Technical Guidance Note
(Abatement)

A5

Abatement of Atmospheric Radioactive Releases from Nuclear Facilities

The Information Centre
Environment Agency
Waterside Drive
Aztec West
Almondsbury
Bristol BS12 4UD

Environment Agency

Abatement of Atmospheric Radioactive Releases from Nuclear Facilities

National Information Centre
The Environment Agency
Rio House
Waterside Drive
Aztec West
BRISTOL
BS12 4UD

Due for return

1/7/98	
1/8/98	

Environment Agency
Information Centre
Head Office

ENVIRONMENT AGENCY
126500

London : The Stationery Office

Commissioning Organisation
Environment Agency
Rio House
Waterside Drive
Almondsbury
Bristol
BS32 4UD
Tel: 01454 624400
Fax: 01454 624409

© Environment Agency 1998

ISBN 0 11 310134 1

All rights reserved. No part of this document may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, without the permission of the Environment Agency.

The views expressed in this document are not necessarily those of the Environment Agency. Its officers, servants or agents accept no liability whatsoever for any loss or damage arising from the interpretation or use of the information, or reliance on views, contained herein.

Diagrams are courtesy of Nuclear Electric, Figures 1, 4, 6, 9, 10, 11, 12, 13, 14, 15; Vokes Ltd, Figures 2, 5, 7; UKAEA, Figures 3a, 3b; BNFL, Figures 8, 16.

Contents

List of Figures

1. Introduction

This Technical Guidance Note (TGN) is issued by the Environment Agency. It is one of a series providing guidance to the Agency's staff and contractors, industry and other interested parties. The series covers both the abatement and the monitoring of releases from nuclear facilities

This Note provides guidance on the main types of equipment used in the abatement of radioactivity in airborne discharges from nuclear facilities and discusses aspects of their operation, maintenance and testing. Key points to be considered by inspectors in the review of plant proposals and in conducting on-site inspections are identified. A separate TGN (reference 1) is being prepared, giving guidance on monitoring discharges to atmosphere. Similar TGNs are being prepared covering abatement (reference 2) and monitoring (reference 3) of discharges of radioactivity in liquid effluents from nuclear facilities.

The main types of abatement plant in use at nuclear facilities are summarised in Section 3 and include high efficiency air particulate filters, coolant gas filters, shield cooling air filters, iodine adsorbers, delay beds, decay tanks and scrubbers. These types of plant are described in further detail in Sections 4 to 10, which also cover the operation, maintenance and testing of the plant. Section 11 gives guidance on the requirements for records of the testing and performance of abatement plant and Section 12 identifies the key issues that should be considered by inspectors in reviewing plant proposals and in inspecting the operation of plant and the performance.

The Agency is grateful to MAFF for producing the initial draft of this document, and to AEA Technology, Alan Martin Associates, AWE, BNFL, the Nuclear Installations Inspectorate, Magnox Electric, Nuclear Electric and UKAEA for their input to, and review of the document.

2. The Regulatory Context

Liquid and airborne effluents from nuclear facilities contain low levels of radioactivity and these discharges are strictly controlled in accordance with limits and conditions laid down in authorisations issued under the Radioactive Substances Act 1993 (RSA 93). For sites in England and Wales, the authorisations are issued by the Environment Agency and in Scotland by the Scottish Environment Protection Agency. In addition to quantitative limits (annual and sometimes shorter term) on the radioactivity discharged, the authorisations require the operator to use Best Practicable Means (BPM) to limit discharges.

This Note does not intend to state definitively what represents BPM in any given application, as the most suitable means will depend on the specific environment. It is however intended that the information provided should be used to aid selection of the most suitable means.

The application of the concept of BPM requires a broader approach and the authorisations currently state that:

"The means to be employed ... shall include:

i) the provision, maintenance and manner of operation of any plant, machinery or equipment used in connection with or giving rise to relevant waste; and

ii) the supervision of any operation involving relevant waste."

The authorisation also imposes requirements on the operator to undertake sampling, measurements, tests and surveys, to maintain specified records and to supply to the Agency information pertaining to the discharges.

The Agency also requires a lower level of documentation to be produced which sets out more detailed arrangements to be employed by operators. This covers, for example, the timing of discharges, techniques for sampling and analysis and the form of records to be retained.

A concept which is be applied to projects for the installation of new plant or significant modifications is that of 'Best Practicable Environmental Option' (BPEO). This refers to the option that is best for the environment as a whole; it implies that decisions on storage and disposal of wastes should be based on an assessment of the occupational and environmental risks, the costs and the social implications of available options. The BPEO should be identified by operators using a systematic approach in which all relevant options are examined and compared. A detailed discussion of BPEO is beyond the scope of this document. However, a consideration of the alternative techniques for the abatement of gaseous effluent discharges set out in this document may form part of a consideration of options.

Nuclear sites are licensed by the Health and Safety Executive under the Nuclear Installations Act 1965 (NIA 65) and the sites are regulated by the Nuclear Installations Inspectorate (NII). In order to minimise any conflicting requirements, there is close liaison between the regulators under the terms of memoranda of understanding. The 1995 Environment Act made provision for HSE to be a statutory consultee of the Agencies for disposal authorisations for nuclear sites and for the Agencies to be statutory consultees of HSE on the waste management implications of licenses granted under the NIA 65.

3. Principles of Abatement

3.1 General

Similar types of abatement plant tend to be used at the various facilities for treating similar types of effluent. Consequently the plant described here can be assumed to have generic applications. Information on specific applications is given where appropriate.

Procedures for the installation and operation of filtration plant have been standardised to some extent in Atomic Energy Codes of Practice (AECPs). These documents, which are more practical derivations of British Standards, are used by operators as guidance documents. AECPs are internal UKAEA documents, although in practice they are used as references by other operators.

The AECPs relevant to filtration plants are as follows:

AECP 1054, Ventilation of Radioactive Areas, reference 4
AECP 1064, Charcoal Traps for Radioiodine, reference 5.

Some operators also have written in-house standards for particular applications, for example references 6.

The main types of abatement plant are described briefly below. These are dealt with in more detail in later sections of this Note.

3.2 Filter

The most common type of abatement plant for gas-borne particulate is the particulate filter. There are various types of filter designed to cater for different types of effluent and ranges of conditions such as level of radioactivity, temperature, pressure, flow rate and particle size. Spark arrestors and burning debris arrestors are used to protect filter installations where there is a significant fire risk.

3.3 Iodine adsorber

For the specific purpose of removing volatile radioiodine in effluent, iodine adsorbers are used. To call them filters would be a misnomer as the process of removal of iodine from the effluent is not filtration but physical adsorption and chemical exchange within the sorption medium, which is usually granulated activated carbon.

3.4 Delay bed

In order to minimise the discharge of radioactivity associated with noble gases from the operation of Pressurised Water Reactors such as Sizewell B, the gases from the Chemical and Volume Control System (CVCS) are passed through a large bed of granulated activated carbon. This "holds up" the gases for a period of up to several weeks and allows the short lived noble gases to decay. The bed also removes any iodine present in the discharges and may reduce emissions of other fission products and activation productions, but this is not its primary purpose. Noble gases (except for argon 41) are a very small constituent of discharges from AGR (Advanced Gas Cooled Reactor) and Magnox stations, so this type of delay bed is not used at these stations.

3.5 Decay tank

An alternative method of noble gas hold-up is a decay tank which stores the noble gases for a period prior to discharge.

3.6 Scrubber

The only other type of abatement plant in common use is the (usually wet) scrubber, which is usually used to clean off-gases from incineration plant prior to filtration. These are used in the large radioactive waste incinerators, such as those operated by Nuclear Electric and British Nuclear Fuels (BNFL); and also for abatement of uranium hexafluoride in the BNFL plants at Springfields. Caustic scrubbers are also used to remove certain radionuclides, notably iodine 129, iodine 131 and carbon 14, from fuel reprocessing plant discharges.

4. High Efficiency Particulate Air (HEPA) Filters

As their name suggests these filters are of very high efficiency (99.95 per cent – 99.99 per cent). Their most common use at nuclear facilities is the filtration of ambient ventilation/conditioning air which serve areas where radioactive materials are handled. For this application, low temperature HEPA units, known as Type I, are used. These are usually type tested at 120°C for 120 minutes and for continuous operation are normally limited to temperatures up to about 70°C. Type II units are type tested at 500°C for 10 minutes and are suitable for high temperature applications. In addition to the difference in rating, Type I units are incinerable to ash.

4.1 Description

4.1.1 Filter inserts

This type of filter has now been standardised for most common high efficiency filtration applications. It consists of a metal or wooden case of dimensions 609 mm x 609 mm x 292 mm (see figure 1). The wooden case has the advantage that, depending on the level of radioactivity, the spent filters can be incinerated, giving a large reduction in the waste volume. Inside the case a continuous sheet of glass fibre paper is pleated round spacers to fill the case, as illustrated in figure 2. This medium is sealed to the case by adhesive bonding. It should be noted that the thickness of the filter is only the thickness of the paper (a common misconception is to assume that the filtration medium has the same thickness as that of the case). The outer faces of the filter are usually protected by a mesh to prevent damage when handling. Glued to one of the case edges is a gasket intended to ensure that there is an adequate seal when the filter is installed in the filter housing. Gaskets are expanded closed cell rubber, normally neoprene on Type I inserts and silicone rubber on Type II inserts. The standard filter insert is designed to cater for 1000 c.f.m. (1700 m^3h^{-1}). Filter installations consist of banks of filters (see Section 4.1.2). The size of the installation required to treat a particular ventilation extract depends upon the total volume throughput of the system: for example a 10,000 c.f.m. system would require a bank of 10 (1000 c.f.m.) filter inserts.

Figure 1
High efficiency particulate filters

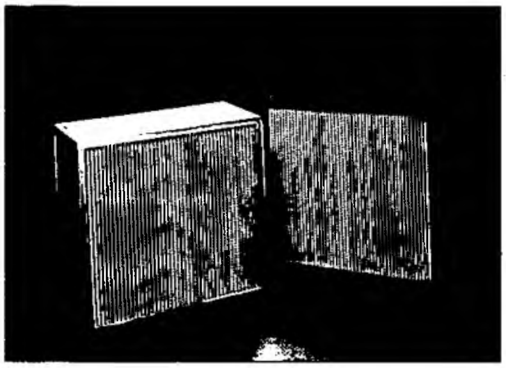
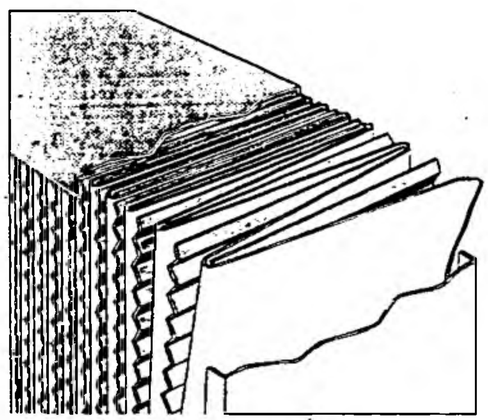


Figure 2
Deep pleat HEPA filter insert



In widespread use is a HEPA filter with a double pleat configuration which effectively doubles the surface area of the filter unit and allows the same size of filter to cater for double the flow rate (3400 m^3h^{-1}). This type of filter has a great attraction because it can significantly reduce the space for installation of filtration plant. It is now in use at many facilities: for example all Heysham 2 HEPA filter installations are designed around use of this type of filter insert.

A recent development is a circular HEPA filter insert. This type of insert is used on some of the newer plants at Harwell, where it was developed. The standard filter insert illustrated in figure 3 with a push-through housing will treat a similar nominal volume flow rate to the standard square insert (1700 m^3h^{-1}). This standard insert is nominally 500mm in diameter by 620mm in length and the differential pressure at the nominal flow rate is around the same as the square insert - 1" wg (2.5 millibars). A higher capacity circular filter to treat a nominal flow rate of 3400 m^3h^{-1} has also been developed. This is slightly larger, being 530mm diameter by 620mm long.

The advantages of a circular configuration are better sealing, more convenient replacement procedures and the spent filter inserts are more easily disposed of by compression and drum containment. In addition to extensive use at Harwell, it has been used in the vent extract plant at BNFL's THORP facility at Sellafield (Thermal Oxide Reprocessing Plant), JET (Joint European Torus) at Culham, and at AWE. They are also coming into use at some power station sites, notably Sizewell A and Oldbury, where systems have been refurbished.

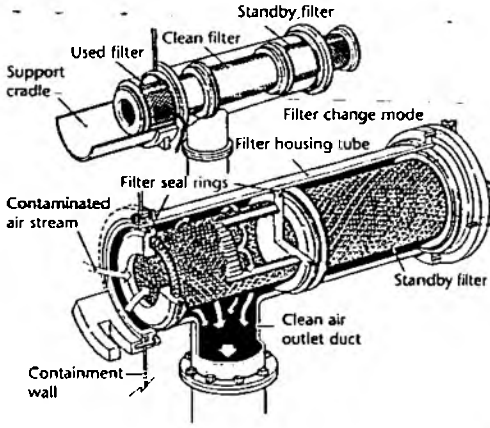


Figure 3a
Push-through filter change system

4.1.2 Filter installation

The simplest, known as the ladder frame installation (figure 4), consists of a framework to which the filter inserts are clamped to ensure an adequate seal. These installations, although simple, are not currently favoured mainly because they are not compact and their big surface area means they are subject to leakage problems due to frame distortion.

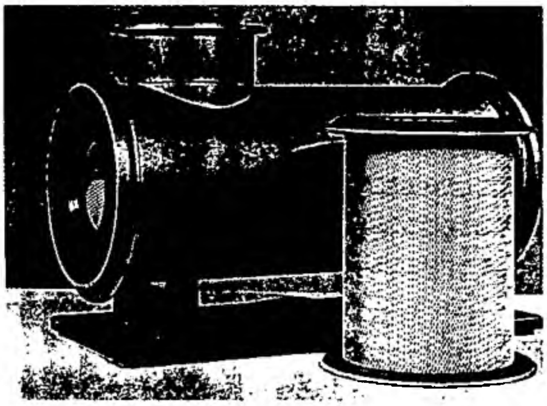


Figure 3b
Push-through filter and housing

The type in most common usage is the canister installation. These filters are totally enclosed in individual housings and a cam lever adjustment is used to ensure they are satisfactorily sealed in the housing. A type of multi-filter installation is shown in figure 5.

The main HEPA filter is often preceded by a pre-filter. These are relatively coarse and are intended to filter out the larger-sized particulate material. This ensures that the higher-cost more efficient HEPA filter is loaded only by the smaller-sized particulate material for which it is intended and thereby prolongs its life. In systems handling high levels of radioactivity, it is common practice to install further pre-filters close to the point of extract to prevent build-up of material in ductwork. Such a build-up can add to radiological problems, particularly in the maintenance and decommissioning of plant. In cases involving fissile material, it can also present a potential criticality problem.

Upstream of the pre-filter there is sometimes a spark arrestor to prevent the filters catching fire and releasing activity. These are usually pads of coarse metal fibre, and need to be located at an appropriate burn-out distance upstream of the filter insert. Burning debris arrestors fabricated from metal mesh are also used in some nuclear facilities.

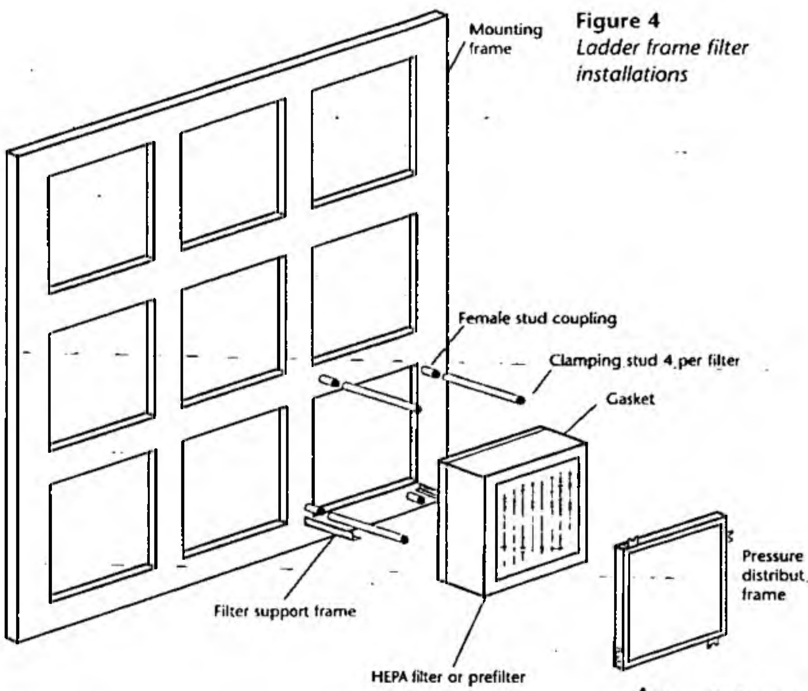
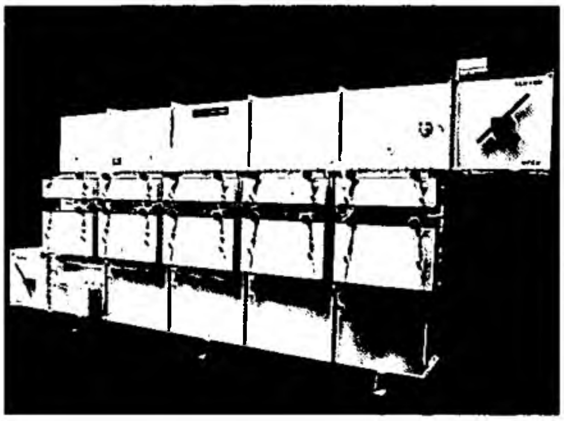
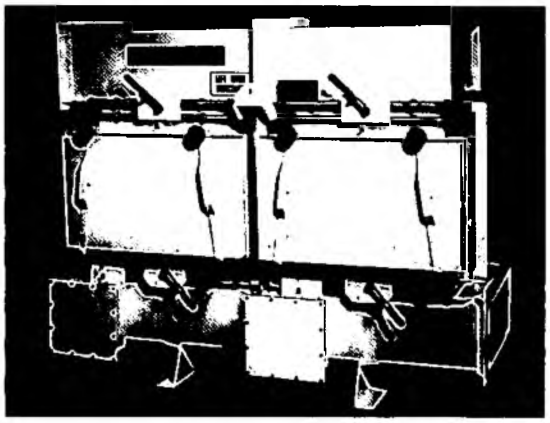


Figure 4
Ladder frame filter installations

Figure 5
Modular Unipak filter system



Five module Unipak filter containment system



Two module Unipak filter containment system incorporating individual isolating dampers on each module

4.2 Operation

The main elements of a ventilation extract system are shown in figure 6. Such a system normally serves a specific area and operates either as a straight extract system or a balanced inlet/extract system.

In the former system air is pulled from rooms/areas through room outlets and ductwork by extract fans to atmosphere. The latter system has a forced inlet as well as an induced extract system and this is balanced to ensure that there is a small net negative pressure relative to unfiltered areas to ensure that outflow occurs only via the filters.

Control is exercised by valves and dampers. Valves are used to shut off parts of the system for maintenance and filter changing. Dampers in the system are used to set up the correct flows. Dampers may also be used as flow isolators. Flow control is also exercised by means of electrical interlocks on fans, especially in systems having a positive clean air supply. For example, supply fans can be set to trip in the event of loss of extract flow, and start-up sequences are arranged to prevent contamination spread as a result of backflow from ventilation systems into working areas.

4.3 Maintenance

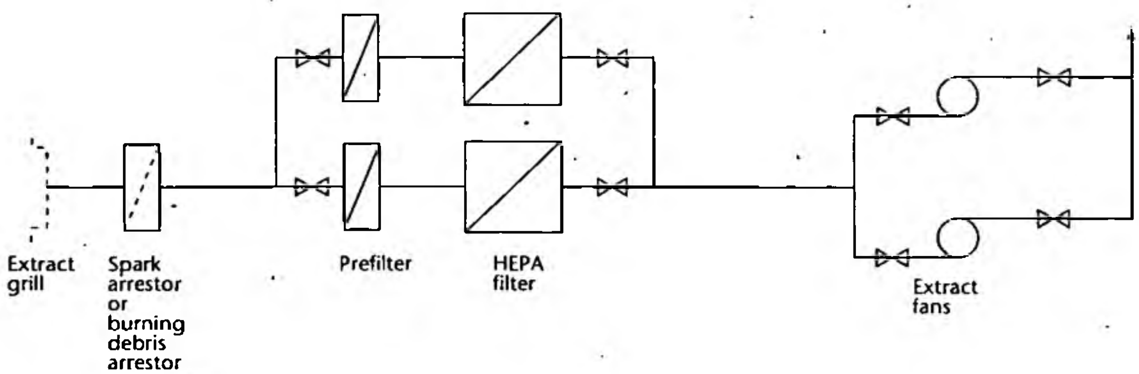
There are three reasons why HEPA filters are changed:

(i) The most common reason is because of high dust loading. The dust loading is checked by the differential pressure (dp) across the filter. The normal "clean" filter usually has a dp of around 1" wg (2.5 millibar). Filters are typically changed when the dp reaches 5" wg (12.5 millibar). The dp is measured using installed pressure differential instruments connected across the filter bank. In some cases, these are simple oil-filled inclined manometers (it should be noted that hydrocarbon-filled manometers should not be used in systems which contain adsorber beds, as the hydrocarbon may poison the activated charcoal used as the adsorbent). The manometers at nuclear power stations are not normally alarmed. Reliance is placed on periodic inspections to check the dp and a knowledge of expected filter life for particular installations.

(ii) The second criterion for changing a filter would be an unacceptable decontamination factor. This would be revealed by periodic in situ testing (see section 4.4).

(iii) Occasionally filters need to be changed on the basis of unacceptable radiation dose due to accumulation of radioactive material in the filter. This is only likely on systems serving areas/rooms where highly radioactive materials are handled, such as in fuel reprocessing plants.

Figure 6
Typical ventilation extract system



Filters are usually changed manually. However where filters are likely to give rise to unacceptable radiation doses due to accumulation of radioactive material, permanent remote changing facilities are installed. Filters are changed by a special procedure to ensure that there is no spread of contamination from the "dirty" filter. Incorporated in each filter housing is spigot attached to a plastic bag enclosing the inner housing. The "dirty" filter is man-handled into this plastic bag, which is sealed before removal from the housing. The "clean" filter is installed from a similar "clean" bag attached to the spigot which is then stored inside the filter housing for the next filter change. This is illustrated in figure 7, on page 12.

4.4 Testing

Individual or batch efficiency testing of filters is usually carried out in the factory prior to dispatch and entails checking each filter in a standard test rig with a standard test aerosol to ascertain its performance. This standard testing procedure is described in a British Standard (BS 3928), reference 7. This BS has become the universal acceptance standard for filters of this type. All HEPA filter inserts procured in accordance with UK nuclear industry specifications are individually tested and certified by the manufacturer.

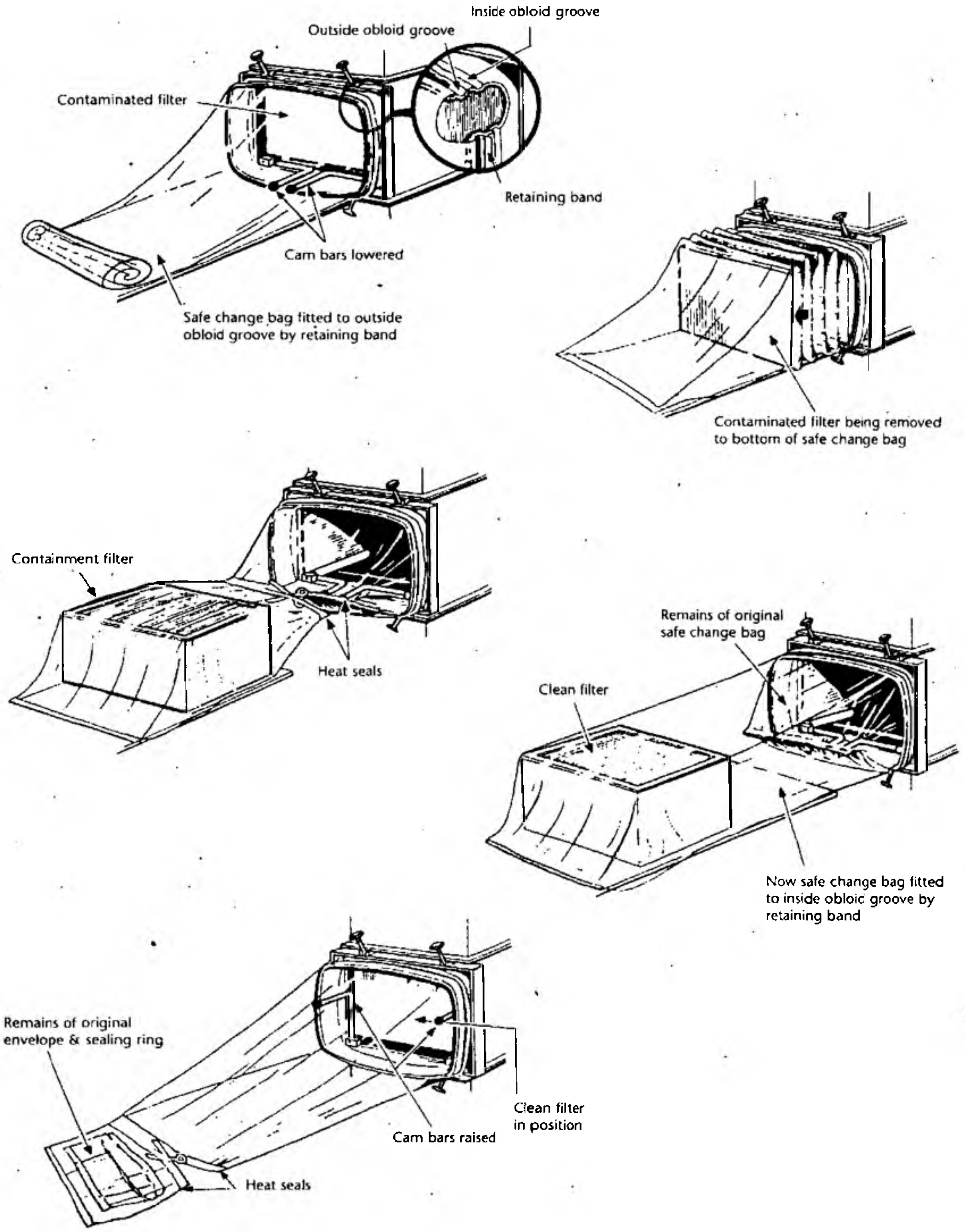
The most common type of HEPA filter now used in nuclear facilities has a rated efficiency of 99.99 per cent, penetration 0.01 per cent, as tested on the basis of BS 3928. In fact most filters exceed this criterion by a significant amount.

Once the filters are installed in the system it is usual to carry out an in situ efficiency test on the complete filter installation. The main purpose of an in situ test is to check that the filter has been installed properly in the housing (no leakage) and has not been damaged during transport and installation. The principle of an in situ test is that a test aerosol is injected far enough upstream (that is, 10-20 duct diameters) of the installation to ensure that adequate mixing is achieved before an upstream sampling point ahead of the filters, and also to ensure that the filters being tested, including their seals, receive a uniform challenge. The amount of aerosol in the gas stream is measured at upstream and downstream sampling points, the ratio being the decontamination factor of the system. The downstream sampling should be far enough from the filters (ideally >30 duct diameters for a single sample, unless a mixing device is employed) to ensure adequate mixing and that leakage from any part of the filter bank will be detected. Duct sampling techniques are used to ensure representative sampling where appropriate mixing distances are not available. Special injectors and mixing devices are sometimes used to ensure full mixing of injected aerosol. Mixing devices are also used downstream of the filters (in this connection, depending on the type of aerosol, ventilation fans can give effective mixing) and specially designed probes assist representative sampling. In the UK there are two main methods for in situ testing, each using a different test aerosol:

Method 1

This method uses "condensation nuclei" (CN) as the test aerosol. These are particles in the range 0.001 to 0.1 mm which can be produced by burning any material. The method used for producing quantities sufficient for testing large HEPA filter systems is to burn a gas such as propane or butane, which has been bubbled through ammonium polysulphide solution, with a bunsen burner. By passing the gas through a chemical such as ammonium polysulphide before combustion, the CN concentration is enhanced by vaporisation of the chemical constituents. The concentration of the CN is measured by growing the aerosol particles in a super-saturated vapour mixture and then detecting by a light scattering technique. It should be noted that this method is effectively a leak test rather than an efficiency test on the filter installation. This means that a throughpath created by either a gasket fault or a hole in the filter will be shown up by CN. However an intact filter will not allow passage of CN particles. It is therefore a "go – no go" test method which is very sensitive to leaks. As CN aerosol is prone to further agglomeration under certain conditions, the test procedure should be standardised in detail if this method is used.

Figure 7
Filter change procedure



Method 2

The second method uses an aerosol of spherical oil droplets predominantly in the size range 0.2 to 0.4 mm. This test is known as the DOP test, originally after the material traditionally used to produce the oil droplets, dioctyl-phthalate. However there has been some concern expressed about the hazards associated with this material and an alternative material now in common use is Ondina EL oil. This oil exhibits similar operational behaviour to that of dioctyl-phthalate. DOP is now taken to stand for Dispersed Oil Particulate.

This method is a true efficiency (penetration) test at the respective aerosol size in that the droplets can penetrate the filters. In fact the size range of particles produced is very close to the most penetrating particle size for HEPA filters under normal operating conditions. Hence this test method should give a pessimistic indication of filter performance, as it represents a challenge to the filter using a "worst case" aerosol.

Further details of the methods can be found in references 8, 9, 10 and 11.

The method in routine use both in the UK and many other countries is the DOP test method. The advantages of this method are:

(i) It is the most widely used in situ test method, and no major usage problems have been reported.

(ii) It is a true efficiency test at the respective aerosol size and can be related to the certified efficiency of the filters. The CN method on the other hand can be regarded as a leak test which is quite adequate for testing filter systems but cannot be related directly to the certified performance of the filters.

It is expected that if the filters have been installed properly then the efficiency of the system should be as good as the efficiency of the individual filters installed in the system, and this is the acceptance criterion adopted by some operators. However in systems with a large number of filters to accommodate a high throughput, the increased seal area is liable to lead to a reduced overall efficiency.

Filters are usually tested in situ biennially or when changed if this is a shorter period. Test reports should be produced showing method of test, result of test and any remedial measures found necessary. A typical test report is reproduced as figure 8. The most common types of faults found when filters are tested in situ are listed (right):

Building	Filter System
2	B6 Vessel vent Filter 1
	Result
Date of test	07/03/94
Mean	D.F. 8790
Previous Mean	D.F. 4000
Date Reported	09/03/94
Investigation Level	1000
Action Level	1000
Comment	

Figure 8
Routine HEPA Filter Test report

(i) gasket leaks due to incorrect sealing pressure
(ii) filter insert damage
(iii) filter insert overloaded with dust
(iv) filter inserts fitted incorrectly. (The filter seal is on one face only. If the filters are fitted the wrong way round the seal is not operable)
(v) filter media/case sealing not intact
(vi) framework distortion/damage
(vii) incorrect type of filter insert fitted
(viii) duct leaks

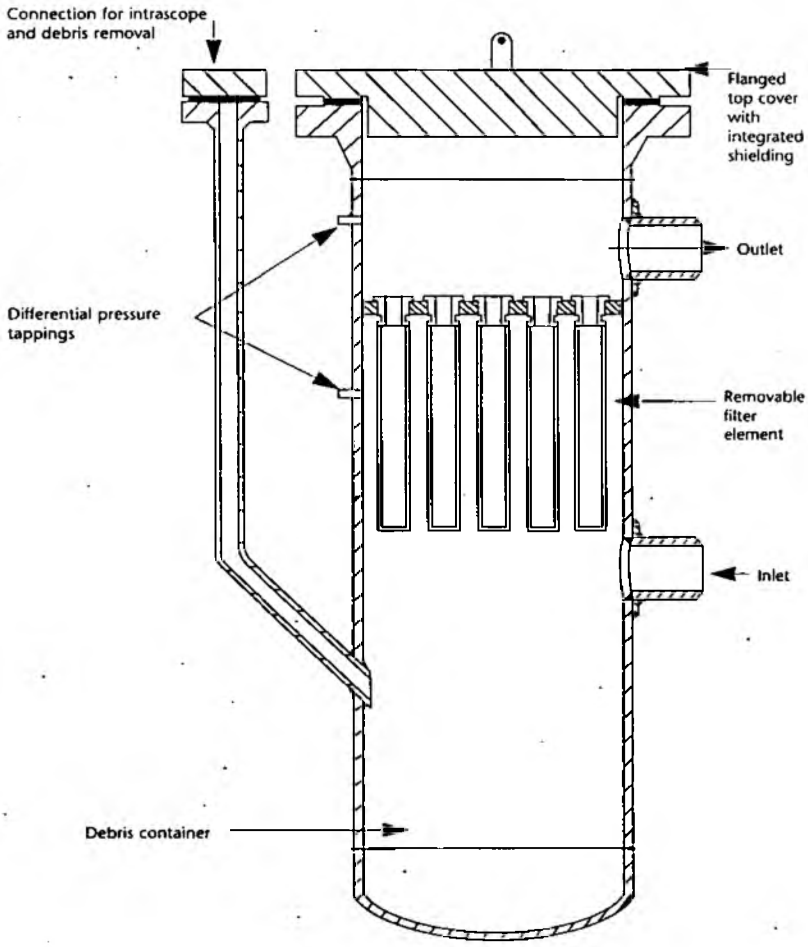
5. Coolant Gas Filters (nuclear power stations)

5.1 Description

Coolant gas filters are designed to cater for the high temperatures (up to 300°C) and pressures (up to 40 bar) of carbon dioxide coolant in gas cooled reactors. A filter assembly typical of this type is shown in figure 9. It consists of a nest of cylindrical filters with one end closed (known as filter candles) attached to a plate (tube plate). This is sealed inside a pressure vessel. The gas enters the filter assembly at the bottom, passes up through the filter elements and out of the assembly. The filter elements are manufactured from flat sheet of sintered stainless steel powder medium welded to end fittings. This forms a porous metallic (sintered) medium which will allow gas to pass through but will arrest particulate material which collects on the outer surface of the filter.

Stainless steel fibre media are also used in many AGR gas filter systems. These media are fabricated into either plain or pleated (extended area) cylindrical filter elements. In general, stainless steel fibre filters have superior flow/pressure drop, efficiency and dirt-holding characteristics when compared with equivalent powder-derived materials.

Figure 9
Coolant gas filter



5.2 Operation

The filters are used to treat coolant gas routinely during normal operation of a reactor and during discharge (blowdown) of the gaseous coolant to atmosphere when the reactor is depressurised for maintenance. They are also used to treat gaseous discharges from ancillary facilities where there is a potential of contaminated gas/air being discharged at high temperature or high pressure or both. Typical of such ancillary plant would be the irradiated fuel handling and disposal facilities.

5.3 Maintenance

The majority of metallic media filters are back flushable. Periodically a back flow is introduced through the units and the material adhering to the outer face is blown off and is collected in the base of the filter assembly. Replacement of the filter units should not be necessary unless they become blocked or damaged. Plant maintenance schedules usually require periodic visual inspection by removing the lid of the pressure vessel. A low flow test where a small flow of air is induced through the filter element and the pressure drop across it measured is sometimes carried out to determine filter blockage. Ultrasonic and other off-line wet cleaning techniques are also used to clean the blocked filter elements. The level of dust in the debris container is also periodically checked by insertion of a remote device into the base of the pressure vessel. The debris container is sized to contain dust arisings for the life of the plant and should not need emptying.

Units not designed to be back flushable, such as reactor safety relief valve filters, need to be replaced if they become fully loaded.

5.4 Testing

Filter media are usually type tested for filtration at works using standard test dusts. These tests can be undertaken using liquid and gas phase carrier fluids. Fabricated filter elements are normally tested at works using a bubble test which gives an indication of nominal pore size distribution. The flow/pressure drop characteristics of filter elements may also be established under known conditions. The trapping efficiency varies significantly with the type and grade of filter medium used.

No in situ testing is normally carried out on the filters for the following reasons:

(a) The filter units are robust and usually installed by welding or screwing them into the tube plate, thus effecting a good seal. Consequently it is not thought there is scope for damage during installation as in the case of the less robust HEPA filters.

(b) Periodic visual inspection of filter candles is carried out and a low flow test is available for determining blockage.

(c) All the discharge routes serviced by these filters are sampled continuously for particulate radioactivity. Thus any deterioration in filter efficiency should become evident from the sampling results.

(d) The testing of such filters in situ under the high pressure and temperature conditions that prevail would be a very difficult task. No routine test techniques are available at present.

(e) Periodic pressure drop tests are carried out on operational plant.

6. Shield Cooling Air Filters (steel pressure vessel nuclear power stations)

Most of the early Magnox nuclear stations have a steel pressure vessel to contain the carbon dioxide coolant. This is surrounded by a thick concrete biological shield. In order to prevent heat damage to the inner face of the biological shield it is necessary to cool it. This is achieved by sweeping the space between the biological shield and the pressure vessel with air which is continuously discharged at a high level. Because this air can collect activated material abraded from the pressure vessel and concrete inner face, it is filtered.

The volume throughput of the coolant air is high (around 30,000 cfm) so large area automatic roll filters are used. As their name suggests these filters consist of rolls of synthetic fibre filter medium which passes over a frame across the extract duct. When the filter gets dirty it is automatically rolled on to be replaced with a new section of filter medium. This operation is activated by a high differential pressure across the filters due to the dust loading. The filters are prone to problems such as tearing of the filter medium and malfunction of the roll on the actuator. Some are currently rolled on manually.

The filters are not of high efficiency (only 90-95 per cent) and are not tested. They are considered to be of benefit in the event of potential releases of particulate radioactivity into the shield cooling air, but the general background levels are usually very low. The shield cooling air discharges are continuously sampled for particulate radioactivity. It should be noted that whilst the reactor is operating there will be a significant radiation dose rate in the vicinity of these filters, proportional to the reactor thermal power.

7. Iodine Adsorbers (nuclear power stations)

7.1 Description

In a nuclear reactor, the vast majority of fission products are retained within the fuel cladding, unless the cladding fails. However, either as a result of low levels of uranium on the surface of cladding or the breach of fuel cladding, fission products can be released into the reactor coolant and, subsequently, into gaseous effluent streams. Among these fission products are the radioiodine species which are relatively volatile and which can be released either in elemental form or in various organic forms, the most common of which is methyl iodine.

These iodine species are not efficiently filtered by the filter systems described in Sections 4 and 5, and iodine adsorption plant based on activated carbon is widely used for removal of iodine from gas streams. Iodine and iodine compounds are trapped on activated impregnated carbon by a combination of physical and chemical processes. The material is highly porous which means that the effective surface area is very high (~1000m² per gram) and the trapping performance is influenced by pore size distribution, the nature of the carbon surface and the presence of impurities in the carbon. For high temperature applications, such as blowdown of reactor coolant gas, the activated carbon is impregnated with potassium iodide (KI), whilst for low temperature applications tri-ethylene diamine (TEDA) is used. The TEDA-impregnated carbon has a superior performance in moist air environments but is unsuitable for use with CO_2.

The trapping performance of activated carbon is adversely affected by two mechanisms, ageing and poisoning. Ageing is thought to be an oxidative process which reduces the availability of active sites on the activated carbon surface. It is promoted by the presence of oxygen and water. Poisoning is caused by the retention of trace impurities, particularly of hydrocarbons and organic solvents, thereby also reducing the availability of active sites on the carbon surface. Ageing and poisoning often limit the service life of activated carbon, especially in plants which treat ventilation air. Further information on the characteristics of activated carbon is given in reference 5.

Adsorber plant is sized to hold as much carbon as necessary to adsorb the iodine likely to be presented to it for a reference accident scenario. For design and safety purposes, the capacity of activated carbon impregnated with 1.5 per cent KI is conservatively assumed to be 50 micrograms of methyl iodide per gram of carbon. Adsorber beds are also designed to achieve adequate contact time between the carbon and the effluent gas, and for deep bed reactor blowdown plants this is generally greater than 0.5 seconds. In Magnox and AGR power stations, iodine adsorbers are used for two distinct purposes – blowdown (discharge) of CO_2 reactor coolant and treatment of gas or air from auxiliary plant.

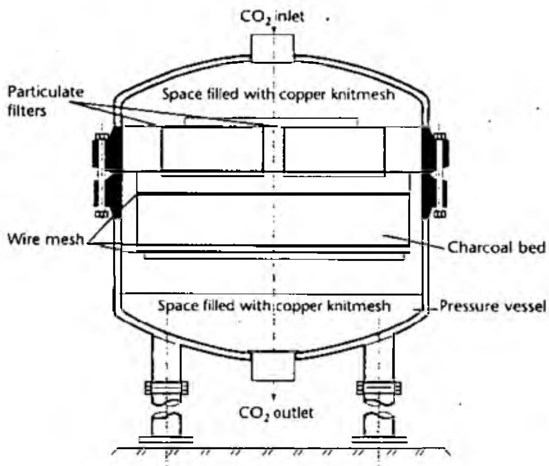


Figure 10
Magnox iodine adsorber

Blowdown

At Magnox stations, iodine adsorption beds are available on standby to trap iodine in coolant blowdown (controlled discharge to atmosphere) under conditions of fuel failure. The plant is designed to operate at high gas temperature and pressure and the carbon is impregnated with KI. A typical unit is illustrated in Figure 10.; the coolant gas enters the unit at the top and leaves from the bottom after passing the bed. The equivalent AGR

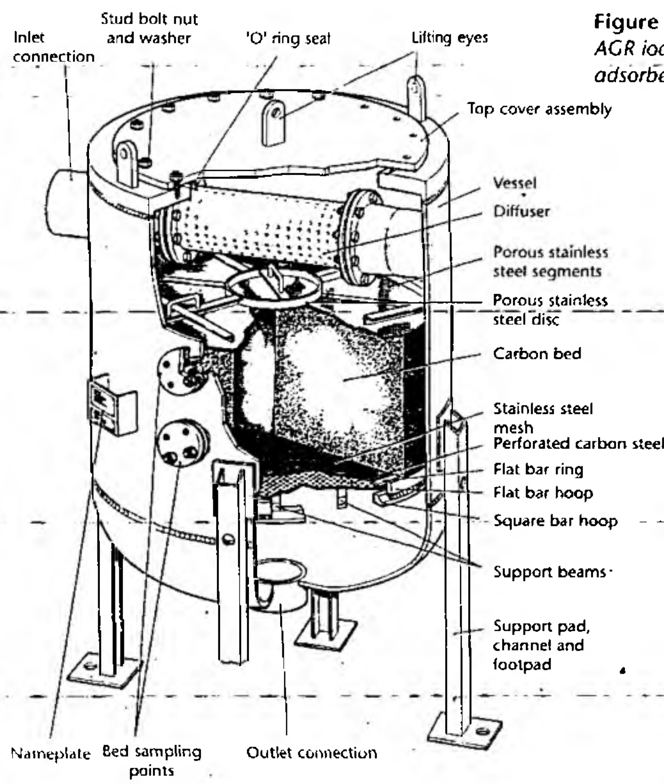


Figure 11
AGR iodine adsorber

iodine adsorber is shown in Figure 11 and incorporates a number of improved features over the Magnox unit. These include the use of a metal gas diffuser to improve flow distribution, a reduced diameter but deeper bed giving reduced breakthrough, and provision of sampling connections. On AGR stations routine discharges from blowdown are made via the iodine adsorption beds, incorporated in the system in addition to the emergency iodine adsorption beds.

Auxiliary plant

Where there is significant potential for fission products, including radioiodine, to be released to plant areas and subsequently discharged via ventilation or cooling air systems, iodine adsorption beds are available for abatement of discharges. This is particularly the case in AGR stations and units are provided containing either modular or deep bed carbon adsorbers. An example of a modular unit is illustrated in Figures 12 and 13. The modules are of the same external dimensions as a HEPA filter and consist internally of a cellular honeycomb structure containing the carbon granules in a divided bed construction. They are known by the trade name of EMCEL. Where the unit is for processing of CO_2 or other gases at high temperature, the activated carbon is impregnated with KI, whilst for treatment of air below about 60°C, TEDA impregnant is used.

The units provided on the pressurised water reactor at Sizewell B have rechargeable adsorber systems operating with TEDA impregnated carbon. The air passes horizontally through shallow vertical beds of carbon arranged in parallel. The beds are fed by an upper hopper and can be discharged via a lower hopper. The packing density of the carbon can be enhanced using vibrators installed at the base of the units. Carbon loading and unloading operations are undertaken by means of pneumatic transfer equipment.

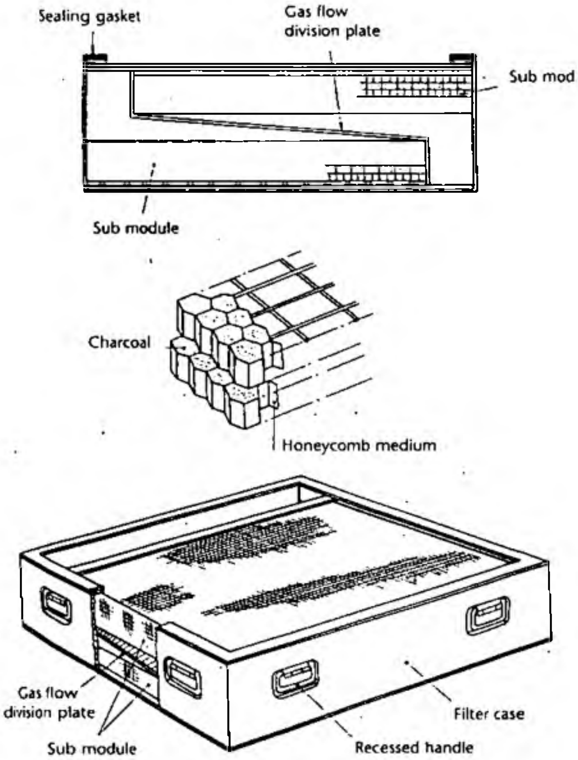


Figure 13
Modular iodine adsorber

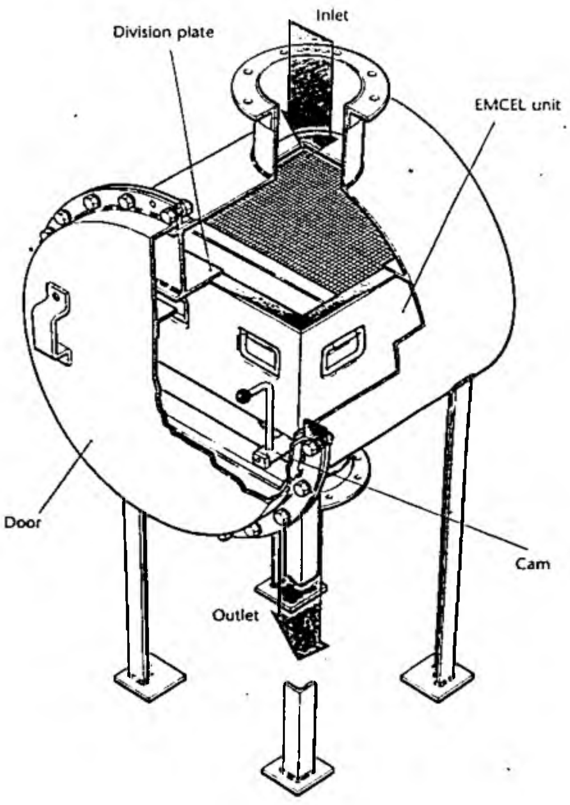


Figure 12
Canister installation modular iodine absorber

7.2 Operation

Typical provisions for iodine adsorption plant for reactor blowdown and for ventilation air from the fuel route in a Magnox station are shown in Figure 14. The adsorption plant for treatment of blowdown is normally on standby and would only be brought into operation in the event of significant fission product contamination of the reactor coolant gas.

A typical arrangement for AGR stations is illustrated in Figure 15, though it should be noted that the arrangements do differ between stations. At AGRs discharges from blowdown are routinely made via the adsorption beds.

The high temperature units have a temperature limit of around 200°C, above which the radionuclide species start to desorb, reducing the efficiency of the bed. Although the gas temperature at reactor outlet may be well above 200°C, the external ductwork is designed to ensure that it will cool to this temperature or below before reaching the carbon bed.

In general, the Sizewell B adsorbers are designed to function in standby mode. During normal operations, the ventilation extract flow bypasses the adsorber units. In the event of an abnormal situation, the extract air would be diverted to pass through the beds before discharge. Adsorber beds are provided in some areas to control radioiodine levels during normal operation. Other beds are included in certain air supply systems to provide protection of key personnel during an emergency.

Activated carbon is a friable material and gives rise to carbon dust which needs to be removed before installation. As a precaution against further dust generation when the bed is in service a particulate filter may be needed downstream to collect the dust, which may contain adsorbed radioiodine. The structure of EMCEL units is very effective in preventing granule movement and abrasion of the carbon, and this type of unit is often used without downstream particulate filters.

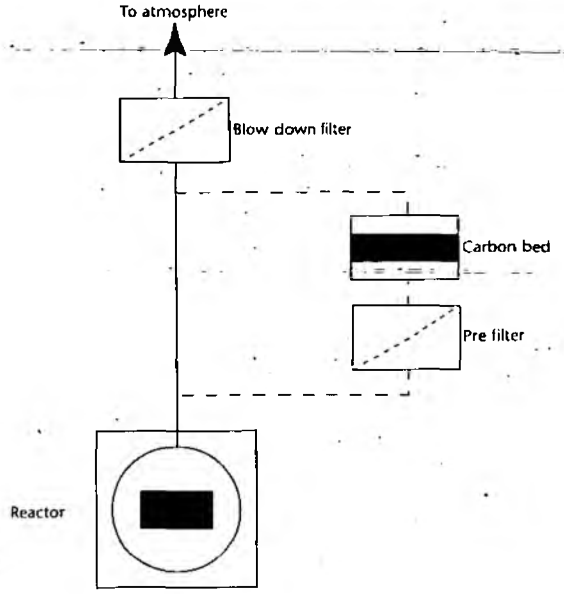


Figure 14
Typical Magnox Reactor Blowdown Route

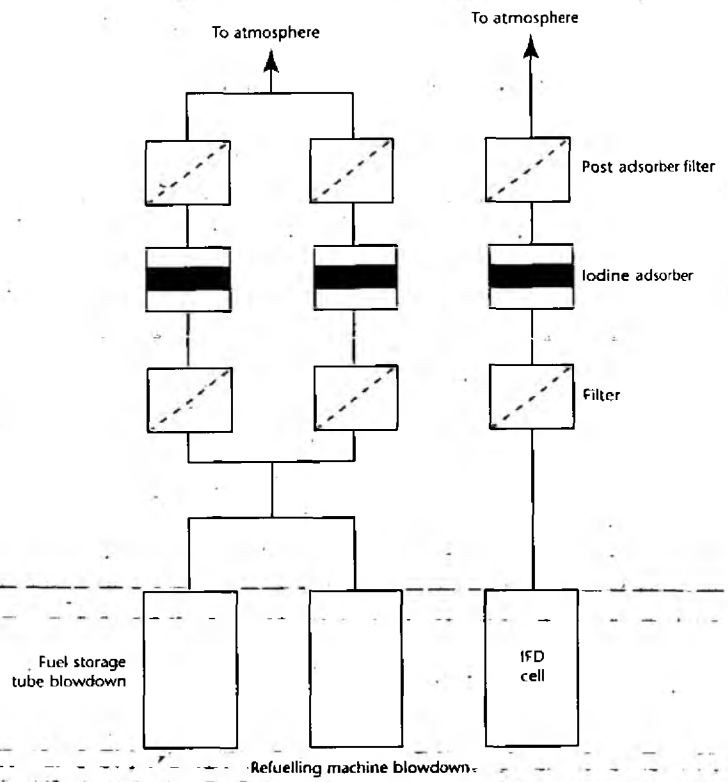
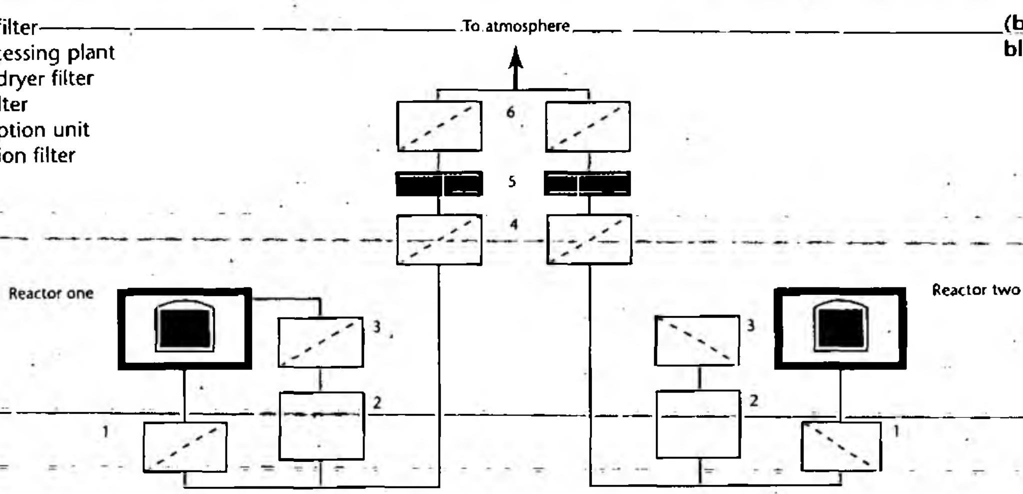


Figure 15
Typical AGR Discharge Systems

(a) Auxiliary gas discharge system



(b) Typical AGR blowdown route

1. Bypass inlet filter
2. Coolant processing plant
3. Bypass post dryer filter
4. Blowdown filter
5. Iodine adsorption unit
6. Post adsorption filter

As mentioned above, the performance of iodine adsorption beds is adversely affected by ageing, which is promoted by exposure to oxygen or moisture, and by poisoning by organic materials. Ageing is reduced if the carbon is exposed only to dry and airless conditions. This means that carbon in plant used to treat CO_2 coolant, which is dry and substantially free from oxygen, ages only slowly, whilst beds exposed to ventilation air can age rapidly. For this reason, plant which is operated in standby mode is normally filled with dry CO_2 when not in use.

7.3 Maintenance

The maintenance of the rechargeable type of adsorber consists mainly of replacing the carbon with fresh material when it is shown on test to be below specification. This is achieved by removing the top of the pressure vessel and internal components, vacuuming out the old carbon and replacing it with fresh material. The main precaution taken is to ensure that the new carbon is kept away from moisture and organic contaminants. This means that it should remain in sealed containers before installation and should be exposed to air for the minimum possible time during the recharging operations. In order to avoid generation of carbon fines, loading techniques used should ensure that any attrition or abrasion of the carbon granules is kept to a minimum.

Modular units are replaced when spent and the old units disposed of, usually by incineration.

7.4 Testing

The science of iodine adsorption by activated carbon has been the subject of much research and development (references 12 & 13). As a result, appropriate testing criteria have been developed for both the assessment of carbon and in situ adsorber performance.

(a) **Carbon performance**
The ability of carbon to adsorb iodine is quantified by an index of performance known as the K-value, being the ratio of the logarithm of the decontamination factor under standard conditions to the residence time in seconds.

From experience it is expected that a satisfactory carbon impregnated with KI will have a K-value of at least $8s^{-1}$. Adsorbers are usually designed to achieve a residence time of gas in carbon of about 0.5 second. On this basis an adsorber filled with carbon of K-value of 8 would have a very high theoretical df, for example in the range 10^{8} to 10^{14}, depending on conditions. For coal based TEDA, the standard K-value is about $12s^{-1}$.

The K-value is measured on activated carbon samples in a special rig under a standard set of conditions (reference 9). This test is usually carried out on samples of newly manufactured carbon and the K-value should be stated on the certification documentation provided with new carbon.

(b) **In situ test**
In situ tests are usually carried out on all plant when new carbon is installed and periodically during life. The reason for initial and periodic in situ testing is basically to ensure that the carbon has been installed correctly and is performing to specification particularly as variable ageing and/or poisoning occurs.

Because of this potential for ageing or poisoning, the decontamination factor of an adsorber containing "new" carbon is designed to be well above what is necessary to cater for the range of potential accidents releasing iodine into the atmosphere. This ensures that operational life of the carbon in the adsorber is maximised.

The standard in situ test is carried out in a similar manner to the particulate (HEPA) filter test and similar precautions are needed to ensure good mixing. Test vapour is injected into the gas stream upstream of the carbon adsorber and the proportion of vapour penetrating the carbon is measured by sampling upstream and downstream of the system. As discussed in relation to particulate filter testing, the source injection point should be far enough upstream (10-20 duct diameters) of the inlet sampling point to ensure adequate mixing.

The most common test source is methyl iodide labelled with iodine 131. The main advantage of this material is that it is representative of the gaseous species of iodine likely to be discharged in the event of an accident and for which the adsorbers are designed.

The samplers consist of packs of activated carbon (Maypacks) through which a proportion of gas is drawn during the test. Subsequent to the test these packs are gamma-counted to ascertain the amount of iodine activity collected. This can then be related proportionally to the total amount in the gas stream if relative flow rates are known.

Two tests are normally carried out. A pre-test using a much lower activity source than the main test ensures the absence of leakage prior to the main test. A main test is then carried out using a higher activity source.

As discussed earlier the theoretical decontamination factor of adsorbers when filled with fresh activated carbon can be very high. Consequently, because of the need to minimise the amount of activity used in the test source it is not always possible to measure the absolute value of the decontamination factor in an in situ test, and "greater than" figures will often be seen in test results. The aim should be to use enough test material to ensure that the decontamination factor is adequate to cater for the period until the next test, and absolute figures in the range 10^4 to 10^5 should be measurable.

The performance of an adsorber should be judged in the light of the decontamination factor required to cater for potential iodine releases in the event of accident. For all design basis accidents at Nuclear Electric plant it is estimated that a decontamination factor of 200 (99.5 per cent efficiency) will ensure that the amount of iodine released to atmosphere will be well below NRPB Emergency Reference Levels (ERLs). Consequently Nuclear Electric set a minimum acceptable decontamination factor of 1000 (99.9 per cent efficiency) for all adsorbers where the refurbishment operation is time consuming and could have an effect on reactor operation. Normally action is taken to refurbish the adsorber when the end of life decontamination factor is expected to fall below this figure. For modular design adsorbers, where refurbishment operations could be effected quickly and easily, an action level could below a decontamination factor of 1000, as long as the functional end of life decontamination factor of 200 could be ensured. However, this judgement must also take account of past adsorber performance. For instance, if the decontamination factor started to fall more rapidly than would be anticipated from experience even if it was significantly higher than 1000, then there would be a case for examining the adsorber to ascertain the cause.

Tests are usually carried out biennially although at Nuclear Electric testing is carried out on a four-yearly basis where experience has shown that ageing is slow and no physical deterioration of the system is expected (for example in emergency standby plant). Conversely, adsorbers used in air systems (modular adsorbers) are usually tested annually. Because of the variable nature of conditions of use for the various adsorbers, testing frequency tends to be based on experience built up over the years, the criterion being that the frequency should be related to the potential carbon ageing and should be such as to reveal any potential downward trends in performance in good time to take remedial action.

(c) **Freon test**

A freon test is a quantitative leak test which can also give a qualitative indication of the state of the carbon. Nuclear Electric uses the freon test on modular and Sizewell B PWR adsorber systems, both of which contain features which could give rise to bypass leakage. Freon testing is backed up with laboratory or in situ active methyl iodide testing.

8. Delay Beds

Another type of adsorber which, in the UK, is used to treat discharges from PWR plant is a delay bed. The discharges from PWR plant potentially include a significant proportion of noble gases. These noble gases, mainly xenon and krypton contain, isotopes of varying half life. In order to minimise the total amount of activity released to atmosphere the release of these noble gases is delayed for a period. This ensures that the shorter-lived noble gases decay and only the long-lived ones contribute significantly to the atmospheric discharges.

The delay is introduced by passing the discharges through a delay bed, consisting of a large volume activated carbon bed. As the noble gases diffuse through the carbon they are held up due to adsorption/desorption for a period (up to 65 days for xenon and five days for krypton). The total effect of this delay at Sizewell B is to reduce the activity of the noble gas discharges by a factor of around 50.

The main delay bed is protected with an upstream "guard bed". The guard bed, also activated carbon but much smaller than the main bed, is intended to prevent moisture and other potentially damaging materials from reaching the main bed.

9. Decay Tanks

An alternative method of noble gas hold-up is the use of decay tanks. The off-gases are stored in pressurised tanks for a period of around 45-50 days, sufficient for the decay of short-lived noble gases. They are then discharged. This method of control is used on US PWRs and was originally planned for Sizewell B. However it was judged that this method was more expensive to install and operate than the delay bed system.

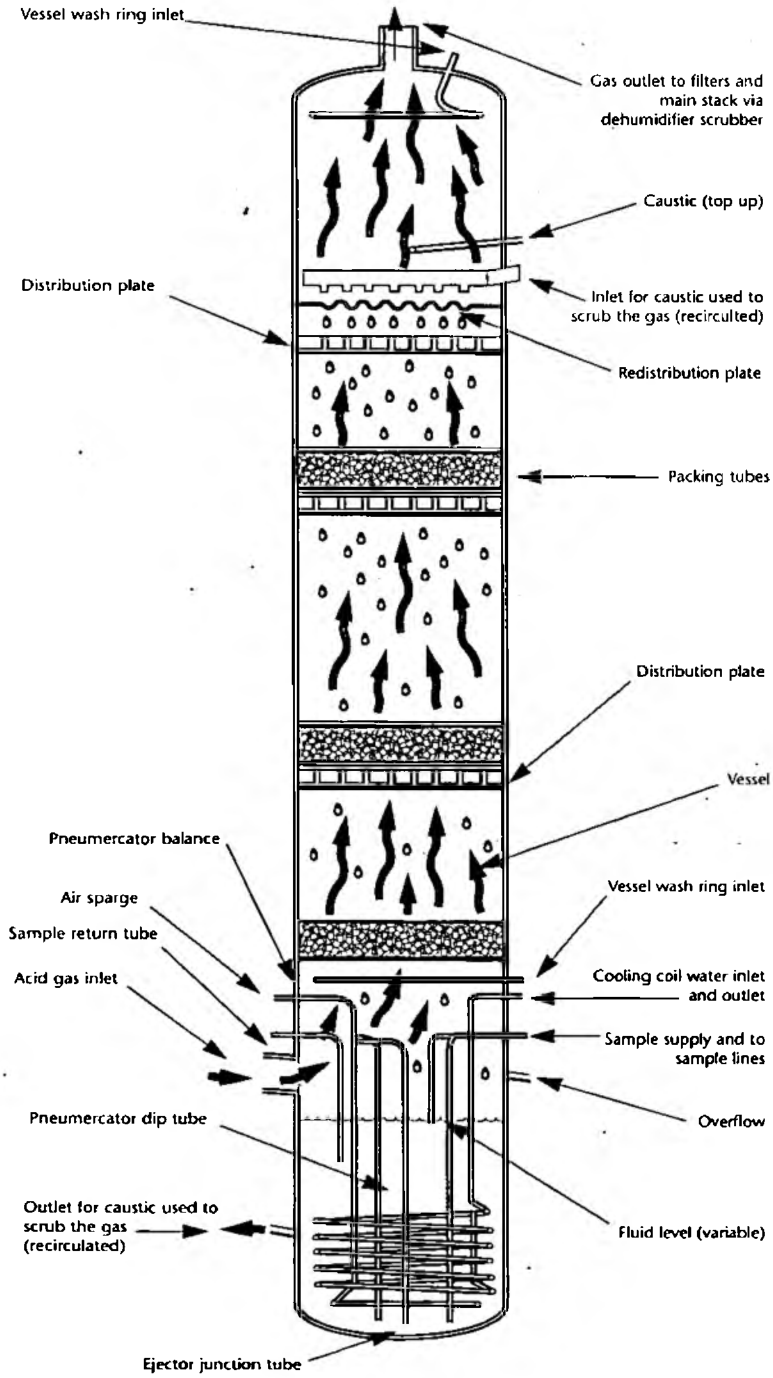
10. Scrubbers

Scrubbers have two main uses as abatement plant. They are used for the treatment of off-gases to remove radioactive material from incinerators for combustible radioactive waste, and they are also used to neutralise as well as to remove radioactive material from acidic off-gases generated by fuel reprocessing plant. These two uses are considered further below.

Incineration plant

Large incinerators for the burning of medium and low-activity combustible waste are operated by several nuclear facilities in the UK. These incinerators have a series of treatment devices for reducing the amount of particulate and volatile material in the off-gases before discharges to atmosphere. A typical arrangement is the deployment of an "after burner" followed by a scrubber and then a re-heater to reduce the moisture levels in the off-gases prior to final particulate (HEPA) filtration.

Figure 16
Typical caustic scrubber



The after burner is essentially a secondary combustion chamber immediately downstream of the main incinerator combustion chamber and it is intended to deal with any unburnt material and combustible gases passing out of the main combustion chamber.

The scrubber is intended to remove both particulate and water-soluble volatile material from the off-gases. It consists of a vertical column which has water or caustic cascading downwards. The off-gases are passed upwards through this cascade and the particulate and volatile material is removed by the cascading water. The contaminated water is collected and treated as liquid effluent. A scrubber, whilst not as efficient as a filter, has the advantage of being able to treat gases which are both heavily laden with material and at a fairly high temperature – typical of off-gases from an incinerator. If filters were used the frequency of cleaning or replacement would be very high. However once the off-gases have been cleaned by scrubbing they can then be treated by a high efficiency particulate filter prior to discharge to atmosphere. This configuration is only fitted to the relatively large incinerators situated at Hinkley Point B and Berkeley Centre. The more common small units for low level combustible radioactive waste incineration are fitted with an after burner but no other form of filtration.

Reprocessing plant

Following decanning of fuel, the metal or oxide fuel is dissolved in nitric acid. The off-gases from this process are both highly radioactive and acidic. In order to neutralise the acidity the off-gases are passed through a caustic scrubber. Re-circulated caustic liquor flows downward through the scrubber vessel while off gases pass upwards. This process is intended to completely neutralise the off-gases as well as removing some radioactive material (notably carbon 14, iodine and particulates). The caustic liquor is re-circulated through the scrubber and has to be changed periodically as it is gradually neutralised. A diagram of a typical scrubber is shown in figure 16.

11. Records

Under the terms of the Certificate of Authorisation for disposal of waste gases, mists and dusts, requirements are placed on the operator with regard to sampling, measurements, tests and surveys. A separate TGN provides information on the monitoring of discharges to atmosphere (reference 1). Requirements are also imposed in relation to the maintenance of records by the operator and the supply of information to the Environment Agency.

Although the primary purpose of the recording and reporting of information is to demonstrate compliance with the numerical limits of the discharge authorisation, the information is also of value in relation to the requirement to use BPM to limit the activity discharged.

For this purpose, it is appropriate that operators undertake appropriate analysis of information from the measurement and testing programme to observe trends. The causes and circumstances of any abnormal discharges should also be investigated. These analyses and investigations are of value both to the operators and inspectors in monitoring the performance of the abatement systems and the effectiveness of operational controls in abating discharges.

12. Key Points for Site Inspections

a) Filter installations should be looked at to ascertain that appropriate types of filters are in use.

b) Filter test equipment should be checked to ensure that it is in calibration and that there is evidence the aerosol generators used are producing the correct size of particle (in the range 0.1 – 0.5 mm).

c) The operators' filter testing methods and acceptance criteria should be examined. These should be documented on site.

d) The operator should have a programme for filter testing.

e) Filter test results should be checked. Note that in situ testing of HEPA and carbon filters to a minimum frequency is a requirement of some discharge authorisations.

f) Occasionally, and when convenient, arrangements should be made with the operator to view a HEPA filter change procedure.

g) Appropriate control and instrumentation systems should be installed and operational to control and indicate the status of plant.

h) Abatement plant must be operated according to detailed written procedures. These should include parameters and limits for filter change.

i) Particular consideration should be given to filtration systems on incinerators. The particulate filters are prone to blocking because of the relative high levels of particulate material in the off-gases. This results in more frequent filter changing and, therefore, increased generation of waste – which reduces the benefits of incineration. A suitable balance needs to be found.

j) Discharge records should be reviewed and trends examined. The reasons for any adverse trends should be examined.

k) The results of investigations into any abnormal discharges should be reviewed to ensure that appropriate corrective actions have been taken by the operator.

13. References

1. *Monitoring of Atmospheric Radioactive Releases from Nuclear Facilities.* M11. Environment Agency (document in preparation).

2. *Abatement of Radioactive Releases to Water from Nuclear Facilities.* A6. Environment Agency (document in preparation).

3. *Monitoring of Radioactive Releases to Water from Nuclear Facilities.* M12. Environment Agency (document in preparation).

4. *Ventilation of Radioactive Areas. Atomic Energy Code of Practice 1054.*

5. *Charcoal Traps for Radioiodine. Atomic Energy Code of Practice 1064.*

6. *Filter Inserts, High Efficiency Particulate Air.* AESS 30/93402 AEA Technology 1991.

7. *Method of sodium flame test for air filters.* British Standard 3928, 1969.

8. *European Committee on the Construction of Air Handling Equipment, Sodium Chloride Aerosol Test for Filters using Flame Photometric Techniques.* Eurovent Document 4/4. Paris.

9. *Testing and monitoring of off-gas cleaning systems at nuclear facilities.* IAEA Technical Report Series No 243 (1984).

10. *A Comparison of the Methods used in the Nuclear Industry to Test High Efficiency Filters.* Dorman R G. CEC V/3603/81EN (1981).

11. *IAEA TECDOC – 355 Comparison of High Efficiency Particulate Testing Methods (1985).*

12. *Iodine Removal from Gaseous Effluents in the Nuclear Industry.* CEC Conference February 1982. V/5283/82-EN, FR, DR.

13. *Gaseous Effluent Treatment in Nuclear Installations.* CEC Conference October 1985.

Appendix 1 Glossary of terms

Abatement plant Any plant used to trap or hold up radioactive material in nuclear facilities.

Activated carbon Carbon which is treated by high pressure steam after manufacture. This is known as activation and makes the carbon highly porous. This facilitates the deposition of large amounts of volatile or vaporous materials on the large internal surface area.

Adsorber A particular abatement device for removing vapour and volatile materials by sorption processes on specified materials, for example carbon.

Atomic Energy Codes of Practice (AECP)
Documents issued by the UK Atomic Energy Authority which describe recommended methods and equipment for operational practices at nuclear facilities.

Decontamination factor The ratio of the amount of radioactive material in the effluent stream upstream of the abatement plant to that downstream. It is a measure of the effectiveness of the abatement plant.

Differential pressure The difference in static pressure between the upstream and downstream side of abatement plant such as a filter. Used to assess the degree of loading of the system for refurbishment purposes.

Efficiency Is a measure of the effectiveness of abatement plant in the same way as the decontamination factor except that it is expressed as a percentage of constituent removed from the stream, that is:

$$\text{Efficiency} = \frac{100(DF-1)}{DF}$$

In situ test A test carried out on an abatement plant during normal operation as distinct from a test carried out on plant or plant component in the laboratory or on a test rig.

Magnox reactor A reactor named after the magnesium alloy material used as a cladding for the uranium fuel elements.

Maypack Proprietary filter pack employing fine grade carbon granules in conjunction with a particulate filter to arrest particulate and volatile elements in the aerial discharges or sampling lines.

Pressurised Water Reactor (PWR)
A nuclear reactor which uses water both as a moderator and as a coolant.

Test aerosol A dispersed material used to carry out a functional test on an abatement plant which can be injected into the effluent and whose concentration in the effluent can be measured. The concentration is usually measured upstream and downstream of the abatement plant to measure the decontamination factor.

Printed in the United Kingdom for the Stationery Office
J40336 C10 3/98 (77569)

MANAGEMENT AND CONTACTS:

The Environment Agency delivers a service to its customers, with the emphasis on authority and accountability at the most local level possible. It aims to be cost-effective and efficient and to offer the best service and value for money.

Head Office is responsible for overall policy and relationships with national bodies including Government.

Rio House, Waterside Drive, Aztec West, Almondsbury, Bristol BS32 4UD
Tel: 01454 624 400 Fax: 01454 624 409

Internet World Wide Web www.environment-agency.gov.uk

ENVIRONMENT AGENCY REGIONAL OFFICES

ANGLIAN
Kingfisher House
Goldhay Way
Orton Goldhay
Peterborough PE2 5ZR
Tel: 01733 371 811
Fax: 01733 231 840

MIDLANDS
Sapphire East
550 Streetsbrook Road
Solihull B91 1QT
Tel: 0121 711 2324
Fax: 0121 711 5824

NORTH EAST
Rivers House
21 Park Square South
Leeds LS1 2QG
Tel: 0113 244 0191
Fax: 0113 246 1889

NORTH WEST
Richard Fairclough House
Knutsford Road
Warrington WA4 1HG
Tel: 01925 653 999
Fax: 01925 415 961

SOUTHERN
Guildbourne House
Chatsworth Road
Worthing
West Sussex BN11 1LD
Tel: 01903 832 000
Fax: 01903 821 832

SOUTH WEST
Manley House
Kestrel Way
Exeter EX2 7LQ
Tel: 01392 444 000
Fax: 01392 444 238

THAMES
Kings Meadow House
Kings Meadow Road
Reading RG1 8DQ
Tel: 0118 953 5000
Fax: 0118 950 0388

WELSH
Rivers House/Plas-yr-Afon
St Mellons Business Park
St Mellons
Cardiff CF3 0LT
Tel: 01222 770 088
Fax: 01222 798 555

For general enquiries please call your local Environment Agency office. If you are unsure who to contact, or which is your local office, please call our general enquiry line.

ENVIRONMENT AGENCY GENERAL ENQUIRY LINE
0645 333 111

The 24-hour emergency hotline number for reporting all environmental incidents relating to air, land and water.

ENVIRONMENT AGENCY EMERGENCY HOTLINE
0800 80 70 60

ENVIRONMENT AGENCY

Technical Guidance Note
(Abatement)

A5

The Stationery Office

Published by The Stationery Office and available from:

The Publications Centre
(mail, telephone and fax orders only)
PO Box 276, London SW8 5DT
General enquiries 0171 873 0011
Telephone orders 0171 873 9090
Fax orders 0171 873 8200

The Stationery Office Bookshops
59–60 Holborn Viaduct, London EC1A 2FD
temporary until mid 1998
(counter service and fax orders only)
Fax 0171 831 1326
68–69 Bull Street, Birmingham B4 6AD
0121 236 9696 Fax 0121 236 9699
33 Wine Street, Bristol BS1 2BQ
0117 9264306 Fax 0117 9294515
9–21 Princess Street, Manchester M60 8AS
0161 834 7201 Fax 0161 833 0634
16 Arthur Street, Belfast BT1 4GD
01232 238451 Fax 01232 235401
The Stationery Office Oriel Bookshop
The Friary, Cardiff CF1 4AA
01222 395548 Fax 01222 384347
71 Lothian Road, Edinburgh EH3 9AZ
(counter service only)

Customers in Scotland may
mail, telephone or fax their orders to
Scottish Publications Sales
South Gyle Crescent, Edinburgh EH12 9EB
0131 622 7327 Fax 0131 622 7017

The Stationery Office's Accredited Agents
(see Yellow Pages)

and through good booksellers

£50

ISBN 0-11-310134-1

9 780113 101344

The SO