Technical Guidance

M 11

ENVIRONMENT AGENCY

Monitoring Series

Monitoring of Radioactive Releases to Atmosphere from Nuclear Facilities

Monitoring of Radioactive Releases to Atmosphere from Nuclear Facilities

Technical Guidance Note
M11

LONDON: THE STATIONERY OFFICE

Commissioning Organisation
Environment Agency
Rio House
Waterside Drive
Aztec West
Almondsbury
Bristol BS32 4UD

Tel 01454 624400
Fax 01454 624409

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Enquiries about the contents of this publication should be made to:
National Compliance Assessment Service
Cameron House
White Gross Industrial Estate
South Road
Lancaster
LA1 4XQ

Telephone: 01524 842704

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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 on the monitoring of releases from nuclear facilities and industrial processes, and on related environmental monitoring.

This Note provides guidance on the monitoring of radioactive releases to atmosphere from nuclear facilities. The equipment used for monitoring and the way the equipment is used are described. Key points to be considered by inspectors in the review of monitoring system proposals and in conducting on-site inspections are identified. A similar Note[1] has been prepared covering the monitoring of discharges of radioactive liquid effluents from nuclear facilities. A separate series of Notes on abatement includes Notes providing guidance on the abatement of emissions to atmosphere[2] and of discharges of radioactive liquid effluents from nuclear facilities[3]. A further TGN is being prepared to give guidance on the analysis of samples collected after monitoring[4].

The regulatory context in which a monitoring programme must operate is described in outline in Section 2. In Section 3 the objectives of a monitoring programme are described. In Section 4, the principles of monitoring of airborne emissions and general sampling techniques are described, followed in Section 5 by a discussion of the design of sampling systems. Techniques for the sampling and measurement of particular nuclides or groups of nuclides are described in Section 6, and the approaches to on-line measurement of emissions in Section 7. The application of quality assurance to gaseous emission sampling is outlined in Section 8. Section 9 identifies key issues that should be considered by Agency staff during inspection visits.

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

2 The regulatory context

Liquid and airborne releases from nuclear facilities contain low levels of radioactivity and 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 numerical limits on the amounts of radioactivity permitted to be discharged, the authorisations require the operator to use Best Practicable Means (BPM) to minimise discharges.

The authorisation also imposes requirements on the operator to undertake sampling, measurements, tests and surveys, to maintain 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 the more detailed arrangements to be employed by operators. This covers, for example, techniques for sampling and analysis, and the form of records to be retained.

3 Objectives of a monitoring programme

The objectives of a liquid effluent monitoring programme may include[5]:

- to ensure that potential discharges are known by the site operator to be within authorised limits;
- to provide information to demonstrate that the operations giving rise to the effluent and the use of abatement plant (if any) and all associated control and management systems are performing as planned;
- to detect rapidly, give warning and identify the nature and extent of any unplanned releases to the environment to allow suitable remedial activities to be instigated;
- to provide a record of the amount of radioactive material discharged to the environment in order to demonstrate compliance with the authorised limits on releases.

A monitoring programme may also:

- identify trends in discharges, especially those which may indicate a chronic plant or process problem;
- provide source term data and other information for modelling studies, for example, for radiological impact assessments;
- indicate requirements for off-site environmental measurements, or a programme of environmental monitoring;
- provide public reassurance.

To meet these aims and objectives, a monitoring programme must be planned in advance. Planning should define:

- The *nuclides* to be included in the programme. This may include not only those nuclides specified in the discharge authorisation but others that may provide additional information on, for example, the efficiency of abatement plant.
- The timing and frequency of *sampling* of the discharge, and the sampling methods to be used. The aims are to ensure that samples are representative and that sufficient data are available to determine total discharges over the discharge authorisationperiod and (in some cases) any trends over time.
- The laboratory *analysis* programme. This is required to ensure that the final data can be used to establish reliably the cumulative discharge and that trends with time are not masked by poor analytical data.

Planning of the monitoring programme, and the finalised programme, should be fully documented and must be related to a Quality Assurance system. Quality aspects are dealt with in further detail in Section 8 of this document.

4 Principles of monitoring of gaseous emissions

4.1 Sampling and on-line instrumental measurement

There are two main techniques for monitoring emissions:

(a) *Sampling for laboratory analysis* normally provides a retrospective measurement of the amount of radioactive material emitted. However, in some cases, such as reactor gas circuits, sampling is carried out prior to blowdown to ensure control within limits. Sampling is normally carried out by passing a representative sample of the effluent for a fixed period of time, typically 24 hours, through a collection device. The amount of radioactivity in the collection device is measured and can be related to the amount of gaseous effluent that has passed through the sampling system in the sampling period to give the activity concentration of the effluent. The total amount of radioactivity emitted can then be estimated from the activity concentration multiplied by the total stack flow during the period. Alternatively, given that the ratio of the sampling flow to stack flow is known (or the ratio of the total flow in the sampling period), the amount of radioactivity emitted can be estimated by multiplying this ratio by the total amount of activity in the collection device.

(b) *On-line instrumental measurements* provide a continuous indication to the operator of the quantity of radioactive material in the emission. This enables rapid corrective action to be taken in the event of any deviation from the norm, by use of alarm levels. On-line instrumental measurement systems are usually provided where there is a potential for sudden and significant changes in the level of radioactive material emitted, especially where this could pose a potential off-site hazard, and can provide information for plant control.

Sampling systems provide a more accurate, albeit retrospective, estimate of emissions and are almost invariably used for accounting purposes to demonstrate compliance with authorisation limits. Consequently sampling techniques are used for routine emission assessment and are the most important from the point of view of authorisation requirements. For this reason this Guidance Note deals mainly with sampling systems although some information is given on on-line measurement systems.

On-line instrumented measurement systems are not usually used to give a measurement of radioactive material emitted for accounting purposes (to show compliance with authorisation limits). However, in some cases, where the collection characteristics of the systems are suitable, the sample collected can also be used for retrospective measurement. On-line measurements may be used for comparison with internal standards within particular organisations.

There may be both on-line measurements and sampling systems on any particular emission route. The on-line measurement systems will be associated with specific processes for the purposes described above. The sampling systems will normally be associated with the final authorised emission point, which may take emissions from several plant areas.

In some circumstances, it may be acceptable to estimate the quantity of radioactivity emitted by means of assessments based on a knowledge of the source or on indirect measurements. In this case, a conservative approach should be adopted to give an upper bound estimate.

4.2 General sampling techniques

Different sampling techniques are required for different physical forms of radioactive materials. The main forms are particulate, vapours and gases. Thus different radioactive species within the same effluent may require separate sample collection and analytical methods. General sampling techniques for each of the above-mentioned forms of radioactive material are described in this section. Particular techniques applicable to specific radionuclides are described in Section 6.

4.2.1 Sample extraction

The primary objective is to ensure that a representative sample is taken for analysis under all conditions of operation of the facility. This involves consideration of the design of extract systems with this objective in mind. Continuous sampling is normally required on major emission routes and it is important that all factors which could affect sampling are taken into account, such as temperature, pressure, humidity and chemical form of the emission.

In order to obtain a representative sample for compliance monitoring purposes, several conditions must be fulfilled, namely:

(a) Sampling must take place downstream of any abatement plant.

(b) The sample must be taken at a position in the emission stack where all constituents are adequately mixed.

(c) The sample must be taken well away from any ductwork features such as dampers, bends and merged streams, which may have a detrimental effect on mixing and flow patterns, or a well mixed flow must be demonstrated at the plane where the sample is taken.

(d) The sample should ideally be taken via a probe and this must be pointing upstream.

(e) The emission velocity and concentration profiles adjacent to the extract plane should be reasonably uniform.

Figure 1 *Positioning of sample extraction point to satisfy 'adequate mixing' criteria.*

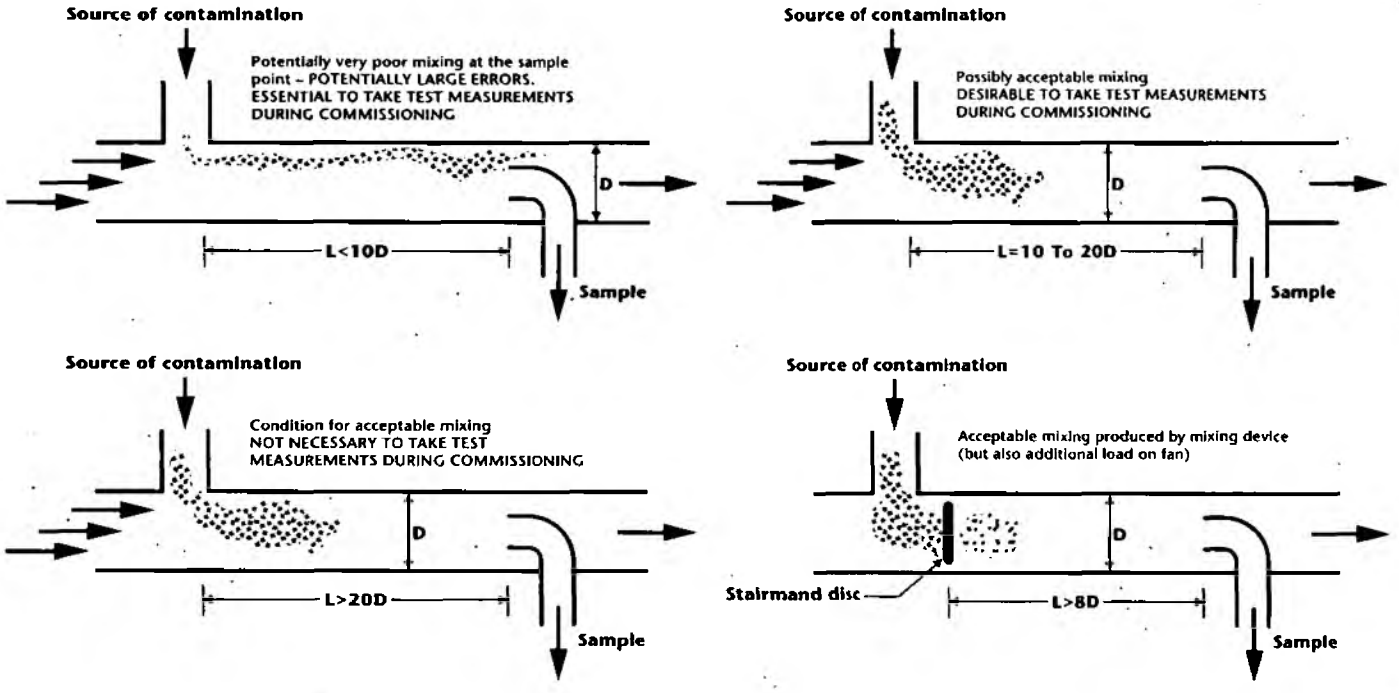

Diagram courtesy of AEA Technology

Rule-of-thumb design rules have been devised in order to meet requirements (b) and (c) and these are illustrated in Figures 1 and 2. It can be seen that, in order to ensure a fully mixed effluent, ideally a minimum distance of 10 to 20 duct diameters downstream from the last major duct feature is required. Anything less requires the addition of special mixing devices[5] or commissioning tests. In this connection, it may be noted that ventilation fans are effective mixing devices. It is important therefore to consider sampling requirements when emission systems are being designed, not as an afterthought.

Determination of concentration profiles during commissioning involves measurement of the concentration of a suitable tracer material, such as a submicron aerosol that will follow the flow streamlines, injected into the system to simulate effluent bypassing the sampling device. It should be normal practice during commissioning to measure both the concentration and the velocity profiles across the duct or stack section to establish the optimum position of the probe. If these are reasonably uniform, then only one probe should be required, usually positioned in the central region of the duct section. If they are non-uniform, more than one probe may be required. Where multiple probes are used, each of these should ideally have its own sample collection system. The use of multiple nozzles manifolded to a single sample can give rise to non-representative sampling if flow balancing is not carried out. More information on this aspect is given elsewhere[5,6].

In the case of particulate material, it is necessary to use a probe with a nozzle designed to ensure that isokinetic sampling is taking place and that the sample being taken is truly representative in respect of particle size distribution, i.e. no

Figure 2 *Positioning of sample extraction point to satisfy 'distance from ductwork' criteria.*

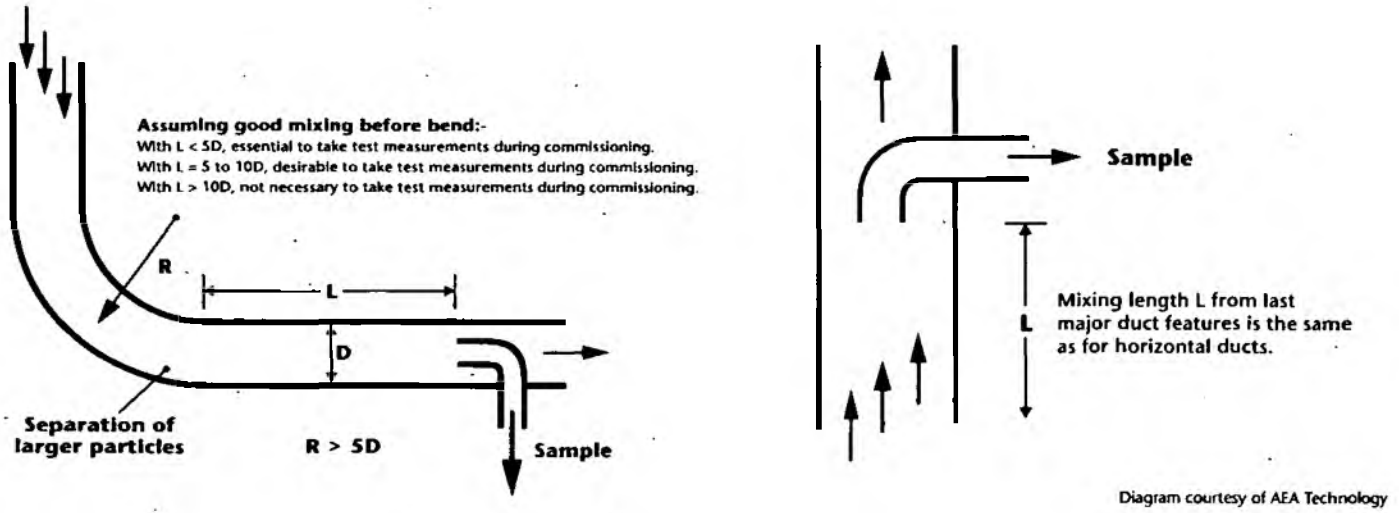

Diagram courtesy of AEA Technology

particles are rejected or preferentially drawn into the sampling probe. This requires the following conditions to be fulfilled:

(a) The entry nozzle of the probe must point upstream.

(b) The velocity at the nozzle inlet due to the sample extraction must be equal to that in the duct or stack.

(c) The nozzle must have a sharp (feathered) leading edge.

(d) In dusty streams, the inside diameter of the nozzle at the inlet generally needs to be ≥10 mm. However, in nuclear plants the particulate loadings are usually very low, because of the use of HEPA filtration. In such cases smaller nozzles may be used to achieve isokinetic sampling conditions.

Probe requirements (a) and (b) are illustrated in Figure 3. In the case of gases and vapours the design of the sample probe is not critical as long as the diameter is appropriate for the sample flowrate. The optimum position in respect of mixing is of course relevant. It is common practice, however, to extract a single sample through a probe designed for isokinetic sampling for the purpose of measuring both particulate and vapour/gas forms of radioactive material in the effluent.

Figure 3 *Conditions for isokinetic sampling*

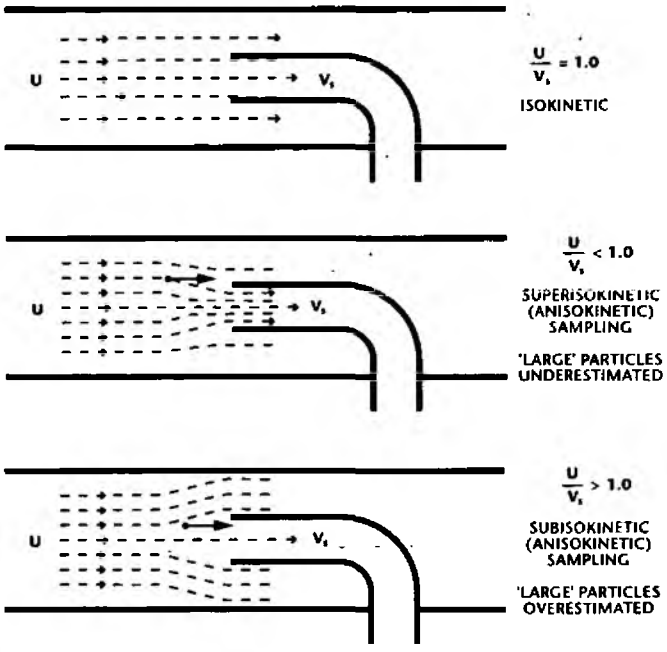

Diagram courtesy of NRPB

In some circumstances, such as when sampling from the top of a high stack, a primary/secondary system is used. Here, a large-diameter (~150 mm) probe is used to extract a sample to a suitably accessible location where the primary sample flow is itself sampled by a conventional small-diameter probe. The primary flow is then returned upstream of the discharge fan, so that it is driven by the fan pressure differential. The primary line is designed to minimise deposition and plate-out effects and is normally trace-heated.

4.2.2 Sample collection

Radioactive material can be emitted in several physical forms and different collection methods are required for each of these forms. These methods are described in general terms below. Specific methods for individual radionuclides are discussed in Section 6.

4.2.2.1 Particulate material

Suspended radioactive particles, generally known as an aerosol, are usually collected by drawing a sample of the effluent through a high-efficiency filter paper, usually of glass fibre but cellulose filters are also used. This is by far the most common collection device for aerosols, although impaction devices and electrostatic precipitators are also sometimes used. See BS5243[6] for more information on these devices.

The amount of radioactive material caught on the filter paper is subsequently measured in the laboratory. If an on-line measurement is required, a detector can be mounted above the filter paper.

4.2.2.2 Vapours

Radioactive material in the form of volatile vapours will pass through a filter paper, and other forms of collection medium are required. Most vapours adsorb on to surfaces and trapping devices are designed to take advantage of this property. The most common material used is granulated activated carbon. This material has a very high surface area per unit mass (1000 m^2/g) and has an extremely good removal efficiency for materials in vapour form. The basic characteristics of carbon and the mechanism of trapping vapours is described elsewhere[6].

Carbon is most commonly used for removal of iodine, but it will also remove other vapour and gaseous forms of radioactive material that may be emitted, such as ^{35}S and ^{36}Cl. A combined particulate (filter paper) iodine (carbon) collection device is illustrated in Figures 4 and 5.

Figure 4 *Maypack insert*

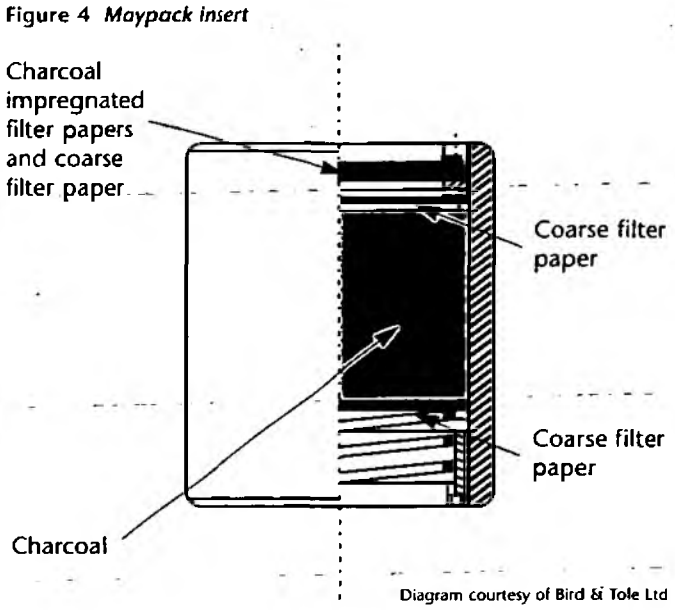

Diagram courtesy of Bird & Tole Ltd

Figure 5 *Stack sampler with Maypack insert*

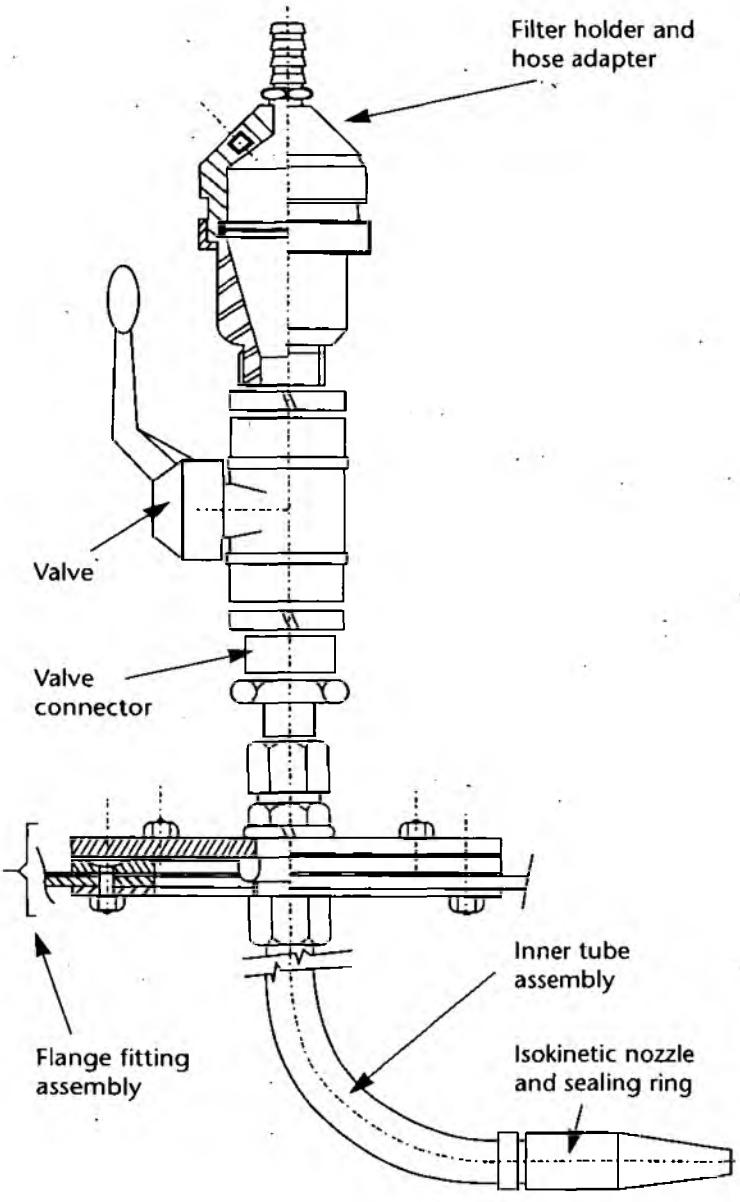

Diagram courtesy of Bird & Tole Ltd

The main drawback with carbon is its vulnerability to contaminants such as moisture, oil and other organic materials that may be present in the emission. Although impregnation of the carbon ensures that its performance is maintained in the presence of high relative humidities, free water as well as oil and other organic materials can 'poison' the carbon; that is, take up adsorption sites and make it less efficient for iodine removal.

It is sometimes the case, particularly for fuel reprocessing plant, that there is a requirement to sample volatile vapours, such as iodine, in the presence of aggressive materials such as nitric acid fume. In this case carbon will not be suitable and alternative collection media are required. The usual alternatives in this situation are zeolite-based materials. These are crystalline aluminosilicates and are known as molecular sieves because of the small size of the porous cavities through which the gas passes. For iodine removal they are impregnated with silver, which enhances their adsorption properties.

For some other volatile vapours, notably ruthenium, a wet scrubber is used as the collection medium. This is described below.

4.2.2.3 Gases

Although vapour collection devices such as carbon will hold up some gaseous forms of radioactive material, the collection efficiency is variable and depends on the specific chemical form. It has been necessary therefore to develop collection devices that are specific to the particular chemical form of the gaseous radioactive material under examination. Some common methods of removal are sample bottles (bubbler traps), cryogenic and scrubbing devices as well as direct measurement of the emission:

(a) *Bubbler traps* are used to effect a reaction between a sample of the gaseous radioactive material and a liquid collection medium, resulting in the transfer of the radioactive material from the effluent stream to the liquid collection medium by a chemical or physical reaction. In order to effect this reaction, the sample gas is passed into a bottle containing the liquid sampling medium through an inlet tube and is allowed to bubble through the liquid to an outlet tube. This ensures good contact between the sample gas and bubbler liquor to ensure a complete reaction. Bubbler traps are widely used for sampling tritium in both elemental and tritiated water (oxide) form. A typical trap is shown in Figure 6.

Figure 6 *Bubbler trap*

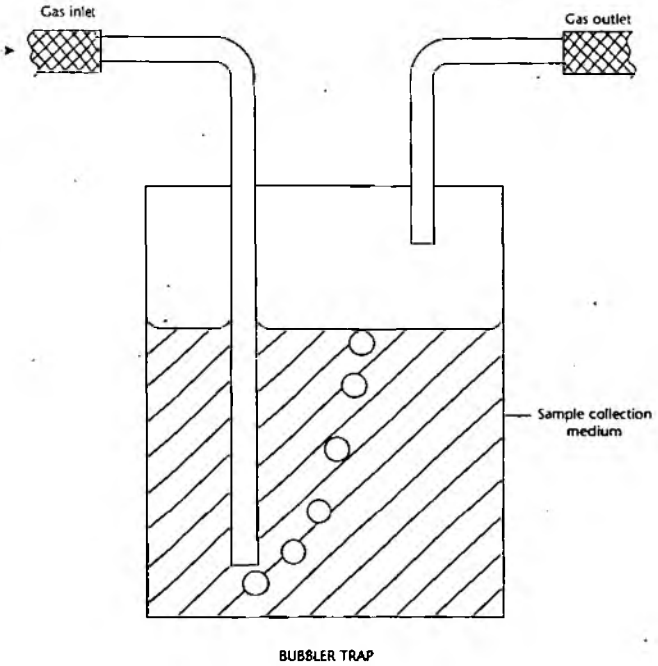

Diagram courtesy of MAFF

(b) *Wet scrubber* is a means of transferring a sample of gaseous radioactive material from the effluent stream to a liquid collection medium. It is primarily used for ruthenium. It operates on the same principle as scrubbers used in the treatment of gas streams to remove radioactive material in particulate or vapour forms. It consists typically of a

glass cylinder filled with glass beads/tubing or other inert material. A recirculating flow of liquor passes down through the cylinder over the inert material whilst the gas to be sampled passes upwards. This arrangement maximises the contact area and hence the mass transfer between the liquid and gaseous media. The radioactive material is removed by the liquor, which can be water or a solution of reacting material. Periodically the liquor is changed and the amount of radioactive material accumulated in the spent liquor is determined. This activity can be related to the amount of sample gas that has passed through the scrubber over the period in question.

(c) *Direct measurement* is used when the chemical form of the radioactive material is such that it is not practicable to remove it from the emission. This is particularly the case for radioisotopes of inert gases such as krypton and xenon. The emission is drawn into a 'measurement chamber', which is of fixed calibrated dimensions and controlled temperature. A detector and associated electronics are positioned to measure the activity in the chamber. This measurement can be related to the fixed volume of sample in the chamber, and the activity concentration can then be assessed making appropriate temperature corrections.

4.2.3 Sample analysis

Samples are analysed retrospectively in the laboratory using counting devices, which consist basically of a detector, a counting chamber and the associated electronics. They vary from the relatively simple Geiger tube and lead castle, which is used for gross beta assessment (e.g. activity on a filter paper), to the more sophisticated liquid scintillation counter, which is used for assessment of soft beta emitters in liquid samples, and to the gamma-ray spectrometer used for assessment of gamma activity in samples.

The common detector types that can be used to measure the above-mentioned modes of decay are listed below:

- *Alpha-emitting radionuclides*
  Zinc sulphide screen counters
  Thin window or windowless proportional counters
  Gas flow counters
  Semiconductor detectors
  Liquid scintillation counters

- *Beta-emitting radionuclides*
  Geiger-Muller counters
  Solid scintillation counters
  Thin-window or windowless proportional counters
  Liquid scintillation counters

- *Gamma emitting radionuclides*
  Geiger-Muller counters
  Thin window proportional counters
  Scintillation counters
  Semiconductor detectors.

The principle of measurement involves counting the sample (say filter paper) and comparing the result with a standard source. Background activity has also to be determined and subtracted by counting a blank sample. For alpha and soft beta emitters, it may be necessary to correct the result for absorption within the sample matrix. Various sophisticated electronic facilities are available to improve counting accuracy and to automate counting procedures.

It may be appropriate to count filter papers at intervals (e.g. at removal, after 24 hours and after 48 hours) to allow for the decay of short-lived radionuclides, e.g. naturally occurring radon daughters.

Samples may be counted repeatedly with a series of absorbers interposed between the sample and the counter to allow differentiation between hard and soft beta emissions.

Standard sources should ideally consist of the same radionuclides as in the sample and should be prepared in the same form and geometry. However, sometimes alternative radionuclides with the same energy of emitted radiation are used as they may be more convenient, i.e. longer half-life. Where gross activity is being assessed, a range of radionuclides are involved, and the standard source has to consist of either a single radionuclide typical of the range or a mixed radionuclide source. Assessment of gamma activity is usually carried out by gamma-ray spectrometry and the standard sources used have either mixed (gamma-emitting) radionuclides or a single radionuclide that emits several gamma-rays. Some typical standard sources are given in Table 1, though others are also used.

Table 1 *Typical standard sources*

Radionuclide	Standard Source
^{35}S	^{14}C
^{14}C	^{14}C
^{131}I	Mixed gamma standard
Beta particulate	^{36}Cl, ^{90}Sr, ^{90}Y
Alpha particulate	^{239}Pu

The choice of a particular instrument for counting the sample activity is dependent on several factors:

(a) The type of radioactive emission, e.g. alpha, beta, gamma.

(b) The type of count. This can be either a gross count to include a range of radionuclides or a specific radionuclide determination. The isolation of a specific radionuclide may be carried out by energy discrimination (spectrometry), radiochemical separation, or a combination of both.

(c) The sensitivity required.

(d) The number and throughput of samples, i.e. manual or automatic counting.

Brief descriptions of the sample analysis methods generally used for the more common sampling methods are given below. A more detailed description appropriate to individual radionuclides is given in Section 6.

(a) *Filter papers.* Using the methods listed above, the particulate alpha and beta activity on filter papers can be determined by direct counting of the filter paper or by ashing the filter paper and preparing a homogeneous source. The filter paper may also be determined by gamma spectrometry to establish the range of gamma-emitting radionuclides on the paper, but this is usually only a qualitative measurement.

(b) *Carbon (Maypack).* Usually specific radionuclides, such as ^{131}I or ^{129}I, are determined in carbon packs. Consequently the carbon pack is counted using a gamma spectrometer with reference to an appropriate standard, usually a mixed gamma standard.

(c) *Bubbler liquor.* This technique is usually used for ^{14}C, ^{35}S and tritium, which are low-energy beta emitters. A portion of the bubbler liquor is mixed with a scintillant and then counted on a liquid scintillation counter with reference to a standard source relevant to the particular radionuclide in question.

(c) *Scrubber.* This technique can be used for ^{106}Ru. A portion of the scrubber liquor is taken and analysed for ^{106}Ru using gamma spectrometry.

These and other methods are described in more detail in Section 6, which covers determination of specific radionuclides.

5 System design

Figure 7 *Typical system for extracting a sample*

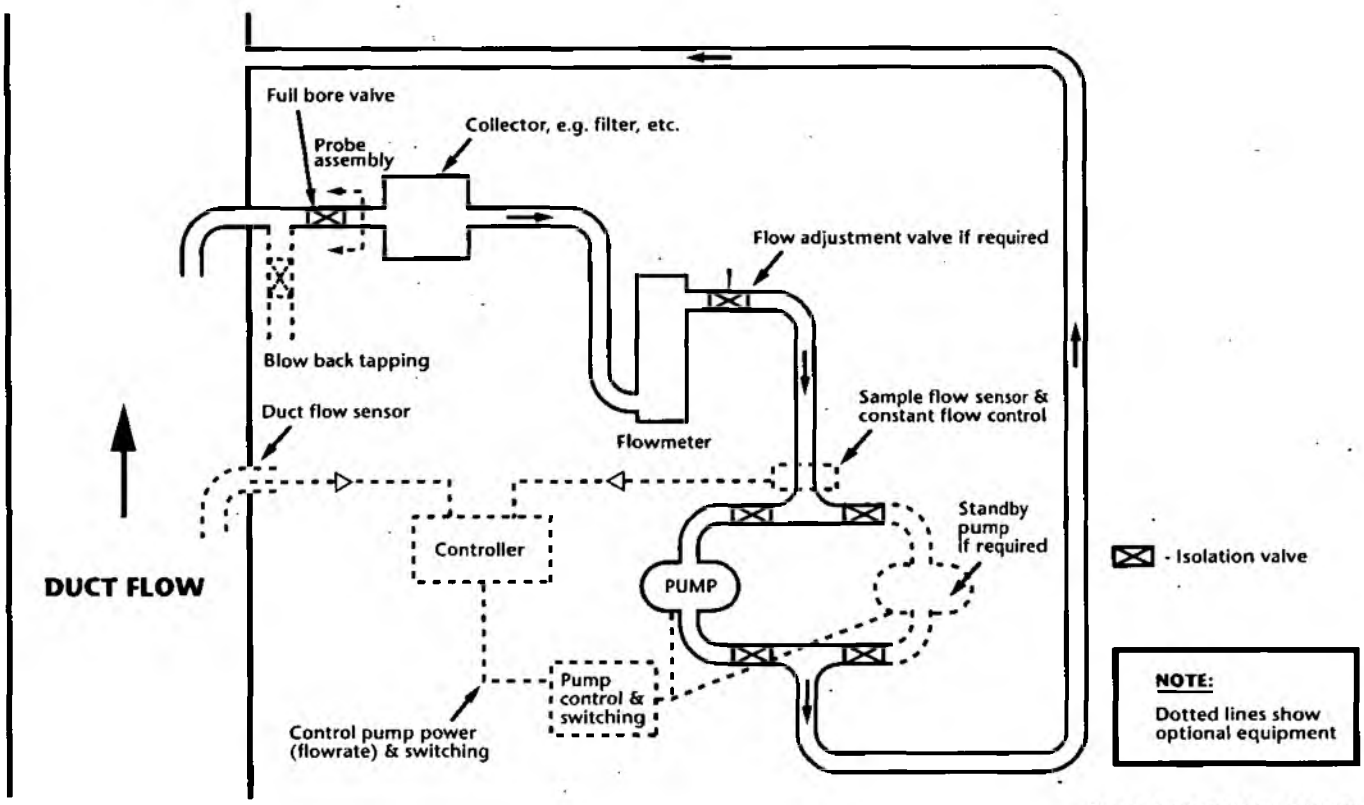

Diagram courtesy of Nuclear Electric

Sampling system components, for either continuous or intermittent sampling, are usually housed in a cabinet. A diagram of a typical sampling system is shown in Figure 7. Most systems contain similar basic components; that is, a sample extraction device (probe), a sample collection device, pumps to draw a sample through the system and a flow meter to measure the sample flowrate. Important aspects of system design are discussed below.

5.1 Sample extraction

The sample extraction methods have been discussed in Section 4. It is particularly important when sampling for particulates and condensable vapours that the length of pipework between the probe and the sample collector is as short as possible in order to minimise condensation/plate-out and avoid unrepresentative sampling. Similarly, bends in the pipework should be minimised so that any deposition of radioactive material by centripetal separation before collection is as small as possible. If bends are necessary, they should be gradual; BS 5243[6] recommends that any bend radius should be greater than 5 times the pipe diameter.

Valves and other equipment such as pumps should be downstream of the collector. In order to eliminate deposition, particulate sample collectors are sometimes positioned inside the duct and have to be withdrawn for filter changing.

5.2 Deposition effects

Some volatile species such as isotopes of iodine and sulphur can 'plate-out' in sample lines. This is particularly enhanced due to thermophoresis deposition when sample lines are cold relative to the effluent. In order to minimise plate-out it is common practice to trace heat sample lines from duct exit to sample collection point. It is important to be aware that plate-out may not become apparent until it is released by a disturbance to the system (e.g. pressure changes or boiler tube leaks on gas-cooled reactors).

In some circumstances, such as where the use of a long sampling line is unavoidable, computer models can be used to access deposition effects and to optimise design of the sampling system.

5.3 Prevention of sample bypass

The design and positioning of the collector must ensure that, as far as practicable, the collection medium cannot be bypassed by the radioactive material being sampled. Thus in the case of a particulate/iodine Maypack the filter holder should preferably be designed to prevent settling of the carbon, otherwise it should be mounted vertically so that any settling of the carbon does not lead to a bypass path past the carbon, which is possible if it is mounted horizontally.

The glass fibre filter papers are fragile and the sample holder must be of such a design that there is as little chance as possible of damage to the paper during removal and replacement resulting in a bypass path. The removal and replacement process should be straightforward and the design of the system should ensure that this operation can be carried out safely and that incorrect replacement is not possible.

5.4 Flow measurement

A flow meter is normally required to indicate the sample flowrate. Exceptionally, a minimum flow criterion can be used which will always underestimate the volume sampled and overestimate the emission. For continuous sampling systems, unless it has been confirmed that the sample flowrate is reasonably constant over the sampling period (i.e. ±10%), an integrating flow meter that indicates the total volume sampled should be provided. Where warranted by the significance under both routine operation and abnormal conditions, a low-flow sensor should be fitted which brings up an alarm at a position that is manned during operation of the facility. Where particulates are being sampled, similar provision should be made to warn of high flow, indicating failure of the filter. Flow meters need to be calibrated at suitable intervals.

Where justified by the importance of the emission stream, electronic control devices may be provided on sampling systems. They are usually installed where there is a large dynamic range of stack flow in order to allow sample flow to be adjusted to follow the stack flow (proportional sampling arrangements).

5.5 System design

One pump and one standby pump should be provided on all systems where high reliability of the sampling system is required. This is particularly the case where continuous sampling systems are being used to monitor emissions to show compliance with authorisation limits. There should be facilities for automatic switch-over to the standby pump or failure of the pump should bring up an alarm in a manned position. Where the estimate of flow is based on fan capacity, the actual flowrate should be confirmed periodically.

Materials used for construction of the system, i.e. pipework, should be chosen to minimise deposition of radioactive material. In this respect material subject to corrosion should not be used. Stainless steel is the ideal material, albeit expensive. Other materials need to be justified by experience or testing, particularly flexible materials, which may be used where movement is required to disconnect components such as samplers.

5.6 System environment

The system should be protected against unauthorised tampering and damage from extraneous materials such as water, oil, etc., usually found in an industrial environment. Depending on location, this is usually accomplished by housing the equipment in a locked cabinet. It is also important that systems are protected against excessive heat, which can enhance evaporation of bubbler liquor and affect electronic components. The general principle is that the equipment environment should be controlled to meet the duty specification of the equipment.

5.7 Maintenance and reliability

It has already been stated that for most sampling systems high reliability is required. This is achieved by routine maintenance and backing up essential components of the sampling system. Operators should have a maintenance schedule for ensuring that appropriate maintenance is carried out. This should include power supply, mechanical pumps, flow meters, etc., as well as checking that joints are leak-tight and alarms are operating satisfactorily. Back-up of essential components either as standby on the system or as designated spares should be provided. The aim should be to achieve the reliability levels quoted in the Code of Practice[5]. These, in summary, suggest that for continuous sampling systems an unavailability criterion of 10^{-3} per year is appropriate. This represents an outage time of less than 9 hours per year. More detailed advice consistent with this general criterion is given in that Code of Practice[5].

6 Nuclide-specific techniques

In the preceding sections of this Note, sampling techniques are discussed in general terms. In this section the specific techniques commonly used to sample and analyse important radionuclides that are emitted from nuclear facilities are discussed. These are generally the radionuclides that are subject to numerical limits in authorisations issued by the Agency. More information is available in specific documentation prepared by individual facilities.

6.1 Argon-41 (nuclear power stations)

^{41}Ar is a noble gas, so there is no sampling medium with which it can interact. The techniques used to make assessments of emissions differ between shield cooling air and coolant emissions.

6.1.1 Shield cooling air

Shield cooling air, used on Magnox reactors with steel pressure vessels, is subject to significant neutron irradiation while passing through the interspace between the pressure vessel and the inner face of the biological shield. ^{41}Ar emitted in the shield cooling air is produced by neutron activation of natural ^{40}Ar in the air supply.

The emission rate of ^{41}Ar is dependent on three factors:

- neutron flux, which is itself a direct function of thermal power;
- shield cooling air flowrate; and
- the residence time of the shield cooling air in the neutron flux.

The latter two factors vary inversely with each other, so their product is constant for a given reactor, assuming that there are no additional factors such as a variety of flow paths through the interspace that might have different significance at different flowrates. Therefore, in practice, the emission of ^{41}Ar can be calculated as a function of thermal power.

The relationship between ^{41}Ar emission and thermal power has been quantified for each steel-pressure-vessel Magnox reactor by a series of measurements of ^{41}Ar in shield cooling air. From these data, the emission of ^{41}Ar for any reporting period can be calculated from the integrated thermal power (MWh) over the same period.

The activity concentration of ^{41}Ar in shield cooling air should be measured periodically (once per year) to ensure that the calibration data are still appropriate for the calculation of emissions.

6.1.2 Reactor coolant

Emissions of ^{41}Ar in reactor coolant derive from neutron activation of ^{40}Ar impurities (mainly due to air) in the circuit. On steel-pressure-vessel Magnox reactors such emissions are likely to be relatively small compared with the ^{41}Ar emitted in shield cooling air. Concrete-vessel reactors do not have shield cooling air, so reactor coolant release is the only mechanism to emit ^{41}Ar from these reactors.

The activity concentration of ^{41}Ar has been measured in coolant at Oldbury, Wylfa and Hinkley Point B power stations. From these measurements, relationships between ^{41}Ar emissions, neutron flux and ^{40}Ar impurities have been quantified, so that future emissions can be calculated.

The specific activity of ^{41}Ar in reactor coolant can be assessed by drawing a sample into a counting chamber (e.g. a Marinelli beaker) and the specific activity of ^{41}Ar determined by gamma spectrometry with reference to an appropriate mixed gamma standard. Emissions are then assessed as the product of the specific activity of ^{41}Ar and the coolant discharge rate.

Most AGRs are provided with on-line gamma spectrometry equipment to measure in-coolant noble gas levels to give early warning of fuel pin failures. This includes the routine measurement of ^{41}Ar specific activity in the circuit. Emissions of ^{41}Ar are calculated from this specific activity and the mass of coolant released.

During steady-state operation coolant loss may be calculated by using the 'helium decay' method whereby a known quantity of stable helium is periodically injected into the pressure vessel and samples taken regularly to determine leakage rate.

6.2 Tritium, carbon-14 and sulphur-35 (nuclear power stations)

Tritium, ^{14}C and ^{35}S are present in gaseous emission from nuclear power stations. These radionuclides arise largely from activation of core materials and associated impurities, are gaseous in form and thus are associated with the CO_2 coolant. The emissions can be assessed either by direct sampling of the coolant or by sampling in the stack prior to being emitted in the manner described below. For all the radionuclides, but particularly ^{14}C, direct sampling of the coolant is the method used. The advantages are:

(a) A more accurate measurement can be made of the undiluted coolant. This is particularly the case for ^{14}C (see Section 6.3).

(B) The combination of CO_2 specific activity measurement and CO_2 loss measurement accounts for all coolant-associated activity emitted. Stack measurements do not necessarily account for all CO_2 lost, e.g. leakage from external ductwork.

(c) Only one sampling system is required to make in-coolant measurements whereas several systems may be required to cover all the stack outlets.

Direct coolant sampling is not continuous; typically a 30 minute 'spot' sample is taken once per day. This means that for the rest of the time there is no check on the levels of activity in the coolant and hence on the emissions. Spot sampling has therefore to be frequent enough to give reassurance that any major changes in coolant activity levels, hence emissions, will be detected. A daily spot sample is generally considered the minimum necessary to achieve this aim. In routine operation, coolant gas conditions are stable for long periods and less frequent sampling may be justifiable. However, during transient periods, more frequent sampling needs to be carried out.

Note: Coolant sampling cannot be used for particulate activity emission measurement. This must be carried out downstream of filtration systems, which are usually provided to treat gaseous effluent prior to being emitted.

The method for sampling ^{35}S in gaseous emissions involves passing a sample through a furnace with an air supply to oxidise the various chemical forms of sulphur present to SO_2 or SO_3. These oxides of sulphur are then dissolved in either demineralised water or a solution of hydrogen peroxide (H_2O_2) to ensure that the dissolved sulphur is retained as sulphate. Gaseous tritium is also oxidised in the furnace to tritiated water (HTO) and this is also removed by the H_2O_2 solution, which can then be analysed for both tritium and ^{35}S in a liquid scintillation counter. A typical system is shown in Figure 8.

The furnace is heated to 1100 degrees C to ensure complete oxidation of the gas sample. The furnace exhausts to a train of sample bottles (bubblers). These are of a nominal 500 ml capacity, although sample solution volumes of the order of 50-100 ml are typically used. The volume/surface area combination should be such as to minimise the loss of bubbler liquor through evaporation and ensure that there is an adequate volume for assessment purposes. The sample train should ideally consist of:

- An empty bottle to trap any carry over from back-pressure applied to the system.
- An absorption bottle containing H_2O_2 for removal of tritium and oxidised sulphur.
- A second absorption bottle also containing H_2O_2 to trap any carry-over from the first absorption bottle.
- An empty bottle to trap any carry-over of liquid due to pressurisation of the system.

A sample of the liquor from the main sample bottle and the carry-over sample bottle is mixed with scintillant and then counted using dual-channel liquid scintillation counting with reference to appropriate tritium and ^{35}S standards.

Figure 8 *Sampling system for tritium, carbon-14 and sulphur-35*

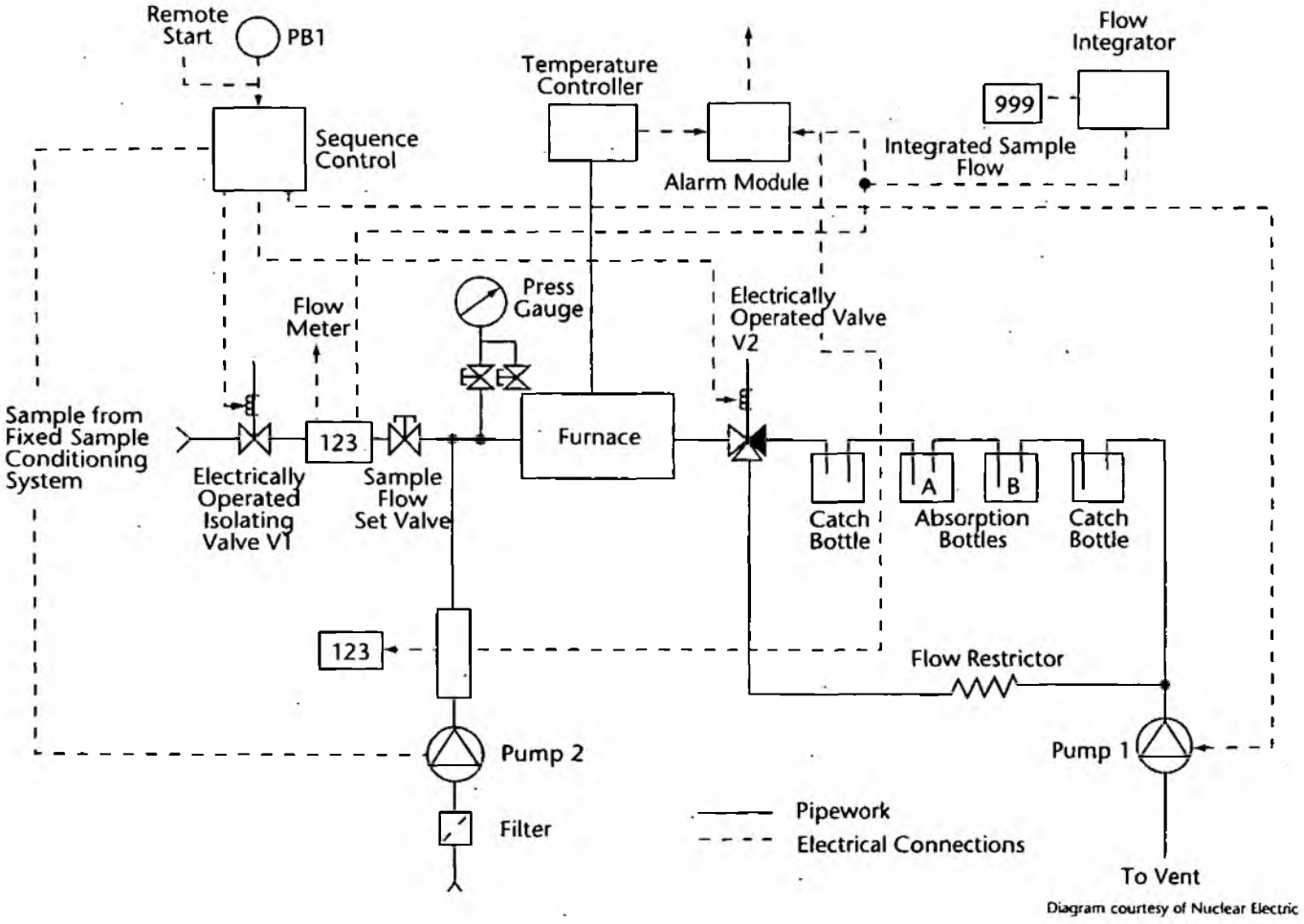

Diagram courtesy of Nuclear Electric

If a higher accuracy is required for ^{35}S it can be precipitated as the sulphate and the precipitate analysed by liquid scintillation counting.

Once the specific activity of the bubbler liquor has been determined, it should be decay-corrected to the date of emission. The activity emitted can be calculated from the specific activity of the bubbler sample, the volume of liquid in the H_2O_2 bubblers and the ratio of the volume emitted to the gas volume passed through the bubbler, both being corrected to standard temperature and pressure (stp).

Ion chambers are used to assess tritium emissions at some locations. The ion chamber provides gas concentration measurements that are integrated electronically to give the total quantity emitted.

6.3 Carbon-14 (nuclear power stations, reprocessing facilities)

The method of sampling ^{14}C in gaseous emissions is similar to that for ^{35}S and tritium; similar furnace and sample bottles (bubblers) are used. Carbon compounds are oxidised in the furnace to CO_2 and this can be absorbed in a known volume of a molar solution of sodium hydroxide (NaOH), potassium hydroxide (KOH) or barium hydroxide ($Ba(OH)_2$). The method is fully described elsewhere[7].

At nuclear power stations, ^{35}S, tritium and ^{14}C are usually emitted together and a single sampling system is generally used with a single train of bubblers to remove all the radionuclides. The train will ideally consist of a similar system to that described in Section 6.2 but with an additional bubbler absorption bottle, containing NaOH to absorb the CO_2, after the H_2O_2 bottle. A typical sampling schematic is shown in Figure 8.

Although the second H_2O_2 bottle collects tritium and ^{35}S, its most significant function is to protect the ^{14}C sample from carry-over of ^{35}S. Any such carry-over would have two effects that would render the ^{14}C measurement meaningless:

- Any ^{35}S in the NaOH solution will be counted erroneously by liquid scintillation as ^{14}C.
- As the first H_2O_2 bottle accumulates sulphur, the solution will become increasingly acidic. Any carry-over of acid will neutralise some NaOH solution, thereby invalidating any assessment based on saturation by CO_2.

Whereas the absorption of tritium and ^{35}S in H_2O_2 is very efficient (well in excess of 90%), the absorption of CO_2 in an alkaline solution is far less efficient, so it is not possible to measure the activity of ^{14}C in the NaOH solution and relate this directly to the volume of gas that has been passed through the sampling train. The techniques available to overcome this are discussed below.

6.3.1 Nuclear power stations

Samples of the bubbler liquor are analysed for ^{14}C by liquid scintillation counting with reference to a ^{14}C standard. Once the activity concentration of ^{14}C in the sample has been determined, the activity emitted is assessed according to whether the sample was taken from coolant or a coolant/air mixture.

6.3.1.1 Sampling ^{14}C in reactor coolant.

Where reactor coolant is being sampled for ^{14}C, then the NaOH absorbent will saturate with CO_2 and a stoichiometric formation of bicarbonate will result in a two-stage reaction, as shown below:

$$2NaOH + CO_2 \longrightarrow Na_2CO_3 + H_2O$$

then

$$Na_2CO_3 + CO_2 + H_2O \longrightarrow 2NaHCO_3$$

From these equations, 1 ml of a molar NaOH solution will absorb 0.001 mol of CO_2, which has a mass of 44 mg. The ^{14}C activity of the coolant gas emitted can then be calculated from the mass of coolant emitted and the ratio of the activity concentration of the sample to the above 44 mg of CO_2.

6.3.1.2 Sampling ^{14}C in other effluents

It is unlikely that stoichiometric absorption of CO_2 in the NaOH bubbler solution will be achieved in any practicable sampling time for other than high concentrations of CO_2. A proposal for the preparation of absorption curves for CO_2 in the NaOH bubbler solution from various coolant/air mixtures at the appropriate sampling rate is given in elsewhere[5]. If the concentration of CO_2 in the CO_2/effluent mixture is determined at the time of sampling, then the mass of CO_2 absorbed can be determined from the appropriate curve. This method is impracticable for routine use.

An alternative approach is to determine chemically the quantity of CO_2 absorbed in the NaOH solution. This can be carried out with alkalinity titrations using phenolphthalein and methyl red indicators (the method is sometimes referred to as 'P and M' titrations after the indicators). This approach will usually give more precise results than extrapolating between CO_2 absorption curves.

6.3.2 Fuel reprocessing facilities

A bubbler system is used, but with barium hydroxide ($Ba(OH)_2$) as the collection medium. This reacts in a similar way to NaOH and KOH:

$$Ba(OH)_2 + CO_2 \rightarrow BaCO_3 + H_2O$$

The precipitated barium carbonate is washed, dried and a portion is then mixed with water and scintillant and counted in a liquid scintillation counter against a blank sample of $BaCO_3$. The activity emitted can be calculated from the measured total activity in the bubbler and the mass of CO_2 emitted.

6.4 Particulate and iodine (most facilities)

As stated in Section 4, particulate samples are collected on an in-line filter paper, typically a Whatman Glass Fibre Absorber (GFA), which has a sampling efficiency of >99% for the most penetrating particles (i.e. 0.1 to 0.5 μm).

The filter housing usually includes a compartment for carbon in order to remove iodine and other volatile vapours. Schematics of typical units are shown in Figures 4 and 5.

If sampling for iodine, the carbon filter housing should be filled with the correct grade of carbon (18/52 mesh), which should be de-dusted prior to use. The container must be filled completely and the retaining grid installed to prevent displacement of the carbon during sampling, which could create gas flow bypass paths through the carbon. For the same reason it is important not to subject the filter to excess gas pressure.

In order to minimise bypassing of the carbon due to displacement, the filter housing should be installed vertically rather than horizontally.

The filter paper and carbon are usually changed every 24 hours. In most housings care is required to avoid damage to the filter paper either through incorrect mounting or as a result of excessive gas pressure resulting from maloperation of valves on the sample flow lines. The filter paper will effectively be bypassed if damaged.

After the particulate filter and carbon have been removed from the housing, the activity on the collection medium is assessed by different methods depending upon the nature of the radionuclides. The activity emitted can be calculated from this sample activity and the ratio of the mass or volume of effluent to the corresponding mass or volume of the sample.

6.4.1 Gamma-emitting radionuclides

These are usually assessed by direct counting of the filter paper, or carbon pack in the case of iodine, using gamma spectrometric methods. Each radionuclide emits characteristic gamma energies and a detector such as a calibrated germanium lithium detector and multichannel analyser is able to distinguish and assess the associated activity in the presence of other radionuclides. The instrument has to be calibrated using a standard source of mixed gamma energy.

In some cases scrubbers are used to sample the off-gases (this is particularly the case for ruthenium) and in this case a sample of the scrubber liquor is counted using gamma spectrometry in the same way as filter papers.

6.4.2 Beta-emitting radionuclides

As well as liquid scintillation counting, it is also the practice to assess the amounts of particulate beta activity by direct counting of filter papers. Beta emissions do not occur at discrete energies but over a continuous energy range up to a maximum energy. Consequently the usual measurement of beta activity is of gross beta activity rather than of discrete beta-emitting radionuclides. Two source preparation techniques are commonly used:

6.4.2.1 Thick source

The source presented to the detector is indistinguishable from one of infinite depth in terms of beta emissions. Thus above about 2 cm source depth even the highest energy beta particulate from the lowest layers are completely absorbed by the material above. Such sources are usually ashed or dried samples and are counted using a Geiger-Muller counter with a thin end window or a proportional counter.

6.4.2.2 Thin source

Here the source is a thin uniform layer of material finely spread over a planchet or possibly a filter paper. In this case there should be very little self-absorption although a self-absorption correction factor may sometimes be necessary. Similar counters to those used for thick sources are used for counting the sources.

6.4.3 Alpha-emitting radionuclides

The very short range over which alpha particles travel necessitates the distance between the source and the detector being minimised. For gross alpha counting, the filter paper is normally counted directly using a zinc sulphide detector or a thin-window proportional counter. When a sample is required to be analysed by alpha spectrometry, the filter paper is dissolved in an organic solvent and a thin source made by evaporating the solution on a planchet, in order to avoid a degradation of the alpha spectrum.

6.5 Krypton-85 (reprocessing plant, PWRs)

^{85}Kr is released in small quantities from PWRs and in much greater quantities from the fuel dissolution process in fuel reprocessing operations. Because ^{85}Kr is a noble gas it is difficult to remove it from the gas stream and direct measurement of the gas is usually practised. At the THORP reprocessing plant, gas is drawn from the effluent duct using an air ejector. The gas sample is passed through a measurement cell that is contained within a temperature-controlled furnace. The furnace is used to keep the sample at a constant temperature above ambient to prevent condensation in the ductwork.

Measurements of the sample cell and duct temperatures are taken so that ^{85}Kr concentrations determined in the sample cell can be transformed to an equivalent concentration in the effluent duct.

The ^{85}Kr gamma emissions are detected using a low-resolution sodium iodide detector, calibrated to monitor the activity in the process duct. Associated electronics are used to calculate the ^{85}Kr emission rate.

7 On-line instrumental measurement techniques

The main aim of on-line measurement is to provide immediate information on the concentration of radionuclides in the emission and to actuate the associated alarms in the event that pre-set levels are exceeded.

The beta/gamma or alpha activity in emissions or from collected samples can be determined directly with appropriate counters, using detectors such as Geiger-Muller tubes, proportional counters, scintillation or semiconductor detectors.

On-line measurement systems can use filters. The moving filter type are often better than the fixed filter type if the activity level is very high, or if the dust loading of the effluent stream is high. An advantage of the fixed filter type is that the filter can be removed at intervals and assessed in the laboratory to provide more detailed 'back-up' information. However, such a procedure does not usually replace the need for a sampler for the reasons discussed in Section 4. Specific nuclide measurement is possible either directly or on collected samples using an appropriate spectrometry system. These include a Ge(Li) semiconductor detector connected to a multichannel pulse-height analyser or a collection medium specific to the nuclide of concern, e.g. carbon for radioiodines.

Where specific nuclide measurement is used, account must be taken of the possibility of errors arising from concentration of other nuclides on the sample medium, for example, fission gases in air sampled for iodine. It is often desirable for the range, thresholds and measurement accuracy of the on-line instruments to meet the requirements for measurement under both Where specific nuclide measurement is used, account must be taken of the possibility of errors arising from concentration of other nuclides on the sample medium, for example fission gases normal and emergency conditions. Where the range of measurement to meet this requirement is not practicable, alternative systems will be needed to cover any identified measurement requirements in accident situations.

On-line measurement equipment should be equipped with warning devices with one or more alarm thresholds, which may need to be adjustable within the entire range of measurement. One threshold may be set at a value just above that which corresponds to the level of the activity released in normal operation. Any actuation of this threshold will indicate an abnormal operating situation that may require corrective action.

Further thresholds may provide alarms at pre-set levels to indicate greater emissions, which may relate to the maximum emission limit and require different corrective actions.

A threshold set below the expected background level should be provided. If the instrument registers below this threshold it should activate an alarm to alert the operators that it may be faulty.

8 Quality assurance

The methods used for monitoring emissions should be documented and linked to or be part of a Quality Assurance (QA) system. Such a system should be designed to assure and demonstrate the accuracy of monitoring results. QA systems should be auditable.

Some considerations specific to the monitoring of atmospheric emissions are as follows.

(a) *QA policy and management*. There should be a general policy statement, covering areas such as provision of quality manuals, appointment of suitably technically qualified staff for all stages of sampling and analysis, and training in the methods used. Documentation should describe all levels of relevant technical and management personnel, and set out lines of responsibility, including organisational charts.

(b) *System design*. Sampling and on-line instrumental measurement systems installed at nuclear facilities should fulfil the requirements of the relevant external standards and codes of practice[5,6]. These codes of practice contain requirements on the operator to ensure, amongst other things, that the equipment used is suitable for the purpose. This means that the equipment should enable a reasonably representative sample of the discharge to be obtained, analysis of the sample to be carried out by proven methods and the accuracy of the methods to be such that compliance with any limits set on individual radionuclides can be demonstrated.

(c) *Procedures*. Written procedures should be produced which state how quality-critical actions for all stages of sample collection, transport, analysis and equipment calibration should be performed. It should be noted that in the case of filter samples, particulate activity can be lost from the filter in the course of transport and that this can give rise to discrepancies.

(d) *Calibration*. The calibration of sampling and on-line instrumental measuring equipment and laboratory measurements should be performed on a regular basis using appropriate reference standards or secondary standards that have been calibrated against reference standards.

At some sites calibration of sampling equipment has revealed that the sampling efficiency of some systems is poor, principally due to problems of deposition/condensation within sample lines. In this case sampling efficiencies have been established for each sample position to allow suitable correction to be made to each result. These corrections are known as Sampling Efficiency Factors (SEFs).

Velocity and concentration profiling of stacks should be undertaken on commissioning and after any modifications to ducts and stacks that could have a potential effect on velocity profiles (e.g. provision of additional tappings or rerouting of ducts). In addition, *in situ* calibration of the overall stack sampling system should be undertaken at regular intervals. It may be appropriate for an operator to consider prioritising calibration frequency, taking into account the ducts or stacks being sampled and the equipment used.

Quality control charts can be used as a means of indicating a development of bias in the results (loss of accuracy) or in the deterioration of precision of analytical techniques.

(e) *Audits and checks*. Audits of the QA system should be carried out by suitable internal or external staff. Accreditation of certain activities may be appropriate; the UK Accreditation Service is the most important UK body responsible for the accreditation of specific laboratory analytical methods.

Independent checks by the operator will typically include the separate analysis of samples to provide assurance of the accuracy of operators' declarations on emissions and to ensure that systematic errors do not occur. This may involve inter-laboratory comparisons.

In addition to these checks, analysis results from the Agency's independent monitoring programme should be compared with the operators' measurements.

(f) *Records*. All relevant information should be recorded to provide an auditable trail from raw data to calculated emissions.

Where practicable, activity balance calculations should be carried out. Discrepancies between known losses and the measurements of emissions could indicate errors in monitoring methods, or could indicate the existence of fugitive emissions.

To ensure that results of the monitoring programme can be compared over time requires that there has been no unknown change in the errors arising in any stage of the monitoring programme, including instrument contamination, operator error, analytical errors, etc. To monitor these errors, requires the use of a continuous Quality Control programme. This is addressed in further detail elsewhere[4].

9 Key points for site inspection

The following are some of the main areas to which inspectors should pay attention in any monitoring programme designed to demonstrate compliance with site discharge authorisation limits, or for other aims and objectives. The list is not necessarily exhaustive.

(a) The sampling programme must be formulated in advance and in consultation with all of those who will be involved with its implementation.

(b) The programme should be described in documentation subsidiary to discharge authorisations and be subject to QA arrangements. In particular:

- The sampling arrangements and associated aspects should be incorporated into a management system, with clear lines of responsibility for the operation and maintenance of equipment.
- Those responsible for sampling should be fully aware of their responsibilities and have the necessary background to understand the requirements and limitations of sampling.
- The sampling programme should be described in appropriately detailed, written and auditable procedures.
- Instruments should be calibrated on a regular basis. They should be maintained and operated by trained personnel under appropriately controlled conditions.
- Documentation should be in use that clearly sets out the methods and data for the calculation of emissions. This should enable a check to be made on the calculational route from the raw data to the estimated emission.
- Analytical results should be recorded in sample analysis reports. Quality control charts should be maintained.
- The programme should make appropriate reference to UK and/or relevant overseas standards. There may be a need to refer out to quality systems operated by the other laboratories.

(c) The sampling programme must take account of the types of nuclides to be monitored (i.e. those in the discharge authorisation plus others that may provide relevant data), and their likely physical and chemical form (e.g. the presence of particulates) in the waste stream.

(d) The sampling programme should be designed to ensure that each sample taken is representative of the waste stream being discharged. This requires considerations of positioning of samplers and factors such as use of isokinetic sampling.

(e) The length of pipework between the probe and sample collection point should be short with few bends. If there are bends, they should be gradual to preclude deposition of particulate activity (see Section 5). Figure 2 illustrates the principle.

(f) There should be no bypass paths round the sample collector. In particular:

- The filter papers used for particulate collection are fragile and prone to damage. Filter paper sample holders should be examined for evidence of filter paper damage. The filter paper changing procedure should be straightforward to preclude filter paper damage and incorrect installation.
- Carbon granules can settle in an incorrectly designed iodine sample holder. Consequently they should be mounted vertically, not horizontally, to preclude bypass paths developing, where carbon settling is a possibility.

(g) Bubbler bottle sample trains used for sampling ^{35}S, tritium and ^{14}C should be as indicated in Section 6. Explanations should be sought for any departures from this arrangement.

(h) Furnaces are sometimes provided to oxidise effluent prior to bubbler collection and these should be operating at 1000 to 1100°C, with appropriate alarms if these temperatures are not attained.

(i) Flow meters to indicate sample flow should be operating with low-flow alarms. These can be checked by temporarily interrupting the flow.

(j) It is important that essential sampling equipment such as pumps, flow meters, etc., can be quickly replaced if faulty. Depending on the function of the sampling system and the importance of the emission route, this can either be by inbuilt standby equipment or by an adequate supply of spares.

(k) Connections, particularly flexible connections, should be leak-tight. Particular attention should be paid to flexible plastic tube connections to bubbler bottles and hoses to particulate samplers.

(l) Bubbler bottles should have the requisite amount of liquid at the correct molar concentration of caustic, etc., and be operational.

(m) Operating and sample changing instructions should be provided adjacent to the sampler, preferably in the cabinets housing the samplers. Where necessary, cabinets should be locked when sampling systems are unattended, to prevent tampering.

(n) Periodic visits should be made to the analytical laboratory to check on the equipment used for counting and the tabulation of data. Most counting is now automatic and a demonstration of methods used is the best way of checking on counting procedures.

(o) Appropriate samples should be provided for analysis as part of the Agency's independent monitoring programme. This arrangement should be in use and the results obtained compared with the operator's data and any discrepancies investigated.

(p) A waste stream monitoring programme furnishes an extensive range of data that must be used to its fullest extent. Areas to which attention should be paid are as follows:

- Monitoring results should be kept in good order and be easily retrievable in a user-friendly (usually computer-compatible) form.
- Monitoring results should be being used to optimise the operation of the plant where waste is produced and associated abatement plant. In particular, the results should be being used to minimise waste arisings and maximise waste stream decontamination.
- The results of the monitoring programme should be made available to all interested parties. For example, it may be appropriate to use the results to optimise the design of future plant.

10 References

1. Monitoring of Radioactive Releases to Water from Nuclear Facilities. *Technical Guidance Note (Monitoring). M12.* 1999. ISBN 0 11 310135 X. Published by the Stationery Office.

2. Abatement of Atmospheric Radioactive Releases from Nuclear Facilities. *Technical Guidance Note (Abatement). A5.* 1998. ISBN 0 11 310134 1. Published by the Stationery Office.

3. Abatement of Radioactive Releases to Water from Nuclear Facilities. *Technical Guidance Note (Abatement). A6.* 1999. ISBN 0 11 310132 5. Published by the Stationery Office.

4. Preparation and Assay of Samples of Radioactive Liquids and Gaseous Effluents. *Technical Guidance Note (Monitoring).* Environment Agency. Document in preparation.

5. Sampling and Monitoring of Airborne Radioactive Discharges. *Atomic Energy Code of Practice 1072.* May 1989.

6. General Principles for Sampling Airborne Radioactive Materials. BS 5243: 1975

7. Doyle AR and Hammond K (1980). *The Estimation of Tritium, Sulphur-35 and Carbon-14 in Reactor Coolant Gas and Gaseous Effluents.* IAEA-SM 245133. International Atomic Energy Agency, Vienna.

Appendix 1 Glossary of terms

Abatement plant	Any plant used to trap or hold up radioactive material from a discharge path from a nuclear facility to the environment. The aim is to concentrate active material into a small volume, before allowing the decontaminated gas to be released.
Accuracy	A measure of the extent to which a specific measurement (e.g. of activity) approaches the true value in the sample.
Activation	Neutron activation (neutron capture) of stable elements inside a nuclear reactor to produce radioisotopes. The most radiologically important is cobalt-60.
Carbon pack (Maypack)	Proprietary filter pack employing carbon granules in conjunction with a particulate filter to arrest particulate and volatile materials in aerial emissions.
Concentration profile	Depending on the context, this can refer to the concentration distribution pattern across the duct or pipe of radioactive materials during operation of the system, or of a tracer material introduced into the system for testing purposes.
Glass fibre filter paper	(Normally) a circular high-efficiency filter made of random glass fibres, which when placed in an appropriate sample holder is used to trap particulate material.
Isokinetic sampling	The condition where the sample velocity, at the point of sampling, is the same as that of the fluid being sampled, thereby ensuring that the sample is representative of the fluid containing particulate matter.
Precision	A measure of the extent to which a specific parameter can be measured reproducibly.
Sampling probe	Device used to extract a sample of effluent from the extract duct/pipe.
Scintillation detector	Type of detector that relies on production of light in certain materials when irradiated by alpha, beta or gamma radiation. Both solid-state scintillators (e.g. NaI(Tl)) and liquid scintillators are used.
Shield cooling air	On Magnox reactors it is necessary to keep the inner face of the concrete biological shield cool. This is done by continuously passing a stream of cooling air through the interspace between the inner face of the biological shield and the reactor pressure vessel.
Spectrometry	Use of radiation detector and associated electronic systems to separate alpha, beta or gamma radiation with different energies from a sample and thus allow measurement of the different types of nuclides present.
Stoichiometric	Describes a chemical reaction in which the reactants combine in the exact proportions to their molecular weights.
Volatile	A substance readily vaporised or sublimed at relatively low temperatures.
Zeolite	An alternative absorption medium for vapours, notably iodine. It is a crystalline aluminosilicate material, also known as a molecular sieve because of the small size of the porous cavities through which the gas molecules can pass selectively.

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www.environment-agency.wales.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

WALES
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