Sellafield Ltd **Engineering Guide** **Title: Ventilation Systems for Radiological Facilities Design Guide**	**EG_0_1738_ 1** Issue : 2 Effective date: 12/2023 Page 1 of 123

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Applicability Review: Purpose of the document	Designers of ventilation systems for radiologically controlled buildings have used AECP 1054 as the UK standard for good practice since the code was first published in 1979. AECP 1054 was rebadged as NF 0166/1 in 1997 before being replaced by NVF/DG001 in 2009, with a commitment to update and maintain the design guidance so that it continued to represent good practice. NVF/DG001 was replaced by this document in 2015 and has been comprehensively updated in subsequent revisions in 2018 and 2023. The document is on a 5 year periodic review and update cycle to continue the commitment to reflect current good practice.

Applicability Review: When should this standard be applied?	As a guide, the document is equally applicable to all tasks.

Applicability Review: Benefit provided by the document to Sellafield Ltd.	The guide has been reviewed by Site Licence Company representatives across the UK Nuclear Industry and ventilation plant manufacturers through the National Nuclear Ventilation Forum. The guide therefore incorporates UK nuclear industry specific learning from experience and site specific learning from experience, which will not always be readily available, and as easily obtainable, elsewhere for non-users of this document.

Category: Design Guide

Executive Summary:

This is a guide for ventilation system design for radiologically controlled buildings within the UK.

Amendment history

Amendments detailed below are those made from:

From	NVF/DG001	To	EG_0_1738_1 Issue 2

Date amendment made	Details of amendment
05/2015 ES_0_1738_1 Issue 1 B Swinnerton	This document replaces NVF/DG001 Document headings changed and document re-formatted into Engineering Standard ES_0_0000_1 template 1 ‘Scope’ rewritten, old clauses 1.1.1, 1.1.4, 1.1.5 deleted, clauses 1.3, 1.4, 1.5 added, ‘Legal Framework’ clauses 1.6.2 to 1.6.4 updated 2 ‘Definitions/Abbreviations’ updated (was clause 1.5) 3 ‘Related UK Legislation and Guidance Documents’ updated (was clause 1.4), clauses 3.6, 3.7 added 4 ‘Radiological Safety’ (was clause 2), clause 4.1.2 updated with latest environmental legislation, clauses 4.3.3 to 4.3.8 rewritten, old clauses 2.4.1 a), c), d) deleted, clause 4.5.1.2 added, clause 4.2.1.2 added from NVF/DG001 Addenda A1 5 ‘Containment’ (was clause 2.6), clauses 5.1.2, 5.1.6 to 5.1.9 updated, clause 5.1.5 added from NVF/DG001 Addenda A1, old clause 2.7.2 replaced with clauses 5.2.2 to 5.2.4, clause 5.3 ‘Amber’ definition expanded, 5.4 updated (old clause 3.1.2) 6 ‘Functions Provided by Ventilation Systems,’ new section added using ISO 17873 7 ‘Design Principles of Ventilation Systems for Radiological Controlled Areas’ (was clauses 1.3 and 3), re-arranged and updated Clause 7.1 ‘What are the hazards?’ added Clause 7.4 ‘Design Process’ (was clause 1.3) minor updates, Figure 1 added Clauses 7.2, 7.3.1, 7.4, 7.5.1, 7.5.3, 7.7.1 & 7.7.3 minor updates, clauses 7.4.5, 7.6.3, 7.6.5 added Clause 7.7.4 added on ‘Rollback’ Clause 7.8 ‘Air Flows in Support of Containment’ (was 3.6) rewritten and NVF/DG001 Addenda A2 incorporated Clause 7.9 ‘Velocities Between Areas of Different Classification’ (was 3.8) rewritten and NVF/DG001 Addenda A2 incorporated Old Clause 3.7 replaced and rewritten with Clauses 7.10 ‘Room air movement,’ 7.11 ‘Filtration on Supply Air Systems’ and 7.12 ‘Clean up (filtration) on Exhaust Air Systems’ Clause 7.13 ‘Design Air Flows’ (was clause 3.9) rewritten, Figure 4 added Clause 7.14 ‘Differential Pressures Between Areas’ (was clause 3.10) rewritten Clause 7.15 ‘Natural Ventilation’ added Clause 7.16 ‘Ventilation of Incident Control Rooms’ (was clause 3.12) minor update and last paragraph (old clause 3.12.2) deleted 8 ‘Glove Box Ventilation,’ rewritten and expanded replacing old clause 4.2, Figures 5 to 11 added 9 ‘Ventilation of Caves and Cells’ (was clause 4.3), clauses 9.1, 9.2, 9.4, 9.6, 9.7, 9.9, 9.10 updated 10 ‘Fume Cupboard Ventilation’ (was clause 4.4) rewritten and expanded 11 ‘Process Vessel Ventilation’ (was clause 4.6) minor updates Old Clause 4.5 ‘Inert Gas Systems’ deleted Old Clause 3.11 ‘Fans and Motorised Dampers’ moved to clause 12.1, clause 12.2 added Old Clause 5 ‘Exhaust Air Clean up Plant and Stack Discharge’ replaced with Clauses 13 to 16 Clauses 13 ‘HEPA Filtration’ (was 5.2), 13.1.4 updated, 13.2 ‘HEPA Filter Type Testing’ updated to reference ES_0_1705_2

	Clause 13.4 'In-situ HEPA Filter Performance Testing' (was 5.5) updated and 13.5 'Filter Ageing' added to incorporate NVF/DG001 Addenda A5 Clause 13.6 'Filter Installations Testing and Monitoring' (was 5.9) updated Old clause 5.6 'Input Filtration System' deleted (covered in clause 7.11) Clause 13.7 'Extract Filtration System' (was 5.7) updated Clause 15 'Pre-filter etc' (was 5.8) minor updates Clause 16 'Exhaust Stacks' (was 5.10), 16.1.1, 16.1.2, 16.1.4, 16.3 added, 16.2, 16.4, 16.7 expanded 17 'Building External Containment' (was clause 6) 17.1.2, 17.5.1 updated, Figure 12 added, 17.6.2 rewritten, 17.6.4, 17.11.2 expanded, clauses 17.2.3, 17.7 added, old clause 6.9, deleted, EPS3 leak test results added to Table 1, 17.9.4 added, 17.10 rewritten 18 'Electrical Supply, Control and Instrumentation' (was clause 7), clause 18.3.1 added, clause 18.3.5 updated with 2 out of 3 voting system, clause 18.4 'Instrumentation' minor updates and ES references added, 18.6.7 updated 19 'Fire Safety' (was clause 8), 19.2.1 to 19.2.3 expanded with BS 9999, BS EN 1366-2 added, 19.2.4, 19.2.10, 19.2.11, 19.2.12 'Access for Fire Damper Maintenance' added 20 'Ductwork Selection' (was clause 9), 20.1.2, 20.3. 20.4.1, 20.5.1, 20.5.3 updated, 20.1.3, 20.4.2 added, old clause 9.4.8 deleted 21 'Testing and Commissioning' (was clause 10), 21.5 updated, old clauses 10.2 to 10.4 deleted (ductwork testing) now covered in ductwork Engineering Standards Old Figures 1 to 10 replaced with new Figures within text Appendix A 'Classification of areas for various nuclear sites' updated Old Appendix B 'In Situ Filter Testing' deleted – now covered by ES_1_1707_1 New Appendix B 'Vortex Amplifiers' added New Appendix C 'ONR Safety Assessment Principles relating to Containment and Ventilation' added. Old Appendix C 'Air Infiltration – Building D9867, Dounreay' deleted – refer to archived NF0166/1 if required
12/2018, EG_0_1738_1 Issue 1 B Swinnerton	This document replaces ES_0_1738_1 Issue 1. Changes from ES_0_1738_1 Issue 1 are: - Document transferred to template SLF 1.02.02.04. References to legislation updated to latest revisions. Clause 1.5 now refers to BAT, BPM and EA RSR. Clause 1.6.3 added re. DNSR. Clause 3.6 Engineering Standards updated. Clause 4 expanded to cover references to Environmental Protection. Environmental considerations also incorporated into clauses 5, 6, 7, 9 & 13. Clauses 6.2.2 to 6.2.7 Asset Protection added. Clause 6.3 Nuclear Materials, Fuel and Waste Package Protection added. Clause 6.8.1 Workplace Regs added. Clause 6.8.2 Building Regs added. Figures 1 & 2 added. Clause 7.4.2 BSRIA design framework added. 2nd glovebox inlet filter added on Figures 6, 7, 8 & 9. Clause 7.17 'Ventilation of battery rooms' added. Clause 7.18 LEV added. Clause 12.1.4 expanded - direct supply to AMBER areas non-preferred. Clause 13.1.4 section on decontamination of contaminated surfaces moved to Decommissioning bullet in clause 7.3.1. Clause 16.7.3.2 ISO & BS standards added for stack monitoring. Figure 14 added in clause 16.8 for typical low active duct drain arrangement. Clause 17.9.3 MSCF EPS3 leak test results added to Table 1. Appendix A EDF Energy classifications added. Appendix D EA Engineering Environmental Principles added. Appendix E 'The development of UK Guides and Standards for nuclear ventilation systems' added.
12/2023, Issue 2 B Swinnerton	5 year periodic review and update. 'Fresh air' replaced with 'Outdoor air' throughout document to comply with BS EN 16798-3 classification of types of Building Air. Clause 1.3 ASME AG-1 added, reference to clause 23 comments on ISO 17873 added. Clause 1.4 amended to refer to guide intent. Clause 1.5 ONR TAG NS-TAST-GD-109 2023 added. Clause 2 definition of 'Cell' expanded & VFD added. Clause 3 Reference document lists updated. Clause 3.7 NNVF Guides added. Clause 3.8 SLP 1.02.10, DDDs & SLM 1.10.03 added. Clause 6.2.1 'Irrespective of whether a building is occupied' added. Clause 6.2.5 2nd sentence added for cooling of switch rooms. Clause 6.2.7 BS EN 13779 noted as withdrawn & last 2 sentences added referring to clause 6.9.2.2 and

	Building Regulations compliance. New clause 6.2.8 added to reference BS EN 16798-3:2017. Clause 6.3.1 5th bullet point added sharing LFE on dehumidification issues. New figure 4 added 'cascade flow across barriers protecting operator,' and clause 6.5 Depression versus flow added. Clause 6.9.2 updated to refer to 2021 edition of Approved Document Part F and CIBSE B2:2016. Clauses 7.3.1 & 7.5.4 bullet points added on whole life energy use, carbon impact & TM 54/65. Clause 7.3.1 EG_0_5144_2 added to last bullet. Clause 7.4.2.1 old 3 stage design process replaced with 5 stages of project delivery and 'For comparison purposes with other industries' added. Old figure 3 Design Process Network Diagram deleted due to the change to the Gated Process in line with SL Manual SLM 1.10.03 and replaced with clause 7.4.1 'Gated Process,' clause 7.5 'Key design deliverables and activities,' clauses 7.5.2, 3, 4, 6, 7, 8, 10 and clause 7.6 'Managing the design process.' Clause 7.5.9 (was 7.4.6) heading changed from Design substantiation to 'Engineering Substantiation – Engineering Schedule.' Clause 7.5.9.3 Design Authority changed to Engineering Authority. Clause 7.7.1 (was 7.5.1) 'The main function' replaced with 'A common function.' Clause 7.10.10 (was 7.8.10) note added for 0.5m/s across open door to refer only to alpha plants. New figure 7 added for 'Air flows across GREEN to AMBER entry facilities in alpha plants.' New clause 7.10.11 added to reference 'claimed' DFs for containment barriers in the RFDB and levels of containment flows. Old clause 12.1.4 moved to clause 7.10.12. New clause 7.10.13 added to refer to new clause 7.18 where the risk of migration is lower. Clause 7.10.16 (was 7.8.13) 'In the absence of other guidance, 1m/s should be used – see clause 7.10.18' added. Clause 7.10.18 (was 7.8.15) updated to provide reference report to RDR0112. New clause 7.10.19 & figure 8 added. Clause 7.11.6 now differentiates between alpha plants 7.10.10 and 7.18 for lower risk plants. Clause 7.11.7 Amber to Red velocity across the open door increased from 0.5m/s minimum to 1 m/s average in line with new figure 8. Old figure 8 Notional flow diagram for a radiological facility replaced with new figures 9 to 14. Clause 7.14.2 1st sentence now references new clause 22. New clauses 7.15.10 to 7.15.12 added to cover new figures 10 & 11 and explain figure 12 pressure differentials. Clauses 7.16.2 & 7.16.3 re. BS EN 12101-13:2022 added. Old clauses 7.14.5 to 7.14.7 moved to new heading under new clause 7.17 'Differential pressures across GREEN to AMBER entry facilities in alpha plants.' New clause 7.18 'Differential pressures across GREEN to AMBER entry facilities in lower risk plants' added with new figures 15(a) & (b). New clause 7.19 'Measurement of differential pressure between rooms' added. Clause 7.22.6 suggested 2m vertical distance in openings added. Clause 8.9.10 much of the text removed and old Appendix B Vortex Amplifiers removed as this information is now in VXA design guide EG_0_1706_1. Clause 11.4 updated to reflect vessel depressions appropriate to the process. Old clause 12.1.4 now moved to 7.10.12. Clause 13.3.1 sodium flame test replaced with DOP for the 99.99% filter efficiency target to align with ES_0_1705_2. Clause 13.3.2 recognised 'claimed' DFs for different filters in the SL RFDB added. Old Clause 13.4.2 DFs in series moved to 13.3.3. Old Clause 13.4.7 laboratory testing DFs moved to13.3.4. Clause 13.5.2 expanded to include service life recommendations. New clause 13.5.3 added to refer to EG_1_1702_1. Clause 13.6.1 (d) (iii) & (iv) added. Clause 13.6.1 (g) last sentence added. Clause 16.8.3 last 2 sentences added re. drains when cowls installed. Clause 18.3.5 expanded to include high alarms in 2 out of 3 voting and hard wired over speed protection for VSDs. Clause 19.2.12 reference to VWG_DD004 added. Old clause 20.5.2 removed which recommended higher velocities, pressure losses and fan power in high integrity ductwork. New clause 22 Sustainability added. New clause 23 Requirements of ISO 17873:2004(E) added. Appendix A 'R' levels removed from Table for AWE and Sellafield as these are considered separate to 'C' classifications, ISO 17873 contamination zones added; Magnox & Dounreay now changed to Nuclear Restoration Services. Appendix E: Wider industry practices on pressure differentials for critical environments added. Environment Agency comments added: Clause 1.6.5 & 4.1.2.2 EA(S)R18 replaced RSA93. Clause 4.1.2.1, 2nd sentence re-written; 4th sentence re-written to include reference to CEAR and BAT demonstration. Clause 4.3.9 last sentence added re. no lower threshold for BAT or ALARA. Clause

	4.4 title changed from Waste Minimisation to ‘Sustainability and Waste Management’ and clause re-written with new Figure 1 added. Clause 4.5.2 “EA Radioactive Substances Regulation: Environmental Principles publications” replaced with “Environment Agency Radioactive Substances Regulation (RSR) Objectives and Principles 2021 and RSR generic developed principles: regulatory assessment, 2021.” Clause 6.8 “to provide process control information” added. Clause 7.5.5.1, 1st sentence, “and monitoring plant” added. Clause 13.1.4 reference to re-cleanable HEPA filters and cyclones added. Clause 14.3 Wider industry guidance added. Clause 16.2.3 added referring to UK Government guidance document ‘Air emissions risk assessment for your environmental permit.’ Clause 16.3 Environmental Protection Act 1990 Technical Guidance Note (Dispersion) D1 recommending minimum stack height of 3m deleted. Clause 16.7.2, last sentence added re. total stack discharge of radioactivity. Clause 22 1st paragraph added. ONR comments added: clause 1.6.4 last sentence added, clause 4.2.1.3 and clause 4.3.1 references to Ionising Radiations Regulations 2017 added. Clause 7.2, 4th last bullet point, consideration of the maintainability to include ensuring adequate access to plant components for maintenance and limiting plant item size for ease of removal and replacement. Clause 7.2 final bullet, reference added to EG_0_0007_1 Design for Decommissioning. Clause 7.3.1 final bullet point, Decommissioning replaced with Decontamination. Clause 7.23.2 added to include LEV Competency Matrix. Clause 10.1 reference to HSE guide G201 added. Clause 13.6.1 (b) explanation added why bagged ‘safe-change’ systems are preferred. Clause 19.2.12 visual confirmation of opening and closing added in relation to fire damper access. Reviewed at NNVF sub-group on 15.09.23

Contents

1 Scope

1.1 This document provides guidance for designers of ventilation systems for radiologically controlled buildings in the UK. It outlines current good practice for identifying the role of ventilation systems in addressing plant specific hazards so as to assist in providing protection, for operators and members of the public, from radioactive emissions in both normal and abnormal operating conditions.

1.2 Relevant statutory and mandatory requirements are identified, and where appropriate, reference is made to Nuclear Decommissioning Authority standards which will be helpful to the designer and operator.

1.3 International design guidance for ventilation systems on Nuclear Licensed sites include: -

- BS ISO 26802:2010 Nuclear Facilities. Criteria for the design and operation of containment and ventilation systems for nuclear reactors
- ISO 17873:2004(E) Nuclear Facilities - Criteria for the design and operation of containment and ventilation systems for nuclear installations other than nuclear reactors
- ASME AG-1-2023 Code on Nuclear Air and Gas Treatment

Clause 6 of this document has been based on information taken from ISO 17873:2004(E).

Clause 23 of this document provides comments on the requirements given in ISO 17873:2004(E) relating to depression values and air change rates.

1.4 As the intent of this guide is to present sufficient information to allow the designer to decide the most appropriate design solution in addressing plant specific hazards, the user of this Engineering Guide shall have achieved a minimum level of competency in the design of ventilation systems for nuclear installations through appropriate professional training and experience under the supervision of a Suitably Qualified and Experienced Person.

1.5 Applicability of this Design Guide for Ageing Facilities

It is recognized that the principles described in this document cannot always be reasonably and practicably applied to existing radiological controlled facilities and decommissioning tasks. In this respect, an ALARP/BAT/BPM demonstration may be used on ageing facilities to justify not fully complying with modern standards. ONR Technical Assessment Guide NS-TAST-GD-005 2018 provides guidance on demonstration of ALARP. ONR Technical Assessment Guide NS-TAST-GD-109 2023 provides guidance on what the ONR considers relevant good practice when looking at ageing, degradation, and obsolescence. Environment Agency RSR: Principles of optimisation in the management and disposal of radioactive waste 2010 provides guidance on the demonstration of BAT.

1.6 Legal Framework

1.6.1 Nuclear site licensed companies 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.

1.6.2 The 36 standard Licence Conditions, published by the Office for Nuclear Regulation and attached to Nuclear Site Licences, place 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.

1.6.3 Some UK defence nuclear sites are also regulated by the Defence Nuclear Safety Regulator (DNSR). They have 36 standard Authorisation Conditions, which are almost identical to the 36 standard Licence Conditions, published by the Office for Nuclear Regulation.

1.6.4 In addition, the Health and Safety at Work Act 1974 places specific duties and responsibilities on all employers and employees. In particular, the Management of Health and Safety at Work Regulations (1999) require employers to assess risks to health and safety and record findings. They must then implement measures to control risks, appoint competent people, set up emergency procedures and provide information and training for employees and anyone else who needs to know. The Ionising Radiations Regulations 2017 is a key piece of regulation made under the Health and Safety at Work Act. Regulation 8 Radiation risk Assessments, Regulation 9 Restriction of exposure and Regulation 11 Maintenance and examination of engineering controls etc and personal protective equipment, are examples of these Regulations applicable to ventilation.

1.6.5 The Environmental Authorisations (Scotland) Regulations 2018, or EA(S)R18, came into force in Scotland in 2018, replacing The Radioactive Substances Act 1993(RSA93). EA(S)R18 comprises of general binding rules, and then more specific permit conditions. In England & Wales, the provisions of The Environmental Permitting Regulations 2016 have superseded RSA93. EPR2016 requires Best Available Techniques (BAT) to be applied to minimise discharges to ensure that resulting doses to the public and to the environment are As Low As Reasonably Achievable (ALARA).

1.6.6 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.

2 Definitions/abbreviations

Term / Abbreviations	Meaning
AHU	Air Handling Unit
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/Radiologically Controlled Area	An area where it is necessary to control access because of potential risks from ionising radiation
Active ventilation	The ventilation of radiologically controlled areas
Aerosol	Solid particles and liquid droplets of all dimensions in suspension in a gaseous fluid
ALARA	As Low As Reasonably Achievable
ALARP	As Low As Reasonably Practicable
Air Change rate	Ratio between the ventilation air flow rate of a space and the volume of this space
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 so that the air flow rates throughout the distribution system are within acceptable tolerances of the flows specified by the designer
Barrier	Normally used to define a structural element which defines the physical limits of a space and prevents or limits the movement of contamination to adjacent compartments. This is not the case when applied to a boot barrier which is a demarcation between areas normally within a change room
BAT	Best Available Techniques
BPEO	Best Practicable Environmental Option
BPM	Best Practicable Means
Care and Maintenance	The condition into which a building is put following its operating life and prior to decommissioning or reuse
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 At facilities where ‘caves’ are used to indicate accessible shielded enclosures; Cell is commonly used to indicate shielded enclosures that are closed or inaccessible In some facilities the term ‘cell’ is also used to designate a room in which glove boxes are housed
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
Change room	Accommodation provided to enable personnel working in potentially radiologically contaminated areas, to change into appropriate working clothing on arrival and back at the end of the working period
CIBSE	Chartered Institution of Building Services Engineers
Client	The client is the relevant Site Licence Company (SLC)
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 plant and building structure provided specifically to limit the escape of radioactive substances
	Note: ISO 17873:2004(E) uses the term “confinement.” It states that the word “confinement” is used in several International Atomic Energy Authority documents to mean the function of confining radioactive or toxic products; whereas “containment” is used to mean the actual physical barrier that achieves the objective of confinement, i.e. a confined area
Containment system	System constituted by a coherent set of physical barriers and/or dynamic systems intended to contain radioactive substances in order to ensure the safety of the workers, the public and protection of the environment
Contamination	Physical matter; very small quantities of radioactive material which is mobile and can become airborne
Controlled Area	An area in which it is necessary for any person who enters or works in the area to follow special procedures designed to restrict significant exposure to ionising radiation in that area or prevent or limit the probability and magnitude of radiation accidents or their effects
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 facility in removing from service with adequate regard for health and safety of workers and members of the public
Decontamination Factor (DF)	Measure of the efficiency achieved typically through filtration corresponding to the ratio of the radiological content of the inlet and outlet of the filtration system. Can also be applied to containment barriers
Depression	A pressure lower than a given reference pressure
Derived Air Concentration (DAC)	That concentration of activity (single nuclide, or mix of nuclides), which, if breathed in by an individual for 2000 hours (in one year), would give rise to an internal effective whole body dose equivalent to one ALI (annual limit on intake) of 20 mSv
Discharge stack	A duct (usually vertical) at the terminal section of a system from which the air or gas is discharged to atmosphere
DSP	Design Safety Principles
Dynamic containment	The directional use of air flow, usually across an opening in a barrier, to limit back-flow of air across the opening and therefore minimise the spread of radioactive substances between adjacent areas/enclosures
EA	Environment Agency
EG	Engineering Guide
EPR2016	The Environmental Permitting Regulations 2016

ES	Engineering Standard
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 change (replace) used filters
Fume cupboard	A ventilated enclosure complying with the requirements specified in BS EN 14175-2. Protective device to be ventilated by an induced flow of air through an adjustable working opening - with an enclosure designed to limit the spread of airborne contaminants to operators and other personnel outside the device, offering a degree of mechanical protection, and providing for the controlled release of airborne contaminants
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 of the glove box enclosure
HAZAN	Hazard Analysis
HAZOP	Hazard and Operability study
HEPA filter	High Efficiency Particulate Air filter to the appropriate standards
ICRP	International Commission on Radiological Protection
IRR	The Ionising Radiations Regulations
Migration	The movement of contamination
ONR	The Office for Nuclear Regulation
Operating area	A working space normally occupied by personnel but where contamination may occur under abnormal conditions
PES	Programmable Electronic System
Plenum system	A term sometimes used (incorrectly) on older facilities for the supply air ventilation system to a building
Post-Operative Clean Out (POCO)	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 or prior to decommissioning
Postulated accident	Any variation from normal operating conditions which needs to be considered in the hazard assessment
Pressurised air fed suit area	An area that may only be entered by personnel wearing pressurised air fed suits
Process ventilation system	A ventilation system which deals specifically with the active gases and aerosols arising within process plant, such as vessels, evaporators and furnaces, but excludes the ventilation of the containment enclosures in which this process plant is located, e.g. glove boxes, fume cupboards, caves and cells
Radiation	Ionising radiation is emitted from radioactive materials as energy waves and exposure to ionising radiation causes damage to living tissue
Radio nuclides	Elements that give rise to ionising radiation
RPA	Radiation Protection Adviser appointed under The Ionising Radiation Regulations 2017

RSA93	The Radioactive Substances Act 1993
Shall	Used to describe a mandatory requirement
SIL	Safety Integrity Level
Should	Used to describe information intended for guidance
Spark arrestor	A device installed upstream of the filter to protect it from glowing debris and sparks
Structure, System or Component (SSC)	When used in a safety argument, a structure, system or component whose performance directly or indirectly, prevents or mitigates radiological, chemotoxic or environmental consequences; has one or more safety functions.
Sub change room	A room, located within the area served by a main change room, which provides for a further change of clothing so that the user can proceed into an area of potentially higher contamination
Supply system	A ventilation system conveying air into a space
Throw	The distance between a supply grille or diffuser 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
Total enclosure	An enclosure (other than a fume cupboard) intended to prevent the escape of any unsealed radioactive substance therein into any workplace
VFD	Ventilation Flow Diagram
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 usually within glove boxes)

3 Related UK Legisaltion and Guidance Documents

3.1 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 shall satisfy themselves that they have taken account of all legislative requirements.

3.2 UK Legislation

- The Health and Safety at Work etc Act 1974
- The Nuclear Installations Act 1965
- The Radioactive Substances Act 1993
- The Pollution Prevention and Control Regulations (separate legislative enactments for Northern Ireland and Scotland)
- The Environmental Permitting Regulations 2016
- The Environmental Authorisations (Scotland) Regulations 2018 - EA(S)R18,
- Energy Act 2013
- Factories Act 1961
- The Ionising Radiation Regulations 2017
- Management of Health and Safety at Work Regulations 1999
- Workplace (Health, Safety and Welfare) Regulations 1992
- The Construction (Design and Management) Regulations 2015
- Provision and Use of Work Equipment Regulations (PUWER) 1998
- Control of Substances Hazardous to Health Regulations 2002
- Supply of Machinery (Safety) Regulations 2008
- The Regulatory Reform (Fire Safety Order) 2005
- Manual Handling Operations Regulations 1992
- Electricity at Work Regulations 1989
- Electrical Equipment (Safety) Regulations 2016
- Electromagnetic Compatibility Regulations 2016
- The Personal Protective Equipment at Work Regulations 1992
- The Control of Noise at Work Regulations 2005
- The Equipment and Protective Systems Intended for Use in Potentially Explosive Atmospheres Regulations 1996
- The Dangerous Substances and Explosive Atmospheres Regulations 2002
- The Construction Products Regulations 2013
- The Building Regulations 2010 and Amendment Regulations 2021 & 2022
- The Energy Performance of Buildings (England and Wales) Regulations 2012
- The Confined Space Regulations 1997

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

3.3 Other Regulator Documents

- ONR Safety Assessment Principles for Nuclear Facilities 2014 Edition, Revision 1 (January 2020)
- ONR Licence Condition Handbook – February 2017
- Environment Agency Radioactive Substances Regulation (RSR) Objectives and Principles 2021 and RSR generic developed principles: regulatory assessment, 2021

3.4 International Documents

- ISO 2889:2021 Sampling airborne radioactive materials from the stacks and ducts of nuclear facilities
- ISO 17873:2004(E) Nuclear Facilities – Criteria for the design and operation of ventilation systems for nuclear installations other than nuclear reactors
- BS ISO 26802:2010 Nuclear Facilities. Criteria for the design and operation of containment and ventilation systems for nuclear reactors
- ICRP Publication 103 The 2007 Recommendations of the International Commission of Radiological Protection
- ICRP Publication 30 Limits for intakes of Radionuclides by Workers
- ICRP Publication 68 Dose coefficients for intakes of Radionuclides by Workers
- IAEA-TECDOC-1744 Treatment of Radioactive Gaseous Waste, International Atomic Energy Agency Vienna, 2014
- ASME AG-1-2023 Code on Nuclear Air and Gas Treatment

3.5 Advisory Documents and Standards

- NS-TAST-GD-005 2023 ONR Nuclear Safety Technical Assessment Guide Guidance on the Demonstration of ALARP (As Low As Reasonably Practicable)
- NS-TAST-GD-022 2022 ONR Technical Assessment Guide Ventilation
- NS-TAST-GD-109 2023 ONR Technical Assessment Guide Ageing and Degradation Management
- Environment Agency Environmental Permitting Regulations (England and Wales) 2010 Regulatory Guidance Series, No RSR 2 The regulation of radioactive substances activities on nuclear licensed sites
- Environment Agency Radiological Monitoring Technical Guidance note 2 Environmental Radiological Monitoring 2010
- Environment Agency RSR Principles of optimisation in the management and disposal of radioactive waste 2010
- Environment Agency Environmental Permitting Regulations (England and Wales) 2010 Criteria for setting limits on the discharge of radioactive waste from nuclear sites

3.6 NDA Ventilation Engineering Guides and Engineering Standards

3.6.1 List of NDA Ventilation Engineering Standards

NDA Ventilation Engineering Standards are Generic Procurement Specifications for the main ventilation plant Items, which are procured for nuclear ventilation systems.

- ES_0_1701_2 Procurement Specification for Coils in Ventilation Systems
- ES_0_1704_2 Procurement Specification for Attenuators in Ventilation Systems
- ES_0_1705_2 Type Testing and Approval of High Efficiency Particulate Air (HEPA) Filters
- ES_0_1706_2 Procurement Specification for Vortex Amplifiers

- ES_0_1708_2 Procurement Specification for Air Handling Units
- ES_0_1710_2 Procurement Specification for centrifugal fans
- ES_0_1711_2 Procurement Specification for filter housings for 470l/s & 950l/s circular plug-in HEPA filters
- ES_0_1713_2 Procurement Specification for bayonet mounting 1.5l/s capacity HEPA canister filters
- ES_0_1715_2 Procurement Specification for Ventilation dampers
- ES_0_1721_2 Procurement Specification for low integrity sheet metal ventilation ductwork
- ES_0_1723_2 Procurement Specification for high integrity ventilation ductwork
- ES_0_1730_2 Procurement Specification for HEPA Filter Media
- ES_0_1731_2 Procurement Specification for rectangular mini pleat 550/850l/s capacity HEPA filter inserts
- ES_0_1732_2 Procurement Specification for rectangular deep pleat 100 - 500l/s capacity HEPA filter inserts
- ES_0_1733_2 Procurement Specification for HEPA Canister Filters 5, 25 and 50 l/s capacities
- ES_0_1734_2 Procurement Specification for screw mounting 3 and 6l/s capacity HEPA filters
- ES_0_1735_2 Procurement Specification for circular push-through 12.5 to 160l/s capacity HEPA filters
- ES_0_1736_2 Procurement Specification for Spark arrestors
- ES_0_1737_2 Procurement Specification for circular plug-in 470 and 950l/s capacity HEPA filter inserts
- ES_0_1739_2 Procurement Specification for bayonet mounting 3 and 6l/s capacity HEPA filters

3.6.2 List of NDA Ventilation Engineering Guides

NDA Ventilation Engineering Guides provide background information to the designer on the related Engineering Standards to explain some of the reasoning behind why the standards specify certain criteria. The guides are also intended to help the designer to complete the Technical Information Sheets in the back of the Engineering Standards for plant procurement.

- EG_0_1701_1 Design Guide for the Specification of Coils in Ventilation Systems
- EG_1_1702_1 Design Guide for filters and filter installations in ventilation systems
- EG_0_1704_1 Design Guide for the Specification of Attenuators and Acoustic Insulation in Ventilation Systems
- EG_0_1706_1 Design Guide for the Specification of Vortex Amplifiers
- EG_1_1707_1 In-situ testing of HEPA Filters – Design of duct mounted test points
- EG_0_1708_1 Design Guide for the Specification of Air Handling Units
- EG_0_1710_1 Design Guide for centrifugal fans
- EG_0_1711_1 Design Guide for filter housings for 470l/s & 950l/s circular plug-in HEPA filters
- EG_0_1715_1 Design guide for Ventilation Dampers
- EG_0_1720_1 Design Guide for Ventilation Ductwork

3.6.3 Other Ventilation related NDA Engineering Guides and Engineering Standards

- EG_0_0007_1 Design for Decommissioning
- ES_0_1503_1 Design of Alpha Glove Box Plant and Equipment
- ES_1_2190_2 The Engineering Standard for E/E/PES Safety Measures Part 2 – Functional Safety Management of E/E/PES Safety System Design
- EG_1_2301_1 Graphical Symbols of Process Instruments (specific to Sellafield)
- EG_1_2306_1 Airflow Measurement in Active Stacks & Ducts
- EG_1_2313_1 Differential pressure measurement for ventilation systems
- ES_1_2469_1 Contract Management Arrangements for Control, Electrical and Instrumentation Systems
- ES_1_2479_1 Programmable Electronic System based Instrumentation and Control
- EG_1_2505_1 Stack & Duct Sampling & Monitoring Principles
- ES_1_2800_1 PES Preferred Technologies
- ES_1_3003_1 Change room Code of Practice
- ES_0_5142_3 Sellafield Painting Specification for Industrial and Decorative finishes
- EG_0_5144_2 Coating of surface in radioactive environments code of practice

Note: Engineering Guides and Standards as listed above, with the pre-fix ES_1, are Sellafield specific standards. For other UK Nuclear Licensed Sites, refer to the local site standards.

3.6.4 Other Relevant NDA Guidance

- NDA Industry Guidance: Interim Storage of Higher Activity Waste Packages – An Integrated Approach, Issue 3, January 2017
- Nuclear Industry Aqueous Waste Management Good Practice Guidance, Issue 1, December 2020
- A Review of the Best Available Techniques for Effluent Treatment at Sellafield, NNL (13) 12525, Issue 3

3.7 National Nuclear Ventilation Forum (NNVF Guides)

- NNVF GPG 104 Practitioners Guide to Disposal of Nuclear Ventilation Filters
- NVF/DG002 An Aid To The Design Of Ventilation For Glove Boxes
- VWG_DD003 Guidance on “safe change” filter housing design
- VWG_DD002 Guidance for the Visual Inspection of HEPA filters
- VWG_DD004 Guidance on Maintenance of Nuclear Ventilation Systems

3.8 Site Practices and Design Definition Documents

- SLP 1.02.10 How do I undertake engineering substantiation?
- SLP 1.06.59.01 How do I Operate and Maintain Ventilation Systems?
- SLP 1.06.59.02 How do I Operate and maintain High Efficiency Particulate Air (HEPA) Filtration?
- RPGN 03 Sellafield Ltd Radiation Protection Guidance Note Designation and Demarcation of Temporary/Non Temporary Areas
- RPGN 05 Sellafield Ltd Radiation Protection Guidance Note Tents
- SLC 2.10.300 The Aerial Effluent Control Working Party (AECWP) Charter
- SLP 2.10.300 How do I Manage and Monitor Radioactive Gaseous Waste?

- SLP 2.10.301 How do I Manage and Register ‘Other Outlets’ for Radioactive Gaseous Discharges?
- SLSP 2.11.109 Determining Public Critical Group and Collective Dose
- SLP 2.16.06 How do I maintain fire protection equipment, systems and structures and record it?
- SLM 1.10.03 Sellafield Gated Process for Major Projects
- DDD_016 Ventilation Flow Diagram
- DDD_033 Ventilation Basis of Design

Note: The site practices as listed above refer specifically to the Sellafield site. For other UK Nuclear Licensed Sites, refer to the local site practices.

4 Radiological Safety and Environmental Protection

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

4.1 Basic Health Physics

4.1.1 Radioactive Materials

4.1.1.1 Radioactive materials are hazardous to people and the environment 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.

4.1.1.2 The best protection for the worker, the public and the environment against these materials is to prevent the radiation emitted from reaching them by shielding from penetrating radiation and by preventing all radioactive substances, particularly the alpha emitters like plutonium, from coming into contact with body tissue, either as skin contamination or by being taken inside the body through breathing, eating, 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 and discharges must at all times be maintained within the permitted levels of contamination.

4.1.1.3 Generally, in areas without excessive air movement particles in the order of 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 become airborne and be inhaled. Thus, the bulk of the activity, of radiological significance as regards inhalation, will be in the range 0.1 to 6 µm.

4.1.2 Environmental Protection

4.1.2.1 Processes which involve the use of nuclear or radioactive material result in the generation of radioactive waste. Gaseous radioactive waste may only be discharged to the atmosphere from nuclear licensed sites via discharge outlets agreed with the Environment Agencies; discharges must be made in strict accordance with limits and conditions laid down by the authorisations, permits and licenses issued by Environment Agencies. 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. There is provision in the Compilation of Environment Agency Requirements (CEAR) Approvals and Specifications for consideration of gaseous discharges via adventitious routes. Also, whether or not discharge outlets are monitored should be subject to BAT demonstration - calculation or estimation of discharges might be demonstrably BAT in some cases.

4.1.2.2 The discharge of radioactive wastes is controlled subject to the Radioactive Substances Act 1993 (Scotland and Northern Ireland), the Environmental Permitting Regulations 2016 (England & Wales) and the The Environmental Authorisations (Scotland) Regulations 2018 (EA(S)R18). Authorisations (EA(S)R18) and Permits (EPR2016) to dispose of gaseous waste can be granted under the corresponding legislation, and include such limitations and conditions as are considered necessary. The regulatory powers are exercised by the Environment Agency in England, Natural Resources Wales in Wales, the Northern Ireland Environment Agency in Northern Ireland, and by the Scottish Environment Protection Agency (SEPA) in Scotland. Before granting authorisations or permits, the appropriate agency is required to consult relevant Government departments, local authorities and other public bodies and consultation may include the general public.

4.1.2.3 The permits and authorisations granted by the appropriate agencies generally call for the waste producer to use BPM or BAT to prevent and minimise the radioactivity in discharges such that resulting doses to the public and the environment are ALARA. Auditable records should be maintained in order to demonstrate that BPM or BAT 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 authorisations or environmental permits at each site. In addition, the authorisation or permit may contain annual limits on the discharges of specified radionuclides or groups of radionuclides. Authorisations and permits, where appropriate, include '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 normally achievable using BPM or BAT. If the notification levels are exceeded on a regular basis then the waste producer will be required to provide a justification to the relevant agency.

4.1.2.4 There is also a requirement to comply, for non-active discharges, with the Pollution Prevention and Control (PPC) Regulations (Scotland and Northern Ireland), and the equivalent PPC provisions of EPR2016 (England & Wales).

4.2 Radiological Protection

4.2.1 General

4.2.1.1 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 radiologically controlled 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 measurement systems are required to demonstrate that the standards are being met.

4.2.1.2 ALARP and BAT principles should always be applied to primarily eliminate/reduce/fix contamination sources to reduce the potential load on the ventilation systems.

4.2.1.3 There is a legal requirement to comply with the Ionising Radiations Regulations 2017. Ventilation associated aspects are specifically listed in several of these regulation sections. These include:

- Regulation 8 ACOP: radiation risk assessment needs to include the consequences of possible failures of control measures – such as electrical interlocks, ventilation systems and warning devices – or systems of work
- Regulation 9 ACOP: under work with unselaed radioactive materials, ventilation should be provided where the containment alone is not sufficent to give the required protection
- Regulation 11 Guidance: all physical control measures including ventilation need to be maintained so that they operate correctly, and active design features such as exhaust ventilation systems shall have a formal programme for inspection and test

4.2.2 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 (e.g. Facility RPA) should be sought on the application of these limits.

4.2.3 Design Implications

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

- Discrete releases from the operation of facilities
- Unintentional recycling of discharged air
- Contaminated working areas (re-suspension)

4.2.3.2 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.

4.2.3.3 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, the corrosive nature of the gases in use or arising from the process; and the corrosive nature of the external environment (e.g. the presence of chloride ions arising from sea spray or adjacent processes with discharges of corrosive gases). 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.

4.2.4 The General Public

The effect of discharges from ventilation systems on members of the public must be addressed in the design of the system and associated abatement. The designer should demonstrate that BPM or BAT has been employed to minimise doses to the public and the environment associated with discharges to ALARA under both normal operations and for reasonably foreseeable events; and that the risk of accident conditions is ALARP.

4.3 Hazard Assessment

4.3.1 Before commencing any ventilation design, a hazard assessment should be carried out so that design safety and environmental principles, and actual targets can be adequately defined. Under the Ionising Radiations Regulations 2017, if radiation exposure is a risk, then a radiation risk assessment must be carried out.

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

4.3.3 The hazard assessment process forms part of the safety and environmental assessment procedures covered by the Licensees' arrangements. This hazard assessment is normally carried out through staged HAZOP studies, which are integrated into the general design process (see section 7.4).

4.3.4 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 Process 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 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 level of clean up required will be defined. Potential fire and explosion hazards plus general industrial hazards will be identified where possible.

4.3.5 After completion of the preliminary hazard assessment, the building/plant is classified into areas of different contamination and radiation potential; and fire zones. The designer then develops the conceptual design in gradually increasing detail through to detail design.

4.3.6 The design needs to be worked up to a reasonable level of detail before a meaningful 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, for which a HAZAN is required.

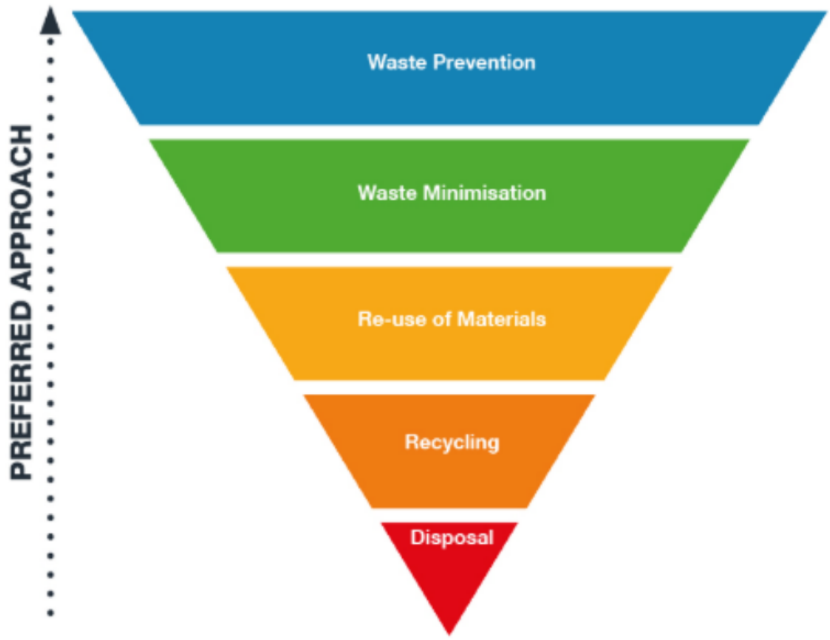
4.3.7 The aerial effluent flow sheet (produced by Process Engineers) would normally quantify the expected levels of activity in the process plant areas and the radiological challenge to the ventilation systems under 'fault conditions,' determined as result of hazard assessment. This would normally help identify the clean-up requirements prior to discharge.

4.3.8 On the Sellafield site, the Aerial Effluent Control Working Party (AECWP) will set the discharge limits for each plant and provide advice and guidance on stack sampling and monitoring systems (SLC 2.10.300). For other UK Nuclear Licensed Sites, refer to the local site practices.

4.3.9 The Office for Nuclear Regulation (ONR) has published Safety Assessment Principles giving a guide to "acceptable" release levels and frequencies 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. There is no lower bound or threshold beneath which the requirement to optimise discharges, via BAT, ALARA is no longer required.

4.4 Sustainability and Waste Management

4.4.1 Waste should be managed through the application of the waste hierarchy (Radioactive Waste Strategy, NDA, 2019 and see Figure 1). Waste prevention is the preferred approach. If waste generation is unavoidable, so far as is reasonably practicable, then the practitioner should look at minimisation, re-use of materials, and recycling to reduce volumes of waste where possible. Only if waste cannot be prevented, minimised, reused, recycled, or recovered should it be disposed of into the environment, and this must only be undertaken in a controlled and authorised manner. A particular consideration for waste is HEPA filters. Cleanable filters that can be reused are now a design option but most existing plants use disposable HEPA filters, which being of low density are very expensive to store or dispose of as radioactive waste. More detailed guidance on the disposal of filters can be found in NNVF GPG 104 Practitioners Guide to Disposal of Nuclear Ventilation Filters.



The waste hierarchy depicting the preferred approach to waste management.

Figure 1 – Waste hierarchy (from Nuclear Industry Aqueous Waste Management Good Practice Guidance)

4.4.2 Following the concentrate and contain principle, it is generally preferable to generate a solid radioactive waste rather than an aqueous or gaseous radioactive waste, where reasonably practicable. However, there are exceptions, for example, evaporation of aqueous wastes can lead to radionuclides (e.g. tritium) being released into the environment. Considerations of which waste form is preferential should take account not only of the qualities of the waste, but also the potential benefits and detriments of the processes that may treat/give rise to the waste. Factors to consider and the practicability of a solution will depend, in part, upon whether the designer is designing a new plant, operating or modifying an existing plant, or re-using an existing plant. However, in all eventualities, a holistic solution should be sought that carefully considers all wastes that may be produced and any issues that may affect other facilities or plant on the site.

4.5 General Safety and Environmental Principles

4.5.1 It arises from the foregoing that certain general safety principles and environmental principles should be followed when designing ventilation systems for radiologically controlled areas. They are: -

- The air flow and air flow patterns in the working environment should contribute to providing protection for the occupants from exposure to airborne contamination.
- The total air flow through the system from inlet to discharge into the atmosphere should be minimised. This will result in energy savings from reduced fan power and minimising the number of filters to be disposed of as radioactive waste.
- Sufficient outdoor air shall be provided to spaces that are normally occupied to ensure acceptable industrial hygiene conditions (see CIBSE guides and The Building Regulations)
- Consideration should be given to prevention of ingress of moisture, particulate material and corrosion ions from coastal atmospheric air; and mitigating the effects of extreme weather conditions, i.e. wind and temperature, and other external hazards. This is particularly important for nuclear material, fuel or waste stores where control of the store's environment is important for maintaining the integrity of the containment of the material, fuel or waste package (see NDA Industry Guidance: Interim Storage of Higher Activity Waste Packages – An Integrated Approach, Issue 4, December 2021).
- 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 maintaining airflow through any breach in the physical containment and/or a negative pressure differential (a depression) within the containment. The system should provide sufficient inward air velocity through unavoidable or accidental openings in containment barriers, to limit the egress of particulates as far as is reasonably practicable.
- The air flows should, as far as is reasonably practicable, be adequate for both the normal conditions and the postulated accident conditions.
- The system should incorporate maximum use of energy efficiency, (e.g. heat reclamation from exhaust air), but this must not compromise the containment, safety and environmental requirements.
- Discharges should be prevented/minimised using BAT/BPM and unavoidable discharges monitored using BAT/BPM.

4.5.2 The ONR Safety Assessment Principles relating to Containment and Ventilation and the EA Environmental Engineering Principles as listed in Appendices C & D should also be followed. In addition there are other ONR Safety Assessment Principles and EA Environmental Principles that are relevant in determining general safety and environmental principles such as those for EMT – Maintenance, inspection and testing, EAD – Ageing and degradation, ECM - Commissioning, EHA - External and internal hazards, EES – Essential services, RSM - Radioactive Substances management and RP – Radiological Protection. These can be found in the ONR Safety Assessment Principles for Nuclear Facilities and the Environment Agency Radioactive Substances Regulation (RSR) Objectives and Principles 2021 and RSR generic developed principles: regulatory assessment, 2021.

5 Containment

5.1 Containment Barriers

5.1.1 In this document, those parts of the plant, building structure and equipment provided specifically to prevent or minimise 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.

5.1.2 A sealed containment is the most effective way to prevent the escape of particulate and gaseous substances. However, perfect sealing is not always possible and since some openings in the containments are necessary to allow personnel access, transfer of materials and equipment, etc., and also since structural cracks could occur over time, a differential pressure across each containment barrier should be maintained to create air flow directions from clean to less clean areas to minimise the potential for back flow of contamination.

5.1.3 The degree of containment, including the number of barriers required, for the particular plant must be determined by a hazard assessment, taking account of the design safety and environmental 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 dispersal (gas, liquid or solid).

5.1.4 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.

5.1.5 The containment performance of each barrier must be appropriate for the enclosed hazard. The actual differential pressure required (and achievable) depends on the leak tightness of the barrier. A poorly constructed containment may require a high extract flow to achieve a suitable depression and inward flow, whereas a good containment will have minimal leakage and easily sustain a depression. There should be a preference for good physical containment (high structural integrity) with minimal extract flow, instead of excessive ventilation to compensate for poor construction. The depression and associated leakage of a given type of containment will vary from plant to plant and may vary from initial construction to decommissioning. This may affect the optimal configuration for older plant.

5.1.6 Where there are multiple barriers, the first will often be that provided by a total enclosure in which the radioactive substance is contained and will be constructed to the highest level of structural integrity in terms of both strength and leak tightness. This may be a cave/cell, vessel, duct or glove box.

5.1.7 Further containment barriers will guard against the release of radioactive material to the workplace or environment. These may be an integral part of the structure of the building and would normally totally surround the inner containment, and must remain effective under postulated accident conditions. These successive outer barriers may be constructed to lesser standards of integrity (than the first barrier), depending on the potential for nuclear material/waste to escape during normal and fault conditions.

5.1.8 The practicalities of handling radioactive materials in a total enclosure may require it to be opened and entered from time to time for the purposes of maintenance and replacement of equipment. This may also be particularly applicable during decommisioning when barriers are breached or removed. 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. The aim here is to continue to maintain a comparable level of containment relative to the ‘clean’ area, whenever access may be required into a total enclosure.

5.1.9 Where normally ‘clean’ areas have raised contamination levels, access to these areas should be through change facilities. The barrier to these areas may be a permanent or temporary structure (colloquially called a tent). In the latter case the associated change facility is also temporary.

5.2 Classification of Working Areas

5.2.1 The Ionising Radiations Regulations 2017 and the associated Approved Code of Practice (L121 Working with ionising radiation 2018) introduce the concept of 'supervised' and 'controlled' areas. The overall classification system employed for radioactive areas must comply with the requirements of these Regulations concerning Designated Areas.

5.2.2 Each plant, and plant surroundings, is evaluated for proper radiological classification by the local Radiological Protection Advisor and the Area Safety Manager.

5.2.3 Area classification shall be determined by the Radiological Protection Advisor and the Area Safety Manager on the basis of:

- Health Physics monitoring data
- Identified potential fault conditions
- Managerial and administrative arrangements that assist the overall control strategy

5.2.4 Guidance on the classification of Radiological Areas for the Sellafield site is given in RPGN 03. For other UK Nuclear Licensed Sites, refer to the local site practices.

5.2.5 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.

5.2.6 The four colour classification used in this document (see section 5.3) 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.

5.3 Containment Area Classification

5.3.1 The classification of working areas described below 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 area classifications against the colour code system used in this guidance, for other UK Nuclear Licensed 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 present 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. The potential for airborne contamination would typically occur on a temporary basis; e.g. during maintenance, when levels may increase during the period say of a breach in containment to an adjacent RED area
>
> **RED** means an area in which contamination levels are so high that there is normally no access without pressurised air-fed suits

5.3.2 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).

5.4 Airborne Contamination

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 potentially give rise to increasing airborne contamination. The process by which airborne contamination is generated should be understood and, if practicable, an approach adopted to lower the likelihood of airborne contamination arising.

6 Functions Provided by Ventilation Systems

6.1 Overall Plant Safety

6.1.1 The ventilation of nuclear facilities contributes to the improvement of radiological and environmental protection by assisting in minimising the spread of contamination to the workers, the general public and the environment. In addition, there may be other hazards within nuclear facilities for which the ventilation provides mitigation. These can include, for example, the dilution of gaseous arisings to avoid the build-up of explosive gases, cooling of nuclear material to prevent containment pressurisation; and providing optimum environmental conditions within stores for nuclear materials, fuel or waste.

6.1.2 The function of the ventilation systems will vary from area to area within a nuclear facility. For example, the ventilation in a RED area may need to maintain a depression, provide dynamic containment, provide cooling or dilution for process arisings. In an adjacent AMBER area it may be only to assist in the provision of containment; whilst the ventilation of a GREEN area will address occupancy requirements and provide air flow for cascade into adjacent AMBER and RED areas.

6.2 Asset Protection – Protection of building structure

6.2.1 Irrespective of whether a building is occupied, ventilation also contributes to asset protection (and thus indirectly to safety) by maintaining the required process conditions and providing a building internal environment to help prevent degradation of the installed plant and building structure.

6.2.2 Buildings are constructed from a variety of materials. The atmospheric conditions to which those materials used in the building structure are exposed needs to be considered, to prevent the degradation of the building structure, and deterioration of the building fabric over time.

6.2.3 This may often require building heating to maintain surface temperatures above the dew point of the ambient air. Cold surfaces can lead to condensation, which can in turn lead to corrosion of the building structure (Fig. 2); and damp leading to mould growth or mildew (Fig. 3)

6.2.4 Building heating and reasonable air distribution throughout the building can help protect against condensation and reduce the relative humidity of the air to below that (typically 70%) where mould will grow.

6.2.5 High rates of outdoor air input are not required for building heating, which can be done using recirculated air or space heating. Outdoor air to avoid mould growth and mildew and to cater for low/transient occupancy can be estimated on a floor area basis. The same would apply for cooling purposes for areas such as switch rooms, sub stations and server rooms, where any cooling load should be met with local cooling provision, rather than cooling larger volumes of air through a central supply system AHU.

6.2.6 BS 5720:1979 'Mechanical ventilation and air conditioning in buildings' (now withdrawn) specified 0.8 $l/s/m^2$ floor area for factories and 1.3 $l/s/m^2$ for offices.

6.2.7 BS EN 13779:2007 'Ventilation for non-residential buildings —Performance requirements for ventilation and room-conditioning systems' (now withdrawn) gives rates of outdoor or transferred air per unit floor area (net area) for rooms not designed for human occupancy. For 'medium indoor air quality,' the recommended rate is >0.7 $l/s/m^2$, with a default value of 0.83 $l/s/m^2$ for room heights up to 3m; with higher air flows recommended for higher rooms. Based on this, it is probably not unreasonable to use a rate of say 1.3 $l/s/m^2$ to 1.6 $l/s/m^2$ for large spaces in excess of 5m high. See also clause 6.9.2.2 for Building Regulations requirements of 1 $l/s/m^2$ for offices and 0.5 $l/s/m^2$ for 'common spaces.' For new build or modifications to existing facilities where UK Building Regulations apply, building regulation values should be used by designers.

6.2.8 BS EN 16798-3:2017 Energy performance of buildings – Ventilation for buildings Part 3: For non-residential buildings – Performance requirements for ventilation and room-conditioning systems (Modules M5-1, M5-4) provides further guidance on outdoor ventilation rates for indoor air quality.

Figure 2 – Examples of corroded building structure

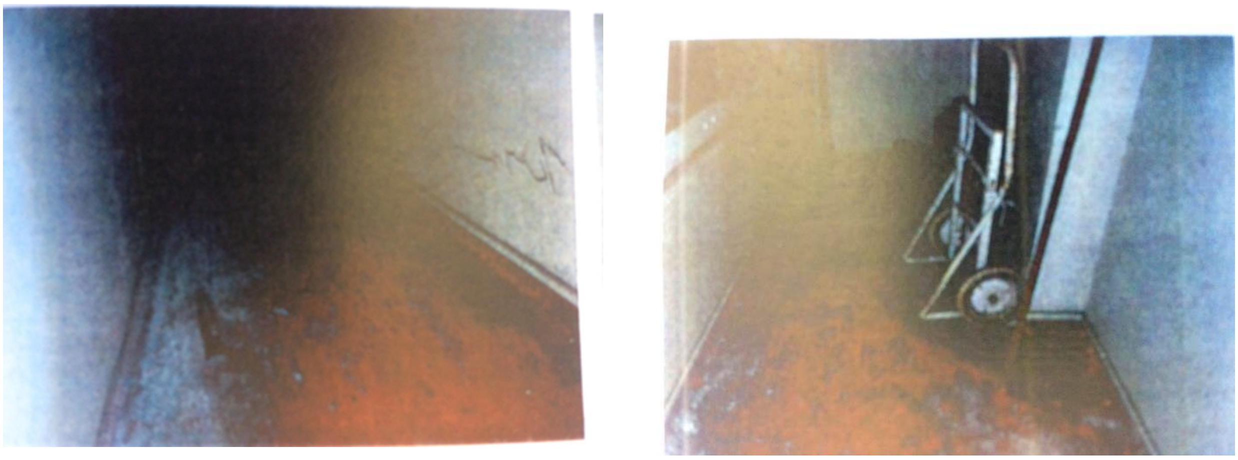


Figure 3 – Damp conditions causing mould growth in unventilated areas

6.3 Nuclear Materials, Fuel and Waste Package Protection

6.3.1 For nuclear materials, fuel or waste stores, the ventilation system contributes to the protection of the containment of packages as well as the store's life-limiting components over the period of storage (see section 6.2). This will usually mean:

- avoiding extremes of heat and cold;
- avoiding condensation, that is keeping the temperature above the dew point;
- controlling potential contaminants, for example aerosols or biological residues;
- where control of contaminants cannot be assured, consideration should be given to controlling the relative humidity away from the deliquescence point (the absorption of water from the air by salts to form a solution) of any contaminant salts on sensitive materials. It is important that cycling of wetting and drying events are avoided, since, in the presence of contaminant salts, such cycles of are likely to maximise the probability of initiating corrosion processes as any salt solutions become concentrated as drying occurs, or dried salts initially re-dissolve;
- Where systems for drying or dehumidifying the store environment are being considered, the designer must consider wider environmental issues and design within context of the site location in the UK. A dehumidification system in a coastal site will generate significant quantity of saline condensate or chemical waste. The design must weigh the economics of management and replacement of this plant, the environmental impact of management of this waste stream (which may be new to the site), the potential these systems have to concentrate contamination and the sustainability balance of operating this plant against alternatives. The optimum solution will often be site specific in relation to air quality challenges.

- providing homogeneous environmental conditions spatially through the store; and
- considering issues associated with transient conditions, for example when packages are imported into or exported from the store.

6.3.2 For more details see NDA Industry Guidance: Interim Storage of Higher Activity Waste Packages – An Integrated Approach, Issue 4, NDA, December 2021.

6.4 Dynamic Containment

6.4.1 Ventilation assists in the containment of a nuclear facility by acting in a dynamic manner in order to protect breaches in the leak tightness of the static containment barriers (walls, engineered enclosures). By engineering a cascade flow of air from areas with a low potential for radioactive contamination to areas with a higher potential for radioactive contamination, dynamic containment supplements the physical barriers between adjacent enclosures/rooms helping to protect the operator by minimising the spread of contamination into the areas of lower contamination potential.

6.4.2 Dynamic containment is assisted by maintaining a depression hierarchy within the facility with areas of high contamination potential being held under the highest depression. GREEN areas and above should be maintained at a nominal depression to minimise uncontrolled release to the external environment.

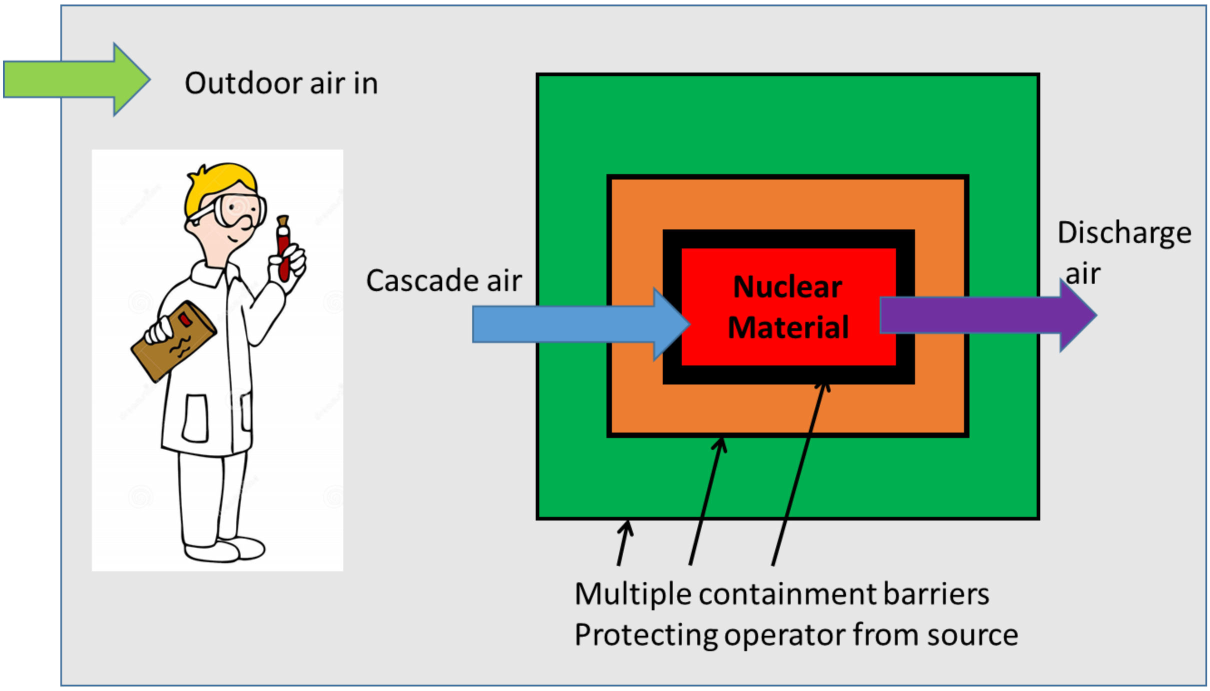


Figure 4 – Cascade air flow across barriers protecting operator

6.5 Depression versus flow

6.5.1 As described in clause 5.1.5 of this document, the containment performance of each physical barrier should be appropriate for the enclosed hazard, and the actual differential pressure required (and achievable) depends on the leak tightness of the barrier. On newly constructed plants, good physical containment with minimal inleakage should be readily achievable and therefore, if required, reasonable depressions will also be readily achievable.

6.5.2 In ageing facilities, there may be structures with poor containment where measurable depressions are difficult to achieve. In such cases there may have to be a reliance on sufficent air flow extracted from the containment to ensure reasonable containment velocities through leakage paths into the containment (see clause 7.10 for containment flows and recommended velocities).

6.5.3 When commissioning ventilation systems for nuclear facilities, it is traditional for CIBSE Commissioning Code A: Air Distribution Systems to be followed by the Commissioning team to initially balance the systems, to acheive the design flow rates given on the Ventilation Flow Diagrams, before the systems are then 'trim balanced' to attempt to achieve the velocities/flows at containment boundaries and, where applicable, target design room depressions. Achievement of these target depressions will be highly dependent on the leak tightness of the room fabric (see clause 7.6.2.4). Some examples are presented, as follows, where depression and/or flow may be the main driver for the performance requirements of the ventilation systems.

6.5.4 For well engineered leak tight containments such as glove boxes, both flow rate and depressions can be readily controlled (see clause 8 of this document, figure 14 and EG_0_1706_1).

6.5.5 Fume cupboards are generally set up to achieve a velocity of 0.5 m/s across the open sash area (see clause 10 of this document) and the depression is typically immaterial to the fume cupboard performance.

6.5.6 Waste handling cells and cells with no personel access ('black cells'), on newly constructed plants, normally provided with substantial shield walls, can be engineered with sufficient leak tight structures to allow both flow rate and depressions to be controlled (see clause 9 and figures 12 & 13 of this document). On older plants, deterioration of the cell fabric and air leakage through seals can make it more difficult to maintain a reasonable design operating depression. In this event, if it is impractical to 're-seal' the cell fabric, a lower in-cell depression may need to be accepted, although efforts should be made to ensure there is sufficient extract flow from the cell to ensure that air flow is always maintained into the cell through leakage paths and adventitious openings. Account should also be taken of pressure gradients created by temperature gradients/ thermal buoyancy.

6.5.7 Vessels within cells will be well engineered plant items constructed to recognised design codes and will be fabricated with sufficient leak tight envelopes to allow both flow rate and depressions to be controlled (see clause 11 of this document).

6.5.8 Target depressions within over buildings i.e. those providing external containment are discussed in clause 17 of this document. If the area immediately inside the building perimeter is classified as an AMBER area, which would arguably not be recognised as good practice on a newly constructed plant, then that area should in principle be maintained at a measurable depression, which is marginally greater than that created by the maximum postulated steady wind speed on its exterior. In this case, the target depression would be more important than the air flow through the area as long as minimum air flows are maintained for other requirements (asset protection, process requirements etc.)

6.5.9 On ageing facilities, depressions within such over buildings may be difficult to achieve. As in clause 6.5.6, in this event, although reasonable efforts should be made to limit air inleakge through the building fabric, it may be impractical to maintain a measuable depression. In such cases, an ALARP approach may show that it is acceptable to ensure extract flow from the over building is sufficient to maintain air flow into the building through leakage paths and adventitious openings as far as reasonably practicable.

6.5.10 Flows across entry facilities between GREEN and AMBER areas in alpha plants are covered in clause 7.10.10. This proposes a design based on velocity across open doors in series for cascade flows into glove box cells/areas, whereas for AMBER areas with a low risk of readily airborne material, a much reduced air flow depression based arrangement across closed doors in series (with only one door open at anytime) is proposed in clause 7.18.

6.6 Process Requirements

The ventilation systems shall be designed to meet the functional needs of the process plant, e.g. cooling, dilution of gases, moisture removal.

6.7 Clean up of Plant Discharges

The ventilation systems will provide extract of aerosols and gases from the different radiological classified areas of the building and will incorporate a level of clean up to the discharge using abatement systems applicable to the radiological challenge provided by the air stream.

6.8 Monitoring of Exhaust Air Streams

The ventilation systems convey the air streams from the different radiological classified areas of the building to controlled discharge points and allow the provision of sampling and monitoring of the discharge air streams to provide process control information and comply with licensing and statutory requirements.

6.9 Occupancy

Ventilation is required in buildings to provide outdoor air for occupancy to comply with the Workplace (Health, Safety and Welfare) Regulations 1992 and Part F (volume 2) of The Building Regulations 2010 (2021 update). Whilst clauses 6.1 to 6.7 deal with functions related to meeting the safety requirements of a facility, operator comfort should be appropriately addressed by the ventilation design to reduce the potential for human risks caused by inadequately controlled internal environmental conditions.

6.9.1 Workplace (Health, Safety and Welfare) Regulations 1992

6.9.1.1 Under regulation 6 of the Workplace Regulations, “Effective and suitable provision shall be made to ensure that every enclosed workplace is ventilated by a sufficient quantity of fresh or purified air.” This provision can be either through natural ventilation, mechanical ventilation or a mixture of both. That outdoor air is needed to remove pollutants and odours and provide reasonable air quality for building occupancy. The Approved Code of Practice and Guidance for the Workplace Regulations L24, states an outdoor air supply rate not to fall below 5 to 8l/s per person.

6.9.1.2 CIBSE Guide A:2015 Table 4.5 gives approximate maximum sedentary CO_2 concentrations associated with CEN indoor air quality standards (BS EN 13779:2007). Based on a range of outdoor concentration of 350-400ppm, Table 4.5 gives a rise in indoor CO_2 concentration of 400-600ppm for ‘medium indoor air quality;’ and 600-1000ppm for ‘moderate indoor air quality.’

6.9.1.3 Indoor air quality measurements could therefore be used to demonstrate compliance with regulation 6 in buildings or rooms where there is an absence of dedicated forced outdoor air supply ventilation (it is generally taken that levels of CO_2 can be used as a good indicator of air quality and is relatively simple and inexpensive to monitor). CO_2 surveys can be conducted to evaluate if sufficient natural ventilation exists to comply with say the ‘moderate indoor air quality’ CO_2 level below 1000ppm during normal occupancy. For buildings on the Sellafield site, this method of demonstrating compliance with the workplace regulations is covered under site procedure SLP 1.06.59.01 ‘How do I Operate and Maintain Ventilation Systems.’

6.9.1.4 The Workplace Regulations 1992 also state, under regulation 7, that the temperature in a workplace needs to reasonable, where L24 suggests ‘reasonable’ should normally be at least 16˚C, or 13°C if work involves rigorous physical effort.

6.9.1.5 These temperatures are broadly consistent with maintaining air temperatures within buildings above dew point, which could typically be about 15°C, such that complying with Workplace Regulations will also serve towards ensuring Asset Protection.

6.9.2 The Building Regulations 2010 Part F

6.9.2.1 The Ventilation of Buildings is also a requirement under UK law through Approved Document F of The Building Regulations 2010, 2021 edition. Although, under Schedule 2 of The Building Regulations, buildings erected on a site under licence of The Nuclear Installations Act 1965 are considered to be Class 1 buildings, which are exempt from all Building Regulations except Part L. However, it would be considered good practice to comply with the Regulations, unless to do so the designer would have to make significant changes purely to comply, or the requirements of nuclear safety prevents application.

6.9.2.2 The Building Regulations 2010 Approved Document Part F Volume 2: Buildings other than dwellings, 2021 edition, stipulates for offices an outdoor air supply to occupiable rooms at whichever is the greater of 10l/s per person or 1l/s per m^2 floor area. Table 1.1 Ventilation for buildings other than offices and car parks, for 'Common spaces' stipulates mechanical ventilation to provide a supply of outdoor air of 0.5l/s per m^2 floor area or natural ventilation by appropriately located ventilation opening(s) with a total opening area of at least 1/50 of the floor area of the common space. For other building spaces it refers out to the recommended ventilation rates given in CIBSE Guide B2 Ventilation and Ductwork (2016).

6.9.2.3 In CIBSE Guide B0:2016 "Applications and activities: HVAC strategies for common building types," sections are included on "Is heating needed?" – which considers if heat losses can be offset by internal gains - and "Is mechanical ventilation needed?" recognising the current drive for increased energy efficiency in Buildings, and the use of natural ventilation where applicable.

6.9.2.4 The 2016 edition Guide B2 deals with Ventilation but doesn't contain any rules of thumb for ventilation rates for factory or workshop type environments or the type which could normally be equated to nuclear facilities. The calculated rates are more directed towards ventilation rates per person based on air quality levels; and ventilation of cavities to avoid interstitial condensation within the building fabric. Guide B2 also references BS EN 13779 for outdoor air ventilation rates. As such, providing 10l/s per occupant, and providing reasonable levels of air movement to satisfy BS EN 13779:2007 should be sufficient to comply with Building Regulations.

6.9.2.5 For occupied spaces CIBSE Guide A:2015 Table 4.1 gives recommended outdoor air supply ventilation rates of 6-10l/s per person for 'moderate indoor air quality,' 10-15l/s per person for 'medium indoor air quality,' and >15l/s per person for 'high indoor air quality,' (to BS EN 13779:2007 quality standards).

7 Design Principles of Ventilation Systems for Radiological Controlled Areas

7.1 What are the Hazards?

7.1.1 The most important aspect of the design of ventilation systems is a clear understanding of the plant specific hazards to allow definition of the functional requirements and objectives of the system.

7.1.2 On most plants, the provision of containment is the principal safety function provided by the ventilation systems. Some plants, however, may have hazards which override the requirement to provide containment alone, and which rely on the ventilation system to provide, for example, a dilution function for gaseous arisings; or a cooling function for waste storage. Similarly buildings may include RED areas which are inerted to minimise the exposure of the radioactive inventory to air/oxygen, in which case, maintaining that RED area at a depression would encourage air leakage and defeat the inerting system which exists to address the principal hazard.

7.1.3 Plant specific hazards, therefore, may lead to consequences which dictate that the most significant safety function provided by the ventilation system is not always the provision of containment.

7.1.4 Consequently the design objectives of ventilation systems may differ between facilities and will be specific to each facility; and the ventilation designer needs to start from first principles for the design of each facility where the design objectives are driven by the hazards specific to that plant.

7.2 Design Objectives

When establishing the specific design objectives for ventilation systems in a radiological facility, the following general objectives should be addressed by:

- Addressing the hazards posed by the radioactive inventory
- Meeting the requirements of the Process
- Ensuring appropriate air flow patterns within areas such that air movement is towards higher sources or potential sources of contamination
- Reinforcing containment by providing the appropriate depressions between areas so that the air always flows into areas of higher contamination potential at sufficient velocity to control back diffusion of contamination
- Where the physical containment of the radioactive area is breached by openings providing, as required by the hazard assessment, appropriate means to maintain the containment in normal operation, unplanned events or in the accident state
- Providing suitable environmental conditions within the containment which may include temperature, pressure, moisture content and control of contaminants, including corrosive ions
- Protecting plant operators and the external environment in normal operation, unplanned events and the accident state
- Minimising the throughput of air
- Minimising any airborne effluent arisings
- Minimising any waste arisings associated with the ventilation treatment plant
- Ensuring that suitable facilities are available for the safe monitoring, status indication, and, where necessary, the continued operation of the ventilation plant and functions during normal and abnormal conditions
- Complying with Statutory Regulations and Site Licensee Policy (including Codes of Practice)
- Giving due consideration to Examination, Inspection, Maintenance and Testing of the system to provide confidence that system meets the on-going claims for design intent,

system performance and equipment reliability, taking account of ageing and degradation effects and decommissioning of the facilities at the end of life. This shall include ensuring adequate access to plant components for maintenance, removal and replacement – and ensuring access routes for bringing replacement plant items into the building. In this respect, consideration should be given to limiting the overall size of central plant items such as fans and air handling units, to suit installation access routes (and access routes for replacement sections on operational plants) and, if required for example, 3 x 50% duty units may be used instead of say 2 x 100% duty units. EG_0_1708_1 gives specific guidance on maximum recommended AHU section sizes.

- Facilitating effective measurement of radioactive discharges for both statutory and operational purposes
- Ensuring that the system incorporates the maximum use of energy efficiency
- Giving due consideration to decommissioning (EG_0_0007_1 provides guidance specifically relating to HVAC considerations)

7.3 Design Considerations

7.3.1 Although this document is primarily concerned with radiological aspects, the design should also consider:

- Physical and chemical processes
- Environmental conditioning and protection
- Conventional Safety
- UK Legislation and Building Regulations (see Section 3)
- Operating principles
- Design life, running costs and energy consumption
- Whole life energy use and carbon impact (using methods in CIBSE TM54 (Evaluating operational energy use at design stage) and TM65 (Embodied carbon in building services: A calculation methodology)
- Manufacture, Installation and Commissioning
- Maintenance and operations
- Decontamination - the internal surface materials on ventilation plant items which handle potentially contaminated airstreams should be carefully considered, and reference made to ES_0_5142_3 which advises on coating systems which have been tested for radiological resistance and 'Ease of Decontamination' and conform to ISO 8690 'Decontamination of radioactive contaminated surfaces. Method for testing and assessing the ease of decontamination.' EG_0_5144_2 offers further guidance on the selection of protective coatings for use in radioactive environments.

7.3.2 Designers should be aware of the ONR's Safety Assessment Principles for Nuclear Facilities (SAPs) and the Environment Agency Environmental Principles (REPs) as pre-requisites of the design. ONR's inspectors use the Safety Assessment Principles, together with the supporting Technical Assessment Guides (TAGs), to guide regulatory decision making in the nuclear licensing permissioning 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. Similarly EA regulators use the REPs when: reviewing environment cases; responding to ONR permissioning; and undertaking permitting. 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 fault conditions.

7.4 Design Process

7.4.1 Gated Process

The design process for a Major Project will follow a number of stages of project delivery, which for the Sellafield site is five stages in line with the Gated Process described in SLM 1.10.03. The objective of this Gated Process, as stated in SLM 1.10.03, is to provide one streamlined sanction and validation process, that can be tailored and utilised throughout the Sellafield community and upwards into NDA and UK Government where necessary and will comply with the UK Government best practice. The five stages of project delivery are:

- Feasibility
- Appraise and select
- Define
- Deliver
- Operate, Embed and Close

At each stage of the design process, it is imperative that the design intent is clearly identified, is carried through to the final operating system, and finally verified as such by a competent authority. The design intent is detailed in the Ventilation Basis of Design document, is supported by the Ventilation Flow Diagrams and underpinned by the appropriate level of calculations.

7.4.2 BSRIA Design Framework

7.4.2.1 Not all sites or projects will use 5 stages of project delivery. For comparison purposes with other industries, BSRIA Guide BG 6/2018 follows the RIBA Plan of Work Stages 0 to 7; where: -

- 0 is Strategic definition
- 1 Preparation and brief
- 2 Concept design
- 3 Developed design
- 4 Technical design
- 5 Construction
- 6 Handover and close out
- 7 In use

7.4.2.2 The BSRIA Guide gives a Summary of main activities and deliverables for a building services designer, at each of these Work Stages.

7.4.2.3 Although the terminology in these activities, taken from the BSRIA Guide, may differ from those presented in SLM 1.10.03, the design deliverables are essentially the same. As the BSRIA Guide states “all projects, whatever their size or complexity, go through a series of design steps where the level of detail is refined as information becomes fixed and more detailed calculations and design procedures are carried out.” This approach is equally applicable to all design processes/frameworks.

7.5 Key design deliverables and activities

Design deliverables serve a number of purposes: -

- provide a method of developing the design intent to produce sufficient design information to enable plant items and ventilation systems to be correctly sized/selected, procured and installed on site
- produce an auditable trail for the sizing and selection of all installed plant and systems
- provide a record of the technical specification of all installed plant and systems
- provide evidence to substantiate that installed plant and systems deliver their design intent

7.5.1 Process Flow Sheet

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

- Area contamination classifications
- Process flows
- Contamination/radiological burden
- Environmental conditions
- Waste and energy requirements

The process flow sheet should contain enough detail to support the assessment of BPM or BAT, safety, and business cases. Further details of the health, safety and environmental requirements are given in section 4. Integrating hazard assessments into the design is an important design development process.

7.5.2 Ventilation Basis of Design

A Ventilation Basis of Design document records the design intent; and sets out how the ventilation systems will be configured to deliver the design intent. For the Sellafield site, DDD_033 gives typical contents of a Ventilation Basis of Design document. The Basis of Design is a 'live' document, written initially to support the concept, or early design phase of a project, and is updated throughout the remaining project phases, as the design and specification of the systems are developed and finalised. At the completion of the project it should be updated to reflect the as-built state of the Plant.

7.5.3 Ventilation Flow Diagrams

Ventilation Flow Diagrams (VFDs) depict a schematic arrangement of each ventilation system within a facility and the associated air flows. For the Sellafield site, DDD_016 gives typical contents for Ventilation Flow Diagrams. They are 'live' documents, produced initially in the concept, or early design, phase of a project and updated with more detail throughout the remaining project phases as the design is progressed and finalised. At the completion of the project they should be updated to reflect the as-built state of the Plant.

7.5.4 Calculations

Calculations provide the basis for establishing ventilation air flow rates within a building and ultimately for sizing and selecting ventilation plant items and systems. The calculations would include both 'handwritten' calculations and computer-generated calculations using proprietary software packages, with both following industry recognised calculation methodology, typically in line with CIBSE Guidance; and will typically cover: -

- building air infiltration
- U values and admittance for building fabric (walls, floors, internal partitions)
- heat gains and heat losses
- air flows and ductwork sizing
- ductwork system resistance
- ductwork supports selection
- fan sizing
- fan vibration isolation
- air in-leakage across containment barriers,
- cascade flows/containment velocities & flows
- plant sizing and selection (air handling units, filters, coils, grilles/diffusers, room heating/cooling units etc.) accounting for heat reclamation and energy optimisation

- room noise levels and attenuator selection
- seismic analysis where applicable
- mathematical modelling using proprietary software packages where applicable
- whole life energy use & embodied carbon assessments (typically in line with TM54 & TM65)

7.5.5 Space management and layout integration

7.5.5.1 From early in the design process, account should be taken of the space requirements for ventilation plant and ductwork and monitoring plant. 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.

7.5.5.2 It should be recognised that nuclear facility ventilation is often 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 inadvertent spread of material. To achieve an effective containment system, it is therefore important that the ventilation, building layout and process designs are tightly integrated and not performed in isolation.

7.5.5.3 This will include demonstrating that containment barriers can be adequately sealed, where practicable, such that the appropriate depressions can be achieved between areas of different radiological classification without excessive air flow rates.

7.5.6 Co-ordinated ductwork arrangement drawings

Since the advent of Building Information Modelling, 3-D models are the preferred method of laying out ventilation plant and ductwork runs in a facility. The 3-D model allows the ventilation systems to be fully coordinated and space managed with other design disciplines (Process, Mechanical, CE&I, Civils Structural & Architects). With the advent of BIM systems and applications, they also provide the opportunities to integrate all design & management information related to a system into a single information point.

A 3-D electronic model, however, will not generally be readily accessible to all; and will not always be the best platform to display the arrangement of the ventilation systems for other design related tasks. In its most basic form and application, the 3-D model will therefore, be used to generate 2-D general arrangement drawings (plans, elevations, sections). The 2-D drawings will typically show: -

- ductwork routing
- ductwork levels
- ductwork sizes
- ductwork support positions
- in-line plant items (AHUs, fans, filters, dampers, coils, grilles, attenuators etc.)
- access and space for maintenance and plant replacement
- instrumentation & tapping points, sampling points and access panels

The ductwork arrangement drawings and/or the 3-D model can be issued to the ductwork fabricator for production of the ductwork fabrication/installation drawings and production of detailed support calculations and drawings.

7.5.7 Plant Procurement Specifications

7.5.7.1 Procurement Specifications are required for the designer to specify and procure ventilation plant items such as fans, AHUs, coils, filter housings, dampers and attenuators. Generic specifications for the procurement of ventilation plant items, specifically for the UK Nuclear Industry, are available as Engineering Standards listed in clause 3.6. The standards have been developed through the National Nuclear Ventilation Forum (NNVF), with input from UK Nuclear Industry Site Licence Companies and plant manufacturers.

7.5.7.2 Each generic Procurement Specification for plant items contains Technical Information Sheets as Appendices for the designer to specify plant specific requirements. Engineering Guides are also available, to provide background information on the content of each related Engineering Standard; and guidance for completing the associated Technical Information Sheets. Engineering Standards are also available for the procurement of consumable HEPA filters.

7.5.8 Plant installation specification

Traditional build projects have often been arranged such that the ductwork installer is contracted to install all plant items within the ventilation systems, to provide a completed installation. Major plant items such as centrifugal fans, AHUs and filter housings are often procured separately and given 'free-issue' to the ductwork installation contractor to install; or can be procured through the ductwork installation contractor. Whichever approach is taken, it is often more practical, although not essential, for smaller in-line plant items such as dampers, attenuators, grilles, and diffusers to be procured through the ductwork installation contractor.

An installation specification is normally required which will cover the specification of the ductwork, the supply of 'non-major' in-line plant items to the appropriate Engineering Standards; and the installation of ductwork and all ventilation plant items to provide complete systems. Ventilation ductwork can be specified using the ductwork Engineering Standards and completion of the appropriate project specific Technical Information Sheets. Guidance for completing the sheets is given in the ductwork Engineering Guide EG_0_1720_1.

7.5.9 Engineering Substantiation – Engineering Schedule

7.5.9.1 The ventilation design should be closely integrated with the facility nuclear safety case, as design substantiation will be required for those system components which are required to meet a Safety or Environmental Function.

7.5.9.2 The process of design substantiation should ensure that the design intent is embedded in the specification, procurement and installation of the ventilation plant, and its performance verified during testing and commissioning. For the Sellafield site see SLP 1.02.10. For other UK Nuclear Licensed Sites, refer to the local site practices.

7.5.9.3 The designer should ensure that the design intent is communicated to those responsible for discharging Design Authority responsibilities. For the Sellafield site, the appointed System Engineer serves as the technical owner of the ventilation systems once in service and will take on Engineering Authority responsibilites (once the system has been handed over by the appointed Design Authority). For other UK Nuclear Licensed Sites, refer to the local site practices.

7.5.9.4 The Engineering Schedule, as part of the Plant Safety Case, will identify structures, systems and components (SSCs) important to plant safety. Its primary function is to present all safety important SSCs with their associated Safety Functions, as taken credit for within the Safety Case. It should facilitate understanding of what is required for safety and what can be delivered by the engineering. It will identify safety functions and Safety Function classes for SSCs. These safety functions may place requirements of ventilation plant to continue to meet their functional requirements following a seismic event.

7.5.10 Engineering substantiation record

7.5.10.1 An Enginering substantiation record provides a visible record of decisions and evidence that substantiates the engineering solutions to meet such Safety Functions and Performance Requirements, which may be placed on parts or the entirety of a ventilation system.

7.5.10.2 The designer will produce the substantiation during the detailed design phase of the project which can be recorded in a number of formats such as a report, a form, a note for the record or within a safety case. Substantiating evidence, at this stage, will refer to design base documents.

7.5.10.3 The sizing and selection of plant items designed to meet the safety functions will be underpinned by the calculations. The configuration of those plant items should be such that they operate as a system to satisfy the Performance Requirements and that is underpinned by the VFDs and the ductwork arrangement drawings. Plant item procurement and installation specifications shall be based on recognised standards and Relevant Good Practice together with experience of past performance and reliability data.

7.5.10.4 As plant is procured, works tested and installed, the substantiation record can be progressively updated to refer to works test results and as-built drawings, to provide progressive assurance that the plant components will perform to their specified design duties and that the installed systems will comply with the design arrangement drawings.

7.5.10.5 After the plant is commissioned, the substantiation record can be updated to refer to commissioning test results that validate the ventilation systems' Performance. Maintenance Instructions and where applicable, periodic proof tests need to be produced to ensure the systems continue to meet the specified Safety Functions and related Performance Requirements during the lifetime of the facility.

7.6 Managing the design process

The number of stages into which a Project is split is largely irrelevant, as long as the final design deliverables issued for plant procurement and installation are fit for purpose and have been fully coordinated between the various design disciplines.

Irrespective of the number of process stages, ultimately the process can be compressed into: -

Design → Procurement & Construction/Installation → Commissioning

For the ventilation plant on any project, the common thread throughout this entire process is the ventilation system designer. To ensure that the design intent is translated into the installed and commissioned plant, and that the design can be substantiated, it is important that the ventilation system designer takes full ownership for the systems, and provides engineering support through the procurement, installation, and commissioning phases.

7.6.1 Key responsibilities for the ventilation system designer

Ownership is not restricted to the production of design deliverables. It runs throughout the process and would include the following key tasks: -

- understanding plant specific hazards
- identifying the functional requirements and design objectives of the ventilation systems to mitigate these hazards and early consideration of the effective use of energy and design for sustainability (see clause 22)
- implementation of designer responsibilities under the Construction Design and Management Regulations
- implementation of responsibilities under the Building Safety Act (if applicable)
- collating a ventilation basis of design document to record design intent
- produce calculations leading to derivation of air flow rates and plant sizing
- production of ventilation flow diagrams depicting the entire systems schematically
- production of co-ordinated ductwork arrangement drawings to issue for procurement
- early engagement of installation contractor during the design phase for constructability input, and to ensure layouts which design for maintenance, plant item replacements during the operational life of the building and for decommissioning
- production of plant and installation specifications for procurement
- early contractor engagement in the procurement phase with the plant item manufacturers and the installation contractor, to agree on all technical aspects of the procurement packages, prior to placing of the main procurement contracts
- review the plant manufacturer's fabrication drawings to ensure they comply with the plant procurement specifications
- review of plant item manufacturer produced documentation such as Inspection and Test Plans and Factory Acceptance Test Plans
- review of ductwork fabrication contractor's detailed manufacturing specifications
- review the ductwork fabrication/installation drawings to ensure they comply with ductwork procurement specifications and co-ordinated arrangement drawings
- review of ductwork support calculations

- works inspection of plant items and ductwork to ensure plant has been fabricated in accordance with the procurement specifications and approved fabrication drawings
- witness Factory Acceptance Testing
- site inspection of installed ventilation systems to ensure installation to the approved installation drawings
- check on site that any agreed design assumptions on the leak tightness of the building and room fabric and any assumed gaps in containment boundaries are ‘as design’ to help ensure that cascade flows and/or design differential pressures between areas can be achieved on commissioning
- produce defects schedule and ensure necessary remedial work done to close out defects
- checking the as-built drawings against the installed systems
- review the Commissioning Work Sheets to ensure they cover the proving of the design intent, particularly with regard to flows/velocities and/or pressure differentials across containment boundaries
- ensuring the commissioning of the systems meets the requirements identified on the ventilation flow diagrams and produce as-commissioned revisions of the ventilation flow diagrams (see DDD_016 for guidance)
- production of design substantiation which references the commissioning results to show that the systems meet the design intent

7.6.2 Co-ordination with other design disciplines

7.6.2.1 The staged design process relies on each of the design disciplines, typically Process, Mechanical, CE&I, Civils Structural & Architects, Ventilation (Mechanical Building Services), working together in a managed co-ordinated fashion. In addition to a multi-disciplined approach to space management, each design discipline will need to discuss interface points and provide timely design information to the other disciplines.

7.6.2.2 For example, the ventilation system designer will need details from Process design relating to requirements to ventilate in-cell plant such as vessels and tanks, process air stream conditions, process air flow envelopes and pressure drops across in-cell aerial abatement systems. In addition Process design would produce an aerial effluent flow sheet, in-cell heat process heat gains and be responsible for specifying any requirements for inerting or dilution of hazardous gases.

7.6.2.3 CE&I design will need to provide the ventilation system designer with heat gains from electrical panels, plant and equipment, allowable operating temperature and humidity bands for that plant, and details of rechargeable batteries to allow battery room ventilation system design. Similarly the ventilation designer will provide an electrical load schedule to CE&I design and a control philosophy or Sequence and Interlock Definition Document (S&IDD), to allow the design of the ventilation control system.

7.6.2.4 Building fabric details will be required from Civils Structural & Architects for HVAC calculations. Equally the ventilation system designer will need to agree sizes and positions of wall and floor penetrations for ductwork and piped services, issue plant weights and agree plant fixing details into the structure, provide requirements for secondary support steelwork and agree interface points with incoming services and drainage. The achievement of cascade flows across zone boundaries and any engineered room depressions depend on the leak tightness of the room fabric. This is fundamental to the multi barrier approach to containment so should be core knowledge to designers of all disciplines for nuclear facilities, although the ventilation system designer should ensure that this is communicated and understood on each Project. To this end the designer should confirm with the Architiects that for all rooms, both the room fabric and all room penetrations need to be well sealed. Based on the observations of the door swing effect on room pressure (see Appendix E.1) , doors on sub-change rooms/entry facilities between GREEN and AMBER areas should be gasketed at the sides and at the top and, if swing door are used, they should open out of the room which has the lower pressure and into the room which has the higher pressure.

7.6.2.5 The ventilation designer will require any heat gains from other Mechanical Plant items and will interface with the Mechanical design discipline for the design of through wall liners, design of in-cell filter housings and any ventilation requirements from Mechanical designed containments.

The ventilation designer should ensure that the Mechanical design discipline understand the need to seal all penetrations of mechanical plant items through wall, floors and ceilings, both to achieve the required leak tightness of containment boundaries and to eliminate 'shine paths.'

7.7 Functional Requirements

See clause 6.

7.7.1 A common function of the ventilation system in radiologically controlled facilities will be to support the physical containment in controlling and minimising the escape and spread of particulate and gaseous contamination.

7.7.2 In the event of breaches in the structural barriers segregating areas of different levels of contamination, the ventilation 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.

7.7.3 To achieve this, the various areas must be maintained at different atmospheric pressure levels. The areas with the highest potential contamination levels (RED) must be maintained at the greatest negative pressures or depressions. The areas with the lowest potential contamination levels (GREEN) will be maintained at the smallest depression. For areas with low potential contamination levels it will not always be necessary to hold the area at a set target depression as a nominal depression will suffice. WHITE areas would not normally be held at a depression and in some cases may require to be held at positive pressure.

7.8 Containment and Area Classification

7.8.1 The concept of multiple containment barriers has been discussed in Section 5 and the role of the ventilation system in support of the containment is summarised in 6.3.

7.8.2 The enclosing structure around a RED area housing a radioactive process provides physical 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.

7.8.3 For ageing facilities it may be impractical to ensure continued good sealing around penetrations. It may be both impractical and unnecessary to increase air flows to maintain a 'high' depression within the RED area. In such cases a pragmatic approach may be appropriate and the safety assessment updated to consider allowing the area to operate at a reduced depression but with sufficient inleakage around penetrations to ensure inward flow. The safety assessment update will need to show the implementation of further measures to the point where the costs of any additional measures (in terms of money, time and trouble) would be disproportionate to the further risk reduction that would be achieved (the safety benefit).

7.8.4 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.

7.8.5 The containment performance should, therefore, match the potential hazard. For example: a fully sealed double door posting system on a RED area enclosure; an airlock on an AMBER area entry; and two doors in series for a GREEN area entry.

7.9 Change of Area Classification

7.9.1 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 (see also RPGN 03).

7.9.2 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.

7.9.3 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 (see RPGN 05 for Sellafield site or local site procedures on other UK licensed sites). 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 reasonably practicable to achieve all the requirements of the higher classification, and a lower standard may be acceptable subject to a safety assessment.

7.9.4 On the Sellafield site, a programme of Radiological Rollback of Controlled Areas has been adopted on some operating facilities. Rollback is focussed upon minimising the size of the contaminated area and retaining contamination at source. The purpose of this programme is to accelerate and embed sustained improvements that collectively will lead to declassification (as far as is reasonably practicable) of current controlled areas. This will result in minimisation of areas under contamination control and allow free access to these areas. In these instances, the declassification of these areas is for operational and housekeeping purposes only and the ventilation systems should continue to operate on the principle of the (higher) potential contamination arisings in these declassified areas rather than the reduced area classification. In such cases it may be pertinent for the Ventilation Flow Diagrams to refer both to the 'Design' room radiological classification and the 'Operational' room radiological classification.

7.10 Air Flows in Support of Containment

7.10.1 Engineered openings in barriers between areas of different radiological classification are required to allow access for people, equipment, to process materials and for services (including ventilation). They should be designed appropriately and to be consistent with the hazards against which protection, in the operational area, is required.

7.10.2 Where these openings occur in the physical barriers, air flow across these openings should always be designed to flow from areas of low contamination potential to areas of higher contamination potential. The air velocity across these openings may vary according to the nature of the opening, and the operational state, e.g. if a door is open or closed.

7.10.3 The minimum air velocity across such openings to limit back-flow of contaminated particles has generally been taken as 0.5 m/s. Designers should also aim to maintain this minimum velocity through adventitious openings where flows may be measurable; e.g. gaps and slots around penetrations such as doors. Other adventitious openings, such as construction gaps and cracks within the containment enclosure may be too small to measure velocities and should be sealed as effectively as possible.

7.10.4 Airflow into a gap forms a 'vena contracta' due to its momentum. This creates vortices ('eddies') close to the wall, giving the potential to trap contamination and transport it against the direction of bulk flow. Eventually the flow re-attaches to the wall and the inward flow direction is established across the whole gap. See Figure 5.

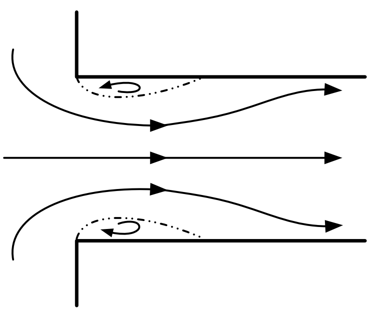


Figure 5 – Typical flow profile into a gap

7.10.5 The strength of the vortices, and their stability, is dependant on the velocity of the air and the geometry of the gap. Shallow gaps, see Figure 6 (a), and high velocities are more likely to allow backflow, than deeper gaps (Figure 6 (b)) with lower velocities. Flanged, flared or extended entry geometry can improve performance.

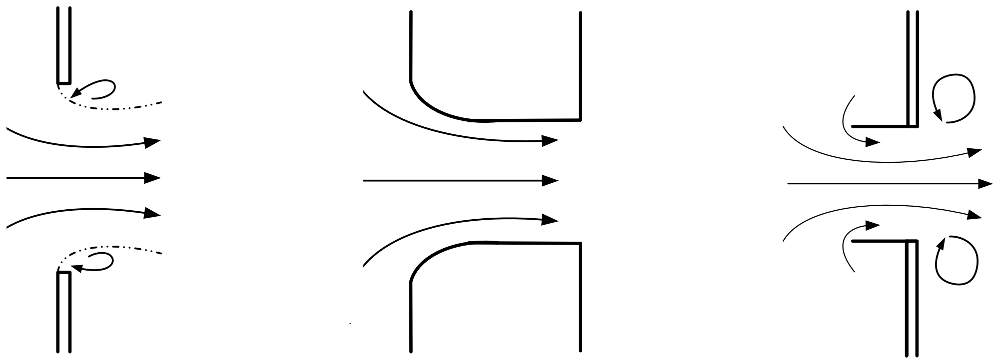


Figure 6 (a) – Shallow gap **Figure 6 (b) – Flared deep gap** **Figure 6 (c) – Re-entrant stub**

7.10.6 The re-entrant stub, see Figure 6 (c), is similar to a glove port. The additional ‘depth’ of the gap improves performance of the thin wall.

7.10.7 The 0.5 m/s minimum velocity (in ventilation containment applications) has been established from past experience in the nuclear industry and elsewhere (such as for fume cupboards). Experience with higher levels of challenge, such as glove boxes containing powder, has led to an accepted minimum 1 m/s required through an open glove port. Higher velocities give stronger vortex effects and the effect of disturbances may be more acute due to the additional momentum within the system.

7.10.8 However, ‘containment velocities’ cannot be based on the ‘one size fits all’ principle and each case needs to be considered based on the nature of the hazard against which protection is required, the type, size, edge detail and aspect ratio of the ‘breach’ in the containment boundary; and the number of ‘containment barriers’ in place between the hazard and the ‘clean’ operating area.

7.10.9 It should also be understood that designing on the basis of a ‘containment velocity’ of 0.5 m/s across a single barrier cannot be guaranteed to prevent back-migration of activity across the barrier in the long-term. Other effects such as personnel or plant item movement, wind and thermal buoyancy can influence flow profiles. The use of ventilation to supplement the containment function of physical barriers is most effective when such ‘containment velocities’ are engineered across multiple barriers in series.

7.10.10 In deriving design air flows between a ‘clean’ GREEN operating area and a potentially contaminated AMBER area, the designer should consider the level of airborne radiological challenge. In alpha plants, which inherently present a higher risk, both in terms of contamination migration, due to the potential for increased levels of airborne activity resulting from the mobility of alpha emitting material, and how little of this material is needed to be extremely hazardous, the entry facility would be designed based on an air flow velocity of 0.5 m/s across the open outermost door into the entry facility and an air flow velocity of 0.5 m/s across the open innermost door on the exit from the entry facility. This follows the principle of ‘cascade airflow.’ If the space between the in-series doors is reasonable (typically 6m) then the bulk air flow through the entry facility should be sufficient to entrain any airborne contamination, that may migrate back into the entry facility from the AMBER area, before it can challenge the door opening into the entry facility from the GREEN area.

7.10.11 Recognised ‘claimed’ Decontamination Factors (DFs) for containment barriers are listed in the Sellafield Release Fraction Database (RFDB) Table 6.4 – DFs for a variety of plant containment barriers. The air flow velocity of 0.5 m/s is relevant for applications at Sellafield and for other users of the RFDB. The RFDB uses ≥ 0.5 m/s as an indication of ‘Good extract,’ ventilation in the range of ≥ 0.25 < 0.5 m/s as 'Poor Extract,' and ventilation <0.25m/s as 'No Extract.' The DFs given in the RFDB, (that can be applied in safety cases for DFs across containment barriers) are variable depending on these levels of containment ventilation. The DF given in the RFDB for 'Good Extract' (which would be equivalent to the air flow arrangement across the open door of an entry facility of ≥0.5m/s) is $1x10^5$.

7.10.12 There is normally no requirement for direct forced (mechanical) supply air into an AMBER area. Where this is unachievable, motorised dampers, operable from a central control area should be considered on supply air ductwork branches to AMBER classified areas to close in the event of fan failure such as to minimise the potential for migration of activity from these areas.

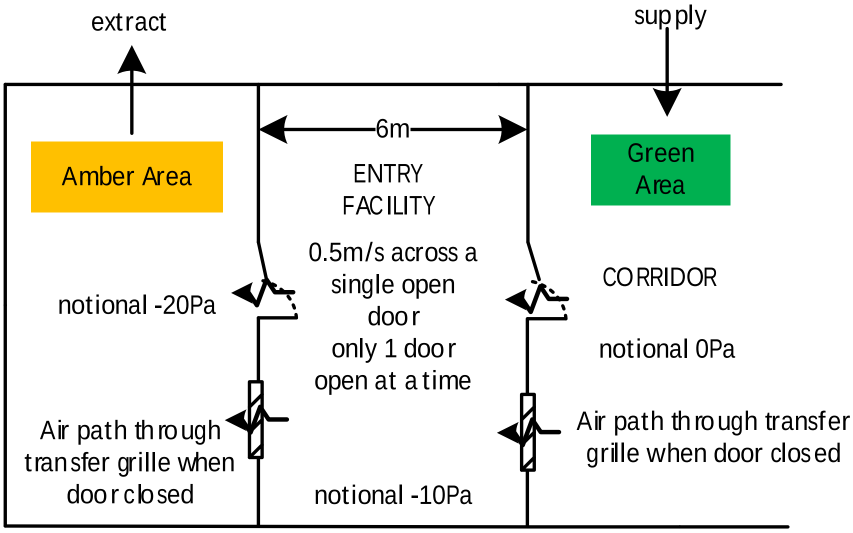


Figure 7 Air flows across GREEN to AMBER entry facilities in alpha plants

7.10.13 For the calculation of air flows in radiologically controlled facilities where the risk of migration from AMBER to GREEN areas is lower (than for an alpha plant), entry facilities have been designed with two doors in series and an air flow velocity of less than 0.5 m/s across an open door. Clause 7.18 gives recommendations for air flows between GREEN and AMBER areas on these 'lower risk' plants, where measurable depressions across closed doors in series (with only one door open at anytime) would maintain acceptable decontamination factors across the entry facility.

7.10.14 For large cross sectional area openings, i.e. greater than a typical size door opening, uniform face velocities across the opening can be difficult or, depending on the size, even impossible to achieve, due to a number of factors. The velocity profile across such large openings can be very inconsistent, and even in the case where the total flow of air through the opening divided by the opening cross sectional area equates to 0.5 m/s or more, there would be no guarantee of avoiding backflow at some points across the opening. Temperature gradients/thermal buoyancy effects can affect the flow profile, as can wind effects across the building, which can cause a differential pressure between the windward and lee sides of the building. The location of furniture, plant items and structural elements either side, and local to the opening, can also affect the velocity profile and cause local effects. In general, therefore, the larger the opening, the more unpredictable are the air flow patterns through that opening and the more difficult it becomes to claim a 'containment velocity.' In these situations, where practicable, it would be preferable to protect such large breaches of containment with additional upstream protection of a further 'containment barrier' where the breach is smaller and velocity profile across the opening is more predictable.

7.10.15 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 m/s, to limit back-flow, can cause eddies and hence loss of protection.

7.10.16 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. In the absence of other guidance, 1m/s should be used – see clause 7.10.18.

7.10.17 For flows at the edges of door openings it has been demonstrated that the effect of profiling (rounding) the edge to produce a smoother air flow, with less eddies, can reduce the likelihood of backflow.

7.10.18 Experimental work (figure 8) based on passing large crates through an opening, using variable geometry airlock doors, demonstrated that, for gaps up to 200mm, a satisfactory containment can be achieved between a minimum velocity of 1 m/s and a maximum velocity of 4 m/s, with the optimum velocity at 1 m/s (*Testing and Evaluation of the Variable Geometry Doors Airlock System* – Sellafield R&D Report RDR 0112 1995). The containment or Decontamination Factor (DF) drops off gradually as the velocity increases up to 4 m/s. At the lower end, the containment drops rapidly as the velocity decreases below 1 m/s. The work also showed that significantly higher DFs are obtained when rounded (profiled) door edges were fitted.

7.10.19 Report RDR 0112 states that the decrease in DF at high velocities is thought to be related to the turbulence on the door edges, which is known to increase with increasing velocity. The turbulence is said to cause a localised 'back diffusion' effect increasing the chances of reverse flow. The report states that the sharp decrease in DF at lower velocities is related to the increasing effect of 'random' air movement (refers to the resulting effect of a number of factors important in determining air direction at low velocities such as heat, brownian motion and local moving objects) with decreasing velocity allowing localised air movement back through the open doors. The resulting DF therefore is dependant on velocity which is dependant on the engineered gap. Although the high velocity is not critical particularly with profiled doors, it is suggested that the limiting velocity should not exceed 4m/s. To reduce the effect of 'random' air movement a minimum velocity of 1m/s should be maintained.

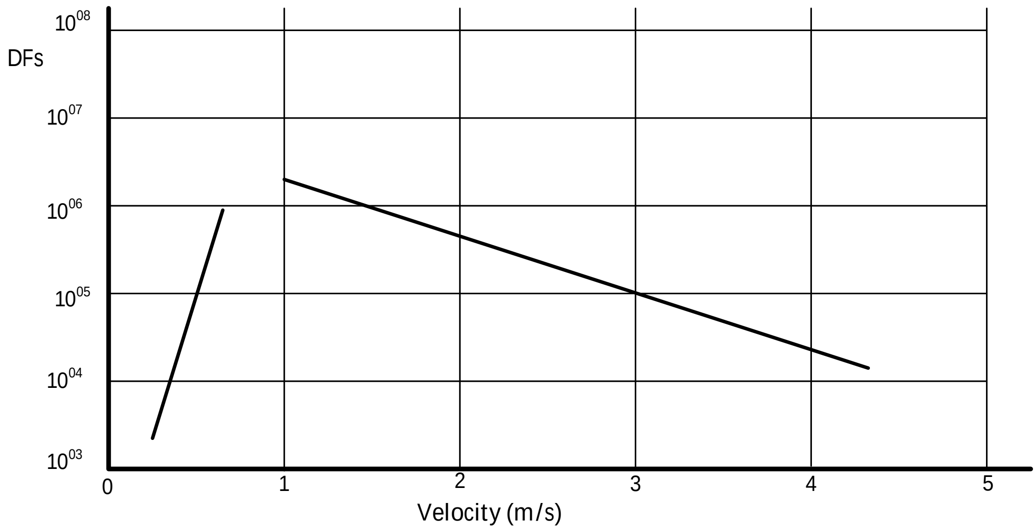


Figure 8 – An example of the type of Variation of DF with velocity around a crate passing through an opening

7.10.20 Similarly effective fume cupboard ventilation can be engineered based on a velocity of 0.5 m/s across the open sash area. Consideration shall be given to the entry profile of the air through the sash to avoid eddies and potential backflow. Consideration shall also be given to reduce the velocity of supply air (from the room air distribution system) in the vicinity of the sash opening to discourage turbulence, eddies and entrainment of air back out of the fume cupboard. Increasing the face velocity across the open sash area in excess of 0.5 m/s does not necessarily improve the 'containment' of the fume cupboard and will, in all likelihood, have a negative effect, as higher supply air flows will be required (leading to an increased chance of turbulence in the vicinity of the sash opening); and a greater chance of inducing backflow from higher edge velocities.

7.11 Velocities Between Areas of Different Classification

7.11.1 Air flows across engineered openings, therefore, are designed to maintain the containment integrity between areas. The containment performance of an engineered opening should match the required containment integrity of the barrier it is part of. Careful design of an opening can improve its containment performance (e.g. seals on a tight fitting door). However, openings are provided for access such that when they are open, any disturbance can cause a change in airflow patterns, resulting in the unpredictable movement and potential escape of airborne contamination.

7.11.2 A given velocity across a single opening, therefore, is not always sufficient to demonstrate good containment. For example 1 m/s through only a single open door directly into a RED area is not recommended. Entry systems must allow for failure of a single barrier, usually by providing additional permanent or temporary barriers (depending on the operational philosophy for the entry point). The use of a single door as an entry system (subject to risk assessment) although not disallowed will require a system for monitoring performance and additional barriers whenever the ‘door’ is opened, must be provided.

7.11.3 Containment barrier good practice is to have two ‘doors’ in series so that only one is opened at any given time. The area between the doors should be managed, to get early warning of contamination at the innermost door (closest to the hazard), and cleaned to prevent an eventual challenge to the outermost door.

7.11.4 Based on the principles discussed in the previous clauses, the following gives guidance on how to address design flows across engineered openings in barriers between areas of different radiological classification.

7.11.5 **WHITE** to **GREEN**: - the potential for airborne contamination in GREEN areas is low and consequently the risk of migration of contamination from GREEN to WHITE area is, in all probability, very small. As such, there is little to be gained from engineering minimum velocities between these areas. However, the transfer of air from GREEN to WHITE areas should still be discouraged. Where access is required between WHITE and GREEN areas, the preference would be to install a lobby area or an air lock, to give positive physical separation between the areas. There would be no absolute requirement to provide ventilation, for containment purposes, to this lobby area. If ventilation is required for other reasons (heating, minimum outdoor air, etc.) then air supplied directly into the lobby would suffice with, if required, a pressure relief device in the lobby wall to relieve air into the GREEN area. However, as these areas are normally transient spaces and not occupied, this also may not be required. On the Sellafield site, ES_1_3003_1 Change room Code of Practice states that consideration should be given to the provision of air locks or two sets of doors at the entry and exit to changerooms, which are normally located on the personnel access route between WHITE and GREEN areas. For other UK Nuclear Licensed Sites, refer to the local site practices.

7.11.6 **GREEN** to **AMBER**: - it is recognised that there is a potential for airborne contamination in AMBER areas. A cascade flow of air across multiple barriers, in series, is therefore recommended in accordance with clause 7.10.10 for alpha plants, and in accordance with clause 7.18 for radiologically controlled facilities where the risk of migration from AMBER to GREEN areas is lower.

7.11.7 **AMBER** to **RED**: - high levels of airborne contamination are expected in RED areas. Where personnel entry, with appropriate PPE and respiratory protection, is required, preferred openings would be via an entry tunnel with doors at either end provided in series. The velocity needs to be sufficient to maintain inward flow at all times, including during any disturbance generated by moving personnel, equipment or opening and closing doors. The velocity should not be too high (see figure 8) when increased turbulence around door edges can lead to localised back flow. It is recommended therefore, that the velocity across the open door should be an average of 1m/s, with the velocity at any measured point over the door opening between 0.8m/s and 1.5m/s. Only one door would be opened at any time. Where openings are provided into RED areas for plant access only, e.g. via shield doors, it is recommended that the air flow through gaps around doors on these openings is designed to give a velocity of 1 m/s. For make up air into RED areas, e.g. glove box inlets and cave or cell engineered inbleeds, backflow protection should be provided such as HEPA filters.

7.12 Room Air Movement

7.12.1 Within the building, air flows should be from areas of lowest contamination potential to those of highest contamination potential (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 minimise back flow 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.

7.12.2 Consideration should also be given to air movement/air patterns within rooms, which are generally a function of the location and selection/sizing of the supply grilles/diffusers; and the differential temperature between supply air and room air.

7.12.3 Most conventional room air distribution systems rely on mixing/dilution where the supply air is discharged into the room from grilles/diffusers with a terminal velocity selected to provide the throw required to reach the occupied zone. This type of system relies on entrainment of room air into the higher velocity supply air stream such as to encourage mixing, and therefore dilution of the air, within the room.

7.12.4 Where ventilation systems are required for dilution purposes, for example to provide dilution for a given quantity of gas within a room, the dilution equation can be applied and consideration given to the room air distribution system to ensure adequate room air mixing.

7.12.5 Laminar flow systems incorporating low velocity air streams, usually with much higher room air change rates may be more applicable in laboratories where, for example, air disturbance at the face of fume cupboards is to be minimised.

7.12.6 In rooms through which air is cascaded, e.g. entry facilities, as long as the room is well sealed, air flows will be engineered to flow in the correct direction across the door penetrations (see clause 7.8.10); i.e. from the area of lowest contamination potential to the area of highest contamination potential. However, the air movement/air pattern within these rooms will be less predictable, although the general direction of air flow will be maintained.

7.12.7 The location of extract points within rooms will normally have little influence on room air movement. In most cases, one large grille at a single extract point can be just as effective as a duct running the perimeter of the room with multiple smaller extract grilles. In some cases, e.g. where there is stratification of room air, or where there are heavier or lighter gases other than air present, it may be appropriate to position extract points at either low level or high level.

7.13 Filtration on Supply Air Systems

7.13.1 Supply air to a radiological controlled facility should be filtered to remove general atmospheric dust and particulate. In addition, all sites, particularly coastal sites, should address the occupational health hazards arising from animal matter (e.g. dead birds, rodents) giving rise to toxic, pathological and microbiological risks to supply air systems. Protective features such as bird guards and insect screens should be considered on air inlets, although readily achievable access to such screens would need to be provided for inspection and cleaning.

7.13.2 The location of air inlet points to buildings should be given careful consideration to minimise the potential for blockages or temporary obstructions. Particular attention should be given to avoiding flood water and rain ingress and minimising the intake of contaminants such as corrosive ions from surrounding process facilities or naturally occurring (e.g. sea spray).

7.13.3 Regularly changed and maintained inlet filters serve to prevent dirt build-up on downstream finned coils, allow the provision of clean air for building occupants and will help to maintain downstream distribution ductwork clean in order to meet Workplace (Health, Safety and Welfare) Regulations. For the Sellafield site, SLP 1.06.59.01 requires supply air distribution systems to undergo a ventilation hygiene inspection at a periodicity not exceeding 5 years. For other UK Nuclear Licensed Sites, refer to the local site practices.

7.13.4 Good housekeeping standards (see SLP 1.06.59.01) and well maintained inlet filters will also help to minimise radioactive waste by reducing the build up of dust on extract filters and may help to prolong extract filter life.

7.13.5 HEPA filters fitted to engineered inbleeds to RED areas will also reduce the build up of dust on extract filters.

7.13.6 In facilities having a higher potential level for airborne contamination (e.g. alpha plants), HEPA filters can be installed on supply air systems to protect against backflow in the event of loss of extract system airflow. In locations in which the building may need to withstand an external contamination event, e.g. incident control rooms, inlet HEPA filters may also be fitted to supply air systems.

7.13.7 The supply air stream may be treated to maintain the designed environmental conditions within the facility. This is particularly important for nuclear materials, fuel and waste stores. To prevent freezing of the input filter system in winter and to prevent matting of the filters during periods of high relative humidity, the filter installation should be preceded by pre-heaters or anti-frost coils. On coastal sites, coalescing filters should be fitted upstream of any air handling plant to remove airborne moisture to reduce the potential for downstream corrosion.

7.13.8 To comply with Workplace (Health, Safety and Welfare) Regulations, suitably located and sized access doors or openings should be provided to enable periodic cleaning of the supply air plant, distribution ductwork and terminal units.

7.14 Clean up (filtration) on Exhaust Air Systems

7.14.1 In radiological controlled buildings, ventilation systems generally operate on the 100% outdoor air, once through principle with air extracted from the rooms within the building, discharged to atmosphere, normally via a stack.

7.14.2 Recirculation is beginning to be used on some storage facilites (see EG_0_1708_1) and is considered in clause 22 of this document for energy saving purposes. The discharge ductwork may incorporate various stages and types of aerial discharge abatement plant in series, prior to the discharge point. This will depend on the potential airborne radiological challenge to the ventilation system from different areas within the building. The aerial effluent flow sheet would normally quantify the radiological challenge to the ventilation systems, and the challenge under 'fault conditions,' determined as a result of hazard assessment, would normally help identify the level and type of clean-up plant installed on the various extract ventilation systems.

7.14.3 Containments for RED areas, such as glove boxes, caves, etc., all contain loose radioactive materials, a proportion of which can be airborne at any time. One of the aims of the ventilation system should be to retain as much of the airborne activity within the primary containment (glove box, cave). By minimising the air flow through the RED area containments, the principle should be to reduce to a minimum the airborne activity carried into the ventilation system where it will load up filters which need to be changed and disposed of.

7.14.4 Unless filtration is installed at the point of extract from the containment, this activity can be entrained in the exhaust flow from the containment, with the subsequent levels of activity in the exhaust air stream being proportional to both the airborne contamination concentration in the containment and the extract flow rate. Multiple stages of HEPA filtration will be provided for the removal of airborne particulate from these air streams.

7.14.5 Other extracted areas are cells, usually incorporating shielding, which house active plant, e.g. solvent extraction, evaporation, effluent treatment. Such plant will usually consist of leaktight vessels, which provide the primary containment, such that the internal cell atmosphere should be free from contamination unless there has been a 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.

7.14.6 There are other 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 airborne 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.

7.14.7 Air in AMBER areas is unlikely to be sufficiently contaminated to require more than one stage of HEPA filtration on the discharge, unless the area is in a building which contains alpha radioactive material. 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 ALARA (and BPM or BAT).

7.14.8 In most cases, with the exception of alpha plants, 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 ALARA (and BPM or BAT).

7.14.9 In cases where the ventilation discharge has low fault condition discharge risk, clean-up systems are not always justified. To avoid 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; such that the system operates unfiltered during normal operations.

7.14.10 Notional air flow diagrams are shown in Figures 9 to 14. 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 air supply ventilation system. There are many variations of this illustrative diagram to suit differing installations. All, however, should comply with the foregoing subsections.

7.15 Design Air Flows

7.15.1 Air flows within radiological controlled buildings will be determined by the radiological requirement to maintain correct depression and air flows between areas. Air flows and hence the number of room air changes will also be driven by the conventional ventilation requirements to cater for outdoor air for occupancy, cooling load, heating, removal of odour, potential asphyxiates, dilution of gases, moisture removal etc.

7.15.2 One of the fundamental principles for ventilation design in a radiological controlled building is to minimise the air flow through the facility (see clause 7.2). Whilst historically suggested room air change rates were given as a rule of thumb for different buildings/room types in conventional buildings, CIBSE Guide B2: 2016 recognises that this is now falling out of favour because of its high dependency on room volume, which fails to reflect the physical need to provide outdoor air or remove heat. Similarly minimum room air change rates would not normally determine the air flow rates through a modern day designed radiological controlled building, where energy use and whole life carbon impacts need to be assessed and minimised.

7.15.3 Note that on many older radiological controlled buildings (pre 1980/90's designs), air flows are considerably higher than for modern design facilities. This was as a result of following the original industry design guidance AECP 1054 where the design emphasis was placed on room air change rates rather than flows across barriers.

7.15.4 Unless minimum air change rates in rooms are required to address specific process requirements, dilution requirements for gaseous arisings, or plant heat gains, they are normally a secondary consideration in nuclear facilities, where flows to support containment normally take precedent.

7.15.5 In those areas where operator access is allowed with respiratory protection and PPE, but which also have the potential for airborne activity (AMBER areas), increasing the air change rate is not likely to lead to a reduction in the airborne activity levels local to the operator. Whilst increased air flow could be argued to reduce the average concentration in the area as a whole, greater air movement resulting from higher air flows would encourage levitation of contamination and hence increase airborne activity levels. Therefore, high flow rates in these areas should be avoided.

7.15.6 In RED areas, air change rates should be the minimum required to meet the process requirements of the area and maintain containment. Increasing the air change rate could lead to greater entrainment of airborne activity into the exhaust air stream. Where filtration is not installed at the point of extract from the containment, this would then lead to a greater potential for accumulation of contamination on internal ductwork surfaces upstream of filters and increased activity on the filters. This could possibly lead to increased shielding requirements for ductwork and filter housings. Excessive entrainment of activity in the ventilation air stream would also not be consistent with the principle of minimising discharges at source.

7.15.7 In certain circumstances, subject to hazard assessment, and by agreement with the responsible safety authority, re-circulation may be employed in areas with low contamination potential (GREEN and WHITE areas. See also section 7.14.2).

7.15.8 For initial design schemes the following approach may be used to estimate the design air flows and hence the size of ventilation plant, using the best process information available at this early stage of the design process: -

- consider first the most hazardous areas (e.g. RED areas) and estimate the flows needed to deal with the process requirements, e.g. heat, moisture or gaseous arisings and flows across leakage paths to maintain design depressions, balanced with the need to, where reasonably practicable, minimise activity entrained/deposited within the ventilation system and down-stream abatement plant, and ultimately discharged into the environment
- consider the flows required in the adjacent areas (e.g. AMBER) to provide the make up flows to the RED areas and also specific ventilation requirements within these areas
- estimate the number of entry facilities (sub-change rooms/air locks) between GREEN and AMBER areas to estimate the cascade flows required across these entry facilities (allow approximately 1 m^3/s per personnel entry facility)
- identify any additional ventilation flow requirements in GREEN areas, over and above, the flow required to achieve the cascade flows into the AMBER areas across the entry facilities. Building Regulations Part F specifies a minimum outdoor air requirement of 10 l/s per person. However, as many radiological facilities will be of low occupancy, it may be more appropriate, for normally occupied areas, to use a minimum outdoor air rate based on floor area (see clauses 6.2.1.5, 6.2.1.6 and 6.8.2.2).

7.15.9 The following arrangements may be used as an aid in the early conceptual design stage of ventilation systems. The figures cover many but not all ventilation sub-system configurations (for example, they do not cover natural ventilation systems, or re-circulated systems). They show some major items of plant required, the direction in which air cascades from one radiological classified area to another, and typical supply and extract arrangements.

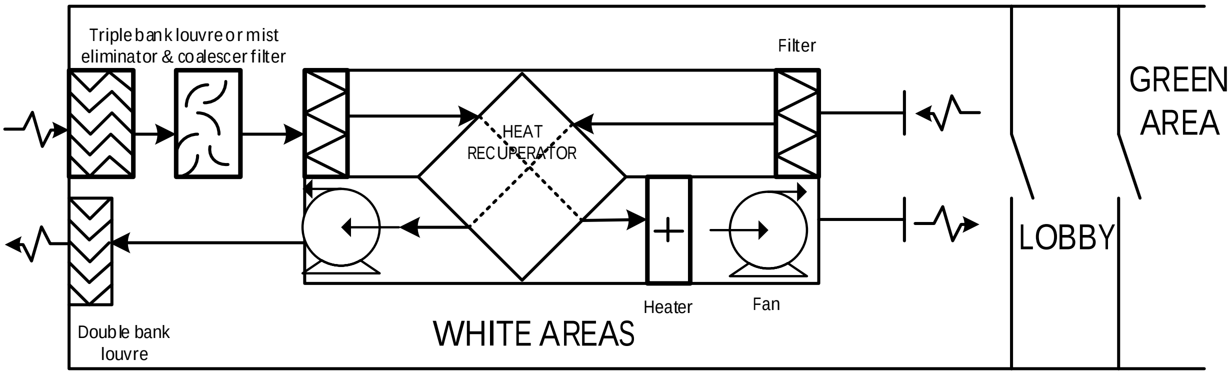


Figure 9 – Ventilation for WHITE areas

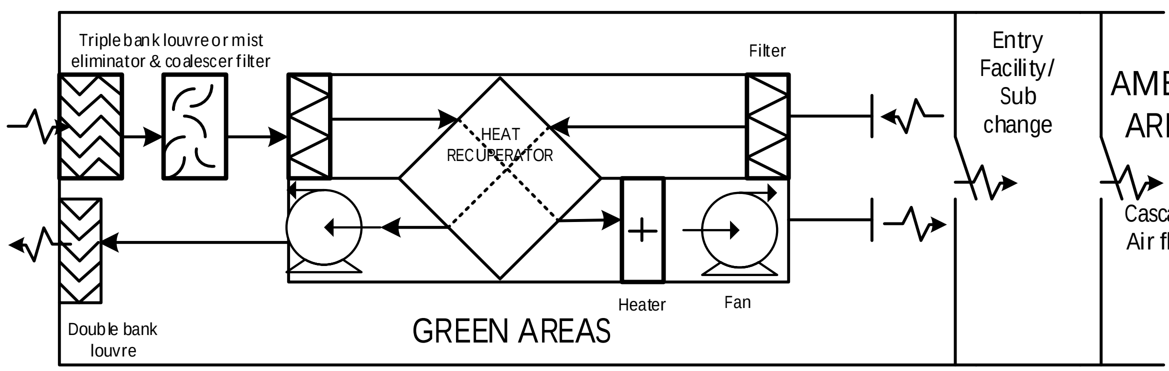


Figure 10 – Ventilation for GREEN areas, example 1

7.15.10 Where the ratio of extract air to supply air for GREEN areas is relatively high, figure 10 using a heat recuperator (plate heat exchanger or thermal wheel) within the air handling unit should show a reasonable level of heat reclaim from the exhaust air stream.

7.15.11 Where the majority of the GREEN area supply system is cascaded into AMBER areas, figure 11 may offer a higher level of heat reclaim from both the GREEN and AMBER exhaust air streams.

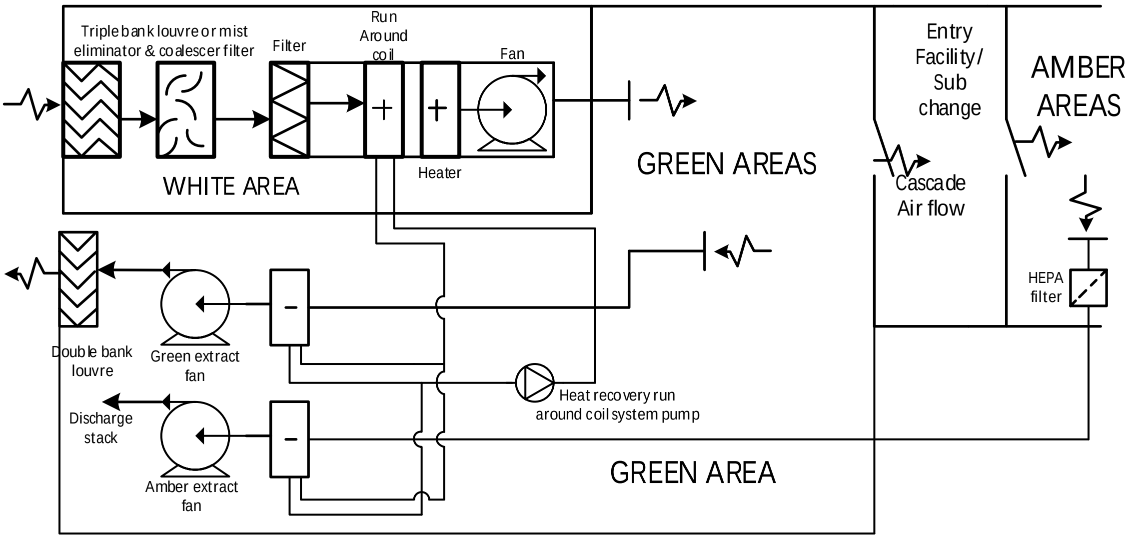


Figure 11 – Ventilation for GREEN & AMBER areas, example 2

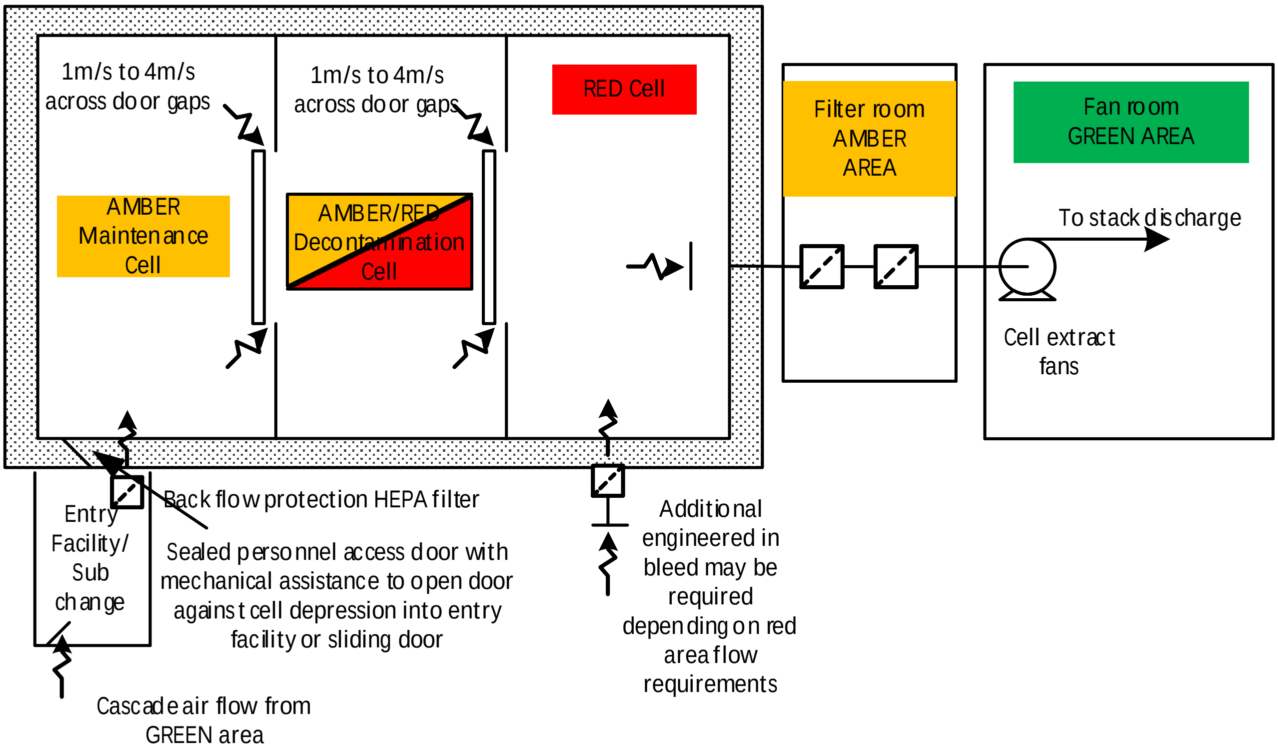


Figure 12 – Ventilation for RED areas, example 1

7.15.12 In figure 12 where shield doors are indicated on the both the containment boundary between the AMBER and AMBER/RED area, and the containment boundary between the AMBER/RED and RED areas for plant access routes, there will be gaps around the edges of the shield doors across which it is recommened that the optimum containment velocity of 1m/s should be targeted and preferably not greater than 4m/s (see figure 8). Such velocities at these containment breaches will give very low differential pressures across these contamination zone boundaries. Hence, if the design depression of the RED cell is in the order of 250Pa, with respect to the GREEN zone (see clause 9), then the majority of this differential pressure will need to be engineered across the entry facility/sub change room between the GREEN and AMBER area. This would typically require a sealed door on the exit from the sub-change room into the maintenance area, with mechanical assistance on the door to enable its opening and closure against the relatively high operating depression. When the door is closed, the cascade flow from the sub-change room would be via a HEPA filtered engineered wall penetration suitably sized to give the required boundary pressure drop (in this case 200 to 250Pa) for the required downstream flow into the AMBER and RED areas.

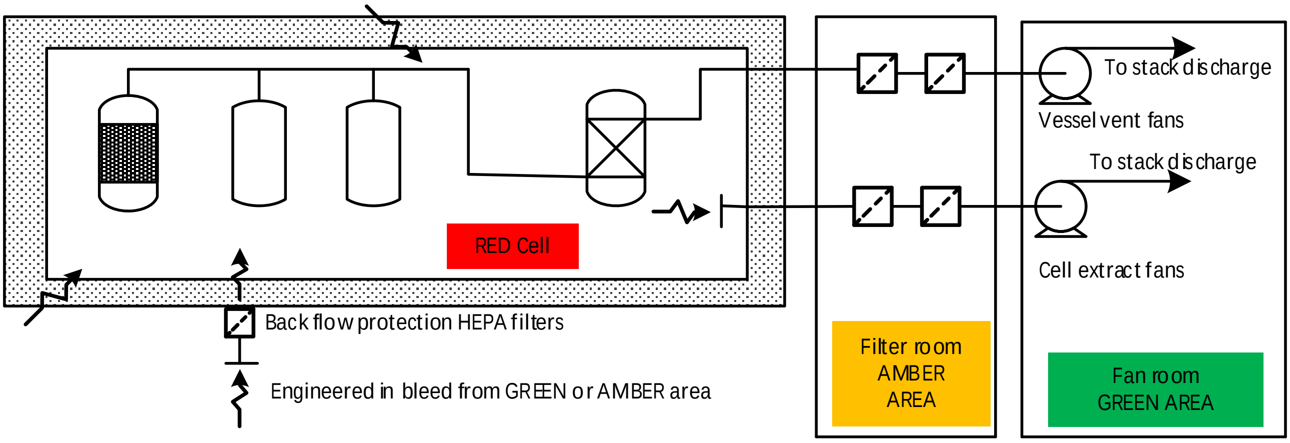


Figure 13 – Ventilation for RED areas, example 2

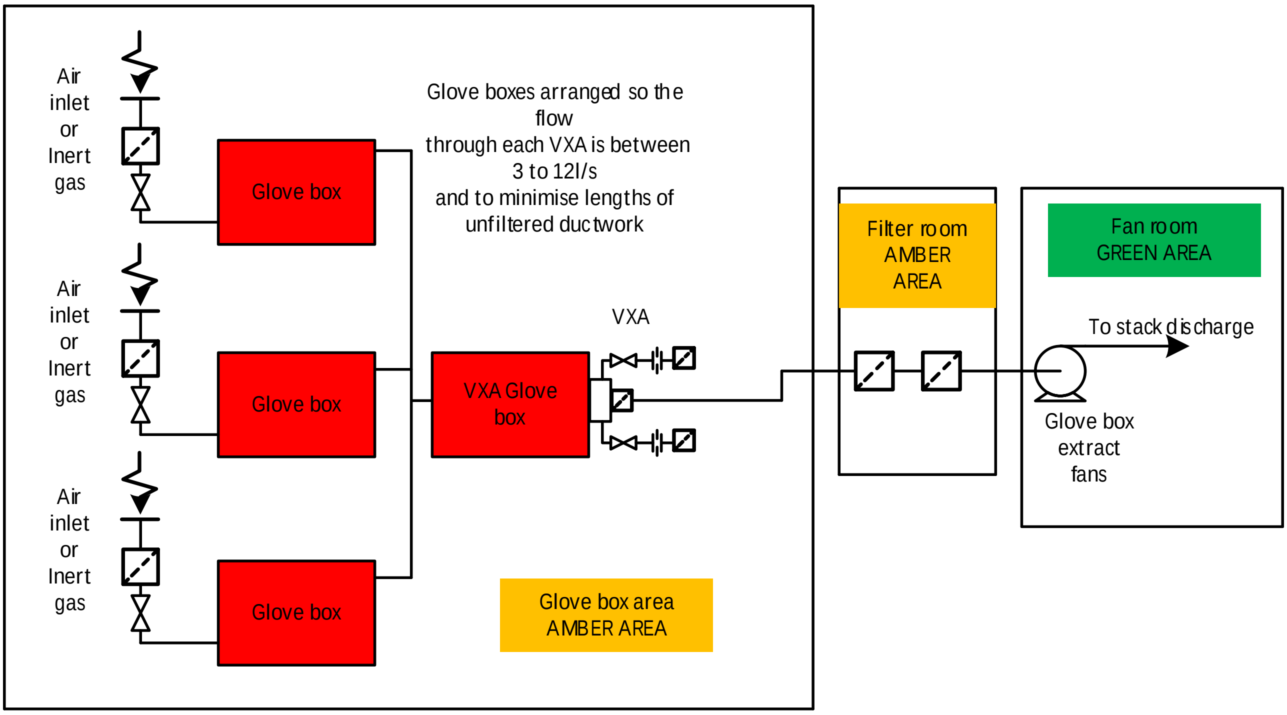


Figure 14 – Ventilation for RED areas, example 3

7.15.13 Note: for alpha plants, additional stages of HEPA filtration are likely to be required on all systems due to the potential for increased levels of airborne activity resulting from the mobility of alpha emitting material and how little of this material is needed to be extremely hazardous.

7.15.14 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 only for typical arrangements – these should not be taken as read and need clear assessment to support their use.

7.16 Differential Pressures Between Areas

7.16.1 Pressure differences between areas of different radiological classification generate the required flow of air through penetrations within the containment boundaries between these areas. Whilst correct fan selection and system balancing ensures that the correct cascaded flow rates between the areas are delivered, the differential pressure across a penetration is also largely influenced by the physical characteristics of the penetration, e.g. geometry of opening, edge effects, length of opening, free area, temperature gradients/thermal buoyancy effects etc.

7.16.2 Clause A.3.1 of BS EN 12101-13:2022 Smoke and heat control systems Part 13: Pressure differential systems (PDS) – Design and calculation methods, installation, acceptance testing, routine testing and maintenance gives a method for the calculation of volume flowrates against differential pressure through openings using the following equation [A.1]:

$$Q_{OPENING} = C_V \times A_{OPENING} \times \sqrt{\frac{2}{\rho}}\,(\Delta P)^{\frac{1}{R}}\ m^3/s$$

Where

$Q_{OPENING}$ is the air flow through the relevant opening	(m^3/s)
C_V is the coefficient of discharge (0.6 – 0.9)	use 0.65 as typical
$A_{OPENING}$ is the opening area	(m^2)
ΔP is the pressure difference across the opening	(Pa)
ρ is the density of air	use 1.2kg/m^3 as typical
R is the coefficient of flow -	Note 2 (from BS EN 12101-13). For wide cracks such as those around doors and large openings, the values of R may be taken to be 2.0, but for narrow leakage paths formed by cracks around windows a more appropriate value of R is 1.6 (laminar v. turbulent flow)

7.16.3 Table A.2 of BS EN 12101-13:2022 gives a typical leakage area for a double leaf door as 0.03m^2 but with the clarification that it is for guidance only as leakage areas are highly dependent on the quality of workmanship. Using equation [A.1] for this leakage area, Table A.2 gives an air leakage of 140l/s for a pressure differential of 30Pa, and 100l/s for a pressure differential of 15Pa.

7.16.4 For RED areas such as caves, cells and glove boxes, large depressions are of the norm; typically 150Pa to 375Pa, or greater, depending on the specific process requirements. As depressions within containments can fluctuate as a result of transient behaviour (e.g. in the process, changes in environmental conditions, movement of arms within the box or partial breaches at penetrations) it is normal to set an operating or 'design' depression for the containment at a value such that any 'normal operating' fluctuations are unlikely to cause the depression measuring instrument to trigger its alarm values.

7.16.5 To achieve these relatively high operating depressions within caves or cells, in which large penetrations may be required to accommodate plant movements (typically protected by shield doors) it will often be necessary to provide multiple containment barriers. The final containment barrier adjacent to the GREEN area should be provided with well sealed penetrations where practicable.

7.16.6 On well sealed containments (such as glove boxes) the depression within the containment, relative to the room, can be controlled. For example; for an air atmosphere glove box, usually by the selection of an inlet filter and a regulating valve on the inlet connection.

7.16.7 Similarly on new cave/cell structures, where penetrations through the cave/cell structure are well sealed, the depression within the cell relative to the surrounding room(s) can be controlled. This is with an engineered inbleed which incorporates correct sizing of inbleed filters and a balance damper on the inlet connection.

7.16.8 Depressions are less controllable on containments which are less leaktight due to, for example; - ageing of the structure, lack of maintenance of seals on penetrations, or the need for large penetrations (which are difficult to seal) within the containment structure. On such structures, the only practicable method of increasing the containment depression (apart from improving the leak tightness of the structure) would be to increase the extract flow rate from the containment.

7.17 Differential pressures across GREEN to AMBER entry facilities in alpha plants

7.17.1 Differential pressures across well sealed entry facilities in alpha plants can be controlled by the sizing and type of air transfer grilles located on the entry facility boundaries, through which the cascaded air is designed to flow when the doors are closed. Based on a typical single door opening of say 2m high x 0.9m wide, a 0.5 m/s velocity across an open door would give an air flow of approximately 0.9 m^3/s. If this air flow was engineered to flow through door mounted transfer grilles, suitably sized single leaf vision proof grilles, using a minimum face velocity of 1 m/s, would typically give a pressure drop of approximately 10 Pa (see figure 7). If a higher pressure drop was required the door transfer grilles could obviously be reduced in size. Increasing the pressure drop too much (say > 25-30 Pa) may give rise to problems with opening the doors or doors not closing correctly.

7.17.2 For entry facilities which are designated as separate fire compartments, it would usually be impractical to use door mounted air transfer grilles, as a fire damper would normally be required on the breach within the fire compartment. In such cases the transfer grille could be installed complete with a fire damper in the wall/partition adjacent to the door. This may often lead to a larger penetration for the same pressure drop (as a door mounted transfer grille) as grilles would be needed on both sides of the fire damper (for personnel protection). However, a greater pressure drop would also serve to limit the air flow through this path when the door is opened which is a requirement to achieve the 0.5 m/s ‘containment velocity.’

7.17.3 The depressions required to drive air flows across penetrations (usually doorways) between GREEN and AMBER areas are, therefore, relatively low and are not easily measurable. However, as in these cases the velocity and hence flow across the boundary is the key parameter for containment purposes, the differential pressure is only indicative and the exact Δp is unimportant as long as the correct flow is maintained.

7.18 Differential pressures across GREEN to AMBER entry facilities in lower risk plants

7.18.1 Both the ASHRAE Journal article referenced in Appendix E.1 and the BSRIA testing referenced in Appendix E.2, which both focus on designs to minimise transmission of airborne contaminant from a source room into an adjacent room, provide relevant learning and correlation to air flow regimes through a lobby/entry facility from a GREEN to AMBER area. Both the ASHRAE and the BSRIA testing demonstrate that small differential pressures between rooms can give effective isolation.

7.18.2 In facilities where there is a lower risk of migration back through an entry facility between AMBER and GREEN areas, than for an alpha plant, figure 15 considers two alternative approaches. Figure 15 (a) is based on the arrangement used for the BSRIA cascading negative pressure test reported in Appendix E.2. Figure 15 (b) is based on a traditional cascade arrangement described in clause 7.10.10 of this document and illustrated in figure 7, but with the transfer grilles omitted and so a significant reliance is made on ensuring the leak tightness of the building fabric (particularly for the AMBER area and the entry facilty) to ensure a sufficient depression cascade can be maintained by the AMBER extract system.

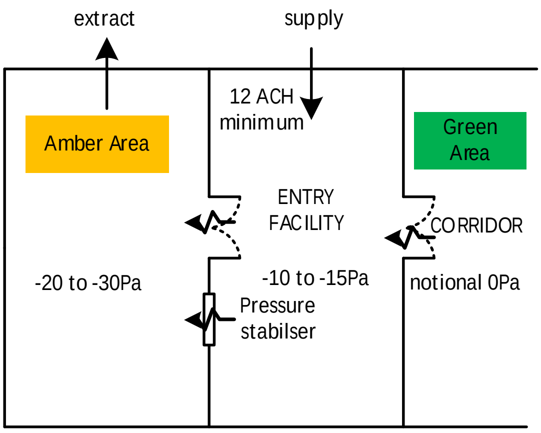


Figure 15 (a)

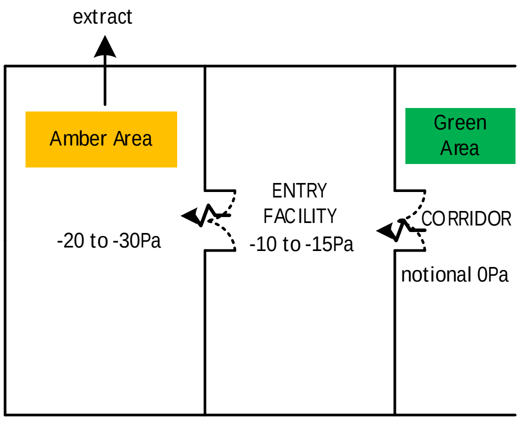


Figure 15 (b)

Options for differential pressure basis for GREEN to AMBER cascade

7.18.3 For the Figure 15 (b) arrangement, with a 10 to15Pa differential pressure across each of the 2 closed door in series on the entry facility, for an R value of 1.64 (see Appendix E2.2), the 10-15Pa differental pressure across door crackage would equate to a velocity in the region of 3.4m/s to 4.4m/s, which is at the upper end of the range of 1 to 4m/s recommended in clause 7.10.19 of the document.

7.18.4 Based on the guidance provided in BS EN 12101-13:2022 and the test data from the healthcare isolation suites discussed in Appendix E.2, the air flow rate to achieve a 15Pa target differential pressure at each door is likely to be in the region of 65l/s to 100l/s; and for a 10Pa target differential pressure at each door a flow in the region of 50l/s to 80l/s. Whilst this is a significant reduction, and would not provide the bulk airflow through the entry facility, compared with the 0.8 to 0.9m^3/s recommended for an alpha plant, for an entry facility typically 6m L x 3m W x 2.8m H, even these reduced flow rates would provide 3.6 to 7 air changes per hour. With the door closed, using the claimed' DFs for containment barriers as listed in the Sellafield Release Fraction Database (RFDB) Table 6.4 – DFs for a variety of plant containment barriers, such an arrangement would give a decontamination factors of $1x10^5$. With the door open, this could be equivalent to change areas with no extract for which decontamination factors of $1x10^3$ have been claimed.

7.18.5 Appendix E.2 refers to BSRIA reports which also highlight that, in addition to air leakage around doors, it is probably unrealistic to assume that the general building fabric of the perimeter walls, floors and ceilings within AMBER areas will be free of leakage. Therefore, the designer should make some allowance for this leakage in the cascade air flow calculations. BSRIA publication *BTS 3/2018* suggests a maximum of 2.5$m^3/h/m^2$ @ 50Pa which would correspond to a value of 1.84$m^3/h/m^2$ @ 30Pa using an R value of 1.67 (see Apendix E2.3).

7.18.6 One of the limitations of this arrangement is that, if the amount of air needed to cascade into the AMBER area is greater than that which could reasonably pass through door leakage then, to avoid having a direct mechanical supply into the AMBER area, additional penetrations/pressure stabilsers would need to be fitted in the walls of both innermost and outermost doors. As the boundary betweeen the corridor and entry facility is likely to be a fire boundary, this could require an unnecessarily complicated detail to incorporate a fire damper with a pressure stabiliser.

7.18.7 Figure 15 (a) would offer a more flexible arrangement and would be suitable for a greater range of air flows. Taking cognisance of the recommendations given in the ASHRAE Journal article (Appendix E.1) the direct mechanical supply to the entry facility allows control over the flow of air through the room, and the recommended 12 air changes per hour can easily be engineered to 'trap' any escaped air from an AMBER area. For an entry facility typically 6m L x 3m W x 2.8m H, this would require a minimum air flow of 168l/s, which is still significantly less than the 800 to 900l/s required to give 0.5m/s across open doors on entry facilities for higher risk alpha plants. This greater air flow (relative to figure 15 (b)) would require a pressure stabiliser, or grille, in the boundary between the entry facility and the AMBER area.

7.18.8 Pressure stabilisers, which are generally available as commercial quality plant items with design lives appropriate to commercial applications, have been known to fail in service over the life of a nuclear plant. They should therefore, if used, be considered as a replaceable item and their use considered where they can be readily accessed for inspection/maintenance and can be easily replaced. Alternatively, a fixed grille could be used and partially blanked off during commissioning to create the desire differential pressure across the boundary.

7.19 Measurement of differential pressure between rooms

7.19.1 In healthcare facilities where a room must have a guaranteed negative pressure against the corridor and nearby rooms to avoid the spread of infectious particles, the measurement of these small differential pressures are maintained using devices such as the Micatrone Micaflex PFA Pressure and Flow transmitter with alarm function and control output.

7.19.2 Devices such as these can provide operating ranges down to 0 to 100Pa with the 4-20mA scaled over the required range 0 to 50Pa. When installing the sensor in the Amber area, clean room sensors are available in polished stainless steel for decontamination. A typical example being the picture below, which shows the VM-BA-1-STD-N-B5 sensor supplied by Fluidic. Model VM-BA-1-PRT-N-B5 shown below provides a through partition wall device.

7.20 Natural Ventilation

7.20.1 The requirement for providing safe and secure storage of radioactive waste and nuclear materials on Nuclear Licensed sites presents a number of challenges for the ventilation designer. Such stores may have 50 to 100 year operating lives. They may often require the ventilation system to provide a cooling function. To continuously maintain this cooling function throughout the life of the plant, a high degree of reliability and availability will be essential for the ventilation system.

7.20.2 Operating costs of mechanical ventilation systems for such stores can be significant. The Engineering Substantiation required to satisfy stringent safety criteria can also prove difficult to achieve with a cooling system utilising mechanical ventilation or forced/mechanical cooling.

7.20.3 There are several examples on UK Nuclear Licensed sites where Natural Ventilation has provided a low running cost option for store design. This gives a self regulating system that can adapt to varying heat loads but requires no operator intervention, or reliance on a control system.

7.20.4 Natural ventilation systems rely on the stack effect and are therefore suited to installations where the nuclear material naturally generates heat.

7.20.5 As the stack effect produces relatively small pressure differentials, pressure drops within the air flow paths need to be kept to a minimum and multiple containment barriers between the nuclear material and the airstream will be needed so filtration of the air stream is not required; i.e. the air stream would need to remain in a WHITE or GREEN classified area.

7.20.6 Due to the absence of filtration, this creates a requirement for high integrity containment of the stored material. Additionally, for long-term storage, the nuclear material would need to be stored in containers where corrosion doesn't become an issue.

7.20.7 A wide spectrum of allowable operating temperatures would be needed to cater for the variation in external ambient conditions.

7.21 Ventilation of Incident Control Rooms

The ventilation systems serving incident control rooms should be designed to continuously maintain comfortable and safe environmental conditions, and to help protect the occupants from being exposed to external airborne contamination. 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 of 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)

(e) Control of temperature and humidity

7.22 Ventilation of Battery Rooms

7.22.1 The ventilation of battery rooms is principally driven by the need to dilute any hydrogen gas evolved from the batteries. The peak rate of hydrogen evolution will normally occur during the charge mode.

7.22.2 BS EN IEC 62485-2:2018 Safety requirements for secondary batteries and battery installations – Part 2: Stationary batteries; recommends ventilating a battery enclosure to maintain the hydrogen concentration below the 4%vol hydrogen Lower Explosion Limit (LEL) threshold. It recommends that the amount of ventilation air flow shall preferably be ensured by natural ventilation.

7.22.3 Battery rooms should wherever possible be in a WHITE classified area, ideally on the external perimeter of the building to facilitate natural ventilation.

7.22.4 For natural ventilation, BS EN IEC 62485-2:2018 requires an air inlet and an air outlet with a minimum free area of opening calculated by the formula:

$$A = 28 \cdot Q$$

with Q = ventilation flow rate of outdoor air in m^3/hr

A = free area of opening in air inlet and outlet in cm^2

with an air velocity assumed of 0.1m/s

7.22.5 The ventilation outdoor air flow rate can be obtained typically from battery manufacturer's data sheet or calculated using the method given in BS EN IEC 62485-2:2018.

7.22.6 BS EN IEC 62485-2:2018 recommends that the air inlet and outlet shall be located at the best possible location to create best conditions for exchange of air, i.e. openings on opposite walls, minimum separation distance of 2m when openings on the same wall. It is suggested that there should be a 2m vertical distance in height for such openings.

7.22.7 Where an adequate air flow Q cannot be obtained by natural ventilation and forced ventilation is used, BS EN IEC 62485-2:2018 recommends that the battery charger be interlocked with the ventilation system or an alarm actuated to secure the required air flow for the mode of charging selected. The air extracted from the battery room shall be exhausted to the atmosphere outside the building.

7.22.8 BS EN 60079-10-1:2015 Explosive Atmospheres. Part 10-1: Classification of areas - Explosive gas atmospheres; provides more detailed requirements and recommendations for the ventilation of areas where flammable gas or vapour hazards may arise. It states that the room ventilation flow rate, relative to the release rate of the flammable substance, is the most important factor that determines the ability of a release in an enclosure to become dilute.

7.22.9 HSE document L138 (Second Edition 2013) is the Approved Code of Practice (ACOP) and guidance for practical advice on how to comply with the Dangerous Substances and Explosive Atmospheres Regulations 2002 (DSEAR). It states that ventilation should be designed to dilute the concentration of any dangerous substances to a safe level (below that which could form an explosive atmosphere) by providing air changes preferably through natural ventilation. Where sufficient natural ventilation cannot be achieved, it recommends that mechanical extract ventilation (MEV), local exhaust ventilation (LEV) and/ or forced ventilation at process and storage areas should be provided.

7.22.10 Advice given on the battery manufacturer’s data sheet relating to recommended storage temperature for battery cells should be followed as continuous operation at room temperatures above those recommended may reduce the battery life. IEEE Std 1635-2012/ASHRAE Guidelines 21-2012 IEEE/ASHRAE Guide for the Ventilation and Thermal Management of Batteries for Stationary Applications; states that the optimal operating range for a battery (Vented lead-acid VLA, valve-regulated lead-acid VRLA, and nickel-cadmium NiCd) is an electrolyte temperature between 20°C and 25°C. Operation in this temperature range provides the best balance between capacity and battery life.

7.23 Local Exhaust Ventilation

7.23.1 HSE document HSG258 (Third Edition 2017) ‘Controlling airborne contaminants at work - A guide to local exhaust ventilation (LEV)’ provides guidance on the design of new local exhaust ventilation (LEV) equipment. HSG258 defines LEV as an engineering control system to reduce exposures to airborne contaminants such as dust, mist, fume, vapour or gas in a workplace.

7.23.2 The Institute of Local Ventilation Engineers has a LEV Competency Matrix with the aim of ensuring that end users and employers of LEV services and systems can be confident that the persons responsible for their LEV plant are suitably qualified and competent to do the work.

8 Glove Box Ventilation

8.1 Use of Glove Boxes

8.1.1 A glove box is designed to confine material and prevent the spread of toxic or radioactive contamination to the operator's environment while permitting operator access to the material.

8.1.2 In some circumstances, the glove box serves as a barrier to prevent the ingress of contaminants (such as oxygen) from the surrounding area rather than containment of internal contamination and special consideration is given to this type of glove box.

8.1.3 To determine if a particular process needs to be carried out within a glove box, several factors need to be considered, such as the nature and throughput of the process, the materials being handled, and the need to control the atmosphere required.

8.1.4 The range of uses and activity levels in glove boxes is varied. Their uses can include 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 certain beta gamma and alpha beta gamma radioactive materials for which shielding is required as well as containment

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

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

(f) Handling of bio-hazardous material

8.1.5 ES_0_1503_1 provides further information on the design, operation and ventilation of glove boxes.

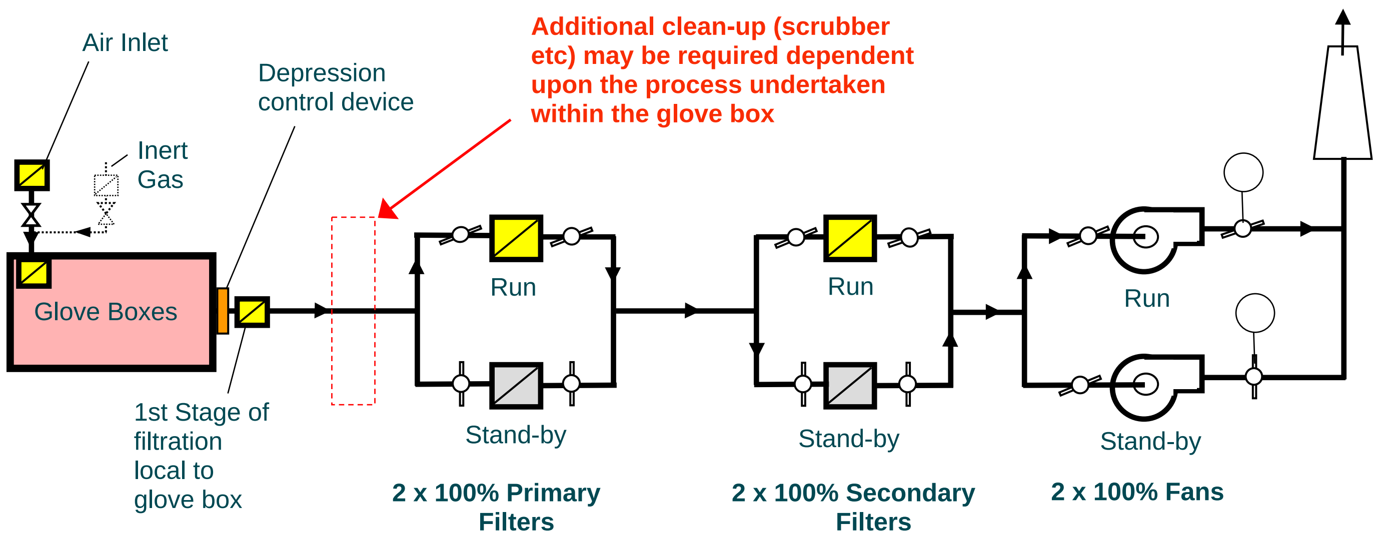


Figure 16 Typical Glove Box Ventilation System Arrangement

8.1.6 A glove box extract ventilation system usually includes three stages of filtration. The first stage is normally located at the glove box to minimise contamination build up in the downstream ductwork. Any such build up of contamination could emit a radiation dose, which could lead to access restrictions and the need to back fit shielding.

8.1.7 There may be a requirement for additional clean-up dependant upon the process being undertaken within the glove box. Gases may require a scrubber or carbon filtration. Such clean-up would commonly be attached to the process within the glove box.

8.1.8 Glove box extract system flow rates are low compared with other extract ventilation systems. The main header size is generally 150 diameter or smaller. Stainless steel pipework is normally used rather than fabricated ductwork.

8.2 Functions of Glove Box Ventilation

The glove box ventilation system is required to provide a number of functions: -

- provide and control an atmosphere in the glove box to the quality required for the process
- prevent accumulations of undesirable gases and vapours within the glove box
- supplement the glove box containment in minimising the escape of radioactive contamination to the working area and to the environment under normal and postulated accident conditions
- remove radioactive/toxic/noxious particulate/gaseous materials from the exhaust gases to such an extent as is necessary for its safe discharge to the environment
- to control a breach in the containment.

8.3 Design Criteria

8.3.1 The nature of the processes to be performed in the glove boxes would normally determine the box atmosphere. The pressure at which the box atmosphere is controlled, together with the flow rate of air or gas/number of air changes per hour of the box atmosphere, should also be considered.

8.3.2 The protection provided by a glove box is enhanced by the depression inside the glove box. This depression draws air into the glove box through any adventitious leakage paths that may exist.

8.3.3 The gloves determine the depression envelope of the glove box. If the depression is too low, the movement of the hands in the gloves can pressurise the glove box, trigger alarms and cause the associated trips of gas supplies leading to shut down of the process. If the depression is too high, the gloves begin to ‘balloon’ on the operators hands, with the resultant loss of tactile sense and a tendency to knock items over when trying to pick them up. A typical operating depression, therefore, is -375 Pa with low/high alarms set at -250 Pa and -500 Pa.

8.3.4 Early glove boxes were held under a depression, but with no purge flow and the result was that the air degraded within the radioactive environment. This degradation of the air produced minute amounts of ozone, which attacked the seals, gaskets and gloves. This resulted in leaking glove boxes and a number of glove failures. The solution arrived at was to have a small amount of flow (purge flow) through the glove box in the order of one air change per hour.

8.3.5 In the event of a glove coming off or a posting port bag failure, the extract system has to be able to remove air from the glove box at such a rate as to establish the required minimum velocity through the breach in containment. The minimum velocity is 1 m/s and the ‘design breach’ is that of an open glove port, 150mm diameter. This gives an emergency flow of approximately 65 m^3/hr.

8.3.6 Thus the basis of the low flow design approach is a small purge flow and a large emergency flow. This design approach requires a glove box depression regulator that will recognise when a breach has occurred and will switch the extract system from small purge flow to emergency flow as required. This low flow option is the preferred standard in the UK.

8.3.7 An alternative approach, as used in the US, is to use a high flow through the glove box at all times. By having a very high flow the throughput is always greater than the flow required for breach conditions and hence, switching between flow regimes is not necessary. Increased air flows however, lead to the potential for increased levels of airborne activity entering the glove box exhaust ventilation air stream, which could increase the amount of activity build up on filters.

8.3.8 In some cases the glove box should be held at a positive pressure; specifically on applications where the ingress of external contaminants has a detrimental effect on the materials being handled within the glove box.

8.3.9 The use of pressurised gases in glove boxes should be avoided if possible. Where unavoidable, such pressurised supplies must be automatically isolated when the emergency system functions and/or if the pressure/flow conditions of the pressurised gas deviate from fixed parameters.

8.4 Glove Box Atmospheres

8.4.1 Glove box atmospheres may be either atmospheric air or special gas to protect the box process. In air systems the air is normally drawn in (through filters) from the zone surrounding the glove box and discharged to waste through the necessary 'clean-up' filtration plant. Purging of the glove box atmosphere may be required for various circumstances such as clean-up at the start-up of the glove box facility from shutdown/maintenance, or provision of a throughput of clean scavenging air/gas for special processes. The purging system is frequently separate from both the normal box ventilation and the emergency extract systems.

8.4.2 Corrosive vapours and gases from the process plant should not be released into the box atmosphere, but if not removed by the process plant (e.g. condensers) should be vented from the process plant 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.

8.4.3 Where corrosive atmospheres are present, the materials used in the ventilation system will need to be selected to prevent corrosion and withstand chemical attack. Polyethylene systems may be used and care should be taken in the material selection for valves and fittings.

8.4.4 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 distribution and/or 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.

8.5 Glove Box Flow Rates

In determining the design flow rate for a glove box a number of factors need to be considered. These are:

- Glove box atmosphere - air atmosphere or a different gas such as nitrogen or argon
- Type of glove box - 'dry' or 'wet' box
- Internal volume of the box
- Amount of heat dissipation within the box - ovens, furnaces, etc.

8.5.1 Dry Processes

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. As static conditions lead to the formation of ozone, due to the radiation effects on the oxygen content, resulting in the breakdown of gloves, flexible connections and seals, some air flow is required. A reasonable flow in dry boxes is 1 to 5 changes per hour, although US designs use higher air change rates of 30/40 per hour. Heat removal may also result in a higher air change rate.

8.5.2 Wet Chemical Processes

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:

- Nature of substance being evaporated and its surface area
- Amount of evaporation
- Temperature of liquid and movement of gas over it
- Temperature of air inside and outside the enclosure
- The temperature of the clean side of the panel

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

8.6 Glove Box Inlets

8.6.1 The simplest glove box inlets are air in-bleeds from the laboratory. In their simplest forms they have either one or more HEPA filters, an isolation valve and a flow control device (which could be a manual diaphragm valve or orifice plate) and an entry into the glove box.

8.6.2 Where a glove box requires a constant flow, the use of an orifice located in the inlet is very effective. The inlet valve is an isolation valve normally fully open and closed during inlet filter change out. The Sellafield preference is for a punched plastic insert as an orifice plate on inlets. A typical air in-bleed arrangement for a glove box is shown in figure 17.

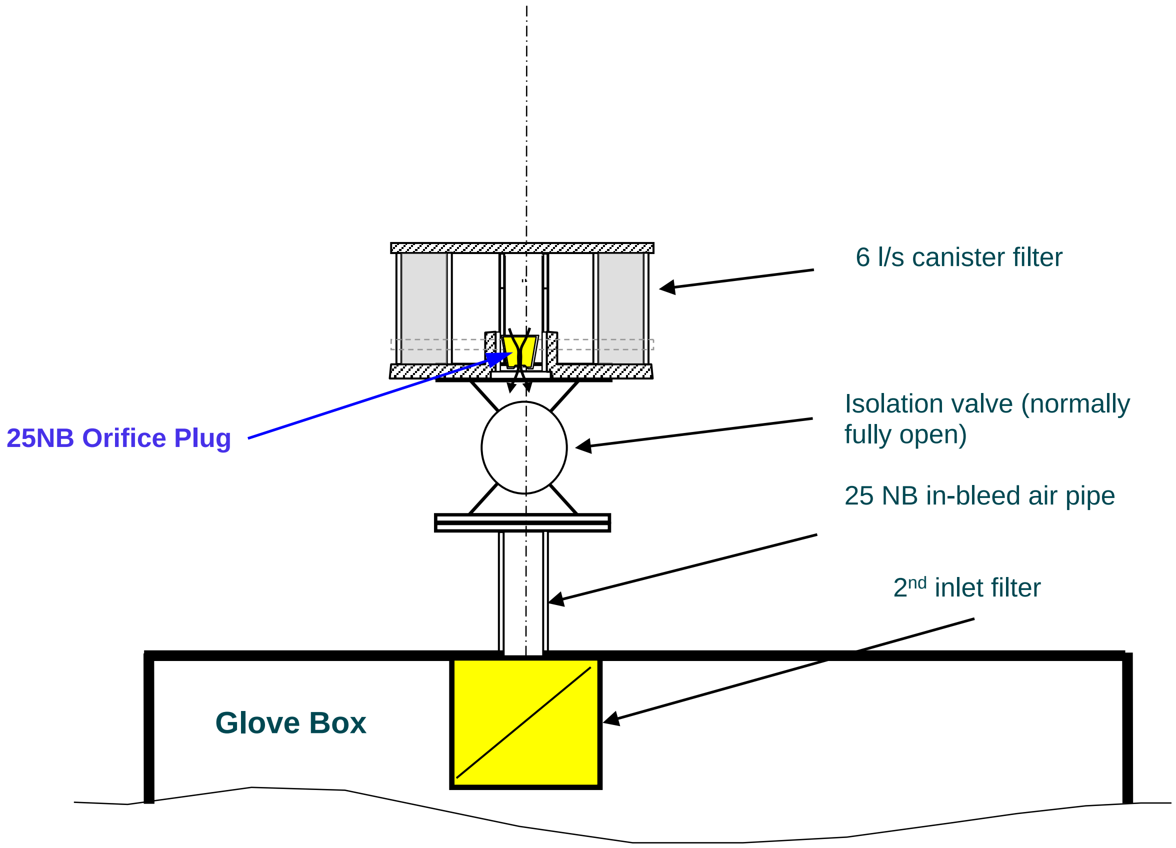


Figure 17 - General Arrangement of Glove Box Air In-bleed

8.7 Glove Box Inert Atmospheres

8.7.1 If the glove box is to be operated in a different atmosphere, such as nitrogen, then the gas flow rate must be determined by assessment of the air in-leakage, the supply gas purity and the required glove box concentration. Account should also be made of any air input due to import/export operations. In inert atmosphere boxes, the problem of ozone production is generally not present due to the very small quantities of oxygen inside the box. Gas flow rates can be as low as 10 litres per minute (equates to 0.5 air changes per hour in a typical Analytical Glove Box) or at the limit of detection for the flow meter on the inert gas supply.

8.7.2 The inert atmosphere is either discharged to waste (once-through), or recirculated through a decontamination and treatment plant. The flow of argon or other special gas will be economically restricted, but must be sufficient to maintain the requisite purity of the glove box atmosphere against contamination by in-leakage of air or by process off-gases and provide 'blanket scavenging' of the box.

8.8 Glove Box Extract Duct Sizing

8.8.1 Historically the glove box header, i.e. the duct between the VXA glove box and index glove box, has been sized at 150 mm diameter. Further calculation and installed systems has proved the header size can be reduced to 100 mm diameter and possibly 80 mm diameter in certain instances.

8.8.2 When sizing the header, the pressure loss in the section of glove box extract duct between the VXA glove box and index glove box should not exceed 100 Pa at breach flow condition.

8.8.3 The depression in the header downstream of the VXA should also be no smaller than -1500 Pa, although it is possible for a VXA to function with a depression in the header downstream of the VXA as small as -1000 Pa.

8.9 Glove Box Depression Control

8.9.1 Loss of depression occurs when a hole (breach) has appeared (typically in a glove or seal) and protection is required at the site of the breach to protect both the operator, and the atmosphere external to the glove box, against material escaping. The response to a breach, therefore, should attempt to retain material within the glove box.

8.9.2 The defence used for a glove box breach is enhanced flow. The flow regime changes from the normal (purge) flow into the box, via the inlet filter or compressed gas supply, to the breach condition where room air enters the box through the containment breach and is exhausted by the glove box extract system.

8.9.3 The simplest method of providing breach flow is to design-in a glove box air change rate, which requires the total normal running extract flow to be in excess of the required breach flow. This option doesn't require a depression control device.

8.9.4 Similarly, where there are multiple glove boxes on a system, a low pressure extract system can be sized to have sufficient flow to maintain constant depression against varying flow conditions and require no depression control devices.

8.9.5 This will require large low resistance branches and a relatively high total system flow under normal operation. 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 system. Containment will be maintained in other gloveboxes attached to the same header as the breached glove box. However, the depression within these other glove boxes will proportionally decrease as the main header depression decreases due to the effect of the breached glove box dropping from -375 Pa to say -1 Pa required for 1 m/s breach flow.

8.9.6 However, if the low flow option has been selected, then the ventilation system will require a depression control device to achieve the change between normal and breach condition, such that it allows for low flow during normal operation and enhanced flow during emergency conditions. There are several depression control devices available for glove boxes as described in the following sections 8.9.7 to 8.9.10.

8.9.7 Donkin Valve Depression Control

8.9.7.1 A Donkin Valve is a diaphragm valve that has the glove box internal depression connected to one side of the diaphragm and a reference pressure on the other side. As the glove box pressure changes, the diaphragm moves and the valve adjusts to compensate. In the case of a breach, the loss of sensed pressure would move the diaphragm a large amount and the valve would move to fully open. Thus the valve can increase the suction on a glove box and hence, create the emergency flow in breach conditions.

8.9.7.2 The sensed pressure is picked up by a small tube built into the body of the valve and as such it does not actually respond to the glove box, but the line leading from the glove box (see Figure 18) In some installations, in order to keep the valve clean and free from debris, a filter is placed between the glove box and the valve.

8.9.7.3 The valve requires routine maintenance. This maintenance requirement brings about the opening of active lines, with the associated loss of containment and potential dose uptake to workers.

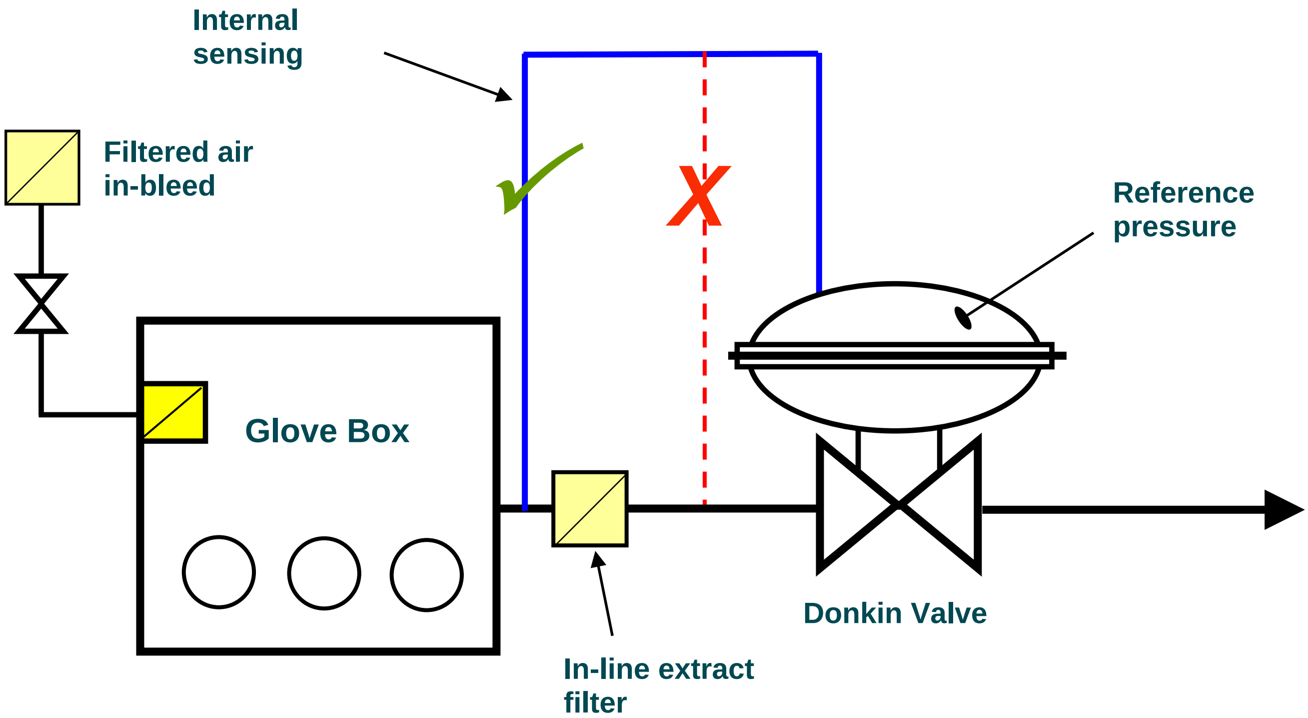


Figure 18 - Donkin Valve Arrangement

8.9.7.4 Figure 18 shows the device schematically. It shows a filter placed between the glove box and the Donkin Valve. The location of the pressure sensing line (dashed line coloured red) shows that the valve does not respond directly to the glove box. As this filter becomes progressively dirty, the glove box depression can fall off without the Donkin valve responding to it. The correct location of the pressure sensing line is the solid line shown coloured in blue.

8.9.7.5 The failure mode of this valve is to move to the open position, that is to apply the maximum suction to the glove box. This is a safe condition with regards to flow, but maximum suction may be above the ‘safe limit’ for the glove box construction. To overcome this problem, the valve has a facility to set the maximum open position and hence, limit the maximum suction placed on the glove box.

8.9.8 Jacomex Valve Depression Control

8.9.8.1 The Jacomex valve is an alternative version of the Donkin diaphragm valve (with a few fundamental differences). It is still a modulating valve with a diaphragm controller, which compares the sensed pressure against a reference as with the Donkin valve. However, the reference is not a pressure but a weight hung from the diaphragm on a chain. The amount of weight required is determined at the commissioning stage.

8.9.8.2 The glove box pressure is measured directly by a remote sensing line. Thus, unlike the Donkin valve, the Jacomex valve responds to what is happening with the glove box depression and not that of the extract line.

8.9.8.3 The valve is a standard control valve and, as with the Donkin valve, it requires routine maintenance. This again brings about the requirement for opening active lines, with the associated loss of containment and potential dose uptake to workers.

8.9.8.4 The failure mode of this valve is to move to the fully closed position and hence to remove the suction from the glove box leaving it without a depression. This is not considered to be a safe position.

8.9.8.5 Thus the Jacomex valve, even though it has improved sensing capabilities, has features that are not desirable and hence is to be considered as a less preferred device than the Donkin valve.

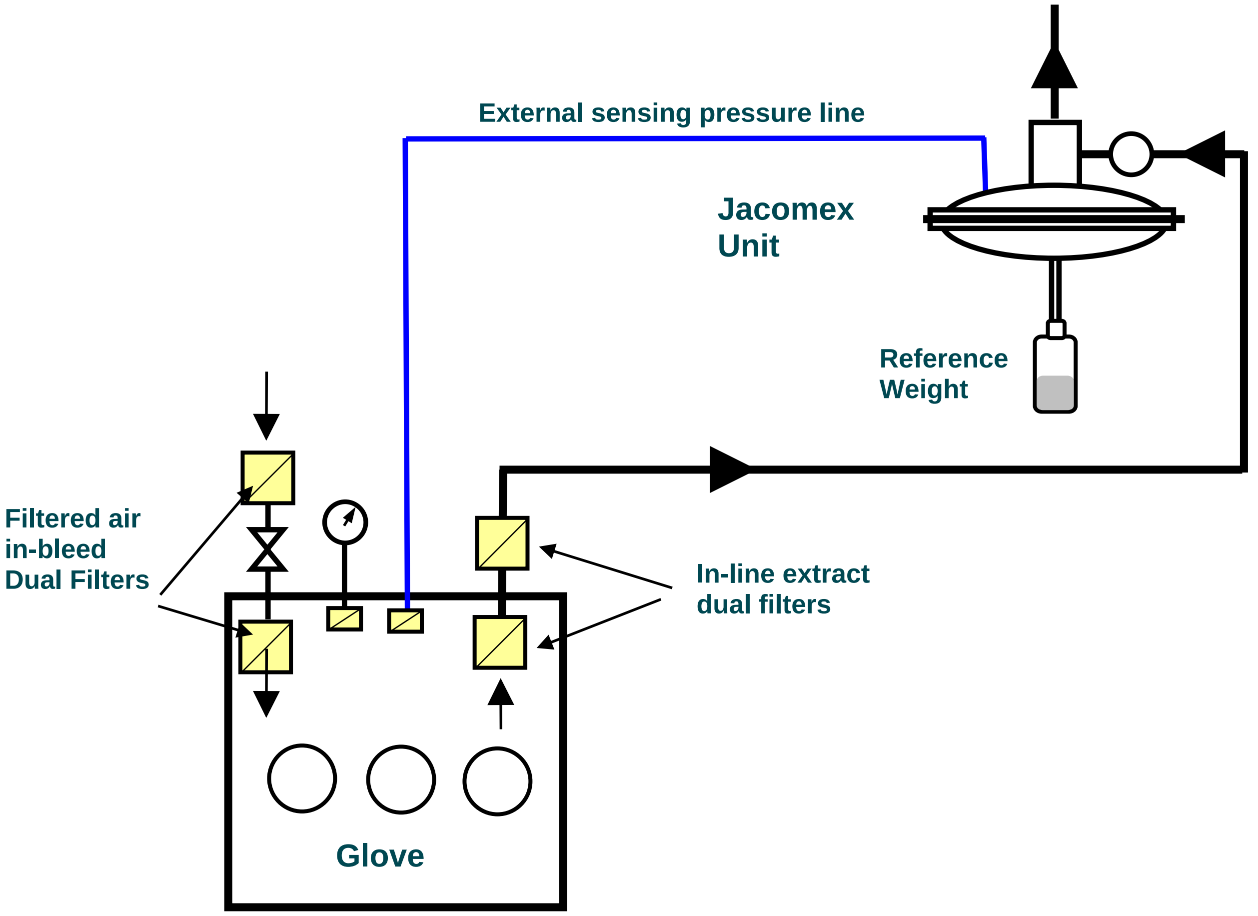


Figure 19 - Jacomex Valve Arrangement

8.9.9 Controlled In-bleed Depression Control

8.9.9.1 A variation of the low pressure extract system described in sections 8.9.4 & 8.9.5 is the addition of a controlled filtered engineered inbleed into the system, where the sum of the normal flows through all of the gloveboxes on the system is still insufficient to guarantee a 1 m/s breach flow through a single glove box.

8.9.9.2 The controlled in-bleed is located downstream of the glove boxes and incorporates a suitably sized orifice, HEPA filter (for back flow protection) and isolation valve. The orifice is sized to create a differential pressure equivalent to the glove box depression at a volumetric flow which, is above the required breach flow. This total flow is equivalent to the sum of the breach flow plus the reduced flow, which will pass through the orifice at the reduced depression during the breach situation.

8.9.9.3 For such a system, it is important that the pressure drop, under normal flow conditions, between each glovebox outlet and the branch connection for the filtered inbleed is as low as possible (preferably 10 to 20 Pa maximum). Therefore, the duct/pipe run from the outlet of the glove boxes to the inbleed connection should be as short as possible to keep losses to a minimum. The depression in the extract main could therefore be no more than about -400 Pa. Compared to a VXA system, where the High Pressure Extract line may operate at a depression of 1.5 kPa, this type of system can enable the fan head to be reduced (potentially by greater than 1 kPa) with the result that, if glove boxes are subjected to full system depression, the integrity of the boxes is less likely to be jeopardised.

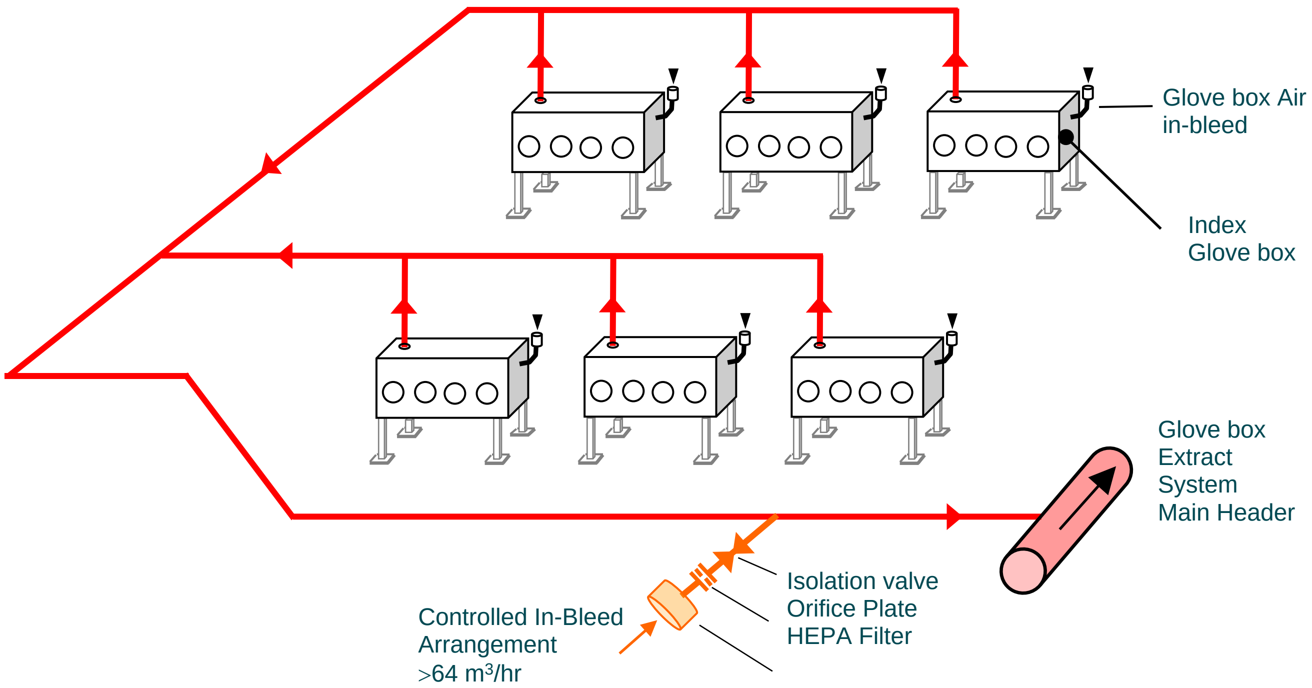


Figure 20 - Controlled in-bleed arrangement to provide breach flow

8.9.9.4 It is normal practice to install terminal (push through) filters on each glove box extract (not shown on the above diagram). Whilst these filters help to maintain the pipe between glove box and primary filter as free from contamination as practicable, the loading of these filters is difficult to monitor at the low flows that are present in the normal flow condition from a glove box. Consequently these terminal filters can be heavily loaded and only show a small increase in pressure drop at the glove box normal flow condition, and it is difficult to measure the relative filter loading. However, when a breach condition occurs, the significant increase in glove box flow would result in a large pressure drop across the dirty filter, which may well prevent the minimum 1 m/s breach flow being attained. Consideration should therefore be given to closely trend, for example, flow from the glove box under normal conditions to estimate progressive loading of the terminal filter such that it can be changed before it is likely to prevent the minimum 1 m/s breach flow being attained.

8.9.10 Vortex Amplifier Depression Control

8.9.10.1 The Vortex Amplifier (VXA) is a fluidic device that does not have any moving parts and is virtually maintenance free (except for changing the control port filters). The VXA uses differing flow path lengths to bring about a change in its resistance and to hence modulate the flow through it.

8.9.10.2 The device is a flow/depression controller and can be used to offset filter dirtying, or the more normal use is to achieve enhanced flow rates in breach conditions on glove boxes.

8.9.10.3 The Vortex Amplifier is relatively expensive in terms of capital costs, but has the advantage of no moving parts or polymer components (such as diaphragm valves). Hence, almost no maintenance is required. There is far less potential operating and maintenance dose uptake associated with the VXA than with the Donkin or the Jacomex valves.

8.9.10.4 The VXA may have the higher initial costs, but it is likely to have the lowest overall lifetime costs when the costs of maintenance and dose to workers over the life of the plant are taken into account. More detailed information on the operation of VXAs is given in EG_0_1706_1 Design Guide for the Specification of Vortex Amplifiers.

8.10 Glove Box Filters

8.10.1 Section 13 of this document gives general information on the use of HEPA filters. Filter design and selection is covered in EG_1_1702_1.

8.10.2 A range of suitable filters are available including:

- 0.25 l/s for sensing lines
- 1.25 l/s for inlet branches
- 5 l/s for inlet and extract branches
- 25 l/s for extract branches
- 35 l/s for extract branches (‘push-through’ filters as used on VXA arrangements)

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

8.10.4 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 in the event of actual pressurisation of the glove box. Many filters are now supplied marked with an arrow indicating the required direction of flow. Inlet filters are normally oversized such that the pressure drop at design flow is small and therefore dirtying of the filter does not lead to a significant flow reduction. The inlet pressure control authority is normally provided by the inclusion of a restrictor such as an orifice as shown in Figure 17.

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

8.10.6 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.

9 Ventilation of Caves and Cells

9.1 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 gaseous arisings (e.g. hydrogen)

(e) The activity arisings and their form under both normal and postulated accident conditions (e.g. fire)

(f) The minimisation of airborne effluent discharges to levels that are As Low As Reasonably Achievable

(g) The long term reliability of the system

(h) The decontamination and decommissioning facilities and procedures

9.2 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 normal breaches of containment. As discussed in section 7.10.12 it is not always practicable to engineer air flows to support containment across large openings and consideration should be given to providing multiple containment barriers.

9.3 Caution 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 an average velocity of 1 m/s through any engineered inlet system and adventitious opening

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

- Limit the amount of in-leakage which requires subsequent treatment
- Ensure that any enclosed process vessel or vessel vent system is held at a greater depression than the cave or cell
- Minimise fan energy consumption

9.4 The design depression for caves and cells based on the above criteria is generally at least -125 Pa, and typically -200 to -250Pa, 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 though be operated safely at depressions less than -125 Pa, dependent on hazard assessment and construction standards.

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

9.6 Where there is a suite of caves, air flows should be engineered from areas with the lowest, to areas with the highest contamination potential from where it is extracted and treated. This method helps to reduce the spread of contamination and minimise the air flow through the system, which in turn reduces the size of the downstream extract air treatment plant.

9.7 Viewing into caves is generally through shielded windows. High illumination levels can give 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.

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

9.9 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 air treatment plant 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 EG_1_1702_1 for special reference to the siting and installation of filtration equipment.

9.10 Where an inlet of air is necessary to a cave or cell, a single stage HEPA filter to minimise migration from potential back flow, with an isolation/air flow regulating damper, is normally provided. This engineered inlet may be required where infiltration, through leakage paths around engineered penetrations for example, is insufficient to cater for the heat load or process within the containment. These inlets are used to control depression in a well sealed cell and may be used to adjust flow/depression through the operating life cycle of the cell.

10 Fume Cupboard Ventilation

10.1 In laboratories, where complete containment is not feasible due to the requirement for operator access, fume cupboards are used. The fume cupboard is designed to envelop, as far as possible, the equipment and processes whilst maintaining variable access to the front face. The BS EN 14175 suite of documents provide requirements for fume cupboards and the HSE Guide G201 Fume cupboards describes good control practice for using a fume cupboard, which is considered as a type of LEV.

10.2 Each fume cupboard is connected to an extract ventilation system from which the gas, after suitable filtration, is exhausted to atmosphere. Additionally, some fume cupboards may be recirculating (see BS 7989:2001 Specification for recirculatory filtration fume cupboards). The air flow rate is designed to maintain a velocity of 0.5 m/s across the fume cupboard variable opening face. This is generally considered to be the optimum face velocity for fume cupboard design. A face velocity in excess of 0.5 m/s can be undesirable, since higher face velocities may create turbulent and uncontrolled air flow patterns leading to releases of contamination (see section 7.10.19). It is recommended that flow indication with some form of fail safe visual and audible alarm be provided (see BS EN 14175-2:2003 Fume cupboards – Part 2: Safety and performance requirements).

10.3 On HEPA filtered fume cupboard extract systems which have fixed speed fans or variable speed fans with open loop control (i.e. manual speed adjustment), the extract flow will decrease as filters dirty. An elevated fume cupboard face velocity should be considered to allow a margin for drop off in flow as filters dirty; e.g. initial face velocity (up to a maximum) of 0.7 m/s and allowing the face velocity to drop to 0.5 m/s before the filters need to be changed. This maintains the fume cupboard face velocity within an acceptable range.

10.4 Consideration should be given to air distribution in the room which houses the fume cupboards, particularly where there are a number of cupboards in one room (see section 7.10.19). In these cases, it is the airflow requirement of the fume cupboards which determine the quantity of air flow into the room itself. With high face velocities involved, and the use of by-pass airflow systems giving constant airflow irrespective of the sash opening, this can give rise to significantly high room air change rates per hour. Correct selection of supply air grilles/diffusers is imperative, not only for operator comfort and to avoid draughts, but also to avoid excessive turbulence in the area directly in front of the fume cupboards. These can compromise the velocity profile across the fume cupboard face.

10.5 Room air flow velocities in excess of 0.2 m/s at the face of a fume cupboard can compromise the containment capability of the fume cupboard. Where high room air change rates are required, the use of laminar flow panels or perforated ceiling should be considered to distribute the supply air to the room maintaining low terminal velocities at the point of distribution.

10.6 The installation of large numbers of constant volume flow fume cupboards will result in high air flows and increased size of air handling plant, which does not align with one of the fundamental principles of ventilation design for radiological controlled areas, i.e. to minimise the air flow through the facility. A more energy efficient alternative to constant volume flow rate fume cupboards would be the use of a variable flow control system to reduce the fume cupboard extract flow, but maintain a constant face velocity as the fume cupboard sash is raised and lowered. However, these are more complex and may require the inlet air flow rate to be altered to match.

10.7 Diversity in the use of fume cupboards should also be considered to minimise volumetric flow, plant size and energy usage.

11 Process Vessel Ventilation

11.1 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 with 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. 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 suitable liquid waste management facilities any liquor which may be carried into it or condensate that may arise within it

(d) The system should, where applicable, deal with slightly acid or alkaline 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

11.2 In addition to the above, there are other specialist 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.

11.3 VV off gases, after treatment, are usually passed through high efficiency filters before discharge into any other ventilation system or direct to atmosphere. Special provision is often required for VV off gases as they are often moist, especially if liquid scrubbing has been carried out. Without provision for moisture removal, the airstream is very likely to contain entrained active mist due to active liquid transfers and/or give rise to active condensate.

11.4 Treatment systems employed typically include high efficiency electrostatic precipitators and corrosion resistant demisters. HEPA filters can also be used, and if so, dilution (using a warm air inbleed to mix with the process air stream and to reduce the relative humidity of the mixed airstream) or preheating should be employed to ensure a moisture level low enough not to impair the HEPA filter medium. The VV system needs to maintain the vessels at a depression relative to the surrounding cell that is appropriate for the process. Whilst a vessel depression of 125 to 500 Pa below the cell atmosphere may be sufficient in some cases, it is not uncommon to operate vessels at -1500Pa relative to its surrounding cell to allow for the considerable drop in vessel depression which can arise during transfers of material between vessels, as it is important that, during such transfers, a minimum transient depression relative to cell is maintained.

11.5 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.

12 Air Handling Plant

12.1 Fans and Motorised Dampers

12.1.1 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.

12.1.2 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.

12.1.3 Dampers shall 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.

12.1.4 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.

12.1.5 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.

12.1.6 Design guidance on the selection of centrifugal fans is provided in EG_0_1710_1.

12.2 Air Handling Units

Design guidance on the selection of air handling units is provided in EG_0_1708_1.

13 HEPA Filtration

13.1 General

13.1.1 Ventilation air flows to the discharge stack from areas of high contamination potential will require to be treated to remove any potential contamination arisings before discharge. In some cases the use of specialised equipment to deal with particular airborne contaminants at source before they are diluted with flows from less potentially hazardous areas may respresent BPM/BAT/ALARP.

13.1.2 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.

13.1.3 The High Efficiency Particulate Air (HEPA) Filter is the usual means of achieving effective particulate capture. Consideration may be given to the use of a pre-filter (see section 15.1).

13.1.4 The purchase, handling and disposal of HEPA filters and other particulate filters is expensive, particularly when significant activity is loaded onto the unit. For this reason, and from the perspective of application of BAT for waste minimisation, it is important to maximise the service life (subject to HEPA filter ageing guidance – see section 13.5) by minimising the arisings of active or inactive particulate. Recleanable HEPA filters are an option where there is a high load of sub-micron dust, for example from cutting operations during decommissioning. Cyclones are also used for larger sized particulate (see clause 15.5) greater than 1 micron.

13.2 HEPA Filter Type Testing

Generally, HEPA filters for nuclear applications should be type approved in line with ES_0_1705_2. In addition, all final discharge HEPA filters and those with specific claims made upon them in the safety and/or environment case, will normally be efficiency tested in situ (see section 13.4 and EG_1_1707_1). Type tests are performed on HEPA filters (made using a particular manufacturing route) to ensure they meet the requirements of the relevant Engineering Standard. These type tests should be carried out, on samples of filters, at five yearly intervals (see ES_0_1705_2). Any subsequent changes in the manufacturing methods or change to materials may require the type test to be repeated.

13.3 Particulate Filtration Decontamination Factors

13.3.1 Standard HEPA filters are manufactured to a rated penetration of not greater than 0.01% when tested with thermally generated Dispersed Oil Particulate (DOP). 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.

13.3.2 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. Recognised 'claimed' DFs for different filters are listed in the Sellafield Release Fraction Database (RFDB) Table 6.6 – DFs for Ventilation Systems. 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

13.3.3 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.

13.3.4 The laboratory testing of filters shows DFs of above 10^5, whereas the claimed performance within the aerial effluent flow sheet of a plant may be 10^2, 10^3 or 10^4 per stage. The laboratory achieved DF should be greater than the required DF to ensure the Safety Case requirement is exceeded by an appropriate margin. The safety margin is such that on-site tests may be better directed to identifying leakage that could compromise the safety margin, rather than trying to prove a particular DF.

13.4 In-situ HEPA Filter Performance Testing

13.4.1 When a guarantee of DF is required, by the safety and/or environment case, for any filter, the installation should be tested to determine that the required DF is being maintained. For the Sellafield site, the perodicity of in-situ filter testing is determined by the plant Safety Case, with a maximum period between tests of 12 months (see SLP 1.06.59.02). For other UK Nuclear Licensed Sites, refer to the local site practices. 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 µm diameter. Smaller and larger aerosols will be retained with a greater efficiency. This functional test will include any bypassing and gasket leakage.

13.4.2 There are several methods of HEPA filter testing in use, including the following: -

- DOP (mono-dispersed bench test or poly-dispersed field test)
- NaCl (BS 3928)
- Paraffin (DIN 24 184)
- Uranine (AFNOR NFX 44.011)
- Condensation nuclei
- Laser particle counting

13.4.3 The results of testing the same filter by different methods do not necessarily give the same efficiency rating. Thus, the efficiency of a filter should be quoted against the method used to test that filter.

13.4.4 The test challenge used in the methods is an attempt to represent the aerosols that the filter will be required to deal with. It is most unlikely however that, under normal plant operating conditions, the aerosol challenge from one plant will be the same as another; and yet the same test challenge aerosol is likely to be used. Additionally, filter installations are designed for accident conditions on their associated plant, and the normal arisings may be orders of magnitude less in terms of concentration. The efficiency test, therefore, is based upon a particular test challenge and cannot accurately determine the performance of the filters when an accident occurs (with potentially significant differences in temperature, pressure, moisture content, etc.)

13.4.5 For an actual installation, the ability to accurately measure an efficiency, with an in-situ test method and apparatus, will be determined by the ability to obtain representative samples of the aerosol in the gas before and after the filters. Thus, the tests carried out are nearer to a method of comparing one installed filter with another, rather than an absolute measurement of efficiency (ref. IAEA, Technical Report Series 243, Testing and Monitoring of Off-gas Clean-up Systems at Nuclear Facilities).

13.4.6 The testing of HEPA filters in-situ is a way of determining that the filters on an installation are in good condition efficiency-wise, and will be able to perform to the standards that HEPA filters have been shown to achieve in the past. The tests are less an absolute determination of DF and more of a measure of confidence in the installation.

13.4.7 Not all HEPA filters will require in-situ testing. The scope of in-situ testing testing and more detailed requirements is covered in EG_1_1707_1.

13.5 Filter Ageing

13.5.1 Some HEPA filters have remained in use well beyond their intended life (remained in use for 20, 30 or even more years). This is often justified on the basis of a successful in-situ DOP test. However, this does not give an indication of filter strength.

13.5.2 Existing HEPA filter service life guidelines have been developed based on studies such as *Maximum HEPA Filter Life W Bergman UCRL-AR-134141*, Lawrence Livermore Laboratory, June 1999 which shows that even in dry air, embrittlement can occur, and with other potential changes, HEPA filters have a limited life. This report presents a conservative interpretation of the ageing studies resulting in a recommendation that the maximum total life (storage and in-service) of HEPA filters for removing highly hazardous aerosols is 10 years from the date of manufacture for applications in dry air systems,and 5 years in applications where the filter can become wet.

13.5.3 As HEPA filter technology is developing over time, there could be a need to review existing filter service life guidelines, particularly with the introduction of HEPA filters re-inforced with additional layers of glass fibre scrim. See EG_1_1702_1 for further guidance on filters including the development of high-strength glass fibre HEPA filters.

13.5.4 In-situ testing gives no indication of the condition of the filter in relation to strength and other physical properties, and cannot determine the filter condition with respect to ageing. For filters that directly affect safety or environmental protection, and that could be subjected to a pressure pulse, it is good practice to assess the filter condition five years after installation. The assessment should look at life limiting factors, such as exposure to damp or corrosive conditions, or unstable flow. The assessment may extend the life of the filter for a further period. In any case, current practice is that filters should be changed after ten years from installation, unless there are ALARP reasons for not doing so (for example if the ventilation system will soon be decommissioned).

13.5.5 For the Sellafield site, SLP 1.06.59.02 requires plants to carry out a filter life assessment prior to 5 years from the date that the filter was fitted. To extend the life of final discharge HEPA filters the air stream conditions must be dry with no potential for corrosive elements, free moisture or heavy turbulence. The assessment will consider the air stream conditions, in-situ filter test history and filter differential pressure history. For non final discharge HEPA filters, which provide a safety function (e.g. back flow protection filters) the assessment will look to confirm that the building supply air is filtered and supply filters have been changed annually in line with SLP 1.06.69.01, that the filters have been visually inspected to ensure good condition, that the filters have not been exposed to damp conditions or corrosive vapour and that the filter location is included in Health Physics and Safety surveys. If authorised, the filter life would normally be extended to 10 years from the date that the filter was fitted. For other UK Nuclear Licensed Sites, refer to the local site practices.

13.6 Filter Installations Testing and Monitoring

13.6.1 Some salient points on the housing of filters are listed below:

(a) The installation should allow safe and efficient filter changing so as to minimise contamination and irradiation of personnel

(b) Proprietary bagged ‘safe-change’ systems which maintain containment are available and are generally preferred to minimise the risk of migration of activity from the filter into the room

(c) Remote changing may be necessary where high radiation levels adjacent to filter housings are likely; and designs are available

(d) Cylindrical (circular) filters should be used on new installations due to the increased sealing efficiency over rectangular filters and therefore:

i. reduced potential for filter wastage resulting from consequent failures of in-situ filter tests.

ii. circular filters have a higher ‘claimable’ DF due to the possibility of poor sealing on rectangular filter installations

iii. the sharp hazard present when bag changing rectangular filters does not affect cylindrical filters.

iv. Cylindrical filters have better waste management features as they can be readily compacted and are designed to locate into standard 210l waste drums

(e) Filters should be fitted in a properly engineered housing on a robust support structure

(f) Where rectangular filters are used, a good standard of flatness and squareness of the filter seating is required to allow satisfactory sealing with the filter gasket. Gasket leakage is a major source of ‘failures’ on historic rectangular filter installations

(g) For certain designs, the filters can be mounted horizontally ("shelf") or vertically ("ladder"). Downward airflow in shelf systems for rectangular filter installations helps minimise particulate loss when changing filters (although seating in ladder systems can be unreliable). The filters should be changed from the upstream side, to minimise the spread of contamination to clean areas. Overall, ladder type arrangements should be avoided (on extract systems) as they do not have a safe change capability and require the operator to be exposed to the contaminated part of the filter housing during change.

(h) Corrosive conditions may require special consideration such as stainless steel filter housings

13.6.2 Extract ducting shall be provided with filter efficiency test points to allow injection and sampling of the test aerosol used for DF determinations. The detailed design of the filter test facilities is of considerable importance if meaningful results are to be obtained. The requirements are covered in EG_1_1707_1 and are summarised as follows :-

(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 upstream of filters

(f) Appropriate services for operation of the test equipment

13.6.3 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).

13.6.4 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.

13.6.5 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 rate to be measured both instantaneous and total. Singular extract nozzles designed for isokinetic sampling flow have historically been used for stack sampling and require the velocity through the nozzle section of the probe to be the same as the velocity in the duct from where the sample is being taken. Isokinetic sample nozzles are therefore sized for a specific velocity in a specific size of duct; and changes to the discharge flow, and therefore velocity, will often require a new sampling probe. Shrouded sample probes are now preferred as they can be used for varying duct velocities of between 5 and 15m/s. (see EG_1_2505_1)

13.6.6 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.

13.7 Extract Filtration System

13.7.1 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 in all cases to credit it in calculating the overall system DF, but it serves to limit the spread of activity outside the working volume.

13.7.2 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 BPM or BAT 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. Preferred practice is to locate filters in a separate filter room as during filter change there will be an increased potential for breach of containment; e.g. if a dirty filter was to be dropped and/or a breach was to occur in a bag containing a dirty filter. The amount of other plant and equipment within the room should therefore be minimised to reduce the amount of plant and equipment that could become contaminated in the event of a contamination release local to the filters.

13.7.3 As there is a potential for the filter room to become contaminated as a result of filter changing, it should thus have floors and walls free from dust traps and be made of materials which can be easily monitored and decontaminated. There must be adequate room to perform the filter change operation, and also to perform decontamination procedures. For hands-on manual change filters, they should be double-bagged utlising the ‘safe-change’ design to ensure that pressurised suit operations are not required for filter changes.

13.7.4 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 EG_1_1702_1.

13.7.5 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.

14 Other Exhaust Air Clean up Plant

14.1 Iodine Adsorption

14.1.1 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.

14.1.2 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.

14.1.3 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 292 mm HEPA filters and may therefore be fitted in standard mountings.

14.2 Inert Gases

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

14.3 Wider industry guidance

For more comprehensive information on the range of aerial effluent clean up plant used on nuclear licenced sites see:

- A Review of the Best Available Techniques for Effluent Treatment at Sellafield, NNL (13) 12525, Issue 4
- IAEA-TECDOC-1744 Treatment of Radioactive Gaseous Waste, International Atomic Energy Agency Vienna, 2014

15 Pre-Filters, Dryers, Spark Arrestors and Other Pre-Treatment Devices

15.1 Pre-filters

Pre-filters fitted upstream of HEPA filters are rarely fitted on modern day 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 significantly increase the life of the following HEPA filter, unless the airstream has a significant quantity of larger particulates – which is rare in nuclear facilities due to distances, duct velocities, large cells, etc.. However, exceptionally there may be an application where a designer can justify the use of a pre-filter.

15.2 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, as standard HEPA filter media is weakened by repeat wet/dry cycling. 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.

15.3 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.

15.4 Other Devices that may be used include inertial collectors, cyclones, wet scrubbers, electrostatic precipitators (ESPs) and demisters (see EG_1_1702_1 for more details). Some of the merits and demerits of these items are described in the following clauses.

15.5 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. Emptying of a cyclone may become a high hazard task and the design will need to adequately address the potential for significant amounts of contaminated dust held within the cyclone.

15.6 Wet Scrubbers

These can be used for treating vessel ventilation streams and sometimes on glovebox ventilation systems (see Figure 8). 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 contaminant is absorbed by the liquid, often followed by chemical reaction (e.g. acid-base reaction) to retain the contaminant in solution. 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) Can be efficient for the removal of reactive volatile contaminants such as NOx or iodine, depending on the scrubbing medium that is chosen

(b) On warm effluent streams it reduces the specific water content of the air stream (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

(d) Compared with dry filters, particularly HEPA filters, wet scrubbers offer relatively poor DFs for particulate contaminants

15.7 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) Difficult to repair or replace if located in-cell

15.8 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.

16 Exhaust Stacks

16.1 Purpose

16.1.1 Vertically discharging exhaust stacks are normally used for the discharge of air from ventilation systems from radiological facilities. ASHRAE HVAC Fundamentals 2013 states that they have the advantage of being subjected only to negative pressure created by wind flow (in any direction) over the tip of the stack. Consequently this protects the operation of the systems and internal space depressions from fluctuating external wind pressures.

16.1.2 Wall or other vertical surfaces are subjected to a wide variation of positive and negative pressures depending on the direction and strength of the wind. Therefore, wall or other horizontal discharges from ventilation systems serving radiological controlled areas (GREEN, AMBER or RED areas) should be avoided wherever possible.

16.1.3 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.

16.1.4 When a typical plume is exhausted from a stack it does so through a combination of its own momentum and buoyancy due to the plume temperature being above the atmospheric temperature. The momentum and buoyancy will combine to propel the plume vertically upwards. However, where the plume exits the stack, it impacts with the wind. The resulting high inertia effects of the wind on the plume cause the plume to deflect from its upward path. Higher wind speeds, cause the plume to be deflected towards horizontal flow more rapidly and the less it rises into the atmosphere. As the plume travels further downwind its travel is less influenced by its initial momentum and buoyancy (as the air cools); and becomes wholly controlled by the atmospheric air flow.

16.2 Effective Stack Height

16.2.1 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. For the Sellafield site, effective stack heights are discussed in SLSP 2.11.109. For other UK Nuclear Licensed Sites, refer to the local site practices.

16.2.2 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 topography). The height of stacks should be assessed and justified based on the discharge requirements. The effective height of the stack may be different (less than) the actual physical height as a result of surrounding buildings affecting the airflow upwind and downwind of the stack, momentum effects due to the efflux velocity and the plume buoyancy as a result of the raised temperature of the stack discharge plume.

16.2.3 The UK Government guidance Air emissions risk assesement for your environmental permit, available on the gov.uk website details how to complete an air emissions risk assessment, including how to calculate the impact of emissions and the standards to be met. The section within this guidance headed ‘PC:dispersion factor’ deals with dispersion rates and effective stack heights.

16.3 Minimum Stack Height

ASHRAE HVAC Applications 2011 refers to a recommended minimum stack height of 3m above the adjacent roof line. Therefore, the minimum recommended height for an exhaust stack should be 3m above the adjacent roof line unless otherwise derived based upon the particular application.

16.4 Efflux Velocity

16.4.1 The efflux velocity must be sufficient to project the exhaust air into the atmospheric air-stream. If the efflux velocity is too low, stack wake downwash can occur where the exhaust air can flow down the stack on the lee side, as it is pulled downwards by negative pressures immediately downwind of the stack. This will have the effect of reducing the effective height of the stack. As a rule of thumb, ASHRAE HVAC Applications 2011 suggests that the efflux velocity should be at least 1.5 times the design wind speed at the discharge height of the stack to avoid wake downwash. It also states that a stack exhaust velocity of 13m/s prevents condensed moisture from draining down the stack and keeps rain from entering the stack.

16.4.2 Guidance on minimum discharge velocities is also given in The Environmental Protection Act 1990 Technical Guidance Note (Dispersion) D1 (withdrawn after the introduction of the reference given in clause 16.2.3, although still available for reference). To prevent the discharged plume suffering from aerodynamic downwash and flowing down the outside of the discharge stack, thereby reducing its effective height, the Guidance Note D1 suggests minimum velocities in the range of 10 to 15m/s depending on heat release and discharge momentum.

16.4.3 For stack discharges where ground level release effective height are being claimed (e.g. for roof top stub stacks terminating 3m above roof line) it is recommended that a minimum stack efflux velocity of 15m/s should be used (although this may not be an effective velocity for taller stacks). For discharges where greater effective stack heights are being claimed it may be more appropriate to use computer based models, sometimes combined with physical modelling through wind tunnel tests to better predict the dispersion of an exhaust plume. In these cases, higher efflux velocities may be more appropriate to increase the effective strack height. An exit nozzle can be used to increase exhaust velocity and plume rise.

16.5 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.

16.6 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.

16.7 Sampling and monitoring

16.7.1 There is normally a need to sample and/or monitor gaseous discharges in order to comply with licensing and statutory requirements. Hence, provision must be made for the installation of an appropriate discharge sampling and monitoring systems as required. (See EG_1_2505_1).

16.7.2 Sampling

Sampling is normally carried out by passing a representative sample of the effluent for a fixed period of time through a collection device and provides a retrospective measurement of the amount of radioactive material discharged. The amount of radioactivity in the collection device is regularly measured and, with knowledge of the amount of gaseous discharge that has passed through the sample system in the sample period, the average activity concentration of the duct or stack discharge can be calculated by combining with the duct or stack flow rate. Similarly, the total stack discharge of radioactivity over a given time period can be calculated and this is typically the information needed to demonstrate compliance with radioactive substances regulation permit limits.

16.7.3 Monitoring

16.7.3.1 Monitoring is the continuous measurement of the aerial discharges so that controlling action can be taken should the discharge approach or exceed the pre-set trigger limits. Although monitors provide real-time data, they are usually not as accurate as retrospective results from samplers. Hence often both samplers and monitors are often required.

16.7.3.2 The detailed requirements of such systems are contained in: BS ISO 2889:2023 Sampling airborne radioactive materials from the stacks and ducts of nuclear facilities; other standards which cover flow measurements, continuous monitoring and monitoring objectives and plans (i.e. ISO 10780:1994; BS EN 60761 series; and BS EN 15259:2007) and additional Environment Agency Technical Guidance Notes. For the Sellafield site, sampling and monitoring requirements are discussed in SLP 2.10.300 and design guidance for sampling and monitoring systems given in EG_1_2505_1. For other UK Nuclear Licensed Sites, refer to the local site practices.

16.8 Drainage

16.8.1 Ventilation stacks (and some ventilation ducts) should incorporate a drain point routed to a suitable collection point or discharge system. Discharge of such liquid effluents to ground is illegal and must be prevented.

16.8.2 Although it is not considered appropriate for a standard drain point engineering configuration to be defined for all installations, and as such there is no recommended standard arrangement specified, a typical external duct drain installation connecting into a low active drain system is illustrated in Figure 21.

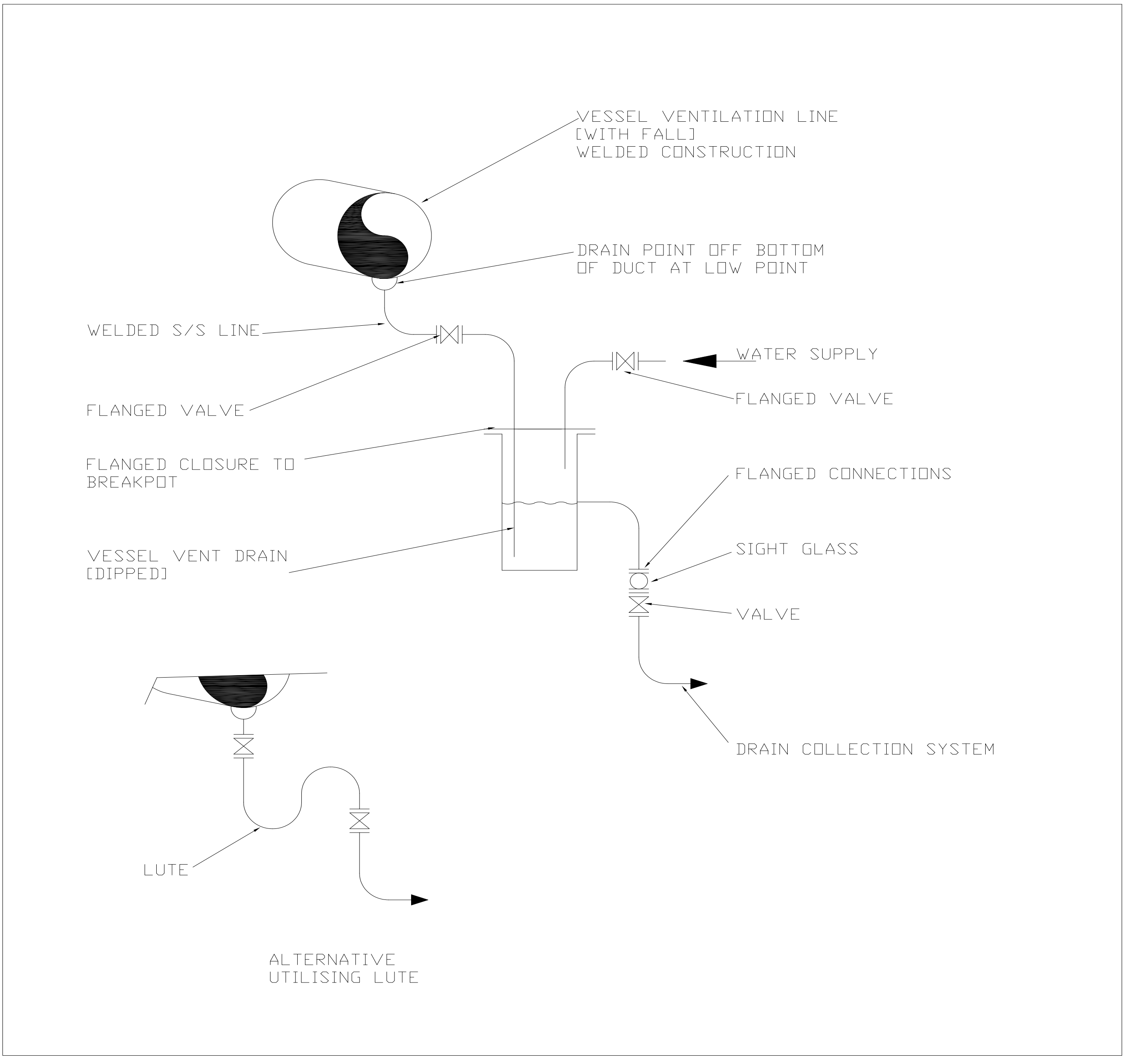


Figure 21 – Ventilation duct drain to low active drain

16.8.3 The breakpot or lute holds liquor to form the atmospheric break between the duct and the drain. The condensate drips into the volume of liquor held and the overflow enters the drain. There is often a requirement to sample this liquor to determine the nature of the condensate and this requirement introduces sample points. Typically a sample point is a method of decanting a small amount of the retained volume of liquor and in its simplest form is an open ended pipe with a single valve that can be used to take away some of the liquor for analysis. This arrangement presents a potential route for the uncontrolled release of active duct condensate to the environment and consequently, consideration must be given to determination of some minimum standard or BAT/BPM for sample points. It is possible that a permanent connection to drain is not necessary. This is especially true where terminal cowl designs are used which can be very effective at eliminating rainwater entry to stacks.

16.9 Multiple Discharges

Where separate ventilation systems discharge into a common exhaust stack, consideration should be given to the incorporation of non-return dampers or motorised isolation dampers interlocked to close on loss of system flow, upstream of the connection to the stack.

17 Building External Containment

17.1 General

17.1.1 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.

17.1.2 The Radiological containment function, Part L of the Building Regulations, and the need for energy (and Carbon) efficiency, may all result in requirements for leakage to be controlled through the building shell. The Designer should consider the Building Regulations, Part L, as the minimum standard.

17.2 Standard of Leak Tightness

17.2.1 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.

17.2.2 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 contamination

(e) Whether the process is contained within multiple containment barriers

17.2.3 In adopting the principle of the multi barrier approach to building containment, the areas adjacent to the building perimeter walls would normally be classified as GREEN or WHITE. If the building layout meant that an AMBER area was adjacent to the external skin then good practice would suggest the addition of a second internal skin because of the increased contamination potential; to limit unmonitored discharges from these areas where the activity concentration is potentially higher than for GREEN areas.

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

- Buildings with a low risk of airborne contamination leakage
- Low leakage buildings

17.3 Buildings with Low Risk of Airborne Contamination Leakage

17.3.1 In most radiological controlled 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. In such cases, designers should refer to Part L of the Building Regulations as a minimum standard.

17.3.2 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.

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

17.4 Low Leakage Buildings

In buildings where the airborne contamination level is potentially 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.

17.5 Wind Speed

17.5.1 Average wind speeds are often available from meteorological observations measured at a height of 10 metres. More comprehensive wind speed data is available on some sites. 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.

17.5.2 Designers should consult Site Licensee's documentation concerning measured winds speeds.

17.6 Wind Pressure

17.6.1 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.

17.6.2 The airflow due to wind over a building will create areas of both pressure and suction on the building surfaces, which will in turn lead to infiltration and outflow from the building. The pressure pattern will depend on the shape of the building, the wind speed and direction relative to the building, and the location and surroundings of the building. Figure 22, taken from CIBSE Guide A:2015 Figure 4.9, illustrates the typical pressure distribution on building surfaces when subjected to a wind perpendicular to one of the vertical surfaces.

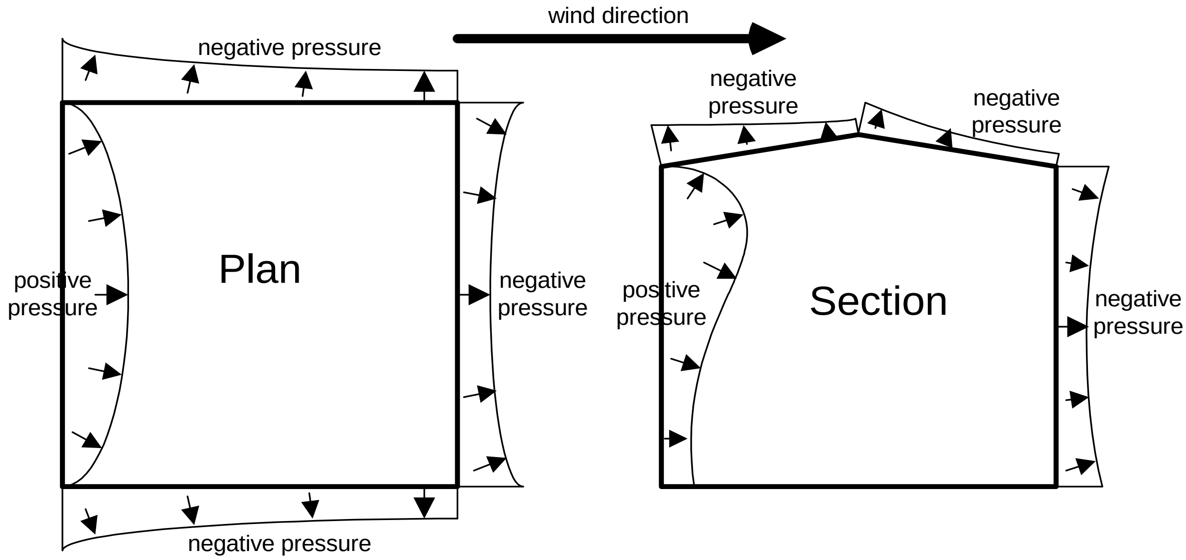


Figure 22 – Wind Pressures on Building surfaces

17.6.3 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.

17.6.4 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. Therefore, it will not be necessary to provide this depression for the maximum wind speed. An estimate should be made of the building leakage and an allowance included in the airflow calculations to encourage the leakage to be predominantly inwards.

17.7 Complying with Environmental Permit for Radioactive Substances

In accordance with the requirements of the Site Licensees' Environmental Permit for Radioactive Substances, all discharge points other than Authorised Gaseous Discharge Outlets must be registered as 'Other Outlets,' which are defined as any discharge likely to discharge radioactive aerial effluent; including building discharge vents/ducts from C2 (GREEN) classified areas or greater. For the Sellafield site, SLP 2.10.301, however, states that if the potential discharge is via the building fabric, passive vents, ventilation inlets or building air escaping via adventitious routes, then there is no requirement to register as an Other Outlet as covered by Compilation of Environment Agency Requirements. For other UK Nuclear Licensed Sites, refer to the local site practices.

17.8 Design Factors

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) Maintaining the building at a depression by the ventilation system

17.9 Leak Tightness of Building Structures

17.9.1 The leak rate into or out of a building is a function of the differential pressure across the building structure including positive and negative wind effects; and the resistance of the leakage paths.

17.9.2 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.

17.9.3 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 four types of building structure are given below as an indication of the order of leakage for these types of building structures.

	Type of Building Construction	Contained Volume m^3	Test Pressure Pa	Typical leakage rate m^3/hr
D9867	Brick building with brickwork painted internally with chlorinated rubber paint, no windows, entry through two successive well-fitting doors.	7,840	130	5,880 m^3/hr
PFR	Concrete panel building, no windows, entry through two successive airlock doors.	75,040	1,000	1,560 m^3/hr
DFR	All-welded metal shell construction, with all welds radio-graphed, entry through engineered airlock doors.	27,400	69,000	0 m^3/hr
EPS3	Sheet metal cladded building constructed to 2010 Building Regulations	12,784m^2 surface area	50	6.61 $m^3/hr/m^2$ surface area (84,564 m^3/hr)
MSCF	Sheet metal cladded building constructed to 2010 Building Regulations	5,991m^2 surface area	50	1.45 $m^3/hr/m^2$ surface area (8,710 m^3/hr)

Table 1 – Leak Tightness of Example Buildings

17.9.4 The figures given in the above table are not design leakage figures. They show actual figures which have been achieved on different types of structure. The minimum standard used should comply with Building Regulations, Part L.

17.10 Radon Gas Build up

17.10.1 Radon is a naturally occurring radioactive gas that can seep out of the ground and build up in houses and indoor workplaces. Radon occurs naturally in many rocks and soils. The highest levels are usually found in underground spaces such as basements, caves and mines. High concentrations are also found in ground floor areas of buildings where radon from the sub-soil underneath buildings enters through cracks and gaps in the floor slab.

17.10.2 To control radon levels, ventilation by dilution with adequate mixing should be considered for ground floor areas. Aggregates used in the building construction for radiological facilities can also be checked to ensure they have a low radon emission before being used.

17.11 Building Containment Structure

17.11.1 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 and shutdown of the ventilation systems.

17.11.2 Where HEPA filters are incorporated within supply systems, excessive depressurisation of the building can occur due to loading of filters and consequent reduction in the supply air flow rate, if filters are not changed frequently. The reduction in supply flow and imbalance of the building ventilation systems could lead to increases in depressions between areas, difficulties with opening doors within the facility and reverse flows. In such cases consideration should be given to variable speed drives (or control dampers) to maintain supply air flows with appropriate alarms to inform personnel of abnormal conditions.

18 Electrical Supply, Control and Instrumentation

18.1 Introduction

18.1.1 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.

18.1.2 The security, diversity and reliability of the system will be dictated by the processes taking place within the building - as reflected in the hazard assessment and other studies. Operational requirements will also need consideration.

18.1.3 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.

18.2 Electrical Supply Philosophy

18.2.1 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.

18.2.2 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.

18.2.3 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. supply/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.

18.2.4 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.

18.2.5 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.

18.3 Control Philosophy

18.3.1 Note on Applicable Engineering Standards

For the Sellafield site, Engineering Standards ES_1_2469_1 Contract Management Arrangements for Control, Electrical and Instrumentation Systems, and ES_1_2479_1 Programmable Electronic System based Instrumentation and Control ensure the acceptable design, engineering, build, testing, documentation, procurement, delivery, installation, and commissioning of control systems. To comply with ONR Safety Assessment Principles for Nuclear Facilities, all safety systems shall be independent of the Basis Plant Control System. However, it is recognised that some Programmable Electronic Systems (PES) may have safety functionality associated with them. For PES with a Safety Integrity Level (SIL) allocated, ES_1_2190_2 The Engineering Standard for E/E/PES Safety Measures shall also be adhered to during the design process and the PES shall be independent of the Basis Plant Control System. The use of preferred technologies shall be taken into account for all PES in accordance with ES_1_2800_1 PES Preferred Technologies – Design Requirements. For other UK Nuclear Licensed Sites, refer to the local site standards.

18.3.2 The control system will be determined by the particular ventilation scheme required and must function during the normal and the postulated plant fault conditions. 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.

18.3.3 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.

18.3.4 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

18.3.5 Automatic start-up of the standby fans should be considered, to cover failure of the main fan (fan failure or electrical 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). To avoid shutdown of plant due to spurious failures from a single instrument, instrument voting systems (2 out of 3) are often preferred. Typically, to detect fan failure outside its normal design conditions, alarms would be initiated by low or high flow, low or high fan differential pressure and low or high fan speed; and fan autochangeover would be carried out only when at least 2 of these alarms are initiated, or on detection of an unplanned closure of a fan isolation damper. High alarms should be included in the voting system as 2 out of 3 'low' alarms only would not cover the range of credible fault scenarios; e.g. a closed manually operated fan inlet damper (with no remote status indication) would give a low flow and high fan differential pressure alarm, with fan speed unchanged; removal of an access door close to the fan may generate a high flow and low fan differential pressure alarm with fan speed unchanged; a fan discharge damper seized in its closed position and the blades fail to open on changeover but limit switches indicating open would give a low flow and high fan differential pressure alarm, with fan speed unchanged. Hard-wired overspeed protection may also be a requirement on fans which employ variable speed drives (see ADN_DES-CAP_MECH_00002_A Fan 7 Variable Speed Device (VSD) Design & Substantiation Guidance Note).

18.3.6 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 supply fan) could cause hazardous overpressure in part of the system, an interlock between the supply and extract fans must be provided to prevent this occurring.

18.3.7 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 plant to keep running or to shut down.

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

18.3.9 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 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.

18.3.10 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.

18.3.11 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.

18.4 Instrumentation

18.4.1 Designers should consider the functionality of the system in determining the parameters that are to be measured and for what the information gained may be used (see EG_1_2313_1).

18.4.2 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 affect the emphasis and interpretation which must be given to some of the following recommendations. On most systems, a combination of flow, temperature, pressure, humidity and position measurements will be needed. Of these, some will be associated with control and others will be informative. For operational and other reasons, there is a requirement to use centralised control which, depending upon the size of the system, may incorporate programmable 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, the control system designer should ensure the Engineering Standards on PESs in safety related applications have been observed.

18.4.3 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. These must be specified, or selected, at the time of ordering to be compatible with the total plant instrumentation design concept and realisation.

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

(a) Duct flow measurements (EG_1_2306_1)

(b) The state of dampers and valves (open/shut); and fans (running/standby)

(c) Inference 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, that any RED area is being held at a negative pressure differential relative to the operating face

(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

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

18.4.6 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.

18.4.7 For plants handling significant activity, there are advantages in replacing control dampers with fluidic control elements such as vortex amplifiers (see section 8.9.10). 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 (see Appendix B). These designs also identify the locations of filters and measurements associated with them, and reference should be made to these applications for guidance.

18.5 Process and Instrument Diagrams (P&IDs)

18.5.1 All control and instrumentation requirements for ventilation systems must be demonstrated on P&IDs or Ventilation Flow Diagrams (VFDs). P&IDs must be produced in accordance with the relevant standards.

18.5.2 P&IDs shall indicate all components of control loops. If control functions are performed by a PLC, the control logic must be demonstrated by showing the individual control loops on the P&ID.

18.6 Activity Monitoring

18.6.1 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 place demands on ventilation system design. For this reason it is still necessary to consider this topic within the context of the document.

18.6.2 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.

18.6.3 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.

18.6.4 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.

18.6.5 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

18.6.6 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 supply and extract 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, 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

18.6.7 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. For the Sellafield site, sampling and monitoring requirements are discussed in SLP 2.10.300 and design guidance for sampling and monitoring systems given in EG_1_2505_1. For other UK Nuclear Licensed Sites, refer to the local site practices.

19 Fire Safety

19.1 General

19.1.1 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.

19.1.2 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.

19.1.3 The potential for a fire must be considered at the start of the design of a 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.

19.1.4 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 important that intended design and operating philosophies be established at an early stage in the project.

19.2 Fire Barriers and Fire Dampers

19.2.1 The building will usually be divided into Fire Zones based on the requirements for Conventional Fire Safety. In addition a Radiological Fire Safety assessment may lead to the allocation of additional fire zones or an increase in rating of a fire zone. Fire zoning will dictate that the building is 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.

19.2.2 Where ductwork passes through a fire compartment zone boundary (fire barrier), then a fire damper is required, where it penetrates that fire barrier. The damper (plus any associated mounting spigot & insulation) shall have the same level of fire resistance as that required by the barrier through which the system passes. If the ductwork passes right through a fire zone, but the duct has no opening into it, then as an alternative fire resistant ductwork can be specified. This will obviate the requirement for a fire damper on one of the fire boundaries. BS 9999:2008 states that metal ductwork can conduct sufficient heat from a fire inside the ductwork or on the fire side of a fire damper, to ignite adjacent combustible materials. As such a separation of at least 500 mm must be maintained between uninsulated ductwork and combustible goods, packaging, partitioning, etc. It is recommended, therefore, that fire resistant ductwork is insulated, for those sections where adequate separation cannot be achieved.

19.2.3 Fire dampers should be type tested and certified by an approved authority in accordance with a nationally recognised standard, e.g. BS EN 1366-2:2015, as specified in ES_0_1715_2. Fire dampers in radiological controlled facilities are typically installed adjacent to a wall or floor by fixing the fire damper to a fire resisting sleeve or fire resisting installation frame, which is built into the fire boundary. The type testing, therefore, should have been carried out to an arrangement that is representative of the typical site installation detail. EG_0_1715_1 includes design guidance on the specification of fire dampers.

19.2.4 The designer shall discuss the proposed fire damper installation details for each facility with the Fire Authority to confirm that the fire dampers specified have been tested to an arrangement which is representative of the proposed installation details. This may involve some additional on-site fire protection provision, e.g. local insulation, to meet Fire Authority requirements for each specific installation detail.

19.2.5 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.

19.2.6 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.

19.2.7 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.

19.2.8 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.

19.2.9 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 such as on those ventilating AMBER areas. In such cases manually initiated closure and reopening as required from a safe location is preferable.

19.2.10 RED area extract systems would not normally incorporate fire dampers. They would not normally have any openings in the ductwork outside of the RED area and would normally be of sufficient integrity to be able to claim fire rated status.

19.2.11 The philosophy for shutdown of ventilation systems in the event of a fire being detected should be discussed with the Fire Authority. It is not uncommon for space ventilation systems to be automatically shutdown, but for RED area ventilation systems (e.g. glove box extract and vessel vent) to remain running.

19.2.12 Access for Fire Damper Maintenance

To comply with The Regulatory Reform (Fire Safety Order) 2005 on the Sellafield site, SLP 2.16.06 states that all fire dampers are maintained in accordance with the British Standard requirements BS EN 15650:2010. The Sellafield site standard for the maintenance of ventilation systems SLP 1.06.59.01 also stipulates the requirement for regular testing of Fire Dampers to comply with BS 9999. To this extent, it is essential that the designer ensures that all fire dampers are readily accessible for such testing, to allow visual confirmation of opening and closing. Where dampers are located at high level, and access cannot be reasonably accommodated by permanently installed platforms, the designer shall ensure that sufficient space is left directly adjacent to the fire damper to allow access using, for example, a Mobile Elevated Working Platform. For other SLCs, refer to the local site practice related to fire damper maintenance. VWG_DD004 Guidance on Maintenance of Nuclear Ventilation Systems gives useful guidance on prioritisation and flexibility in the testing regime.

19.3 Ductwork

19.3.1 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 will need to be confirmed by the fire safety engineer (see also 19.2.2).

19.3.2 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.

19.4 Transfer Grilles

19.4.1 Transfer grilles should not normally be fitted in fire boundaries. If fitted, they must be fire-dampered to the same standard as the nominated barrier (see clause 7.14.6)

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

19.5 HEPA Filtration

19.5.1 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 airborne particulate, which may perforate the filter media with possible resultant release of previously trapped radioactive material.

19.5.2 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.

19.5.3 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.

19.5.4 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 of 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 their 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 can have a tendency to collect high levels of radioactive particulate 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.

19.5.5 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.

19.6 Automatic Fire Detection

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.

19.7 Fire Control Philosophy

The form and implementation of the control of a fire situation will depend strongly on the particular design philosophy adopted. It should 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 source of the fire. Radiologically controlled facilities, in general, will help to promote personnel safety since air is drawn into the contaminated areas thereby keeping corridors and workplaces free of smoke due to the higher pressure levels in these areas.

20 Ductwork Selection

20.1 Ductwork Standards

20.1.1 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.

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

(a) High integrity low leakage mild steel or stainless steel ductwork to ES_0_1723_2

(b) Fabricated ductwork to ES_0_1721_2 (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 tube

(e) Plastic ductwork to DW/154 or plastic tube

(f) Glass fibre ductwork to DW/191

(g) Flexible ductwork

20.1.3 Ductwork design guide EG_0_1720_1 provides typical design criteria, which may aid the designer in selecting which ductwork specification will best suit the ventilation system and atmospheric requirements.

20.2 Ductwork Serving WHITE and GREEN Areas

The specification for space ventilation ductwork serving WHITE and GREEN areas generally follows good industrial engineering practice. Such ductwork would normally be manufactured to ES_0_1721_2 (DW/144) although other materials and construction standards have limited applications.

20.3 Ductwork Serving AMBER Areas

20.3.1 Ductwork extracting from AMBER areas, and ductwork connected to backflow protection HEPA filters, is often required to be of a higher quality (e.g. in leak tightness, pressure rating, structural integrity). Such ductwork would normally be high integrity low leakage mild steel ductwork manufactured to ES_0_1723_2. In some cases high integrity low leakage stainless steel ductwork manufactured to ES_0_1723_2 may be preferred for enhanced corrosion resistance.

20.3.2 If attenuators are required on AMBER extract systems, they should be installed downstream of the filters and the splitter pods should be fixed within a ductwork section manufactured to the appropriate high integrity ductwork standard (ES_0_1723_2).

20.4 Ductwork Serving RED Areas

20.4.1 Ductwork extracting from RED areas would normally be constructed from high integrity low leakage stainless steel ductwork, pipework or tube manufactured to ES_0_1723_2. Pipework or rectangular tubing can be used for circular ductwork up to 150 mm diameter or rectangular ductwork up to 200mm x 200mm, although larger diameter pipework may be employed in some applications. Joints would normally be welded within cells or other inaccessible locations; elsewhere flanged joints are acceptable.

20.4.2 Where long term deterioration of high integrity low leakage ductwork is considered to be acceptable, mild steel ductwork to ES_0_1723_2 can considered if this results in a cost saving.

20.4.3 Consideration should be given to the routing of ductwork downstream of the extract fans, since it is under positive pressure and any leakage will be into the surrounding area. Particular consideration should be given to the adequate sealing of dampers and other such components which have penetrations in the ductwork containment (spindles etc.).

20.4.4 Plastic ducting or tubing 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.

20.4.5 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.

20.5 Flow Velocities in Ductwork

20.5.1 The velocities in air ducts should be in line with general ventilation good practice. Table 2.16 of CIBSE Guide B2:2016 gives recommended maximum duct velocities for Industrial buildings, where noise generation is the controlling factor. These range from 5 m/s to terminal units, 8 m/s in branch ducts and 10 m/s in main ducts. 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 and transport of dust, heavy gases and fumes.

20.5.2 The fluid operating conditions (pressure/temperature) need to be determined for the normal operating and abnormal operating conditions of the plant; and stated in the technical information accompanying the ductwork specifications.

20.6 Glovebox Ductwork

Glove box extract ductwork local to the 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 a sufficiently 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.

20.7 In-cell Ductwork

Extract ductwork within caves and cells should always be kept to a minimum since process equipment and associated pipework is generally complex and space is 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.

20.8 Material Compatibility

20.8.1 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.

20.8.2 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.

20.8.3 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.

20.8.4 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.

21 Testing and Commissioning

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

21.1.2 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/proof testing in accordance with the design substantiation requirements of each system

21.1.3 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.

21.1.4 The designer shall 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.

21.1.5 Adequate tests should be carried out to ensure that the correct air velocities are being achieved to support containment; e.g. at the entrances to fume cupboards and fume hoods and at the engineered breaches in containment boundaries. For other uncontrolled leakage paths in containment boundaries, smoke tests may be used (subject to COSHH assessment) to prove the correct flow directions.

21.1.6 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 would typically 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 supply 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.

22 Sustainability

Building on the success of the waste management hierarchy, Government strategy is placing greater emphasis on resources. A UK government policy paper Resources and waste strategy for England, which is available on the gov.uk website, sets out a strategy seeking to redesign waste out of the system, using the zero waste hierarchy as encouraged by Zero Waste Europe. This aligns with global aspirations for sustainability that recognises the role of the circular economy in decoupling resource use from growth in consumption. Sustainable nuclear ventilation seeks to ensure that the ventilation system (from air supply and to discharge) is as efficient and effective as possible and does not compromise the needs of future generations. By considering nuclear ventilation, and considering the environmental, social and economic impacts of the process, it is possible to realise significant beneficial outcomes across the entire system, which is illustrated in the government policy paper referred to above. Practitioners should consider nuclear ventilation within this wider framework of sustainability to maximise benefits and minimise impacts. For example, the failure to consider in the early planning stage the potential upstream prevention/minimisation of gaseous waste volumes can result in the construction and operation of an oversized gaseous waste treatment plant with avoidable detrimental environmental, social and economic impacts.

22.1 Design for energy efficiency

22.1.1 Design considerations for reducing energy usage on operating ventilation systems are covered in various clauses of this document, viz:

- Clauses 4.5.1 & 7.2 minimise the total air flow through the system from inlet to discharge into the atmosphere and incorporate maximum use of energy efficiency
- Clause 4.5.1. system to incorporate maximum use of energy efficiency (heat reclamation from exhaust air)
- Clause 6.2.5 avoidance of high rates of outdoor air for building heating and cooling purposes
- Clause 6.9.2 minimum outdoor air rates for ‘common spaces’ of 0.5l/s per m^2 of floor area to comply with building regulations
- Clause 7.3 design to consider running costs and energy consumption
- Clause 9.3 optimisation of cell depressions to minimise fan energy consumption
- Clause 10.6 variable flow control system for fume cupboards to reduce fan power

22.1.2 Reduction of energy usage is also covered in related Engineering Standards such as:

- ES_0_1708_2 specifies A+ Eurovent Energy rated bag filters for occupied facilities
- ES_0_1708_2 specifies a plate heat exchanger on combined supply and extract system AHUs to comply with the The Ecodesign for Energy-Related Products Regulations 2010 + Amendment Regulations 2015
- EG_0_1708_1 gives guidance on the application of maximum specific fan power to comply with the energy efficiency requirement of the Building Regulations

22.2 Minimising air flow through the building

22.2.1 Minimising air flow rates through a radiologically controlled facility is a fundamental objective for the designer. This will ensure that ventilation plant items are not oversized, to minimise embodied carbon within the manufacturing phase. It provides reduced fan power, gives reduced outdoor air heating load and minimises the number of filters to be disposed of as radioactive waste.

22.2.2 The ventilation air provided by the central plant for radiologically controlled areas within a building (normally GREEN, AMBER and RED areas) generally operate on the 100% outdoor air, once through principle with air extracted from the rooms within the building, discharged to atmosphere, with no recirculation. The winter season heating load for this type of system is significant in cases where heat reclamation from exhaust air is not used.

22.2.3 On a once through system, use of the outside air to meet the building heating load is very inefficient and should be avoided if practicable with direct heating sources considered and credit taken for internal plant gains.

22.2.4 Overall, this guide acknowledges that there will be a limit on how effective a ‘once through’ cascade ventilation system engineered for nuclear containment purposes can be on minimising operational energy use (and therefore carbon) while still maintaining its safety function. As stated elsewhere in the guide, it is therefore important that the designer provides information on the whole life energy and carbon impact of the systems to put the design into its correct context (e.g. Appendix D4.4 references Engineering Standards which specifiy plant items with a more robust construction that are designed to last well beyond the design life of COTS plant).

22.3 Exhaust air heat reclamation

22.3.1 Industry guidance suggests the following typical thermal efficiencies for a plate heat exchanger recuperator, in a clean condition, fitted within a combined supply and extract system AHU:

Air Infiltration and Ventilation Centre Brussels, V.I.P No. 6
Cross flow – seasonal net efficiency 45-60%
Contra flow – seasonal net efficiency 60-75%
CIBSE Guide B2 Ventilation and Ductwork (2016)
Cross flow – up to 70%
Counter flow – up to 90% with low velocities

22.3.2 The maximum air leakage for Eurovent Certified Performance air to air plate heat exchanger under ECP 08 (Revision 05-2020) is 0.5%. As the plate heat exhanger is commonly positioned on the suction side of both the supply and extract fans, with the suction pressure on the supply fan, where the air passes through the plate heat exchanger, likely to be higher (i.e. more negative) than the suction pressure on the extract fan, the resulting leakage in this instance would be from the exhaust air stream into the supply air stream.

22.3.3 Should a plate heat exchanger be deployed in the exhaust air stream on a HEPA filtered extract system, in this instance, the suction pressure on the extract fan, where the air passes through the plate heat exchanger, is likely to be higher (i.e. more negative) than the suction pressure on the supply fan, so the resulting leakage would be from the supply air stream into the exhaust air stream. However, the plate heat exchanger in this example would need to be constructed to withstand the negative pressure, on the downstream side of the HEPA filter.

22.3.4 The most efficient method of exhaust heat reclamation method on a 100% outdoor air once through ventilation system appears to be the use of an integrated heat pump combined with a heat recovery device such as a thermal wheel. However, unless the pressure on the supply air side of the thermal wheel is greater than on the return air side, the Exhaust Air Transit Ratio (EATR) will be increased. A low EATR will only be maintained if the wheel is kept in good condition through inspections and regular maintenance/cleaning, which could be prohibitive in a radiological controlled building. Plate heat exchanger recuperators could also be used with an integrated heat pump but would not be the best solution for sub-zero outside air temperatures. This is because the heat recovery device is best positioned to ‘receive’ air at the outside condition on the supply/inlet air stream and at the return building air condition in the extract/return air stream where the temperature differential between the two air streams will be greatest at the extreme conditions and therefore offer greater potential for heat energy transfer between the two air streams. If the outside air into the heat recovery device is say -3°C, the return air could be cooled within 2°C of this incoming air stream temperature to say -1°C which would likely lead to blockage of a plate heat exchanger as the moisture in the return air would freeze at this temperature. For this reason a frost coil may be needed on the incoming air supply upstream of the plate heat exchanger although this would reduce the temperature differential between the two air streams and reduce the heat energy transfer.

22.3.5 BSRIA Test Report No. 53820/1 details testing on a combined supply and extract system incorporating an integrated heat pump and thermal wheel. The outside air enters the AHU through a bag filter, then through a thermal wheel to pre-heat the incoming air, before passing through the supply air refrigerant (condenser) coil and is delivered to the building by the supply fan. The building return air enters the AHU through a panel filter, then through a thermal wheel, and is delivered by the extract fan through the exhaust air refrigerant (evaporator) coil before exhaust from the building. The report details results from testing showing significant energy savings.

22.3.6 The range of tests covered in the report shows that the integrated heat pump can operate (through reverse cycle) in either heating or cooling mode.

22.3.7 Heat recovery run around coils designed for a closed loop water/glycol circuit can recover heat from the building extract air to pre-heat the incoming outside air and can also be designed to achieve the following typical thermal efficiencies.

Air Infiltration and Ventilation Centre Brussels, V.I.P No. 6
seasonal net efficiency 45-55%
CIBSE Guide B2 Ventilation and Ductwork (2016)
40-60%

22.3.8 These may be more applicable for use on HEPA filtered extract air steams downstream of the filters.

22.4 Reducing air flows across GREEN to AMBER boundaries

22.4.1 Clause 7.10.10 gives the recommendation of a ‘containment velocity’ of 0.5m/s across open doors on entry facilities between GREEN and AMBER areas, which in issue 1 of this guide, was recommended for all radiologically controlled facilities. This approach is based historically on ventilation of alpha plants which inherently present a higher risk. The disadvantage of this approach is that it promotes a relatively high air flow across the entry facility (in the region of 0.8 to 0.9m^3/s depending on door opening size) which is less than ideal for sustainability, considering the ventilation system is running continuously and yet the doors on the entry facility are probably open for less than 1% of the time. Similarly, on loss of the ventilation system the entry facility will have significant size unventilated penetrations in the two walls separating it from the GREEN area which will represent a larger breach than two closed doors in series.

22.4.2 NVF/DG001, a predecessor of this document recommended that, where two doors are provided in series and only one door is opened at any time, the 0.5m/s airflow through openings between GREEN and AMBER areas only applies to openings across the closed door. Whilst this is no longer recognised as good practice for modern facilities, with sustainability now a factor, an approach which promotes a level of leakage around entry facility closed doors which is sufficient to maintain a measurable differential pressure across those doors, as recommended in clause 7.18, can provide an acceptable level of containment in facilities where the airborne challenge is not significant. A specific risk assessment will be required to determine the nature of the likely airborne contamination hazard and potential for back migration.

22.5 Partial recirculation of return air

22.5.1 In facilities where the minimum outdoor air requirements (see clauses 6.2.7, 6.9.2, 7.15.8) are exceeded when calculating the supply air flow rate from an AHU, partial air recirculation could be considered for return air from those areas which do not require a HEPA filter within the extract ductwork. A specific risk assessment will be required in this instance and this would unlikely be recommended in an alpha plant.

22.5.2 During the SARS-CoV-2 outbreak of 2020 there was much discussion on whether recirculated air would be appropriate without HEPA filters installed in the return air stream based on the assumption that the viruses such as SARS-CoV-2 are transmitted in sub-micron size droplets.

22.5.3 A report produced during the outbreak using evidence gathered from the Addenbrooke’s Hospital - *The removal of airborne SARS-CoV-2 and other microbial bioaerosols by air filtration on COVID-19 surge units, Conway Morris, A, et al* - provides evidence for the circulation of

SARS-CoV-2 in a ward within airborne droplets of >1 µm. It stated that "*droplets of 1–4 µm are likely a key vehicle for SARS-CoV-2 transmission, as they remain airborne for a prolonged period and can deposit in the distal airways. Recent data have shown that exertional respiratory activity, such as that seen in patients with COVID-19, increases the release of 1–4 µm respiratory aerosols, relative to conventionally defined 'aerosol generating procedures' such as non-invasive respiratory support*"

22.5.4 Filters classified with an ePM1 efficiency rating under BS EN ISO 16890-1 can provide a high level of efficiency for removal of airborne particulate >1 µm. For example, if an ePM1 70% bag filter is fitted in the return air stream and is mixed with outdoor air which is then passed through 2 x ePM1 70% bag filters in series, the recirculated air would have been subjected to an equivalent efficiency of 97.2% for removal of airborne particulate >1 µm. Alternatively, if an ePM1 85% bag filter is fitted in the return air stream and is mixed with outdoor air which is then passed through a single ePM1 85% bag filter, the recirculated air would have been subjected to an equivalent efficiency of 97.75% for removal of airborne particulate >1 µm.

22.5.5 The designer should be aware that paragraph 145 of NS-TAST-GD-022 2022 ONR Technical Assessment Guide Ventilation, within the advice to Inspectors on protection against pathogens, suggests that recirculation should be minimised with maximum use of outdoor air through air handling units. It also acknowledges that energy efficiency implications also need to be appropriately assessed. It is recommended that within such an assessment, as stated in clause 22.5.1 partial recirculation should only be considered where the minimum outdoor air requirements (see clause 6.9.2) are exceeded.

22.5.6 Experience with recirculating systems on ILW stores, in which tritium has been present in the return air, and where the recirculation path has included a cooling coil, has given rise to tritiated water in the condesate off the cooling coil. This would need collecting, monitoring and safely discharging. In this instance therefore, a risk assessment would need to be carried out to determine if recirculation is the best option, or if other methods of heat reclamation as detailed in the previous clauses would be preferred.

22.6 Reducing System Effects in the detailed design phase

22.6.1 Typical system effects on fan performance are discussed in the Engineering Guide for fans EG_0_1710_1 and for air handling units EG_0_1708_1. If system effects can be designed out then 'unnecessary' losses in static pressure can be avoided and energy 'wastage' from the operating fan minimised.

22.6.2 System effects can be embedded in the detailed design phase if plantrooms are not correctly sized to allow good practice to be followed in ductwork layouts connecting to stand alone centrifugal fans and air handling units. Sufficient consideration in particular needs to be given to the velocity profile in the ductwork immediately upstream and downstream of centrifugal fans.

22.6.3 On inlets to centrifugal fans, sufficient space is needed to provide straight lengths of ductwork equivalent to between 3 and 5 duct diameter lengths to give a reasonable velocity profile into the fan inlet and minimise losses in fan performance. The duct transformation piece onto the fan inlet should also be sized with a maximum angle of 15°.

22.6.4 Good fan outlet conditions can be more critical to reducing unnecessary static pressure losses. The discharge velocity from the fan can typically be up to 20m/s (or sometimes higher) and the connecting ductwork header will usually be sized for a lower air velocity (say 8-12m/s). A fan outlet diffuser with an angle preferably 15° but not exceeding 22.5° is needed to increase the likelihood of recovering the available static pressure (from the loss in velocity pressure). Where the outlet duct is larger than the fan discharge connection, CIBSE Guide B2 Ventilation & Ductwork 2016 recommends a 'gradual transition' with a following section of straight duct having a length equivalent to 3 duct diameters. The fan outlet isolation damper should be positioned away from the fan at a point where the velocity profile is uniform to reduce the static pressure loss across the open damper. This also allows the static pressure tapping (required upstream and downstream of centrifugal fans and positioned on the fan side of the fan isolation dampers) to be located at a point away from the fan discharge where the reading is more stable. Low leakage single blade butterfly isolation dampers can also give low pressure drops across the open blade when used as fan isolation dampers.

22.6.5 Where air handling units have ducted discharges directly off a centrugal fan, the same considerations need to be given as the previous paragraph to recover the available static pressure.

22.7 Use of circular ductwork

The Engineering Guide for ductwork EG_0_1720_1 discusses the use of circular versus rectangular ductwork. In terms of sustainability, circular ductwork has several advantages with less stiffening requirements, lower sheet thicknesses for higher working pressures and therefore lower embodied carbon.

22.8 Use of Variable Speed Drives

Variable speed drives have been prevalent in the Building Services industry since the 1980s. The use of a balancing/control damper to ‘trim the flow’ and remove static pressure on the main duct upstream or downstream of a fan is energy inefficient and should be avoided. Variable speed drives allow the fan speed to be set at the exact speed required to deliver the total system design flow without installing such a balance damper in the main duct. As filters gradually load up, the variable speed drive can be adjusted, if necessary, to marginally increase fan speed to maintain the overall system design flow. Hard-wired overspeed protection may be a requirement on fans which employ variable speed drives (see ADN_DES-CAP_MECH_00002_A Fan 7 Variable Speed Device (VSD) Design & Substantiation Guidance Note).

22.9 CIBSE TM65 – Embodied Carbon in Building Services

22.9.1 CIBSE document TM65:2021 *Embodied carbon in building services: a calculation methodology* considers assessments of embodied carbon of Building Service products. Embodied carbon is understood as the greenhouse gas emissions (GHG) associated with the making of a product, its installation, its maintenance, repair, replacement, and then its end of life including deconstruction and disposal. It covers the whole life cycle, excluding operational aspects and the potential recovery, reuse or recycling of materials.

22.9.2 Due to the lack of Environmental Product Declarations developed for Building Service Products, TM65 gives a methodology for manufacturers to provide sufficient information for designers to produce an embodied carbon footprint for the product.

22.9.3 The TM65 Embodied Carbon Calculator Input Form is intended to facilitate data collection from Mechanical, Electrical, Public Health (MEP) product manufacturers to help build embodied carbon data sets for calculating embodied carbon of MEP products and systems where no Environmental Product Declarations are available.

22.9.4 Engineers are being asked by CIBSE to feedback their findings on the embodied carbon of products, to help establish guidance on actions that reduce the embodied carbon associated with Building Services systems and allow informed choices on whole life carbon thinking – and not just operational carbon emissions.

22.9.5 A large proportion of embodied carbon (typically >90%) is associated with the product stage, as the majority of Building Services components are made of metals, electronics and plastics, and have a complex supply chain. The product stage includes the carbon emissions associated with extraction, transport and processing of materials and the energy consumption used to manufacture the product.

22.9.6 The most effective way of reducing the embodied carbon of systems is to specify them with:

- Low refrigerant GWP and no refrigerant leakage in normal use
- Reduced overall weight and extend lifetimes
- Materials of low embodied carbon

22.9.7 TM65 contains embodied carbon coefficients in $kgCO_2e/kg$ for different construction materials. The coefficients relate to the extraction, transport and manufacture of the raw material.

22.9.8 Designers are encouraged to use the calculation methodology presented in TM65 to build a knowledge base of embodied carbon values for the Building Service plant items they specify and share this information with CIBSE. Nuclear industry collaboration is needed between designers and suppliers/manufacturers to help collate the information needed to assess each product in completing the TM65 Manufacturer's form.

22.9.9 Future updates of the ventilation Engineering Standards (see clause 3.6.1) will contain a request for Contractors to complete the TM65 Embodied Carbon Calculator Manufacturer's Form for the plant items covered under the scope of their supply.

22.10 Design of plant items for extended lifetimes

22.10.1 As detailed in clause 22.9.6 of this document, TM65 recognises the reduction in embodied carbon that can be realised with extended lifetimes of plant items.

22.10.2 Appendix D.4 of this document presents both the economic case, and the requirement for increased plant item integrity, for reasons to design plant items for a nuclear licensed site to a more robust standard than Commercial Off The Shelf or COTS piece of mechanical plant.

22.10.3 This approach is therefore consistent with CIBSE recommendations in reducing overall life cycle embodied carbon in nuclear facilities.

22.11 Silent hours plant operation

22.11.1 For ventilation systems which are not required to operate continuously to maintain containment flows, consideration should be given to switching off the ventilation plant or reducing the air flow rates during non-occupied periods, e.g. night-time, weekends.

22.11.2 If water coils are installed in AHU air intakes then some method of frost protection will be needed to prevent freezing of the water during cold spells when the ventilation system is not running. Typically 2 stages of frost protection could be employed. The first stage would be initiated when the outdoor temperature sensors record a temperature ≤4°C, when a signal is sent to motor the valves on the coils to fully open and circulate water through the coils. The second stage would be initiated if the water return temperature from the coils drops to ≤15°C, at which point the heating source would be controlled to raise the the water temperature to 30°C.

23 Requirements of ISO 17873:2004(E)

Clause 1.3 of this document refers to ISO 17873:2004(E) *Nuclear Facilities - Criteria for the design and operation of containment and ventilation systems for nuclear installations other than nuclear reactors.* This is an International Standard which "*specifies the applicable requirements concerning the design and use of ventilation systems in nuclear installations such as hot cells, nuclear fuel fabrication and examination laboratories, plutonium-handling facilities, reprocessing plants, enrichment facilities, nuclear-waste treatement station, storage facilities. etc*." This section highlights requirements within ISO 17873:2004(E) which, based on past experience of operating such installations, may require some latitude and thought given to the plant specific arrangements, when specifying current good practice for the UK nuclear industry.

23.1 Guide to depression values

23.1.1 Table 3 of ISO 17873:2004(E) gives a guide to depression values in areas of different "Containment class" as "necessary to create the required inflow of air through permanent or accidental openings of not less than specific average velocity during normal and abnormal conditions."

23.1.2 Whilst this is true, consideration also needs to be given to the geometry of these permanent or accidental openings, as the depression can, in some circumstances, be driven by the velocity required through these openings – rather than depression being the driver. The reason for this is that 'depression driven flows' (i.e. flows sized purely to give a pressure drop across an opening) can result in velocities and flows through openings/breaches in containment which are higher than required/recommended.

23.1.3 For example, clause 7.10.18 of this document refers to experimental work on containment flows for gaps up to 200mm, giving the optimum velocity at 1 m/s with containment dropping off gradually as the velocity increases up to 4 m/s and dropping rapidly as the velocity decreases below 1 m/s.

23.1.4 If operating depressions were to be considered for say a shielded waste processing cell (RED area), which may typically have connecting shielded maintenance or breakdown cells (AMBER areas), each separated by shield doors, good practice would typically suggest an operating depression within the waste processing cell of 200 to 250Pa (see clause 9.4) relative to the occupied (GREEN) areas in the facility.

23.1.5 When 'calculating' the pressure drop between the waste processing cell and the adjacent maintenance or breakdown cells, the optimimum 1m/s through gaps around the shield doors may equate to a differential pressure across these gaps of only several pascals which would be difficult to measure. If Table 3 of ISO 17873:2004(E) were to be used in this instance, it may inadvertently drive the designer to engineer much higher air flows/velocities across these gaps/openings, as Table 3 could be interpreted to suggest a target differential pressure across this boundary in the region of 100Pa or above.

23.1.6 In this instance, it is suggested that the vast majority of the depression of 200 to 250Pa between the occupied (GREEN) area and the (RED) would be 'engineered' between the personnel access route into the (AMBER) maintenance areas (see Figure 12 and clause 7.15.12 of this document). This would typically require a sub-change room on the entry point to the maintenance area with a sealed door on the exit from the sub-change room into the maintenance area, with mechanical assistance on the door to enable its opening and closure against the relatively high operating depression. When the door is closed, the cascade flow from the sub-change room would be via a HEPA filtered engineered wall penetration suitably sized to give the required boundary pressure drop (in this case 200 to 250Pa) for the required downstream flow into the waste processing cell.

23.1.7 A second example where Table 3 of ISO 17873:2004(E) may unintentionally influence the designer to provide an inappropriate design solution could be for a glove box facility. Typical UK glove box operating depressions are 375Pa relative to the (AMBER classified) glove box 'cell'/room in which the glove box is located. If Table 3 were to be followed in this case, it could suggest to the designer that a glove box operating depression of around 200Pa was adequate.

Similarly as cascade flows from GREEN to AMBER areas across sub-change rooms in alpha plants could follow the guidance given in clause 7.10.10 of this document, (based on an air flow velocity of 0.5 m/s across the open outermost door into the entry facility and an air flow velocity of 0.5 m/s across the open innermost door on the exit from the entry facility), the depressions required to generate these velocites would be insufficient to achieve the suggested (120 to 140Pa depression) for the C3 controlled areas in Table 3.

23.1.8 A further example of the limitations of Table 3 of ISO 17873:2004(E) could be in establishing an appropriate depression within an in-cell vessel containing liquid radiological inventory. It is not uncommon to operate such vessels at -1500Pa relative to its surrounding cell. This is to allow for the considerable drop in vessel depression which can arise during transfers of material between vessels, as it is important that, during such transfers, a minimum transient depression relative to the cell is maintained. In this instance, the 220 to 300Pa depression stated in Table 3 of ISO 17873:2004(E) would be more appropriate for this minimum transient depression rather than the normal operating depression.

23.1.9 In conclusion, to reiterate the comment made in clause 7 of this document, the most important aspect of the design of ventilation systems is a clear understanding of the plant specific hazards. Consequently a ‘one size fits all’ approach is not applicable to the design of nuclear facilities which are often unique. Whilst it is acknowledged that ISO 17873:2004(E) can be useful for guidance purposes, because the scope of ISO 17873:2004(E) is phrased as a specification of requirements, it is suggested that by following Table 3, (based on the requirements of these target pressure differentials between different classified areas), it could direct a designer to provide less than optimum design solutions.

23.1.10 In contrast, the purpose of this design guide, rather than setting out requirements for the design of ventilation systems in nuclear installations, is to present sufficient information to allow the designer to decide the most appropriate design solution in addressing plant specific hazards.

23.2 Guide to air-change rates

23.2.1 Table 4 of ISO 17873:2004(E) gives a guide to “the conventionally adopted air-change rates” as the first of four iterative steps in the “calculation of ventilation air-change rates for areas, containment enclosures and rooms.”

23.2.2 Table 4 is a copy of Table 1 from NVF/DG001, which is a predecessor of this current document, but the table has since been removed as it does not represent current good practice (see clause 7.15 of this document).

23.2.3 In addition to the fact that generic room air change rates are no longer used as a means of determining room air flows in a radiologically classified facility - and in line with CIBSE Guide B2: 2016 - neither in conventional buildings, it could be inferred, from Table 4 of ISO 17873:2004(E), that higher flow rates are required as the contamination classification is increased (C1 to C4). Dilution of the airborne activity concentration within a containment is not a method which should be used for determining air flows. The concentration of airborne activity within an enclosure, that would make it an acceptable breathing zone, is so low to make it impractical to use ventilation to reduce the concentration of any airborne activity by an amount which would be significant in determining the radiological classification of that area; i.e. the ventilation flow rate through a primary containment will have an insignificant effect on the airborne activity level at the threshold where it can cause harm to people.

23.2.4 Earlier nuclear industry ventilation design guides, such as AECP 1054, promoted increasing air change rates for areas which had increasing potential for airborne activity (presumably based on the dilution principle). Experience and advancements in understanding have shown this previously accepted method to be no longer considered as good practice. Air change rates within a containment, therefore, are not a method which should be used as a driver to determine air flow rates through that containment.

23.2.5 Unless minimum air change rates in rooms are required to address specific process requirements, dilution requirements for gaseous arisings, or plant heat gains, they are normally a secondary consideration in nuclear facilities, where flows to support containment normally take precedent.

23.2.6 Consequently, as outlined in clause 7.15 of this document, in RED areas, air flows should be the minimum required to meet the process requirements of the area and maintain containment, since increasing the air flow could lead to greater entrainment of airborne activity into the exhaust air stream with a greater potential for accumulation of contamination on internal ductwork surfaces upstream of filters and increased activity on the filters. This could possibly lead to increased shielding requirements for ductwork and filter housings.

A Appendix A: Classification of areas for various nuclear sites

The table below shows the approximate relationship between working area classifications at various UK nuclear licensed sites and the containment area classification system 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.

<table>
<tr><th>Site
Classification</th><th>Aldermaston</th><th>Nuclear Restoration Services (Dounreay)</th><th>Sellafield Ltd</th><th>Nuclear Restoration Services</th><th>EDF Energy</th><th>ISO 17873</th></tr>
<tr><td rowspan="2">WHITE</td><td rowspan="2">Undesignated</td><td rowspan="2">Undesignated or Supervised</td><td>C0
Unclassified Area</td><td rowspan="2">C1
Supervised</td><td rowspan="2">C0/WHITE</td><td rowspan="2">C1</td></tr>
<tr><td>C1
Supervised area</td></tr>
<tr><td rowspan="2">GREEN</td><td>C1</td><td rowspan="2">LOW (Controlled area Operational)</td><td rowspan="2">C2
Controlled area</td><td rowspan="2">C2
Controlled area</td><td rowspan="2">C2
LOW/GREEN</td><td rowspan="2">C2</td></tr>
<tr><td>C2</td></tr>
<tr><td>AMBER</td><td>C3</td><td>MODERATE (Controlled area Restricted)</td><td>C3
Controlled area</td><td>C3
Controlled area</td><td>C2
HIGH/AMBER</td><td>C3</td></tr>
<tr><td rowspan="2">RED</td><td rowspan="2">C4</td><td rowspan="2">HIGH (Controlled area Exclusion)</td><td>C4
Controlled area</td><td rowspan="2">C4
Controlled area</td><td rowspan="2">C3/RED</td><td rowspan="2">C4</td></tr>
<tr><td>C5
Controlled area</td></tr>
</table>

B Appendix B: ONR Safety Assessment Principles relating to Containment and Ventilation

The following Engineering Principles for Containment and Ventilation are as listed in the ONR Safety Assessment Principles for Nuclear Facilities 2014 Edition: -

Engineering principles: containment and ventilation: containment design	Prevention of leakage	ECV.1
Radioactive material should be contained and the generation of radioactive waste through the spread of contamination by leakage should be prevented.		
Engineering principles: containment and ventilation: containment design	Minimisation of releases	ECV.2
Containment and associated systems should be designed to minimise radioactive releases to the environment in normal operation, fault and accident conditions.		
Engineering principles: containment and ventilation: containment design	Means of confinement	ECV.3
The primary means of confining radioactive materials should be through the provision of passive sealed containment systems and intrinsic safety features, in preference to the use of active dynamic systems and components.		
Engineering principles: containment and ventilation: containment design	Provision of further containment barriers	ECV.4
Where the radiological challenge dictates, waste storage vessels, process vessels, piping, ducting and drains (including those that may serve as routes for escape or leakage from containment) and other plant items that act as containment for radioactive material, should be provided with further containment barrier(s) that have sufficient capacity to deal safely with the leakage resulting from any design basis fault.		
Engineering principles: containment and ventilation: containment design	Minimisation of personnel access	ECV.5
The need for access by personnel to the containment should be minimised.		
Engineering principles: containment and ventilation: containment monitoring	Monitoring devices	ECV.6
Suitable and sufficient monitoring devices with alarms should be provided to detect and assess changes in the materials and substances held within the containment.		
Engineering principles: containment and ventilation: containment monitoring	Leakage monitoring	ECV.7
Appropriate sampling and monitoring systems should be provided outside the containment to detect, locate, quantify and monitor for leakages or escapes of radioactive material from the containment boundaries.		
Engineering principles: containment and ventilation: import and export of nuclear material	Minimisation of provisions for import or export of materials or equipment	ECV.8
Where provisions are required for the import or export of materials or equipment into or from containment, the number of such provisions should be minimised.		
Engineering principles: containment and ventilation: import and export of nuclear material	Containment and ventilation system design	ECV.9
The design should ensure that controls on fissile content, radiation levels, and overall containment and ventilation standards are suitable and sufficient.		
Engineering principles: containment and ventilation: ventilation design	Ventilation system safety functions	ECV.10
The safety functions of the ventilation system should be clearly identified and the safety philosophy for the system in normal, fault and accident conditions should be defined.		

C Appendix C: EA Environmental Engineering Principles

The following Engineering Principles are as listed in the EA Radioactive Substances Regulation. RSR generic developed principles: regulatory assessment, 2021.

Principle ENDP1 – Inherent Environmental Protection: **The underpinning environmental aim for any facility should be that the design inherently protects people and the environment, consistent with the operational purpose of the facility.**

Principle ENDP2 – Avoidance and Minimisation of Impacts: **Radiological impacts to people and the environment should be avoided and where that is not practicable minimised commensurate with the operations being carried out.**

Principle ENDP3 – Defence in Depth: **A facility should be designed as to allow for defence in depth against the occurrence of radiological impacts to people and the environment.**

Principle ENDP4 – Environment Protection Functions and Measures: **Environment protection functions under normal and fault conditions should be identified, and it should be demonstrated that adequate environment protection measures are in place to deliver these functions.**

Principle ENDP5 – Human Factors: **Human actions should be taken into account in the design of a facility and in operating procedures.**

Principle ENDP6 – Engineering Codes and Standards: **Environment protection measures should be designed, manufactured, constructed, installed, commissioned, quality assured, maintained, tested and inspected to the appropriate standards.**

Principle ENDP7 – Reliability: **A facility should be so designed and operated that the environment protection measures are reliable.**

Principle ENDP8 – Ageing and Degradation: **The working life of an environment protection measure that is intended to deliver an environment protection function should be assessed to ensure that the measure will be effective during its intended lifetime.**

Principle ENDP9 – Fault Sensitivity: **The sensitivity of the facility to potential faults that could have radiological impacts to people and the environment should be minimised.**

Principle ENDP10 – Quantification of Discharges: **Facilities should be designed and equipped so that best available techniques are used to quantify the gaseous and liquid radioactive discharges produced by each major source on a site.**

Principle ENDP11 – Maintenance, Inspection and Testing: **Structures, systems and components that are, or comprise part of, environment protection measures should receive regular and systematic examination, inspection, maintenance and testing.**

Principle ENDP12 – Commissioning: **Before operating any facility or process, commissioning tests should be defined and carried out to demonstrate that, as built, the facility or process will be capable of delivering the environment protection functions.**

Principle ENDP13 – External and Internal Hazards: **External and internal hazards that could affect the delivery of an environment protection function should be identified and the best available techniques used to avoid or reduce any impact.**

Principle ENDP14 – Control and Instrumentation - Environment Protection Systems: **Best available techniques should be used for the control and measurement of plant parameters and releases to the environment, and for assessing the effects of such releases in the environment.**

Principle ENDP15 – Mechanical Containment Systems for Liquids and Gases: **Best available techniques should be used to prevent and/or minimise releases of radioactive substances to the environment, either under routine or accident conditions.**

Principle ENDP16 – Ventilation Systems: **Best available techniques should be used in the design of ventilation systems.**

Principle ENDP17 – Civil Engineering: **It should be demonstrated that structures which are, or comprise part of, environment protection measures are sufficiently free of defects such that the relevant environment function(s) is not compromised, that identified defects are tolerable, and that the existence of defects that could compromise the environment protection function can be established throughout their life-cycle.**

Principle ENDP18 – Essential Services: **Best available techniques should be used to ensure that loss of essential services does not lead to radiological impacts to people or the environment.**

D Appendix D: The development of UK Guides and Standards for nuclear ventilation systems

D.1 United Kingdom Atomic Energy Authority

D.1.1 The UK Atomic Energy Authority (UKAEA) was responsible for producing Nuclear Industry standards from the 1960s to the 1990s. These Atomic Energy Standard Specifications (AESSs) included standards for the specification of ventilation ductwork AESS 6008 Parts 1 to 3; and AESS 6019 for the specification of fans.

D.1.2 Along with a number of UK Nuclear Site Licensees, the UKAEA formed the Filter Development and Standards Working Party (FDSWP) who were responsible for the production of AESS purchasing specifications for HEPA filters. To meet the requirements of the HEPA filter purchasing specifications, filters had to be Type Approved. Type Approval of HEPA filters was carried out at the Atomic Energy Research Establishment Harwell laboratory. Filter developments were coordinated by the Nuclear Industry wide FDSWP and the Containment and Ventilation Treatment Working Party (CVTWP). Both of these committees and the filter testing service at Harwell were closed down in the early to mid-1990s. As the type testing facility, as written into the AESS filter specifications no longer existed, type approval of HEPA filters supplied to UK sites had time expired by approximately 2000.

D.1.3 An Atomic Energy Code of Practice AECP 1054 was published in June 1979 to be used throughout the UK Nuclear Industry as an aid to designing ventilation systems for radiological facilities. The Code of Practice was prepared by the Working Party – AECP 1054 'Ventilation of Radioactive Areas' – comprising members from the UKAEA and other UK Nuclear Site Licensees.

D.1.4 Following the break-up of the UKAEA and the demise of the cross industry FDSWP and CVTWP committees in the 1990s, collaboration between the various UK Nuclear Site Licensees was much reduced and some of the licensed sites produced their own versions of the standards.

D.2 Institution of Mechanical Engineers Nuclear Ventilation Seminars

D.2.1 The loss of the UKAEA and the cross industry FDSWP and CVTWP committees inevitably led to a period of reduced dialogue and knowledge sharing in the nuclear ventilation discipline between the UK site licensees. In the late 1990s the lack of cross industry education and training specifically in the area of nuclear ventilation was recognised, and The Nuclear Power Committee of the Institute of Mechanical Engineers (IMechE) arranged for a ventilation seminar to be held in 2000 organised by a group made up from BNFL and Nuclear Installations Inspectorate (now the ONR). The one day event focused on raising the level of awareness of ventilation issues across the nuclear industry.

D.2.2 Subsequent seminars held in 2002 and 2005 became 2 day events with more wide ranging ventilation topics and case studies presented. The audience was looking for more up to date UK industry wide guidance on the design of ventilation systems for nuclear facilities as the last issue of AECP 1054 had been published in 1989. From the 2005 seminar, a cross industry group started to update AECP 1054 and this group evolved into the National Nuclear Ventilation Forum (NNVF). The IMechE Seminars continue to be held every 2 years to provide education, learning and knowledge share across the UK nuclear ventilation community.

D.3 National Nuclear Ventilation Forum

D.3.1 The UK National Nuclear Ventilation Forum (NNVF) meets 3 times per year to discuss and document good practices relating to nuclear ventilation. The forum is open to representatives from all UK nuclear ventilation industry companies. The Ventilation Working Group (VWG) is for Site licensees and Regulators to discuss the implementation of ventilation practice on licensed sites. The VWG guide the NNVF work programme and endorse documentation.

D.3.2 The NNVF is a sub-group of the Nuclear Engineering Directors Forum. The Strategic priorities of the Nuclear Engineering Directors Forum are Standards, Asset & Ageing Management and Skills. To this end, the NNVF has taken an active role in the production and update of UK

Nuclear Industry Guides and Standards. Although Sellafield Ltd is responsible for producing and maintaining the UK Engineering Standards and Guides on behalf of the UK Nuclear Decommissioning Authority, it does so through collaboration with and input from the NNVF. Hence, from 2014 all ventilation Engineering Standards and Guides have been reviewed and updated through the National Nuclear Ventilation Forum (NNVF).

D.3.3 Input into the Engineering Standards and Guides from site licensees and the supply chain has aimed to improve the standards, feed Learning From Experience (LFE) into updates of the standards, and establish them as UK common Nuclear Industry standards, which provides clarity for plant manufacturers if they can manufacture plant items to the same standard irrespective for which UK Nuclear Licensed site the plant item is specified.

D.4 Why UK nuclear industry specific Guides and Standards are required

D.4.1 Nuclear facilities often cost hundreds of millions, or sometimes billions of pounds, to construct. To get a good return on the investment and because of the high cost to replace these facilities, operating lives can be relatively long - 50 years plus in some cases - with many facilities continuing to operate even beyond their original design lives.

D.4.2 Costs to replace worn out plant items on a Nuclear Licensed Site can often be many times the actual purchase cost of the plant item itself. Typically when taking into account the associated design costs, project planning work, modifications to interfacing systems, the possible installation of temporary systems, the lengthy process and the many procedures that are required to be followed on a Nuclear Licensed Site to modify or replace a plant item that may have a role in providing a Safety Function, then the overall costs can run into the millions of pounds to replace a piece of plant with a purchase cost of say in the tens of thousands. Hence, overall replacement costs of worn out plant items in nuclear facilities can be vastly disproportionate to the basic purchase cost of that plant item.

D.4.3 Many nuclear sites are in coastal locations and the ventilation systems operate with highly corrosive salt laden inlet air streams. The pictures below are taken from the inside of an Air Handling Unit on the Sellafield site.

D.4.4 In this type of environment, a standard Commercial Off The Shelf or COTS piece of mechanical plant, may have to be replaced every 15 years or so. Compared to that, there are examples of fans on the Sellafield site that have been operating in excess of 50 years; evidence that plant items specified with a more robust construction can last well beyond the design life of COTS plant. As a result those disproportionate replacement costs can be reduced significantly; and in the long term, this could reduce overall life cycle costs for a facility by a considerable margin.

D.4.5 There are also plant integrity issues to be considered for ventilation systems which move potentially contaminated air. In such cases, those systems have to be virtually leak tight to ensure that airborne contamination cannot leak out. Plant procurement standards are therefore required to specify plant, which is more robust and of higher integrity than standard COTS plant.

D.4.6 Recognised policy is to use British Standards, International Standards or other relevant National Standards wherever possible. Although there aren't any single BS/EN or ISO standards which can be used as turnkey specifications for these high integrity nuclear ventilation plant items, the

Engineering Standards refer out to many BS, EN or ISO standards, and other industry standards, for the specification of materials, components, fabrication methods and testing. Consequently, BS, EN, ISO and other industry standards are specified where appropriate.

D.4.7 The Office for Nuclear Regulation (ONR) Technical Assessment Guide NS-TAST-GD-077 'Supply Chain Management Arrangements for the Procurement of Nuclear Safety Related Items or Services' includes a section on mitigating measures to be deployed to reduce the risk of Counterfeit, Fraudulent and Suspect Items (CFSI) being deployed on a Nuclear Licensed Site. Those measures include robust Supply Chain Management (SCM) and procurement process arrangements including effective Supply Chain oversight and assurance, including inspection and testing. The NDA Ventilation Engineering Standards include Master Inspection and Test Plans and documentation requirements such that the appropriate oversight and assurance arrangements can be specified by the designer in the defence against CFSI.

D.5 UK HEPA filter standards

D.5.1 With the disbanding of the cross industry Filter Development and Standards Working Party and the closure of the filter testing service at Harwell in the early to mid-1990s, the UK AESS HEPA filter standards were no longer maintained and type approval of HEPA filters supplied to UK sites no longer carried out.

D.5.2 This led in 2013 to a review, carried out by the Health and Safety Laboratory, of the adequacy of HEPA filters manufactured for use in the UK's Nuclear Industry. The review established that whilst the overall quality of HEPA filter manufacture for the nuclear sector was high, there were concerns around the reliance upon standards which have not been revised for over 20 years. As a result the AESS HEPA filter standards were updated and replaced by Engineering Standards.

D.5.3 An NNVF filter sub-group was formed with representatives from site licensees and filter manufacturers to improve the standards, feed LFE back into updates of the standards and establish them as new UK Nuclear Industry filter standards. In addition HEPA filter Type Testing has now been re-established in the UK with filter manufacturers responsible for commissioning type testing of their own filters.

D.5.4 There are now 11 Engineering Standards covering HEPA filters, filter media and type testing. These cover the conventional 850l/s (1800cfm) rectangular filters, used on legacy plants, the 950l/s (2000cfm) radial flow filters used on modern plants, push-through glovebox filters, canister filters, screw on filters and spark arrestors.

D.5.5 All of the UK HEPA filter Engineering Standards are based on the use of filter media which complies with ASME AG-1; and with some additional production tests on the media covering bursting strength and media stiffness. The media qualification testing requirements are the same as ASME AG-1. The standards require that all HEPA filters are production tested for air flow resistance and efficiency. In addition the Type Testing Standard ES_0_1705_2 requires every type of HEPA filter to be tested at 5 yearly intervals. These type tests cover efficiency, pressure drop, dust loading, performance testing after oven heating and pleated media tensile strength testing.

E Appendix E: Wider industry practices on pressure differentials for critical environments

The following clauses consider wider industry guidelines and results from empirical testing to establish recommendations for adopting differential pressure as the basis for achieving good containment across entry facilities between GREEN and AMBER areas. These clauses provide the basis for the recommended differential pressures between GREEN and AMBER areas in facilities where there is a lower risk of migration back through an entry facility (as opposed to an alpha plant) as detailed in clause 7.18.

E.1 ASHRAE guidance on room pressure for critical environments

E1.1 The ASHRAE Journal February 2003 article *Room Pressure for Critical Environments, Brian Wiseman* discusses the amount of differential airflow required to achieve room pressurisation. The article considers ‘current literature’ for establishing room pressurisation and reports the findings of field testing for a biosafety research laboratory and a healthcare positive pressure isolation room.

E1.2 The review of literature and guidelines concluded that leakage from the room fabric is a key factor in establishing room pressurisation with the leakage function defined by the ‘power law equation’

$Q = c\,(\Delta P)^{n}$

Where

Q is the volumetric flow rate through an orifice

c is a flow coefficient based on the geometry of the orifice

ΔP is the pressure differential across the orifice

n is the pressure exponent, commonly around 0.65 per ASHRAE

E1.3 Based on the range of source material within the review, the article recommends that rooms should have a differential airflow to obtain, as a minimum, a 0.01” w.g. (2.49Pa) to 0.05” w.g. (12.45Pa) differential pressure. Various sources are considered in the article relating to the flow differentials required to achieve the recommended room differential pressure with examples given of 47l/s and 61l/s of transfer air through a door undercut to give a 12.45Pa differential pressure across a closed single door. The article reports evidence of increased door swing velocities affecting the containment or exclusion of contaminants and recommends slow door opening and closing with the travelling speed controlled and accomplished with an adjustable dampened door closure device.

E1.4 The field testing for the biosafety research laboratory ensured that the wall, floors and all penetrations were sealed including electrical conduits. There was one door entry, the doorjamb not sealed, and a 12.7mm door undercut. An airflow direction indicator penetrating the wall was used to self check the air flow direction in/out of the room when the door was opened. The test initially used a room with a 10% differential airflow to give a negative room pressure confirmed by the through wall airflow direction indicator. The differential airflow required to give a negative room pressure of 0.015” w.g. (3.735Pa) was approximately 71l/s made up through the 12.7mm door undercut.

E1.5 The first test was done with the door swinging into the room. When the door was opened, the direction indicator indicated that the room was transiently under a positive pressure and a smoke test showed the smoke trailing the door travel with portions of the smoke in the door’s wake pushed out of the room. The same test was performed with the door closing, which showed the room going into further negative pressure with the smoke contained in the room, establishing that closing of a door which swings into a negative pressure room has no detriment.

E1.6 The test was repeated on this negative pressure room with the door opening out of the room. When the door was opened, the article reports that the eddy smoke trails followed the door in the beginning of the door travel, but the smoke was sucked back into the room.

E1.7 The article reports subsequent tests using this setup to explore the capture velocity of a partially opened door as a function of room differential pressure, with the door opened and held partially open to observe the trail of smoke plume in the plane of the door. The purpose of these tests was to challenge a source, reported in the article, which suggested that a minimum differential pressure of 0.001" w.g. (0.249Pa) was sufficient to achieve a directional air flow into or out of a room. These subsequent tests showed the smoke plume not being captured at 0.001" w.g. (0.249Pa), the plume about to be captured at 0.003" w.g. (0.747Pa); and the capture significantly improving at 0.008" w.g. (1.992Pa).

E1.8 The article concludes that, based on the observations of the door swing effect on room pressure, for a negative or positive pressure room, the entry doors should be gasketed at the sides and at the top, and a sliding door entry preferred over a swing door. If a swing door is used, the article suggests it should open out of the room which has the lower pressure and into the room which has the higher pressure. It also emphasises what should be standard practice for nuclear facilities that to achieve the required differential pressures the room fabric and all room penetrations need to be well sealed.

E1.9 The article recommends that an airlock (anteroom) should be used wherever possible to 'trap' any escaped air from a negative pressure room. To provide an effective 'trap' it recommends a high air change rate in the airlock of around 12 air changes per hour or higher. It concludes that rooms should have a 0.01" w.g. (2.49Pa) to 0.05" w.g. (12.45Pa) or higher differential pressure, with a pressure stabiliser specification for a negative room for supply make up air of +0%/ -10%. For negative rooms the make up air should be provided via a supply outside of the room.

E.2 BSRIA testing for pressure differentials across healthcare isolation wards

E2.1 For comparative purposes, the ventilation of isolation suites in UK healthcare facilities is equally of relevance. BSRIA publication *BTS 3/2018 Air Permeability Testing of Isolation Facilities* gives an example of an isolation suite which includes a pressurised entrance lobby, where pressure differentials and ventilation are used to contain airborne infection.

E2.2 BSRIA Presentation *Application of Airtightness to Healthcare Buildings- Dr Blanca Beato-Arribas (IMechE Nuclear Ventilation Conference 2019)* shows some air leakage testing of isolation suites using the ATTMA Technical Standard, including the calculated air leakage across the door gaps on such an entrance lobby. The results showed leakage of approximately 100l/s across the double doors at a 30Pa differential pressure; with an extrapolated area of opening of approximately 0.015m^2. At a pressure differential of 15Pa the leakage rate would be approximately 65l/s. This presentation also highlights that the assumption in clause A.3.1, Note 2 of BS EN 12101-13:2022 (see 7.16.2) suggesting that the value of R for door cracks taken as 2.0, should be treated with some caution, as the actual test data suggested that the cracks around the door gaps gave an R value around 1.64, suggesting that the air flow is moving from turbulent towards laminar through the narrow door gap.

E2.3 These BSRIA references also highlight that, in addition to air leakage around doors, it is probably unrealistic to assume that the general building fabric of the perimeter walls, floors and ceilings within AMBER areas will be free of leakage. Therefore, the designer should make some allowance for this leakage in the cascade air flow calculations. BSRIA publication *BTS 3/2018* suggests a maximum of 2.5m^3/h/m2 @ 50Pa which would correspond to a value of 1.84m^3/h/m^2 @ 30Pa using an R value of 1.67.

E2.4 Other BSRIA presentations looking at cascading pressure zones which can offer useful guidance on the effectiveness of cascade air flows across entry facilities in nuclear buildings include the consideration of a Neutral Pressure Isolation Room and a Negative Pressure Isolation Room.

E2.5 BSRIA Presentation *Validation of a Neutral Pressure Isolation Room - Andrew Fletcher, William Booth and Blanca Beato Arribas BSRIA Ltd. UK,* reports on a test facility for the physical modelling of a Positively Pressurised Ventilation Lobby isolation room, with a CFD model constructed for comparison purposes. This arrangement was shown to provide a 'protection factor' of 10^5 between the corridor and the isolation room with all doors closed. Figure 23 shows the room arrangement for this test facility.

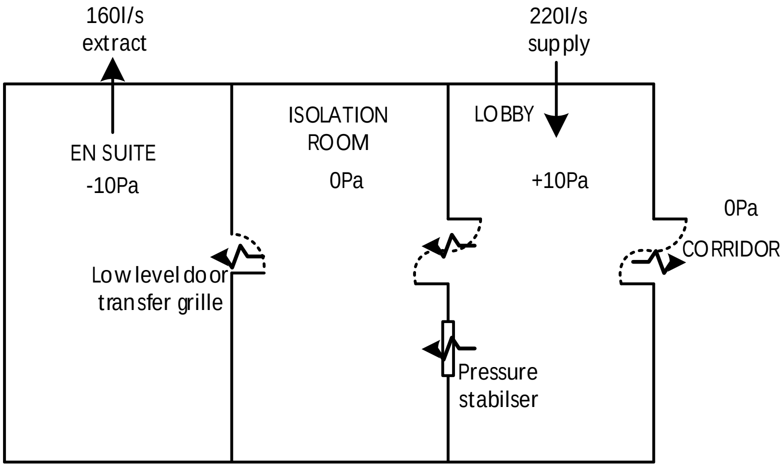


Figure 23 – Positively Pressurised Ventilation Lobby, Neutral pressure isolation room

E2.6 As the lobby is pressurised, this arrangement provides both protection from infections originating in the isolation room (equivalent to a negative pressure isolation room in Figure 24) and protection from infections originating in the corridor (which would not normally be required if we were considering contamination spread in a nuclear facility).

E2.7 The conclusion from the report considers the Positively Pressurised Ventilation Lobby design to be validated. The report stated that, although it would not be expected that the door between the lobby and isolation room would be left open for a prolonged period, the tracer gas tests demonstrated that the isolation room still behaved as a single zone, but with some air interchange between the lobby and the isolation room. The report considered single failure modes to include supply and extract fan failures. The simulated supply fan failure indicated no significant leak of tracer gas into the corridor, with the isolation room remaining under negative pressure. Extract fan failure led to increased levels of detection within the isolation room as expected, but the lobby still provided a layer of protection to the corridor. Consequently, it was concluded that a patient vulnerable to infection in the isolation room would not be at a significantly higher risk as long as the doors remained closed in this particular failure mode. The worst-case failure mode explored within the report was for the lobby door to be left propped open. Tests show that under these conditions the tracer gas passed into the lobby, with barely detectable levels reaching the corridor.

E2.8 A further BSRIA Presentation *Application of Airtightness to Healthcare Buildings - William Booth, Tom Jones and Blanca Beato Arribas BSRIA Ltd. UK*, discusses the application of airtightness testing to two full scale models of isolation rooms to validate two different isolation room designs (one with an en suite and the other without) as a neutral pressure isolation room (as Figure 23) and under a cascading negative pressure configuration.

E2.9 For the first room design under test (with ensuite) the arrangement was as figure 23. To then achieve a cascading negative pressure design, the report states that the room was modified with an extract built into the isolation room and only the top blade of the pressure stabiliser used to give the results shown in Figure 24 (a).

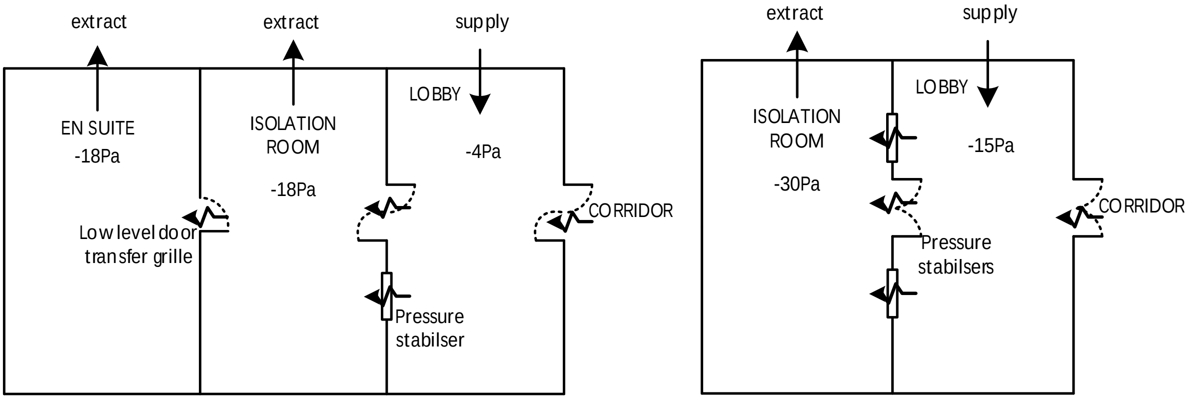


Figure 24 (a) **Figure 24 (b)**

En suite & non en suite designs modified for cascading negative pressure test

E2.10 For the second room design under test (without ensuite) for the Positively Pressurised Ventilation Lobby, the lobby was pressurised to +10Pa with the air passing through to the 0Pa isolation room via two pressure stabilisers above the door. The air was extracted from the isolation room.

E2.11 To then achieve a cascading negative pressure design, the report states that the supply and extract flows were modified, the doors changed to open into the corridor and the pressure stabilisers set to open at a differential pressure of 15Pa giving the results shown in Figure 24 (b).

E2.12 Figure 25 taken from the report shows the key component flows in a UK typical negative pressure isolation room with en suite and entrance lobby, designed to provide protection from infections originating in the isolation room from migrating into the corridor.

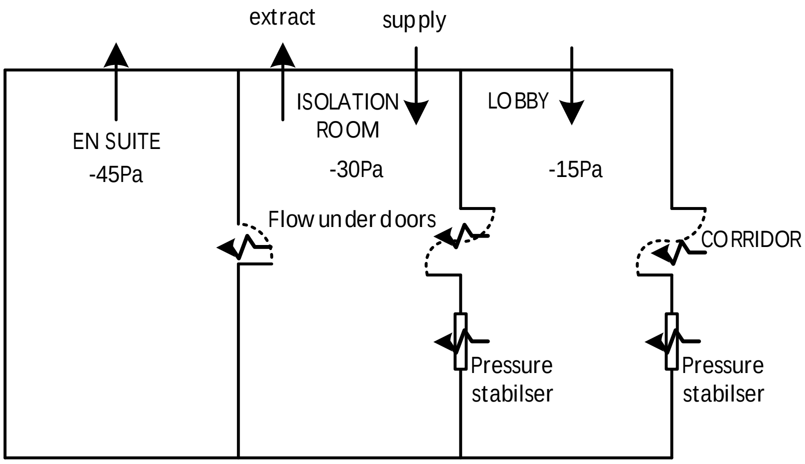


Figure 25 – Typical negative pressure isolation room