTWORK

8.3.1 Where a duct passes through a nominated fire barrier, the gap around the edge of the duct or damper at the penetration should be as small as practicable, and fire-stopped to prevent the passage of fire or smoke. When the possibility exists that combustibles may be located adjacent to fire barrier penetrations, past recommendations have been that the duct insulation properties should be improved by fire rating the duct to the same level as the barrier for a distance of at least 1 m either side of the barrier. This is known to be inadequate in many cases and current advice should be sought from a competent fire engineer.

8.3.2 Where a hazard assessment shows that ductwork could be exposed to high temperatures (due to fire), the need for expansion joints in the ductwork should be considered. Ducts should be made entirely of non-combustible materials.

8.4 TRANSFER GRILLES

8.4.1 Transfer grilles should not normally be fitted. If fitted, they must be fire-dampered to the same standard as the nominated barrier.

8.4.2 Where transfer grilles are fitted the airflow should be such as to keep smoke away from escape routes. These grilles should always be located at low level.

8.5 HEPA FILTRATION

8.5.1 HEPA filters do not constitute a fire barrier even when constructed of non-combustible materials, and therefore they should be positioned or protected so that they are unlikely to be damaged by hot combustion products from a fire. They are susceptible to flying brands, which may perforate the filter media with possible resultant release of previously trapped radioactive material.

8.5.2 For the majority of installations Spark arrestors are not required. The extract grilles will limit the size of burning material entering the duct and the flight time to the filters is commonly sufficient to provide protection. If hazard assessment shows a specific hazard, then Spark/debris arrestors may be required.

8.5.3 Spark/debris arrestors are sometimes fitted to guard against flying debris. They function as a sieve, and in consequence should be fitted so as to allow a time for burn-out of the penetrating brands before they strike the filter medium. The distance upstream required will depend on the air velocity in the duct, and should be such as to allow a burn-out time of two seconds.

Spark arrestors do not guard against a fire in a duct where combustible dusts (lint, etc.) are present and an ignition source is introduced. Counter-measures against this accident scenario include:

(a) Reducing the dust burden entering the duct by filtering the facility input air to reduce background, and by filtering at the point extract;

(b) Using low velocities in the facility to minimise dust transfer, and high velocities in the duct to minimise fall-out.

(c) Seeking to prevent ignition sources entering the duct. Spark arrestors can be fitted at the point of extract, but they may themselves collect dust and become a fire hazard or blockage. The preferred option is to avoid there use.

(d) Spark arrestors are ineffective for flammable liquid spill when either vapours or the liquid itself can enter the duct. It is notable that spark arrestors located within contaminated extract streams have a tendency to absorb high radioactive concentration levels and hence change requirements result in high dose rates for maintenance personnel. Particular consideration should therefore be given to the location of and change facilities for spark arrestors.

8.5.4 Filters and Spark arrestors will be blinded rapidly in a fire by the products of combustion if the ventilation flow is maintained. However, if fire dampers are fitted and closed early enough, the filtration capacity is preserved. This has the post fire advantage that extract ventilation can be rapidly restored, or alternatively standby filters may be provided. The options can only be refined and eliminated by close consultation between all interested parties.

8.6 AUTOMATIC FIRE DETECTION

8.6.1 The ventilation may affect the operation of some fire detectors, primarily due to unfavourable air flow patterns within an area, and high air change rates. Existing guidance may not have kept pace with recent developments, and therefore the advice of a fire safety engineer should always be sought early in the ventilation design process.

8.7 FIRE CONTROL PHILOSOPHY

8.7.1 The point must be emphasised again that the form and implementation of the control of a fire situation will depend strongly on the particular design philosophy adopted, and it is only possible in this document to indicate general areas of interpretation. It should also be noted that one of the prime objectives should be the protection of means of escape for the safe evacuation of the building and for fire fighters access to the seat of the fire. Active facilities, in general, will help to promote personnel safety since air is drawn into the contaminated areas thereby keeping corridors and work places free of smoke due to the higher pressure levels in these areas. This technique of pressurisation to maintain smoke free escape routes is further detailed in BS 5588.

8.7.2 For areas having only a low dispersible radiotoxic inventory in the fire situation and which have unfiltered access to the outside, the object must be to isolate the fire within the fire zone. If appropriate the heat and smoke should be vented to prevent neighbouring areas being endangered, and allow manual fire fighting. The response of the ventilation system and associated fire dampers should be automatic and preferably under the control of building management from a protected area. This manual override facility will also allow operation in the case of delay in the automatic system response. These fire dampers, which are not part of a ventilation system, should operate automatically perhaps actuated by detectors suitable for the fire type revealed by the hazard analysis (i.e. smoky, hot, etc.). These dampers will not normally be remotely re-settable, though if possible their state should be relayed to a master control panel.

8.7.3 For areas which have a high inventory of dispersible radiotoxic material, or for a multi-compartment building, where spread of smoke through the ducting may be a problem, then containment must be a prime consideration. Manual control of the ventilation system and associated fire dampers is recommended, though automatic response with manual override may be necessary for larger buildings, and where manual intervention may be delayed. Automatic or manual tripping of the main inlet and extract fire dampers should be considered, so that the building can be isolated from the environment in an emergency situation. Control should be from a panel situated in a safe location, where the full state of all the relevant information is displayed, including pressure drops on filters, etc. Power operated re-settable fire dampers should be fitted, with remote manual operation from the control panel. Fire dampers should be engineered to fail either open or closed depending on fire safety and radiological implications.

8.7.4 The consequences of any action likely to be taken in a fire emergency, or in testing the operation of fire dampers or other emergency controls, must be fully assessed to ensure that all risks and operational problems are minimised.

9. THE SELECTION OF FABRICATED DUCTWORK OR TUBE FOR ACTIVE VENTILATION SYSTEMS

9.1 INTRODUCTION

9.1.1 Ductwork should be designed to address requirements for containment, pressure duty, structural stability and environmental conditions (internal and external). Ductwork should be fabricated to the referenced standards or the client's equivalent.

9.1.2 An extensive range of fabricated ductwork and tube is employed for active ventilation requirements including:

(a) High integrity (very low leakage) fabricated mild (AESS 6008 Part 2) or stainless steel ductwork (AESS 6008 pt 3);

(b) Fabricated ductwork to (AESS 6008 pt 1) DW 144 high or low velocity requirements (galvanised mild steel sheet riveted or folded construction);

(c) Fabricated ductwork in stainless steel or other materials to DW 144;

(d) Copper or stainless steel tube;

(e) Plastic or fibreglass ductwork or tube;

(f) Flexible ductwork.

9.2 DUCTWORK FOR WHITE, GREEN AND AMBER AREAS

9.2.1 The specification for space ventilation ductwork in the WHITE, GREEN and AMBER are as generally follows good industrial engineering practice. Such ductwork would normally be manufactured to DW144 although other materials and construction standards have limited applications.

9.2.2 Hazard analysis may in some instances require ductwork to be of a higher quality (e.g. in leak tightness, corrosion resistance or both of these attributes). In these instances ductwork may be manufactured to AESS 6008 Part 2 or AESS 6008 pt 3;

9.2.3 The use of silencers on GREEN or AMBER extract systems should be avoided whenever possible as they tend to gather activity and are not easily decontaminated.

9.3 DUCTWORK FOR RED AREAS

9.3.1 Ventilation systems serving RED areas are usually constructed from high integrity (very low air leakage) ductwork or tube. Copper or stainless steel seamless or welded tubes are normally selected for low flow rate applications requiring diameters up to 300 mm, although larger diameter tube may be employed in some applications. Joints are normally made by

welding or brazing within cells or other inaccessible locations, elsewhere flanged or soldered joints may be acceptable.

9.3.2 Fabricated stainless steel ductwork of high integrity construction is the normal choice for applications requiring larger sections, although there is a limited application for the less expensive welded mild steel ductwork of the same integrity for temporary installations or installations where the risk of long term deterioration is acceptable. External discharge stacks together with the connecting ductwork outside the building, and in exceptional cases ductwork downstream of the final filters within the building may, in some instances, be made to a lower standard. Consideration should be given to the standard of ductwork, and in routing it after the fans, since it is under positive pressure and any leakage will carry with it activity from the discharge air. Particular consideration should be given to the adequate sealing of dampers and other such components which have penetrations in the ductwork containment (spindles etc.).

9.3.3 Plastic ducting or tube has a limited application where stainless steel is not resistant to the vapours carried, e.g. when extracting hydrochloric acid fumes, but any application of plastic materials must be reconciled with the required fire standards and the hazard assessment. Note that when the recommended material for extract ductwork for fume cupboards is UPVC tubing or welded sheet material, both can be externally reinforced by layering with glass reinforced plastic, using a fire retardant resin. This construction has a good resistance to most chemicals and solvents, and its long service life may justify the initial capital outlay. Plastic ductwork located where the potential for it to be subjected to mechanical damage (e.g. at low level) should be externally protected.

9.3.4 The whole or part of some RED area ventilation systems may not be accessible for maintenance, and may require to be shielded, or designed, to survive seismic or fire incidents. The designer should determine any such requirements at an early stage.

9.3.5 The velocities in air ducts should be in line with general ventilation practice. These range from 5 m s-1 to 8 m s-1 for smaller installations and where noise levels must be restricted. Higher velocities may be required in the main extract ducts of large installations but care should be taken to avoid noise and vibration problems. High velocities may also be required to ensure entrainment of heavy gases and fumes. In order to reduce the cost of high integrity installations it is recommended that they should operate at velocities greater than those employed for space ventilation applications. Air flow generated noise is not normally a problem and air velocities up to 15 m s-1 with pressure losses of 3 Pa m-1 run are acceptable design criteria for fabricated ductwork. Higher pressure losses are often acceptable for tube. However, it should be borne in mind that such an increase will affect the fan running costs and may restrict the potential for future system expansion.

9.3.6 The design pressure, depression, acceptable leak rate and temperature of the ventilation installation is determined by the normal operating, and defined abnormal operating, conditions of the plant. These parameters must be clearly stated in the contract documents for all plant and equipment forming a RED area ventilation installation.

9.4 GENERAL

9.4.1 Ductwork adjacent to glove boxes is usually of such a diameter that it enables standard piping to be used, but attention must be paid to the design to ensure that the ductwork has low

frictional resistance to cater for emergency conditions. The High Pressure Extract main however, and some branches, may be of such section as to require fabricated ducting.

9.4.2 Extract ductwork within caves and cells should always be kept to a minimum since process equipment and associated pipework is generally complex and space limited. Where required ductwork should be arranged to slope down to the area of highest contamination potential, and hence to be self draining, and should be provided with drains piped to a suitable disposal point. Ductwork is normally routed within shielding until after the appropriate treatment.

9.4.3 All components of the ventilation system including ductwork, fans, dampers etc. should be compatible with each other, the vapours being conveyed and the environment in which they are situated. It should also be borne in mind that there are applications where zinc, as a protective coating, is not acceptable.

9.4.4 Although mild steel ductwork is normally protected against corrosion by metallic zinc, this treatment is often followed by an additional coating, where appropriate, to improve the ease of decontamination.

9.4.5 Care must also be exercised in the selection of materials which may be subject to high radiation fields since some materials may be degraded under such conditions.

9.4.6 Where ductwork is handling high beta/gamma contamination, assessments must be made as to the requirements for the shielding of ductwork during both normal and accident situations.

9.4.7 General guidance on design pressures/depressions and acceptable leakage rates is given in Section 10.

9.4.8 Ducting referred to in this section involves the utilisation of coatings and finishes, welding rods, fluxes and process gases, solvents sealants etc. Any such processes involved in the manufacture and installation will require assessment to ensure compliance with COSHH Regulations.

10. TESTING AND COMMISSIONING

10.1 GENERAL

10.1.1 Testing and commissioning of ventilation systems for radioactive areas should, in addition to the requirements for normal industrial ventilation systems, include the special requirements listed below.

10.1.2 Provision should be made so that the components of the ventilation systems can be tested as follows:

(a) Before and during commissioning, for acceptance;

(b) Periodically for operability and required functional performance in accordance with the design specification.

Provision should be included to allow periodic measurements of air flows to be taken in ducts, equipment enclosures, glove boxes, fume cupboards, fume hoods etc.

10.1.3 The designer is to ensure that sufficient test points are provided and located within the ventilation system to enable airflow commissioning of suitable accuracy in accordance with the requirements of the system. Particular consideration should also be given to the location of test points with regard to the potential for build up of contamination adjacent to them.

10.1.4 Adequate tests should be carried out to ensure that the correct airflow patterns are being achieved. In many cases, e.g. at the entrances to fume cupboards and fume hoods and at contamination control boundaries, an acceptable test method is by smoke release.

10.1.5 The complete ventilation system should be tested to ensure that it meets the functional requirements both during normal operation and under simulated fault conditions. This should include tests of the automatic control devices such as the following:

(a) Those associated with the start up of the standby fan in the event of failure of the normal operating fan (where such a system is installed);

(b) Stopping of input fans and closure of associated dampers in the event of failure of the system extract fans;

(c) Transfer to alternative power sources in the event of failure of the normal supply etc.

10.2 PRESSURE/DEPRESSION AND LEAK RATE TESTING

10.2.1 Unless indicated otherwise in the following sections, every ventilation installation will be tested at positive pressure and where required at a depression to prove that there is no gross failure of the installation. Additionally, unless indicated otherwise installations will be tested to show that the leakage rate does not exceed the requirements of the installation. On large installations it is advisable to carry out these tests on convenient sections as the installation

progresses so as to more easily locate problems, but, the final tests shall be on the complete installation.

10.2.2 The test pressures and test depressions should equal the maximum pressures or depressions that the system is capable of generating in the most onerous fault condition. This would normally be determined by the pressure developed by the fan when operating against the worst combination of damper position or airflows, although a careful analysis of the system should be undertaken to ensure that this is the case.

10.3 HIGH INTEGRITY INSTALLATIONS (NORMALLY ASSOCIATED WITH RED AREAS)

10.3.1 Fabricated ductwork and fabricated fittings Including fans, heaters dampers and filters will be pressure and depression tested at the manufacturers works. The installation, in sections and when complete, will also be pressure, depression and leak tested on site.

Installations between and including the inlet filter and final filter of a cave, cell or glove box will be pressure, depression and leak tested to a standard no less onerous than that required for the cave, cell or glove box. These requirements will be specified and no general advice can be given.

10.3.2 Other high integrity installations will be pressure, depression and leak tested at the maximum perceivable system pressures under fault conditions.

- Installations normally working at a depression with respect to the surroundings will have a leakage rate not exceeding 0.5% of the contained volume per hour.
- Installations normally working at a pressure with respect to the surroundings will have a leakage rate not exceeding 1% of the contained volume per hour.
- Stacks and ductwork external to the building and after the point of discharge monitoring may be exempt from this more stringent requirement.

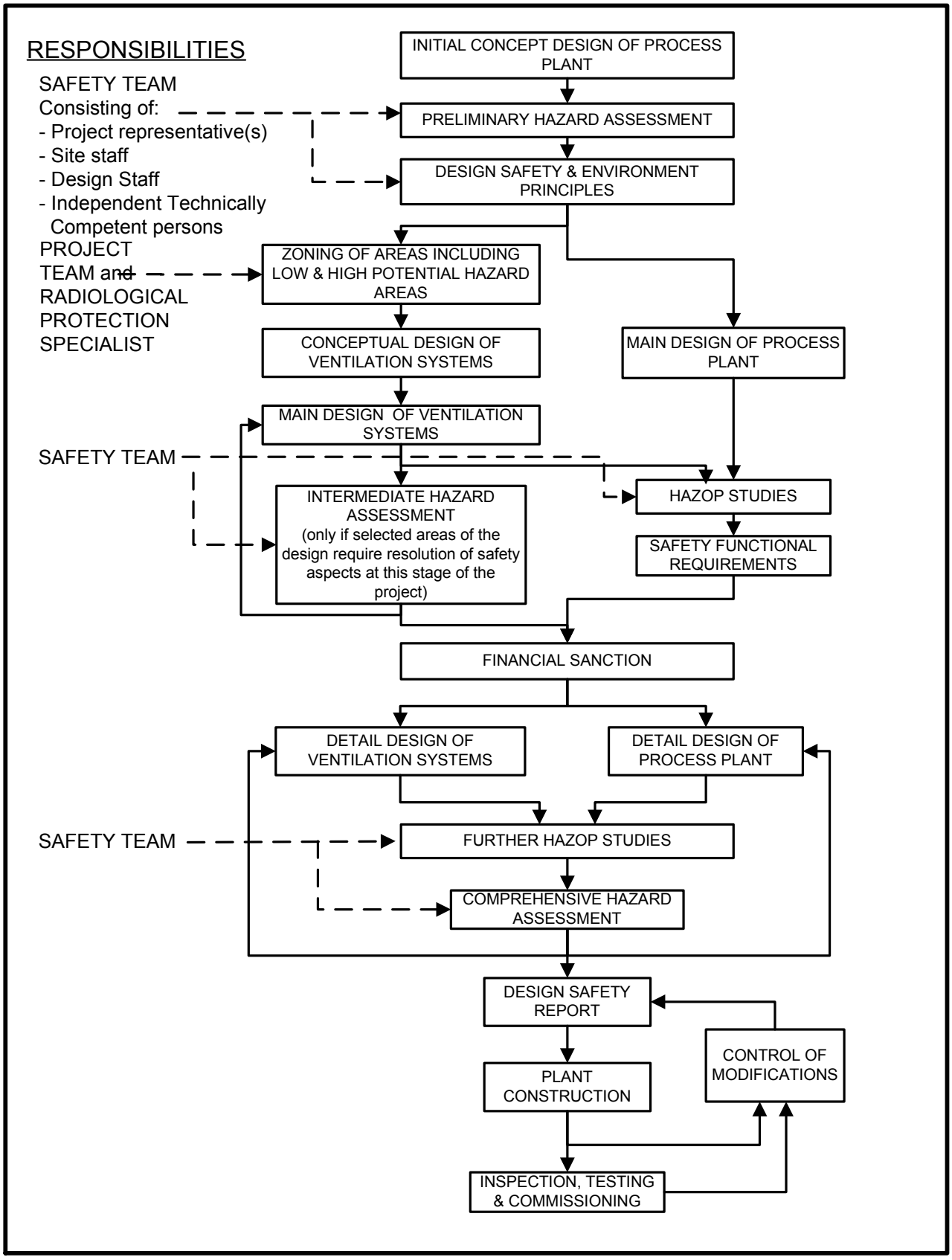
Specific systems may however require more onerous testing than above and should be individually considered.

10.4 OTHER INSTALLATIONS

10.4.1 High and medium pressure ductwork installations manufactured to DW144 high velocity shall be pressure, depression and leakage tested at pressures not less onerous than the maximum perceivable system pressures. The maximum permissible leakage will be as required for high velocity ductwork in accordance with DW 144.

Low pressure ductwork installations manufactured to DW144 low velocity, are not normally pressure or leak tested but are subjected to a visual examination under static and running conditions.

11. FIGURES


RESPONSIBILITIES
SAFETY TEAM
Consisting of:
- Project representative(s)
- Site staff
- Design Staff
- Independent Technically Competent persons
PROJECT TEAM and RADIOLOGICAL PROTECTION SPECIALIST
SAFETY TEAM
SAFETY TEAM
SAFETY TEAM
INITIAL CONCEPT DESIGN OF PROCESS PLANT
PRELIMINARY HAZARD ASSESSMENT
DESIGN SAFETY & ENVIRONMENT PRINCIPLES
ZONING OF AREAS INCLUDING LOW & HIGH POTENTIAL HAZARD AREAS
CONCEPTUAL DESIGN OF VENTILATION SYSTEMS
MAIN DESIGN OF PROCESS PLANT
MAIN DESIGN OF VENTILATION SYSTEMS
INTERMEDIATE HAZARD ASSESSMENT (only if selected areas of the design require resolution of safety aspects at this stage of the project)
HAZOP STUDIES
SAFETY FUNCTIONAL REQUIREMENTS
FINANCIAL SANCTION
DETAIL DESIGN OF VENTILATION SYSTEMS
DETAIL DESIGN OF PROCESS PLANT
FURTHER HAZOP STUDIES
COMPREHENSIVE HAZARD ASSESSMENT
DESIGN SAFETY REPORT
CONTROL OF MODIFICATIONS
PLANT CONSTRUCTION
INSPECTION, TESTING & COMMISSIONING

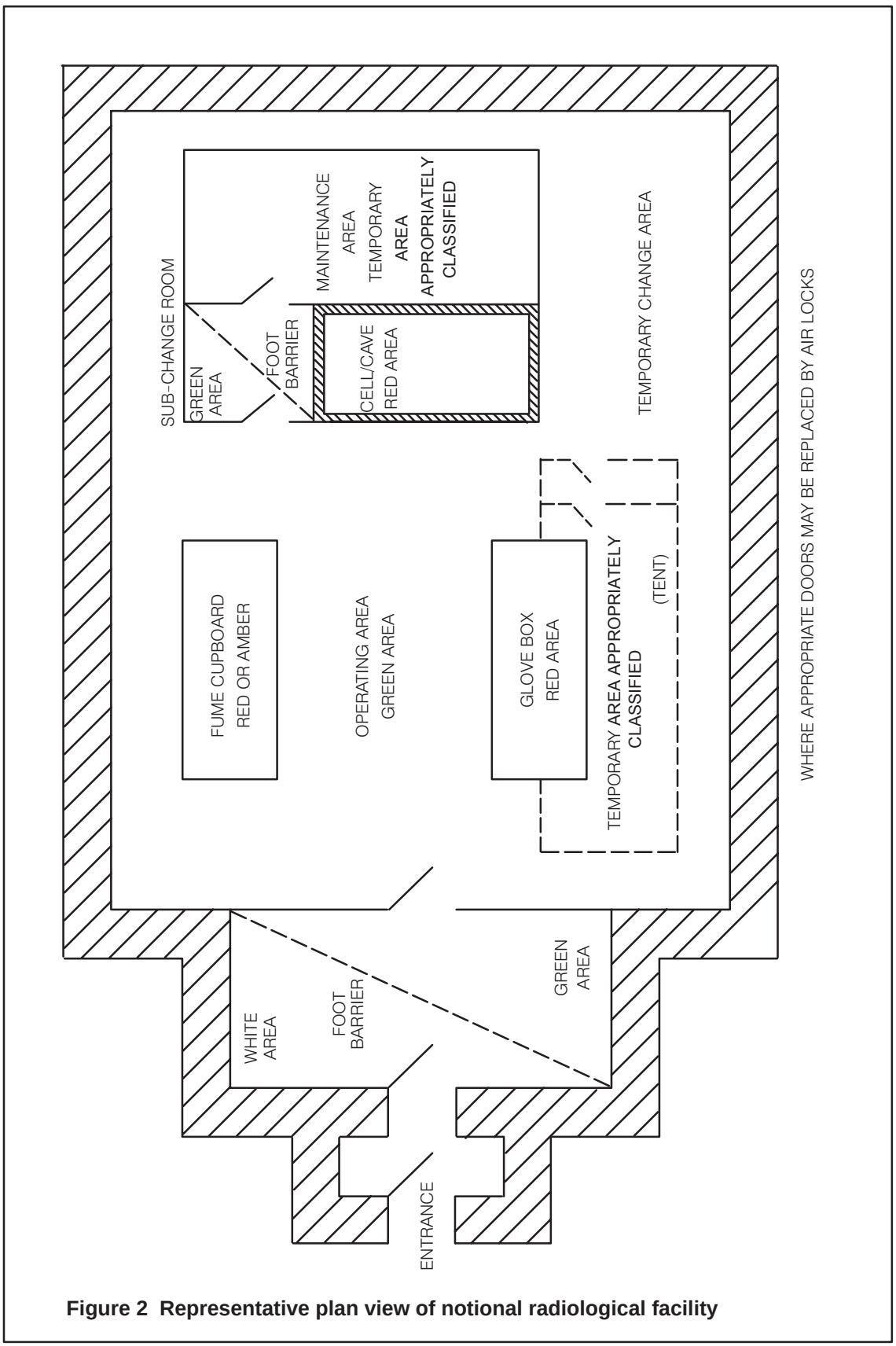


Figure 2 Representative plan view of notional radiological facility

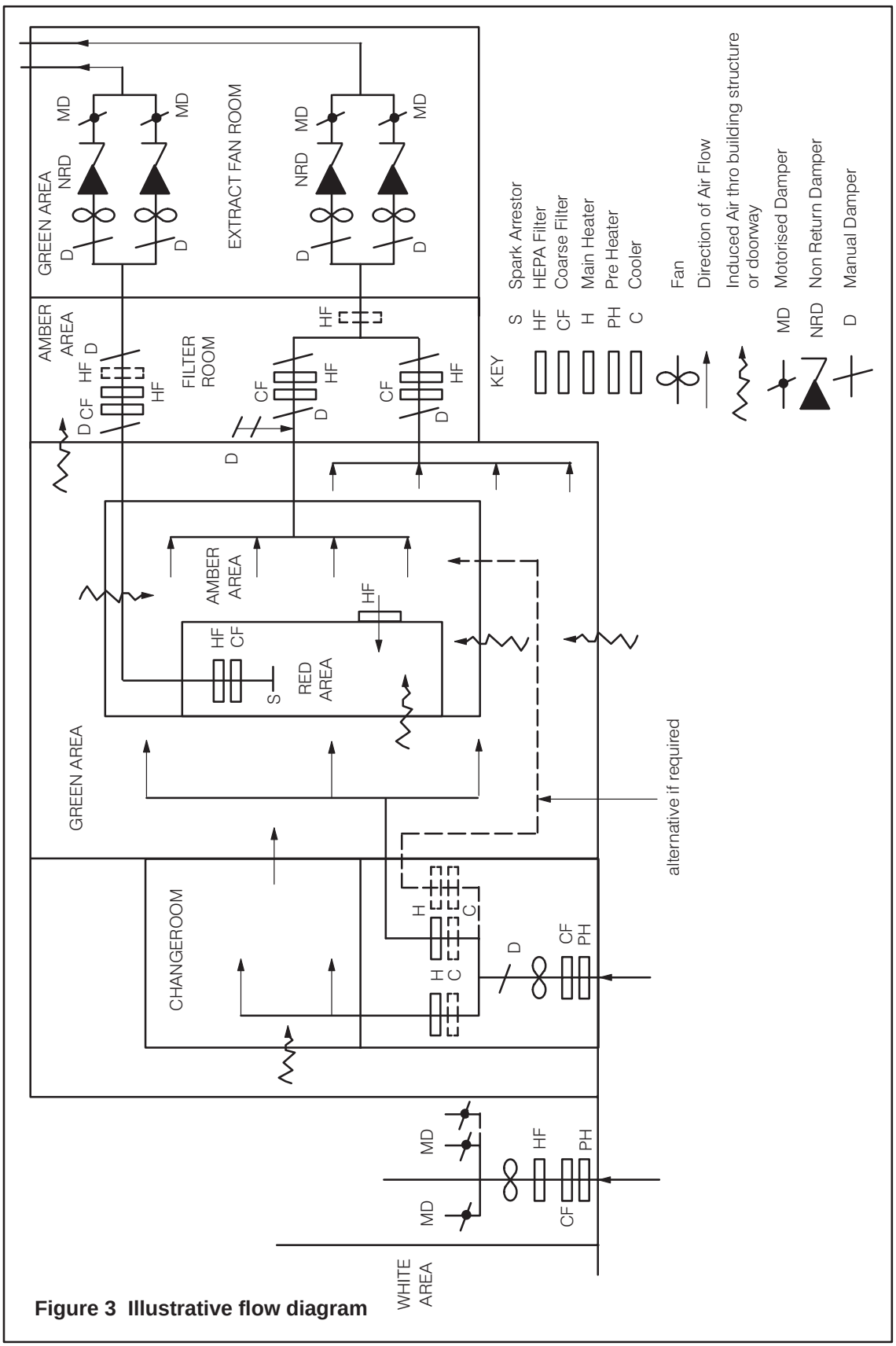
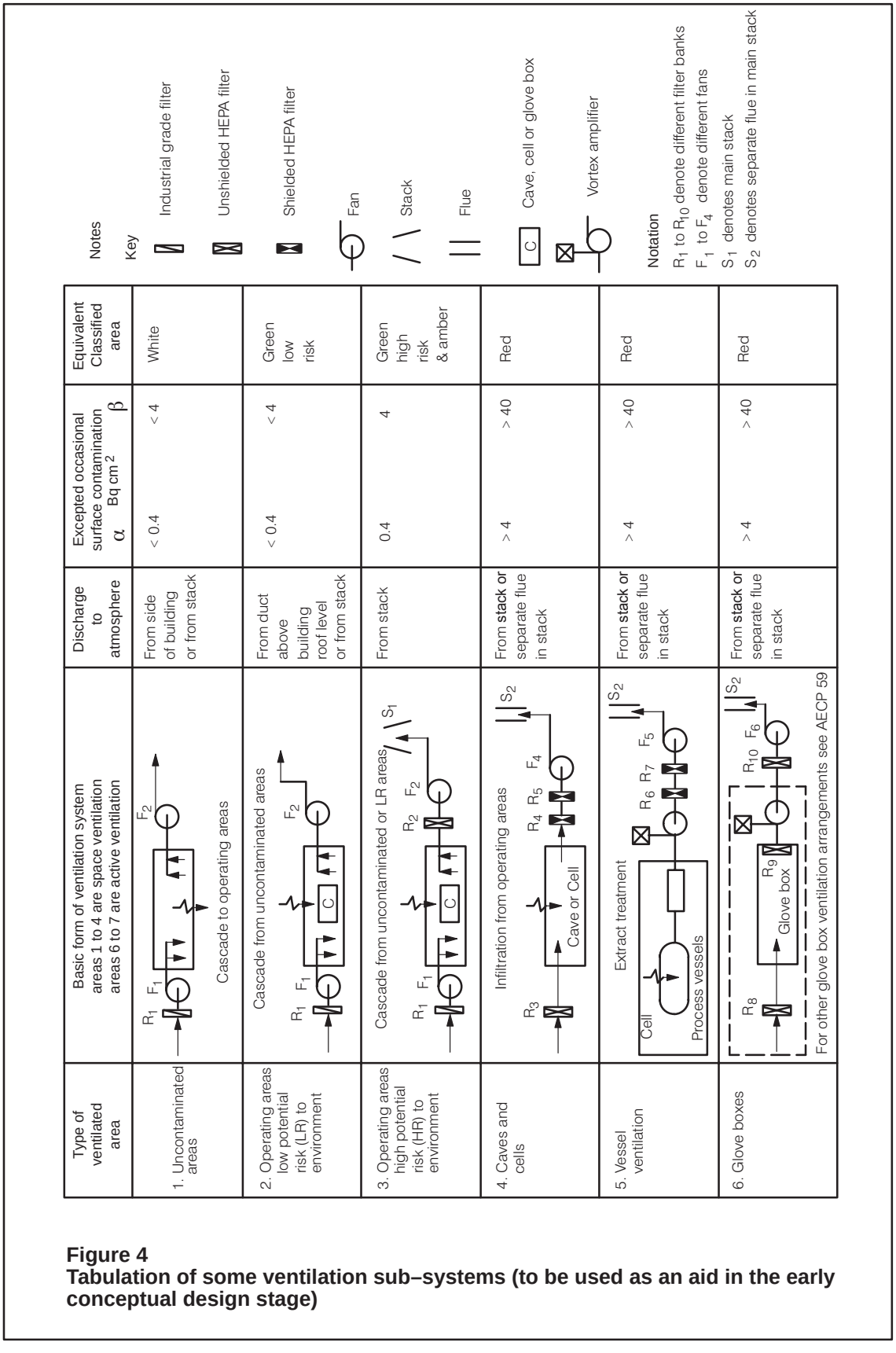
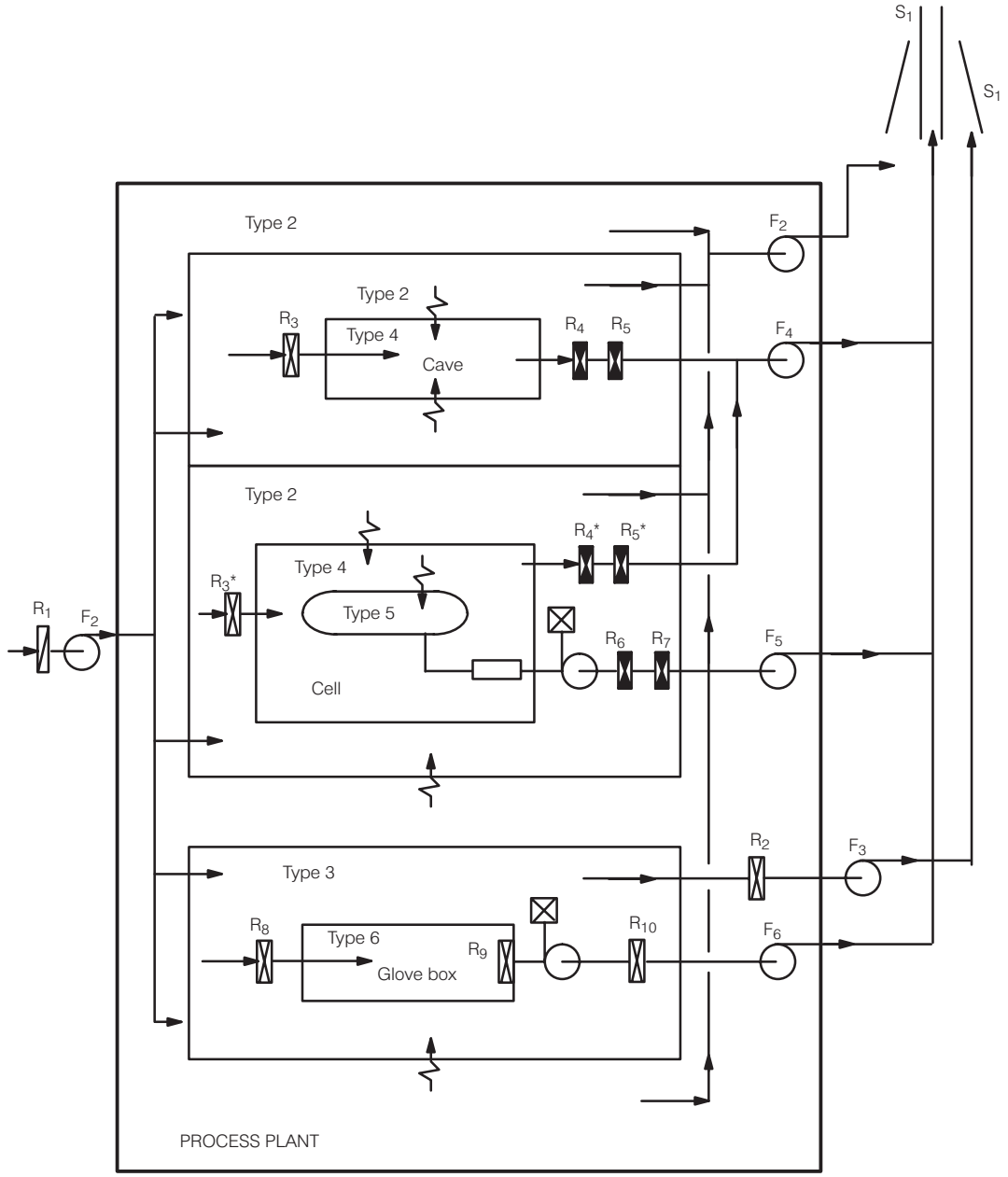


Figure 3 Illustrative flow diagram



Type of ventilated area	Basic form of ventilation system areas 1 to 4 are space ventilation areas 6 to 7 are active ventilation	Discharge to atmosphere	Excepted occasional surface contamination α Bq cm^2	β	Equivalent Classified area
1. Uncontaminated areas		From side of building or from stack	< 0.4	< 4	White
2. Operating areas low potential risk (LR) to environment		From duct above building roof level or from stack	< 0.4	< 4	Green low risk
3. Operating areas high potential risk (HR) to environment		From stack	0.4	4	Green high risk & amber
4. Caves and cells		From **stack or** separate flue in stack	> 4	> 40	Red
5. Vessel ventilation		From **stack or** separate flue in stack	> 4	> 40	Red
6. Glove boxes		From **stack or** separate flue in stack	> 4	> 40	Red

Figure 4
Tabulation of some ventilation sub–systems (to be used as an aid in the early conceptual design stage)



Note:
1. Type 2. Type 3 etc refer to 'Type of Ventilated Area' in Figure 4.
1. R_3*, R_4* and R_5* are indicated with a star for the cell ventilation (Type 4) system since they are physically separate filters from R_3, R_4, and R_5 for the cave ventilation (Type 4) system. The cave and cell extracts may be combined if they have similar contamination levels and then filtered through a single set of filters R_4 and R_5.

Figure 5 Possible application of Figure 4 to a process plant

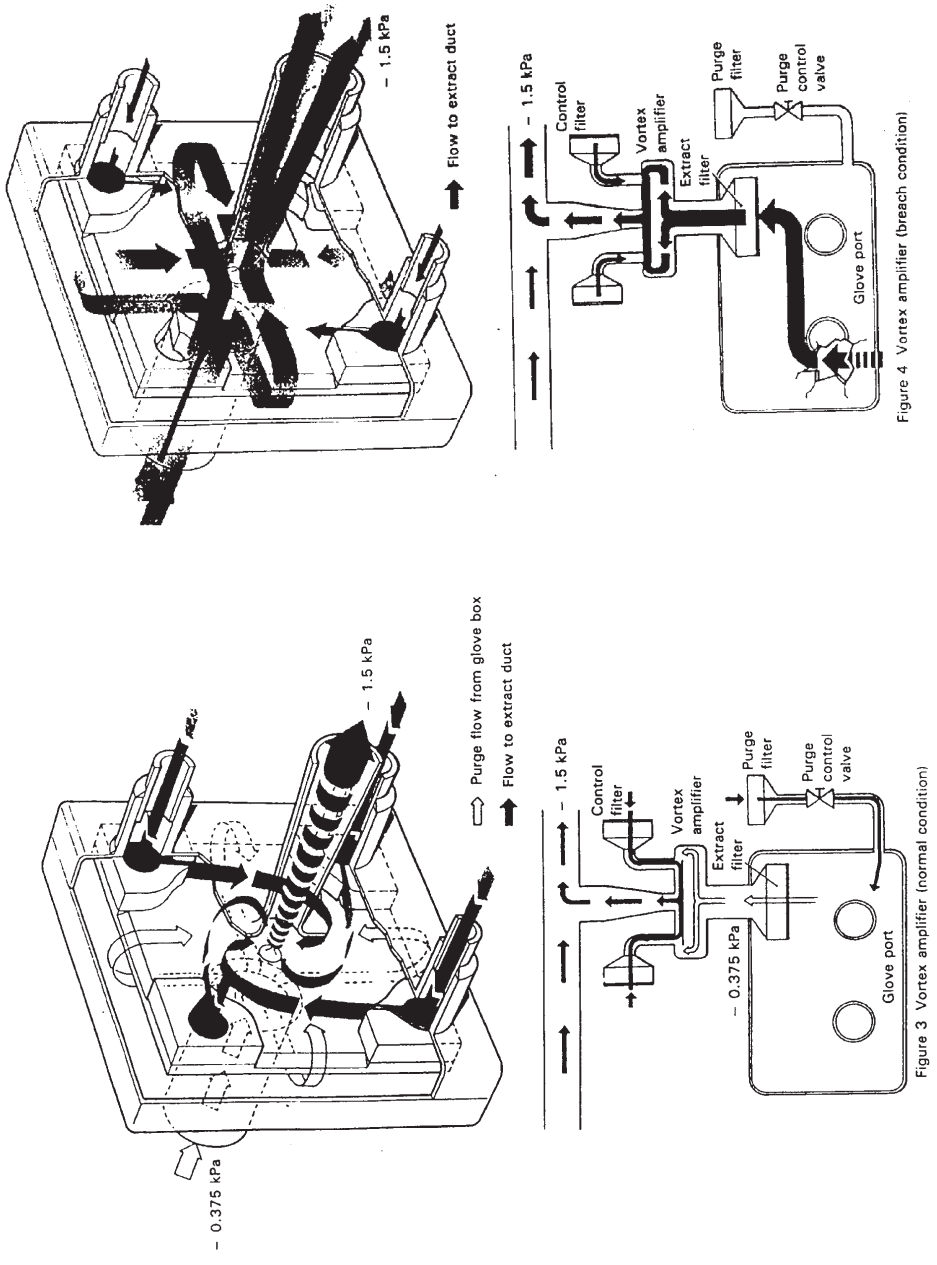


Figure 6
Vortex amplifier (vortex resistance type pressure controller)

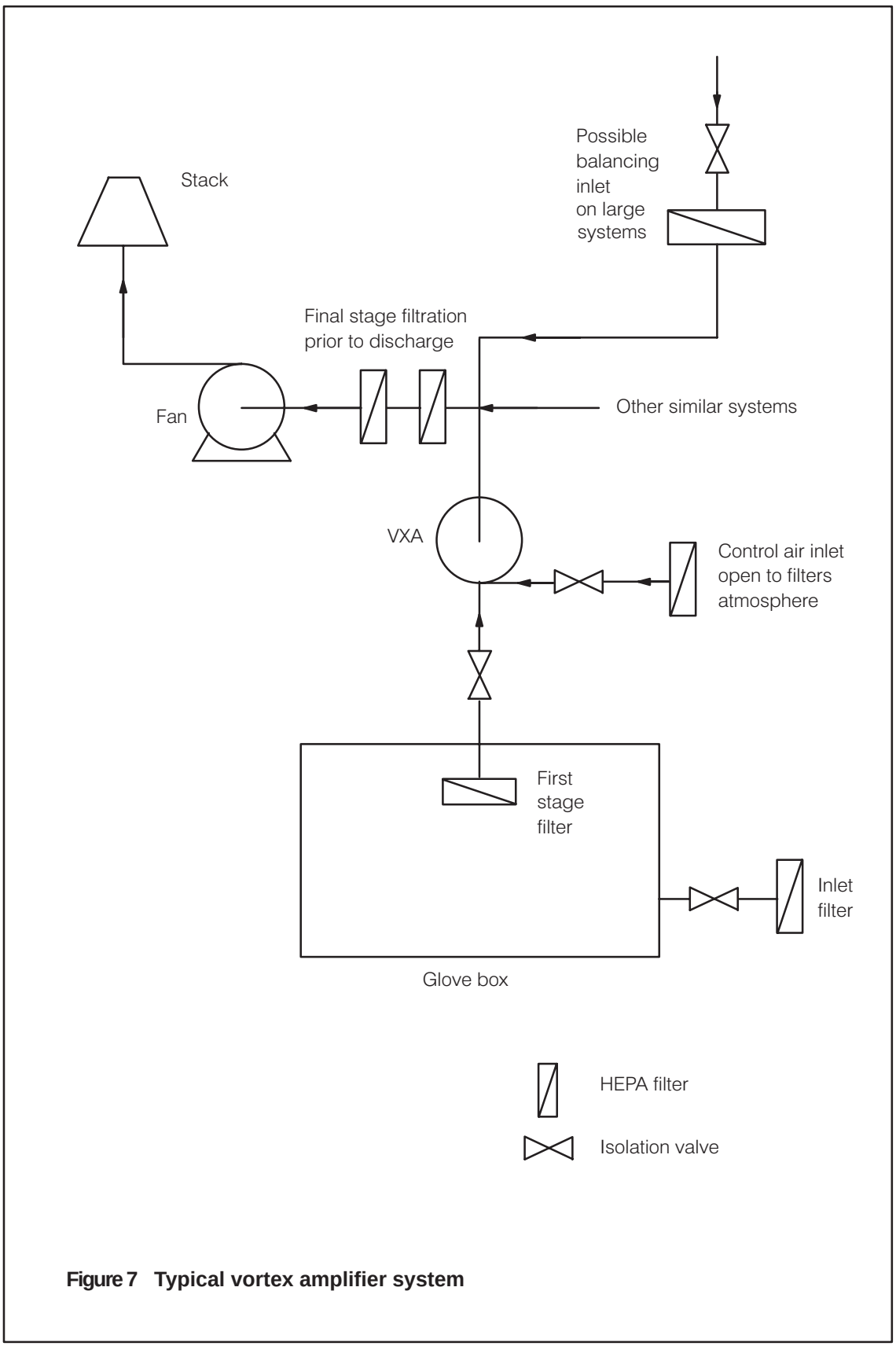


Figure 7 Typical vortex amplifier system

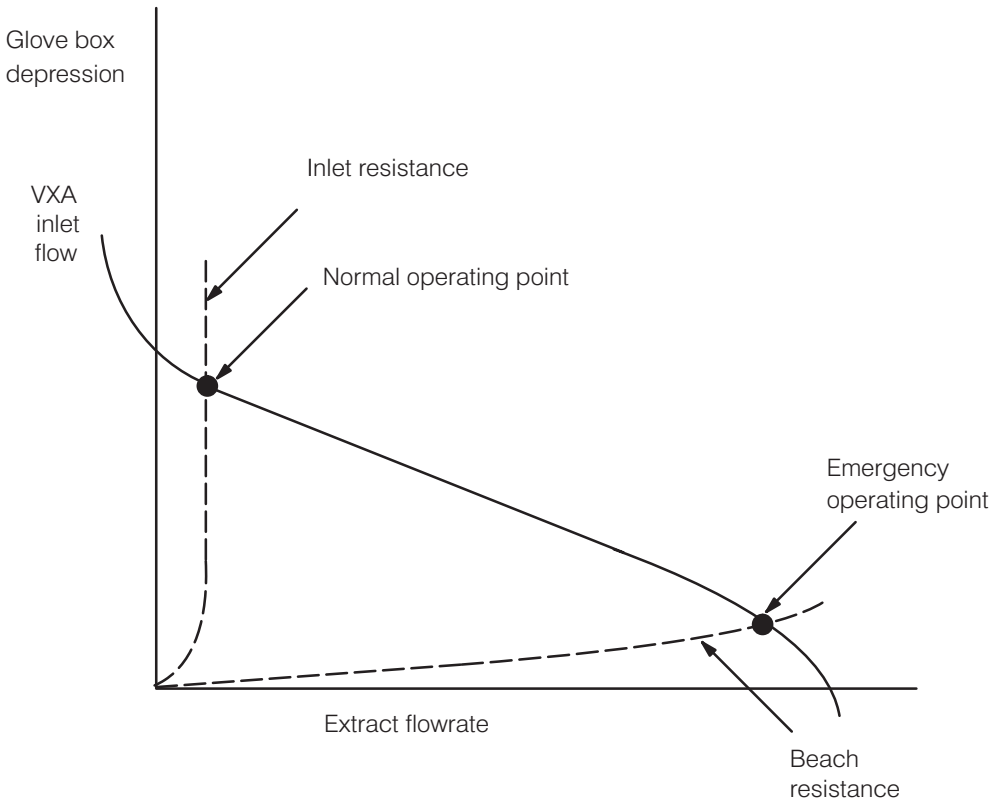


Figure 8 Typical vortex amplifier ventilation control system characteristic

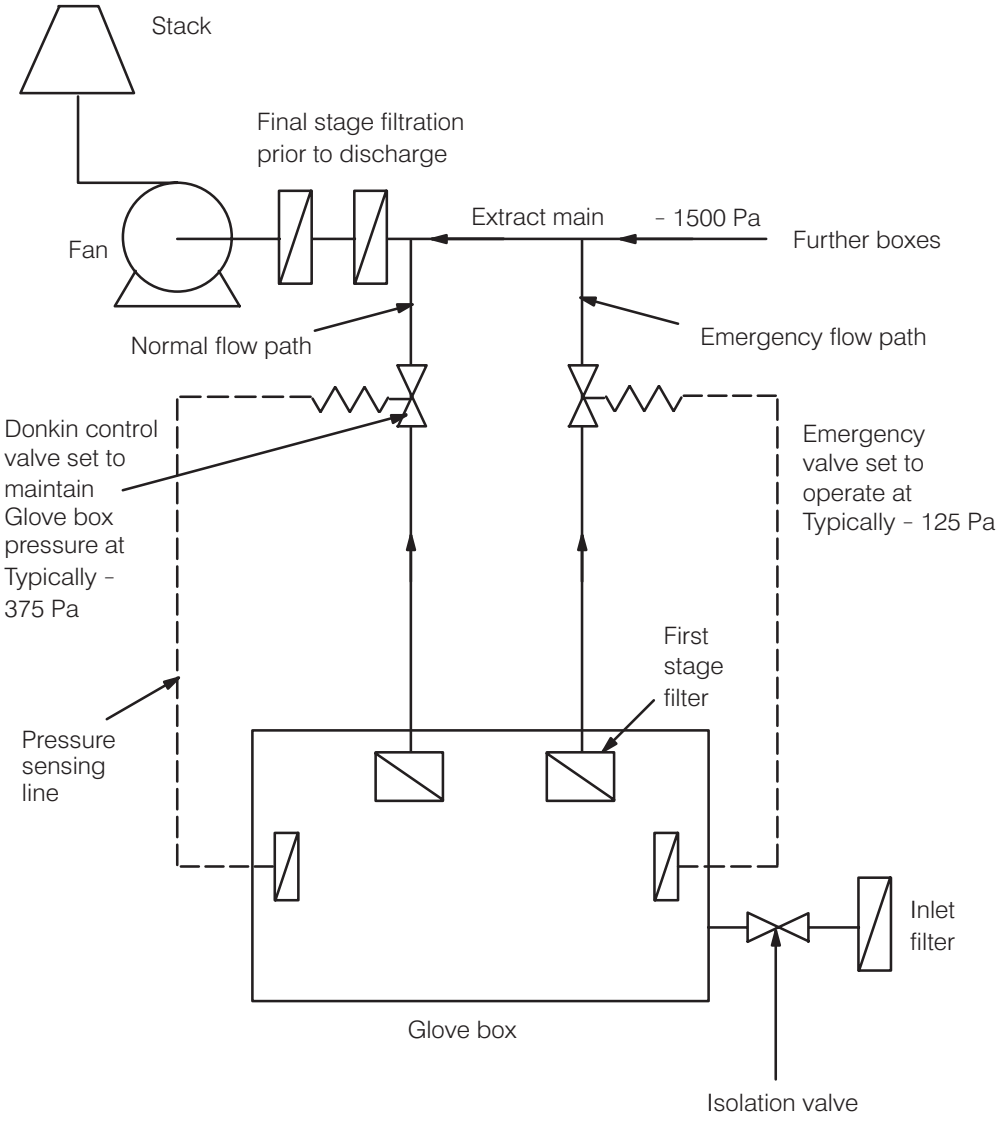


Figure 9 Typical donkin valve air ventilation control system

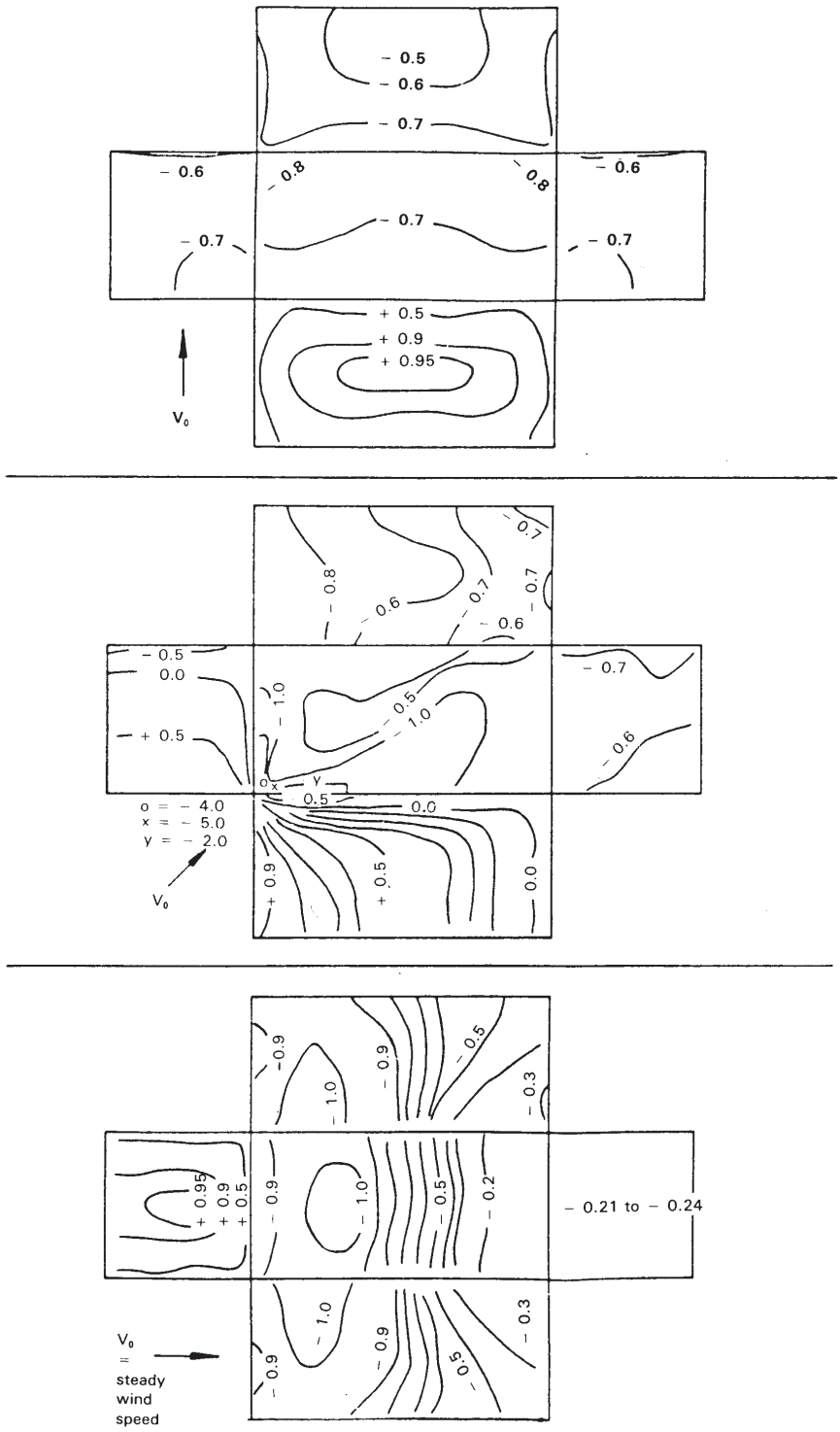


Figure 10
Approximate wind pressure distribution on an elementary building form in terms of wind velocity head factors

Approximate relationship between working area classifications at several nuclear sites and the containment area classification used in this document.

Designers must refer to the appropriate Company procedures for full details of the system used and relevant controls for the site.

Note:
1. Any classification system for working areas must comply with the requirements of the Ionizing Radiation Regulations.
2. Other licensees may have alternative classification systems that must be considered by the designer.

Site / Classification	Aldermaston	Dounreay	Sellafield	Magnox North & Magnox South
WHITE	C1/R1	Supervised	R1/C1 Supervised area	C1
GREEN	C2/R2	LOW	R2/C2 Controlled area	C2 Controlled area
AMBER	C3/R3	MEDIUM	R3/C3 Controlled area	C3 Controlled area
RED	C4/R4	HIGH	R4/C4 and R5C5 Controlled area	C4 Controlled area

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APPENDIX B IN SITU TESTING OF HIGH EFFICIENCY PARTICULATE AIR (HEPA) FILTER INSTALLATIONS

B1 DESIGN PHILOSOPHY

B1.1 In-situ testing is necessary in order to measure the efficiency of the air clean-up filtration system, particularly with respect to the Decontamination Factor (DF) required by the plant safety clearance. It may also be used to check that the filter has been installed correctly, and without damage, and to locate faults should they occur in service.

To test a filter in-situ, a challenge aerosol is injected upstream of the filter. The aerosol mixes with the duct flow and representative samples of this mixed flow are taken upstream and downstream of the filter.

B1.2 Since it is not possible to produce a test challenge aerosol which will simulate the actual in-situ challenge to a filter, it is universal practice to use a test aerosol containing particles in a size range which is theoretically and practically found to be the most penetrating for HEPA filters, viz. a challenge of 0.2 to 0.3 micron Mass Median Diameter (MMD) particles. The DOP (dispersed oil particulate) test is conventionally used, although only thermally generated or "hot" DOP gives challenge particles of approximately 0.3 micron, MMD. An alternative is compressed air driven “cold” generated DOP which produces particles of approximately 0.6 micron, MMD (see B5). On some sites liquid Ondina EL is used instead of DOP. A further alternative method is a test using thermally generated sodium chloride particles, but this provides more corrosive conditions for some plant and equipment.

The Condensation Nuclei (CN) test may be specified if a filter leak test is acceptable. This method uses a test aerosol containing smaller particles than that of the most penetrating size for HEPA filter media.

B1.3 Representative samples should generally be taken from the ventilation system by using installed sample probes. However, by scanning across the duct with a movable probe, the test methods can also be used to measure the variations in the concentration of aerosol particles across a duct section (for uniformity of mixing), and by extracting the sample close to the filter, to detect streaming through holes in the filter or filter seal.

B1.4 Since the test aerosol is submicron in diameter, aerosol separation by inertial effects is unlikely and hence isokinetic sampling is not necessary.

B2 DESIGN CONSIDERATIONS

B2.1 So that the efficiency measured for the system is reasonably representative of the actual overall efficiency:

(a) The filter must receive a particulate challenge having a uniform concentration. This ensures that at any leak point the challenge is of average, and therefore of known, concentration;

(b) Samples extracted must be representative of the aerosol content of the airflow.

What is 'reasonable' should be considered in terms of:

(c) The accuracy required to meet the safety justification for the plant or facility;

(d) The inherent error in the measuring instruments, generation rate of the challenge, etc. Under ideal conditions (good mixing of the test aerosol, ± 10% on the mean) the filter penetration measured by a single test should be well within ± 40%.

As the ideal conditions are not always encountered in practice, errors of measurement of about ± 80% are not uncommon with existing plant designs.

B2.2 Uniform concentration profile for the challenge aerosol is achieved by allowing an adequate mixing length between the injection point and the sample extraction point before the filter. This extraction point can be as close to the filter as plant design constraints and sample probe geometry allow.

The precise mixing length required will depend on the particular system under consideration, and especially on the flow regime (laminar or turbulent). Table 2 gives values, deduced from an experimental rig (5,000 to 10,000 m^3/hr, 600 mm square duct, 17 ms^{-1} injection velocity) which suggests that some 25 duct diameters are required for natural mixing ±10% on the mean from a central injection point. (Past work suggests that using the previously recommended mixing length of 10 duct diameters might introduce a variation of three between maximum and minimum concentrations.)The duct length for mixing is also seen to be dependent on the velocity of the sample injection. For injection at around the duct velocity, which is the case for a leak on a filter, or for an injection system which uses the depression in the duct to induce the sample (i.e. the hot DOP generator), then natural mixing lengths (±10%) are greater than 30 diameters. If however mixing energy is introduced by forcing in the sample under pressure (i.e. the cold DOP generator), then experiments (1988) suggest that there is a minimum injection velocity (about 17 ms^{-1} for the rig concerned) below which mixing is only achieved at greater distance than indicated in table 2.

For plant arrangements other than those indicated in Table 2, extra tapping point bosses should be incorporated into the ductwork and “Fingerprinting" carried out during commissioning. The resulting information may then be used in assessing the accuracy of the DF measurement.

B2.3 Where there is not a complete run of straight ductwork for mixing, the above mixing lengths are to be interpreted as follows:

(a) Where the mixing length consists of 2 lengths of straight ductwork separated by one bend (with an angle up to and including a U bend), then the mixing length refers to the distance along the duct centreline including the bend;

(b) Where the mixing length consists of several straight lengths of ductwork each of which is separated by a bend of any geometry, then the mixing length refers to the sum total of the several lengths of straight ductwork (i.e. excluding the lengths of the bends).

It should be noted that in the above context the term duct diameter strictly means hydraulic diameter of the duct cross section. Hydraulic diameter is equal to four times the duct cross sectional area divided by the perimeter of the duct cross section. For a circular duct the hydraulic diameter is equal to the duct diameter; for a square duct the hydraulic diameter is equal to the length of a side of the duct cross section.

It is important not to confuse the above mixing lengths with those quoted in AECP 1072 for stack sampling. In general, the requirements for filter testing are more demanding than those for stack sampling because:-

(c) In filter testing two separate samples are required from the duct (upstream and downstream of the filter) and errors accumulate;

(d) In filter testing the concentration of test aerosol across the upstream filter face must be very uniform (± 10% on the mean);

(e) In stack sampling, a concentration profile within ± 20% on the mean is considered acceptable.

The joining of branch ducts to the main duct within the mixing length (these branch ducts feeding air into the main duct) should be avoided.

B2.4 Mixing lengths can be reduced by using multipoint aerosol injection, and by creating increased turbulence by the use of mixing devices.

(a) The use of a multipoint injection array effectively reduces the duct section served by each injection hole and this produces a mixed flow in a shorter distance. However, experimental work has shown that the decrease in mixing length is not as great as might be expected from simple theory.

If a multi-point array is used, the holes in the array must not become obstructed, so that each can give an equal flow. Therefore, an array which can be inspected and cleaned is preferred.

(b) Mixing devices can be very effective at shortening mixing distances, but with the disadvantage of having increased pressure drops. For proprietary devices the manufacturer should be consulted concerning the pressure/flow characteristic of the selected mixing device. An option is to use devices such as the Stairmand Disc, or for greater efficiency a ring and doughnut, which can be mounted so that it can be rotated and hence feathered when not required for testing purposes. Table 2 shows that mixing ±10% with a central injection point is achieved in 10 duct diameters using a 50% area Stairmand Disc and forced (cold) injection. Using the hot DOP generator with the same Stairmand Disc increases the mixing length to 14 duct diameters for mixing ±10%.

Experimental work has shown that by dividing the Stairmand Disc into three equal parts and using three points of injection, see Table 2 and figure 11, the mixing length can be reduced to approximately six duct diameters.

B2.5 The mixing length required to ensure that a representative sample is extracted after a filter will be greater than that required to mix the challenge aerosol before the filter since the emission (leak) point of the downstream aerosol may not be in the centre of the filter. The figures quoted in Table 2 suggest mixing lengths of greater than 30 duct diameters without a mixing device, and 15 duct diameters with a 50% Stairmand Disc in order to detect an 'edge' leak to within ±10% variation on the mean.

Sampling extraction positions should be in a region of unobstructed straight ducting, which is free from static air or eddying. Since the test aerosol is submicron in diameter, aerosol separation by inertial effects is unlikely and hence isokinetic sampling is not necessary. Probe positions should be easily accessible to facilitate use.

Except for CN tests, the fan is an acceptable mixing device, and it is recommended that the sample extraction point should be at least four duct diameters downstream of the fan to avoid the worst of the induced turbulence (BS 893). Small air in-leakages through, for example fan shaft bearing/seals, can prevent systems being testable when CN is used.

B2.6 An alternative approach, which is of particular value for multi-filter banks, is the use of a Multiple Orifice Sampling Probe (MOSP) for downstream sample extraction. In this the probe has a number of holes which are positioned such that the sample drawn from the device represents the true mixed aerosol concentration, even though the probe itself is in an incompletely mixed flow. In order to ensure consistent sampling, each hole must be run at 'choked flow' conditions. The MOSP is of no advantage for upstream measurements, since there is still the necessity to challenge the filter with a uniform concentration of test aerosol.

It must be emphasised that the design of the MOSP will be installation dependent, and that testing will be required to ensure that the sample extracted will be adequately representative. With a well designed and evaluated probe, sampling lengths can be reduced to about four duct diameters.

MOSPs can also be used to identify a leaking filter in a bank of filters, if a separate MOSP is provided downstream of each filter.

B2.7 Where a system is designed with filters in series, then the filters should normally be separated by sufficient distance to allow aerosol injection and representative sampling upstream of the downstream filter, as well as mixing and sampling downstream of the upstream filter. This will allow separate testing of each filter, and hence the full worth of each unit can be claimed in the safety case.

Where filters in series cannot be individually tested adequately due to lack of separation, then the limitation on the sensitivity of current measurement instruments, suitable for in-situ testing, will limit the accuracy of the DF which can be measured and hence claimed for the system of two filters in series. Individual filters/banks of filters can be tested during filter change operations, but this will not be sufficient to prove the overall performance of a system when all filters are installed.

B3 PLANT COMMISSIONING

B3.1 The adequacy of the design must be demonstrated during commissioning.

B3.2 The Test Schedule. It is the designers responsibility to ensure that the design is testable and to provide the test schedule for the commissioning of the ventilation system. This schedule will define, amongst other things, the test method and apparatus for which the installed testing facilities were intended. The schedule should also describe the way of carrying out the tests, and sufficient time must be allowed to reach a full understanding of the filter system flow characteristics as they affect the measurement of filter efficiency.

It is recommended that the test schedule should record the results of 'fingerprinting' the filter system at the commissioning stage, see B3.3.

B3.3 'Fingerprinting' ('Characterisation'). This term has been coined to describe the process of testing and recording the characteristics of the filter system including, for example, the aerosol injection rate, and the required sensitivity and range of sensitivity of the necessary instrumentation. 'Fingerprinting' will allow demonstration, to plant management and safety authorities, that the proposed future routine testing during the operational life of the plant will accurately measure the true filter efficiency, whether it be in normal or abnormal operational circumstances.

'Fingerprinting' can obviously be best undertaken during inactive commissioning. It must certainly include sampling scans across the duct, using a test aerosol at the sample extraction point positions, both upstream and downstream of the filter. The scans should be done in two direction, perpendicular to each other and the duct axis, and engineered access may be required to achieve this. In some circumstances it may be possible to extract the sample downstream of the filter after the fan. In this case duct traverses may not be required as the fan should act as a good mixer. The commissioning can also be done using a deliberately faulty filter, having a hole, say, in the medium at one side or corner, or more realistically perhaps a defective gasket seal. The filter can be repositioned and tested so as to try different leak positions. A faulty filter can also be fitted in different locations in a bank of filters, so that the effect on the sampling can be seen. (The presence of a leaking filter in a bank may not unduly affect the overall efficiency of the bank: however, the presence of a substandard filter does perhaps not meet the criterion of ALARP.)

B4 TEST METHODS

B4.1 Three test methods are briefly described here:

(a) The DOP test method is normally recommended though other chemical liquids may also be used in the same manner;

(b) The British Standard 3928 sodium chloride test is used for production testing of simple filters: it is not convenient for in-situ work. However a variation uses a thermal generator and may be suitable for multi-filter systems.

(c) Although condensation nuclei (CN) are readily retained by low and high efficiency filter media, the CN test can be used to establish the leak tightness of a filter system. As such it cannot be used to determine the DFs of a filter or filter system even though DOP and CN test may in many circumstances give the same result.

B5 THE DOP METHOD

B5.1 Dispersed Oil particulate is a low vapour pressure liquid which can be atomised to form a stable aerosol of small particle size. For in-situ testing two methods of generation can be used. In the cold DOP generator, compressed air is applied to a nebuliser which produces a poly dispersed aerosol with a mass median diameter of approximately 0.6 micron depending on the equipment used. The alternative thermopneumatic method uses carbon dioxide or nitrogen to atomise the liquid prior to heating and re-condensing. The poly dispersed aerosol produced has a mass median diameter of approximately 0.3 micron.

B5.2 Upstream and downstream measurements are made using an optical detector (usually of the forward light scattering type) with an analogue display. Consideration may be given to the use of a chart recorder or integrating circuitry to help resolve the continual variations due to eddying, etc., particularly at lower concentrations.

B5.3 Using the appropriate generator aerosol can be produced at a rate up to about 10g min^{-1}, hence allowing filter DF determination of better than 10^5 at flow rates up to 10^5 m^3 hr^{-1} using a suitably sensitive detector and a fully experienced operator with an adequately designed system.

B6 THE SODIUM FLAME METHOD

B6.1 Sodium chloride aerosol can be used for filter testing, using a flame photometer as the detector. The standard BS 3928 test caters for production testing of single filters. It employs an aqueous sodium chloride solution in the nebuliser which dries when dispersed in the air stream.

B6.2 An alternative higher output 'salt-stick' generator has been developed for installed filter systems. This employs a solid rod of mainly sodium chloride which is fed into an oxy-propane flame to generate the solid aerosol by vaporisation and condensation. Aerosol size is in the range 0.15 to 0.4 micron, and the largest generator available has an output up to 10 g min^{-1}.

B6.3 The use of hydrogen for the flame photometer, and the propane for the salt stick generator may be unacceptable in areas of significant radioactivity because of the potential fire/explosion risk. The corrosive effects of sodium chloride have also been questioned. For these reasons, the method is not often used for in-situ testing.

B7 THE CN (CONDENSATION NUCLEI) METHOD

B7.1 Condensation nuclei are in the size range 0.1 to 0.001 micron and occur in naturally large quantities from combustion and other chemical processes. They can be used in a leak test method (round or through the filter) when only the downstream concentration needs to be measured since a perfectly sealed filter will stop the particles almost completely (as predicted by filtration theory). To obtain a quantitative assessment of filter system leakage, both upstream and downstream concentrations need to be determined.

B7.2 In order to achieve satisfactory results over a wide range of filter installation leakage or in situations where the upstream air is filtered, it is normal to augment the ambient concentration of nuclei by using a generator. A variety of liquid and gases can be used and a convenient method is to burn a solution of ammonia sulphide in methylated spirits.

B7.3 In order to detect the particles it is necessary to increase their size by condensing a liquid onto them hence allowing optical methods of measurement. The older method uses pressurisation and depressurisation of the samples in the presence of water vapour , with the degree of obscuration of a light source the being proportional to the concentration of nuclei. A more recent instrument uses butylalcohol as the condensing liquid and achieves particle growth by cooling the continuous sample flow. Forward light scattering techniques are used to give a wide range pf particle concentration measurement. The method of detection of the CN particles (by either type of instrument) means that results are obtained from the number of particles present, not their concentration.

B7.4 Variation is CN concentrations can occur for many reasons, including:

(a) Welding

(b) Combustion products from vehicle exhausts

(c) Some chemical plant operations, such as the use of steam ejectors

(d) Vibration causing intermittent effects

(e) Duct leaks, fan seal leaks

In consequence considerable care is needed in positioning sample extraction points, carrying out measurements and interpreting the results.

TABLE 2 - GUIDE TO MIXING DISTANCES

Position	Type or aerosol injection	Method of mixing aerosol	Minimum number of duct diameters to a single point sample probe (position of mixed flow)
Upstream of filter	Central single point injection	Natural mixing	25 D from injection point
	Central single point injection	Stairmand disc	*10 D from injection point
	3 point injection	3 part Stairmand disc	6 D from injection point
Downstream of filter	Single edge leakage	Natural mixing	30 D from filter
	Single edge leakage	Stairmand disc	15 D from filter

NOTES:

1. The results in the table are obtained from a 600 mm square section experimental rig running at a duct velocity of 4 to 8 m s^{-1}. The test was conducted utilising cold generated DOP injected at 17 m s^{-1}.

2. Mixing defined as $\frac{\text{Max concentration - Min concentration}}{\text{Mean concentration}}$ ± 10% across whole duct.

3. The Stairmand disc is 50% of duct area and positioned centrally.

4. The Stairmand disc is 0.5D downstream of a central injection point or 2D downstream of a filter.

5. The 3 part Stairmand disc is 0.5D downstream of the 3 point injection, see figure 11.

6. If there is a bend of any geometry between either of the above types of Stairmand discs and the filter(i.e. upstream of the filter) then the disc must be situated upstream of the bend. If necessary the disc can be situated at the start of then bend (i.e. zero duct diameters upstream of the bend).

7. The results in the table also apply to Ondina (injected in the same manner as cold generated DOP).

8. Use of hot generated DOP increases the mixing lengths in the table.

9. For rectangular ducts and square ducts other than 600mm square section and where the duct velocity is 8ms^{-1}.cold generated DOP (or Ondina) should be injected at a velocity 2.5 times the duct velocity.

* The same mixing length was achieved in a rig with a 300mm diameter duct, a velocity of up to 13ms-1 and a cold DOP injection velocity of 17ms-1. The type of aerosol injection and method of mixing were the same as for the 600mm square section rig.

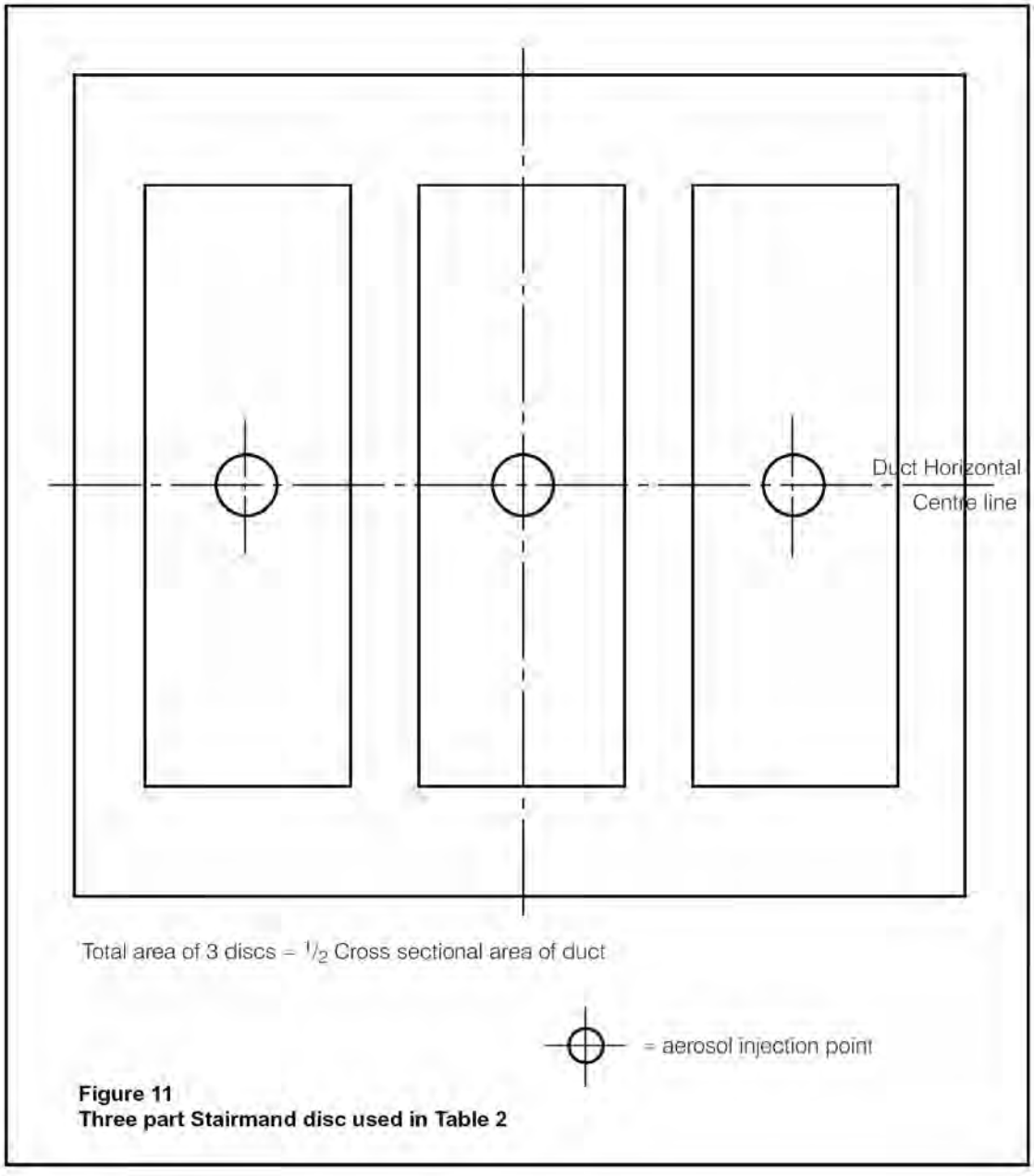

Figure 11
Three part Stairmand disc used in Table 2

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