

# **Environmental and Discharge Radioactivity Monitoring in the European Union**

## **Overview of Current Methodologies and Technical Guidance for Improved Implementation of the Article 35 of the Euratom Treaty**

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Annex A      Methodology, applicable standards and recommended best practices for environmental monitoring programmes

Annex B      Methodology, applicable standards and recommended best practices for discharge monitoring programmes

## Foreword *[to be completed]*

Article 35 of the Euratom Treaty requires that each Member State shall establish the facilities necessary to carry out continuous monitoring of the levels of radioactivity in air, water and soil and to ensure compliance with the Basic Safety Standards.

European Commission carries out a programme under Euratom Treaty Article 35 to verify the efficiency of operation of Member States' facilities necessary to carry out continuous monitoring of the level of radioactivity in the air, water and soil and to ensure compliance with the basic radiation safety standards.

This guidance describes the current technical arrangements used in monitoring both environmental radioactivity and radioactive discharges, including guidance on relevant standards and best practice methodologies.

Article 35 verifications can be carried out on a large variety of targets, ranging from complete national monitoring programmes to individual monitoring devices in facilities using radioactive substances. This guidance document is not meant to be exhaustive, but it aims to cover the common methodologies used in monitoring environmental radioactivity and radioactive discharges. The technical parts of the guidance are based on the Commission study "*Overview of National Radioactive Discharge and Environmental Monitoring Requirements in the European Union in Furtherance of Article 35 of the Euratom Treaty*<sup>1</sup>".

Unit ENER D3, Radiation protection and nuclear safety, is responsible for updating this document in line with technical and legal developments.

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Head of Unit ENER D.3

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<sup>1</sup> G.J.Hunt, K.S.Leonard, B.D.Smith, D.J.Swift, C.A.Smedley and S.Newstead (Newstead Consulting Ltd.), *Overview of National Radioactive Discharge and Environmental Monitoring Requirements in the European Union in Furtherance of Article 35 of the Euratom Treaty*, The Centre for Environment, Fisheries & Aquaculture Science, Lowestoft Laboratory, Pakefield Road, Lowestoft, NR33 0HT, UK. Under contract to the European Commission, Contract No. TREN/06/NUCL/S07.58756 (CEFAS), Cefas contract No. C2380.



# 1 INTRODUCTION

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Article 35 of the Euratom Treaty stipulates that *“Each Member State shall establish the facilities necessary to carry out continuous monitoring of the level of radioactivity in the air, water and soil and to ensure compliance with the basic standards. The Commission shall have the right of access to such facilities; it may verify their operation and efficiency.”* The Commission therefore carries out a verification programme in Member States (MSs) of the European Union under Article 35. The primary objectives of these verifications are to establish the effectiveness of all facilities installed for the measurement of environmental radioactivity and of radioactive discharges and the adequacy of the environmental monitoring programmes carried out by both the operator(s) and the authority(ies) in each MS.

## ***[General intro text to be added]***

Section 2 provides an overview of the status of regulatory provisions and their use for implementing Article 35 over the range of industries and the means by which these provisions are enforced. Comments are made on variations in practices, comparing and contrasting different requirements, and presenting views on best practice where relevant.

Section 3 presents a synthesis of the range of sampling and monitoring devices and methods used in environmental surveillance, comparing and contrasting a range of relevant technical and administrative factors, highlighting best practice and any sub-standard provisions.

Section 4 presents a synthesis for the measurement of radionuclides in discharges, both in airborne and in liquid form. Again, a range of relevant technical and administrative factors is compared and contrasted with comments on best practice and provisions which may be sub-standard.

Section 5 addresses general verification issues typical for both environmental and discharge monitoring.

Section 6 of this document outlines the conduct of Article 35 verifications by the Commission and makes recommendations on the practical arrangements, timing and selection of verification targets.

Two technical guidance documents are introduced in section 7 and presented in Annexes A and B. These introduce the methodology, applicable standards and recommended best practices for environmental surveillance (Annex A) and discharge monitoring (Annex B). Annexes A and B have been drafted as stand-alone documents for separate use if required.

## **2 NATIONAL REGULATORY FRAMEWORK**

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### **2.1 Regulatory provisions**

All EU Member States have regulations in place consistent with the EURATOM BSS Directive (EC, 1996 and EC, 2013) and for the purpose of implementing Article 35. In some MSs, provisions have been recently enacted or upgraded to ensure compliance. This includes MSs with no nuclear power programmes. The following sections examine particular aspects of regulatory provisions.

### **2.2 Discharge authorisations**

Authorisations according to the BSS Directive for releases of radionuclides to the environment are in place for the major industries involved. However in some cases for the mining and NORM industries the authorisation status may need to be confirmed. Which practices this may apply to in a given MS would need to be established at the time of the Article 35 verification.

There are differences in application of the principle of optimisation to reduce discharges. Optimisation is an important feature of the dose limitation process recommended by the ICRP. Best practice for the authorisation process and on-going operation is to include the role of optimisation within the envelope set by authorised limits.

### **2.3 Discharge limits in force**

There are four main ways in which discharge limits are expressed in regulations by MSs. The first, most common, is where the limits are the rates of individual or grouped radionuclides released, e.g. TBq/y. The second is where the limits are expressed in terms of concentration, e.g. Bq/m<sup>3</sup>. The third method is to express the limit in terms of dose to the critical group or representative person. The fourth method is to use a formula for limitation which allows for the radiological significance of different radionuclides. Thus there is significant diversity in expression of discharge limits.

There can be a disparity in the expected level of discharges compared to authorised limits, i.e. the allowable “headroom”. If limits are set directly on the basis of dose criteria of the BSS, this can produce a very generous authorisation. Authorisations need to take into account the principles of justification and optimisation in identifying demonstrable need to make releases.

Discharge limits need to be reviewed periodically to ensure they are still relevant in the light of changing operational needs but also in view of changing radiological circumstances, e.g. critical groups, exposure pathways and peoples habits. Such reviews should take place over the timescale during which such changes may be expected to happen, probably about 5 years for most sites, according to radiological significance. This is an essential part of active, rather than passive, management. It is not clear that such reviews happen in all MSs.

### **2.4 Reporting obligations**

There are some wide variations in the reporting of discharges and environmental monitoring expected of operators by the regulatory bodies, both in amount and frequency. Requirements vary from no reporting at all, through daily monitoring, to continuous on-line

reporting of some parameters at nuclear facilities, as well as special reporting of exceeding a notification level. The required reporting is usually specified in the site authorisations, and tends to be site-specific. Best practice is to involve, for all facilities, a need to report potential breaches of authorisation or exceeding a notification level rapidly, e.g. within 24 hours, with ongoing discharge levels and environmental concentrations being reported monthly or quarterly, depending on radiological significance. All nuclides specified in the authorisation should be reported, plus any others detailed in the authorisation documentation. This should also apply to component discharge streams where specified in the authorisation. An annual summary should be produced, suitable for publication.

Availability of data to the public is a matter, which should be discussed during each verification. There are large variations between MSs – some MS produce a national report on the radiological status of the environment on annual basis and may also issue site-specific reports on monitoring results whereas some MS make data available only when specifically requested either by individual citizens or by environmental organisations. Similarly, some MS make the dose rate data from automatic monitoring networks available on-line, whereas others do not.

Regardless of the national policy for making data available to the public, each MS has an obligation to report the results of the environmental monitoring to the European Commission under Article 36 of the Euratom Treaty. It is indeed possible, although undesirable, that the only way a private citizen can have information about the radiation status in his/her own country is to consult the Commission, either via Article 36 reports or the EURDEP website for on-line data.

## **2.5 Environmental surveillance**

There is a generally harmonised view amongst MSs that it is mainly the nuclear fuel cycle establishments (including those with research reactors) which need to have environmental surveillance programmes as part of regulatory provisions. The radiological implications of other sites are almost universally adjudged to be small enough to be estimated, if necessary, by modelling calculations based on discharges rather than environmental monitoring. This observation includes the non-nuclear MSs, where no regulatory programmes are specified. There are a very few exceptions to this observation in connection with NORM industries (including mines) and larger medical facilities. The regulatory provisions for surveillance are usually expressed through individual site authorisations, where they are amenable to adjustment in the light of changes in discharges and radiological factors such as changing critical groups. Whether the assumption about radiological significance remains true for non-nuclear establishments needs to be kept under review, and flexibility maintained to specify surveillance near a given site if doses to the critical group become significant.

There is significant diversity in the range and amounts and frequencies of environmental surveillance for given industry sectors specified as part of regulatory provisions. Programmes range from very little surveillance other than continuous external dose rate monitoring, through fairly limited programmes involving external dose rates, air, water and soil, to more intensive programmes also involving milk, foodstuffs and other indicators. Surveillance carried out by the regulators also varies, again from very little to substantial, even duplicative, programmes. The “polluter pays” principle implies that the operator should carry out the bulk of the environmental surveillance, with the regulator carrying out a smaller, but effective, check programme covering the essential pathways and thereby verifying the operator’s results as they may apply in more detailed areas.



## **2.6 Discharge monitoring**

The majority of MSs have regulatory provisions for monitoring of radioactive discharges from all except the smallest waste-producing sectors, not just those of the nuclear industry. A minority of MSs require monitoring of discharges only from their nuclear establishments, and a few non-nuclear MSs do not have regulatory provision for monitoring of discharges. Where there is no discharge monitoring, as for some small laboratories and hospitals, any necessary quantification of discharges required to demonstrate compliance with authorisations is carried out by stock and usage assessments. The regulatory provisions for monitoring discharges are usually expressed in individual site authorisations, though in a few MSs there is a standardised ordinance and/or regulatory guide in which the requirements are specified.

Compared with environmental surveillance, for a given industry group there is less diversity in the discharge monitoring carried out, with release points being monitored for relevant radionuclides. However the extent of check monitoring by regulatory bodies does vary: in some cases there is no regulators' programme; in others either liquid wastes or gaseous wastes are omitted; in other cases there is much duplication.

Best regulatory practice for discharge monitoring would be for the authorising body to specify a monitoring programme in which all discharge streams are sampled and analysed (or directly monitored) to provide quantification of the releases to the environment. This programme should be set out as part of the authorisation, or in other ways. Substandard practice is to rely on assessments of source usage, though for very small users this may be acceptable. In addition to the operator's programme, a smaller check programme should be carried out by the regulator. This check programme should involve witnessing of sampling if samples of effluents are taken by the operator.

It is noted that on 18 December 2003 the European Commission recommended standardised information on reporting of radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation (2004/2/EURATOM).

## **2.7 Obligatory technical requirements**

A few MSs have regulatory guides which are part of the statutory provisions, and these also specify relevant technical requirements. Best practice would seem to be for all technical requirements to be spelt out transparently for the operators and all stakeholders. This can be achieved either through a comprehensive set of authorisation documents for a given site or a combination of site-specific documents with an authoritative regulatory guide.

## **2.8 Enforcement**

The provision for enforcement varies amongst MSs from a low level at some small, non-nuclear countries, to more elaborate systems in MSs with nuclear programmes. A minimum requirement would start from the principle that the regulatory body that grants authorisations according to Directive 96/29 EURATOM for disposals of radioactive wastes should be clearly independent of any body representing the interests of that industry, with powers to, and capable of, enforcing the conditions laid down in the authorisations. In most MSs the regulatory bodies include inspectors who are empowered to enforce the conditions laid down in the site authorisations. This represents best practice, but what is also important is the extent to which inspectors are used to oversee the conditions of authorisation. In

some MSs regulatory bodies merely examine reports from operators. However to enable effective regulation including early awareness of potential problem areas, more active liaison is needed, albeit at a lower frequency for minor users. Inspector effort should reflect the radiological importance of the facility. In some MSs there are inspectors on permanent attachment to particularly important facilities. Examples of the areas of work that inspectors should carry out as part of their overall duty to enforce compliance with authorisations include:

- Invigilating site operations which affect discharges to the environment
- Invigilating optimisation of operations to reduce discharges
- Invigilating monitoring of discharges by the operator
- Invigilating monitoring of the environment by the operator
- Checking of reports produced by the operator
- Organising independent check monitoring and analysis of discharges and samples (includes witnessed sampling)
- Organising independent check monitoring and analysis of the environment and samples (includes witnessed sampling)
- Investigating discrepancies in operator data
- Investigating discrepancies between operator data and independent check monitoring data for discharges and the environment
- Investigating breaches or suspected breaches of notification levels or authorisations themselves
- Undertaking unannounced inspection visits

To carry out these duties, inspectors need to have powers delegated to them (or able to set in train the powers of the authorising body) to be able to enforce specific actions or to prohibit specific operations, as well as to be able to take appropriate legal action if needed.

Some MSs' authorising bodies use, or have used in the past, contractors to carry out inspection activities. Whilst this practice may provide a satisfactory outcome, it requires considerable caution to ensure that the contractor continues to act in the interests of the authorising body and has no other function which may lead to a suspicion (e.g. by a member of the public) of dual allegiance, leading to loss of credibility.

## **2.9 Independent oversight**

This term, "independent oversight" is understood by MSs as the mechanism for invigilation of operators' activities, as carried out by the authorising body. This type of oversight is essentially covered by the previous section on enforcement. However the word "independent" may also be understood as separate both from operators and government, and would apply if a third body were providing oversight. This body may represent other stakeholders, such as the public living near a particular facility. Some facilities in a few MSs have local stakeholder groups, or "Local Liaison Committees" to provide a channel of communication with those affected by operation of site facilities. Such groups may receive or hear reports from site operators and/or authorising bodies and form their own views on adequacy of control measures. It can also advise on the practicality of local plans in case of a site emergency. Best practice for all major facilities, especially those with nuclear operations,

would be to have some degree of stakeholder involvement, meeting perhaps twice a year, to be apprised of site developments and to allow feedback.

## **3 TECHNICAL PROVISIONS FOR ENVIRONMENTAL MONITORING**

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### **3.1 Introduction**

The information on environmental monitoring provided is summarised in common format in the accompanying tables of data to Annex A. The range of types of monitoring reported by MSs is covered in this section and follows the listing in Annex A, Table C 1.

### **3.2 Sampling and monitoring methodology**

#### **3.2.1 Gamma dose rate monitoring**

Each of the following types of gamma dose rate monitoring may represent best practice in the circumstances mentioned, depending on the objectives.

The basic instrument used across all industrial sectors in view of its low cost is the energy-compensated Geiger-Mueller (GM) counter or the more sensitive but less common NaI-scintillator which exist in a number of manufacturer's types. These are used where portable instruments are called for, e.g. at unsecure and varying locations. Readings are spot readings taken usually at 1m height over, say, 5 minutes and usually repeated close by to ensure representativity and to eliminate errors. Instruments require regular calibration (e.g. annually) against relevant standards; Cs-137 is usually used if the instrument is to be used to measure dose rates from man-made radionuclides including fission products or Ra-226 if the enhanced radiation is of natural origin. Appropriate facilities are needed for calibration and in many cases instruments are dispatched to a central laboratory with the necessary calibration sources which should be traceable to national standards. It is also possible to use high-pressure ionisation chambers to measure ambient gamma dose rate. These are capable of good accuracy but are generally in fixed locations and rather large for portable use.

For integrated dose measurements over time at secure locations, usually around nuclear facilities, arrays of thermoluminescent dosimeters (TLDs) are in use though these are in many cases being replaced by on-line GM counters (see below). TLDs are normally collected quarterly and read using TLD readers, providing an integrated dose. They can be collected and read during an emergency, though the results will be delayed compared to the on-line method. TLDs need to be calibrated using appropriate standards as above, and laboratory facilities need to be more elaborate with TLD reading machines.

Dose rate readings over short timescales (e.g. minutes) can be obtained from an array of multiple, networked GM or scintillation counters which are now provided around many nuclear facilities as well as for national monitoring purposes. These counters can be set to alarm at given dose rate levels set appropriately to allow for ambient background levels depending on local geology. Instruments need checking and recalibrating on the same timescale as the portable instruments, and appropriate laboratory facilities are needed to ensure uniform performance.

### **3.2.2 Airborne particulate sampling**

#### **(a) Medium or high volume air sampling**

These samplers consist of an appropriate airborne dust filter through which air is drawn by a motor and air pump; good sampling rates (medium volume  $\sim 10 \text{ m}^3/\text{h}$ ; high volume  $>100 \text{ m}^3/\text{h}$ ) are needed to collect sufficient airborne radioactivity for counting, and decay time is usually allowed following removal and prior to counting for radon daughters to be eliminated. The result is an integrated concentration over time, usually 1-2 weeks. Filters are analysed for alpha, beta or gamma emitters in a suitable laboratory. Gamma emitters are usually measured non-destructively using gamma spectrometry. Alpha emitters are measured non-destructively by use of a ZnS screen and scintillator or semiconductor surface barrier detector. Beta emitters may be measured with a plastic scintillator. Alternatively, better measures of alpha and beta activity may be obtained destructively using radiochemical analysis, however this is more labour-intensive and time-consuming. The sampling rate needs measurement with a flow meter and allowance should be made for the fall in sampling rate with filter loading. Some samplers are self-compensating for this.

#### **(b) Passive cloth collectors**

These collectors are pieces of cloth (sometimes impregnated with a sticky resin) mounted on a suitable frame and suspended at locations around a facility to pick up airborne contamination. They are removed after a period (2-4 weeks) and analysed. These collectors have the advantage that no power supplies are needed and are of very low cost, but they are only indicative of contamination and do not provide measurements in  $\text{Bq}/\text{m}^3$ . The main use would be to trigger more quantitative monitoring. They would not generally represent “best practice” except as a low-cost indicator.

### **3.2.3 Airborne iodine sampling**

In order to sample airborne iodine ( $\text{I-131}$ ) in emergency situations the air samplers can in most cases be fitted with activated carbon filters, which accumulate iodine from the airflow. Iodine is not present in normal circumstances, so the cartridges are used only if a reactor accident has taken place and there is a possibility of a release of radioactive iodine.

### **3.2.4 Deposition collectors**

These consist of a large tray or funnel of known area which drains into a tank or bottle; the liquid is removed at intervals (up to a month) and analysed for alpha, beta or gamma emitters. These collectors are not especially site-specific, being more of use for fallout and activity of distant origin.

### **3.2.5 Grass/herbage**

This monitoring may be used as an indicator of contamination which may be of potential concern for e.g. food pathways. Samples of grass from an undisturbed location are cut over a measured area (or number of areas from a wider plot) and analysed for radionuclides. Consistency is needed (i.e. an agreed protocol) on the depth of grass and elimination of soil.

### **3.2.6 Soil**

Soil is a useful indicator of contamination which may be of concern in food pathways. Samples are taken over a measured undisturbed area or areas down to a measured depth (usually 2-5 cm). Cores may be taken to greater depth using a coring device if the radioactivity distribution with depth is needed. Consistency is needed on root removal,

removal of stones and homogenising. Samples are analysed for alpha, beta and gamma-emitting radionuclides.

### **3.2.7 Milk and dairy products**

Milk and dairy product monitoring is an important direct measure of a potential radiological exposure pathway. Representative samples are collected from a farm in the locality of the facility (or from a supplier if the sampling is over a wider area, or part of national monitoring) and analysed for radionuclides in an appropriate laboratory.

### **3.2.8 Cereals**

Again, this is an important direct measure of a potential radiological exposure pathway. Relevant cereals are sampled representatively from the locality of the facility, or over a wider area for national monitoring, and submitted to an appropriate laboratory for analysis for radionuclides.

### **3.2.9 Meat and meat products**

These are sampled where they can form an important part of the diet and are produced locally. Sampling, including of the appropriate parts of animals, should be representative of what is actually eaten. Samples are transported to an appropriate laboratory for analysis for radionuclides. As for all food analyses, preparation should be the same as used for eating, discarding the non-edible fraction.

### **3.2.10 Eggs, honey, game, wild berries and mushrooms**

These can be important foods in the vicinity of a facility and are often sampled where they form part of the local diet. Again the emphasis is on representative sampling, e.g. for the appropriate edible parts of the relevant foods.

### **3.2.11 Fruit and vegetables**

These are also representatively sampled where relevant and sent to a laboratory for radionuclide analysis. Peel and outer, non-edible parts are discarded.

### **3.2.12 Wildlife**

This category represents animals not usually eaten; edible animals are included in section 4.2.9. The main principle would be to sample representatively of wildlife in the relevant locality.

### **3.2.13 In-situ gamma spectrometry**

In-situ gamma spectrometry can be used as an addition to portable monitoring of gamma dose rates, and the results are spot measurements. The advantage is to obtain a spectrum of the effects of the whole range of gamma emitters of local importance mainly from deposited activity, though detectors are sensitive to airborne discharges and direct gamma radiation from facilities. The detectors are usually of the Ge type to obtain the best resolution but NaI(Tl) scintillators may also be used, connected to a pulse-height analyser with appropriate software to convert measured spectra into activity ( $\text{Bq/m}^2$ ) or dose rate. Instruments require calibration against mixed nuclide sources, and this is carried out in an appropriate laboratory. Measurements are conventionally made at 1 m height and the ground needs to be level for the calibration to be correct.

### **3.2.14 Surface water**

Surface water is often monitored to check the effect of local liquid discharges; it can be a source of drinking water and therefore of dose to the local population, or be an important indicator of the releases. Spot samples may be made into suitable containers or continuous samples taken using appropriate samplers. Tracers or preservatives to prevent algal growth may be added prior to transport to a suitable laboratory for analysis for alpha, beta or gamma-emitting radionuclides. Samples may be filtered prior to analysis to obtain the solid fraction.

### **3.2.15 Ground water**

This refers to water within the ground and is sampled from a borehole often drilled for the purpose. Sampling is usually of a spot amount into a suitable bottle or container, and then treated as in section 4.2.14 prior to transport to the laboratory.

### **3.2.16 Drinking water**

This represents sampling of a direct radiation exposure pathway. There is a specific European Directive on monitoring radioactivity in drinking water (EC, 2013). Sampling is from a water supply used for drinking by the public, into suitable bottles and treated as in section 4.2.14 prior to transport to a laboratory.

### **3.2.17 Freshwater sediment**

This can be a source of exposure to people near river banks or lakes from external irradiation and/or inhalation of resuspended material. In addition, sediments can be indicative of contamination of importance. Samples should be of the surface (up to 1 cm) and taken from a range of locations over a radius of e.g. 5 m to ensure representativity. Cores may be taken if the distribution of radioactivity with depth is needed. Samples are transported to a laboratory for radionuclide analysis. A protocol is needed to ensure consistency over removal of gravel or stones.

### **3.2.18 Leachate**

This is essentially water seeping from ground which is potentially contaminated or in which wastes may be present. It can be a source of contamination of the water supply and is indicative of the activity present in the ground becoming remobilised. Samples may be taken directly or from boreholes in appropriate containers and may be treated as in section 4.2.14 prior to transport to a suitable laboratory for analysis.

### **3.2.19 Sewage and sludges**

Monitoring of these materials is used as an indicator of contamination which may be present as part of low-active waste disposal under authorisation, or contaminated by a non-authorised release. Sampling of the liquid fraction would be as for waters and sampling of sludges would be as for sediments. Appropriate homogenisation is needed.

### **3.2.20 Road drain sediment**

This is used as a convenient indicator of contamination on roadways usually from atmospheric deposition. Sediments are removed from drain settlement pots or chambers into suitable containers and transported to a laboratory for radionuclide analysis.

### **3.2.21 Waste water**

This is used as an indicator of contamination in streams of industrial effluent which are normally classed as non-radioactive. Sampling is as for other waters with transport to a suitable laboratory for analysis.

### **3.2.22 Freshwater fish/shellfish**

These organisms may be eaten, in which case they would be a direct representation of a public exposure pathway, or they can act as useful indicators of radioactivity present in the freshwater environment, as they may concentrate particular radionuclides. Samples are taken by normal fishing methods or by electrofishing, and transported to the laboratory for preparation, storage by freezing and subsequent analysis using suitable techniques.

### **3.2.23 Freshwater plants**

These too may be eaten or can act as useful indicators of radioactivity present, having the advantage of integrating over time in a fixed location. Sampling should be of recent growth and into suitable containers prior to transport to the laboratory for analysis.

### **3.2.24 Estuary/coastal dose rate monitoring**

This usually takes the form of gamma dose rate monitoring using portable instruments as described in section 4.2.1 as the measurement locations tend to be non-secure, but fixed detectors are possible. Monitoring can also take place using in-situ gamma spectrometry (section 4.2.13). The methodology is the same as in these sections.

### **3.2.25 Contamination monitoring: fishing gear, etc.**

Fishermen and those working in the marine/aquatic environment can receive dose to hands and other parts of the body due mainly to beta-emitters adsorbed on sediments which become entrained in fishing gear. This is monitored using a wide range of available contamination monitors, usually based on thin-window gas proportional counters. Monitoring needs to follow an established protocol to ensure consistency. Appropriate facilities are needed for calibration in terms of contamination by the appropriate radionuclides and in many cases instruments are dispatched to a central laboratory with the necessary calibration sources which should be traceable to national standards.

### **3.2.26 Estuary/coastal contamination monitoring: small particles**

Particles of contamination may have been released to the marine environment or may have accumulated on objects or organisms; they may become released and deposited on beaches or other substrates where they can present a hazard to the public. Monitoring takes place to locate such particles, which usually contain alpha and/or beta emitters. Monitoring devices can be deployed on moving vehicles if the substrate is amenable, or hand-held instruments are used. Detectors are usually based on thin window gas proportional counters or scintillation counters. Alpha contamination is most usually detected by its association with beta emitters. Once located, particles are removed and transported to a suitable laboratory for further characterisation and analysis. A wide range of laboratory facilities is needed to carry out the necessary identification.

### **3.2.27 Sea water**

Monitoring of sea water is used as an indicator of radioactivity present from releases of radioactivity to the marine environment. In itself it represents only a minor pathway for

direct exposure of the public through swimming, boating, inhalation, etc. It is usually more effective as a measure of dispersion/dilution of radioactivity for use in dose assessment models. Samples are taken of sea water from the surface or at different depths using suitable sampling equipment, and transported to a suitable laboratory for analysis. With appropriate research vessel capabilities some analyses may be carried out whilst on board ship.

### **3.2.28 Estuarine/coastal sediments**

This can be a source of direct exposure to people on estuarine coasts or beaches from external irradiation or inhalation of resuspended material. In addition, sediments can be indicative of contamination of importance. Samples should be of the surface (up to 1 cm) and taken from a range of locations over a radius of e.g. 5 m to ensure representativity. Cores may be taken if the distribution of radioactivity with depth is needed. Samples are transported to a laboratory for radionuclide analysis. A protocol is needed to ensure consistency over removal of gravel or stones.

### **3.2.29 Seaweed**

Some seaweeds may be eaten giving a direct exposure pathway; alternatively, seaweeds may be good indicators of particular radionuclides. Care may be needed in selection of appropriate and consistent species. Samples should be taken from new growth. Consistency is needed in sampling and processing prior to analysis for radionuclides at a suitable laboratory.

### **3.2.30 Sea fish**

Fish are usually monitored as a direct food consumption pathway. The species needs to be selected appropriately, and the sizes need to be typical of what are regularly caught and eaten. It may be best practice to sample from a commercial supplier provided one can be sure of the location of catches. A number of fish should be taken to provide a statistically representative sample. Preparation should be done to replicate the practices of consumers and the sample homogenised prior to analysis for radionuclides.

### **3.2.31 Sea fish meal**

Fish meal is the product of industrial fishing or recycling of fish offal and provides a food source for pigs, poultry and farmed fish. Hence it represents an indirect pathway for public radiation exposure, and sampling is also done for indicator purposes. Samples need to be sourced appropriately prior to homogenisation and analysis at a suitable laboratory.

### **3.2.32 Sea shellfish (crustaceans, molluscs)**

Generally, the same principles apply as for fish, with the advantage that shellfish tend to be more sedentary and location-specific, and usually having greater uptake factors for non-soluble radionuclides. Preparation methods (as for fish, following the practices of consumers) need to be set down clearly to enable consistency.

## **3.3 Monitored radionuclides**

For the reprocessing plants in the EU, comprehensive environmental monitoring programmes are carried out as may be expected, and the radionuclides monitored reflect their radiological importance and the rates of discharge (in TBq/y). Radionuclides tend to be analysed specifically, without undue reliance on gross measurements of alpha or beta



activity to cover for them. Transuranic nuclides feature widely in the monitoring near these establishments, again reflecting the potential for discharges and doses received.

For the uranium facilities (mining/milling; enrichment; and fuel fabrication), the extent of monitoring, especially of mines (including those decommissioned and being decommissioned) is variable across the EU, and it is possible that some facilities may not be subject to adequate monitoring. However where monitoring is done, it is generally for appropriate radionuclides (uranium, radium and daughters; thorium and daughters; technetium-99 in the case of reactor-recycled U). Sometimes the monitoring is supplemented by gross alpha and beta monitoring.

In the case of nuclear power stations, the radionuclides discharged are a function of reactor type. Thus it is difficult to compare all nuclear power stations together. Even for a given reactor type, with the PWR being most common, there are variations in philosophy. Some countries put greater emphasis on the use of gross alpha and/or gross beta monitoring. This is satisfactory provided that (i) there are resources available to deal with any queries should a high gross measurement need further investigation and (ii) the laboratory is aware that the gross measurements are very sensitive to the operator's competence and that the results may change dramatically with the change of the overall relation between different radionuclides. Broadly however the radionuclides selected for monitoring reflect the expected discharges.

Large research establishments, by definition, have a wide variety of activities which generate different radionuclides in discharges. Broadly the monitoring carried out reflects the radionuclides mentioned in the authorisations. The issue is slightly different in the case of research establishments, in that the monitoring programme needs to be flexible enough to cope with changing research priorities.

Industrial processing establishments (including radiopharmaceutical production); radioactive waste facilities, and NORM facilities have monitoring programmes (where in operation) set to focus on radionuclides in line with authorised releases. Medical facilities and small research establishments do not, in general, have environmental monitoring programmes carried out either by the operator or the regulator.

### **3.4 Limits of detection**

The lower limit of detection (LLD) is the activity level ( $\text{Bq}$  or  $\text{Bq/kg}$  or  $\text{Bq/m}^3$ ) at which the overall count rate can be positively distinguished from the background count rate. It is defined more quantitatively in Annex A section 9.10.

#### **3.4.1 Gamma dose rates**

For gamma dose rates, usually measured either as air kerma rates (in  $\mu\text{Gy/h}$  or  $\text{nGy/h}$  in air) or as ambient dose equivalent rates (in  $\mu\text{Gy/h}$  or  $\text{nGy/h}$ ), the important measure is the increase over natural background. This is typically at a level of  $0.05\text{--}0.1 \mu\text{Gy/h}$ , the lower level being typical for beach sands and the upper for muddy substrates, but the level can be much higher in particularly high natural background areas. Best practice would be to be able to distinguish a level from background by say  $0.01 \mu\text{Gy/h}$  over a counting time of 5-10 minutes, as is possible with portable GM devices currently available. This would also be adequate for networked detectors, which provide an alarm if there is a significant rise in ambient dose rates. TLD arrays are usually deployed over a long timescale, up to say 3 months, not being intended to provide short-term alarms, and are capable of measuring this level of increase in ambient level.

### 3.4.2 Beta contamination monitoring

Portable beta contamination monitors are used for measuring contamination, for example, on items of fishing gear which are handled by fishermen in the course of their work. Detection limits equivalent to dose rates of 0.1  $\mu\text{Sv/h}$  are achievable with hand-held devices and this is adequate, since a fisherman handling gear for say 2000 h/y would then receive a dose of 0.2 mSv which is only 0.4% of the appropriate limit prescribed in the EU Basic Safety Standards.

### 3.4.3 Gross alpha counting

Alpha counting may be carried out for specific radionuclides after suitable radiochemical separation, or for total or gross alpha activity. LLDs for specific alpha emitters are discussed in section 4.4.5. Gross alpha counting is often used for monitoring of airborne dust filters (after a suitable period of decay for radon daughters) and waters. Whilst LLDs depend on the type of sample and its physical characteristics, typical best-practice LLDs reported by MSs for gross alpha activity using proportional counters or ZnS detectors are 30-40 mBq, or the converted quantity in  $\text{Bq/m}^3$  or  $\text{Bq/L}$ . Gross alpha detection is particularly important for monitoring of drinking water, where a screening value of 0.1  $\text{Bq/L}$  is needed, and better than this can be achieved using evaporation and proportional counting or liquid scintillation counting.

### 3.4.4 Gross beta counting

Similarly, beta counting may be carried out for specific beta emitters after radiochemical separation (section 4.4.5) or for gross beta activity. Care is needed because the efficiency of detection of beta particles may fall significantly at low energies. Thus the method used and beta-emitter used for calibration are important. Whilst, again, LLDs depend on the type of sample etc., typical best-practice LLDs reported by MSs for gross beta activity using proportional counters are about 0.1 Bq or the converted quantity in  $\text{Bq/m}^3$  or  $\text{Bq/L}$ .

### 3.4.5 Specific radionuclides

Alpha- and beta- emitting radionuclides are usually measured specifically after suitable radiochemistry to separate the radionuclide of interest. Gamma-emitters are usually measured by gamma spectrometry, usually with a Ge detector but NaI(Tl) scintillators are also used. LLDs, as before, depend on the type of sample and other factors. Typical LLDs currently achieved are listed in the table below for common radionuclides:

Radionuclide	Method	Typical LLDs currently achievable*
Tritiated water	Liquid scintillation	5 $\text{Bq/L}$
Tritium in solid sample	Liquid scintillation	30 $\text{Bq/kg}$
C-14	Liquid scintillation	20 $\text{Bq/kg}$
Mn-54	Gamma spectrometry	0.2 $\text{Bq/kg}$
Co-58	Gamma spectrometry	0.3 $\text{Bq/kg}$
Fe-59	Gamma spectrometry	0.5 $\text{Bq/kg}$
Co-60	Gamma spectrometry	0.2 $\text{Bq/kg}$
Zn-65	Gamma spectrometry	0.4 $\text{Bq/kg}$
Sr-90	Beta counting	0.05 $\text{Bq/kg}$
Zr-95	Gamma spectrometry	0.5 $\text{Bq/kg}$
Nb-95	Gamma spectrometry	0.5 $\text{Bq/kg}$
Tc-99	Beta counting	2 $\text{Bq/kg}$

Ru-106	Gamma spectrometry	1 Bq/kg
Ag-110m	Gamma spectrometry	0.5 Bq/kg
Sb-125	Gamma spectrometry	0.4 Bq/kg
Cs-134	Gamma spectrometry	0.1 Bq/kg
Cs-137	Gamma spectrometry	0.1 Bq/kg
Ce-144	Gamma spectrometry	1 Bq/kg
Eu-154	Gamma spectrometry	1 Bq/kg
Eu-155	Gamma spectrometry	1 Bq/kg
Pu, Am, Cm alpha-emitting radionuclides	Alpha spectrometry	0.0001 Bq/kg or less
Pu-241	Beta counting	0.2 Bq/kg

\*For gamma spectrometry, the LLD depends strongly on the type of sample and the other radionuclides present in a sample

### 3.5 Continuous measurement versus sampling

Continuous measurement needs to be distinguished both from continuous sampling, which is done over a period of time and the result integrated, and periodic sampling, which is not continuous. Continuous measurement has the advantage over both types of sampling that there is a potential for more rapid information on any enhanced levels which may be of concern. The disadvantages of continuous measurements are that they are not always available as an option and the necessary equipment can be expensive. The most common form of continuous measurement practised by MSs is of dose rates using on-line gamma dose rate monitors; this technique is suitable to be used for an array around a site or number of sites, and can give rapid information on levels of concern. There is normally a finite integrating time, usually some minutes, but in this context the measurement can be considered as continuous.

Where continuous measurement is unavailable, continuous sampling may have advantages over periodic sampling to reduce the risk of missing pulses of enhanced activity. However with environmental monitoring, the effects of raised releases will usually have involved a period of environmental dispersion thus the risk of missing pulses is lower than for information on discharges themselves. The types of monitoring most frequently carried out by MSs are of airborne particulates, using a medium or high volume sampler, and water samples by continuous sampling from a watercourse.

For environmental monitoring, periodic sampling is often the only option due to the need for installations to sample continuously, and for such sites to remain secure. Consideration of the appropriate period between samples needs to take account of the objectives of the programme and the potential rate of change of radioactivity concentrations.

### 3.6 Continuity of operation

It is important for MSs to ensure that the monitoring programmes carried out (by both operators and the regulators) do not suffer interruption. Having stressed the importance of continuity, it is also important that environmental monitoring programmes are kept under review to take account of changes in discharges, habits or environmental conditions, whilst also maintaining some degree of continuity for particular indicators to allow trends to be followed.

### **3.7 Alarms on abnormal results**

For environmental monitoring, the main examples of alarms and supporting automation are the networked arrays of gamma dose rate monitors operated nationally, and in some cases shared between MSs. There may be two levels of “alarm”: a lower level to indicate a warning and an upper level representing greater concern. It would not be appropriate to specify typical alarm levels because they need to be set depending upon local geological conditions which affect the amount of natural radiation emitted.

For non-automated systems typical of most environmental monitoring, higher results than normal require some form of action, indeed this is one of the main objectives of the monitoring itself. The first action would normally be further investigation followed by further monitoring and if confirmed, leading to more intensive investigation and if necessary curtailment of releases and/or remediation. Reporting to the regulatory authority would be expected at an appropriate stage. It would be expected that a system for alerting would be in place as this is closely related to the purpose of the monitoring. That this is so needs to be a part of the verification process. It is inappropriate to specify levels for triggering actions as a number of local factors are relevant. However levels should be traceable to doses to the public as fractions of the dose limit.

### **3.8 Data management and values below the detection limit**

Data processing at most facilities within MSs, including small establishments, makes use of computer technology with associated software to process analytical data. The software is often provided by suppliers of the counting devices. In addition, particularly for the larger facilities, sample management systems may be in use, which provide databases for the results of monitoring.

There are variations in dealing with values below the detection limit or decision threshold. For environmental monitoring, the main question is how to combine data, some of which are positive and some below this threshold. Some organisations take a cautious approach when combining data of assuming that the radionuclide is present at the decision threshold, except when there are reasons to rule out its presence (e.g. because the relevant discharge does not include it). However this same question has been dealt with in relation to discharges, in recommendations on standardised information [EC, 2003] and the arguments would be similar here. When combining data, the recommendation is to use, conservatively, one-half of the decision threshold for those data which are quoted as below it. However if repeated values are below the threshold and there is no reason (e.g. as before) to expect that the radionuclide may be present, then it may reasonably be taken as zero.

## **4 TECHNICAL PROVISIONS FOR DISCHARGE MONITORING**

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### **4.1 Introduction**

The range of types of monitoring is covered in this section and draws on the information provided in Annex B.

### **4.2 Sampling and monitoring methodology**

#### **4.2.1 Airborne discharge monitoring**

For airborne discharge monitoring, continuous monitoring is carried out under most conditions and is the normal practice; periodical (batch) sampling can only be justified if the discharge is steady and predictable, and of low radiological significance. On-line systems with continuous monitoring have the advantage of early warning, with the capability of alarms and possibility for early stoppage of discharges; however on-line gamma detecting systems (the most usually used) do not lend themselves to accurate accountancy because of shielding. Thus for the more potentially significant discharges such on-line systems represent best practice when provided with additional accountancy where necessary.

Within each category of continuous or periodical sampling, the following physical forms of airborne releases need to be considered:

- particulates
- vapours (volatilised liquids or solids that can be condensed at lower temperatures)
- gases.

For sampling of particulates, best practice is to sample isokinetically in order to preserve the particle size distribution and hence volume activity concentration of the discharge. Sampling methods involve filtration on glass fibre, cellulose (paper) or polystyrene filters. In some cases a continuous filter strip is used and this has distinct advantages in presenting a time series of data and continuous measurement, with the possibility of on-line data reporting and alarms. The latter represents best practice for potentially more significant discharges of particulates.

The filters are analysed radiometrically to provide a measure of the radioactivity present in the discharge. For alpha emitting radionuclides, methods are: ZnS detectors; gas proportional counters; Si surface barrier and PIPS detectors; specific radionuclide analysis using radiochemical techniques. For beta emitters methods are: GM detectors; gas flow proportional counters; plastic scintillators; and specific analysis. Gamma emitters are measured using NaI or Ge spectrometry. Each of these methods may represent good practice if set up and calibrated adequately. However a preference should be expressed for a specific radionuclide measurement where this is the objective, rather than using a “gross” method as a surrogate. Often, however, “gross” methods are used to provide a rapid method to demonstrate compliance, with the potential for more specific analysis following release if needed.

For sampling of vapours, the method used and what is best practice depends very much on the nature of the determinand and the relevant physical or chemical conditions. For radioiodine, activated charcoal is often used, sometimes impregnated with NaI; depending

on the chemical conditions, aluminosilicate sieves, impregnated with  $\text{Ag}(\text{NO}_3)_2$  can be used. Methods for analysing the filters, usually for radioiodine, involve gamma spectrometry using NaI or Ge detectors in a suitably calibrated geometry.

For gases, a number of methods are used. Again, what is best practice depends on the determinand and the conditions, for example:

- bubbler traps - the gas is bubbled through a liquid either to dissolve it or to react chemically with it. This method is often used to collect tritium. The liquid is regularly changed and analysed to measure the collected gas.
- wet scrubbers – the gas is passed against a flow of liquid, the surface area usually increased by the use of glass beads, either to dissolve the gas or for it to react chemically. Again, the liquid is regularly changed for analysis.
- direct measurement – the gas enters a vessel that is fitted with a measurement device (e.g. scintillation detector) to give a direct (usually gamma) count. The vessel can be pressurised to improve counting efficiency, or the gas may be cryogenically separated (usually for Kr-85). The direct measurement method is usually used for inert (noble) gases.

Position of sampling equipment on the discharge line needs careful consideration in order to be representative, and a number of considerations is involved. Examples of good practice are referred to in Annex B which provides technical guidance.

Analytical methods for liquids from bubblers or wet scrubbers are: evaporation followed by gas proportional counting; liquid scintillation counting; gamma spectrometry; and radiochemical separation for specific radionuclides. For direct measurement, radionuclides are usually measured by NaI or Ge spectrometry. Each method may represent good practice if set up and calibrated adequately, with a preference for specific rather than “gross” methods, depending on the need for rapid analysis.

A less preferable method of estimating airborne discharges sometimes carried out for releases of low radiological significance is to rely on radionuclide source usage, and knowledge of the processes used at that facility to give rise to radioactive airborne releases. This method is sometimes employed for discharges from hospitals or small research establishments. It represents a sub-standard practice at larger facilities and should be permissible only if releases are very low.

#### **4.2.2 Liquid discharge monitoring**

Both continuous sampling of liquid discharge streams and spot or grab sampling of effluents from tanks or directly from outlets are used for liquid discharge monitoring. Best practice is to retain control of the discharge, that is, not to release effluent until the radioactivity content of a representative sample has been measured and cleared for discharge. In this way an alarm can be raised if necessary. This process most usually takes place in a final tank (“sentencing tank”). However continuous monitoring of released effluent or, less preferably, spot sampling, may be permissible if the discharges are of very low radiological significance and predictable.

Best practice is also for the sample to be representative. This means that continuous samples should be flow-proportional using an appropriate sampler. Sentencing tanks, if sampled directly, should be fully homogenised by stirring or recirculating before samples are taken.

Guide to best practice on positioning of sampling devices on discharge lines is provided in Annex B. The samplers need to be positioned such that the samples are representative, and are placed after any abatement plant and at the last point under control by the operator.

Analytical techniques for liquid discharge samples are as follows:

- for alpha emitters, evaporation followed by proportional or ZnS counting; liquid scintillation counting;
- for beta emitters, evaporation followed by GM or proportional counting; liquid scintillation counting;
- for gamma emitters, spectrometry using NaI or Ge detectors;
- specific radionuclide analysis following radiochemical separation.

Each method may represent good practice if set up and calibrated adequately, with a preference for specific rather than “gross” methods, depending on the need for rapid analysis.

On-line monitoring of liquid discharges may be carried out, usually using gamma spectrometry of a hard gamma emitter in view of the shielding effect of the liquid and pipework. This represents a useful real-time warning device but additional means are usually needed for accountancy purposes.

In the same manner as for airborne releases, a less preferred method of estimating liquid discharges sometimes carried out for releases of low radiological significance is to rely on radionuclide source usage and knowledge of the processes leading to liquid releases. This method is sometimes employed for discharges from hospitals or small research establishments. It represents a sub-standard practice for larger facilities and should be permissible only if releases are very low.

### **4.3 Monitored radionuclides**

For the reprocessing plants in the EU, comprehensive discharge monitoring programmes are carried out as may be expected, and the radionuclides (or groups of radionuclides in the case of gross measurements) monitored reflect their radiological importance and the rates of discharge. Recommendations have been promulgated on standardised information on discharge reporting for reprocessing plants and nuclear power reactors in normal operation (EC, 2003). There is some reliance on gross measurements of alpha or beta activity to cover for specific radionuclides, but this is done for speed of information with the potential for more specific analysis if needed. Radionuclides are also analysed specifically. Transuranic nuclides feature widely in the monitoring of discharges from these establishments, again reflecting the potential for discharges and doses received.

For the uranium facilities (mining/milling; enrichment; and fuel fabrication), the extent of discharge monitoring, especially of mines (including those decommissioned and being decommissioned) is variable across the EU and some mines may not be subject to adequate monitoring. However where monitoring is done, it is generally for appropriate radionuclides (uranium, radium and daughters; thorium and daughters; technetium-99 in the case of reactor-recycled U; actinides in the case of MOX facilities). In some MSs initial reliance is placed on gross alpha and beta monitoring.

In the case of nuclear power stations, the radionuclides discharged are a function of reactor type. Thus it is difficult to compare all nuclear power stations together. Even for a given

reactor type, with the PWR being most common, there are variations in discharge monitoring. Some MSs put greater emphasis on the use of gross alpha and/or gross beta monitoring. This is satisfactory provided there are resources available to deal with any queries should a high gross measurement need further investigation.

Large research establishments, by definition, have a wide variety of activities which generate different radionuclides in discharges. Broadly the monitoring carried out reflects the radionuclides mentioned in the authorisations. The issue is slightly different in the case of research establishments, in that the discharge monitoring programme needs to be flexible enough to cope with changing research priorities.

Industrial processing establishments (including radiopharmaceutical production); radioactive waste facilities, and NORM facilities have discharge monitoring programmes (where in operation) set to focus on radionuclides in line with authorised releases.

## 4.4 Limits of detection

### 4.4.1 General

The lower limit of detection (LLD) is the activity level (Bq or Bq/L or Bq/m<sup>3</sup>) at which the overall count rate can be positively distinguished from the background count rate. It is defined more quantitatively in Annex A section 9.10.

In the context of discharge monitoring, the LLD should be at a sufficiently low level to be able to detect increases in concentrations of radionuclides above background which, when combined with the flow rate, may be of radiological concern, and would be lower than the level at which an alarm may be triggered to cease discharges, and well below authorised limits set by regulatory authorities.

### 4.4.2 Airborne discharge monitoring

The following table provides example LLDs for airborne discharges:

Form of discharge	Radioactivity	Example concentration LLD,
Particulate:	gross alpha	~ 1 mBq/m <sup>3</sup>
	gross beta	~ 4 Bq/m <sup>3</sup>
	Co-60 or Cs-137	~ 1 mBq/m <sup>3</sup>
	Sr-89, Sr-90	~ 0.1 mBq/m <sup>3</sup>
Gaseous:	tritium	~ 100 Bq/m <sup>3</sup>
	C-14	~ 10 Bq/m <sup>3</sup>
	Noble gases, specific gamma	~ 10 kBq/m <sup>3</sup>



#### 4.4.3 Liquid discharge monitoring

The following table provides example LLDs for liquid discharges:

Radioactivity in liquid discharge	Example LLD, concentration
Gross alpha	~ 500 Bq/m <sup>3</sup>
Specific alpha after analysis e.g. Am-241	~ 10 Bq/m <sup>3</sup>
Sr-89, Sr-90	~ 200 Bq/m <sup>3</sup>
Tritium	~ 10 kBq/m <sup>3</sup>
Specific gamma, e.g. Cs-137	~ 500 Bq/m <sup>3</sup>

#### 4.5 Continuous measurement versus sampling

Continuous measurement, termed “on line” if the results are channelled electronically to a central control point, needs to be distinguished both from continuous sampling, which is done over a period of time and the result after analysis integrated, and from periodic sampling, which is not continuous. Continuous measurement has the advantage over both types of sampling that there is a potential for more rapid information on any enhanced levels which may be of concern. The disadvantages of continuous measurements are that they are not always available as an option and the necessary equipment can be expensive; further, they may not provide accurate accountancy of discharges. Continuous measurement practised by MSs for airborne discharges may be carried out directly using appropriately placed gamma monitors, or on continuous samplers using GM detectors, proportional counters, scintillation or semiconductor detectors. Continuous measurement of liquid discharges may be carried out using gamma monitors appropriately placed on discharge lines, though the need for this is offset by the usual and preferred practice of retaining liquid discharges in tanks until accountancy and sentencing is complete.

For discharges, continuous sampling should always be preferred to periodic sampling unless discharges are known to be steady, predictable and of low radiological significance.

#### 4.6 Continuity of operation

Most MSs have on-going programmes for monitoring of radioactive discharges carried out by operators as part of their authorisations, and in many cases check monitoring by regulatory authorities. It is clearly important for MSs to ensure that these programmes do not suffer interruption. Therefore, best practice would be to have built-in redundancy or duplication in provision of discharge monitoring devices and procedures against the possibility of breakdown, or the possibility to retain discharges whilst spare equipment is brought into operation.

It is always important that discharge monitoring programmes are kept under review to take account of changes in discharges, plant and equipment developments as well as changes in requirements of regulatory bodies.

#### 4.7 Alarms on abnormal values

For discharge monitoring, there are alarms and supporting automation usually linked to continuous measurement or sampling of releases; if alarm levels are exceeded, this would

trigger cessation of discharge or enabling of filters and/or evacuation of staff. There may be two levels of “alarm”: a lower level to indicate a warning and an upper level representing greater concern. It would not be appropriate to specify typical alarm levels because they need to be set depending upon local conditions.

For discharge data in general, higher results than normal require some form of action; indeed this is one of the main objectives of the monitoring itself. The first action would normally be further investigation followed by repeat monitoring or analysis and if confirmed, leading to more intensive investigation and if necessary curtailment of releases and/or remediation. Reporting to the regulatory authority would be expected at an appropriate stage, and often there are trigger levels set for this. It would be expected that a system for alerting would be in place as this is closely related to the purpose of the monitoring. That this is so would need to be a part of the verification process. Again it would be inappropriate to specify levels for triggering actions as a number of local factors would be relevant. However levels should be traceable to doses to the public as fractions of the dose limit.

#### **4.8 Data management and values below the detection limit**

Data processing at most facilities within MSs, including small establishments, makes use of computer technology with associated software to process analytical data. The software is often provided by suppliers of the counting devices. In addition, particularly for the larger facilities, sample management systems may be in use, which provide databases for the results of monitoring.

For discharge monitoring, decision thresholds as described in Annex B section 9.10 may be used. The question also arises of how to combine data, some of which are positive and some below this threshold. Some organisations take a cautious approach when combining data of assuming that the radionuclide is present at the decision threshold, except when there are reasons to rule out its presence (e.g. because the relevant discharge does not include it). This same question has been dealt with in recommendations on standardised information [EC, 2003] and the arguments would be similar here. When combining data, the recommendation is to use, conservatively, one-half of the decision threshold for those data which are quoted as below it. However if repeated values are below the threshold and there is no reason (e.g. because the relevant discharge does not include it) to expect that the radionuclide may be present, then it may reasonably be taken as zero.

## **5 OTHER MONITORING ISSUES**

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### **5.1 Independent oversight - witnessed sampling**

The normal practice for environmental monitoring, following the widely-accepted “polluter pays” principle, is for the majority of the work to be carried out by the operator of a given facility, or a contractor working on his behalf. To maintain public reassurance, this work needs to be overseen, and this is usually done by the regulatory authority, or again a suitable contractor (where the choice of contractor would be more crucial, to maintain confidence). In many cases, particularly those of greater radiological significance, oversight is exercised by carrying out a parallel, “check”, environmental monitoring programme by the regulator or contractor. This programme may be a smaller one, and involve sampling of similar or complementary items or pathways. In some cases samples taken by the operator are shared with the regulator, either as part of a regular programme or for one-off comparative purposes (for some samples, e.g. high volume air samples, it might be duplicative for the operator and regulator to operate independent systems). To provide reassurance that an operator has taken a prescribed sample at a stipulated time and location, the sampling can be witnessed by a representative of the regulator. Some MSs’ regulatory bodies have programmes of witnessed sampling as part of their control measures.

Witnessed sampling is to be encouraged as another control available to a regulator whether or not there is a separate regulator’s environmental monitoring programme, but particularly if there is not. It is important that the witness is truly independent of the operator, and not, for example, a representative of the same contractor as is carrying out work for the operator.

### **5.2 Role of accreditation of procedures**

The need for accreditation of monitoring and analytical procedures is increasingly recognised amongst MSs, with many of the regulatory authorities’ analysts as well as operators now reporting that their procedures are accredited. Accreditation plays an important role in assuring users of the data that the results have been derived following recognised standards, and may be accepted by other MSs as meeting these standards, as a desirable objective across the EU. Thus, whilst laboratory techniques may be adequate, not being accredited is becoming less than the norm, even sub-standard. For some facilities there is no accreditation. Some facilities are working towards it. Some facilities have accreditation to ISO 9001 [ISO, 2000], however this is a generic standard and does not address the technical aspects relevant to environmental or discharge monitoring. For this purpose ISO 17025 [ISO, 2005] has become the reference standard, including the technical requirements for measurements, sampling and laboratory analysis. Many facilities are now accredited to this standard, and it is best practice. Conformance is usually invigilated by national accreditation bodies.

Accreditation includes the need to carry out suitable intercomparison exercises, without which the reliability of data goes unchecked. Such intercomparisons should include relevant exercises carried out at international level to ensure comparability of data between MSs.

### **5.3 Availability of written procedures**

One of the first essentials of good practice, including with radiation monitoring, is to have, and to follow, clearly written procedures for carrying out of all aspects of the work. Accreditation depends on the existence and following of such written procedures. Without such procedures, the monitoring and analysis would certainly be very sub-standard. It is emphasised that the existence of written procedures is only a first step towards a comprehensive quality management system.

### **5.4 Adequacy of laboratory facilities**

Laboratory facilities provided by both operators and regulators need to be fit for the purposes of the monitoring programmes they are required to support. There are also associated issues such as provision of the necessary staff, motivation and training which are important resources for effective working. There are a number of pointers to the overall effectiveness of a laboratory. One would be to examine performance in intercomparison exercises, which all competent laboratories should carry out. Indeed it is a condition of accreditation. Another is the timeliness of the results reported; undue delays are unsatisfactory and may lead to necessary action being taken at a late stage. An effective, albeit manpower consuming, method would be to visit relevant laboratories during a verification mission and discuss resources with local staff.

### **5.5 Level of computerisation including data transfer systems**

Data processing at most facilities within MSs use computer technology, especially for the more modern types of counting equipment such as spectrometers and scintillation counters. This is true also at some of the smaller facilities as well as at the large establishments. Even the older types of counting equipment, such as GM and proportional counters, rely on signal processing techniques and computerised data storage. Newer detection systems have associated software to process analytical data. This software is often provided by suppliers of the counting devices. Thus a level of computerisation is required by the nature of the work being done. Its advantage is the ease with which large amounts of data can be quickly processed; the disadvantage is in the risk of erroneous programming and uncritical acceptance of the results.

Following the gathering of data by separate counting systems, particularly for the larger facilities, sample management systems may be in use which transfer the data and provide databases for the results of discharge monitoring. These systems often include various quality assurance checks. It is essential that these systems are specified appropriately for the required tasks and collation of data; the main objective is usually to produce a report for the facility management, regulatory body or, possibly in abridged form, for the public.

### **5.6 Stakeholder involvement**

For the more radiologically significant or otherwise sensitive facilities, there can be local “stakeholder” groups. Such groups consist of representatives of the local community who have an interest in the operations of that facility and its effects. Members of stakeholder groups represent, for example, the operators, the regulatory bodies, the local district authorities and elected representatives, the emergency services, and possibly relevant interest groups although these might be represented by their elected local authority members. Meetings would preferably be chaired by an independent person, but chairing could alternate between the operators and local authority. Such groups are already

organised in some MSs (e.g. with the name “Local Liaison Committees”). The agenda of meetings could typically include updates on the facility and plant operations, the levels of discharges, the results of environmental monitoring, and developments in emergency planning. The purpose is to provide information and allow any concerns to be raised, and act as a channel of information to the public local to the facility and indeed further afield. Stakeholder groups can also be seen as another part of “independent oversight”.

## **6 VERIFICATIONS UNDER THE ARTICLE 35 OF THE EURATOM TREATY**

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### **6.1 Scope of verifications**

Conduct of Article 35 verifications is described in the Commission Communication *"Verification of environmental radioactivity monitoring facilities under the terms of Article 35 of the Euratom Treaty - Practical arrangements for the conduct of verification visits in Member States to the Member States (2006/C 155/02)"* of 4 July 2006. Communication is not legally binding, but the Commission follows its text closely when carrying out the verification programme.

The industrial sectors subject to Article 35 verifications can be defined as follows:

1. Reprocessing plants
2. Mining, milling etc. of U and Th
3. Enrichment of U
4. Fabrication of nuclear fuel
5. Nuclear power stations
6. Large research establishments (including research reactors)
7. Industrial processing and radiopharmaceuticals
8. Radioactive waste facilities
9. Facilities processing naturally occurring radioactive materials (NORM)
10. Medical facilities using radioisotopes (radionuclides for radiomedicine or radiodiagnostics)
11. Research establishments

This classification is similar to that used within the context of Article 37 of the Euratom Treaty. The Commission holds the view that the environment starts where the discharges pass out of operational control and that Article 35 verifications therefore include the facilities for monitoring the aerial and liquid discharges of installations. Such facilities may be located within or outside the installation’s premises.

In each MS there is a national environmental monitoring programme in addition to any specific site-related monitoring programmes. Indeed for some MSs (particularly those without nuclear power programmes) the national programme forms the majority of the

environmental monitoring for radioactivity. National programmes, as well as providing surveillance for extraneous sources and accidents (e.g. Chernobyl), also fulfil the requirements to report data to the Commission under Article 36. The objectives of national programmes are separate from site-specific regulatory requirements, both being relevant to verification under Article 35.

The primary objective of the Commission's verifications is to satisfy itself of the operation and efficiency of the facilities established for the measurement of environmental radioactivity and of radioactive discharges and the adequacy of the environmental monitoring programme. The scope of the conclusions to be drawn from the verifications does not include any assessment of the source or the magnitude of the environmental impact of discharges or the levels of radioactivity in the environment, i.e. the Commission does not judge the discharge limits laid down by the national authorities.

An important task of the verification programme is to foster the harmonisation of methods for the measurement of environmental radioactivity and of radioactive discharges. Therefore the Commission continuously compares arrangements under verification to similar arrangements in other MSs.

Commission verifications should enable a judgement to be made as to the:

- (a) Operation of the environmental and discharge monitoring facilities, i.e. their set-up and use in accordance with the design characteristics of the equipment or measuring devices used,
- (b) Suitability of sampling and sample preparation methods,
- (c) Suitability of analytical methods,
- (d) Compliance with any national requirements in terms of sampling and analysis,
- (e) Efficiency, defined as the effectiveness of the equipment in the monitoring undertaken (sensitivity, detection parameters, etc.),
- (f) Management of records of radioactivity discharges and of environmental monitoring results,
- (g) Management of sample archives where applicable,
- (h) Data handling and reporting procedures,
- (i) Quality control measures, including participation in intercomparison exercises. National accreditations will not be questioned.

Part of the verification consists of checking the consistency of the actual set-up of monitoring facilities with the information reported under Articles 36 or 37 of the Euratom Treaty. General data supplied under Article 37 of the Euratom Treaty can be used where necessary to compare the originally planned environmental monitoring programme with the actual one.

## **6.2 Verification timeline**

Carrying out an Article 35 verification from initial announcement to final reporting takes at least 8-9 months. There are time intervals in the process, which need to be respected, for

example timely announcement and sufficient time for the verification of the factual accuracy of reports.

A typical verification timeline is the following:

T-6 months	Formal verification announcement to the Member State
T-4 months	Sending of the pre-verification questionnaire
T-1 month	Sending of the draft verification programme
T	Verification visit (3-5 days)
T+2 months	Sending of the draft verification report to the Member State
T+4 months	Deadline for MS comments to the draft verification report
T+5 months	Sending of the final verification report to the Member State
T+7 months	Verification report and possible MS comments available to the public (allowing 6 weeks for formal comments by the Member State)

### **6.3 Verification targets**

Programme of the verification visit is agreed in advance with the MS competent authority. Details of the programme are agreed in the opening meeting of the verification visit. Typical verification targets are the following:

#### **Verification of environmental monitoring (air, water, soil, foodstuffs)**

- Legal basis and competent authorities
- Sampling sites and arrangements for air, water and soil
- Automatic monitoring systems
- TLD locations
- Analysis laboratories
- Quality assurance arrangements
- Monitoring network data centres
- Mobile monitoring systems (special vehicles, helicopters, etc.)
- Foodstuffs and mixed diet sampling arrangements
- Emergency monitoring arrangements and equipment
- Sample and data archives

#### **Verification of discharge monitoring**

- Legal basis and discharge authorisations
- Discharge sampling systems and locations

- Automatic monitoring systems
- Analysis laboratories
- Quality assurance arrangements
- Facility control rooms
- Emergency monitoring arrangements and equipment
- Sample and data archives

## 6.4 Reporting

After the verification visit a verification report is drafted. In addition to reporting the actual verification the report contains a description of the monitoring systems and the legal basis and authorisations on which it is based.

The verification report can include *recommendations* and *suggestions*. Recommendation is a clear signal that there is a need for a corrective action in order to maintain compliance with Article 35 and there may be a need for a re-verification to confirm compliance with the recommendation. Suggestion is an indication of room for improvement in terms of reaching the best practise level.

The structure of the technical report of the verification is the following:

- 1 Introduction
- 2 Preparation and conduct of the verification
- 3 Monitoring programmes and responsible organisations
- 4 Legal framework for environmental radioactivity monitoring
- 5 Legal framework for discharge radioactivity monitoring
- 6 Environmental radioactivity monitoring in the MS
- 7 Site-specific environmental radioactivity monitoring at site X
- 8 Discharge monitoring at site X
- 9 Verifications
- 10 Conclusions

Verification findings (recommendations and suggestion) are described and justified in section 9; the other parts of the report are descriptive.

Recommendations are outlined also in a separate 'Main findings' document. The purpose of this document is to communicate the main outcome of the verification in a concise form. Main findings do not include suggestions, which can be found in the technical report.



## **6.5 Verification follow-up**

When sending the main findings document and the final technical report to the Member State, the Commission informs that the report will be made available to the public after six weeks of sending it formally to the Member State, and any comments made by the Member State will be made available alongside the report. This way the Member State is given opportunity to present their views on the recommendations and inform about possible corrective actions.

If recommendations are given, the Member State is requested to provide a report of actions taken based on the verification typically after one year. When this report is received, it is also made available to the public alongside the verification report.

The Commission may carry out a re-verification after 2-3 years in case there has been recommendations clearly implying possible lack of compliance with the Article 35. Re-verification is carried out the same way as the first verification and it is not limited to the scope of the first verification.

## **7 TECHNICAL GUIDANCE**

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Two technical guidance documents are provided as part of this document. These set out technical recommendations for environmental surveillance (Annex A) and discharge monitoring (Annex B). Each annex addresses the relevant technical considerations to meet the needs of operators and regulators interested in reviewing and improving the level of implementation of Euratom Treaty Article 35. The annexes have been drafted as stand-alone documents for separate use if required. They are based on surveys of available guidance and standards on environmental monitoring and discharge monitoring, as referenced in these annexes.

## References

- EC, 1996. Council Directive 96/29/EURATOM of 13 May 1996 laying down basic safety standards for the protection of the health of workers and the general public against the dangers arising from ionising radiation.
- EC, 2002. Guidance on the realistic assessment of radiation doses to members of the public due to the operation of nuclear installations under normal conditions. Radiation Protection 129. European Commission.
- EC, 2003. Commission Recommendation of 18 December 2003 on standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation (2004/2/EURATOM).
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- EC, 2006. Verification of environmental radioactivity monitoring facilities under the terms of Article 35 of the Euratom Treaty. Practical arrangements for the conduct of verification visits in Member states. Official Journal of the European Union. OJEC Notice 2006/C155/02, 4 July 2006.
- IRPA, 2008. Guiding Principles for Radiation Protection Professionals on Stakeholder Engagement.
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- ISO, 2000. ISO 9001:2000. Quality Management Systems – Requirements.
- ISO, 2005. ISO/IEC 17025:2005, General requirements for the competence of testing and calibration laboratories.
- EC, 2013. Council Directive 2013/51/EURATOM of 22 October 2013 laying down requirements for the protection of the health of the general public with regard to radioactive substances in water intended for human consumption.
- EC, 2013. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom.

## **Annex A**

# **Technical guidance for environmental monitoring programmes**

### **CONTENTS**

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## **1 Introduction**

- 1.1 This annex provides technical guidance on the requirements for developing an environmental monitoring programme for surveillance of the effects of radioactive discharges to the environment under Article 35 of the EURATOM Treaty. The guidance makes use of a study by Cefas for the UK Environment Agency [Leonard, 2007].
- 1.2 Section 2 provides information on relevant legal provisions of Article 35 of the EURATOM Treaty and includes background information on verification visits [EC, 2006].
- 1.3 Section 3 describes the generic objectives for planning an environmental monitoring programme, including guidance on the independent oversight by national regulators of environmental monitoring programmes undertaken by site operators.
- 1.4 Section 4 summarises the different monitoring strategies that can be adopted for environmental monitoring, including the criteria for selection of on-line continuous measurement, the use of portable monitoring instruments, and continuous or spot sampling.
- 1.5 Section 5 presents a classification of environmental media for monitoring purposes.
- 1.6 Section 6 provides a review of published, mainly international, guidance on methods of monitoring of environmental media.
- 1.7 Section 7 provides guidance on best-practice methodologies for environmental monitoring, including sampling methods and selection of technical devices such as samplers, instruments and laboratory apparatus and techniques.
- 1.8 Section 8 provides guidance on the analysis of samples taken in the course of environmental monitoring and on data processing.
- 1.9 Section 9 provides guidance on the statistical aspects of environmental monitoring including consideration of measurement uncertainty, detection limits and decision thresholds.
- 1.10 Section 10 provides guidance on quality assurance matters including relevant standards and accreditation.

## **2 The Euratom Treaty**

- 2.1 Article 35 of the Euratom Treaty requires that each Member State shall establish the facilities necessary to carry out continuous monitoring of the levels of radioactivity in air, water and soil and to ensure compliance with the basic safety standards.
- 2.2 Article 35 also gives the European Commission the right of access to such facilities in order that it may verify their operation and efficiency. The main purpose of verifications performed under Article 35 of the Euratom Treaty is to provide an independent assessment of the adequacy of monitoring facilities for:
  - Liquid and airborne discharges of radioactivity into the environment by a site (and control thereof).
  - Levels of environmental radioactivity at the site perimeter and in the marine, terrestrial and aquatic environment around the site, for all relevant exposure pathways.
  - Levels of environmental radioactivity on the territory of the Member State.

2.2.1 For the purposes of such assessments a verification team from the European Commission visits relevant sites within a Member State. Historically the arrangements for such visits were agreed with the relevant Member State in a bilateral protocol. However, in July 2006 the European Commission published a Commission Communication defining the practical arrangements for the conduct of such verification visits [EC, 2006]. Past verification visit reports are available at <http://ec.europa.eu/energy/node/1221>.

2.4 Under Article 36 of the Euratom Treaty and its secondary legislation, Member States regularly provide the European Commission with relevant data on environmental radioactivity, so that it is kept informed of the level of radioactivity to which the public is exposed.

### **3 Environmental monitoring programme objectives**

3.1 The high level objectives of environmental monitoring programmes are largely defined by European directives, national legislation, national regulations, decrees, etc. More site specific requirements are detailed in licences, ordinances, permits, consents, prescriptions or authorisations (referred to hereafter as licences). In turn these requirements are informed and based upon guidance published by the IAEA, national competent authorities, international, European and national standards bodies, international and national institutes and major nuclear site operators.

3.2 Environmental monitoring programmes that have been designed to meet the legal requirements and guidance referred to above should in principle satisfy the requirements of Article 35 of the Euratom Treaty.

3.3 All relevant radiological exposure pathways need to be considered, with emphasis on monitoring those pathways likely to be of main importance. The Article 31 Group of experts has set out recommendations in Radiation Protection Publication 129 [EC, 2002]. For atmospheric discharges, the pathways of greatest importance are likely to be:

- Ingestion of radionuclides in terrestrial food (e.g. milk, meat, cereals, vegetables and fruit, plus wild foods where relevant);
- Inhalation of radionuclides in the atmosphere;
- External irradiation from radionuclides in the atmosphere and deposited on the ground.

For aquatic discharges, i.e. to rivers, lakes, estuaries and the sea, the pathways of greatest importance are likely to be:

- Ingestion of radionuclides in aquatic foods (e.g. fish, crustaceans, molluscs and where relevant edible seaweeds and other biota);
- External irradiation from beta/gamma-emitting radionuclides on beaches or sediments (including while on houseboats) and whilst swimming.

3.4 The radionuclides to be monitored in an environmental monitoring programme may be selected by a regulatory authority and specified in a site licence because:

- of their potential radiological impact;
- the radionuclides may be representative of the mix in the waste streams;
- a particular radionuclide may be present in the waste stream at relatively large concentrations compared to others albeit its radiological significance is not great;
- it presents an easily monitored indicator of radiological impact.

- 3.5 An environmental monitoring programme should be designed to provide the following outputs:
- An estimate of public radiation exposure, using appropriate additional data and models.
  - Evidence of compliance with regulatory requirements.
  - If carried out by a regulator, information sufficient to check the results provided by a site operator.
  - A means of surveillance for inadvertent or unrecorded discharges.
  - Information to provide public reassurance.
- 3.6 An environmental monitoring programme may also provide information on:
- Trends in environmental levels, especially those which might indicate a chronic plant or process problem, but also due to environmental changes.
  - Data to enable improved dispersion modelling and radionuclide behaviour studies.
  - Information on which to improve the monitoring programme.

#### ***Self-monitoring arrangements***

- 3.7 It is common practice for the majority of environmental monitoring at a given site to be carried out by the site operator under self-monitoring arrangements. It is important to understand that self-monitoring is not self-regulation. Rather it is a practicable way of securing the most comprehensive and cost effective monitoring programme and ensuring that an operator takes full responsibility for all aspects, including the consequences, of its site's discharges [IMPEL, 1999]. In order to promote public confidence in self-monitoring arrangements and to ensure that they work satisfactorily regulators should specify the monitoring requirements and provide independent oversight by carrying out regular and comprehensive checks.
- 3.8 The following requirements for a self-monitoring programme should be specified by the regulator in the site licence:
- The measurements and samples to be taken, their locations and frequency.
  - In samples, the radionuclides and/or groups of radionuclides (e.g. gross beta) to be measured.
  - The methods of monitoring to be employed (e.g. continuous on-line instrumentation, continuous or periodic sampling with laboratory analysis, estimation).
  - The sampling and analytical methods (e.g. CEN Standard methods), appropriate calibration standards (e.g. <sup>137</sup>Cs for gross beta) to be employed.
  - Quality assurance needs (e.g. certification of a quality management system to ISO 9001, laboratory accreditation to EN 17025).
  - Data record keeping and reporting.
- 3.9 The regulator should have arrangements in place to check that operators are carrying out their self-monitoring programmes satisfactorily. These can include:
- Independent audits by certification and/or accreditation bodies related to ISO 9001 quality management systems and/or EN 17025 of laboratory and field measurement

respectively. However, in their generic format these audits may not provide sufficient in-depth focus on the technical aspects of the monitoring programme to meet all the regulator's requirements.

- Systematic audits or inspections by the regulator. Audits can be described as vertical investigations carried out by experts in measurement. For example, this could involve following a sample from the time it is taken, through laboratory analysis to final reporting. Inspections can be described as horizontal investigations carried out by site inspectors who will have a broad but not necessarily in-depth understanding of measurement. For example, they might focus on the totality of results for a given period, looking for trends, missing data and anomalies.
- Witnessed sampling. This involves an inspector or person contracted by the regulator to be present at the time when samples are being taken. This could provide, for example, for independent checks to be made that the measurements or samples are being taken at the right time, from the correct location and in the prescribed way. The inspector may request to have a replicate sample taken at the same time for the regulator's independent analysis.
- Independent analysis. This involves replicate samples (or sub-samples) from the self-monitoring programme being supplied by the operator to one or more of the regulator's laboratories for analysis. This can provide cost-effective and valuable independent checks on the reliability of the operator's results and analytical methods. However, without the witnessed sampling being applied on at least a selective and periodic basis the arrangement lacks true independence because of the reliance on the operator to supply the sample. It is important also that the analytical laboratories used by the operator and regulator are independent of one another, ie that both operator and regulator do not contract the same firm of analysts, unless arrangements are in place to ensure independence, in which case these arrangements should be fully understood and documented.
- Check monitoring programmes. These require the regulator or independent body contracted by the regulator to undertake take a parallel, but probably less extensive, environmental monitoring programme for analysis by the regulator's laboratory. Differences in results should be discussed between the operator and regulator, and can be investigated by narrowing the sources of potential discrepancy, e.g. by using replicate sampling, witnessed if necessary.

#### **4. Monitoring strategies**

4.1 Several different strategies can be used for environmental monitoring. These broadly fall into the following categories:

- On-line instrumentation. This can provide a real time continuous measurement, most usually of the ambient dose rates, and can form part of a geographical network. The results can trigger an alert and/or more specific monitoring.
- Instrumentation installed at given locations, active (e.g. high volume air samplers) or passive (e.g. TLDs or deposition collectors).
- Mobile instruments, hand-held or vehicle-mounted, e.g. gamma dose rate monitors or beta contamination monitors.
- Sampling and laboratory analysis. This is usually necessary for determination of specific radionuclides especially for alpha and beta emitters.

- Estimation. This is included here to indicate that for some sites, mainly those with discharges of very low radiological significance; it may be justifiable not to operate an active environmental monitoring programme but instead to estimate the radiation exposure of the public on the basis of the discharges and using appropriate models for radionuclide dispersion and dose.

4.2 The selection of the preferred monitoring strategy should take into account:

- The radiological significance of the site discharges.
- The radiological exposure pathway of interest.
- The objectives of the programme.
- The availability of instrumentation with appropriate detection capabilities, (e.g. detection limit, response time, sensitivity, discrimination).
- The availability of appropriate sampling equipment and locations.
- The availability of appropriate analytical facilities.

## 5. Classification of monitoring/sample types

5.1 For the purposes of this guidance the monitoring is classified into different types, as shown in Table C 1. The first classification step is into environmental sector, i.e. terrestrial or aquatic. The terrestrial environment is affected primarily by aerial discharges although there is some crossover due to processes such as irrigation and spreading of sewage sludge. The aquatic environment is affected primarily by liquid discharges though deposition and fallout/rainout can be important in some situations. The aquatic environment is divided into separate freshwater and maritime (ie marine/coastal) compartments as it is also possible to consider freshwater pathways as part of the terrestrial environment. For ease of cross-reference with section 6, each type of monitoring/sampling has been ascribed a number as shown in the last column.

**Table C 1. Monitoring/sample types**

Environment	Sample/monitoring type	Type number
Terrestrial	Terrestrial dose rate monitoring	T1
	Passive cloth collectors	T2
	High volume air samplers	T3
	Wet, dry, total deposition collectors	T4
	Grass/herbage	T5
	Soil	T6
	Milk	T7
	Fruit and vegetables	T8
	Meat and meat products	T9



	Eggs, honey, game, wild berries and mushrooms	T10
	Cereal	T11
	Contaminated land	T12
	Wildlife	T13
	In-situ (mobile) gamma spectrometry (including airborne)	T14
Freshwater	Surface water	F1
	Ground (borehole) water	F2
	Drinking water	F3
	Freshwater sediment	F4
	Leachate	F5
	Sewage and sludges	F6
	Road drain sediment	F7
	Waste water	F8
	Freshwater fish/shellfish	F9
	Freshwater plants	F10
Maritime	Estuary/coastal dose rate monitoring	M1
	Estuary/coastal contamination monitoring: general contamination	M2
	Estuary/coastal contamination monitoring: small particles	M3
	Contamination monitoring: fishing gear etc.	M4
	Sea water	M5
	Estuarine/coastal sediments	M6
	Seaweed	M7
	Fish	M8
	Shellfish	M9

## **6. Review of relevant guidance**

- 6.1 The relevant monitoring types or environmental media are classified according to Table C 1. The results of the review are presented in tabular form in Table C 2. References in the table are given in short form directly rather than at the end of this Annex.

**Table C 2 Guidance and standards for radiological monitoring and sampling of the environment**

Reference Source	Summary	Status	Sampling / Monitoring type (Codes given in Table 1)	Notes
Measurement of radioactivity in the environment. Soil - Part 1 General guide and definitions. ISO18589-1:2005(E)	Contains general requirements (guidelines, definitions, including sampling) for radio-assay on soil samples.	Standard (International)	T6	
Measurement of radioactivity in the environment. Soil - Part 2 Method for the selection of sampling strategy sampling and pre-treatment of samples. ISO/DIS 18589-2	Contains information on different approaches or sampling strategies, ensuring sample is representative of soil type. Includes information on storage, and pre-treatment to ensure physical-chemical characteristics are constant over time.	Standard (International)	T6	
Soil quality. Sampling - Part 1. Guidance on design of sampling programmes. ISO 10381-1:2002	Contains general principles to be applied in the design of sampling programmes for the purpose of characterising and controlling soil quality and identifying sources and effects of contamination of soil and related material.	Standard (International)	T6, F2	ISO 10381:2002 not specific to radioactivity
Soil quality. Sampling Part 2. Guidance on sampling techniques. ISO10381-2: 2002	Contains guidance on techniques for taking and storing soil samples. Provides information on typical equipment to enable specific sampling procedures to be carried out and representative samples to be collected. Guidance is given for use to enable both disturbed and undisturbed samples to be taken at different depths.	Standard (International)	T6, F2	
Soil quality. Sampling - Part 3: Guidance on safety. ISO 10381-3:2001	Contains information on personal protection, protection of buildings and installations, and protection of the environment.	Standard (International)	T6	
Soil quality. Sampling - Part 4: Guidance on the procedure for investigation of natural, near-natural and cultivated sites ISO 10381-4:2003	Contains information on the sampling of soils from areas used for agriculture, horticulture and special crop-cultivation. It sets out appropriate strategies for the design of sampling programmes, field procedures and subsequent treatment of samples for transport and storage prior to sample pre-treatment (e.g. drying, milling).	Standard (International)	T6	

Reference Source	Summary	Status	Sampling / Monitoring type (Codes given in Table 1)	Notes
Soil quality. Sampling - Part 5: Guidance on the procedure for the investigation of urban and industrial sites with regard to soil contamination. ISO 10381-5:2005	Provides guidance on the procedure for the investigation of urban and industrial sites, where either it is known that soil contamination is present, or the presence of soil contamination is suspected. It is used to establish the contamination status of a site, or to establish the environmental quality of a site for other purposes.	Standard (International)	T6, T12	
Soil quality. Pre-treatment of samples by freeze-drying for subsequent analysis. ISO 16720:2005	Specifies a method for pre-treatment of soil samples by freeze-drying for subsequent analysis. It applicable to soil samples for subsequent determination of elements recognised as non-volatile under freeze-drying conditions. and can also be applied to samples from other sediments.	Standard (International)	T6, F4, F6, F7, M6	
Milk and milk products. Guidance on sampling. ISO 707:2012	Provides guidance on methods of sampling milk and milk products. Includes information on sampling equipment and preservation, storage and transport of samples.	Standard (International)	T7	
Water Quality Sampling - Part 1: Guidance on design of sampling programmes. BS6068-6.1:1981, ISO5667-1:1980, EN25667-1:1994	Sets out the general principles to be applied for the purposes of quality control, quality characterisation, and identification of sources of pollution of water, including bottom deposits and sludges.	Standard (International)	F1,F2, F3, F5, M5	
Water Quality Sampling - Part 2: Guidance on sampling techniques. BS6068-6.2:1991, ISO5667-2:1991, BSEN25667-2:1993	Provides guidance for techniques used to obtain the data necessary to make analyses for the purposes of quality control, quality characterisation and identification of sources of pollution of waters.	Standard (International)	F1,F2,F3,F5, M5	Does not include detailed instructions for specific sampling situations

Reference Source	Summary	Status	Sampling / Monitoring type (Codes given in Table 1)	Notes
Water Quality Sampling - Part 3: Guidance on the preservation and handling of water samples. BS6068-6.3: 2003, ISO 5667-3:2003 BSENISO5667-3: 2003	Provides general guidelines on the precautions to be taken to preserve and transport all water samples including those for biological analyses but not those intended for microbiological analysis. These guidelines are particularly appropriate when spot or composite samples cannot be analysed on-site and have to be transported to a laboratory for analysis.	Standard (International)	F1,F2,F3,F5, M5	Provides detailed instructions for specific determinands
Water Quality - Part 6: Sampling. Section 6.4 Guidance on sampling from lakes, natural and man-made. BS6068-6.4: 1987, ISO5667-4: 1987	Presents detailed principles to be applied to the design of programmes, techniques and the handling and preservation of samples of water. The main objectives are measurements of quality characterisation, of quality control and for specific reasons (specific phenomena e.g. fish mortality). Microbiological examinations are not included.	Standard (International)	F1	
Water Quality - Part 6: Sampling. Section 6.5 Guidance on sampling drinking water and water used for food and beverage processing. BS6068-6.5: 1991, ISO5667-5: 2009	Provides guidance on design of sampling programmes, sampling techniques and the handling and preservation of samples. Includes the sampling of water in a treatment plant and the distribution system.	Standard (International)	F3	
Water Quality - Part 6: Sampling. Section 6.6 Guidance on sampling of rivers and streams. BS6068-6.6: 1991, ISO5667-6: 2014	Sets out the principles to be applied to the design of sampling programmes, sampling techniques and the handling of water samples from rivers and streams for physical and chemical assessment.	Standard (International)	F1	

Reference Source	Summary	Status	Sampling / Monitoring type (Codes given in Table 1)	Notes
Water Quality - Part 6: Sampling. Section 6.8 Guidance on sampling wet deposition. BS6068-6.8: 1993, ISO5667-8: 1993	Provides guidance on the design of sampling programmes and the choice of instrumentation and techniques for the sampling of the quality (main components) of wet deposition. Does not cover measurement of the quantity of rain, dry deposition or other types of wet deposition such as mist, fog and cloudwaters. The main objectives are control of local emissions and assessment of long range transport of airborne pollutants.	Standard (International)	T4	
Water Quality - Part 6: Sampling. Section 6.9 Guidance on sampling from marine waters. BS6068-6.9: 1993, ISO5667-9: 1992	Provides guidance on the principles to be applied to the design of sampling programmes, sampling techniques and the handling and preservation of samples of sea water from tidal waters.	Standard (International)	M5	
Water Quality - Part 6: Sampling. Section 6.10 Guidance on sampling from waste waters. BS6068-6.10: 1993, ISO5667-10: 1992	Contains details on the sampling of domestic and industrial waste water, i.e. the design of sampling programmes and techniques for collection of samples including safety aspects. Covers waste water in all its forms. Sampling of accidental spillages is not included, although the methods described in certain cases may also be applicable to spillages.	Standard (International)	F8	
Water Quality- Part 6: Sampling. Section 6.11 Guidance on sampling of ground waters. BS6068-6.11: 1993, ISO5667-11: 1993	Provides guidance on the design of sampling programmes, sampling techniques and the handling of water samples taken from groundwater for physical, chemical and microbiological assessment. The general purpose of sampling programmes for groundwaters is to survey the quality of groundwater supplies, to detect and assess groundwater pollution, to assist in groundwater resource management, and other more detailed objectives.	Standard (International)	F2	

Reference Source	Summary	Status	Sampling / Monitoring type (Codes given in Table 1)	Notes
Water Quality- Part 6: Sampling. Section 6.12 Guidance on sampling of bottom sediments. BS6068-6.12: 1996, ISO5667-12:1995	Provides guidance on the sampling of sediments from rivers, streams, lakes and similar standing waters and estuaries. Sampling of industrial and sewage work sludges and ocean sediments are excluded.	Standard (International)	F4	
Water Quality- Part 6: Sampling. Section 6.13 Guidance on sampling of sludges from sewage and waste water treatment plants. BS6068-6.13: 1998, ISO5667-13:1998	Provides guidance on sampling of sludges from sewage and water treatment works, water treatment works and industrial processes. It is applicable to all types of sludge.	Standard (International)	F6	
Water Quality - Part 6: Sampling. Section 6.14 Guidance on quality assurance of environmental water sampling and handling. BS6068-6.14: 1998, ISO5667-14: 1998	Provides guidance on the selection and use of various quality assurance techniques related to the manual sampling of surface, potable, waste, marine and ground waters.	Standard (International)	F1,F2,F3,M5	
Water Quality - Part 6: Sampling. Section 6.15 Guidance on the preservation and handling of sludge and sediment samples. BS6068-6.15: 1999, ISO5667-15:2009	Provides guidance on preservation and handling of sludge and sediment samples.	Standard (International)	F4,F6	
Water Quality - Part 6: Sampling. Section 6.17 Guidance sampling of suspended sediments. BS6068-6.17: 2000, ISO5667-17:2008	Provides guidance that is applicable to the sampling of suspended solids for the purpose of monitoring freshwater and particularly flowing freshwater systems (rivers and streams). Certain elements may be applicable to freshwater lakes and reservoirs.	Standard (International)	F4	
Water Quality - Part 6: Sampling. Section 6.18 Guidance sampling of groundwater at contaminated sites. BS6068-6.18: 2001, ISO5667-18:2001	Provides guidance on the sampling of groundwater at potentially contaminated sites. It is applicable where contamination of the subsurface could exist as a result of downward migration of contaminants.	Standard (International)	F2	

Reference Source	Summary	Status	Sampling / Monitoring type (Codes given in Table 1)	Notes
Water quality -- Sampling -- Part 19: Guidance on sampling of marine sediments ISO 5667-19:2004, BS 6068-6.19:2004	Provides guidance for the sampling of sediments in marine areas for analysis of their physical and chemical properties for monitoring purposes and environmental assessments. It encompasses sampling strategy, requirements for sampling devices, observations made and information obtained during sampling, handling, and packaging and storage of sediment samples.	Standard (International)	M6	
Agricultural food products - Layout for a standard method of sampling from a lot ISO 7002:1986	General rules for drafting standard methods; they cannot be used itself for sampling products. Rules for drafting individual aspects, such as title, introduction, scope, field of application, references, definitions, principle, administrative arrangements sampling equipment, procedures, packing, sealing and marking, precautions during storage and transportation of samples, sampling report.	Standard (International)	T8, T9, T10,T11	Food products in general
General principles for sampling airborne radioactive materials. BS5243:1975, ISO 2889:1975	Provides general principle to obtaining representative samples of airborne radioactive materials for gas and particle sampling.	Standard (International)	T2, T3	BS & ISO do not conflict
Compliance monitoring for remediated sites Chapter 4 IAEA-TECDOC-1118 October 1999	Includes an overview of monitoring techniques (measurements and sampling).	Guidance (International)	T1	
Collection and preparation of bottom sediment samples for analysis of radionuclides and trace elements IAEA-TECDOC-1360 July 2003	Provides information on the methods for collecting sediments, the equipment used, and the sample preparation techniques for radionuclide and trace metals.	Guidance (International)	F4, M6	
Soil sampling for environmental contaminants IAEA-TECDOC-1415 October 2004	A review to evaluate existing techniques with regard to their practicability, reliability and applicability to different purposes.	Guidance (International)	T6	



Reference Source	Summary	Status	Sampling / Monitoring type (Codes given in Table 1)	Notes
Environmental and Source Monitoring for Purposes of Radiation Protection. IAEA Safety Guide RS-G-1.8 Vienna, 2005	International guidance on strategy for monitoring of radioactive discharges at source, in the environment, and for individuals, both in normal situations and in interventions.	Guidance (International)	All	
Cereals and pulses -- Determination of hidden insect infestation -- Part 2: Sampling ISO 6639-2:2001	Shows general principles, apparatus, sampling times and places, pre-sampling inspection and identification of lots, sampling of bulk grain, sampling of grain in bags, preparation of laboratory sample, and packing, labelling and dispatch of laboratory samples.	Standard	T11	Not specific to radioactivity
EU Good Practice Guide on the Microbiological Monitoring of Shellfish Harvesting Areas	Provides guidance on the collection and processing of molluscan shellfish for human consumption.	Guidance	M9	Not specific to radioactivity
Gamma-ray spectrometry in the environment. ICRU report 53 (1994)	Guidance on use of in-situ gamma spectrometry in measurement of substrate concentrations and dose rates.	Guidance	T14	
Sampling for radionuclides in the environment. ICRU report 75 (2006)	Guidance on statistical selection of sampling points to provide representative data.	Guidance	All	

## **7. Best practice methodologies**

- 7.1 Best practice methods for the development of environmental monitoring programmes for relevant exposure pathways are presented below in Table C 3A for terrestrial monitoring, Table C 3B for freshwater-related monitoring, and Table C 3C for maritime monitoring.

**Table C 3A Best practice methodologies – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Dose rate monitoring (fluctuating dose rates and secure location)	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> - To provide integrated measurements of external radiation dose from airborne and deposited radionuclides, and direct radiation. Close to nuclear establishments, there may also be a significant contribution due to direct radiation (shine) from the site and this monitoring therefore provides a measure of total external dose to the most exposed (critical) population groups.</li> <li>• <b>Baseline</b> - Routine monitoring also provides baseline levels in the event of a radiological incident.</li> </ul>	<ul style="list-style-type: none"> <li>• Select passive dose rate monitor (e.g. TLD, film badge).</li> <li>• Instrument should meet defined performance criteria.</li> <li>• Ensure secure location.</li> <li>• Establish cosmic background.</li> <li>• Results reported as <math>\mu\text{Gy/h}</math> air kerma (state whether corrected for cosmic).</li> </ul>	<ul style="list-style-type: none"> <li>• Locate at height of 1 – 1.5 m in a secure location.</li> <li>• Locate such that shielding from source of exposure is minimised (e.g. away from walls, trees, hedges and roads).</li> <li>• Instruments to be deployed to meet defined dose rate measurement limit subject to a maximum period of 3 months to minimise loss of monitoring data if instrument is lost/fails.</li> <li>• Take measurements to ensure dose rate is representative over a scale of up to 5-10 m. This may be checked with spot dose rate measurements.</li> </ul>	
Dose rate monitoring (fluctuating dose rates and secure location)	<ul style="list-style-type: none"> <li>• <b>Continuous monitoring</b> - To monitor any changes due to releases from local or distant sources</li> </ul>	<ul style="list-style-type: none"> <li>• Multiple GM or scintillation counters networked to central electronic processing system.</li> </ul>	<ul style="list-style-type: none"> <li>• Locate at height of 1 – 1.5 m in a secure location.</li> <li>• Locate such that shielding from source of exposure is minimised (e.g. away from walls, trees, hedges and roads).</li> </ul>	

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Dose rate monitoring (non-secure location)	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> - To provide spot measurement of external radiation dose from airborne and deposited radionuclides, and direct radiation. Close to nuclear establishments, there may also be a significant contribution due to direct radiation (shine) from the site and this monitoring therefore provides a measure of total external dose to the most exposed (critical) population groups.</li> <li>• <b>Baseline</b> - Routine monitoring also provides baseline levels in the event of a radiological incident.</li> </ul>	<ul style="list-style-type: none"> <li>• Select instrument to take spot measurement (e.g. Mini 6-80, energy compensated NaI(Tl) detector).</li> <li>• Instrument should meet defined performance criteria, to include : <ul style="list-style-type: none"> <li>- Inherent background dose rate <math>&lt;0.015 \mu\text{Gy/h } ^{226}\text{Ra } \gamma</math></li> <li>- Cosmic ray response <math>&lt;0.07 \mu\text{Gy/h } ^{226}\text{Ra } \gamma</math></li> <li>- Air kerma based response <math>\pm 30\%</math> of the response to <math>^{137}\text{Cs } \gamma</math> radiation over the energy range 80 keV to 1.25 MeV</li> <li>- Adequate polar response</li> <li>- Precision</li> </ul> </li> <li>• Establish cosmic &amp; intrinsic background.</li> <li>• Ensure instrument is calibrated regularly (e.g. annually).</li> <li>• Ensure instrument is functioning before and after monitoring survey period (or weekly).</li> <li>• Correct measurements for cosmic &amp; intrinsic detector background.</li> <li>• Results reported as <math>\mu\text{Gy/h}</math> air kerma.</li> </ul>	<ul style="list-style-type: none"> <li>• Take measurement at height of 1 m.</li> <li>• Locate such that shielding from source of exposure is minimised (e.g. away from walls, trees, hedges and roads).</li> <li>• Take reading over sufficient time period to achieve sufficient statistical confidence at the defined minimum dose rate measurement limit.</li> <li>• Take measurements to ensure dose rate is representative over a scale of up to 5-10 m. Normally, a single dose rate measurement (e.g. Mini 6-80) will be representative at this scale, although dose rate can be measured at 2-3 locations at distances of 10 m apart over the same ground type and an average result reported).</li> <li>• Note that where geology is changing rapidly it may be difficult to choose a reference background dose rate for comparison</li> </ul>	

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
High/Medium Volume Air Sampling (HVAS / MVAS)	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> - inhalation exposure pathway for particulate radionuclides.</li> <li>• <b>Reassurance</b> – To detect abnormal releases.</li> <li>• <b>Model check</b> – To check reported discharges and air dispersion modelling.</li> <li>• <b>Environmental indicator</b> - To monitor the long-term concentrations of radionuclides in air from routine releases, resuspension and sea to land transfer.</li> </ul>	<ul style="list-style-type: none"> <li>• Ensure secure site and power supply.</li> <li>• Ensure noise is minimised.</li> <li>• HVAS/MVAS needs to collect total particulate (i.e. not specific size range) – This is cautious for the objectives.</li> <li>• Air flow to be measured with defined uncertainty (best practice instrument maintain flowrate automatically) – calibration will be required.</li> <li>• Filters should trap &gt;95% of particle size &gt;0.3 µm AMAD .</li> <li>• Mass of particulate collected to be measured (e.g. filters weighed before and after collection).</li> <li>• Results reported as Bq/m<sup>3</sup>.</li> </ul>	<ul style="list-style-type: none"> <li>• Cross-contamination to be avoided (e.g. sealed in polythene bags, take blank filters to field).</li> <li>• Ensure filters can be identified (e.g. uniquely label filters).</li> <li>• Sample for a period to ensure that defined detection limits can be achieved and avoid filter blinding (2 weeks is typical).</li> </ul>	

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Total deposition (wet and dry)	<ul style="list-style-type: none"> <li>• <b>Environmental indicator</b> – To monitor the long-term deposition of radionuclides from routine releases.</li> <li>• <b>Model check</b> –To provide field data to check reported discharges and air dispersion and deposition modelling.</li> <li>• <b>Reassurance</b> – To detect abnormal releases.</li> </ul>	<ul style="list-style-type: none"> <li>• Collect in a deposition collector (e.g. rain gauge).</li> <li>• Minimise adsorption of radionuclides to container (e.g. pre-soak containers and use carrier solutions).</li> <li>• Minimise growth of algae (e.g. use brown collection bottle).</li> <li>• Report results as Bq/L or Bq/m<sup>2</sup>/s.</li> </ul>	<ul style="list-style-type: none"> <li>• Record area of collection funnel and duration of time sample collected.</li> <li>• Ensure sample collection period will not cause sample container to over-flow, but sufficient sample is collected to ensure detection limit can be achieved. A typical collection period is one 2-4 weeks.</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C).</li> <li>• Filter samples through a 0.45µm membrane and analyse filtrate and residue if the monitoring objective requires information on the partitioning between dissolved and particulate phases (e.g. particulate deposition).</li> <li>• Ensure representative sub-sample is taken for analysis (e.g. shake liquid samples).</li> <li>• Bulk or concentrate samples (e.g. through ion exchange or evaporation) to achieve detection limits, if required.</li> </ul>

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Grass/ Herbage	<ul style="list-style-type: none"> <li>• <b>Environmental indicator</b> – To indicate whether there is likely to be significant concentrations in milk which is an important exposure pathway.</li> <li>• <b>Reassurance</b> – To detect abnormal releases. Can be more sensitive than milk as animals graze over a large area.</li> <li>• <b>Model check</b> – To check reported discharges and air dispersion/deposition modelling.</li> </ul>	<ul style="list-style-type: none"> <li>• Area may be fenced off to prevent removal of grass and unwanted additions (e.g. animal droppings, fertiliser). Also enables growth since last sample to be collected.</li> <li>• Samples should be collected at same location as soil samples if the objective is to validate dispersion, deposition and transfer modelling.</li> <li>• Report results as Bq/kg (fresh weight) and Bq/m<sup>2</sup>.</li> </ul>	<ul style="list-style-type: none"> <li>• Obtain a reasonably representative sample over a scale of up to 5-10 m from a known total area. This may be achieved by collecting 5 grass samples from a 0.25 - 1 m<sup>2</sup> quadrat at the points of a W shape or the ends and centre of an X shape over a circle of 10 m diameter. Grass/herbage samples should be representative of that present at a scale of up to 5-10 m. The samples may be bulked.</li> <li>• Trim sample approx 10mm above soil surface with shears (or similar), taking care not to collect any soil and excluding non-herbage (i.e. woody) material.</li> <li>• Store sample to prevent deterioration (e.g. airtight container).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight and preventing fusing of sample (e.g. oven dry 40-105°C or freeze dry). (May need to analyse wet for volatile radionuclides).</li> <li>• Record dry/wet ratio.</li> <li>• Ensure representative sub-sample is taken for analysis (e.g. use blender).</li> </ul>

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Soil	<ul style="list-style-type: none"> <li>• <b>Environmental indicator</b> – To indicate whether there is likely to be significant transfer into grass, and hence into milk which is an important exposure pathway.</li> <li>• <b>Model check</b> – To check recent reported discharges and air dispersion/deposition modelling.</li> <li>• <b>Wildlife</b> – To determine doses to wildlife.</li> </ul>	<ul style="list-style-type: none"> <li>• Samples should be collected from undisturbed permanent pasture</li> <li>• The area may be fenced off to protect the collection site.</li> <li>• Samples of soil in the root zone should be collected to achieve these objectives (typically 2-5cm).</li> <li>• It is normal to remove roots as far as reasonably practicable from the sample to achieve these objectives. However, it may be appropriate to include all the roots in the sample in certain circumstances.</li> <li>• Report results as Bq/kg (dry weight).</li> </ul>	<ul style="list-style-type: none"> <li>• Obtain a reasonably representative sample over a scale of up to 5-10 m. This may be achieved by collecting 5 soil samples from the points of a W shape or the ends and centre of an X shape over a circle of 10 m diameter. The samples may be bulked.</li> <li>• Remove surface litter and overlying vegetation.</li> <li>• Collect soil samples such that excessive damage to the collection site is minimised and that the sample is to a known depth. This may be achieved by collecting 4 – 10 cm diameter cores to a depth of 5 cm.</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight and preventing fusing of sample (e.g. oven dry 40-105°C or freeze dry). (May need to analyse wet for volatile radionuclides).</li> <li>• Record dry/wet ratio.</li> <li>• Remove gravel component by sieving to &lt;2mm and discarding &gt;2mm fraction.</li> <li>• Ensure representative sub-sample is taken for analysis (e.g. by grinding and coning and quartering).</li> </ul>



**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Soil core	<ul style="list-style-type: none"> <li>• <b>Model check</b> – To check historical discharges and air dispersion/deposition modelling.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> </ul>	<ul style="list-style-type: none"> <li>• Samples should be collected from undisturbed permanent pasture</li> <li>• The area may be fenced off to protect the collection site.</li> <li>• Samples will need to be sufficiently deep to achieve monitoring objectives. A typical practical depth is 15 cm.</li> <li>• Report results as Bq/kg (dry weight) and Bq/m<sup>2</sup>.</li> </ul>	<ul style="list-style-type: none"> <li>• Obtain a reasonably representative sample over a scale of up to 5-10 m. This may be achieved by collecting 5 soil samples from the points of a W shape or the ends and centre of an X shape over a circle of 10 m diameter. The samples may be bulked.</li> <li>• Remove surface litter and overlying vegetation.</li> <li>• Collect soil samples such that excessive damage to the collection site is minimised and that the sample is to a known depth. This may be achieved by collecting 4 – 10 cm diameter cores to a depth of 15 cm.</li> <li>• Record the area from of the sample (e.g. area of the core).</li> <li>• Section core into slices which enable the monitoring objectives to be achieved. Account may need to be taken of compression of the core, particularly for wet sediments. There is no need to section cores where the total deposition is being established for a baseline. Cores are typically sectioned into 5-10 cm slices. Clean core sectioning tool (blade) between slices.</li> <li>• Subsample from centre of each core slice to reduce smearing.</li> </ul>	<ul style="list-style-type: none"> <li>• As above</li> </ul>

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Milk and milk products	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To monitor the radiological exposure pathway from consumption of radioactivity in terrestrial foodstuffs.</li> <li>• <b>Reassurance</b> – Provide reassurance through the detection and monitoring of abnormal releases, contaminated foodstuffs.</li> <li>• <b>Environmental indicator</b> - monitor the long-term behaviour of radionuclides in foodstuffs arising from routine authorised releases.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> <li>• <b>Distribution</b> – Determine the spread of radionuclides through foodstuffs/the environment from radioactivity arising from routine authorised releases</li> <li>• <b>Model check</b> – Provide data that, along with other monitoring of soil, air and water, may be useful to check reported discharges and dispersion and transfer models.</li> </ul>	<ul style="list-style-type: none"> <li>• Two methods of preparation either the analysis of the raw edible fraction (e.g. milk collected directly from the farm) or via culinary preparation (in the case of milk this might mean sampling processed butter, milk etc.).</li> <li>• Report results as Bq/L. If results are reported as dry weight then the fresh/dry weight ratio should be provided.</li> </ul>	<ul style="list-style-type: none"> <li>• Rinse collection apparatus and container with sample (if milk).</li> <li>• Select a representative sample of the source material. Consider the area over which cattle have been grazing, if taken at the farm, how many animals should be sampled, sampling from the tanker etc.</li> <li>• Record the provenance of the sample to ensure traceability of the sample back to the field (links to representative nature of the sample).</li> <li>• Add carrier or preservative to milk as appropriate depending upon the radionuclide.</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. store in air tight containers, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Select a representative sub-sample for analysis (e.g. shake milk sample).</li> <li>• Concentrate sample if needed (e.g. evaporation, ion-exchange, freeze drying).</li> </ul>

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Cereal	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To monitor the radiological exposure pathway from consumption of radioactivity in terrestrial foodstuffs.</li> <li>• <b>Reassurance</b> – Provide reassurance through the detection and monitoring of abnormal releases, contaminated foodstuffs.</li> <li>• <b>Environmental indicator</b> - monitor the long-term behaviour of radionuclides in foodstuffs arising from routine authorised releases.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> <li>• <b>Distribution</b> – Determine the spread of radionuclides through foodstuffs/the environment from radioactivity arising from routine authorised releases</li> <li>• <b>Model check</b> – Provide data that, along with other monitoring of soil, air and water, may be useful to check reported discharges and dispersion and transfer models.</li> </ul>	<ul style="list-style-type: none"> <li>• Prepare the raw edible fraction (e.g. mature grain) for analysis. Culinary preparation may need to be taken into account (in the case of cereal this might mean sampling bread).</li> <li>• Approach outlined is for longer lived radionuclides that will still exist by the time the food product is available for human consumption.</li> <li>• For the objective of understanding distribution in the field, analysis does not need to focus on mature grain and any stage of the crop may be sampled and analysed fresh and immediately to detect short lived radionuclides.</li> <li>• Consider the need for local sampling versus retail sampling for national averages.</li> <li>• Report results as Bq/kg (fresh weight). If results are reported as dry weight then the fresh/dry weight ratio should be provided.</li> </ul>	<ul style="list-style-type: none"> <li>• Identify cereal type.</li> <li>• Sample the material at an appropriate time (e.g. as mature grain straight from the field or as grain that has been harvested).</li> <li>• Select a representative sample of the source material. When sampling in the field consider the location and size of area to be sampled (e.g. in the field collect sample from the ends of a W or X shaped sampling pattern). When sampling grain from sacks after harvesting, consider how many samples, which sacks etc. to sample.</li> <li>• Record the provenance of the sample to ensure traceability of the sample back to the field (links to representative nature of the sample).</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. store in air tight containers).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples in lab to prevent deterioration (e.g. chill at about 4°C or freeze)</li> <li>• Prepare samples to provide edible fraction (may require culinary preparation depending upon the objective).</li> <li>• Dry sample to constant weight (e.g. air dry, oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sampled in mill or blender or blending fresh samples, Cone and quarter if appropriate).</li> </ul>

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
<p>Meat &amp; meat products including wild or game foods such as:</p> <p>Hare, Rabbit</p>	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To monitor the radiological exposure pathway from consumption of radioactivity in terrestrial foodstuffs.</li> <li>• <b>Reassurance</b> – Provide reassurance through the detection and monitoring of abnormal releases, contaminated foodstuffs.</li> <li>• <b>Environmental indicator</b> - monitor the long-term behaviour of radionuclides in foodstuffs arising from routine authorised releases.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> <li>• <b>Distribution</b> – Determine the spread of radionuclides through foodstuffs/the environment from radioactivity arising from routine authorised releases</li> <li>• <b>Model check</b> – Provide data that, along with other monitoring of soil, air and water, may be useful to check reported discharges and dispersion and transfer models.</li> </ul>	<ul style="list-style-type: none"> <li>• Prepare the raw edible fraction for analysis (e.g. from a mature animal that would be sold commercially. Culinary preparation may need to be taken into account).</li> <li>• Approach outlined is for longer lived radionuclides that will still exist by the time the food product is available for human consumption.</li> <li>• Consider the need for local sampling versus retail sampling for national averages.</li> <li>• Report results as Bq/kg (fresh weight). If results are reported as dry weight then the fresh/dry weight ratio should be provided.</li> </ul>	<ul style="list-style-type: none"> <li>• Identify sample type and determine a representative cut/part of the animal (e.g. the thigh, neck etc to ensure select the edible fraction that would be consumed).</li> <li>• Select a representative sample noting that it may not be possible to be selective (e.g. some wild foods may be collected from road kills/natural deaths as opposed to culling).</li> <li>• Select sample(s) of muscle, liver and kidney as these cover the main sites of radionuclide accumulation and are all consumed in significant quantities.</li> <li>• Record the provenance of the sample to ensure traceability of the sample back to the field (links to representative nature of the sample).</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. store in air tight containers).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples in lab to prevent deterioration (e.g. chill at about 4°C or freeze).</li> <li>• Prepare samples to provide edible fraction (may require culinary preparation depending upon the objective).</li> <li>• Dry sample to constant weight (e.g. oven dry 40 – 105°C, freeze-dry). Analyse fresh if detection limits can be achieved and a representative sub-sample can be taken; or if volatile radionuclides are present).</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sample in mill or blender; or mincing fresh sample. Cone and quarter if appropriate).</li> </ul>

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
<p>Poultry, eggs and honey including wild or game foods such as:</p> <p>Goose, Mallard, Partridge, Pheasant, Pigeon, Teal</p>	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To monitor the radiological exposure pathway from consumption of radioactivity in terrestrial foodstuffs.</li> <li>• <b>Reassurance</b> – Provide reassurance through the detection and monitoring of abnormal releases, contaminated foodstuffs.</li> <li>• <b>Environmental indicator</b> - monitor the long-term behaviour of radionuclides in foodstuffs arising from routine authorised releases.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> <li>• <b>Distribution</b> – Determine the spread of radionuclides through foodstuffs/the environment from radioactivity arising from routine authorised releases</li> <li>• <b>Model check</b> – Provide data that, along with other monitoring of soil, air and water, may be useful to check reported discharges and dispersion and transfer models.</li> </ul>	<ul style="list-style-type: none"> <li>• Prepare the raw edible fraction for analysis (e.g. from a mature bird that would be sold commercially). Culinary preparation may need to be taken into account.</li> <li>• Approach outlined is for longer lived radionuclides that will still exist by the time the food product is available for human consumption.</li> <li>• Consider the need for local sampling versus retail sampling for national averages</li> <li>• Report results as Bq/kg (fresh weight). If results are reported as dry weight then the fresh/dry weight ratio should be provided.</li> </ul>	<ul style="list-style-type: none"> <li>• Identify sample type and determine a representative cut/part of the food stuff (e.g. the thigh or breast for the bird to ensure select the edible fraction).</li> <li>• Select a representative sample noting that it may not be possible to be selective (e.g. some wild foods may be collected from road kills/natural deaths as opposed to culling)</li> <li>• Select sample(s) of muscle, liver and kidney as these cover the main sites of radionuclide accumulation and are all consumed in significant quantities.</li> <li>• Record the provenance of the sample to ensure traceability of the sample back to the field (links to representative nature of the sample).</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. store in air tight containers).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples in lab to prevent deterioration (e.g. chill at about 4°C or freeze).</li> <li>• Prepare samples to provide edible fraction (may require culinary preparation depending upon the objective).</li> <li>• Dry sample to constant weight (e.g. air dry, oven dry 40 – 105°C, freeze-dry). Analyse fresh if detection limits can be achieved and a representative sub-sample can be taken; or if volatile radionuclides are present).</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sample in mill or blender; blending/whisking/stirring honey/eggs; or mincing fresh sample. Cone and quarter if appropriate).</li> </ul>

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
<p>Fruit &amp; Vegetables including wild foods such as:</p> <p>Apple, Bilberry, Blackberry, Cherry, Chestnut, Chive, Cobnut/hazelnut, Crab apple, Damson, Dandelion, Elderberry, Elderflower, Garlic, Hawthorn berry, Horseradish, Mayflower, Mint, Mushroom, Nettle, Peppermint, Plum, Raspberry, Rose hip, Rowanberry, Sloe, Strawberry, Watercress</p>	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To monitor the radiological exposure pathway from consumption of radioactivity in terrestrial foodstuffs.</li> <li>• <b>Reassurance</b> – Provide reassurance through the detection and monitoring of abnormal releases, contaminated foodstuffs.</li> <li>• <b>Environmental indicator</b> - monitor the long-term behaviour of radionuclides in foodstuffs arising from routine authorised releases.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> <li>• <b>Distribution</b> – Determine the spread of radionuclides through foodstuffs/the environment from radioactivity arising from routine authorised releases</li> <li>• <b>Model check</b> – Provide data that, along with other monitoring of soil, air and water, may be useful to check reported discharges and dispersion and transfer models.</li> </ul>	<ul style="list-style-type: none"> <li>• Prepare the raw edible fraction (e.g. mature fruit/vegetable as may be sold commercially) for analysis. Culinary preparation may need to be taken into account.</li> <li>• Approach outlined is for longer lived radionuclides that will still exist by the time the food product is available for human consumption.</li> <li>• Consider the need for local sampling versus retail sampling for national averages.</li> <li>• Report results as Bq/kg (fresh weight). If results are reported as dry weight then the fresh/dry weight ratio should be provided.</li> </ul>	<ul style="list-style-type: none"> <li>• Identify sample type.</li> <li>• Collect sample and remove any extraneous material.</li> <li>• Select a representative sample of the source material. When sampling in the field consider the location and size of area to be sampled (e.g. collect sample from the ends of a W or X shaped sampling pattern). For wild foods consider number of plants sampled (e.g. for blackberries and other hedgerow species, sample from along a 10m length of hedge).</li> <li>• Record the provenance of the sample to ensure traceability of the sample back to the field (links to representative nature of the sample).</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. store in air tight containers).</li> </ul>	<ul style="list-style-type: none"> <li>• Wash in water to remove soil (vegetables) and chemicals (fruit).</li> <li>• Store samples in lab to prevent deterioration (e.g. chill at about 4°C or freeze)</li> <li>• Prepare samples to provide edible fraction (may require culinary preparation depending upon the objective).</li> <li>• Dry sample to constant weight (e.g. air dry oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sample in mill or blending fresh samples. Cone and quarter if appropriate).</li> </ul>

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Wildlife (All species but not domesticated species such as cattle, sheep etc.)	<ul style="list-style-type: none"> <li>• <b>Wildlife</b> – To determine the radiological exposure to wildlife.</li> <li>• <b>Environmental indicator</b> - Monitor the long-term behaviour of radionuclides in wildlife arising from routine authorised releases.</li> </ul>	<ul style="list-style-type: none"> <li>• Report results as Bq/kg (fresh weight). If results are reported as dry weight then the fresh/dry weight ratio should be provided.</li> </ul>	<ul style="list-style-type: none"> <li>• Select species for required sampling.</li> <li>• Correctly identify species and collect road kill or cull if needed (bearing in mind the legal protection afforded to some species).</li> <li>• Record the provenance of the sample to ensure traceability of the sample back to the field (links to representative nature of the sample).</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. store in air tight container, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples in lab to prevent deterioration (e.g. chill at about 4°C or freeze)</li> <li>• Prepare samples as whole (including entrails) OR prepare specific portion of sample (e.g. thyroid).</li> <li>• Record weights of parts required for analysis and for discarded parts.</li> <li>• Dry sample to constant weight (e.g. oven dry 40 – 105°C, freeze-dry). Analyse fresh if detection limits can be achieved and a representative sub-sample can be taken; or if volatile radionuclides are present).</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sample in mill or blender; or mincing fresh sample. Cone and quarter if appropriate).</li> </ul>

**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Wildlife (cont.) (All species but not domesticated species such as cattle, sheep etc.)	<ul style="list-style-type: none"> <li>• <b>Reassurance</b> – Provide reassurance through the detection and monitoring of abnormal releases.</li> <li>• <b>Contamination</b> - To determine the potential for wildlife to spread radionuclide contamination.</li> </ul>	<ul style="list-style-type: none"> <li>• This is likely to be ad hoc monitoring or based on sample availability rather than routine targeted sampling.</li> <li>• Report results as Bq/kg (fresh weight). If results are reported as dry weight then the fresh/dry weight ratio should be provided.</li> </ul>	<ul style="list-style-type: none"> <li>• Select species for required sampling.</li> <li>• Correctly identify species and collect road kill or cull if needed (bearing in mind the legal protection afforded to some species) or sample faeces or live monitor. If faeces collected then guidance on storage and preparation of sewage sludge should be considered.</li> <li>• Record the provenance of the sample to ensure traceability of the sample back to the field (links to representative nature of the sample).</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. store in air tight containers, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples in lab to prevent deterioration (e.g. chill at about 4°C or freeze).</li> <li>• Prepare samples as whole (including entrails) OR prepare specific portion of sample (e.g. feathers).</li> <li>• Record weights of parts required for analysis and for discarded parts.</li> <li>• Dry sample to constant weight (e.g. oven dry 40 – 105°C, freeze-dry). Analyse fresh if detection limits can be achieved and a representative sub-sample can be taken; or if volatile radionuclides are present).</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sample in mill or blender; or mincing fresh sample. Cone and quarter if appropriate).</li> </ul>



**Table C 3A Continued – Terrestrial monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
In-situ (mobile) gamma spectrometry, including airborne	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> - To provide spot measurement of external radiation dose from airborne and deposited radionuclides, and direct radiation. Spectrometry can differentiate these components and from background.</li> <li>• <b>Mapping of concentration/dose rates</b>- Deposition of gamma emitters and resulting dose rates can be mapped.</li> <li>• <b>Baseline</b> - Routine monitoring also provides baseline levels in the event of a radiological incident.</li> </ul>	<ul style="list-style-type: none"> <li>• Select instrument to meet objective, e.g. NaI(Tl) detectors for efficiency or Ge detectors for good resolution</li> <li>• Ensure instrument is calibrated regularly (e.g. annually) against a standard or mixed nuclide set of standards to achieve objective of measurement, i.e. deposition or dose rate.</li> <li>• Ensure instrument is functioning before and after monitoring survey period (or weekly).</li> <li>• Correct measurements for cosmic background.</li> <li>• Results reported as <math>\mu\text{Gy/h}</math> air kerma or <math>\text{Bq/m}^2</math>.</li> </ul>	<ul style="list-style-type: none"> <li>• Take measurement at height of 1 m. if ground-based, otherwise at calibrated height.</li> <li>• Take reading over sufficient time period/speed of moving detector to achieve appropriate statistical confidence.</li> <li>• Note that where geology is changing rapidly it may be difficult to choose a reference background dose rate for comparison</li> </ul>	

**Table C 3B – Freshwater-related monitoring, best practice**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Surface freshwater (e.g. rivers, streams, lakes)	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> - To determine the dose from consumption of drinking water, consumption of irrigated crops and consumption of meat products where animals drink water.</li> <li>• <b>Wildlife</b> – To determine doses to wildlife.</li> <li>• <b>Environmental indicator</b> - To monitor the long-term concentrations.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> <li>• <b>Model check</b> – To check historical discharges and air dispersion/deposition modelling.</li> </ul>	<ul style="list-style-type: none"> <li>• Determine appropriate sample container dependent upon radionuclide(s) to be sampled.</li> <li>• Report results as Bq/L.</li> </ul>	<ul style="list-style-type: none"> <li>• Rinse collection apparatus and container with sample.</li> <li>• Collect representative sample.</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to minimise growth of algae and avoid degradation of sample (e.g. chill at about 4°C in the dark).</li> <li>• Filter samples through a 0.45µm membrane and analyse filtrate and residue if the monitoring objective requires information on the partitioning between dissolved and particulate phases.</li> <li>• Ensure representative sub-sample is taken for analysis (e.g. shake water sample).</li> <li>• Concentrate sample if needed (e.g. through ion exchange or evaporation).</li> <li>• Preserve with nitric acid for long storage (analysis dependant).</li> </ul>

**Table C 3B continued – Freshwater-related monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Freshwater sediments	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> - To determine the potential source of exposure through inhalation and inadvertent ingestion during recreational activities.</li> <li>• <b>Wildlife</b> – To determine doses to wildlife.</li> </ul>	<ul style="list-style-type: none"> <li>• Take samples from exposed river bed or banks of river (if regularly inundated).</li> <li>• Use hand-held detectors to guide sampling</li> <li>• Report results as Bq/kg (dry weight).</li> </ul>	<ul style="list-style-type: none"> <li>• Take samples from predominant sediment type.</li> <li>• Obtain a sample which is reasonable representative over a scale of up to 5-10 m. This may be achieved by selecting sampling positions from 5 points along the exposed river bed or bank at distance of 1 m apart. Samples may be bulked.</li> <li>• Collect surface sediment samples (0-1 cm) with flat hand shovel (or appropriate tool) over selected area.</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight and preventing fusing of sample (e.g. oven dry 40-105°C or freeze dry). (May need to analyse wet for volatile radionuclides).</li> <li>• Record dry/wet ratio.</li> <li>• Remove gravel component by sieving to &lt;2mm and discarding &gt;2mm fraction.</li> <li>• Ensure representative sub-sample is taken for analysis (e.g. by grinding and coning and quartering).</li> </ul>
	<ul style="list-style-type: none"> <li>• <b>Environmental indicator</b> - To monitor the long-term concentrations.</li> <li>• <b>Distribution</b> – Examine areas of deposition / concentration.</li> </ul>	<ul style="list-style-type: none"> <li>• As above</li> </ul>	<ul style="list-style-type: none"> <li>• As above</li> </ul>	<ul style="list-style-type: none"> <li>• As above</li> <li>• May need to restrict grain size fraction (e.g. sieve to &lt;250 µm) or report factors which can influence concentrations (e.g. grain size, loss on ignition at 450°C which is a good surrogate for grain size). Results may be normalised by these factors to reduce variability .</li> </ul>

**Table C 3B continued – Freshwater-related monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Freshwater sediments (cont.)	<ul style="list-style-type: none"> <li>• <b>Investigative/model check</b> – To investigate the impact of historical discharges and check models against these discharges.</li> </ul>	<ul style="list-style-type: none"> <li>• This may require sampling over water in a boat.</li> <li>• Report results as Bq/kg (dry weight).</li> </ul>	<ul style="list-style-type: none"> <li>• Take core samples using an appropriate device.</li> <li>• Obtain a sample which is reasonably representative across the width of the river. This may be achieved with 5 core samples of 10 cm diameter taken equidistant across the river.</li> <li>• The depth of the core should be enable the monitoring objectives to be achieved, but may be limited to 5-10 cm, if there is little sediment above the bedrock. It should be noted that longer cores can be affected by compression, with this being greatest near the (wetter) top. Account of this will need to be taken when preparing the core further.</li> <li>• Section core into slices which enable the monitoring objectives to be achieved. Cores are typically sectioned into 5-10 cm slices. Clean core sectioning tool (blade) between slices.</li> <li>• Subsample from centre of each core slice to reduce smearing.</li> <li>• Bulk the same sections of cores together as appropriate.</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight and preventing fusing of sample (e.g. oven dry 40-105°C or freeze dry). (May need to analyse wet for volatile radionuclides).</li> <li>• Record dry/wet ratio.</li> <li>• Remove gravel component by sieving to &lt;2mm and discarding &gt;2mm fraction.</li> <li>• Ensure representative sub-sample is taken for analysis (e.g. by grinding and coning and quartering).</li> </ul>

**Table C 3B continued – Freshwater-related monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Road drain sediments (gully pots)	<ul style="list-style-type: none"> <li><b>Environmental indicator</b> – To provide an indicator of authorised or unauthorised fugitive releases, land contamination and migration of contamination.</li> </ul>	<ul style="list-style-type: none"> <li>Determine when gully pot last cleaned.</li> <li>Report results as Bq/kg (dry weight).</li> </ul>	<ul style="list-style-type: none"> <li>Check that drain is receiving water run-off.</li> <li>Collect sediment sample with appropriate tool (e.g. long handled trowel).</li> <li>Arrange for cleaning of road drain post-sampling, to provide better information on timing of any contamination.</li> </ul>	<ul style="list-style-type: none"> <li>Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chilled at about 4°C or freeze).</li> <li>Dry sample to constant weight and preventing fusing of sample (e.g. oven dry 40-105°C or freeze dry). (May need to analyse wet for volatile radionuclides).</li> <li>Record dry/wet ratio.</li> <li>Remove gravel, litter etc. by sieving to &lt;2mm and discarding &gt;2mm fraction.</li> <li>Ensure representative sub-sample is taken for analysis (e.g. by grinding and coning and quartering).</li> </ul>
Leachate (landfill)	<ul style="list-style-type: none"> <li><b>Environmental indicator</b> – To provide an indicator of land contamination and migration of contamination.</li> <li><b>Critical group dose</b> – To assess dose if leachate is disposed of to sewage treatment works and then into the environment.</li> </ul>	<ul style="list-style-type: none"> <li>Detailed guidance on collection of samples from boreholes is provided in References 1 – 5.</li> <li>Report results as Bq/L (for dissolved and particulate phases) and kg/l of particulate (if appropriate).</li> </ul>	<ul style="list-style-type: none"> <li>Determine sample collection depth based on monitoring requirements.</li> <li>Select collection apparatus (e.g. bailer or pump) – use pump only if content &lt; 5% solid. Suction pumps are only recommended for depths of &lt;8m. A submersible pump is required for deeper boreholes.</li> <li>Purge borehole (3 borehole volumes).</li> <li>Rinse collection apparatus and container with sample.</li> <li>Collect representative sample.</li> <li>Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions).</li> </ul>	<ul style="list-style-type: none"> <li>Store samples at laboratory to minimise growth of algae and avoid degradation of sample (e.g. chill at about 4°C or freeze in the dark).</li> <li>Filter samples through a 0.45µm membrane and analyse filtrate and residue if the monitoring objective requires information on the partitioning between dissolved and particulate phases (e.g. migration of leachate into groundwater).</li> <li>Ensure representative sub-sample is taken for analysis (e.g. shake liquid samples).</li> </ul>

**Table C 3B continued – Freshwater-related monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Sewage/sludges	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To assess dose to sewage treatment workers and other exposed groups as a result of disposal of sludge.</li> <li>• <b>Environmental indicator</b> – To check discharge of radioactivity into sewerage systems.</li> <li>• <b>Model check</b> – To check models for transfer of radionuclides to sludge.</li> </ul>	<ul style="list-style-type: none"> <li>• Report results as Bq/L or Bq/kg (dry weight) depending on water content.</li> </ul>	<ul style="list-style-type: none"> <li>• Collect sample in a container which minimises any offensive smell.</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight and preventing fusing of sample (e.g. oven dry 40-105°C in a well ventilated oven or freeze dry). (May need to analyse wet for volatile radionuclides or if smell is too offensive to allow drying).</li> <li>• Record dry/wet ratio.</li> <li>• Ensure representative sub-sample is taken for analysis (e.g. shake liquid samples).</li> </ul>

**Table C 3B continued – Freshwater-related monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Drinking water (tap water)	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To monitor the radiological exposure pathway from consumption of radioactivity in drinking water.</li> <li>• <b>Reassurance</b> – Provide reassurance through the detection and monitoring of abnormal releases, contaminated water.</li> <li>• <b>Environmental indicator</b> - monitor the long-term behaviour of radionuclides in drinking water arising from routine authorised releases.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> </ul>	<ul style="list-style-type: none"> <li>• Determine appropriate sample container dependent upon radionuclide(s) to be sampled.</li> <li>• Decide upon whether you want mains tap water or the water from within the household pipework.</li> <li>• Record site location of sample.</li> <li>• Follow radon specific protocol if measuring for radon.</li> <li>• Report results as Bq/L.</li> </ul>	<ul style="list-style-type: none"> <li>• Rinse collection apparatus and container with sample.</li> <li>• Take representative sample bearing in mind the need to allow tap to run for adequate time interval depending upon sample type requirement (household or mains water).</li> <li>• Collect water sample directly into the container.</li> <li>• Minimise radionuclide adsorption to container walls by adding a carrier or preservative to water as appropriate (dependent upon the radionuclide).</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions).</li> </ul>	<ul style="list-style-type: none"> <li>• Minimise growth of algae and avoid degradation of sample (e.g. by keeping sample cool and in the dark during storage).</li> <li>• Do not filter sample.</li> <li>• Concentrate sample if needed (e.g. through ion exchange or evaporation).</li> </ul>

**Table C 3B continued – Freshwater-related monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Drinking water (wells or groundwater - assumed to be local consumers direct from groundwater via borehole or spring)	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To monitor the radiological exposure pathway from consumption of radioactivity in drinking water.</li> <li>• <b>Reassurance</b> – Provide reassurance through the detection and monitoring of abnormal releases, contaminated water.</li> <li>• <b>Environmental indicator</b> - monitor the long-term behaviour of radionuclides in drinking water arising from routine authorised releases.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> </ul>	<ul style="list-style-type: none"> <li>• Detailed guidance on collection of groundwater samples is provided in References 1 – 5.</li> <li>• Determine appropriate sample container dependent upon radionuclide(s) to be sampled.</li> <li>• If used, confirm borehole is suitable for sampling and representative of the water consumed.</li> <li>• Record site location of sample.</li> <li>• Follow radon specific protocol if measuring for radon.</li> <li>• Report results as Bq/L.</li> </ul>	<ul style="list-style-type: none"> <li>• Identify geochemical strata (water origin).</li> <li>• Select collection apparatus (e.g. bailer or pump) – use pump only if content &lt; 5% solid. Suction pumps are only recommended for depths of &lt;8m. A submersible pump is required for deeper boreholes.</li> <li>• Purge borehole (3 borehole volumes).</li> <li>• Rinse collection apparatus and container with sample.</li> <li>• Collect representative sample.</li> <li>• Minimise radionuclide adsorption to container walls by adding a carrier or preservative to water as appropriate (dependent upon the radionuclide).</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions).</li> </ul>	<ul style="list-style-type: none"> <li>• Keep sample cool (away from heat sources) and in the dark during storage.</li> <li>• Do not filter sample.</li> <li>• Concentrate sample if needed (e.g. through ion exchange or evaporation).</li> </ul>



**Table C 3B continued – Freshwater-related monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Freshwater fish and shellfish	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To monitor the radiological exposure pathway from consumption of radioactivity in terrestrial foodstuffs.</li> <li>• <b>Reassurance</b> – Provide reassurance through the detection and monitoring of abnormal releases, contaminated foodstuffs.</li> <li>• <b>Environmental indicator</b> - monitor the long-term behaviour of radionuclides in foodstuffs arising from routine authorised releases.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> <li>• <b>Distribution</b> – Determine the spread of radionuclides through foodstuffs/the environment from radioactivity arising from routine authorised releases</li> <li>• <b>Model check</b> – Provide data that, along with other monitoring of soil, air and water, may be useful to check reported discharges and dispersion and transfer models.</li> </ul>	<ul style="list-style-type: none"> <li>• Select species to meet monitoring objective (e.g. stage of growth, availability).</li> <li>• Report results as Bq/kg (fresh weight).</li> </ul>	<ul style="list-style-type: none"> <li>• Correctly identify species caught by net or line.</li> <li>• Store samples during transport to prevent deterioration.</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Prepare the raw edible fraction for analysis. Culinary preparation may need to be taken into account.</li> <li>• Dry sample to constant weight (e.g. oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/wet ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sample in mill or blending fresh samples. Cone and quarter if appropriate).</li> </ul>

**Table C 3B continued – Freshwater-related monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Freshwater plants	<ul style="list-style-type: none"> <li>• <b>Environmental indicator</b> – Provides a good indicator of recent discharges, particularly for more soluble radionuclides.</li> <li>• <b>Model check</b> – To check historical discharges and aquatic dispersion modelling.</li> </ul>	<ul style="list-style-type: none"> <li>• Consider seasonal (annual) cycle on sampling strategy.</li> <li>• Selection of recent growth for analysis will provide a better indicator of recent discharges than analysis of a whole frond which will lead to an indicator of integrated discharges over a few years.</li> <li>• Report results as Bq/kg (fresh weight)</li> </ul>	<ul style="list-style-type: none"> <li>• Correctly identify single species (including hybrids) as determined to meet objective.</li> <li>• Collect and trim recent growth from fronds.</li> <li>• Note presence of fruiting bodies which may affect results, due to changes in plant physiology.</li> <li>• Wash in water to remove particulate and epiphytes.</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight (e.g. air dry, oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sampled in mill or blender or blending fresh samples, Cone and quarter if appropriate).</li> </ul>
	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To assess dose to exposed population groups from consumption as food.</li> </ul>	<ul style="list-style-type: none"> <li>• Consider seasonal (annual) cycle on sampling strategy.</li> <li>• Report results as Bq/kg (fresh weight)</li> </ul>	<ul style="list-style-type: none"> <li>• Correctly identify food species.</li> <li>• Collect fresh plant (recent growth) or parts used for food according to local practice.</li> <li>• Wash in water to remove particulate and epiphytes.</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight (e.g. air dry, oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sampled in mill or blender or blending fresh samples, Cone and quarter if appropriate).</li> </ul>

**Table C 3B continued – Freshwater-related monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Freshwater plants (cont.)	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To assess dose from use of plant as compost and consumption of food.</li> </ul>	<ul style="list-style-type: none"> <li>• Consider seasonal (annual) cycle on sampling strategy.</li> <li>• Report results as Bq/kg (fresh weight)</li> </ul>	<ul style="list-style-type: none"> <li>• Correctly identify the species used for compost and collect sample (according to local practice).</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight (e.g. air dry, oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sampled in mill or blender or blending fresh samples, Cone and quarter if appropriate).</li> </ul>

**Table C 3C – Maritime monitoring, best practice**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Estuary/coastal dose rate monitoring	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> - To provide measurements of external radiation dose from radionuclides incorporated in sediments.</li> <li>• <b>Model check</b> - To check reported discharges and dispersion and dose rate models.</li> <li>• <b>Baseline</b> - Routine monitoring also provides baseline levels in the event of a radiological incident.</li> <li>• <b>Reassurance</b> – To detect abnormal releases and to reassure members of the public using inter-tidal areas.</li> </ul>	<ul style="list-style-type: none"> <li>• Identify and note sediment type and weather conditions.</li> <li>• Select instrument to take spot measurement (e.g. Mini 6-80, energy compensated NaI(Tl) detector ).</li> <li>• Instrument should meet defined performance criteria, to include : <ul style="list-style-type: none"> <li>- Inherent background dose rate <math>&lt;0.015\mu\text{Gy/h }^{226}\text{Ra } \gamma</math></li> <li>- Cosmic ray response <math>&lt;0.07\mu\text{Gy/h }^{226}\text{Ra } \gamma</math></li> <li>- Air kerma based response <math>\pm 30\%</math> of the response to <math>^{137}\text{Cs } \gamma</math> radiation over the energy range 80 keV to 1.25 MeV</li> <li>- Adequate polar response</li> <li>- Precision</li> </ul> </li> <li>• Establish cosmic &amp; intrinsic background.</li> <li>• Ensure instrument is calibrated regularly (e.g. annually).</li> <li>• Ensure instrument is functioning before and after monitoring survey period (or weekly).</li> <li>• Correct measurements for cosmic &amp; intrinsic detector background.</li> <li>• Results reported as <math>\mu\text{Gy/h}</math> over sediment type (including natural background).</li> </ul>	<ul style="list-style-type: none"> <li>• Take measurement at height of 1 m.</li> <li>• Operator should stand at least 10 m away from the detector to prevent effects of shielding.</li> <li>• Take reading over sufficient time period to achieve sufficient statistical confidence at the defined minimum dose rate measurement limit.</li> <li>• Take measurements to ensure dose rate is representative over a scale of up to 5-10 m. Normally, a single dose rate measurement (e.g. Mini 6-80) will be representative at this scale, although dose rate can be measured at 2-3 locations at distances of 10 m apart over the same ground type and an average result reported).</li> <li>• Note that where geology is changing rapidly it may be difficult to choose a reference background dose rate for comparison.</li> </ul>	-

**Table C 3C continued – Maritime monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Estuary/coastal dose rate monitoring (cont.)	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> - To establish <math>\beta</math> and <math>\gamma</math> dose rate over sediments to enable doses to people in close proximity to them (e.g. seated anglers) to be assessed.</li> </ul>	<ul style="list-style-type: none"> <li>• Identify and note sediment type and weather conditions.</li> <li>• Select instrument to take spot measurements (e.g. Berthold 122)</li> <li>• Instrument should meet defined performance criteria, to include: <ul style="list-style-type: none"> <li>- Detection efficiency / sensitivity capability</li> <li>- Precision</li> <li>- Energy response that matches the quantity of interest</li> </ul> </li> <li>• Ensure instrument is calibrated regularly (e.g. annually).</li> <li>• Ensure instrument is functioning before and after monitoring survey period (or weekly).</li> <li>• Results reported as <math>\mu\text{Gy/h}</math> over sediment type (including natural background).</li> </ul>	<ul style="list-style-type: none"> <li>• The height at which to take the measurement should be appropriate to the habit being assessed (e.g. 15cm for seated anglers).</li> <li>• Take appropriate number of readings across the surface, to be representative of the item being monitored, with shield on (<math>\gamma</math> only) and without shield (<math>\beta</math> and <math>\gamma</math>).</li> <li>• Take reading over sufficient time period to achieve defined dose rate measurement limit (using integrating function of instrument).</li> </ul>	-

**Table C 3C continued – Maritime monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Estuary/coastal contamination monitoring – Strandline and small particles and objects ( <i>by foot</i> )	<ul style="list-style-type: none"> <li>• <b>Reassurance / investigation</b> – to look for anomalies (areas of elevated activity) and to detect and remove any hot particles (defined by significantly elevated count rate) or objects with elevated activity on beaches.</li> </ul>	<ul style="list-style-type: none"> <li>• Monitoring by foot where this is more cost effective than monitoring by vehicle.</li> <li>• Identify and note point in the tidal cycle. Allow for tide times to ensure access.</li> <li>• Identify and note the weather conditions.</li> <li>• Select instrument to take measurements (e.g. probe with Geiger-Muller detector)</li> <li>• Instrument should meet defined performance criteria, (to enable a hot particle as defined to be detected) to include: <ul style="list-style-type: none"> <li>- Detection efficiency / sensitivity capability</li> <li>- Precision</li> <li>- Detector should be chosen to maximise the ability to detect the potential contaminant taking account of the local background</li> <li>- Response time</li> </ul> </li> <li>• Ensure instrument is calibrated regularly (e.g. annually).</li> <li>• Ensure instrument is functioning before and after monitoring survey period (or weekly).</li> <li>• Results reported as counts/s.</li> <li>• Also <math>\mu\text{Sv/h}</math> from the hot particle or object (if appropriate conversion factors available).</li> </ul>	<ul style="list-style-type: none"> <li>• Monitor strandline (order of importance; most recent tide-line, the extreme high water mark and wind-blown debris above the extreme high water mark) by walking with instrument. Crevices can be investigated as necessary.</li> <li>• Probe should be kept just above the ground surface and moved in side to side sweeps at a defined rate allowing for instrument response time (e.g. <math>&lt; 0.5\text{m/s}</math>). Looking to detect an increase in counts.</li> <li>• Procedures should be defined for what action to take if a hot particle is found. These will need to address health &amp; safety requirements, responsibility for custody and detailed analytical requirements.</li> <li>• If increased count rate is associated with a wider area of contamination may need to move in to a characterisation phase to determine its extent.</li> <li>• Record general count rate range for the defined transect that has been surveyed.</li> </ul>	-

**Table C 3C continued – Maritime monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Estuary/coastal contamination monitoring – Strandline and small particles and objects ( <i>by vehicle</i> )	<ul style="list-style-type: none"> <li>• <b>Reassurance / investigation</b> – to look for anomalies (areas of elevated activity) and to detect and remove any hot particles or objects with elevated activity on beaches.</li> </ul>	<ul style="list-style-type: none"> <li>• Monitoring by vehicle where this is more cost effective than monitoring by foot.</li> <li>• Identify and note point in the tidal cycle. Allow for tide times to ensure access.</li> <li>• Identify and note the weather conditions.</li> <li>• Select instrument to take measurements (e.g. NaI (TI) detectors, vehicle/detectors)</li> <li>• Instrument should meet defined performance criteria, (to enable a hot particle as defined to be detected) to include: <ul style="list-style-type: none"> <li>- Detection efficiency / sensitivity capability</li> <li>- Precision</li> <li>- Detector should be chosen to maximise the ability to detect the potential contaminant taking account of the local background</li> <li>- Response time</li> </ul> </li> <li>• Ensure instrument is calibrated regularly (e.g. annually).</li> <li>• Ensure instrument is functioning before and after monitoring survey period (or weekly).</li> <li>• Results reported as <math>\mu\text{Sv/h}</math> from the hot particle or object (if appropriate conversion factors available).</li> </ul>	<ul style="list-style-type: none"> <li>• Rate of vehicle travel to be defined to allow for time for the instrument response and defined detection criteria to be met.</li> <li>• Travel the area using sweeps, at intervals to meet defined detection criteria.</li> <li>• Procedures should be defined for what action to take if a hot particle is found. These will need to address health &amp; safety requirements, responsibility for custody and detailed analytical requirements.</li> <li>• If increased count rate is associated with a wider area of contamination may need to move in to a characterisation phase to determine its extent.</li> <li>• Record general count rate range for the defined transect that has been surveyed.</li> </ul>	-

**Table C 3C continued – Maritime monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Estuary/coastal contamination monitoring – areas where hot particles are prone to accumulate.	<ul style="list-style-type: none"> <li>• <b>Reassurance / investigation</b> – to look for hot particles in areas where they are prone to accumulate.</li> </ul>		-	-
Contamination monitoring of objects (ropes, nets, lobster pots)	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> - To establish <math>\beta</math> and <math>\gamma</math> contact dose rate to enable dose to skin to be assessed.</li> <li>• <b>Reassurance</b> – To provide reassurance to fishermen etc.</li> </ul>	<ul style="list-style-type: none"> <li>• Select instrument to take spot measurements (e.g. Berthold 122)</li> <li>• Instrument should meet defined performance criteria, to include: <ul style="list-style-type: none"> <li>- Detection efficiency / sensitivity capability</li> <li>- Precision</li> <li>- Energy response that matches the quantity of interest</li> <li>- Appropriate calibration factor developed</li> </ul> </li> <li>• Ensure instrument is calibrated regularly (e.g. annually).</li> <li>• Ensure instrument is functioning before and after monitoring survey period (or weekly).</li> <li>• Results reported as <math>\mu\text{Gy/h}</math>.</li> </ul>	<ul style="list-style-type: none"> <li>• Take measurement at just above the material being monitored, ensuring that window membrane is not punctured.</li> <li>• For ropes and nets, monitor in the manner used by fishermen.</li> <li>• Take appropriate number of readings across the surface, to be representative of the item being monitored, with shield on (<math>\gamma</math> only) and without shield (<math>\beta</math> and <math>\gamma</math>).</li> <li>• Take reading over sufficient time period to achieve defined dose rate measurement limit (using integrating function of instrument).</li> </ul>	-



Table C 3C continued – Maritime monitoring

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Seawater	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – External dose and dose from inadvertent consumption of seawater during leisure activities or fishing activities.</li> <li>• <b>Wildlife</b> – To determine doses to wildlife.</li> <li>• <b>Environmental indicator</b> - To monitor the long-term concentrations. Provide precursory information with regard to incorporation of radionuclides in sediment, fish and shellfish.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> </ul>	<ul style="list-style-type: none"> <li>• Beach collection of seawater samples.</li> <li>• Minimise adsorption of radionuclides to container (e.g. pre-soak containers and use carrier solutions).</li> <li>• Report results as Bq/L.</li> </ul>	<ul style="list-style-type: none"> <li>• Allow for tide times to ensure access (for beach collection).</li> <li>• Rinse collection apparatus and container with sample.</li> <li>• Collect water (use water submersible pump for large volume samples or bucket/carboy for small volume samples).</li> <li>• Continuous automatic sampling maybe required.</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to minimise growth of algae and avoid degradation of sample (e.g. chill at about 4°C in the dark).</li> <li>• Filter samples through a 0.45µm membrane and analyse filtrate and residue if the monitoring objective requires information on the partitioning between dissolved and particulate phases.</li> <li>• Ensure representative sub-sample is taken for analysis (e.g. shake water sample).</li> <li>• Concentrate sample if needed (e.g. through ion exchange or evaporation).</li> <li>• Preserve with nitric acid for long storage (analysis dependant).</li> </ul>
	<ul style="list-style-type: none"> <li>• <b>Model check</b> – To check historical discharges and sea dispersion modelling.</li> <li>• <b>Distribution</b>- To provide an inventory in a given area.</li> </ul>	<ul style="list-style-type: none"> <li>• Need to determine whether beach collection would meet the monitoring objective.</li> <li>• May involve sampling off shore in a boat.</li> <li>• Need to determine whether surface water, samples from depth, averaged water column samples are required to meet monitoring objective.</li> <li>• Minimise adsorption of radionuclides to container (e.g. pre-soak containers and use carrier solutions).</li> <li>• Report results as Bq/L.</li> </ul>	<ul style="list-style-type: none"> <li>• Rinse collection apparatus and container with sample.</li> <li>• Collect representative sample from water surface or at depth using pump or containers which are triggered to collect a sample at a particular depth.</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to minimise growth of algae and avoid degradation of sample (e.g. chill at about 4°C in the dark).</li> <li>• Filter samples through a 0.45µm membrane and analyse filtrate and residue if the monitoring objective requires information on the partitioning between dissolved and particulate phases.</li> <li>• Ensure representative sub-sample is taken for analysis (e.g. shake water sample).</li> <li>• Concentrate sample if needed (e.g. through ion exchange or evaporation).</li> <li>• Preserve with nitric acid for long storage (analysis dependant).</li> </ul>

**Table C 3C continued – Maritime monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Estuary/coastal sediments	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> - To determine the potential source of exposure through inhalation and inadvertent ingestion during recreational activities.</li> <li>• <b>Wildlife</b> – To determine doses to wildlife.</li> </ul>	<ul style="list-style-type: none"> <li>• Allow for tide times to ensure access.</li> <li>• Ensure depositional environment.</li> <li>• Report results as Bq/kg (dry weight).</li> </ul>	<ul style="list-style-type: none"> <li>• Take samples from predominant sediment type.</li> <li>• Obtain a reasonably representative sample over a scale of up to 5-10 m. This may be achieved by collecting 5 surface sediment samples from the points of a W shape or the ends and centre of an X shape over a circle of 10 m diameter. The samples may be bulked.</li> <li>• Collect surface sediment samples (0-1 cm) with flat hand shovel (or appropriate tool) over selected area.</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight and preventing fusing of sample (e.g. oven dry 40-105°C or freeze dry). (May need to analyse wet for volatile radionuclides).</li> <li>• Record dry/wet ratio.</li> <li>• Remove gravel component by sieving to &lt;2mm and discarding &gt;2mm fraction.</li> <li>• Ensure representative sub-sample is taken for analysis (e.g. by grinding and coning and quartering).</li> </ul>
	<ul style="list-style-type: none"> <li>• <b>Environmental indicator</b> - To monitor the impact of recent discharges on environmental concentrations.</li> <li>• <b>Distribution</b> – Examine areas of deposition / concentration.</li> </ul>	<ul style="list-style-type: none"> <li>• As above</li> </ul>	<ul style="list-style-type: none"> <li>• As above</li> </ul>	<ul style="list-style-type: none"> <li>• As above</li> <li>• May need to normalise or report factors which can influence concentrations (e.g. grain size (loss on ignition at 450°C a good proxy), total organic carbon) or restrict grain size (e.g. &lt;250µm).</li> </ul>

**Table C 3C continued – Maritime monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Estuary/coastal sediments (cont.)	<ul style="list-style-type: none"> <li>• <b>Investigative / model check</b> - To provide check of historical discharges and sea dispersion modelling.</li> </ul>	<ul style="list-style-type: none"> <li>• Allow for tide times to ensure access.</li> <li>• Identify sample location with depositional history.</li> <li>• Report results as Bq/kg (dry weight).</li> </ul>	<ul style="list-style-type: none"> <li>• Take core samples using an appropriate device (able to withstand saline environment).</li> <li>• Obtain a reasonably representative sample over a scale of up to 5-10 m. This may be achieved by collecting 5 cores from the points of a W shape or the ends and centre of an X shape over a circle of 10 m diameter.</li> <li>• The depth of the core should be enable the monitoring objectives to be achieved. It should be noted that longer cores can be affected by compression, with this being greatest near the (wetter) top. Account of this will need to be taken when preparing the core further.</li> <li>• Section core into slices which enable the monitoring objectives to be achieved. Cores are typically sectioned into 5-10 cm slices. Clean core sectioning tool (blade) between slices.</li> <li>• Subsample from centre of each core slice to reduce smearing.</li> <li>• The same sections of cores may be bulked together as appropriate.</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight and preventing fusing of sample (e.g. oven dry 40-105°C or freeze dry). (May need to analyse wet for volatile radionuclides).</li> <li>• Record dry/wet ratio.</li> <li>• Remove gravel component by sieving to &lt;2mm and discarding &gt;2mm fraction.</li> <li>• Ensure representative sub-sample is taken for analysis (e.g. by grinding and coning and quartering).</li> </ul>

Table C 3C continued – Maritime monitoring

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Seaweed	<ul style="list-style-type: none"> <li>• <b>Environmental indicator</b> – Provides a good indicator of recent discharges, particularly for more soluble radionuclides.</li> <li>• <b>Model check</b> – To check historical discharges and sea dispersion modelling.</li> </ul>	<ul style="list-style-type: none"> <li>• Consider seasonal (annual) cycle on sampling strategy.</li> <li>• Selection of recent growth for analysis will provide a better indicator of recent discharges than analysis of a whole frond which will lead to an indicator of integrated discharges over a few years.</li> <li>• Report results as Bq/kg (fresh weight)</li> </ul>	<ul style="list-style-type: none"> <li>• Allow for tide times to ensure access (for beach collection).</li> <li>• Correctly identify single species (including hybrids) as determined to meet objective.</li> <li>• Collect and trim recent growth from fronds.</li> <li>• Note presence of fruiting bodies which may affect results, due to changes in plant physiology.</li> <li>• Wash in water to remove particulate and epiphytes.</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight (e.g. air dry, oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sampled in mill or blender or blending fresh samples, Cone and quarter if appropriate).</li> </ul>
	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To assess dose to exposed population groups from consumption as food.</li> </ul>	<ul style="list-style-type: none"> <li>• Consider seasonal (annual) cycle on sampling strategy.</li> <li>• Report results as Bq/kg (fresh weight)</li> </ul>	<ul style="list-style-type: none"> <li>• Allow for tide times to ensure access (for beach collection).</li> <li>• Correctly identify food species.</li> <li>• Collect fresh seaweed (recent growth) or parts used for food according to local practice.</li> <li>• Wash in water to remove particulate and epiphytes.</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight (e.g. air dry, oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sampled in mill or blender or blending fresh samples, Cone and quarter if appropriate).</li> </ul>

**Table C 3C continued – Maritime monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Seaweed (cont.)	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To assess dose from use of seaweed as compost and consumption of food.</li> </ul>	<ul style="list-style-type: none"> <li>• Consider seasonal (annual) cycle on sampling strategy.</li> <li>• Report results as Bq/kg (fresh weight)</li> </ul>	<ul style="list-style-type: none"> <li>• Allow for tide times to ensure access (for beach collection).</li> <li>• Correctly identify the species used for compost and collect sample (according to local practice).</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Dry sample to constant weight (e.g. air dry, oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/fresh ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sampled in mill or blender or blending fresh samples, Cone and quarter if appropriate).</li> </ul>

Table C 3C continued – Maritime monitoring

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Fish	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To monitor the radiological exposure pathway from consumption of radioactivity in fish.</li> <li>• <b>Reassurance</b> – Provide reassurance through the detection and monitoring of abnormal releases, contaminated foodstuffs.</li> <li>• <b>Environmental indicator</b> - monitor the long-term behaviour of radionuclides in foodstuffs arising from routine authorised releases.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> <li>• <b>Distribution</b> – Determine the spread of radionuclides through foodstuffs/the environment from radioactivity arising from routine authorised releases</li> <li>• <b>Model check</b> – Provide data that, along with other monitoring of sediment and seawater, may be useful to check reported discharges and dispersion and transfer models.</li> </ul>	<ul style="list-style-type: none"> <li>• Select species to meet monitoring objective (e.g. benthic versus pelagic, stage of growth, availability in the fishing ground).</li> <li>• Report results as Bq/kg (fresh weight).</li> </ul>	<ul style="list-style-type: none"> <li>• Correctly identify species caught by net or line.</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Prepare the raw edible fraction for analysis. Culinary preparation may need to be taken into account.</li> <li>• Dry sample to constant weight (e.g. oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/wet ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sample in mill or blending fresh samples. Cone and quarter if appropriate).</li> </ul>

Table C 3C continued – Maritime monitoring

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Fish (cont.)	<ul style="list-style-type: none"> <li>• <b>Wildlife</b> - To determine the radiological exposure to fish.</li> </ul>	<ul style="list-style-type: none"> <li>• As above</li> </ul>	<ul style="list-style-type: none"> <li>• As above</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Prepare samples as a whole (including entrails) OR prepare specific portion of sample (e.g. thyroid).</li> <li>• Record weights of parts required for analysis and for discarded parts (to allow for total body burden).</li> <li>• Dry sample to constant weight (e.g. oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/wet ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sample in mill or blending fresh samples. Cone and quarter if appropriate).</li> </ul>

Table C 3C continued – Maritime monitoring

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Crustaceans / Molluscs	<ul style="list-style-type: none"> <li>• <b>Critical group dose</b> – To monitor the radiological exposure pathway from consumption of radioactivity in crustaceans/molluscs.</li> <li>• <b>Reassurance</b> – Provide reassurance through the detection and monitoring of abnormal releases, contaminated foodstuffs.</li> <li>• <b>Environmental indicator</b> - monitor the long-term behaviour of radionuclides in foodstuffs arising from routine authorised releases.</li> <li>• <b>Baseline</b> – To provide a baseline in the event of a radiological incident.</li> <li>• <b>Distribution</b> – Determine the spread of radionuclides through foodstuffs/the environment from radioactivity arising from routine authorised releases</li> <li>• <b>Model check</b> – Provide data that, along with other monitoring of sediment and seawater, may be useful to check reported discharges and dispersion and transfer models.</li> </ul>	<ul style="list-style-type: none"> <li>• Select species to meet monitoring objective.</li> <li>• Report results as Bq/kg (fresh weight).</li> </ul>	<ul style="list-style-type: none"> <li>• Correctly identify species.</li> <li>• Collect by hand sampling or using pots or digging as appropriate for species.</li> <li>• Do not depurate.</li> <li>• Store the sample to prevent deterioration in transit to the lab (e.g. cool, dark conditions, cool box).</li> </ul>	<ul style="list-style-type: none"> <li>• Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>• Prepare the raw edible fraction for analysis. Culinary preparation may need to be taken into account.</li> <li>• Dry sample to constant weight (e.g. oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>• Record dry/wet ratio.</li> <li>• Select a representative sub-sample for analysis (e.g. by homogenising dry sample in mill or blending fresh samples. Cone and quarter if appropriate).</li> </ul>



**Table C 3C continued – Maritime monitoring**

Sample type	Objective	General	Sampling/Monitoring	Sample preparation
Crustaceans / Molluscs (cont.)	<ul style="list-style-type: none"> <li><b>Wildlife</b> - To determine the radiological exposure to crustaceans/molluscs.</li> </ul>	<ul style="list-style-type: none"> <li>As above</li> </ul>	<ul style="list-style-type: none"> <li>As above</li> </ul>	<ul style="list-style-type: none"> <li>Store samples at laboratory to prevent degradation and loss of volatiles, if appropriate (e.g. chill at about 4°C or freeze).</li> <li>Prepare softer shelled species (e.g. shrimps etc.) whole. For harder shelled species (e.g. lobsters, whelks etc.) prepare samples in two portions: 1) flesh &amp; 2) shells. Treat as two separate samples in subsequent stages OR prepare specific portion of sample (e.g. gut).</li> <li>Record weights of parts required for analysis and for discarded parts (to allow for total body burden).</li> <li>Dry sample to constant weight (e.g. oven dry 40 – 105°C, freeze-dry), but analyse fresh for volatile radionuclides.</li> <li>Record dry/wet ratio.</li> <li>Select a representative sub-sample for analysis (e.g. by homogenising dry sample in mill or blending fresh samples. Cone and quarter if appropriate).</li> </ul>

## **8. Sample analysis and data processing**

8.1 The main objectives of laboratory analytical and data processing programmes are to produce results that:

- Are consistent, with adequate precision and accuracy, and reliable.
- Can be compared over time and with data produced by other laboratories.
- Reflect real changes in the nature of the radionuclide distributions in the environment.
- Are not affected by cross-contamination, sample preparation errors, incorrect calibration of instruments, etc.; where such errors are present, they must be known and quantified and controlled to known and acceptable limits.

8.2 These objectives are generally best secured by requirements for laboratories to be accredited to the European Standard EN17025. In particular adherence to the following elements of good practice should provide for reliable and quality results:

- Close co-operation between the sample provider, customer for the results (this may be the same as the sample provider) and the analytical laboratory. This co-operation should include written agreement not only on samples to be analysed but also on requirements for precision, accuracy and limits of detection.
- The provision of samples to the laboratory that are representative of the relevant environmental media.
- Operation of the laboratory of a documented internal quality control procedure.
- Use by the laboratory of appropriate radioactive standards (including where available natural matrix reference materials) of established national or international traceability.
- Use by the laboratory of validated and fully documented analytical procedures. (Any departure from these procedures should be fully documented and justified.)
- The laboratory should participate in national and international inter-comparisons.
- The reports of analytical results should include an estimate of their uncertainties and information on the method used to derive them.
- The laboratory should employ skilled and motivated analysts in well-equipped laboratories operating to accredited procedures and within an effective quality control system.

### ***Sampling***

8.3 Methods of sampling have been dealt with in detail in sections 6 and 7. This section deals only with those aspects of sampling that are of particular interest to the receiving analytical laboratory. All relevant information relating to a sample should be provided in written form to the laboratory by the sample provider. A pro-forma can be useful to ensure that all of this information is captured and should form part of the chain-of-custody arrangements. The relevant information should include;

- Sample description (e.g. medium and/or species).

- Sampling location (e.g. grid reference).
- Identification of person who took the sample.
- Time and date of sampling, and any relevant operational information.
- Any results from instrumental measurements (e.g. dose rate or contamination monitors).
- Any other relevant information such as weather conditions.

8.4 The laboratory should maintain a register of all samples received and should allocate each sample with a unique sample identifier which should be used on all related documentation.

8.5 The laboratory should continue to exercise the kind of precautions taken during the collection of the samples in the field. These will include:

- *Sample integrity on receipt.* The integrity of the sample container should be checked by the laboratory on receipt.
- *Avoidance of cross-contamination.* This is especially important in laboratories that, as well as handling environmental samples, also handle samples with much higher activities (e.g. radioactive waste). In addition, the storage and handling of the latter may increase background count rates around instruments being used for the assay of low-level samples.
- *Representative subsampling.* Special care is required with regard to particulates that may have formed or settled out in transit. To avoid missing these, samples must be fully mixed prior to subsampling. Best practice to separate particulates by filtration is to use the whole sample delivered to the laboratory.
- *Avoidance of losses of constituents.* This is especially important for potentially volatile radionuclides such as tritium and iodine isotopes unless this is a planned part of the sample procedure.
- *Chain of custody.* Correct and unambiguous labelling/logging of samples and all prepared subsamples is necessary.

### ***Sample preparation***

8.6 The laboratory may be handling samples of process liquors, discharges and environmental media. The radioactive contents of these disparate samples could vary over several orders of magnitude. Samples of aerial and liquid discharges are likely to be radioactive at the medium and high activity levels. In order to avoid cross-contamination, both during and after sample preparation, the samples should be handled in segregated high, medium and low level activity areas.

8.7 Sub-samples for analysis should be taken in such a way as to ensure that they remain representative of the bulk sample. This is not likely to be a requirement for solid samples of aerial discharges as the entire sample should be counted directly or taken into solution. When taking sub-samples from a liquid any solids present in the sample should be: dissolved using appropriate reagents, or, kept in suspension when making the division, or, if acceptable removed by filtration and discarded. Alternatively, if the solids fraction is of interest then the two phases should be analysed separately.

- 8.8 It may be necessary to concentrate the sample before proceeding to chemical separation or direct measurement. Depending on the nature of the sample this may involve evaporation, ashing or precipitation. There is potential for losses or contamination during these procedures. For example, dry ashing can lead to losses through sputtering or volatility, or to the creation of substances that can interfere with later chemical separation processes. Consequently, dry ashing should be carried out carefully in a furnace the temperature of which can be adequately controlled to prevent ignition of the sample. Alternatively, if dry ashing could still lead to loss of the determinand a wet ashing procedure should be considered. In all cases where the physical state is altered the sample weight before and after must be determined so that the final concentration of the determinand can be referred to the appropriate state.

#### ***Radio-analytical methods***

- 8.9 A radiometric analysis generally involves comparing the response of a detector to the determinand in the sample to that of a known source. The method may involve direct measurement of the sample (i.e. non-destructive) or it may require chemical separation of the determinand (i.e. destructive, or radiochemical). The main components in a radiation detection system used for the analysis of samples are listed at Table C 4.
- 8.10 Analytical methods must be validated. This can be achieved by analysis of a natural matrix reference material (NMRF). If the result was in agreement with stated activity of the NMRF then the method has been validated. NMRFs are not readily available and therefore reliance is usually placed on inter-laboratory comparison tests using labelled materials. Validated methods should be fully documented and strictly adhered to. Where deviations from the method are made these should be recorded and justified.
- 8.11 The results of analysis may be affected by contamination arising from the repeat use of the analytical procedures. Possible sources of contamination include: the re-use of apparatus, cross-contamination between samples, impurities in reagents and yield tracers, contaminated detectors. The laboratory should have procedures in place to check for contamination. This should include the analysis of samples at activity concentration known to be below the limit of detection for the relevant method, or the reagents alone. The performance of the method should also be checked by the analysis of samples with well-defined activity concentrations.
- 8.12 Samples are normally analysed in a radiochemical laboratory by non-destructive methods, screening techniques and/or methods requiring prior radiochemical separation of the determinand of interest.
- *Non-destructive methods.* Gamma-ray spectrometry is the most common non-destructive method. Following sample preparation an aliquot of the sample is measured directly. Sometimes it is necessary to treat the sample to obtain improved geometry, to pre-concentrate the sample or carry out some form of radiochemical separation in order to achieve the required detection sensitivity or specificity. The method then becomes destructive. Direct alpha spectrometry is another non-destructive method.
  - *Screening techniques.* These provide rapid means of detecting activity levels but lack sensitivity and specificity. The usual methods are “total alpha” and “total beta” activity measurements. Often the term “gross” is used rather than “total” to emphasise that the methods cannot determine all of the alpha or beta

emitting radionuclides in a sample. The activity detected is compared with that of a specified radionuclide measured under identical conditions. However, these methods cannot detect all radionuclides with equal efficiencies so the usual quality assurance criteria cannot be applied. The results should therefore be used with caution; nevertheless, these methods are convenient, cheap and easy to use. Sometimes laboratories report “total gamma-ray activity”. This should be considered to be only a semi-quantitative measurement as the response of a gamma-ray detector is very dependent on the energy of the emissions.

- *Radio-chemical separation.* These methods are used to isolate the determinand of interest from its matrix in a form which may be measured by appropriate techniques. The separation methods are: ion exchange, solvent extraction and precipitation procedures. Commonly several stages may be required to achieve the desired separation. Complete recovery of the determinand at each stage can be difficult. Consequently, a tracer or carrier is used as a yield indicator. In order for this to function reliably complete chemical equilibrium between the determinand and yield tracer has to be achieved. This can involve oxidation/reduction cycles to ensure that the determinand and yield indicator are present in the same ionic form. More difficult cases can require destruction of organic material or dissolution of refractory material by fusion techniques. A target recovery of the yield tracer should be set, say 40% with results from yield recoveries of less than 20% being rejected.

**Table C 4. Components in a radiation detection system used for the analysis of samples**

Component	Function	Comments
<b>Power supplies</b>  Low and high-voltage power supplies	Supply power to detector and all electronic components in system.	Stabilised supplies are required to ensure consistent performance and data from all parts of the system. Uninterruptible Power Supply (UPS) advisable.
<b>Detectors</b> <b><i>Gamma spectrometry</i></b> Sodium iodide scintillation detectors with photomultiplier  Semiconductor detectors, Ge(Li), HPGe.  <b><i>Alpha analysis</i></b> Liquid scintillation detectors Gas-filled detectors (proportional counters or Geiger tubes) Surface barrier	Convert into electrical pulses alpha, beta or gamma radiation from samples prepared in a given geometry	One type of detector may respond to more than one type of radiation in the sample, producing pulses of differing intensities for each one. Alpha, beta and gamma radiation of different energies (due to differing nuclides in the sample) may also produce pulses of differing intensities. All of these pulses are sorted by the multichannel analyser. This then allows the differing types of nuclide to be identified by the final computer software system (see

semiconductor detectors  <b>Beta analysis</b> Gas-filled detectors Liquid scintillation counters		below). In some cases, absorbers may be used in front of the detector to prevent entry of certain types of radiation (e.g. aluminium may allow beta radiation of different energies to be selectively filtered out).
<b>Pulse shaper and 'energy window'</b>	Shapes pulses from detector so they are suitable for further electronic processing.	These components may also carry out some initial sorting of pulses according to their energy, allowing, for example, pulses due to alpha and beta radiation to be separated.
<b>Multichannel analyser</b>	Sorts pulses according to their energy and records them in one of a number of channels (up to 8192 [can be 512, 1024, 2048, 4096 or 8192]) and displays these as an alpha, beta or gamma 'spectrum' of the sample.	Use of a standard mixture of nuclides of known abundance allows each channel in the spectrum to be ascribed to a specific alpha, beta or gamma energy (in keV or MeV). This allows the nuclides in an unknown sample to be identified. Comparison of the intensity of the peaks (counts per channel) with that of the standard allows the abundance of nuclides in the sample to be established.
<b>Computer system</b>	Records all data and carries out data analysis.	Software package carries out calibration, identification of the nuclides and the quantities present.

8.13 The common detector types that can be used to measure alpha, beta and gamma emitting radionuclides are listed in Table C 5.

**Table C 5. Common detector types for different radionuclide groups**

Alpha-emitting radionuclides	Beta-emitting radionuclides	Gamma-emitting radionuclides
Zinc sulphide screen counters	Geiger-Mueller counters	Geiger-Mueller counters
Thin window or windowless proportional counters	Thin window or windowless proportional counters	Thin window proportional counters
Gas flow counters	Solid scintillation counters	Scintillation counters
Semiconductor counters	Liquid scintillation counters	Semiconductor counters
Liquid scintillation counters		

- 8.14 The principle of measurement involves counting the sample and comparing the result with a standard source. Background activity is also determined by counting a blank sample and subtracting from the sample count. For alpha and soft beta (low energy) emitters it can be necessary to correct the result for absorption within the sample matrix. Most laboratories now use sophisticated electronic facilities to improve counting accuracy and to automate counting procedures.
- 8.15 Soft and hard beta emitters can be differentiated by repeat counting of samples with different absorbers interposed between sample and counter.
- 8.16 Standard samples should ideally consist of the same radionuclides as in the source sample and should be prepared in the same form and geometry. However, in practical situations, for example for a nuclide with a short half-life, an alternative radionuclide of longer half-life with the same energy of emitted radiation may be used if available. Where gross activity is being determined, a range of radionuclides is involved and the standard source has to consist of a single radionuclide with an emission energy accepted as being typical of the range or a mixed radionuclide source. Determination of gamma activity is usually carried out by gamma-ray spectrometry and the standard sources used consist either of mixed gamma emitting radionuclides that emit gamma-rays of different energies or a single radionuclide that emits several gamma-rays of different energies. Some typical alternative standard sources are listed in Table C 6.

**Table C 6. Common surrogate standard sources**

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

- 8.17 The choice of a particular instrument for counting a sample activity is dependent on the following factors:
- The type of radioactive emission, i.e. alpha, beta, gamma.
  - The required determination. This can be for gross alpha or gross beta or gross gamma which would include a range of radionuclides or for a specific radionuclide. Where a specific radionuclide is to be determine this may be carried out by spectrometry using energy discrimination, radiochemical separation, or a combination of both.
  - The required sensitivity.
  - The number and throughput of samples (and availability of manual or automatic counting).

## 9. Statistical considerations

9.1 There are two main statistical considerations that should be taken into account when designing and carrying out a discharge monitoring programme. These are:

- Measurement uncertainty.
- Detection limits and decision thresholds.

### ***Measurement uncertainty***

9.2 Dose rates in the environment are usually measured as air kerma rates in the form  $\mu\text{Gy} [\text{T}^{-1}]$ . Concentrations of radionuclides are usually expressed in the form  $\text{Bq} [\text{M}]^{-1}$  or  $\text{Bq} [\text{L}]^{-3}$ , that is, the total amount of a radionuclide (or group of radionuclides) in becquerels per unit mass or volume of sample, either dry weight or fresh weight.

9.3 Environmental monitoring results are, like all measurement results, subject to uncertainties. These arise from the combination of uncertainties of parameters associated with the individual measurements that make up the final calculation of the air kerma rates or radionuclide concentrations. It has not been common practice in the nuclear industry to estimate these uncertainties because air kerma rates/radionuclide concentrations have historically been well below derived limits or limits specified in site licences and it has been possible to demonstrate that even gross uncertainties do not change the significance of impact assessments with respect to radiological protection criteria. Nevertheless, the systematic tightening of licence limits by regulatory authorities and of radiological protection criteria by the International Atomic Energy Agency and the International Committee on Radiological Protection raises the potential significance of the uncertainties in monitoring data.

9.4 The uncertainty in a measurement is quantified by two numbers: the margin, that is the interval within which the result is expected to be; and the confidence level, which states how sure the true value is within that margin [IAEA, 1978]. For example: an activity concentration of 100 Bq/kg plus or minus 10 Bq/kg at the 95 percent confidence level may be reported as

100 +/- 10 Bq/kg, at a level of confidence of 95%

This method of reporting states that there is a 95% confidence that the concentration is between 90 and 110 Bq/kg.

9.5 The overall uncertainty arises from errors and uncertainties in the many actions and measurements that are carried out to determine the dose rate or the concentration values. In order to calculate the uncertainty of a measurement, the potential sources of uncertainty must first be identified, then estimated, and finally the contributions combined to provide an overall figure according to relevant rules [e.g. Bell, 2001].

9.6 Uncertainty estimates should cover potential errors which can arise from:

- Measurand: what is being measured should be well-defined and the measurement method should address exactly that measurand. The measurand signal generally needs to be compensated for incomplete efficiency and interference from other signals and background events. Generally, laboratories have the performance of their routine procedures under constant scrutiny through in-house quality control (QC) procedures (e.g. Shewhart charts, blanks,



reference materials and internal standards) and participation in external proficiency testing schemes.

- Sampling. Obtaining a representative environmental sample can be difficult even under good conditions. . Inhomogeneous distribution of activity is a common problem. On-site practicalities will add to the difficulties.
- The measuring instrument. Each technique has its limitations in efficiency, resolving power, precision, linearity, etc. in determining the measurand. Additionally, their good operation can be compromised by bias, drift arising from ageing, wear, environmental conditions, poor readability, fluctuations in the electrical supply (background noise), etc.
- Radiochemical techniques. It may be difficult to interpret radiation spectra for complex samples thereby requiring extensive sample clean-up and preparation before counting.
- Instability of the sample. These may arise from sample matrix effects like chemical and biological reactions or diffusion. Also the changing decay rate of short-lived radionuclides, the ingrowth of daughter nuclides, and the build-up or loss of noble gasses may influence the radioactivity assay.
- Calibration uncertainties. Standards and procedures for calibrating instruments have their own uncertainties which are propagated into the uncertainty budget of the measurand.
- Operator skill. Some measurements may be dependent on the skill and judgement of the operator. (Note that gross mistakes are not taken into account when determining measurement uncertainties.)

9.8 Where the size and effect of an error are known, a correction must be applied to the measurement result. But in general, uncertainties from the sources listed above and others are individual inputs contributing to the overall uncertainty budget of a measurement:

- Type A evaluations use uncertainty estimates from statistics assessments from repeat measurements.
- Type B evaluations use uncertainty estimates from any other information, such as: calculations, estimates based on past experience of the measurements, calibration certificates, manufacturer's specifications, published information, etc..

9.9 In outline the main steps involved in evaluating measurement uncertainty include:

- Identifying the measurand, i.e. what needs to be determined. For example, the concentration of a given nuclide per kilogram of fresh weight of sample.
- Identifying the necessary measurements. For example, laboratory analysis by gamma spectrometry of a radionuclide in a sample.
- Carrying out the required measurements on a representative sample.

- Estimating the uncertainty of each input quantity that feeds into the final result. Express all uncertainties in similar terms and at the same confidence level by converting them to standard uncertainties. (A standard uncertainty is a margin whose size can be thought of as “plus or minus one standard deviation”.)
- Calculating the result of the measurement (including any known corrections such as calibration, efficiency, interference and background subtraction).
- Finding the combined standard uncertainty from all the individual inputs using the standard method for summation in quadrature. (Note that if the errors of the input quantities are not mutually independent correlations need to be taken into account in the uncertainty calculation.)
- Expressing the uncertainty in terms of an uncertainty interval and a level of confidence (or 'coverage factor'  $k=1$  for standard uncertainty and  $k=2$  for 95% coverage)..
- Writing down the measurement result and the uncertainty, and stating how both have been derived.

#### ***Detection limits and decision thresholds***

- 9.10 Detection limits are used to determine whether analytical techniques or instruments are suitable for their proposed measurement purpose. In general terms, the detection limit for a determinand can be defined as the lowest amount (or concentration) that can be detected at a stated confidence level. In the case of radiochemical measurements the detection limit can be considered to be the activity level at which the counts from the sample (including background contributions) can be positively distinguished from the background count. The background count includes contributions from the detector background and the response to blank samples. The relevant standard is ISO 11929-7 (ISO, 2005A) which is interpreted in the KTA Standards [KTA, 2002; KTA 2007] giving the following mathematical expressions for detection limit and decision limit;

$$G_N = f \cdot k_N \cdot S$$

Where:

$G_N$  = Detection limit

$f$  = Calibration factor

$k_N$  = Factor for the statistical certainty at the detection limit

$S$  = the standard deviation of the count rate.

- 9.11 The decision limit is used to decide whether or not the activity of the measured radionuclide is present in the sample at a level above background and can therefore to be considered to be present at elevated levels in the environment from which the sample was taken. If this is found to be the case then it should be reported. The decision limit is calculated using the following equation:

$$G_E = f \cdot k_E \cdot S$$

Where:

$G_E$  = Decision limit

$f$  = Calibration factor

$k_E$  = Factor for the statistical certainty at the decision limit

$S$  = the standard deviation of the count rate.

9.12 The standard deviation,  $S$ , of the count rate is calculated using the applicable formula from the list below.

(a) In the case of an integral digital measurement:

$$S = \sqrt{\frac{R_0}{t_0} \left( 1 + \frac{t_0}{t_m} \right)}$$

(b) In the case of an analogue measurement:

$$S = \sqrt{\frac{R_0}{2\tau}}$$

(c) In the case of gamma spectrometry:

$$S = \sqrt{\frac{2b \cdot \bar{R}_0(E_\gamma)}{t_m}}$$

(d) In the case of alpha spectrometry:

$$S = \sqrt{\frac{\sum R_0(E_\alpha)}{t_0} \left( 1 + \frac{t_0}{t_m} \right)}$$

With the nomenclature listed in the box below.

## NOMENCLATURE

$G_N$	detection limit	Bq
$G_E$	decision limit	Bq
$f$	calibration factor	Bq . s
$k_N$	factor of the statistical certainty at the detection limit	$kE + 1.645$ *
$k_E$	factor of the statistical certainty at the decision limit	$1.645$ ** $3.0$ ***
$R_0$	background pulse rate	$s^{-1}$
$\overline{R}_0(E_\gamma)$	Average background pulse rate per channel or eV at the energy level $E_\gamma$	$s^{-1}$
$b$	base width of a gamma peak (base width of peak ); $b = 1.7h$ , with $h$ being equal to the half-value width of the gamma peak	number of channels or eV
$R_0(E_\alpha)$	count rate of background level in the vicinity of the alpha peak	$s^{-1}$
$t_0$	Duration of background	s

## **10 Alarms including resultant actions**

- 10.1 One of the important objectives of an environmental monitoring programme is to act as a means of surveillance for inadvertent or unrecorded discharges, which may be due to the specific site being monitored, or to extraneous sources. It is therefore important to have preset levels for each category of monitoring at which further investigations may be triggered. In view of the very different conditions existing at different sites and for different environmental materials and background levels, such investigation or alarm settings are probably best established by site operators in consultation with regulators. There would probably be justification for several levels of “alarm” with appropriate resultant actions. At a low level, measured values would be compared with those typical of recent experience by such methods as the use of Shewhart charts; if an outlier were identified, this could trigger an analytical investigation, e.g. with the possibility of repeat analyses. Confirmation of significantly increased levels would then trigger external investigation, for example of increased discharges or changed environmental conditions. The level of “significantly” would need to be preset by the monitoring organisation, in consultation with the regulator after consideration, for example, of statistical factors. Systematically higher levels would indicate increased levels of investigation and action, if appropriate, to reduce the source term.
- 10.2 Continuous on-line network systems have the ability to respond rapidly to changing conditions and form part of some Member States’ national monitoring programmes, especially of environmental gamma dose rates. These are usually alarmed, characteristically at two levels to give a first indication of a fluctuation, then confirmation at a higher level. Some operate at fixed levels, e.g. 0.2  $\mu\text{Sv/h}$  then 0.4  $\mu\text{Sv/h}$ , whilst others operate at multiples of the running average background level at each site to account for wide variations in local background. It would not seem appropriate to be prescriptive because of variations in conditions across the European Union. However it is important to have an established plan, and if a site is involved this should be decided between operators and regulators.
- 10.3 At an upper level, there are implications of triggering a site incident or emergency. It is expected that detailed plans will have been set down for this eventuality for each site by Member States to comply with Article 50 of the Basic Safety Standards (EC, 2013) with any necessary evacuation of staff and public and other emergency actions such as administration of stable iodine prophylaxis. Following an incident there is also the triggering of Community Food Intervention Levels (EC, 1989) which would imply monitoring levels relevant in the case of foodstuffs.

## **11 Quality Assurance (QA) and Quality Control (QC)**

- 11.1 Environmental monitoring should be carried out within a comprehensive quality management system (QMS). The purpose of this QMS should be to ensure that accurate and reliable results are obtained from all aspects of discharge monitoring. International Standard ISO 9001 [ISO, 2000] has been the most commonly used basis for defining a QMS. However ISO 9001 is a generic standard applicable to all organisations irrespective of size, type or field of operation and does not address the technical aspects of measurements, sampling and laboratory analysis. Consequently, European Standard EN 17025 [ISO, 2005B] is now the standard for laboratory and field measurement work. EN 17025 has two major parts which address management and technical requirements. The

management part incorporates the requirements of ISO 9001. Conformance with EN 17025 can be demonstrated by third party accreditation by national accreditation bodies. This accreditation provides for recognition of results across Europe through the mutual accreditation agreement established by the European cooperation for Accreditation of Laboratories.

11.2 The key elements of a well-documented and comprehensive QMS, as it applies to environmental monitoring, are:

- A quality policy. There should be a general policy statement signed off at senior management level and setting out the organisation's approach and commitment to achieving quality.
- Management responsibilities. There should be an organisational plan clearly identifying responsibilities for particular aspects of the QMS at different management levels and setting out lines of responsibility. The responsibilities for implementing the monitoring programme should be carried out by organisationally separate staff from those responsible for operation of the plant so as to safeguard the integrity of the monitoring work from day to day commercial and operational pressures.
- A quality manual should be in place that documents all relevant aspects of the quality management system in a logical manner. A hierarchical approach ranging from the quality policy statement, through programme design, specifications for sampling facilities and instrumentation, staff training, down to procedures for sampling and analysis is commonly adopted. The quality manual should contain procedures for investigating complaints, queries, unexpected results and anomalies. A clear document control system should be used to ensure that all documents and amendments are authorised and only the latest versions of the documents making up the quality manual are used.
- Staff training. All staff involved in carrying out the monitoring programmes should be trained in the relevant procedures and skills, and shown to be competent to carry out their work. On-going training should be provided and documented. Staff responsible for the design of the monitoring programme should be kept up to date with national and international developments that are relevant to their duties.
- System design. Sampling equipment and instrumentation should be fit for purpose, installed and commissioned correctly so that the objectives of the monitoring programmes can be achieved in particular with regard to required levels of accuracy, availability and reliability.
- Procedures. Written procedures should be produced detailing how the quality critical actions at all stages of the monitoring programmes (e.g. sample collection, transport, laboratory analysis and equipment calibration) should be carried out.
- Calibration. On-line and laboratory based sampling equipment and instrumentation should be calibrated at regular intervals using appropriate standards. (In the case of instrumentation both the frequency of calibration and the standards may be specified by the manufacturer.)

- Sampling. The appropriateness of sampling locations, equipment and methods for the taking of representative samples should be established.
- Quality Control (QC). QC charts (e.g. Shewhart or Cusum charts) should be maintained for all measurement systems to indicate any development of bias in the results or loss of precision of analytical techniques. Blank samples and reference materials should be regularly analysed. Laboratories should participate in inter-laboratory comparisons so as to provide external checks on their performance. A comprehensive QC programme should provide for the comparison of results produced over time through an understanding and knowledge of changes such as instrument contamination, adoption of new analytical techniques, operational failures.
- Internal Audits. Internal audits of conformance with procedures should be carried at regular intervals by trained staff. This should lead to feed back in the form of observations and corrective actions with procedures for ensuring that they are closed out appropriately within agreed timescales.
- Records. All relevant data, observations and results should be recorded in a manner that provides an auditable trail from raw data to calculated results.

11.3 The quality and usefulness of monitoring results depends on how well the monitoring programme has been conceived, designed, assigned, specified, executed, assessed and reported. It is therefore important that the QMS addresses each of these stages as they form a quality link because the quality achieved at one stage affects what is achievable at all subsequent stages. Therefore, the best results are obtained by considering and optimising each stage in turn, and by applying appropriate quality systems and safeguards.

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# **Annex B**

## **Technical guidance for discharge monitoring programmes**

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## **1 Introduction**

- 1.1 This annex provides technical guidance on the requirements for monitoring of radioactive aerial and liquid discharges to the environment under Article 35 of the EURATOM Treaty. The guidance is based on a study by Newstead Consulting Ltd.
- 1.2 Section 2 provides information on the legal provisions of Article 35 of the EURATOM Treaty and includes background information on verification visits [EC, 2006] and the Commission's recommendations for the standardisation of reporting [EC, 2004].
- 1.3 Section 3 describes the generic objectives for planning a monitoring programme including guidance on the independent oversight by regulators at the national level of discharge monitoring programmes undertaken by site operators.
- 1.4 Section 4 summarises the different monitoring strategies that can be adopted for both aerial and liquid discharge monitoring.
- 1.5 Section 5 provides guidance on the use of instrumentation for the monitoring of aerial and liquid discharges, including:
  - The selection of technical devices, (such as on-line monitors, on-line samplers and laboratory apparatus and techniques).
  - The positioning of on-line monitors, sampling devices, and sampling points so as to ensure that measurements are representative of the discharge.
  - The criteria for selection of on-line continuous measurement, on-line continuous sampling, or spot sampling.
  - The provision of alarms, action levels, automation and reactive actions.
- 1.6 Sections 6 and 7 provide guidance on the sampling of aerial and liquid discharges respectively. This includes consideration of:
  - The specific requirements for iso-kinetic sampling in ducts and chimneys of aerial emissions to ensure that samples are representative of the discharge.
  - Sample collection, the design of sampling systems and flow measurement of aerial discharges.
  - Sampling of batch and continuous liquid discharges including composite sampling, alternatives to composite sampling, precautions to be taken when sampling.
- 1.7 Section 8 provides guidance on the analysis of samples of both aerial and liquid discharges.
- 1.8 Section 9 provides guidance on the statistical aspects of monitoring including consideration of measurement uncertainty, detection limits and decision thresholds.
- 1.9 Section 10 provides guidance on quality assurance matters including relevant standards and accreditation, documentation and staff training.
- 1.10 Section 11 provides generic information on the monitoring of discharges from non-nuclear sites.

- 1.11 Section 12 lists the documents that have been specifically referenced during the preparation of this guidance document.

## **2 The Euratom Treaty**

- 2.1 Article 35 of the Euratom Treaty requires that each Member State shall establish the facilities necessary to carry out continuous monitoring of the levels of radioactivity in air, water and soil and to ensure compliance with the basic safety standards.

- 2.2 Article 35 also gives the European Commission the right of access to such facilities in order that it may verify their operation and efficiency. The main purpose of verifications performed under Article 35 of the Euratom Treaty is to provide an independent assessment of the adequacy of monitoring facilities for:

- Liquid and airborne discharges of radioactivity into the environment by a site (and control thereof).
- Levels of environmental radioactivity at the site perimeter and in the marine, terrestrial and aquatic environment around the site, for all relevant exposure pathways.
- Levels of environmental radioactivity on the territory of the Member State.

- 2.3 For the purposes of such assessments a verification team from the European Commission visits relevant sites within a Member State. Historically the arrangements for such visits were agreed with the relevant Member State in a bilateral protocol. However, in July 2006 the European Commission published a Commission Communication defining the practical arrangements for the conduct of such verification visits [EC, 2006]. Past verification visit reports are available at <http://ec.europa.eu/energy/node/1221>.

- 2.4 Under Title II, Chapter 3, of the Euratom Treaty and its secondary legislation, Member States regularly provide the European Commission with relevant data on environmental radioactivity. At the end of 2003, the European Commission published Recommendation 2004/2/Euratom [EC, 2004] which proposed a standardised approach to reporting information to the Commission on radioactivity discharged to the environment from nuclear power reactors and reprocessing plants in normal operation. The aim of the Recommendation is to allow data on radioactive discharges to be comparable on a Community-wide scale. The Recommendation is not binding in law and Member States are currently consulting their national stakeholders before providing formal responses to the Commission.

- 2.5 The Recommendation contains the following main provisions:

- A prescribed methodology, based on international standard ISO 11929-7 [ISO, 2005A], for reporting results above decision thresholds that are half the limit of detection (LoD).
- Specified detection limits that should be used for certain key radionuclides, detailed in Annex 1 of the Recommendation.

- A list of radionuclides, detailed in Annex 1 of the Recommendation, for which annual discharges, sampling methods used and, in some cases, the chemical/physical form should be reported.
- 2.6 Detection limits and decision thresholds are considered further in Section 9 of this Technical Guidance document.

### **3 Discharge monitoring programme objectives**

- 3.5 The high level objectives of a discharge monitoring programme are largely defined by European directives, national legislation, national regulations, decrees, etc. More site specific requirements are detailed in licences, ordinances, permits, consents, prescriptions or authorisations (referred to hereafter as licences). In turn these requirements are informed and based upon guidance published by the IAEA [IAEA, 2005], national competent authorities, international, European and national standards bodies, international and national institutes and major nuclear site operators.
- 3.6 Discharge monitoring programmes that have been designed to meet the legal requirements and guidance referred to above should in principle satisfy the requirements of Article 35 of the Euratom Treaty.
- 3.7 All aerial and liquid discharge streams should be identified. The radionuclides to be monitored in a discharge are likely to have been selected by a regulatory authority and specified in a site licence because of their radiological significance; preponderance in and/or representativity of the radionuclide mix in the waste stream.
- 3.4 Consequently, a radionuclide may be selected because its discharge and subsequent behaviour in the environment could pose a significant radiological impact and therefore knowledge of the amounts being discharged is necessary for control and protection purposes. Or a radionuclide may be selected because it is present in relatively large concentrations compared to others in the waste stream albeit its radiological significance is not great. Or a radionuclide may be selected because its relationship to the process and/or other radionuclides in the waste stream is well understood and it presents an easily monitored indicator of process performance and overall waste stream composition.
- 3.7 A discharge monitoring programme should be designed to provide the following outputs:
- Evidence that the radioactive content of a discharge is compliant with the numerical limits and any non-numerical conditions specified in the relevant licence.
  - A record of the amount of radioactive material discharged to the environment.
  - Information on an on-going basis to the site operator so that he can ensure that discharges and potential discharges (e.g. from sentencing tanks) are within licensed limits.
  - Information to demonstrate that operations and process plant (including related controls and management systems) giving rise to the discharge are performing as planned.
  - Detection, warning and identification of unplanned discharges in time for the operator to take remedial actions, such as changes to or shut down of process operations and emergency monitoring of the receiving environment.

3.6 A discharge monitoring programme may also provide:

- Discharge trends, especially those which might indicate a chronic plant or process problem.
- Source term data for process and/or dispersion modelling and radiological impact studies.
- Information on which to design a monitoring programme for the receiving environment.
- Assurance to the public that a discharge is, for example, within licensed limits, of known composition and consistent with past discharges.

***Self-monitoring arrangements***

3.7 It is common practice for discharge monitoring to be carried out by the site operator under self-monitoring arrangements. It is important to understand that self-monitoring is not self-regulation. Rather it is a practicable way of securing the most comprehensive and cost effective monitoring programme and ensuring that an operator takes full responsibility for all aspects of its site's discharges [IMPEL, 1999]. In order to promote public confidence in self-monitoring arrangements and to ensure that they work satisfactorily regulators should specify the monitoring requirements and provide national independent oversight by carrying out regular and comprehensive checks.

3.8 The following requirements for a self-monitoring programme should be specified by the regulator in the site licence:

- The relevant discharge streams to which the programme applies.
- The radionuclides and/or groups of radionuclides (e.g. gross beta) to be monitored in each relevant discharge stream.
- The methods of monitoring to be employed (e.g. continuous on-line instrumentation, continuous or periodic sampling with laboratory analysis, estimation).
- The sampling and analytical methods (e.g. CEN Standard methods), appropriate calibration standards (e.g. <sup>137</sup>Cs for gross beta) to be employed.
- Quality assurance needs (e.g. certification of a quality management system to ISO 9001, laboratory accreditation to EN 17025).
- Data record keeping and reporting.

3.9 The regulator should have arrangements in place to check that operators are carrying out their self-monitoring programmes satisfactorily. These can include:

- Independent audits by certification and/or accreditation bodies related to ISO 9001 quality management systems and/or EN 17025 of laboratory and field measurement respectively. In their generic format these audits may not provide sufficient in-depth focus on the technical aspects of the monitoring programme to meet the regulator's requirements. It may be that the regulator and certification/accreditation body have agreed that dedicated audits will be

undertaken that address all of the regulator's interests. If this is so the agreement should be formally documented.

- Systematic audits or inspections by the regulator. Audits can be described as vertical investigations carried out by experts in measurement. For example, this could involve following a sample from the time it is taken, through laboratory analysis to final reporting. Inspections can be described as horizontal investigations carried out by site inspectors who will have a broad but not necessarily in-depth understanding of measurement. For example, they might focus on the totality of results for a given period, looking for trends, missing data and anomalies.
- Witnessed sampling. This involves an inspector or person contracted by the regulator to be present at the time when samples are being taken. This could provide, for example, for independent checks to be made that the samples are being taken at the right time, from the correct location and in the prescribed way. Depending on the practicalities of the sampling arrangements, it may be possible for the inspector to have a replicate sample taken at the same time for the regulator's independent analysis.
- Check monitoring. This requires an inspector or person contracted by the regulator to take a sample from a waste stream for analysis by the regulator's laboratory. The sampling aspect can be prohibitive for practical reasons including health & safety considerations, in which case the arrangements for witnessed sampling and independent analysis might be the best available.
- Independent analysis. This involves replicate samples (or sub-samples) from the self-monitoring programme being supplied by the operator to one or more of the regulator's laboratories for analysis. This can provide cost-effective and valuable independent checks on the reliability of the operator's results and analytical methods. However, without the witnessed sampling being applied on at least a selective and periodic basis the arrangement lacks true independence because of the reliance on the operator to supply the sample. It is important also that the analytical laboratories used by the operator and regulator are independent of one another, i.e. that both operator and regulator do not contract the same firm of analysts, unless arrangements are in place to ensure independence, in which case these arrangements should be fully understood and documented.

#### **4. Monitoring strategies**

4.1 Several different strategies can be used to monitor both aerial and liquid discharges of radioactive wastes. These broadly fall into the following categories:

- On-line instrumentation. This can provide a real time continuous measurement of the discharge.
- Sampling and laboratory analysis. This can provide a prospective (for discharges of liquid wastes from tanks) or retrospective (for continuous discharges of aerial and liquid wastes) measurement of the discharge. For the monitoring of liquid discharges sampling techniques can be further sub-divided into: sampling of batch discharges, continuous sampling and spot sampling.

- Estimation. This can provide a retrospective assessment of the discharge without the need for the routine use of instrumentation or sampling and analysis techniques.

4.2 The selection of the preferred monitoring strategy should take into account:

- The radiological significance of the discharge.
- The availability of instrumentation with appropriate detection capabilities, (e.g. detection limit, response time, sensitivity, discrimination).
- The availability of appropriate sampling equipment and locations. (e.g. continuous samplers operating on a flow proportional basis).
- The type of discharge (e.g. continuous, batch, intermittent).
- The characteristics of the discharge (e.g. stable and well characterised).
- The ease of access to install and maintain instrumentation and sampling equipment, and/or to take spot samples.

4.3 The monitoring of discharges with significant radiological impacts should provide for the greatest amount of control. The following hierarchical approach should be followed when considering the appropriate monitoring strategy:

- Prospective determination of the radioactive content of a waste prior to discharge using instrumentation or sampling and laboratory analysis of samples. This strategy can provide for abnormal and/or non-compliant discharges to be retained for further investigation and/or treatment. The practical difficulties of retaining aerial discharges means that this strategy is only applicable to liquid discharges that can be held in delay or sentencing tanks.
- Continuous monitoring using instrumentation that can provide a real time measure of the radioactive content of the waste being discharged. This strategy can provide for process plant operators to be notified immediately of abnormal and/or non-compliant discharges so that remedial action, including possible process shut down can be taken. In principle this technique can be used for both aerial and liquid discharges.
- Continuous sampling. This strategy involves taking samples using on-line sampling equipment from flowing waste streams to collect bulk or spot samples continuously over a certain period for subsequent laboratory analysis for selected radionuclides. The sampling rate may be time proportional or flow proportional. In combination with measurement or estimation of the discharge flow (rate or quantity) a retrospective determination of the total activities of specified radionuclides in the discharge can be made.
- Spot sampling. This strategy involves taking samples, either using on-line sampling equipment or by hand, at set or irregular times to collect instantaneous (spot) samples over a certain period for subsequent laboratory analysis for selected radionuclides. In combination with measurement or estimation of the discharge flow (rate or quantity) a retrospective determination of the total activities of specified radionuclides in the discharge may be estimated. A statistical model may be used to demonstrate compliance with percentile limits over a stated period, typically a year.

- Estimation. This strategy involves estimating the radioactive content of a discharge using process operating data and possibly indirect measurements applied to a characterised and stable discharge source for which both the flow rate and radionuclide content do not vary significantly over time. The assessment is retrospective. It can be based on knowledge of process operations, the determination of process parameters, such as flow, and/or the monitoring of key radionuclides to give an overall understanding of the radioactive content of a discharge.

4.4 It has to be appreciated that practical considerations such as the availability of appropriate instrumentation, sampling equipment and access to the optimum sampling location can dictate the selection of the monitoring strategy. In many cases an appropriate mix of the strategies identified above will be the best solution (e.g. with conventional sampling and laboratory analysis being employed in tandem with instrumentation. See sections 5, 6 & 7).

## 5. Instrumentation

5.1 On-line instrumentation can be used in the following arrangements:

- As a legal requirement to provide results for accountancy purposes.
- As a legal requirement to give assurance that a discharge is below a pre-set limit. In this arrangement accountancy requirements are met by additional sampling and laboratory analysis at the same point in the discharge. (However, in the circumstance where the on-line instrumentation is located at the approved accountancy point and the instrumentation uses a sample collection medium, for example a filter paper, this may also be analysed retrospectively in a laboratory to provide a measurement suitable for accountancy purposes.)
- As part of an operator's in-house arrangements to ensure compliance with discharge limits by providing a continuous and real time indication of the levels of radioactive material in a discharge from a particular process plant. The plant may only be a contributor to a combined discharge to which the licensed limits apply. This arrangement may or may not be formally recognised within a licence by the competent authority.

5.2 The use of on-line instrumentation under all of the above arrangements can provide for rapid corrective process control actions to be taken in the event that the measurements indicate abnormally high discharge levels. However, the last arrangement may achieve this objective better because the instrumentation can be sited on process plants and thereby closer to the source of individual discharges. Alarm systems may be included within these arrangements.

### ***On-line instrumentation for monitoring aerial discharges***

5.3 On-line instrumentation can be used to provide a continuous and real-time measure of the levels of radioactive material in a discharge. The German Nuclear Safety Standards Commission (KTA) has incorporated certain requirements for the use of instrumentation into their Safety Standard: KTA 1503.1 [KTA, 2002]. Box 1 provides a copy from KTA 1503.1 of a schematic example of the deployment of a range of equipment for monitoring aerial discharges.



- 5.4 Gross beta/gamma or alpha activity in discharges or collected samples (e.g. filter papers) can be determined directly with appropriate counters, such as Geiger-Mueller tubes, proportional counters, scintillation or semiconductor detectors. Where a radionuclide specific determination is required measurement can be made either directly or on a collected sample using an appropriate spectrometer. These include Ge semiconductor detectors connected to multichannel pulse-height analysers or collection media specific to the nuclide of interest e.g. carbon for radioiodines. Errors may occur because of the presence of other radionuclides in the discharge, such as fission gases in a discharge sampled for iodine. In these cases the discharge should be fully characterised and the instrumentation capable of measuring all relevant radionuclides above appropriate thresholds and within satisfactory ranges and accuracies.

***On-line instrumentation for monitoring liquid discharges***

- 5.5 The German Nuclear Safety Standards Commission (KTA) has incorporated certain requirements for the use of instrumentation into their Safety Standard KTA 1504 [KTA, 2007]. Box 2 provides a copy from KTA 1504 of a schematic example of the deployment of a range of equipment for monitoring liquid discharges from a Pressurised Water Reactor. The requirements for on-line instrumentation relate to the monitoring of discharges of service cooling water, waste water from the turbine building, water from the auxiliary steam supply, main cooling water and (where separate) main water. These applications of instrumentation are a legal requirement to give assurance that discharges are below pre-set limits with accountancy requirements being met by additional sampling and laboratory analysis at the same point in the discharge.
- 5.6 On-line instrumentation can be used to provide a continuous and real-time measure of the levels of radioactive material in a liquid discharge. However this technique is generally applicable only to hard gamma-emitting radionuclides because the detector has either to be mounted outside the tank or pipe containing the waste or within a waterproof assembly within the tank or pipe. Either arrangement means that the detector is substantially shielded from the radiation and with additional self-shielding effects caused by the water matrix there are difficulties with obtaining accurate measurements. These shielding effects preclude on-line detection of alpha emitters (e.g. actinides) and low-energy ("soft") beta emitters (e.g. tritium and  $^{14}\text{C}$ ). Consequently, on-line instrumentation is not frequently used for accountancy purposes but is used as an operational tool, in combination with alarms, to alert process operatives to take rapid remedial actions in the event that an abnormal discharge is detected.
- 5.7 Most on-line instrumentation uses sodium iodide (NaI(Tl)) scintillation detectors for the measurement of gamma-emitters. Typical detection limits for commercial on-line NaI(Tl) monitors are  $\sim 4 \times 10^3 \text{ Bq m}^{-3}$ . Semiconductor gamma detectors are seldom used for on-line monitoring applications because of requirements for cooling. The sensitivity of NaI(Tl) detectors depends on the following factors:
- Size of detector and geometry. Large detectors have higher sensitivities. Sensitivity can be maximised by the use of several detectors around the circumference of a pipe carrying the waste liquid.
  - Liquid volume. The sensitivity of the detector depends on source-detector geometry. This can be improved by positioning the detector at a location where it can view the largest volume of waste liquid, for example on a large diameter pipe.

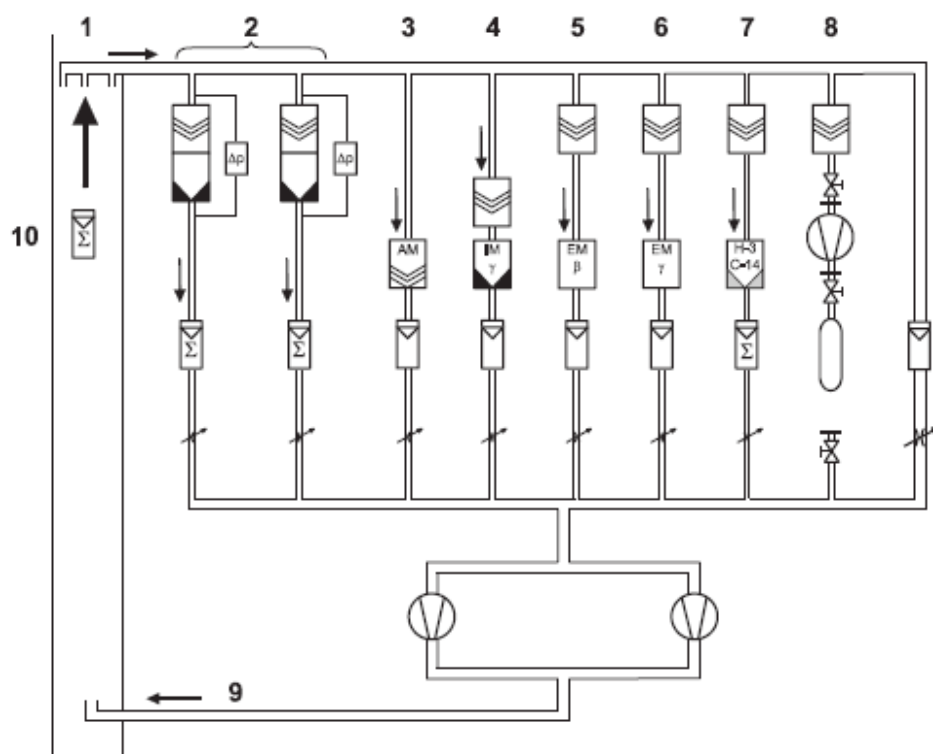
- Flowrate. The total activity detection limit for a homogenous liquid containing only soluble radionuclides flowing in a pipe is independent of flowrate. However, for a single active particle, the likelihood of detection increases at low flowrate (since the time for which this particle is viewed by the detector increases).

5.8 For both aerial and liquid discharges the instrumentation should be linked to activate alarms when levels rise above one or more pre-set values. For example, one alarm can be set at a value just above the normal emission level and another at a value close to a maximum discharge level for the process which if activated would require immediate corrective action. Similarly, an alarm should be set at a value below the expected background reading to indicate when the instrument may be faulty. On-line instrumentation should be used where a process plant has the potential to generate rapid and significant changes in discharge levels, particularly where this could lead to a breach of licensed levels and the possibility of off-site hazard.

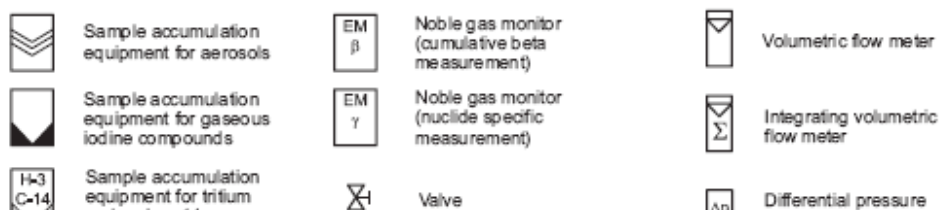
## Box 1

### Example of equipment for monitoring aerial discharges

(Diagram courtesy of KTA)



- 1 Sample extraction equipment
- 2 Sample accumulation equipment for the detailed assessment of the radioactivity release of aerosol-bound radioactive substances and of iodine compounds
- 3 Aerosol monitor
- 4 Iodine monitor
- 5 Noble gas monitor (cumulative beta measurement)
- 6 Noble gas monitor and nuclide specific measurement equipment for the detailed assessment of the radioactivity release of radioactive noble gases
- 7 Sample accumulation equipment for the detailed assessment of the radioactivity release of tritium and carbon 14 compounds
- 8 Discontinuous sample extraction
- 9 Return pipe
- 10 Volumetric flow measurement in the stack



**Schematic example of the deployment of a range of equipment for monitoring liquid discharges from a Pressurised Water Reactor**

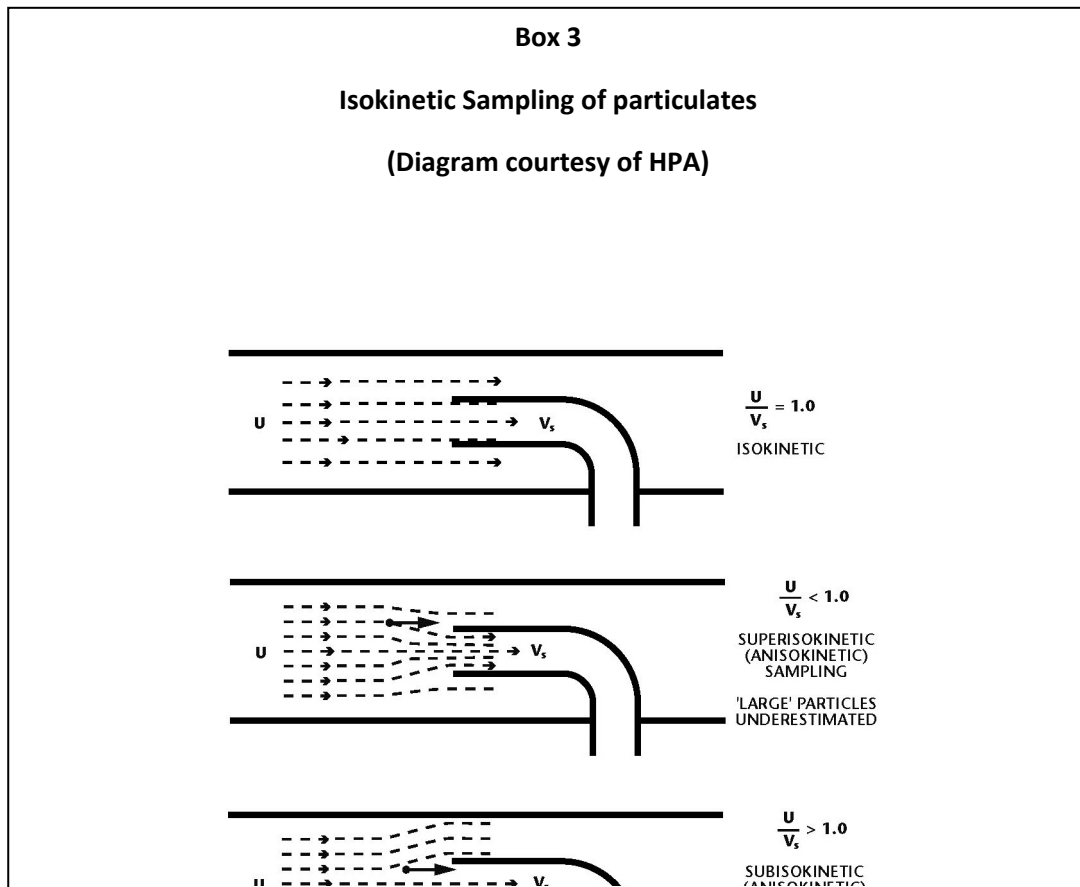
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## **6. Sampling of aerial discharges**

- 6.1 Radioactive materials can be present in particulate, vapour or gaseous physical form in aerial discharges. It is possible for one or more of these physical forms to co-exist in a discharge containing different radionuclides. Consequently, sampling techniques appropriate to the physical forms of the radioactive materials must be used.
- 6.2 In order to obtain a reliable measurement of the radioactive content of a discharge a representative sample must be taken. Continuous sampling is normally required but periodic sampling may be permitted for discharges from stable sources and/or discharges of low radiological significance.
- 6.3 The selection of the appropriate location (on a duct or chimney stack), sampling plane and sampling point (within the duct or stack), procedure, and equipment for sampling gaseous and particulate emissions is technically complicated and should be made in accordance with relevant European or international Standards [ISO, 2007; BSI, 1975; BNFL, 1992].
- 6.4 Whether continuous or periodic sampling is employed the location and design of the sampling arrangements should be such that a representative sample of the discharge can be taken. This requires consideration of:
- The spatial aspect of where within the duct or stack the sample is taken.
  - The sample must be taken downstream of any abatement plant.
  - The sample must be taken at a position in the discharge stack where all constituents are adequately mixed.
  - Sampling for particulates should be carried out under isokinetic flow conditions to ensure that the particle size distribution of the discharge is not distorted. In order to achieve this, the flow characteristics across the duct must be determined and an appropriately sized probe nozzle used. Sampling anisokinetically, when the velocity of the sampled air entering the sample probe is significantly different from the velocity of the air in the stream being sampled, can result in larger (sample air velocity lower than stream velocity) or smaller particles (sample air velocity higher than stream velocity) being preferentially collected. See Box 3 for further information on isokinetic sampling.
  - The potential for chemical reactions between the sample and the sampling system, particularly the sample collection medium. (See below for further details.)
  - The optimum position for the probe should be established at the design stage and confirmed during commissioning by measuring concentrations of a suitable tracer (e.g. SF<sub>6</sub>) material and velocity profiles across the stack or duct. The discharge velocity and concentration profiles across the sampling plane should be reasonably uniform. Note that as well as the need to consider isokinetic sampling for particulates it cannot be assumed that gaseous discharges will be well mixed.
  - For ducts with a diameter of less than 200mm a single sampling point should be adequate to obtain a representative sample. For larger ducts multipoint sampling at several points across the duct should be considered. The number would depend on the shape and cross-sectional area of the duct, and the variability of

the flow pattern at the sampling plane. However, the design of a multiple point system for simultaneous sampling across a duct is likely to meet practical difficulties and should only be used where the flow pattern is such that a representative sample cannot be taken using a single sampling probe at a position determined to be optimal by investigation of the flow pattern.

- The sample must be taken well away from any ductwork features such as dampers, bends and merged streams, which could 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.



- The sampled air must be returned to the duct or stack from which it was drawn at a location downstream of the sampling position.
- The sample should ideally be taken using an upstream pointing probe.
- Possible chemical reactions between the sample and the sampling systems should be considered. Reactive vapours such as radioiodine may adsorb or react with materials used to construct the sampling equipment.
- Sample line losses should be minimised by:
  - Using lines of less than 2 metres length, where this is not possible an assessment of possible losses should be made.

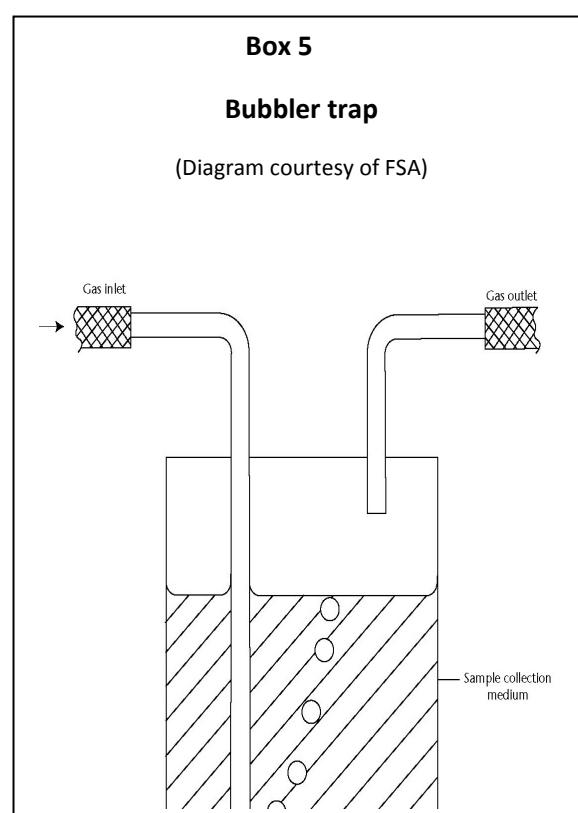
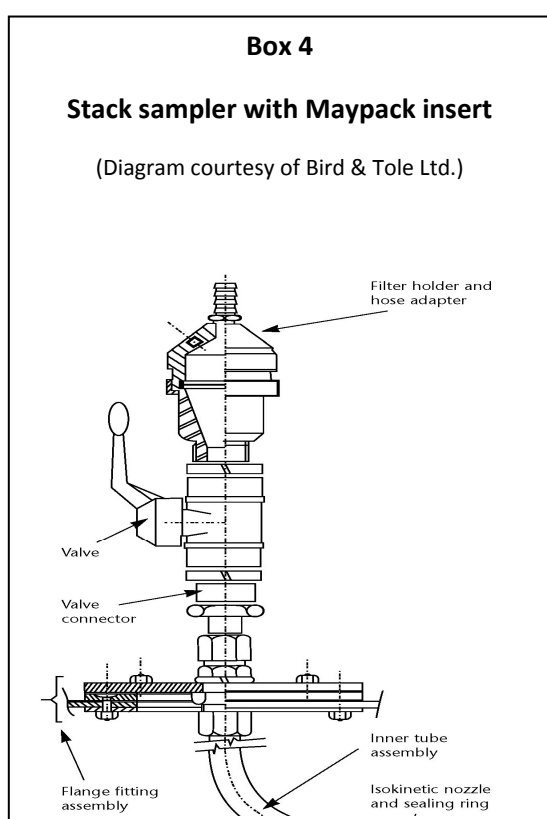
- Avoiding sharp bends in the line. (Elbows should not be used and bends should have a minimum radius of 5 times the internal diameter of the sample pipe.)
- Minimising the number of bends in the sample line. (Ideally there should be only the one bend associated with the sample nozzle in the duct.)
- Minimising turbulent deposition by using a minimum sample line diameter of 20mm for a typical sample flowrate of 40 litres per minute.
- Using trace heating of the line and sample collection system if condensation may take place. Condensation of water vapour from saturated discharges may block sampling lines or weaken filter media.

### ***Sample collection***

- 6.5 Sample collection methods have to be used that are suitable for the different physical forms in which radioactive materials can exist in discharges. Appropriate methods for collecting samples of particulates, vapours and gases are summarised below.
- 6.6 *Particulates:* suspended radioactive particles, often referred to as aerosols, are most usually collected on glass fibre or cellulose filter papers.
- 6.7 *Vapours:* Radioactive materials in the form of volatile vapours will pass through a filter paper but can be collected by adsorption onto granulated activated carbon (see Box 4). This medium is commonly used to collect radioiodine, but it will also absorb <sup>35</sup>S and <sup>14</sup>C. The performance of carbon for absorbing iodine can be improved by impregnation with KI. However, carbon is vulnerable to contamination by moisture, oil and other organics that may be present in the discharge. Free water will take up adsorption sites thereby rendering the carbon less efficient for iodine capture. Carbon is also not a suitable capture medium when sampling discharges that contain aggressive chemicals such as nitric acid. In these cases alternative collection media such as molecular sieves manufactured from crystalline aluminosilicates (impregnated with silver for iodine capture) can be used. For some other vapours, such as ruthenium, a wet scrubber can be used as the collection medium (see below for gases).
- 6.8 *Gases:* the collection efficiency of carbon for some gaseous forms of radioactive material is variable. Consequently, other collection media are used that are specific to the chemical form of the gaseous radioactive discharge to be measured. Bubbler traps, wet scrubbers and direct measurement are the techniques most commonly used.
- Bubbler traps (see Box 5) utilise a physical or chemical reaction between the gaseous radioactive material and a liquid collection medium to capture the required sample. The reaction is facilitated by directing the sample gas to bubble through the liquid medium contained in a bottle thereby ensuring good contact between the sample gas and bubbler liquid and complete reaction. Bubbler traps are widely used to collect tritium in both elemental and tritiated water form.
  - Wet scrubbers promote contact between the sample gas and a recirculating flow of liquor contained in a glass cylinder to ensure that the radioactive material is trapped by the liquor. Glass beads or other finely divided inert material that provides a large contact area is contained in the cylinder to maximise the transfer of radioactive material to the liquor. The liquor can be water or a solution that is chemically reactive with the radioactive material of interest. The

reaction is facilitated by directing the sample gas to flow up over the inert contact material and the scrubber liquor to flow downwards. The liquor is periodically changed and analysed to determine the amount of the radioactive material that has been trapped during the period. This activity can then be related to the quantity of sample gas passed through the scrubber

- Direct measurement is used when the chemical form of the radioactive material of interest prevents its easy separation from the discharge, for example, for the inert gases Krypton and Xenon. The sample gas is drawn into a chamber of known dimensions and which is maintained at a constant temperature. A detector and associated electronics are positioned to measure the activity in the chamber. The resulting measurement can be converted to a measure of the radioactive material in the emission using the known volume, temperature and sampling rate.



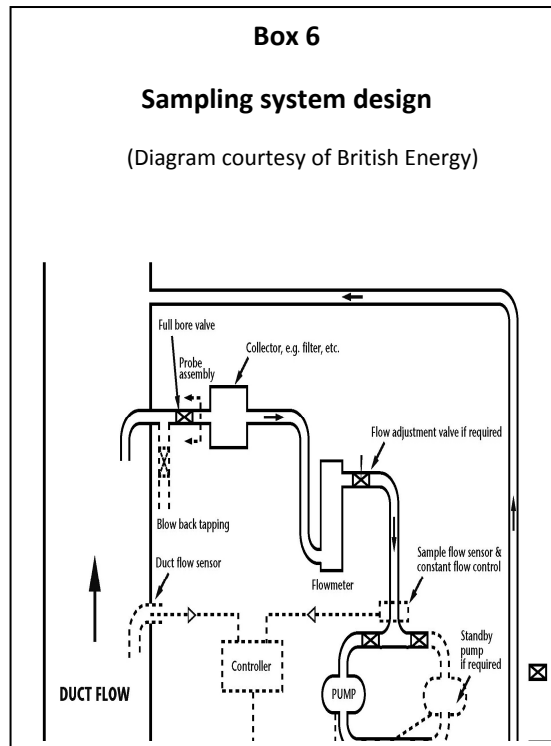
### ***Sampling system design***

6.9 Sampling systems are often housed in cabinets. Box 6 provides a schematic diagram of a typical system for extracting a sample. Most sampling systems consist of:

- A probe fitted with a nozzle for extracting the sample of gas from the duct or stack.
- A sample collection device, such as a filter paper in a housing or a bubble trap.
- Pumps to draw the sample through the system.



- A flow meter to record the sample flowrate and/or sample volume.
- In the case of isokinetic sampling for particulates sensors to measure the flowrate in the duct and to adjust the sample flowrate.



6.10 Some important aspects to take into account when designing sampling systems are: sample extraction, deposition effects, prevention of sample bypass, flow measurement, materials of construction, back up equipment, environmental conditions, tamper protection, and maintenance.

- Extraction systems for particulates and condensable vapours should use short lengths of pipework between the probe and sample collector so as to minimise the possibilities of plate out or condensation leading to unrepresentative sampling. Particulate sample collectors can sometimes be positioned immediately after the nozzle and inside the duct from which they then have to be withdrawn to change the filter. Opportunities for deposition of radioactive material by centripetal separation between the probe and sample collector should be minimised by avoiding bends in the pipework. If bends are unavoidable then the radius of curvature of the bend should exceed 5 times the pipe diameter. Pumps and other equipment should be positioned downstream of the sample collector.
- Deposition effects can be caused by “plating out” of some volatile species, such as iodine and sulphur, onto the sample lines. This may be enhanced by thermophoresis deposition where the sample lines are cold relative to the sample gas. This deposition may not be apparent until a disturbance to the sampling system releases the plated out material resulting in a spike in the emission. Plate out can be minimised by trace heating of the sampling line from duct exit to sample collector.

- Prevention of sample bypass can be achieved by attention to the design and positioning of the sample collector. Filter papers for particulates should be sealed tightly in the filter housing. The design of this arrangement should be simple and effective so as to minimise the chances of damaging the fragile filter papers during removal and replacement which could result in a bypass channel. Carbon used for adsorbing iodine should be housed vertically so that settling cannot lead to slumping thereby creating gas bypass channels.
- Flow measurement is made using a flow meter and where continuous sampling is employed an integrating flow meter that records the total volume sampled should be employed. Sensors to activate alarms should be used to detect low and high flows. The latter is important when sampling for particulates as an abnormally high flow could indicate that the filter had failed. Flowmeters should be calibrated at regular intervals in accordance with the manufacturer's instructions.
- Back up equipment, such as pumps, should be in place to allow for simple changeovers to be carried out where high reliability of the sampling system is required, for example where continuous sampling systems are used.
- Environmental conditions around the sampling system should be controlled so as to avoid adverse climatic impacts, for example, excessive heat could cause bubbler liquids to evaporate or electronics to malfunction.
- Tamper protection should be provided to guard against deliberate or accidental adjustments, damage or vandalism of sampling systems by housing the equipment in a locked cabinet.
- Maintenance schedules should be in place and followed to ensure that sampling systems have high reliabilities. These should include regular checking of pumps, flow meters, the leak-tightness of joints in sampling lines and the correct functioning of alarms. Equipment outage for continuous sampling systems should not exceed  $10^{-3}$  per year. This approximates to an outage time of less than 9 hours per year.

### ***Flow measurement***

- 6.11 On-line instrumentation, sampling and laboratory analysis and estimation, typically provide a measure of the concentration ( $\text{Bq/m}^3$ ) of a radionuclide in a discharge. In order to calculate the total amount (e.g. TBq) of the radionuclide discharged over time (e.g. the period specified in the permit, typically a month) for accountancy purposes knowledge of the air flow rate in the discharge stack is required. Air discharge flow rates can be determined continuously or periodically using:
- Flow meters.
  - Airflow grids (e.g. a Wilson flow grid).
  - Pitot tubes.
  - Calculation and estimation procedures
- 6.12 Flow meters should be capable of measuring and recording the volumetric flow ( $\text{m}^3/\text{s}$ ) and the integrated flow (i.e. total flow over time,  $\text{m}^3$ ).

6.13 Airflow grids (e.g. a Wilson flow grid) provide a simple means of measuring clean air flow in ducts and pipes, for example on ventilation systems. Airflow grids are suitable for clean air velocities in the range 1.5 to 30 m/s. and are available in different standard configurations and can be custom made. Grids of cross-sectional area up to 0.64m<sup>3</sup> are factory calibrated; larger grids have to be calibrated in-situ. If accurate duct dimensions are known, the volumetric flow can be measured to within +/- 5%. The grid consists of a row of tubes forming a fence across the duct. Some of the tubes are perforated with small holes facing upstream which measure the total pressure of the air flow. Other tubes have similar holes facing downstream which measure the substatic pressure. The pressure difference between the two arrays of small holes provides an output signal which can be transmitted to an electronic transducer, for example a liquid-filled manometer to convert the differential signal into a usable reading.

6.14 Pitot tubes are commonly used as fixed or portable instruments for the determination of air flows in ducts and chimney stacks. Pitot tubes are tubular devices consisting of a cylindrical head attached perpendicularly to a stem allowing measurements of a differential pressure from which the flow rate of the air can be determined. Pitot tubes are used in combination with a manometer to determine the difference between the total and static pressures at points in the moving air. The key stages in the use of pitot tubes are:

- Measurement of the dimensions at the section of the duct or stack where the flow measurements are to be made. This section must be normal to the direction of flow in order to determine the cross-sectional area.
- Definition of the position and number of the measuring points within the cross-section. The number must be sufficient to allow satisfactory determination of the velocity profile.
- Measurement of the differential pressure existing between the total and static pressures of the pitot tube placed at these measuring points.
- Determination of the local velocity of the flow, using given formulae.
- Determining the discharge velocity from these values.
- Calculating the volume rate of flow equal to the product of the cross-sectional area and the discharge velocity.

International Standard ISO 10780 [ISO, 1994] specifies the Reference Method for determining air flow rate through a stack or duct but is not specific to nuclear facilities where dust loadings can be expected to be much lower. The Standard recommends the use of a S-type pitot tube when making measurements in dusty environments to avoid risk of dust plugging the ports of the pitot. The ISO/DIS Standard 2889 [ISO, 2008] recognises that this should not be a concern in the nuclear industry and recommends the use of Prandtl-type pitotstatic tubes (Type-L in ISO 10780) as the reference apparatus.

6.15 Calculation/estimation may be used to establish an air flow where the dimensions of the duct or chimney stack are well known and the flow rate has been measured at the commissioning stage probably with pitot tubes or anemometers. This approach is only acceptable where the flow is well understood and stable over time. Anemometers are available in two types: vane anemometers and hot-wire anemometers. A vane anemometer relies on the airflow hitting the vane thereby making it rotate. The speed of rotation of the vane can be measured by an optical or magnetic sensor which

converts the speed to an air velocity measurement. The volume of air flow can be displayed by entering the cross-sectional area of the duct or stack into the meter. Hot wire anemometers rely on the principle of heat transfer. The wire is heated to a temperature above ambient by passing an electrical current through it. The heat is lost to the air flowing over it in the duct or stack. The meter maintains the temperature of the wire by supplying more current. The increase in current can be related to the air flow velocity over the wire. And as for vane anemometers the volume of air flow can be displayed by entering the cross-sectional area of the duct or stack into the meter. Hot wire anemometers can typically be used in small ducts and tight spaces where air flow rates are low, typically in the range m/s.

## **7 Sampling of liquid discharges**

- 7.1 Samples of liquid wastes can be taken from batch and continuous discharges using continuous and spot (grab) sampling methods to collect discrete or composite samples.

### ***Sampling of batch discharges***

- 7.2 Samples of liquid discharges may be obtained from sentencing or delay tanks by taking a spot sample after first agitating the tank by means of a paddle or a re-circulating pump. In the latter case the sampling point is often located at a convenient point on the re-circulation line. An alternative method is to take a composite sample of the contents of the tank during discharge using a flow proportional sampler. However, this method does not provide advanced results on which to base a decision to discharge so in practice a combination of both methods is often used.
- 7.3 The spot sample is often used to screen the waste liquid, for example for gross alpha, gross beta and gross gamma to provide sufficient information on which to sanction discharge. A more detailed analysis is then carried out on the composite sample taken from the discharge to provide accountancy results. These results from each tank may represent only one discrete data point in the period of discharge defined by the licence. Consequently, the overall discharge has to be calculated from the individual tank volumes and analytical results.

### ***Sampling from continuous discharges***

- 7.4 Samples are normally taken from continuous discharges of liquid wastes (including the taking of samples from discharges from delay tanks as described above) using automated samplers which can collect composite samples on a time proportional or flow proportional basis. The composite sample may be made up in one of the following two ways:
- from discrete samples taken on a near continuous basis thereby covering all of the period of the discharge, or,
  - from discrete samples taken at predetermined intervals during the course of the discharge.
- 7.5 An example of the latter case would be a composite sample made up by mixing together several discrete samples taken during a tank discharge. This might represent a small time increment of the total discharge licence period (i.e. this discharge is one of only many that might be made during the licence period). A number of these composite samples would be collected over the whole discharge period and would form the basis of accounting for the total discharge and any trends.

7.6 The advantages of composite sampling are:

- The number of samples to be analysed is reduced (thus reducing costs).
- The result for each composite sample yields an average result for the activity in the waste stream over the period in which it was taken, providing the correct number of discrete samples is used to form each composite sample. Taken over the whole discharge licence period, use of composite samples averages out trends with time, so simplifying interpretation of the data.

7.7 Nevertheless, care is required when considering how many composite samples are taken over the whole discharge licence period. Too many composite samples will reduce the advantages of the method; too few produce a few average results, thus precluding reliable estimation of the cumulative discharge and masking any trends with time. Factors to be considered in the number of composite samples taken in the discharge licence period are:

- *Batch discharges from tanks.* It is usual either to take a number of discrete samples during each tank discharge (generally a matter of hours) and then mix these to form a single composite sample, or to take a continuous sample over the discharge period. Results of all of the composite samples taken over the discharge licence period then form the basis for characterising the waste stream from that tank (that is, quantifying the total activity discharged and establishing any trends with time).
- *Continuous discharges.* It is routine to collect composite samples covering all weeks or months in the whole discharge licence period, the results of which are then used for accountancy purposes and to provide information on trends.

7.8 It is also necessary to consider that, over the period represented by each composite sample; there could be random or cyclic variations in the discharge. The ideal is to obtain a composite sample with an activity as close as possible to the mean activity of the waste stream in the sampling period over which the composite was taken. To achieve this, the following should be considered:

- In the case of a discharge from a batch or sentencing tank, normal practice is to mix the tank prior to discharge and this will minimise variations in the discharge itself. The frequency and number of discrete samples taken in the discharge period to form the final composite sample therefore become less critical.
- In the case of a continuous discharge, the number of discrete samples needed to form a single representative composite sample may be estimated by published methods for systematic sampling [Hunt and Wilson, 1986; IAEA, 1978].

7.9 The individual, discrete samples used to form each composite sample should be taken and mixed in a manner appropriate to any changes in the rate of the discharge:

- Where the rate of discharge is constant, it is common practice to take samples of equal volume at regular intervals over the sampling period. This can be most easily achieved by using automated time-proportional samplers.
- Where the rate of discharge varies over the sampling period, the volumes of the individual samples should reflect this. That is, during a period of high flow, the volumes of each discrete subsample used to form the final composite sample should

be proportionally greater than those taken in periods of low flow. This can be most easily achieved by using automated flow-proportional samplers which have an in-built capability to measure the discharge flow rate.

- 7.10 Ideally, the composite sample should use the entire volume of all of the discrete samples taken in the sampling period. This single, large composite sample should then be delivered to the analytical laboratory where any subsampling required can be carried out. Subsampling of the composite sample on-site introduces sampling errors additive to those due to subsampling in the analytical laboratory, especially where particulates are present.

#### ***Methods of composite sampling***

- 7.11 At most nuclear establishments, collection of composite samples is usually carried out using a device called a 'proportional sampler'. These take individual aliquots at a rate proportional to the effluent flow and deliver them to a single large bottle. Some designs use a carousel where each subsample is retained in its own bottle until these are collected and mixed manually. All of these devices are controlled by some form of programmer.
- 7.12 Flow-proportional samplers should be capable of meeting the design requirement with regard to size and number of subsamples to be taken to make up a composite sample of a given size. Consideration should also have been given to providing interlocks with the outlet/inlet valves on batch tanks so that, in the event of a failure in the composite sampler, the discharge is stopped until the fault is rectified.

#### ***Alternatives to composite sampling***

- 7.13 Less frequently the following alternative strategies may be used:
- Sampling from the waste stream via a system that achieves a low but continuous sample flow. Most of these rely on sampling via a capillary or similar flow-reducing device. These can result in non-representative sampling of particulates. Also, in long capillary columns there can be plate-out (and thus loss) of some constituents. Such columns are also susceptible to blockage.
  - Continuous sampling through a device that passively concentrates the nuclides of interest from the sample stream. This is usually carried out by passing the sample stream through a small bed of ion exchange resin (e.g. for sampling  $^{90}\text{Sr}$  and  $^{137}\text{Cs}$ ) or activated carbon (for actinides). The concentrated composite sample is then removed for separate analysis.

#### ***Sampling precautions***

- 7.14 Once the overall strategy of sampling has been decided, a number of precautions need to be taken in the practical execution of the sampling programme. The primary aim is to ensure that the sample reaching the analytical laboratory is fully representative of the liquid discharge at the time it was taken. The following points should be considered [Hunt and Wilson, 1986; IAEA, 1978; Colley, 1989]:
- Representative sampling.
  - Sample size.
  - Avoidance of sample contamination.

- Avoidance of sample degradation.
- Sample container materials and design.
- Use of trip blanks and sample stability tests.
- Sample pre-treatment, labelling and transport.
- Chain of custody.

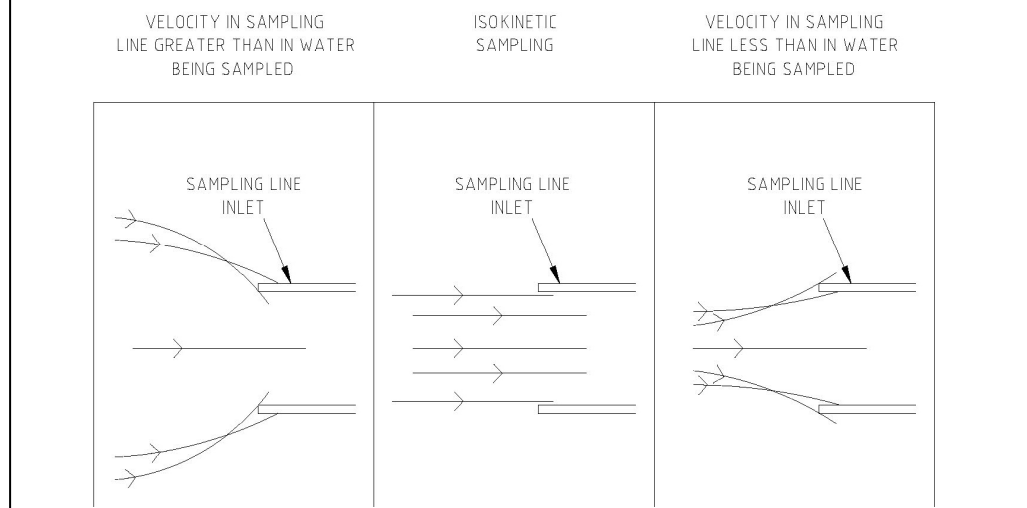
7.15 *Representative sampling.* In order to obtain a representative sample, several conditions should be met with regard to the point of sampling:

- Sampling must be carried out downstream of any abatement plant but upstream of any point where further dilution of the waste stream occurs, e.g. with water in a cooling water outfall.
- There must be no significant preferential sampling of particular phases in the discharge (especially of particulates which may include those with high activities, so called 'hot' particles). Where information on the relative importance of these phases is of interest, sampling must be carried out to accommodate this requirement.
- Prior to taking single grab samples, the contents of sentencing or hold up tanks must be mixed and sampling must take place prior to any period during which settling of particulates may occur. Problems of imperfect mixing or settling out of particulates may be partially compensated by use of proportional sampling (effectively a large number of grab samples, taken over the entirety of the tank discharge period), but this must extend over the whole of the tank discharge period.
- Even after mixing, particulate material is rarely homogeneously distributed in a waste stream. In pipes and gullies, any particles flow close to the walls ('wall effect'). In regions of low flow in a sampling system or tank, particulates fall out from suspension. Small particles often agglomerate into larger ones that have higher settling velocities, especially after some period of standing. These effects need to be taken into account in the design of sampling probes or other devices that withdraw samples from a large pipe or gulley. Sample heads should be positioned in the main flow and there may be a need to achieve isokinetic conditions at the sample head to obtain a representative sample of particles in the waste stream (that is, the rate of sampling must match the rate of flow in the main pipe or gulley). Box 7 illustrates these effects [Hunt and Wilson, 1986].

### Box 7

#### Isokinetic and anisokinetic sampling effects from a flowing liquid discharge

*(Reproduced by permission of the Royal Society of Chemistry)*



- Spot samples taken manually from outfalls using bottles also need to take account of these effects, as well as any tendency to sample preferentially the surface of the water (where an oil film may be holding higher levels of active material) or particulates disturbed from the base of the stream flow.

7.16 **Sample size.** Samples should be of a size commensurate with that required by the analytical laboratory and sufficient sample must be taken to meet the following requirements:

- Liquid samples must be of sufficient volume to allow all of the required analyses to be carried out, with provision of spare material for repeat analyses and (if required) sample archiving.
- In large samples, the ratio of container wall area to sample volume is low and they are therefore less susceptible to plating out of radionuclides than small samples (plating out is the loss of nuclides on to the sample container walls by processes such as adsorption). However, large samples are more difficult to transport, handle and mix prior to any sub-sampling.
- Generally, sample containers should be completely filled to minimise loss of volatile constituents to a headspace. However, sample containers that are completely full can be difficult to mix properly prior to withdrawing sub-samples for analysis.

7.17 **Avoidance of sample contamination.** Sampling programmes need to take account of the potential effects of sample contamination from extraneous sources of activity. Typical examples are:



- Sample containers that have been used for other waste streams may retain traces of activity and represent the most obvious source of cross-contamination.
- Equipment that has been used to handle active material on-site can act as a source of contamination if it is then used to handle low-activity samples. Good policy is to use disposable gloves for sample handling and specific dedicated equipment for taking the samples (bailers, etc.).
- Cross-contamination in the analysis laboratory is also a potential problem. This can occur as containers are prepared for dispatch, washed, stored open, or during analytical procedures.
- All sample containers should be cleaned prior to use taking into account the following points:
  - It is sometimes recommended that sample containers are pre-rinsed two or three times with the liquid to be sampled before being finally filled. If this is carried out, care should be taken to ensure that all of the material used for the rinse stages is drained from the bottle. In particular, particulates tend to drain last from a bottle, and if retained after the rinsing will result in preferential sampling of particulates (which may include hot particles that contain the bulk of the activity in the waste stream).
  - New sample containers can be used but these may have walls that are more adsorptive than pre-used ones. In this case it may be better to 'age' new containers with distilled water or tap water prior to use.
  - Where old sample containers are re-used, a stringent programme of container cleaning is required. All traces of residual activity from older samples must be removed. To avoid cross-contamination, care is required when cleaning or otherwise handling sample containers in laboratories where more active material is handled/analysed. In addition, some cleaning activities (especially those involving use of strong acids or detergents) can affect surface properties of container walls so that they start to show increased tendency to adsorb nuclides from samples. Where sample containers are re-used, they should be retained specifically for the monitoring programme and kept segregated from those used for other purposes/monitoring programmes. They should also be cleaned by a standardised method.
  - It is good practice to keep all sample containers full of demineralised water prior to use. This not only assists in cleaning but also serves to 'age' the container walls so that they show a lesser tendency to adsorb nuclides when re-filled by the samples
- All of the factors and considerations applicable to the cleanliness of sample containers also apply to sample lines, pumps, bailers, etc., that may be used to extract samples from the waste stream, especially proportional samplers where the sample may be in contact with the sampling kit for some period of time. The entries to isokinetic and other sample probes inside pipes carrying waste streams require periodic cleaning to avoid blockage or non-isokinetic sampling effects. Sample lines must be of the correct length to give isokinetic sampling. They must also be inert (to avoid deposition of material in the line) and designed to avoid

settling out of particulates in dead legs, etc. The final containers for the composite sample must also be suitably protected from ingress of airborne dust, etc.

7.18 *Avoidance of sample degradation.* Physical and chemical changes in a waste stream sample can result in the loss of one or more radionuclides prior to analysis. To ensure that these effects are minimised after the sample is taken, careful attention needs to be paid to sample container preservation, sample transport, pre-treatment and labelling. Particular attention needs to be paid to the following:

- Ions in solution are uniformly distributed (and should remain so) by simple mixing. However, changes in pH (caused by loss or uptake of carbon dioxide or by bacterial activity) can cause some nuclides to precipitate out of a solution (the usual effect is precipitation of iron, which then co-precipitates the radionuclides; the iron will be visible as a cloudy brown or red precipitate in the sample).
- Species can be lost by adsorption (plate-out) on to the walls of the sample container.
- Gases can be lost from solutions on standing or in areas of turbulence or where pressure is reduced (e.g. during the pumping of a sample). Gases can also diffuse through certain plastics.
- Short-lived nuclides will decrease in concentration and new daughters may grow in.
- Evaporation will lead to preferential loss of volatile nuclides, notably tritium (in the form of tritiated water). This can even occur in closed bottles.

7.19 *Sample container materials and design.* The following points should be considered when selecting sample containers:

- Sample containers may be of glass or of the various types of plastics. Glass is used where gases must be retained in solution. Borosilicate and soda glass bottles are both applicable and easier to clean than plastics but easier to break in transit. Clear glass is to be preferred to allow samples (and any associated sediment, particulates, etc.) to be inspected.
- Plastic containers such as HDPE or polypropylene are often used for trace metal nuclides, but are permeable to gases, including water vapour. Loss of active gas radionuclides or changes in pH due to uptake or loss of carbon dioxide both need to be considered.
- The same types of sample container should be used throughout the whole part of the sample and analysis programme. Any effects on the results of the monitoring programme due to changes in the type of sample container used (or in the methods used for cleaning the containers, or those used for preservation) should be investigated. This can be carried out by collection/analysis of some samples, for a short period of time, in both types of container (or using both methods of cleaning/preservation).
- All sample containers must have secure leak-proof caps/lids to minimise leaks and evaporative losses. Good policy is to use PTFE or similar lid inserts to effect the best possible seal. PTFE tape may also be used.

- Where a range of different nuclides need to be analysed in a sample, and especially if there is also a need to carry out other measurements on the sample (e.g. volatile organic compounds or oil content), it is likely that several aliquots of each sample will need to be taken using different sample containers, both glass and plastic. This is also required because samples to be analysed for different parameters may require differing treatments for preservation.

7.20 *Use of trip blanks and sample stability tests.* The following ways of checking for sample contamination and stability should be considered:

- A trip blank is a useful exercise in demonstrating that contamination is not a problem in the sampling programme. This involves filling a sample container in the laboratory with a sample or blank of known composition. This is then placed with the sample containers and transported out to the sample site and then returned and analysed with the samples. If the results obtained prior to and after this exercise are inconsistent then sample contamination should be suspected.
- A number of tests can be carried out on the stability of samples by taking large composite samples and analysing these over a period of time. Again, it is important that any changes due to storage are separated from trends and errors due to the analysis programme itself.

7.21 *Sample pre-treatment, labelling and transport.* Immediately after a sample has been taken, changes start to occur and affect its composition. The aim must be to minimise these changes during transport and prior to analysis by consideration of the following points:

- The use of appropriate sample containers and materials used in the sampling system.
- The following sample treatments can also be used to minimise changes:
  - Sample filtration. Radioactivity in a waste stream sample may be present in both soluble form and associated with particulate materials. Filtration in the field (usually to 0.45  $\mu\text{m}$ ) is commonly used to form the basis on which a distinction is drawn between these two forms of activity.
  - Sample acidification. The clear filtrate can be stabilised by addition of a few millilitres of nitric acid to lower the pH and thus avoid precipitation of iron and other radionuclides or plating out of radionuclides on to the walls of the container.
  - The acidified sample and filter are then delivered to the laboratory for separate analyses.
  - Filtration in the field also reduces errors due to subsequent subsampling in the laboratory, e.g. due to preferential decanting off of particulate matter. As a general rule, samples should not be acidified before filtration. This can result in leaching of radionuclides from what may be a few highly active particulates.
  - Refrigeration. Sample preservation may be assisted by refrigeration or storage in cool boxes, but for samples that have been filtered and acidified this is rarely required.

- In some sampling programmes, long-term archiving of samples is required for up to one year or more. In these cases, samples should be acidified and kept refrigerated. Freezing of samples should be avoided since this can result in irreversible changes in the characteristics of the sample on thawing, especially with regard to the ratio of active material in particulate and dissolved form.
  - A vital part of any sample and analysis programme is unambiguous labelling of the samples. Labelling of samples and any associated recorded information are required to provide information to the analysis laboratory and are also needed for meaningful interpretation of the final data. This may include important decisions such as the rejection of outlying results or their consideration (with consequent economic and other implications). Labels must properly adhere to (or be tied to) bottles, and as a minimum will include time, date and location of the sampling. Bar code systems may allow both more efficient and more reliable labelling of samples.
  - After a sample has been taken it should be transported to the analytical laboratory as soon as possible. Transport within 24 hours is usually stipulated, but is not always possible.
- 7.22 *Chain-of-custody records.* As samples are transported to the laboratory, they may pass through several sets of hands, from the sampler to the carrier, etc. In such cases custody records should be maintained so the movement of the sample through the system, from initial sampling to final laboratory receipt, can be tracked. This may be a legal requirement for compliance monitoring data.

### ***Flow measurement***

- 7.23 The methods described above, based on on-line instrumentation, sampling and laboratory analysis provide a measure of the concentration ( $\text{Bq/m}^3$ ) of a radionuclide in a discharge. In order to calculate the total amount (e.g. TBq) of the radionuclide discharged over time (e.g. the period specified in the licence, typically a month) for accountancy purposes a knowledge of the volume of liquor discharged is required. In the case of sentencing tanks this can be computed from the known volume in each tank discharge and for continuous flows a range of flowmeters capable of both recording flow rate and total discharge are commercially available. Flow rate measurements and tank discharge quantities are subject to uncertainties that are important when calculating total amounts of discharged radionuclides (see section 6).
- 7.24 Calculation / estimation may be used to establish liquid discharge volumes where the dimensions of the sentencing tanks and/or discharge channels or pipes are well known and the flow rate can be calculated or has been measured at the commissioning stage. This approach is only acceptable where the flow is well understood and not liable to change.

## **8. Sample analysis**

- 8.1 The main objectives of the laboratory analysis programme are to produce results that:
- Are consistent, with adequate precision and accuracy, and reliable.
  - Can be compared over time and with data produced by other laboratories.

- Reflect real changes in the nature of the discharge.
- Are not affected by cross-contamination, sample preparation errors, incorrect calibration of instruments, etc.; where such errors are present, they must be known and quantified and controlled to known and acceptable limits.

8.2 These objectives are generally best secured by requirements for laboratories to be accredited to the European Standard EN17025 [ISO, 2005B]. In particular adherence to the following elements of good practice should provide for reliable and quality results:

- Close co-operation between the sample provider, customer for the results (this may be the same as the sample provider) and the analytical laboratory. This co-operation should include written agreement on requirements for precision, accuracy and limits of detection.
- The provision of samples to the laboratory that are representative of the relevant discharge.
- Operation of the laboratory of a documented internal quality control procedure.
- Use by the laboratory of appropriate radioactive standards (including where available natural matrix reference materials) of established national or international traceability.
- Use by the laboratory of validated and fully documented analytical procedures. (Any departure from these procedures should be fully documented and justified.)
- The laboratory should participate in national and international inter-comparisons.
- The reports of analytical results should include an estimate of their uncertainties and information on the method used to derive them.
- The laboratory should employ skilled and motivated analysts in well-equipped laboratories operating to accredited procedures and within an effective quality control system.

### ***Sampling***

8.3 Methods of sampling have been dealt with in detail in sections 6 and 7. This section deals only with those aspects of sampling that are of particular interest to the receiving analytical laboratory. All relevant information relating to a sample should be provided in written form to the laboratory by the sample provider. A pro-forma can be useful to ensure that all of this information is captured and should form part of the chain-of-custody arrangements. The relevant information should include;

- Sample description (e.g. airborne particulate material, collection medium (charcoal, bubbler liquor), waste water from a particular discharge).
- Sampling location (e.g. stack A, point B).
- Identification of person who took the sample.
- Time and date of sampling, and any relevant operational information.

- Any results from on-plant instrumental measurements (e.g. gross activity levels on filter papers).
  - Any other relevant information.
- 8.4 The laboratory should maintain a register of all samples received and should allocate each sample with a unique sample identifier which should be used on all related documentation.
- 8.5 The laboratory should continue to exercise the kind of precautions taken during the collection of the samples in the field. These will include:
- *Sample integrity on receipt.* The integrity of the sample container should be checked by the laboratory on receipt.
  - *Avoidance of cross-contamination.* This is especially important in laboratories that, as well as handling liquid waste samples, also handle samples with much higher activities (e.g. intermediate-level waste). In addition, the storage and handling of the latter may increase background count rates around instruments being used for the assay of low-level samples.
  - *Representative subsampling.* Special care is required with regard to particulates that may have formed or settled out in transit. To avoid missing these, samples must be fully mixed prior to subsampling. Best practice to separate particulates by filtration is to use the whole sample delivered to the laboratory.
  - *Avoidance of losses of constituents.* This is especially important for potentially volatile radionuclides such as tritium and iodine isotopes unless this is a planned part of the sample procedure.
  - *Chain of custody.* Correct and unambiguous labelling/logging of samples and all prepared subsamples is necessary.

### ***Sample preparation***

- 8.6 The laboratory may be handling samples of process liquors, discharges and environmental media. The radioactive contents of these disparate samples could vary over several orders of magnitude. Samples of aerial and liquid discharges are likely to be radioactive at the medium and high activity levels. In order to avoid cross-contamination, both during and after sample preparation, the samples should be handled in segregated high, medium and low level activity areas.
- 8.7 Sub-samples for analysis should be taken by in such a way as to ensure that they remain representative of the bulk sample. This is not likely to be a requirement for solid samples of aerial discharges as the entire sample should be counted directly or taken into solution. When taking sub-samples from a liquid any solids present in the sample should be: dissolved using appropriate reagents, or, kept in suspension when making the division, or, if acceptable removed by filtration and discarded. Alternatively, if the solids fraction is of interest then the two phases should be analysed separately.
- 8.8 It may be necessary to concentrate the sample before proceeding to chemical separation or direct measurement. Depending on the nature of the sample this may involve evaporation, ashing or precipitation. There is potential for losses or contamination during these procedures. For example, dry ashing can lead to losses through sputtering or volatility, or to the creation of substances that can interfere with later chemical

separation processes. Consequently, dry ashing should be carried out carefully in a furnace the temperature of which can be adequately controlled to prevent ignition of the sample. Alternatively, if dry ashing could still lead to loss of the determinand a wet ashing procedure should be considered. In all cases where the physical state is altered the sample weight before and after must be determined so that the final concentration of the determinand can be referred to the appropriate state.

### ***Radio-analytical methods***

- 8.9 A radiometric analysis generally involves comparing the response of a detector to the determinand in the sample to that of a known source. The method may involve direct measurement of the sample (i.e. non-destructive) or it may require chemical separation of the determined (i.e. destructive, or radiochemical). The main components in a radiation detection system used for the analysis of samples are listed at Table D1.
- 8.10 Analytical methods must be validated. This can be achieved by analysis of a natural matrix reference material (NMRF). If the result was in agreement with stated activity of the NMRF then the method has been validated. NMRFs are not readily available and therefore reliance is usually placed on inter-laboratory comparison tests using standard solutions. Validated methods should be fully documented and strictly adhered to. Where deviations from the method are made these should be recorded and justified.
- 8.11 The results of analysis may be affected by contamination arising from the repeat use of the analytical procedures. Possible sources of contamination include: re-use of apparatus, cross-contamination between samples, impurities in reagents and yield tracers, contaminated detectors. The laboratory should have procedures in place to check for contamination. This should include the analysis of samples at activity concentration known to be below the limit of detection for the relevant method, or the reagents alone. The performance of the method should also be checked by the analysis of samples with well-defined activity concentrations.
- 8.12 Samples are normally analysed in a radiochemical laboratory by non-destructive methods, screening techniques and/or methods requiring prior radiochemical separation of the determinand of interest.
- *Non-destructive methods.* Gamma-ray spectrometry is the most common non-destructive method. Following sample preparation an aliquot of the sample is measured directly. Sometimes it can be necessary to pre-concentrate the sample or carry out some form of radiochemical separation in order to achieve the required detection sensitivity or specificity. The method then becomes destructive. Direct alpha spectrometry is another non-destructive method.
  - *Screening technique.* These provide rapid means of detecting activity levels but lack sensitivity and specificity. The usual methods are “total alpha” and “total beta” activity measurements. Often the term “gross” is used rather than “total” to emphasise that the methods cannot determine all of the alpha or beta emitting radionuclides in a sample. The activity detected is compared with that of a specified radionuclide measured under identical conditions. However, these methods cannot detect all radionuclides with equal efficiencies so the usual quality assurance criteria cannot be applied. The results should therefore be used with caution, nevertheless, these methods are convenient, cheap and easy to use. Sometimes laboratories report “total gamma-ray activity”. This should be

considered to be only a semi-quantitative measurement as the response of a gamma-ray detector is very dependent on the energy of the emissions.

- *Radio-chemical separation.* These methods are used to isolate the determinand of interest from its matrix in a form which may be measured by appropriate techniques. The separation methods are: ion exchange, solvent extraction and precipitation procedures. Commonly several stages may be required to achieve the desired separation. Complete recovery of the determinand at each stage can be difficult. Consequently, a tracer or carrier is used as a yield indicator. In order for this to function reliably complete chemical equilibrium between the determinand and yield tracer has to be achieved. This can involve oxidation/reduction cycles to ensure that the determinand and yield indicator are present in the same ionic form. More difficult cases can require destruction of organic material or dissolution of refractory material by fusion techniques. A target recovery of the yield tracer should be set, say 40% with results from yield recoveries of less than 20% being rejected.

**Table D1. Components in a radiation detection system used for the analysis of samples**

Component	Function	Comments
<b>Power supplies</b>  Low and high-voltage power supplies	Supply power to detector and all electronic components in system.	Stabilised supplies are required to ensure consistent performance and data from all parts of the system.
<b>Detectors</b>  <i><b>Gamma spectrometry</b></i> Sodium iodide scintillation detectors with photomultiplier  Semiconductor detectors, Ge(Li), HPGe.  <i><b>Alpha analysis</b></i> Liquid scintillation detectors Gas-filled detectors	Convert alpha, beta or gamma radiation from prepared sub-samples into electrical pulses	One type of detector may respond to more than one type of radiation in the sample, producing pulses of differing intensities for each one. Alpha, beta and gamma radiation of different energies (due to differing nuclides in the sample) may also produce pulses of differing intensities. All of these pulses are sorted by the multichannel analyser. This then allows the differing types of nuclide to be identified by the final computer software system (see below). In some cases, absorbers may be used in front of the detector to prevent entry of certain



(proportional counters or Geiger tubes)  Surface barrier semiconductor detectors  <i><b>Beta analysis</b></i>  Gas-filled detectors  Liquid scintillation detectors		types of radiation (e.g. aluminium may allow beta radiation of different energies to be selectively filtered out).
<b>Pulse shaper and 'energy window'</b>	Shapes pulses from detector so they are suitable for further electronic processing.	These components may also carry out some initial sorting of pulses according to their energy, allowing, for example, pulses due to alpha and beta radiation to be separated.
<b>Multichannel analyser</b>	Sorts pulses according to their energy and records them in one of a number of channels (up to 8192 [can be 1024, 2048, 4096 or 8192]) and displays these as a alpha, beta or gamma 'spectrum' of the sample.	Use of a standard mixture of nuclides of known abundance allows each channel in the spectrum to be ascribed to a specific alpha, beta or gamma energy (in keV or MeV). This allows the nuclides in an unknown sample to be identified. Comparison of the intensity of the peaks (counts per channel) with that of the  standard allows the abundance of nuclides in the sample to be established.
<b>Computer system</b>	Records all data and carries out data analysis.	Software package carries out all calibration, identification of the nuclides and the quantities present.

8.13 The common detector types that can be used to measure alpha, beta and gamma emitting radionuclides are listed below.

<b>Alpha-emitting radionuclides</b>	<b>Beta-emitting radionuclides</b>	<b>Gamma-emitting radionuclides</b>
Zinc sulphide screen counters	Geiger-Mueller counters	Geiger-Mueller counters
Thin window or windowless proportional counters	Thin window or windowless proportional counters	Thin window proportional counters
Gas flow counters	Solid scintillation counters	Scintillation counters
Semiconductor counters	Liquid scintillation counters	Semiconductor counters
Liquid scintillation counters		

- 8.14 The principle of measurement involves counting the sample, for example a filter paper, and comparing the result with a standard source. Background activity is also determined, by counting a blank sample, and subtracted from the sample count. For alpha and soft beta (low energy) emitters it can be necessary to correct the result for absorption within the sample matrix. Most laboratories now use sophisticated electronic facilities to improve counting accuracy and to automate counting procedures.
- 8.15 Soft and hard beta emitters can be differentiated by repeat counting of samples with different absorbers interposed between sample and counter.
- 8.16 Standard samples should ideally consist of the same radionuclides as in the source sample and should be prepared in the same form and geometry. However, practicalities, for example for a nuclide with a short half-life, an alternative radionuclide of longer half-life with the same energy of emitted radiation may be used if available. Where gross activity is being determined, a range of radionuclides are involved and the standard source has to consist of a single radionuclide with an emission energy accepted as being typical of the range or a mixed radionuclide source. Determination of gamma activity is usually carried out by gamma-ray spectrometry and the standard sources used consist either of mixed gamma emitting radionuclides that emit gamma-rays of different energies or a single radionuclide that emits several gamma-rays of different energies. Some typical standard sources are listed below.

<b>Radionuclide</b>	<b>Standard Source</b>
$^{35}\text{S}$	$^{14}\text{C}$
$^{14}\text{C}$	$^{14}\text{C}$
$^{131}\text{I}$	Mixed gamma standard
Beta particulate	$^{35}\text{Cl}$ , $^{90}\text{Sr}$ , $^{90}\text{Y}$
Alpha particulate	$^{239}\text{Pu}$

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

- The type of radioactive emission, i.e. alpha, beta, gamma.
- The required determination. This can be for gross alpha or gross beta or gross gamma which would include a range of radionuclides or for a specific radionuclide. Where a specific radionuclide is to be determined this may be carried out by spectrometry using energy discrimination, radiochemical separation, or a combination of both.
- The required sensitivity.
- The number and throughput of samples (and availability of manual or automatic counting).

### ***Analysis of aerial discharge samples***

8.18 The analytical techniques generally used for analysing samples collected using filter papers, carbon traps, bubbler liquors and scrubber liquors are:

- Filter papers: the alpha and beta activities associated with particulates captured on filter papers can be determined by direct counting of the filter paper or by ashing the filter paper and preparing a homogenous source. A qualitative assessment of the presence of gamma-emitting radionuclides can also be determined by direct counting of the filter paper using a gamma spectrometer. Naturally occurring radon daughters can be present on filter papers. These are short lived and so their contribution can be determined by counting the filter papers at intervals, for example at removal from the sampling system, after 24 hours and after 48 hours.
- Carbon traps: these are usually used to trap  $^{131}\text{I}$  or  $^{129}\text{I}$  which can be determined by counting using a gamma spectrometer calibrated to an appropriate mixed gamma standard.
- Bubbler liquors: these are usually used to trap the low energy beta emitters  $^{14}\text{C}$ ,  $^{35}\text{S}$  and tritium. A scintillant is added to a sub-sample of the liquor and then counted on a liquid scintillation counter with reference to a standard source relevant to the radionuclide of interest.
- Scrubber liquors: these are commonly used to trap  $^{106}\text{Ru}$ . A sub-sample of the scrubber liquor is counted using gamma spectrometry calibrated with a  $^{106}\text{Ru}$  standard.

8.19 Radionuclide specific techniques can be used to sample and determine  $^{41}\text{Ar}$ , tritium,  $^{14}\text{C}$ ,  $^{35}\text{S}$ , and  $^{85}\text{Kr}$  in certain discharges.

### ***Argon-41 from nuclear power stations***

8.20 Discharges of  $^{41}\text{Ar}$  from nuclear power stations arise from neutron activation of  $^{40}\text{Ar}$  in air impurities in the reactor coolant circuit. In the UK the Advanced Gas-cooled Reactors are fitted with facilities for sampling both  $^{40}\text{Ar}$  and  $^{41}\text{Ar}$  in the coolant gas. Because Ar is a noble gas there is no sampling medium with which it can interact and therefore sample volumes have to be collected in appropriate containers.

8.21  $^{40}\text{Ar}$  is sampled for routine chemical monitoring of reactor coolant gas and is measured in volume parts per million (vpm). It is analysed weekly using gas chromatography as part of routine chemical monitoring of reactor coolant gas. The quantity of  $^{41}\text{Ar}$  present

in the coolant gas can be determined by empirical calculation from the  $^{40}\text{Ar}$  concentration using the following equation:

$$^{41}\text{Ar} \text{ (MBq/te)} = \text{constant} \times \text{reactor power (MW}_{\text{thermal}}) \times ^{40}\text{Ar (vpm)}$$

- 8.22  $^{41}\text{Ar}$  is measured in MBq/te and therefore the sampling method must provide samples of known mass. It may be necessary to know the transit time for the gas from the reactor coolant to the sample if it is significant relative to the half-life of  $^{41}\text{Ar}$ . The following three sampling methods can be used:

- Collection in a 1 litre polythene bottle. The bottles that are used have a fixed shape and size, and material of construction to allow for the determination of  $^{41}\text{Ar}$  by direct gamma spectrometry. The sample bottle is purged with the coolant gas to ensure that the sample taken is representative of fresh reactor gas. The sample in the bottle is reduced to atmospheric pressure and the dimensions of the bottle then define the volume and mass of the sample. It is also then directly comparable with a commercially available gas standard.
- Pressurised Gas Bottle. A fresh reactor gas sample is collected in a suitably pressure rated stainless steel bottle. The bottle is first purged with the coolant gas to ensure that the sample taken is representative of fresh reactor gas.
- Gaseous Activity Monitoring (GAM). A continuously replenished sample of fresh reactor coolant gas is passed through a suitably pressure rated chamber of known dimensions. The pressure of the gas in the chamber can be regulated and measured so as to control the mass of the gas sample. GAM monitoring is used during on-load periods to provide for a daily measure of the specific activity of  $^{41}\text{Ar}$  in reactor coolant gas. However, sampling as described above is required to provide a backup in case of failure of the GAM system.

### ***Tritium, carbon-14 and sulphur-35 from nuclear power stations***

- 8.23 Tritium,  $^{14}\text{C}$  and  $^{35}\text{S}$  arise in gaseous emissions from power stations because of activation of core materials and associated impurities. The emissions can be assessed either by direct sampling of the reactor gas coolant combined with a known rate of loss or by sampling in the discharge stack. At Advanced Gas-coolant Reactors in the UK direct sampling of the gas coolant is the preferred method for the following reasons:

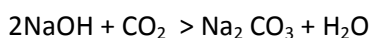
- Measurement of the undiluted coolant (particularly for  $^{14}\text{C}$ ) is more accurate.
- The combination of  $\text{CO}_2$  specific activity measurement and  $\text{CO}_2$  loss measurement accounts for all discharges of radioactivity associated with the coolant gas. Measurement at the stack would not necessarily account for all  $\text{CO}_2$  lost because of leakage from external ductwork.
- Only one sampling system is required for in-coolant measurements whereas several systems may be required to cover all stack outlets. (However, coolant sampling cannot be used to determine particulate activity in discharges because this must be carried out downstream of filtration systems which are normally fitted immediately prior to discharge to the atmosphere.)

- 8.24 Direct sampling of coolant is not normally carried out continuously but involves the taking of a 30 minute spot sample. Consequently, the frequency of sampling has to be sufficient to provide confidence that any changes in coolant activity and hence

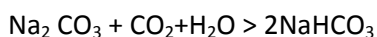
discharges will be detected. Coolant gas conditions are usually stable for long periods and so a routine of daily sampling is considered to be adequate. However, during transient periods more frequent sampling is required.

- 8.25 The amount of tritium,  $^{14}\text{C}$  and  $^{35}\text{S}$  is determined by passing a sample of the coolant gas through a furnace at  $1100^\circ\text{C}$  with an air supply sufficient to oxidise all of these radionuclides to tritiated water (HTO),  $\text{CO}_2$ ,  $\text{SO}_2$  or  $\text{SO}_3$ . Prior purging of the sample lines is required to ensure that a representative sample is obtained. The tritiated water and oxides of sulphur are then captured in a bubbler vessel containing deionised water and the  $\text{CO}_2$  is captured in a bubbler vessel containing 0.25 molar solution of NaOH. The bubbler liquors can then be analysed for tritium,  $^{14}\text{C}$  and  $^{35}\text{S}$  using liquid scintillation counting with reference to appropriate tritium,  $^{14}\text{C}$  and  $^{35}\text{S}$  standards.

- 8.26 Where reactor coolant gas ( $\text{CO}_2$ ) is being sampled for  $^{14}\text{C}$  the NaOH absorbent saturates with  $\text{CO}_2$  and a stoichiometric formation of bicarbonate results in the two-stage reaction:

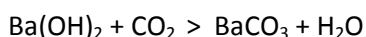


then



From these equations, 1ml of a molar NaOH solution will absorb 0.001 mole of  $\text{CO}_2$  which has a mass of 44mg. The  $^{14}\text{C}$  activity of the coolant emitted can then be calculated from the mass of the coolant emitted and the ratio of the activity concentration of the sample to the above 44mg of  $\text{CO}_2$ .

- 8.27 When sampling for  $^{14}\text{C}$  in other discharges it is unlikely that sufficient  $\text{CO}_2$  will be present in the sample to achieve stoichiometric absorption of  $\text{CO}_2$  in the NaOH bubbler solution for any practicable sampling time. In these circumstances the quantity of  $\text{CO}_2$  absorbed in the NaOH is determined chemically by alkalinity titrations using phenolphthalein and methyl red indicators\*. An alternative approach used on reprocessing facilities is to use barium hydroxide [ $\text{Ba}(\text{OH})_2$ ] solution as the bubbler liquor. This reacts with  $\text{CO}_2$  in accordance with the following equation:



The precipitated barium carbonate is washed, dried and a portion is then mixed with water and a scintillant, and counted in a liquid scintillation counter against a blank sample of  $\text{BaCO}_3$ . The activity of  $^{14}\text{C}$  emitted can then be calculated from the measured total activity in the bubbler liquor and the mass of  $\text{CO}_2$  emitted.

#### ***Particulate and iodine from most facilities***

- 8.28 Particulate samples are collected on filter papers which have a retention factor of >99% for the most penetrating particles (i.e. those within the particle diameter range of 0.1 to 0.5 micrometres). Where iodine is to be simultaneously sampled a compartment containing granulated (18/20 mesh) carbon is incorporated into the sample housing. The filter paper and carbon are usually changed every 24 hours.

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\* Often referred to as a "P & M" titration after the indicators.

8.29 The activity on the filter paper and carbon can be assessed after removal from the housing by the following counting methods depending on the radionuclides of interest:

- Gamma emitting radionuclides. Each radionuclide emits gamma rays at characteristic energy levels. These can be distinguished and the activity levels for each radionuclide determined by a germanium detector and multichannel analyser without the need for chemical separation. The instrument has to be calibrated with a standard source of mixed energy gamma emitters.
- Beta emitting radionuclides. Direct counting of particulate beta activity is often carried out as an alternative to liquid scintillation counting. This is normally a measure of gross beta activity as beta emissions occur over a continuous range of energies (rather than at discrete energy levels which is characteristic of alpha and gamma emitters). The following two types of source preparation techniques are used:
  - Thick source. This type of source is indistinguishable from one of infinite depth with regard to beta emissions. At depths greater than 20mm even the highest energy emissions from the lowest layers are completely absorbed by the layers of sample above. These sources are usually made from ashed or dried samples and are counted using a Geiger-Muller counter with a thin end window or a proportional counter.
  - Thin source. This type is a thin layer of sample material finely spread over a planchet or possibly a filter paper. The thinness of the sample means that there is very little self-absorption of the beta emissions, although, it may sometimes be necessary to use a self-absorption correction factor. A Geiger-Muller counter with a thin end window or a proportional counter is also used for counting these sources.
- Alpha emitting radionuclides. The very short range of alpha particles means that the distance between the source and the window of the detector must be kept to a minimum. Filter papers are often counted directly for gross alpha activity using a zinc sulphide detector or a thin-window proportional counter. If the activities of individual alpha emitting radionuclides are to be determined then an alpha spectrometer has to be used. The sample is prepared for alpha spectrometry counting by first dissolving the filter paper in an organic solvent and then a thin source is made by evaporating the solution on a planchet.

***Krypton-85 from reprocessing plant and Pressurised Water Reactors (PWR)***

8.30  $^{85}\text{Kr}$  is released in small quantities from PWR and in larger amounts at the fuel dissolution stage of fuel reprocessing operations. Because Krypton is a noble gas it cannot be collected from a waste stream by any of the conventional trapping techniques and direct measurement of a known quantity of sample gas is used. The sample gas is drawn from the discharge duct into a cell of known dimensions and maintained at a constant temperature (above ambient to prevent condensation). The temperatures of the duct gas and the sample gas in the cell are recorded for back calculation of the  $^{85}\text{Kr}$  concentration from that determined in the cell to the gas in the duct. The  $^{85}\text{Kr}$  gamma ray emissions are counted using a low resolution sodium iodide detector, calibrated with an appropriate standard source for  $^{85}\text{Kr}$  detection.

### ***Analysis of liquid discharge samples***

8.32 The analysis of radionuclides in liquid samples from a monitoring programme may be broadly divided into:

- Gross alpha activity.
- Analysis of individual alpha-emitting nuclides.
- Gross beta activity.
- Liquid scintillation counting for soft beta emitters ( $^3\text{H}$  and  $^{14}\text{C}$ ).
- Analysis of individual beta-emitting nuclides.
- Gross gamma activity.
- Gamma spectrometry to identify individual gamma-emitting nuclides.

8.33 The majority of analyses involve determination of the specific activities in a sub-sample of known volume or weight ( $\text{Bq m}^{-3}$  or  $\text{Bq kg}^{-1}$ ). These activities are determined using a measuring system that has been suitably calibrated by a standard of known composition/activity. The two main stages involved are:

- Calibration of the detector using a source or standard of known activity.
- Counting of the sample under the same instrument conditions as those used during calibration.

## **9. Statistical considerations**

9.1 There are two main statistical considerations that should be taken into account when designing and carrying out a discharge monitoring programme. These are:

- Measurement uncertainty.
- Detection limits & decision thresholds.

### ***Measurement uncertainty***

9.2 Discharge limits in nuclear site licences are usually expressed in the form  $\text{Bq [T]}^{-1}$ , that is, the total amount of a radionuclide (or group of radionuclides) in becquerels permitted to be discharged in a given time: typically a month, calendar year or rolling twelve months. The primary purpose of discharge monitoring is to provide evidence of compliance (or non-compliance) with these limits. However, the monitoring results can also be used to provide valuable information on trends in the amounts of radioactivity being discharged over time and source data for estimating radiological impacts.

9.3 Discharge monitoring results are subject to uncertainties. These arise from the combination of errors associated with the individual measurements that make up the final calculation of the amount of radioactivity discharged in the specified time. It has not been common practice in the nuclear industry to estimate these uncertainties because discharges have historically been well below licence limits and it has been possible to demonstrate that even gross uncertainties in discharge data do not change the significance of impact assessments with respect to radiological protection criteria. Nevertheless, the systematic tightening of licence limits by regulatory authorities and of

radiological protection criteria by the International Atomic Energy Agency and the International Committee on Radiological Protection raises the potential significance of the uncertainties in discharge results.

- 9.4 The uncertainty in a measurement is quantified by two numbers: the margin, that is the interval within which the result is expected to be; and the confidence level, which states how sure the true value is within that margin [IAEA, 1978]. For example: a discharge of 100 MBq plus or minus 10 MBq at the 95 percent confidence level may be reported as

100 MBq +/- 10 MBq, at a level of confidence of 95%

This method of reporting states that there is a 95% confidence that the discharge is between 90 and 110 MBq.

- 9.5 Discharge results are calculated by combining the volume of the discharge and the concentration of the radionuclide of interest in it. For example: the above result may have been calculated from an on-line flow measurement of 1,000,000 m<sup>3</sup> and a laboratory measurement on a sample of the discharge of 100 Bq m<sup>-3</sup> as follows:

$$1,000,000 \text{ m}^3 \times 100 \text{ Bq m}^{-3} = 100,000,000 \text{ Bq} = 100 \text{ MBq}.$$

- 9.6 The overall uncertainty arises from errors and uncertainties in the many actions and measurements that are carried out to determine both the flow and the concentration values. In order to calculate the uncertainty of a measurement, the potential sources of uncertainty must first be identified, then estimated, and finally the contributions combined to provide an overall figure according to relevant rules [e.g. Bell, 2001].

- 9.7 Errors and uncertainties can arise from:

- The measuring instrument. These can suffer from errors including bias, drift arising from ageing, wear, environmental conditions, poor readability and fluctuations in the electrical supply (background noise), etc.
- Radiochemical techniques. Generally, laboratories have the performance of their routine procedures under constant scrutiny through in-house quality control (QC) procedures (e.g. Shewhart charts, blanks, reference materials and internal standards) and participation in external proficiency testing schemes.
- Instability of the sample. These may arise from sample matrix effects or in the case of short lived radionuclides radioactive decay.
- The radiochemical technique. It may be difficult to interpret radiation spectra for complex samples thereby requiring extensive sample clean-up and preparation before counting.
- Calibration uncertainties. Standards and procedures for calibrating instruments have their own uncertainties which are incorporated into the measurement technique used in the discharge monitoring programme.
- Operator skill. Some measurements may be dependent on the skill and judgement of the operator. (Note that gross mistakes are not taken into account when determining measurement uncertainties.)



- Sampling. Obtaining a representative sample from an aerial or waste water discharge can be difficult under ideal conditions. On-site practicalities will add to these difficulties.

9.8 Where the size and effect of an error are known, for example from a calibration certificate, a correction may be applied to the measurement result. But in general, uncertainties from the sources listed above and others are individual inputs contributing to the overall uncertainty uncertainties in a measurement:

- Type A evaluations use uncertainty estimates from statistics assessments, for example from repeat measurements. These will be readily available from a competent laboratory operating a QC system.
- Type B evaluations use uncertainty estimates from any other information, such as: past experience of the measurements, calibration certificates, manufacturer's specifications, calculations, published information, and common sense.

9.9 In outline the main steps involved in evaluating measurement uncertainty include:

- Identifying what needs to be determined. For example, the quantity of  $^{137}\text{Cs}$  discharged in a particular waste water stream per calendar month.
- Identify the necessary measurements. For example, laboratory analysis by gamma spectrometry of  $^{137}\text{Cs}$  in samples of the waste water and continuous measurement of the flow rate and total quantity of waste water discharged per month.
- Carry out the required measurements.
- Estimate the uncertainty of each input quantity that feeds into the final result. Express all uncertainties in similar terms and at the same confidence level by converting them to standard uncertainties. A standard uncertainty is a margin whose size can be thought of as "plus or minus one standard deviation".
- Calculate the result of the measurement (including any known corrections for things such as calibration).
- Find the combined standard uncertainty from all the individual inputs using the standard method for summation in quadrature. (Note that if the errors of the input quantities are not independent of each other some additional calculations or information are needed.)
- Express the uncertainty in terms of a coverage factor, together with a size of the uncertainty interval, and state a level of confidence
- Write down the measurement result and the uncertainty, and state how both have been derived.

#### ***Detection limits & decision thresholds***

9.10 Detection limits are used to determine whether analytical techniques or instruments are suitable for their proposed measurement purpose. In general terms, the detection limit for a measurand can be defined as the lowest amount (or concentration) that can be detected at a stated confidence level. In the case of radiochemical measurements the detection limit can be considered to be the activity level at which the counts from the

sample (including background contributions) can be positively distinguished from the background count. The background count includes contributions from the detector background and the response to blank samples. The relevant standard is ISO11929-7 (ISO 2005A) interpreted in the KTA Standards [KTA 2002; KTA, 2007] giving the following mathematical expressions for detection limit and decision limit;

$$G_N = f \cdot k_N \cdot S$$

Where:

$G_N$  = Detection limit

$f$  = Calibration factor

$k_N$  = Factor for the statistical certainty at the detection limit

$S$  = the standard deviation of the count rate.

- 9.11 The decision threshold is used to decide whether or not the activity of the measured radionuclide is present in the sample at a level above background and can therefore be considered to be present at elevated levels in the waste stream from which the sample was taken. If this is found to be the case and if the radionuclide is subject to a discharge limit then it should be measured and reported for accountancy purposes. The decision limit is calculated using the following equation:

$$G_E = f \cdot k_E \cdot S$$

Where:

$G_E$  = Decision threshold

$f$  = Calibration factor

$k_E$  = Factor for the statistical certainty at the decision limit

$S$  = the standard deviation of the count rate.

- 9.12 The standard deviation,  $S$ , of the count rate is calculated using the applicable formula from the list below.

- (a) In the case of an integral digital

measurement:

$$S = \sqrt{\frac{R_0}{t_0} \left( 1 + \frac{t_0}{t_m} \right)}$$

- (b) In the case of an analogue

measurement:

$$S = \sqrt{\frac{R_0}{2\tau}}$$

(c) In the case of gamma spectrometry:

$$S = \sqrt{\frac{2b \cdot \bar{R}_0(E_\gamma)}{t_m}}$$

(d) In the case of alpha spectrometry:

$$S = \sqrt{\frac{\sum R_0(E_\alpha)}{t_0} \left(1 + \frac{t_0}{t_m}\right)}$$

With the nomenclature listed in the box below.

NOMENCLATURE		
$G_N$	detection limit	Bq
$G_E$	decision threshold	Bq
f	calibration factor	Bq . s
$k_N$	factor of the statistical certainty at the detection limit	$k_E + 1.645 *$
$k_E$	factor of the statistical certainty at the decision threshold	$1.645 **$ $3.0 ***$
$R_0$	background pulse rate	$s^{-1}$
$\bar{R}_0(E_\gamma)$	Average background pulse rate per channel or eV at the energy level $E_\gamma$	$s^{-1}$
b	base width of a gamma peak (base width of peak ); $b = 1.7h$ , with h being equal to the half-value width of the gamma peak	number of channels or eV
$R_0(E_\alpha)$	count rate of background level in the vicinity of the alpha peak	$s^{-1}$
$t_0$	Duration of background	s

9.13 The EC Recommendation on standardised information on radioactive airborne and liquid discharges [EC, 2004] recognises that compliance with ISO/IS 11929-7 [ISO, 2005A] gives decision limits below half of the detection limit. Nevertheless, for practical purposes it proposes the use of “decision thresholds” equal to half the detection limits.

9.14 The Council Recommendation proposes that Member States should report annual discharge values for all radionuclides prescribed in an Annex to the Recommendation if at least one measurement is above the specified decision threshold in the relevant period. Required detection limits are specified for key radionuclides.

## **10 Quality Assurance (QA) and Quality Control (QC), including documentation and staff training**

10.1 The monitoring of atmospheric and waste water discharges should be carried out within a comprehensive quality management system (QMS). The purpose of this QMS should be to ensure that accurate and reliable results are obtained from all aspects of discharge monitoring. International Standard ISO 9001 [ISO, 2000] has been the most commonly used basis for defining a QMS. However ISO 9001 is a generic standard applicable to all organisations irrespective of size, type or field of operation and does not address the technical aspects of measurements, sampling and laboratory analysis. Consequently, European Standard EN 17025 [ISO, 2005B] is now the standard for laboratory and field measurement work. EN 17025 has two major parts which address management and technical requirements. The management part incorporates the requirements of ISO 9001. Conformance with EN 17025 can be demonstrated by third party accreditation by national accreditation bodies. This accreditation provides for recognition of results across Europe through the mutual accreditation agreement established by the European cooperation for Accreditation of Laboratories.

10.2 The key elements of a well-documented and comprehensive QMS, as it applies to the monitoring of atmospheric and waste water discharges from nuclear facilities, are:

- A quality policy. There should be a general policy statement signed off at senior management level and setting out the organisation’s approach and commitment to achieving quality.
- Management responsibilities. There should be an organisational plan clearly identifying responsibilities for particular aspects of the QMS at different management levels and setting out lines of responsibility. The responsibilities for implementing the monitoring programme and process plant operation should be carried out by organisationally separate staff so as to safeguard the integrity of the monitoring work from day to day commercial and operational pressures.
- A quality manual should be in place that documents all relevant aspects of the quality management system in a logical manner. A hierarchical approach ranging from the quality policy statement, through programme design, specifications for sampling facilities and instrumentation, staff training, down to procedures for sampling and analysis is commonly adopted. The quality manual should contain procedures for investigating complaints, queries, unexpected results and anomalies. A clear document control system should be used to ensure that all documents and amendments are authorised and only the latest versions of the documents making up the quality manual are used.

- Staff training. All staff involved in carrying out the monitoring programmes should be trained in the relevant procedures and skills, and shown to be competent to carry out their work. On-going training should be provided and documented. Staff responsible for the design of the monitoring programme should be kept up to date with national and international developments that are relevant to their duties.
- System design. Sampling equipment and on-line instrumentation should be fit for purpose, installed and commissioned correctly so that the objectives of the monitoring programmes can be achieved in particular with regard to required levels of accuracy, availability and reliability.
- Procedures. Written procedures should be produced detailing how the quality critical actions at all stages of the monitoring programmes (e.g. sample collection, transport, laboratory analysis and equipment calibration) should be carried out.
- Calibration. On-line and laboratory based sampling equipment and instrumentation should be calibrated at regular intervals using appropriate standards. (In the case of instrumentation both the frequency of calibration and the standards may be specified by the manufacturer.)
- Sampling. The appropriateness of sampling locations, equipment and methods for the taking of representative samples from a discharge should be demonstrated at the plant commissioning stage. In the case of atmospheric discharges this should include tests to establish the flow profile (in terms of gas velocities, swirl and possible reverse flow at different points across a duct or chimney stack) at the proposed sampling location.
- Quality Control (QC). QC charts (e.g. Shewhart or Cusum charts) should be maintained for all measurement systems to indicate any development of bias in the results or loss of precision of analytical techniques. Blank samples and reference materials should be regularly analysed. Laboratories should participate in inter-laboratory comparisons so as to provide external checks on their performance. A comprehensive QC programme should provide for the comparison of results produced over time through an understanding and knowledge of changes such as instrument contamination, adoption of new analytical techniques, operational failures.
- Internal Audits. Internal audits of conformance with procedures should be carried at regular intervals by trained staff. This should lead to feed back in the form of observations and corrective actions with procedures for ensuring that they are closed out appropriately within agreed timescales.
- Records. All relevant data, observations and results should be recorded in a manner that provides an auditable trail from raw data to calculated discharges. Results should be cross-checked where practicable by activity balance calculations. These may lead to the identification of monitoring failures and/or the existence of fugitive losses.

10.3 The quality and usefulness of monitoring results depends on how well the monitoring programme has been conceived, designed, assigned, specified, executed, assessed and reported. It is therefore important that the QMS addresses each of these stages as they form a quality link because the quality achieved at one stage affects what is achievable

at all subsequent stages. Therefore, the best results are obtained by considering and optimising each stage in turn, and by applying appropriate quality systems and safeguards.

## **11. Monitoring of radioactive discharges from non-nuclear sites**

11.1 Atmospheric and waste water discharges of radioactive wastes can arise from several non-nuclear operations. These include:

- Industrial processing of NORM (naturally occurring radioactive materials).
- Production of radiopharmaceuticals and radioactive compounds for use in the life-sciences.
- Medical and small research uses of radioactive substances.

11.2 The industrial processing of raw materials containing naturally occurring radionuclides at low concentrations can inadvertently give rise to radioactive discharges, sometimes at enhanced concentration levels. Examples of these industries are:

- Coal fired power stations. Coal combustion results in wastes containing enhanced concentrations of radionuclides in the U-series, Th-series and  $^{40}\text{K}$ .  $^{222}\text{Rn}$ ,  $^{210}\text{Po}$  and  $^{210}\text{Pb}$  are most enhanced because of their volatile nature. They are discharged to atmosphere in fly ash at concentrations generally below regulatory control.
- Phosphate ore processing. Chemical processing of phosphate ores results in enhanced concentrations of uranium in fertilisers. Radium concentrates in the phosphogypsum waste. Atmospheric discharges from thermal processing of ore contain about 30% of  $^{210}\text{Po}$  and all of the Rn. Waste water discharges from the sulphuric acid processing of ore contain  $^{210}\text{Po}$ ,  $^{226}\text{Ra}$  and  $^{210}\text{Pb}$  and arise in leachate from rainwater percolating through piles of phosphogypsum wastes, and from the discharge of phosphogypsum as a slurry or in solution.
- Oil and gas production. Naturally occurring radioactivity is present in varying concentrations in hydrocarbon deposits. The principal radionuclides are  $^{226}\text{Ra}$ ,  $^{210}\text{Pb}$ ,  $^{228}\text{Ra}$  and  $^{228}\text{Th}$ . These concentrate in scales and sludges which are discharged as waste water slurries from both on and off shore facilities.
- Rare earths and zirconium ores. These ores are used in the manufacture of catalysts, refractories, glasses and zirconia production. The related waste streams are atmospheric discharges of mainly  $^{232}\text{Th}$  associated with airborne dusts and waste water discharges containing  $^{232}\text{Th}$  and  $^{238}\text{U}$ .
- Metal smelters. The processing of ores and metal rich residues containing natural radioactivity concentrates  $^{238}\text{U}$  and  $^{232}\text{Th}$  in solid waste slags, the more volatile radionuclides, mainly  $^{210}\text{Po}$  appear in atmospheric discharges. Radioactivity levels in waste water discharges are not significant.

11.3 All EU Member States have arrangements in place to exempt materials containing naturally occurring radionuclides from regulations where the concentrations are below defined levels. Occasionally a process generates a waste stream containing some of the naturally occurring radionuclides at concentrations above the defined limits. In these cases the national regulations for controlling radioactive wastes apply and a monitoring programme is required. The principles and practices already described for the

monitoring of radioactive discharges from nuclear sites are then applicable and may be incorporated into the monitoring programme that the site carries out under industrial pollution control. For example, a sample of dust from an atmospheric discharge from a metal smelter taken for metals analysis can also be radiochemically analysed for  $^{210}\text{Po}$ . However, both atmospheric and waste water discharges from industrial processes are likely to contain much higher loadings of dust or suspended solids and present more complex sample matrices than from nuclear plants. Moreover, the knowledge of professional staff and process operatives about radioactivity is likely to be much lower and the operator is more likely to rely on external expertise than to have an in-house capability for dealing with radioactive matters.

***Production of radiopharmaceuticals, etc.***

- 11.4 Radiopharmaceuticals are used extensively in health care for diagnostic and treatment purposes. Their production is carried out at sites in the UK and Germany. Radiopharmaceuticals incorporating  $^{131}\text{I}$ ,  $^{123}\text{I}$ ,  $^{99\text{m}}\text{Tc}$ ,  $^{111}\text{In}$ ,  $^{201}\text{Tl}$ ,  $^{18}\text{F}$  and  $^{67}\text{Ga}$  with half-lives of a few days down to a few hours are commonly used. The production of radiopharmaceuticals gives rise to discharges of both aerial and liquid wastes. Production is carried out in glove boxes from which aerial discharges are conducted via abatement plant such as HEPA or activated charcoal filters and ducts to stacks. Sampling of aerial discharges uses the sample collection techniques described at Section 6 for nuclear plants such as, bubblers and MayPack charcoal filters. The control of liquid waste discharges uses delay and sentencing tanks to take advantage of the short half-lives of the radionuclides and thereby minimise the quantities of radioactivity being discharged. Liquid waste discharges are directed first to delay tanks local to the production plant and then by pipe to central sentencing tanks. Sampling follows the practices described in Section 7 for nuclear installations. Laboratory analytical procedures are specific to the radionuclides being processed and can include coincidence counting for  $^{18}\text{F}$ , and the direct counting and/or radiochemical techniques described in Section 8.
- 11.5 The production of radioactive materials for use in the life-sciences generally involves the incorporation of  $^3\text{H}$  and  $^{14}\text{C}$  into organic compounds. These are then widely used in research establishments for investigations into the production of radiopharmaceuticals and the behaviour of organic compounds in biological processes. The production of these radioactive compounds gives rise to discharges of both aerial and liquid wastes. These discharges are managed in much the same way as described above for radiopharmaceutical production except that the long half-lives for  $^3\text{H}$  and  $^{14}\text{C}$  means that the minimisation of radioactivity in liquid discharges by retention in delay tanks for decay is not a practicable option.

***Medical and small research uses of radioactive substances***

- 11.6 Radioactive substances are used widely for medical purposes. Radionuclides are administered to patients for therapeutic purposes (e.g.  $^{131}\text{I}$  for the treatment of thyroid cancer), and for diagnostic purposes (e.g.  $^{99\text{m}}\text{Tc}$  for brain and bone scans), and others are used by hospital laboratories for in-vitro tests. Their keeping and use, and the discharge of associated wastes are normally regulated under national legislation for the control of radioactive substances.
- 11.7 Radioactive substances are widely used in universities and research establishments as tracers and as part of diagnostic tests. These can lead to discharges of radioactivity from fume cupboard extraction systems and in waste waters to sewers, sewage treatment works and direct to rivers or the sea.

- 11.8 All of these uses lead to aerial and liquid discharges of radioactivity from hospitals to sewers and sewage treatment plants. These discharges are rarely routinely measured. Rather the quantities discharged are estimated for accountancy purposes from knowledge of the behaviour of individual radionuclides in humans or in laboratory tests. For example, radiopharmaceuticals may be assumed to be wholly excreted by patients and end up in sewers and sewage treatment plants. In some laboratory tests the radionuclide may be known to partition to a solid fraction, or to a waste liquor or to be off-gassed via the fume cupboard extraction system.
- 11.9 In some Member States the regulatory authority may require the use of delay tanks for the sentencing of radioactive waste waters. Periodic monitoring of sewers, sewage treatment plants and final effluents may also be carried out to demonstrate that the discharges are not of radiological significance (for example to sewage treatment plant operatives).

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