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Radiological Monitoring for Protection of the Public and the Environment

DRAFT SAFETY GUIDE

DS505

Revision of RS-G-1.8

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CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Radiological monitoring programmes are required to verify compliance with the safety requirements related to the control and assessment of public exposure (see para. 3.127 of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [1]). Governments, regulatory bodies, operating organizations in charge of facilities and activities, organizations in charge of preparedness and response to a nuclear or radiological emergency, technical support organizations and other agencies that may be involved in such radiological monitoring have different responsibilities, ranging from the definition of the policies to the implementation of such programmes.

1.2. Monitoring for protection of the public and the environment includes monitoring at the source (source monitoring), monitoring in the environment (environmental monitoring) and, in very specific cases, individual monitoring of members of the public.

1.3. Facilities and activities that discharge radionuclides to the environment are required to prospectively evaluate the radiological impact on the public and the environment (see Requirement 31 of GSR Part 3 [1]). Recommendations on implementing these requirements are provided in IAEA Safety Standards Series No. GSG-10, Prospective Radiological Environmental Impact Assessment for Facilities and Activities [2], and GSG-9, Regulatory Control of Radioactive Discharges to the Environment [3].

1.4. The regulatory body may establish requirements for monitoring the impact of discharges using a graded approach. In some facilities or activities, routine monitoring — both at the source of the discharge and in the receiving environment — is an important and essential element in the process of control of the discharges and verification of compliance with discharge authorization conditions. Recommendations on including a graded approach within the licensing process are provided in IAEA Safety Standards Series No. GSG-8 [GSG 8].

1.5. Despite measures to prevent and minimize the consequences of accidents, uncontrolled releases of radionuclides to the environment might still occur. Monitoring of an accidental release at its source, and of the resulting radioactive contamination[1] in the environment is necessary for the assessment and implementation of actions for protection of persons and the

[1] Contamination is defined as radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable, or the process giving rise to their presence in such places [4].

environment. The requirements for radiation monitoring in emergency exposure situations are established in IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [5]. In some cases, individual monitoring of the public may be appropriate.

1.6. In areas contaminated with long lived radionuclides from past activities that were not subject to appropriate control, or as a result of a nuclear or radiological accident after the emergency has been declared to be ended, monitoring may be needed to aid decisions on the protection of the public, including for implementing practical measures to reduce the exposures to the population , including remediation activities, where justified.

1.7. Although the IAEA safety standards contain general provisions for the protection of the environment from the harmful effects of radiation, GSR Part 3 [1] does not have specific requirements for the explicit assessment of the exposure (and hence the level of protection) of flora and fauna. Nevertheless, GSR Part 3 [1] identifies the protection of the environment as an issue necessitating assessment, while allowing for flexibility in incorporating into decision making processes the results of environmental assessments that are commensurate with the radiation risks. The usual environmental monitoring programmes for the protection of the public, as described in this Safety Guide, are generally sufficient to validate the assessment of the level of protection of the populations of other species.

1.8. This Safety Guide supersedes IAEA Safety Standard Series No. RS-G-1.8[2], Environmental and Source Monitoring for Purposes of Radiation Protection, which was published in 2005. This Safety Guide improves consistency with IAEA Safety Standards published after 2005, namely IAEA Safety Standards Series No. SF-1, Safety Fundamentals [6] and the associated safety requirements, in particular in GSR Part 3 [1] and GSR Part 7 [5].

OBJECTIVE

1.9. The objective of this Safety Guide is to provide recommendations on implementing the requirements established in GSR Part 3 [1], GSR Part 7 [5] and to provide recommendations and guidance to help in the implementation of other IAEA Safety Requirements publications [7–11] relevant for source, environmental and individual

[2] IAEA Safety Standards Series No. RS-G-1.8, Environmental and Source Monitoring for Purposes of Radiation Protection, IAEA, Vienna (2005).

monitoring for the protection of the public and the environment. This includes planned exposure situations, emergency exposure situations, and existing exposure situations.

1.10. This Safety Guide provides recommendations for governments, regulatory bodies, and other relevant authorities responsible for developing the legal and regulatory frameworks for source and environmental monitoring and, where applicable, individual monitoring of the public. This Safety Guide also provides recommendations for those responsible for developing and implementing monitoring strategies and programmes.

1.11. This Safety Guide provides recommendations on confirmatory monitoring programmes conducted by the regulatory body (or by other organizations on their behalf) in relation to the operation of facilities and the conduct of activities and where a responsible operating organization cannot be identified.

1.12. This Safety Guide also provides recommendations on the interpretation of monitoring results, including for use in dose assessment as well as recommendations for data management, recording and reporting for providing information to interested parties, including the general public.

SCOPE

1.13. This Safety Guide applies to all exposure situations for which, in accordance with their radiological characteristics and the applicable national regulations or international agreements, monitoring is required to verify the level of radiological protection of the public and the environment. It applies to source monitoring, environmental monitoring and individual monitoring, as relevant.

1.14. This Safety Guide applies to monitoring relating to the control of discharges to the environment from authorized facilities and activities in planned exposure situations. It considers the changes in the monitoring requirements over the different stages of the lifetime of a facility, as appropriate.

1.15. General aspects of monitoring for nuclear installations are provided in this Safety Guide. Specific recommendations on site evaluation for nuclear installations are provided in IAEA Safety Standards Series No. DS529, Investigation of Site Characteristics and Evaluation of Radiation Risks to the Public and the Environment in Site Evaluation for Nuclear Installations [12].

1.16. General aspects of monitoring performed in response to a nuclear or radiological emergency are also considered in this Safety Guide. More detailed recommendations on monitoring during a nuclear or radiological emergency are provided in IAEA Safety Standards Series Nos GS-G-2.1, Arrangements for Preparedness for a Nuclear or Radiological Emergency [13], GSG-11, Arrangements for the Termination of a Nuclear or Radiological Emergency [14], and SSG-65, Preparedness and Response for a Nuclear or Radiological Emergency Involving the Transport of Radioactive Material [15]. This Safety Guide only addresses the source and environmental monitoring for facilities and activities in emergency situations where an off-site release has occurred or is foreseen to occur.

1.17. This Safety Guide also addresses general aspects of monitoring related to residual radioactive materials dispersed in the environment following a nuclear or radiological emergency, as a result of activities that were never subject to regulatory control or that were subject to regulatory control but not in accordance with the requirements of the current Standards. More detailed recommendations on monitoring related to the remediation processes are provided in IAEA Safety Standards Series No. GSG-15, Remediation Strategy and Process for Areas Affected by Past Activities or Events [16].

1.18. This Safety Guide considers the analysis of the content of radionuclides in food and drinking water only where they are considered environmental matrices relevant to public exposures, as part of environmental monitoring programmes. Monitoring for control of exposures to the general population due to radionuclides in commodities, such as construction and building materials, food and feed, and drinking water, or for the purpose of quality control for international trade is out of the scope of this Safety Guide. Practical guidance on the regulatory control of building and construction materials is provided in Ref. [17], and information in relation to the management of food in various circumstances where radionuclides are, or could be, present, excluding any nuclear or radiological emergency, is provided in Ref. [18].

1.19. Monitoring related to assessment of exposures to flora and fauna is not addressed in this Safety Guide. This assessment can be done using a generic reference approach as described in ICRP Publication 108 [19] and in Ref. [2].The monitoring programmes for members of the public would be sufficient to validate the generic assessment for flora and fauna. For very specific cases, for example when dealing with endangered species or in protected areas, the government or the regulatory body could decide whether specific monitoring for a particular flora or fauna would be necessary.

1.20. This safety Guide does not cover the protection of workers against radon which is addressed in IAEA Safety Standards Series No. DS519, Protection of Workers Against Exposure Due to Radon [20]. In addition, it does not cover the protection of the public against exposure indoors due to radon. Recommendations on exposure indoors to radon and other natural sources of radiation are provided in IAEA Safety Series No. SSG-32, Protection of the Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation [21].

1.21. This Safety Guide does not provide recommendations on monitoring for the purpose of assessing exposures from the transport of radioactive material and exposures: this is addressed in IAEA Safety Standards Series No. TS-G-1.3, Radiation Protection Programmes for the Transport of Radioactive Material [22].

1.22. This Safety Guide does not address the monitoring of radioactive waste disposal facilities, as this is addressed in in IAEA Safety Standards Series No. SSG-31, Monitoring and Surveillance of Radioactive Waste Disposal Facilities [23].

1.23. This Safety Guide does not address the monitoring of workers or the workplace. Recommendations on monitoring of workers and workplaces are provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [24] and in Ref. [20].

1.24. The Safety Guide does not address monitoring for nuclear security or safeguards purposes.

1.25. This Safety Guide does not address monitoring of non-radiological contaminants or physical stressors; however, the chemical and physical properties relevant for the assessment of radiological impacts should be considered in a monitoring programme for radiological protection of the public and the environment.

STRUCTURE

1.26. Section 2 sets out the IAEA safety requirements for monitoring in different exposure situations. Section 3 presents basic concepts relevant to monitoring for the protection of the public and the environment. Section 4 provides recommendations on the responsibilities of governments, operating organizations (registrants, licensees), regulatory bodies and other relevant authorities with regard to monitoring. Sections 5, 6 and 7 provide recommendations on monitoring programmes for planned exposure situations, emergency exposure situations, and existing exposure situations, respectively. Specific responsibilities, objectives, monitoring procedures and considerations on dose assessment, interpretation and reporting of

monitoring results which are applicable for each type of exposure situation are addressed. Section 8 provides recommendations on a systematic process for the development of monitoring programmes and technical considerations for sampling and measurements. Section 9 provides recommendations on data management, analysis, interpretation and reporting of monitoring results, including recommendations on the use of monitoring results for dose assessment and consideration on uncertainties.

1.27. Additional supporting information is provided in the annex, which addresses technical considerations for sampling and measurements for routine discharges in planned exposure situations.

2. SAFETY OBJECTIVES AND REQUIREMENTS RELEVANT TO MONITORING

GOVERNMENTAL, LEGAL AND REGULATORY FRAMEWORK

2.1. SF-1 [6] establishes principles to be applied to achieve the fundamental safety objective of protecting the public and the environment, now and in the future, from harmful effects of ionizing radiation. This safety objective has to be achieved without unduly limiting the operation of facilities and the conduct of activities that give rise to radiation risks. To ensure that facilities are operated and activities conducted so as to achieve the highest standards of safety that can reasonably be achieved, measures have to be taken, among others, to control the radiation exposure of people and the release of radioactive material to the environment.

2.2. IAEA Safety Standards Series No. GSR Part 1 (Rev. 1), Governmental, Legal and Regulatory Framework for Safety [25] establishes requirements on the governmental, legal, and regulatory framework for safety. These requirements include the need to establish a national policy and strategy for safety and to promulgate the necessary laws and statutes.

2.3. GSR Part 3 [1] establishes requirements for the protection of people and the environment from harmful effects of ionizing radiation and for the safety of radiation sources, including monitoring for radiological protection purposes. GSR Part 3 [1] establishes requirements relevant to the various interested parties (e.g. the government, the regulatory body, the operating organization) with responsibilities related to monitoring. Requirements for radiation monitoring in emergency exposure situations are established in GSR Part 7 [5].

2.4. Requirements for monitoring in the evaluation of sites for nuclear installations are established in IAEA Standards Series No. SSR-1, Site Evaluation for Nuclear Installations [7]. Requirements for monitoring in relation to the predisposal management of radioactive waste, including the discharge of radionuclides, are established in IAEA Safety Standards Series No. GSR Part 5, Predisposal Management of Radioactive Waste [8]. Requirements for monitoring in relation to the disposal of radioactive waste are established in IAEA Safety Standards Series No. SSR-5, Disposal of Radioactive Waste [26]. Requirements for monitoring in relation to the design and operation of nuclear power plants are established in IAEA Standards Series Nos SSR-2/1 (Rev. 1) Safety of Nuclear Power Plants: Design [9], and SSR-2/2 (Rev.1) Safety of Nuclear Power Plants: Operation [10]. Requirements for monitoring in relation to all stages of the life cycle of fuel cycle facilites are established in IAEA Standards Series No. SSR-4 Safety of Nuclear Fuel Cycle Facilities [11].

2.5. Paragraph 2.23 of GSR Part 3 [1] states:

> "The government shall ensure that arrangements are in place for the provision of technical services relating to protection and safety, such as services for personal dosimetry, environmental monitoring and the calibration of monitoring and measuring equipment."

2.6. Paragraph 2.5(5) of GSR Part 1 (Rev.1) [25] states that "The government shall establish a legal and regulatory framework that includes "Provision for the involvement of interested parties and for their input in decision making".

2.7. The responsibilities and requirements for monitoring varies depending on the exposure situation. Responsibilites specific to the three exposure situations identified in GSR Part 3 (planned exposure situations, emergency, exposure situations and existing exposure situations) are discussed in detail in Secion 5, 6 and 7 of this Safety Guide.

REQUIREMENTS FOR MONITORING IN PLANNED EXPOSURE SITUATIONS

2.8. Requirement 14 of GSR Part 3 [1] states that: "**Registrants and licensees and employers shall conduct monitoring to verify compliance with the requirements for protection and safety.**"

2.9. Paragraph 3.37 of GSR Part 3 [1] states:

> "The regulatory body shall establish requirements that monitoring and measurements be performed to verify compliance with the requirements for protection and safety. The regulatory body shall be responsible for review and approval of the monitoring and measurement programmes of registrants and licensees."

2.10. Paragraph 3.38 of GSR Part 3 [1] states that:

> "Registrants and licensees and employers shall ensure that:
>
> (a) Monitoring and measurements of parameters are performed as necessary for verification of compliance with the requirements of these Standards;
>
> (b) Suitable equipment is provided and procedures for verification are implemented;
>
> (c) Equipment is properly maintained, tested and calibrated at appropriate intervals with reference to standards traceable to national or international standard;
>
> (d) Records are maintained of the results of monitoring and verification of compliance, as required by the regulatory body, including records of the tests and calibrations performed in accordance with these Standards;

(e) The results of monitoring and verification of compliance are shared with the regulatory body as required."

2.11. Requirement 30 of GSR Part 3 [1] establishes the responsibilities of relevant parties related to public exposure in planned exposure situations. In this regard, Paragraph 3.127 states:

"Registrants and licensees, for sources under their responsibility, shall establish, implement and maintain:

……

(f) Provision for appropriate monitoring equipment, monitoring programmes and methods for assessing public exposure.

(g) Adequate records of monitoring programmes."

2.12. Requirement 32 of GSR Part 3 [1] states:

"**The regulatory body and relevant parties shall ensure that programmes for source monitoring and environmental monitoring are in place and that the results from the monitoring are recorded and are made available.**"

2.13. Paragraphs 3.135–3.137 of GSR Part 3 [1] establish the responsibilities for monitoring programmes for planned exposure situations. Paragraph 3.135 of GSR Part 3 [1] states:

"The regulatory body shall be responsible, as appropriate, for:

(a) Review and approval of monitoring programmes of registrants and licensees, which shall be sufficient for:

(i) Verifying compliance with the requirements of these Standards in respect of public exposure in planned exposure situations;

(ii) Assessing doses from public exposure.

(b) Review of periodic reports on public exposure (including results of monitoring programmes and dose assessments) submitted by registrants and licensees.

(c) Making provision for an independent monitoring programme.

(d) Assessment of the total public exposure due to authorized sources and practices in the State on the basis of monitoring data provided by registrants and licensees and with the use of data from independent monitoring and assessments.

(e) Making provision for maintaining records of discharges, results of monitoring programmes and results of assessments of public exposure.

(f) Verification of compliance of an authorized practice with the requirements of these Standards for the control of public exposure."

2.14. Paragraph 3.136 of GSR Part 3 [1] states that:

"The regulatory body shall publish or shall make available on request, as appropriate, results from source monitoring and environmental monitoring programmes and assessments of doses from public exposure."[3]

2.15. Paragraph 3.137 of GSR Part 3 [1] states that:

"Registrants and licensees shall, as appropriate:

(a) Establish and implement monitoring programmes to ensure that public exposure due to sources under their responsibility is adequately assessed and that the assessment is sufficient to verify and demonstrate compliance with the authorization. These programmes shall include monitoring of the following, as appropriate:

(i) External exposure due to such sources;

(ii) Discharges;

(iii) Radioactivity in the environment;

(iv) Other parameters important for the assessment of public exposure.

(b) Maintain appropriate records of the results of the monitoring programmes and estimated doses to members of the public.

(c) Report or make available to the regulatory body the results of the monitoring programme at approved intervals, including, as applicable, the levels and composition of discharges, dose rates at the site boundary and in premises open to members of the public, results of environmental monitoring and retrospective assessments of doses to the representative person.

[3] In addition, para. 4.30 of IAEA Safety Standards Series No. GSG-6, Communication and Consultation with Interested Parties by the Regulatory Body [27] states that: "A communication strategy should include a logical, coherent and efficient process for communicating and consulting with interested parties. This process should allow the regulatory body to, inter alia...[p]ublish or make available on request, as appropriate, results from source monitoring and environmental monitoring programmes and assessments of doses from public exposure."

(d) Report promptly to the regulatory body any levels exceeding the operational limits and conditions relating to public exposure, including authorized limits on discharges, in accordance with reporting criteria established by the regulatory body.

(e) Report promptly to the regulatory body any significant increase in dose rate or concentrations of radionuclides in the environment that could be attributed to the authorized practice, in accordance with reporting criteria established by the regulatory body.

(f) Establish and maintain a capability to conduct monitoring in an emergency in the event of unexpected increases in radiation levels or in concentrations of radionuclides in the environment due to an accident or other unusual event attributed to the authorized source or facility.

(g) Verify the adequacy of the assumptions made for the assessment of public exposure and the assessment for radiological environmental impacts.

(h) Publish or make available on request, as appropriate, results from source monitoring and environmental monitoring programmes and assessment of doses from public exposure."

REQUIREMENTS FOR MONITORING IN EMERGENCY EXPOSURE SITUATIONS

2.16. Requirement 43 of GSR Part 3 [1] states that "**The government shall ensure that an integrated and coordinated emergency management system is established and maintained.**" Related to this requirement, paragraph 4.5 of GSR Part 3 [1] states that "The emergency management system shall provide for essential elements at the scene, and at the local, national and international level, as appropriate, including the following:

……

(k) Provision for individual monitoring and environmental monitoring and for dose assessment."

2.17. Paragraph 3.43 of GSR Part 3 [1] states (citation omitted):

"If the safety assessment indicates that there is a reasonable likelihood of an emergency affecting either workers or members of the public, the registrant or licensee shall prepare an emergency plan for the protection of people and the environment. As part of this emergency plan, the registrant or licensee shall include arrangements for the prompt identification of an emergency, and for determining the appropriate level of the

emergency response. In relation to the arrangements for the emergency response at the scene by the registrant or licensee, the emergency plan shall include, in particular:

(a) Provision for individual monitoring and area monitoring, and arrangements for medical treatment;

(b) Arrangements for assessing and mitigating any consequences of an emergency."

2.18. GSR Part 7 [5] establishes a series of requirements on the monitoring needs in response to a nuclear or radiological emergency. Requirements 7, 9 ,14, 16, 18, 24 and 26 address monitoring aspects for protecting the public and the environment.

2.19. Requirement 5 of GSR Part 7 [5] states:

"The government shall ensure that protection strategies are developed, justified and optimized at the preparedness stage for taking protective actions and other response actions effectively in a nuclear or radiological emergency."

2.20. Paragraph 6.24 of GSR Part 7 [5] states:

"Emergency response facilities or locations to support an emergency response under the full range of postulated hazardous conditions shall be designated and shall be assigned the following functions, as appropriate:

……

(g) Coordination of monitoring, sampling and analysis."

2.21. Paragraph 5.40 of GSR Part 7 [5] states:

"Within emergency planning zones and emergency planning distances, arrangements shall be made for the timely monitoring and assessment of contamination, radioactive releases and exposures for the purpose of deciding on or adjusting the protective actions and other response actions that have to be taken or that are being taken."

2.22. Once the emergency is terminated, monitoring is required to be subject to the requirements for planned exposure situations or existing exposure situations, as appropriate (see para. 5.101 of GSR Part 7 [5]).

REQUIREMENTS FOR MONITORING IN EXISTING EXPOSURE SITUATIONS

2.23. The requirements in GSR Part 3 [1] for monitoring in existing exposure situations are only established within the context of remediation. Nevertheless, monitoring could provide essential data to satisfy a number of other requirements for existing exposure situations.

2.24. Requirement 47 of GSR Part 3 [1] states :

> "**The government shall ensure that existing exposure situations that have been identified are evaluated to determine which occupational exposures and public exposures are of concern from the point of view of radiation protection.**"

2.25. Requirement 48 of GSR Part 3 [1] states that "**The government and the regulatory body or other relevant authority shall ensure that remedial actions and protective actions are justified and that protection and safety is optimized.**"

2.26. Paragraph 5.8 of GSR Part 3 [1] states:

> "All reasonable steps shall be taken to prevent doses from remaining above the reference levels. Reference levels shall typically be expressed as an annual effective dose to the representative person in the range of 1–20 mSv or other corresponding quantity, the actual value depending on the feasibility of controlling the situation and on experience in managing similar situations in the past."

2.27. Requirement 49 of GSR Part 3 [1] establishes the responsibilities for remediation of areas with residual radioactive material. Paragraphs 5.10, 5.12, 5.13, 5.16 and 5.17 state the responsibilities for monitoring before, during remediation, post-remediation and monitoring for public information.

2.28. Paragraph 5.10(d) of GSR Part 3 [1] states:

> "For the remediation of areas with residual radioactive material deriving from past activities or from a nuclear or radiological emergency (para. 5.1(a)), the government shall ensure that provision is made in the framework for protection and safety for:
>
> …
>
> An appropriate system for maintaining, retrieval and amendment of records that cover the nature and the extent of contamination; the decisions made before, during and after remediation; and information on verification of the results of remedial actions, including the results of all monitoring programmes after completion of the remedial actions."

2.29. Paragraph 5.12 of GRS Part 3 [1] states:

"The persons or organizations responsible for the planning, implementation and verification of remedial actions shall, as appropriate, ensure that:

…

(e) A mechanism for public information is in place and interested parties are involved in the planning, implementation and verification of the remedial actions, including any monitoring following remediation.

(f) A monitoring programme is established and implemented."

2.30. Paragraph 5.13 of GRS Part 3 [1] states that "The regulatory body … or other relevant authority shall take responsibility, in particular for:

…

(c) Review of work procedures, monitoring programmes and records."

2.31. Paragraph 5.14 of GRS Part 3 [1] states:

"The person or organization responsible for carrying out the remedial actions:

…

(c) Shall monitor the area regularly during the remediation so as to verify levels of contamination, to verify compliance with the requirements for radioactive waste management, and to enable any unexpected levels of radiation to be detected and the remedial action plan to be modified accordingly, subject to approaval by the regulatory body or other relevant authority".

2.32. Paragraph 5.16 of GSR Part 3 [1] states:

"The person or organization responsible for post-remediation control measures shall establish and maintain, for as long as required by the regulatory body or other relevant authority, an appropriate programme, including any necessary provision for monitoring, to verify the long term effectiveness of the completed remedial actions for areas in which controls are required after remediation."

2.33. Paragraph 5.17 of GRS Part 3 [1] states:

"For those areas with long lasting residual radioactive material, in which the government has decided to allow habitation and the resumption of social and economic activities, the government, in consultation with interested parties, shall ensure that arrangements

are in place, as necessary, for the continuing control of exposure with the aim of establishing conditions for sustainable living, including:

…

(b) Establishment of an infraestructure to support continuing 'self-help protective actions' in the affected areas, such as by the provision of information and advice, and by monitoring."

TRANSBOUNDARY IMPACTS

2.34. There are no specific provision covering monitoring associated with transboundary impacts in GSR Part 3 [1] and GSR Part 7 [5], but there are requirements for transboundary impacts that are relevant to monitoring. For example, para. 3.124 of GSR Part 3 [1] states:

"the government or the regulatory body:

(a) Shall ensure that the assessment for radiological impacts includes those impacts outside the territory or other area under the jurisdiction or control of the State;

…

(c) Shall arrange with the affected State the means for the exchange of information and consultations, as appropriate."

2.35. Requirement 22 of GSR Part 7 [5] states:

"**The government shall ensure that arrangements are in place for the coordination of preparedness and response for a nuclear or radiological emergency between the operating organization and authorities at the local, regional and national levels, and, where appropriate, at the international level**".

2.36. Paragraph 6.13 of GSR Part 7 [5], states:

"When several different organizations of the State or of other States are expected to have or to develop tools, procedures or criteria for use in the response to an emergency, arrangements for coordination shall be established to improve the consistency of the assessments of the situation, including assessments of contamination, doses and radiation induced health effects and any other relevant assessments made in a nuclear or radiological emergency, so as not to give rise to confusion."

GRADED APPROACH

2.37. GSR Part 1 (Rev. 1) [25], GSR Part 3 [1] and IAEA Safety Standards Series No. GSR Part 4, Safety Assessment for Facilities and Activities [28] establish specific requirements for the implementation of a graded approach. Regarding monitoring for the protection of the public and the environment, the graded approach should reflect that the type of monitoring programme, as well as its scale and extent, should be commensurate with the characteristics of the practice or the source and the magnitude of the radiation risk and the extent to which the exposure is amenable to control.

3. CONCEPTS AND TERMS relevant for monitoring

ENVIRONMENTAL MATRICES

3.1. ‘Environmental matrices’ is used in this Safety Guide to refer to the environmental compartments from which samples are collected and analysed as part of the environmental monitoring programmes. This includes environmental samples relevant to human exposure, such as air, surface and underground water, soils, sediments, drinking water, crops, animals and vegetables in the human food chain and other foodstuffs, as well as bioindicator organisms.[4]

ENVIRONMENTAL RELEASES

3.2. A discharge is a planned and controlled release of (usually gaseous or liquid) radioactive substances to the environment [4]. More specifically, in this Safety Guide, ‘discharges’ refers to releases arising from sources within facilities and activities in planned exposure situations. The release of radioactive material to the environment in an emergency or the migration through the environment in an existing exposure situation are referred to as ‘release’ or ‘environmental release’, respectively. Discharges and releases may include solid and liquid aerosols.

EXPOSURE AND EXPOSURE PATHWAYS

3.3. GSR Part 3 [1] defines exposure as “the state or condition of being subject to irradiation.” External exposure is defined as “exposure to radiation from a source outside the body, and internal exposure as “exposure to radiation from a source within the body” [1]. Exposure pathway is defined as “a route by which radiation or radionuclides can reach humans and cause exposure” [1]. Typical pathways for external exposures are irradiation from radionuclides in an atmospheric plume or deposited on the ground or on sediments. Typical pathways for internal exposures are inhalation, and ingestion of food and drinking water.

3.4. An exposure pathway defines routes from a source of radionuclides or radiation to a target receptor or population through media in the environment. Transport and migration over different time periods are considered. One important purpose of monitoring is to provide data

[4] Bioindicator organisms are biota that might not be significant in relation to pathways of human exposure and are therefore not used for dose assessment purposes, but that concentrate radionuclides effectively and so can be utilized as sensitive indicators for assessing trends in environmental radiation levels and activity concentrations of radionuclides in the environment. Indicator materials are selected because they concentrate radionuclides which are therefore usually more readily detectable than in foodstuffs, so the indicator organisms or materials provide a more sensitive indicator of environmental contamination.

that enable the assessment of doses to the public and to exposures to fauna and flora when required (see paragraphs 1.6, 1.21 and 5.15).

EXPOSURE SITUATIONS

3.5. Paragraph 1.20 of GSR Part 3 [1] distinguishes between three different exposure situations: planned exposure situations, emergency exposure situations and exisiting exposure situations. Paragraph 1.20 of GSR Part 3 states:

> "(a) A planned exposure situation is a situation of exposure that arises from the planned operation of a source or from a planned activity that results in an exposure due to a source. Since provision for protection and safety can be made before embarking on the activity concerned, the associated exposures and their likelihood of occurrence can be restricted from the outset. The primary means of controlling exposure in planned exposure situations is by good design of facilities, equipment and operating procedures, and by training. In planned exposure situations, exposure at some level can be expected to occur. If exposure is not expected to occur with certainty, but could result from an accident or from an event or a sequence of events that may occur but is not certain to occur, this is referred to as 'potential exposure'.
>
> (b) An emergency exposure situation is a situation of exposure that arises as a result of an accident, a malicious act or any other unexpected event, and requires prompt action in order to avoid or to reduce adverse consequences. Preventive measures and mitigatory actions have to be considered before an emergency exposure situation arises. However, once an emergency exposure situation actually arises, exposures can be reduced only by implementing protective actions.
>
> (c) An existing exposure situation is a situation of exposure that already exists when a decision on the need for control needs to be taken. Existing exposure situations include situations of exposure to natural background radiation. They also include situations of exposure due to residual radioactive material that derives from past practices that were not subject to regulatory control or that remains after an emergency exposure situation."

MEMBER OF THE PUBLIC AND THE REPRESENTATIVE PERSON

3.6. For the protection of the public, it is necessary to define a person whose dose can be used for determining compliance with dose constraints and dose limits. This is called the

‘representative person' [29], who is a person that receives a dose that is representative of the more highly exposed individuals in the population. The representative person is generally a hypothetical construct and not an actual individual. Factors, such as the spatial distribution of radionuclides in the environment, the location, age, diet, and habits of the population group to which the representative person belongs, as relevant, should be considered when identifying the representative person and estimating the dose received.

3.7. The term ‘representative person’ applies to planned exposure situations, exisiting exposure situations and emergency exposure situations [29]. However, the particular characteristics of the representative person in each situation, such as his or her location, habits and age group, may be different.

MONITORING STRATEGY AND MONITORING PROGRAMME

3.8. ‘Monitoring strategy’ in the context of this Safety Guide refers to the national approach to establish the responsibilities of and interactions among the organizations that will conduct activities related to monitoring. For emergency exposure situations, the monitoring strategy is related to the monitoring arrangements as part of the protection strategy[5] [5].

3.9. ‘Monitoring programme’ in the context of this Safety Guide refers to the means (including, resources, tools and techniques) designed to observe and characterize the source or environment and assess the radiological impact on the public and environment. It includes, for example, sampling locations and frequency, types of environmental matrix, sampling and measurement techniques and the interpretation of the data obtained.

SOURCE

3.10. A source is anything that may cause radiation exposure — such as by emitting ionizing radiation or by releasing radioactive substances or radioactive material — and can be treated as a single entity for purposes of protection and safety [4]. If a facility or an activity releases radioactive substances into the environment, the facility or the activity as a whole may be regarded as a source; if radioactive substances are already dispersed in the environment, the portion of them to which people are exposed may be considered a source.

[5] Protection strategies are developed at the preparedness stage for taking protective actions and other response actions effectively in a nuclear or radiological emergency [5].

3.11. ‘Source monitoring’ refers to the measurement of activity in radionuclides being released to the environment or of external dose rates due to sources within a facility or activity [4].

3.12. ‘Environmental monitoring’ refers to the measurement of external dose rates due to sources in the environment or of radionuclide concentrations in environmental media [4]. Environmental monitoring is considered as the monitoring conducted outside the site giving rise to the exposure. Environmental monitoring programmes include measurements of radiation fields and radionuclide activity concentrations in environmental matrices relevant to human exposure, primarily in air, drinking water, sediments, soils, agricultural produce and foodstuffs, aquatic foods, as well as in bioindicators that concentrate radionuclides and provide a measure of trends in activity levels. Environmental monitoring programmes also include other physical, chemical and biological factors that can affect exposures.

3.13. ‘Individual monitoring’ refers to monitoring using measurements by equipment worn by individuals, or measurements of quantities of radioactive substances in or on, or taken into, the bodies of individuals, or measurements of quantities of radioactive substances excreted from the body by individuals [4]. Individual monitoring for members of the public would only be necessary for certain emergency exposure situations.

4. RESPONSIBILITIES FOR MONITORING

RESPONSIBILITIES OF THE GOVERNMENT, REGULATORY BODY, OPERATING ORGANIZATIONS, AND OTHER PARTIES

4.1. The government or the regulatory body should make specific provisions in the regulatory framework to ensure that appropriate monitoring strategies and programmes are in place, and that responsibilities are clearly assigned, to provide an appropriate level of protection of the public and the environment. The government is required to ensure that arrangements are in place for prompt monitoring and assessment in a nuclear or radiological emergency (see para. 5.76(b) of GSR Part 7 [5]).

4.2. States might have legislative obligations to conduct environmental monitoring to protect people and the environment from non-radioactive pollutants. The framework for radiological monitoring should be compatible and consistent with such obligations.

4.3. With regard to planned exposure situations, the regulatory body is required to review and approve monitoring programmes and review periodic reports on monitoring data and public exposures, make provisions for an independent environmental monitoring programme, and assess the cumulative radiological impact of multiple sources (see para. 3.135 of GSR Part 3 [1]). The regulatory body should assist in the coordination of environmental monitoring and individual monitoring in an emergency.

4.4. The government or the regulatory body might delegate specific responsibilities for monitoring to other parties. These parties should remain independent of any government department and of any parties that are responsible for the promotion and development of the practices being regulated, as well as of any registrant, licensee, designer or constructor of the facilities or activities being regulated. The government might delegate these responsibilities directly, or through the regulatory body. The delegated responsibilities might include the following:

(a) Testing and calibration of monitoring equipment;

(b) Review of quality management systems;

(c) Design and regular performance of environmental monitoring or source monitoring to verify the quality of the results provided by the operating organization;

(d) Verification of the assessment of the doses to members of the public made by the operating organization;

(e) Implementation of the environmental monitoring programme to assess the cumulative radiological impact of multiple facilities on the public and on the environment;

(f) Environmental monitoring and individual monitoring and dose assessment in emergency exposure situations;

(g) Collection and retention of monitoring data and related dose assessments provided by operating organizations, government agencies and international bodies;

(h) Nationwide environmental monitoring.

4.5. The operating organization or other responsible party[6] for monitoring of a facility, activity, or site as established in the legal or regulatory framework should define the objectives of the monitoring programme(s) in accordance with the prevailing radiological characteristics and regulatory requirements.

4.6. The responsibilities of the operating organization, regulatory body and government may differ depending on the exposure situation. Table 1 presents an indication of such responsibilities. Detailed recommendations on the responsibilities for planned exposure situations, emergency exposure situations and existing exposure situations are provided in Sections 5, 6 and 7, respectively.

[6] The other parties with a role in monitoring might include technical support organizations (TSOs), non-governmental organizations, food authorities, water authorities, public health authorities, and emergency preparedness and response organizations.

TABLE 1. RESPONSIBILITIES FOR SOURCE MONITORING AND ENVIRONMENTAL MONITORING AND DOSE ASSESSMENT

Exposure Situation		Operating organization[a]	Regulatory body	Government
Planned	Exempted or cleared	No monitoring required		Not applicable
	Registered practice/source	Source monitoring	Review and approve of monitoring programmes of registrants and licensees Review periodic reports on public exposure including dose assessments, as appropriate[b]	Ensure arrangements are in place for monitoring
	Authorized practice/source	Source and environmental monitoring, dose assessment	Conduct limited confirmatory environmental monitoring, as appropriate[b]	
	Multiple sources	Source monitoring of its own facility, site specific environmental[b] monitoring, dose assessment[b]	Review monitoring data and prepare dose assessments cumulative over the relevant period, as appropriate Conduct environmental monitoring to assess cumulative radiological impact	Ensure arrangements are in place for management of nationwide surveys
Emergency	–	Source monitoring, site specific environmental monitoring[b]	Coordinate large scale and near field environmental monitoring Coordinate individual monitoring of the public, as appropriate	Ensure resources and capabilities are available to respond Ensure arrangements are in place for management of nationwide monitoring networks
Existing	Areas with residual radioactive material	Source monitoring, site specific environmental monitoring, dose assessment[c]	Review monitoring data and dose assessments Conduct near field environmental monitoring, as appropriate	To screen areas where the radiological impact is of potential concern and a radiological survey is considered necessary Decide on the need for control/monitoring Ensure arrangements are in place for management of existing exposure sites, including monitoring, as they arise

[a] The operating organization can delegate the monitoring to another party, but should maintain the responsibility.

[b] Only for authorized practices/sources (see Table 2).

[c] In the cases in which remediation have been determined to be justified, the operating organization is the responsible party authorized to conduct remediation [16]. If the operating organization is not present, the regulatory body has those responsibilities.

5. MONITORING IN A PLANNED EXPOSURE SITUATION

5.1. The need for monitoring in a planned exposure situation should be determined by the regulatory requirements that apply to the facility or activity.

5.2. Monitoring is not required for sources that give rise to exposures that are deemed to be not amenable to control and therefore are excluded from the scope of GSR Part 3 [1]. Examples of excluded exposures are provided in IAEA Safety Standards Series No. GSG 17, Application of the Concept of Exemption [30] and include exposures from ^{40}K in the human body or cosmic radiation at the surface of the Earth, unmodified concentrations of radionuclides of natural origin in soil, including those in high natural background radiation areas, other primordial radionuclides (e.g. ^{87}Rb,^{138}La,^{147}Sm,^{176}Lu) present in unmodified activity concentrations, and fallout resulting from past atmospheric nuclear weapon tests.

5.3. Monitoring is not required for exempted practices or sources (see Schedule I of GSR Part 3 [1]). An example of an exempted practice is a laboratory that utilizes small amounts of radionuclides for which either the total activity or the activity concentration is below the exemption levels specified in Table I.1 of GSR Part 3 [1]. For practices which notification alone is sufficient there is no requirement for monitoring in GSR Part 3 [1].

5.4. Material that meets the clearance levels[7] is no longer considered radioactive material and can be used, recycled or disposed of without further regulatory consideration regarding the radiological aspects [31]. Hence, once a material has been cleared there is no requirement for monitoring. The processes and procedures leading to clearance should be well defined in the national regulatory framework and in the authorization conditions for the facility or activity.

5.5. For authorized practices[8] [1], routine monitoring programmes are required (see para. 3.127(f) of GSR Part 3 [1]). Nuclear installations, large research establishments and radioisotope production facilities typically have specific license conditions and are expected to have source and environmental monitoring programmes in support of verification of regulatory compliance. These monitoring programmes might also form the basis for the emergency monitoring programme at

[7] Radioactive material or radioactive objects within notified or authorized practices can be cleared of regulatory control. GSG-18 provides guidance [30] on the application of the concept of clearance of materials, objects and buildings that are to be released from regulatory control in the framework of planned exposure situations.

[8] Sources or practices for which neither exclusion nor exemption is appropriate are required to be authorized by the regulatory body [1]. The authorization can take the form of either a registration or a license. Examples of licensed practices are nuclear power plants and other fuel cycle installations. Examples of registered practices are those conducted at small research institutes and small hospitals, where the usage of short lived radionuclides and the corresponding discharges to the environment are low.

these facilities, although not all facilities and activities will need full emergency monitoring capability.

5.6. For registered practices, the regulatory body might require source monitoring to be performed, but routine environmental monitoring is usually not necessary. The regulatory body should consider requiring a single confirmatory source and environmental monitoring campaign, for example at the time of giving the authorization[9]. The regulatory body should provide guidance on how to conduct this monitoring, involving, as necessary, the technical support organizations.

5.7. During the authorization process, the conditions of the operation of facilities that are likely to discharge radioactivity to the environment, which are related to the management of gaseous, airborne and liquid effluents should be defined by the regulatory rody. In general, the following data should be established as part of the authorization process[10] [3]:

(a) The total inventory of radionuclides in the facility or activity;

(b) The total activity of radionuclides expected to be discharged during a defined period in different operational states;

(c) The exposure pathways that contribute to the doses to the public;

(d) The expected doses to the public due to discharges;

(e) The discharge limits.

RESPONSIBILITIES FOR MONITORING IN PLANNED EXPOSURE SITUATIONS

5.8. Operating organizations have primary responsibility for carrying out source monitoring to demonstrate compliance with operational limits, including the authorized limits for discharges. Source monitoring for a specific facility or activity should be performed by the operating organization in all applicable stages in the lifetime of the facility or activity. The operating organization should establish, implement and maintain the appropriate equipment and programmes to monitor discharges.

5.9. The regulatory body is responsible for ensuring that the operating organization complies with regulatory requirements for source and environmental monitoring. The regulatory body should establish technical requirements for such monitoring and should regularly review them.

[9] In addition to fulfilling a regulatory obligation, this measurement would provide reassurance for the neighboring populations.

[10] GSG-9 [3] provides recommendations for the establishment and authorization of discharge limits and the related operational conditions.

The regulatory body should check the monitoring data provided by operating organizations and publish (or make available on request) evidence that that authorized facilities and activities are being suitably monitored and controlled.

5.10. The regulatory body is required to make arrangements for an independent monitoring programme of source and environmental measurements to verify the quality of results provided by the operating organization and to confirm that the doses to members of the public are below dose constraints (see para. 3.135(c) of GSR Part 3 [1]. The regulatory body may implement itself or delegate through agreements the implementation of this independent programme of source and environmental monitoring to other parties, such as technical support organizations with adequate technical resources; however, the responsibility for such a programme remains with the regulatory body.

5.11. The regulatory body is required to assess the total radiological impact based on the results of monitoring conducted by operating organizations and other parties (see para. 3.135(d) of GSR Part 3 [1]. For the assessment of the total public exposure due to multiple authorized sources and practices that might have impact on the same population groups, the cumulative radiological impact should be considered.

OBJECTIVES FOR MONITORING IN PLANNED EXPOSURE SITUATIONS

5.12. The objectives of a monitoring programme for the protection of the public and the environment in a planned exposure situation, should be as follows:

(a) To demonstrate compliance of the facility or activity with the authorized discharge limits and operational conditions concerning the impact on the public and the environment;

(b) To provide information and data for the radiological environmental impact assessment [2], including the evaluation of doses to the representative person;

(c) To check the conditions of operation and verify the adequacy of controls on discharges from a source and to provide an early warning of unanticipated operational occurrences, which might trigger the need of additional monitoring, mitigation and corrective actions on the facility or activity;

(d) To provide input to the periodic safety reviews, including the re-assessment of the environmental radiological environmental impact and, if necessary, the review of the discharge limits;

(e) To detect unexpected or unauthorized discharge, including fugitive releases;

(f) To detect any unexpected increase in radionuclide concentrations in the environment;

(g) To assess the buildup of activity concentrations in the environment arising from discharges;

(h) To verify or validate environmental models used in the prospective radiological environmental impact assessment;

(i) To provide information for interested parties.

(e) To evaluate long term trends.

5.13. If required in the national regulations, dose rates to the representative animals and plants may also be evaluated with a methodology as described in annex I of GSG-10 [2], based on the ICRP approach for the protection of the environment [20]. To the extent possible, monitoring programmes for environmental protection should be integrated to fulfill dose assessment objectives for the protection of people and flora and fauna. The environmental media and locations sampled to support human dose assessment might also be useful for the dose assessment of flora and fauna as radionuclide activity concentrations in biota are likely to be estimated from activity concentrations measured in environmental media (e.g. water, soil, sediments) taking account of relevant exposure pathways.

MONITORING OVER THE DIFFERENT STAGES IN THE LIFETIME OF FACILITIES

5.14. For certain facilities, for example, nuclear power plants and other nuclear installations, there are generally a number of stages throughout the lifetime of the facility [32]. For such facilities, the nature of the monitoring programme should be appropriate for the characteristics of these different stages and consider, for example, the extension, scope and frequency of the sampling and the type of environmental matrices to be monitored to reflect the changes in the facility. The resources devoted to the monitoring programmes in each of these stages should be optimized on the basis of previous results.

5.15. In the early stages of the operation of a facility, more frequent and detailed environmental measurements should be conducted to confirm the predictions of environmental models used to simulate the transfer of radioactivity through the environment. Subsequently, when more information and experience are gained, it might be appropriate to reduce the scale and extent of both source and environmental monitoring. Nevertheless, any decision to reduce the frequency of sampling or the scope of the environmental monitoring programme should be

justified, and account should be taken of potential changes in the discharge regimes or unexpected releases, as well as any concerns raised by the public.

5.16. Monitoring programmes should be reassessed when changes are anticipated in operations of the facility or activity, which affect the radionuclides composition or magnitude of the discharges, leading for example to a modification of the discharge authorization, or when significant changes in the local environment or in the habits of the local population are observed.

Pre-operational stage

5.17. Pre-operational studies[11] should be performed in planned exposure situations to establish baseline[12] environmental radiation levels and activity concentrations for the purpose of subsequently determining the radiological impact of the source. Pre-operational assessments should also provide information for use in the prospective assessment of doses to the public [2], such as information on the expected inventories of radionuclides during normal operation of a facility, the possible discharge pathways and the likely amounts that will be discharged to the environment, with due consideration of the effluent treatment systems that will be installed. Pre-operational studies should include the monitoring of the environmental matrices mentioned in para. 3.1 in this Safety Guide. The prospective assessment of doses to the public should be considered by the regulatory body before issuing an authorization for discharges to the environment [3].

5.18. The pre-operational monitoring programme should evaluate the need to identify suitable bioindicator organisms or indicator materials for particular radionuclides. The pre-operational monitoring programme should also serve to train staff and to test the instruments, and organization of the monitoring programmes for the operational stage.

5.19. The pre-operational monitoring programme should be initiated in sufficient time before the start of operation, (e.g. for nuclear installations it should be undertaken 2–3 years before the start of operation) to be able to study the possible effect of the annual variability in the local environment on the measurements and the results obtained. The results of this pre-operational

[11] For those facilities and activities for which a site evaluation is part of the authorization process.

[12] At the pre-operational stage, a baseline characterization study is designed to establish baseline activity concentrations and radiation dose rates in the environment. The results from the baseline characterization studies can be used for future evaluation of the impact of the facility on the site and the surrounding area from its operation, determining acceptability of proposes decommissioning options and establishing end state criteria and demonstrate compliance with the proposed end state [33–35].

monitoring should be used as an input to the development of the monitoring programme for the operational stage.

5.20. At the pre-operational stage, one or more areas for control measurements[13] that are beyond the range of impact from the facility or activity, should be identified. If such areas are not covered in national environmental monitoring programmes, pre-operational monitoring should also be undertaken in these areas.

Operational stage

Source monitoring

5.21. The design of the source monitoring programme in the operational stage should enable the verification of compliance with the authorized limits and conditions of discharges specified by the regulatory body. The monitoring of radioactive discharges may entail measurements for specific radionuclides or gross activity measurements, as appropriate. If the discharge limits are given in terms of total alpha activity and/or total beta activity, and not for specific radionuclides, radionuclide specific measurements on a routine basis might not be necessary. However, a full determination of the radionuclide composition in the discharges should be performed at least once and when changes in the radionuclide composition of releases could be conceived.

5.22. Source monitoring should normally be performed before dilution occurs or at the point of discharge (e.g. at the stack for atmospheric discharges or at the pipeline for a liquid discharge). In the case of batch discharges, the material due to be discharged should be adequately characterized by the volume of the batch and the radionuclide composition of a sample taken from the homogenized batch prior to discharge. For continuous discharges, time integrated or continuous measurements should be used to ensure that a correct assessment of the release has occurred.

5.23. The choice of the sampling and measurement procedures should consider the following:

(a) The characteristics and amounts of discharged radionuclides and the sensitivity of the measurement system;

[13] Areas for control measurements are locations that can be assumed as not being impacted by the radiological situation under consideration. For example, areas outside a contaminated area or locations upstream of the point of discharge.

(b) The expected variation with time in the discharge rates of the radionuclides and in the radionuclide composition;

(c) The likelihood of unplanned discharges requiring prompt detection and notification.

5.24. Regardless of the type of sampling and measurement, provisions should be made for the accurate determination of the volume of material discharged as a function of time so that the total activity discharged over a given time can be computed from measurements of activity concentration. To calculate the radiation dose to the representative person, relevant meteorological and hydrological dispersion data should also be collected. Other parameters that should be consider for properly evaluating the impact of the discharges include the following:

(a) The physical and chemical form and solubility of the radionuclide(s) discharged;

(b) The particle size distribution in the case of airborne discharges;

(c) The pH in the case of water based liquid discharges.

5.25. In selecting the instrumentation for source monitoring, possible abnormal and unexpected releases should also be considered to ensure that the measurement range is sufficient and that alarms levels are adequately set. It should be also considered that the radionuclide composition and physical and chemical characteristics of an accidental release are likely to be different from the discharges in normal operation, to ensure that sufficient flexibility of response in designing the monitoring system for accidental releases is achieved [36].

Environmental monitoring

5.26. Measurements should be made, and sampling performed, at appropriate locations outside the boundary of the facility. This should include, as appropriate, measurements of external radiation levels and of radionuclide activity concentrations in all relevant environmental matrices, including food products and drinking water. The locations for measurements and sampling should be determined on a site specific basis, with the aim of assessing radiation doses to the representative person and identifying the areas with the highest levels of radiation. Additionally, environmental sampling could be conducted regularly in nearby population centres, for reassurance, as well as in areas for control measurements for comparison.

5.27. In addition to measurements that directly relate to exposure pathways to humans, the measurement of activity concentrations in ‘indicator’ organisms or materials should be considered. This includes measurements on seaweeds, lichen or suspended particulate matter

which are not direct parts of the food chain, to provide data on trends and the buildup of radionuclides in the environment.

5.28. When environmental monitoring is performed to assess the impact of a particular facility or activity it should enable the verification of the results of source monitoring. It should also enable the assessment of the doses to members of the public.

5.29. Where there are several facilities or activities giving exposure to the same group of individuals, there could be a need to select sampling locations from which the aggregate effect of all discharges can be assessed. For the proper design of such a monitoring programme, information on the direct irradiation and the radionuclides discharged from each of the contributing sources may be needed, as well as the chemical and physical form of the radionuclides and the intervals at which discharges are made, so that appropriate collection and measurement techniques can be employed.

Facility decommissioning

5.30. During decommissioning, the monitoring programme should reflect changes in the characteristics of the discharges (e.g. radionuclide composition, discharge rates). As decommissioning proceeds, the impact on the public from direct irradiation and changes in the discharged radionuclides compared to the impact during the operational stage should be considered[14]. The monitoring programme for the source and the environment that were in place during operation of the facility should be re-evaluated to determine whether they remain appropriate. Any new arrangements for source and environmental monitoring should be documented in the decommissioning plan.

Source monitoring

5.31. When defining the source monitoring programmes during decommissioning, the possible changes of quantities, radionuclides composition and physicochemical characteristics of the releases should be considered, as well as the changes in the external radiation fields around the facility. The objectives of source monitoring should be essentially the same as for

[14] Radioactive discharges in liquid form will be likely to change as a result of the decommissioning process and will eventually be eliminated. However, the decontamination and dismantling activities integral to decommissioning may result in radioactive releases through the creation, suspension and resuspension of contaminated aerosols. For a nuclear power plant, once reactor operations have ceased, there are no more short lived fission products in the discharges; however, the occurrence and re-suspension of aerosols might increase the discharges of activation products. In addition, area sources are more likely to occur, whereas the potential for large emergency releases becomes unlikely [34].

the operational stage; however, extended area sources may emerge and should be considered. As the facility undergoes the transition to decommissioning, the monitoring programme should be reviewed and adapted to ensure that it still enables verification of compliance with the authorized discharge limits and criteria for external radiation levels as specified by the regulatory body.

5.32. During decommissioning, the selection of the sampling procedures and the characteristics of measurement instruments, such as sensitivity, should be adapted based on the characteristics of the possible new discharges and the likelihood of unplanned releases that would require prompt detection and notification.

Environmental monitoring

5.33. Environmental monitoring during the decommissioning of a facility might be similar to that for the operational stage but should be modified to take account of changes in the source term (e.g. radionuclides composition, magnitude of discharge, release rate) exposure pathways and representative persons. The necessary changes for the measurement of external dose rates and radionuclide activity concentrations in the environment should be considered and incorporated in the updated environmental monitoring programme.

Release from regulatory control

5.34. Prior to the release from regulatory control, monitoring should be conducted to verify compliance with the authorized end state criteria[15]. Recommendations for monitoring in this stage are provided in IAEA Safety Standards Series No. WS-G-5.1, Release of Sites from Regulatory Control on Termination of Practices [37].

PUBLIC DOSE ASSESSMENT FOR A PLANNED EXPOSURE SITUATION

5.35. The results of source monitoring and environmental monitoring should be used to confirm that the dose to the public due to radioactive discharges during normal operation comply with the appropriate dose limits and dose constraints.

5.36. The calculation of doses on the basis of the results of environmental monitoring should be used when sufficient results of measurements of the activity concentration of radionuclides

[15] End state criteria is predetermined criteria defining the point in which a specific task or process is to be considered completed. Used in relation to decommission activities as the final state of decommissioning of a facility [4].

in air, water and foods are available to avoid significant statistical uncertainties. In many cases, only some of the discharged radionuclides can be measured above the detection limits[16] in the relevant environmental media. The calculation of doses from the results of environmental monitoring should therefore be complemented with calculations made on the basis of the results of annual discharges derived from source monitoring combined with environmental models.

5.37. When possible, the models used for the prospective radiological impact assessment should be validated through a comparison of the results predicted by environmental models with the actual data from measurements. Data from environmental monitoring for the operational stage of a facility or activity can be used to verify compliance with discharge limits, dose limits and dose constraints, and also to confirm that the environmental models, assumptions, and parameters used in the prospective assessment are adequate [2].

5.38. Doses from external exposures should include, as relevant, the external irradiation from the source(s) within the facility and the external irradiation from radionuclides in an atmospheric plume or deposited on the ground. The assessment of doses from external irradiation from the source within the facility using direct dose rate measurments is straightforward, at least in principle. The radiation fields in its vicinity may be measured or calculated using simple radiation detectors. Additonal recommendations on dose assessment from monitoring results are provided in Section 9.

INTERPRETATION, REPORTING AND COMMUNICATION OF MONITORING RESULTS FOR A PLANNED EXPOSURE SITUATION

5.39. For planned exposure situations, source and environmental monitoring results should be used to verify compliance of the actual radiation conditions with regulatory limits by comparison with one or some of the following criteria:

— Discharge limits for the facility or activity;

— Environmental limits (as appropriate – see para. 5.42);

— Dose constraints for the facility or activity;

— Dose limits for members of the public.

[16] Both measurement results above the detection limit and measurement results below the detection limits could be used for dose assessment purposes. However, it should be noted that, in the cases when measurements are below the detection limits, the use of detection limits as substitutive values might substantially overestimate the estimated dose.

5.40. Discharge limits in authorizations granted to operating organizations are usually expressed as annual discharge limits; however, discharge limits for shorter periods may also be included. Reports from source monitoring programmes should include the discharge data in the periods specified to demonstrate that the discharges were within the respective authorized limits.

5.41. Discharge limits generally include a margin of flexibility to provide for operational variability and for anticipated operational occurrences [3]. Whenever discharge limits have been exceeded, the operating organization is required to report promptly to the regulatory body (see para. 3.137(d) of GSR Part 3 [1]). The report should also include the cicumstances of the release, the results of any additional monitoring and estimation of doses to the public from the event.

5.42. Authorizations may also include environmental limits, such as radiation levels at the site boundary or limits on the concentrations of radionuclides or categories of radionuclides in specific environmental compartments. Data from environmental monitoring should be used to ensure that actual radiation levels and radionuclide concentrations are below these limits.

5.43. Operating organizations should report promptly to the regulatory body a significant unexpected increase in environmental radiation fields or activity concentrations, or an unplanned release of a significant quantity of radionuclides. The report should include a description of the investigation that has been initiated, the preliminary results, the immediate actions that have been taken in relation to discharge operations (e.g. stopping batch discharges) and the actions that are anticipated for the immediate future (e.g. resuming discharge operations).

5.44. The operating organization is required to report the results of the monitoring programme for a facility or activity to the regulatory body (see para. 3.137(c) of GSR Part 3 [1]). This should include the results of dose assessments derived from the source monitoring or the environmental monitoring data and other data that are relevant to the dose assessment. A comparison with dose limits and dose constraints should also be presented. The analysis should discuss any trends observed by comparison with previous results.

6. MONITORING IN AN EMERGENCY EXPOSURE SITUATION

6.1. Monitoring during a nuclear or radiological emergency is a key tool to assess the impact on the public of an accidental release and assist in the implementation of protective actions to prevent or minimize the radiological consequences. For a nuclear or radiological emergency, the government is required to ensure the clear allocation of responsibilities (see Requirement 2 of GSR Part 7 [5]). This should include the responsibilities for monitoring in accordance with the possible radiological consequences of the accident.

6.2. In an emergency exposure situation, monitoring has two principal aims: to provide decision makers with timely and reliable information required for protection of the people, the environment and the property; and to facilitate dose assessment for the protection of the public and the environment.

6.3. Monitoring during an emergency may be undertaken by different organizations (e.g. the operating organization, the regulatory body, technical support organizations). The coordination between these organisations in relation to monitoring should be established to make the best use of resources available to deliver the most effective response. The different organizations with responsibilities for monitoring should establish mechanisms to ensure the sharing of monitoring data collected during the emergency.

6.4. The monitoring strategy for an emergency exposure situation should be developed at the preparedness stage as part of the protection strategy to protect the public and emergency workers, and to provide information necessary to make decisions on protective actions[17] and other response actions [5, 13, 38]. The monitoring strategy should be established on the basis of the hazard assessment that is the responsibility of the government (see Requirement 4 of GSR part 7 [5]).

6.5. Depending on the severity of a nuclear or radiological emergency, all three types of radiation monitoring — source monitoring, environmental monitoring and individual monitoring — could be performed, in accordance with a graded approach.

6.6. The monitoring strategy for an emergency exposure situation should take into account both national and transboundary impacts. States should establish national strategies to respond

[17] Protective actions may include on the site and off the site urgent protective actions, early protective actions and other response actions. Most of these actions are taken as a matter of urgency. Some of the actions involve more detailed assessment primary based on monitoring and can be taken within days or weeks [14]. For details on the requirements and recommendations on emergency planning and response see Refs [5, 14, 39, 40].

to a nuclear or radiological emergency that may occur in other States. Arrangements should be in place between potentially affected States to ensure appropriate exchange of information and, where necessary, coordination in the monitoring activities. The national strategy for monitoring should consider the establishment of a network of monitoring stations for early warning and follow the evolution of the environmental conditions at the regional scale.

RESPONSIBILITIES FOR MONITORING IN AN EMERGENCY EXPOSURE SITUATION

6.7. The government should ensure that a monitoring strategy for each type of emergency exposure situation has been developed at the preparedness stage. Each type of monitoring strategy should take account of the resources required to undertake monitoring and should stipulate priorities for the different phases of the emergency[18], in accordance with the protection strategy.

6.8. The regulatory body or other competent authorities[19] should ensure that arrangements for monitoring during an emergency are established by the operating organization and are routinely tested. This should include ensuring the capability for rapid monitoring under emergency conditions.

6.9. The operating organization should establish and maintain an adequate capability to carry out monitoring on the site and its vicinity for which a license is warranted, in accordance with an emergency plan approved by the regulatory body.

6.10. The government is required to ensure that there is coordination between all the organizations involved in emergency preparedness and response (see Requirement 22 of GSR Part 7 [5]). This should include identifying or establishing a governmental organization responsible for the coordination of all the monitoring activities involved in emergency preparedness and response.

6.11. The government should ensure that in the event of an emergency resulting in long term exposures due to residual radioactive material in the environment, where necessary, monitoring of the existing exposure situation will be maintained after the emergency has been declared terminated (see GSG-11 [14]). The government is required to ensure that responsibilities for

[18] GSG-11 [14] proposes a sequence of various phases of a nuclear or radiological emergency, as follows: Urgent response phase, with typical duration of hours to days after emergency onset; Early response phase, with typical duration of days to weeks after emergency onset; Transition phase with typical duration of days to year after emergency onset.

[19] Competent authority is "any body or authority designated or otherwise recognized as such for any purpose in connection with regulation". Although the term is generally applicable in the context of transport regulations, it is used here to indicate that in an emergency situation the responsible is not necessarily the regulatory body but could be any competent organization indicated by the government [4].

monitoring in the transition from the emergency exposure situation to the existing exposure situation are clearly assigned (see Requirement 46 of GSR Part 3 [1]).

OBJECTIVES FOR MONITORING IN EMERGENCY EXPOSURE SITUATIONS

6.12. The objectives of monitoring for the protection of the public and the environment in an emergency exposure situation are as follows:

(a) Guide decision makers on the need to take protective actions and other response actions mainly on the basis of defined operational criteria[20] (e.g. see Refs [39-41]);

(b) Assess doses and provide information for the protection of the public, emergency workers and helpers;

(c) Provide information on the radiological, physical and chemical characteristics of the radiological hazard;

(d) Confirm the efficiency of the protection strategy;

(e) Assist to identify individuals needing specialized medical care health screening or longer term medical follow-up;

(f) Provide technically correct information required to keep the public informed and maintain public trust;

(g) Facilitate the coordination of and consistency of national emergency arrangements with the relevant international emergency arrangements.

SOURCE MONITORING AND ENVIRONMENTAL MONITORING IN AN EMERGENCY EXPOSURE SITUATION

Source monitoring

6.13. Decisions regarding the urgent protective actions to be taken in the event of a nuclear or radiological emergency depend on the prevailing conditions at the facility or on the environmental monitoring. In addition, source monitoring should be conducted to provide information for emergency classification[21] and facilitate the assessment of the magnitude of

[20] GSR Part 7 [5] defines operational criteria as values of measurable quantities or observable conditions (i.e. observables) to be used in the response to a nuclear or radiological emergency in order to determine the need for appropriate protective actions and other response actions. Operational criteria include operational intervention levels (OILs) and emergency action levels (EALs).

[21] Emergency classification using monitoring data is based on emergency action levels (EALs).

hazard and possible development of conditions throughout a nuclear or radiological emergency in order to promptly initiate an effective response and revise the protection strategy, as appropriate. Source monitoring is also particularly helpful to obtain information for the estimation of the actual source term and to assist the implementation of environmental monitoring.

6.14. For facilities that might experience an accidental release that could warrant urgent protective actions, early protective actions or other response actions, a continuous or batch monitoring system, able to measure the potential range of activity concentrations, should be established at all potential release points, such as stacks and discharge points of radioactive liquid effluents. Additional technical information about source monitoring in emergency exposure situations is provided in Ref. [42].

6.15. The arrangements for source monitoring should consider that for certain accidents, further releases may occur through different locations (e.g. due to building leaks). For such cases, the source monitoring arrangements should include means to urgently deploy special monitoring equipment. In such cases, source terms can also be derived from other measurement devices on site or at the boundaries of the facility.

Environmental monitoring

6.16. Environmental monitoring should provide information on the need and extent of protective actions and other response actions, and facilitate the following:

(a) Calculation of the source;

(b) Assessment of doses to members of the public, facility operating personal, emergency workers and helpers;

(c) Assessment of risks of health effects and provide information to identify needs for individual monitoring;

(d) Confirm if the urgent protective actions implemented, such as evacuation, sheltering, relocation, iodine thyroid blocking, are appropriate.

6.17. Depending on the duration of the release[22] , environmental monitoring may include measurements of dose rates and the sampling of radionuclides from the plume to compare with

[22] In many cases the significant release will be over by the time results of environmental measurements are available; and could be difficult to take and analyze air concentrations in a sample in a timely manner [39].

operational criteria. Once the release has stopped and the radioactive plume has passed, monitoring should be directed to the measurement of deposited radionuclides (including dose rates from the ground) and food contamination, taking into account the pathways of radiation exposure. Additional technical information about environmental monitoring during and after the passage of the plume is provided in Ref. [42].

6.18. During and immediately after the onset of a nuclear or radiological emergency, dedicated monitoring resources could be insufficient, particularly in a severe nuclear accident. The available resources should be utilized as effectively and efficiently as possible, in a timely manner, by setting priorities. It might be necessary to request support from other organizations including those for which monitoring is not their normal responsibility. The monitoring strategy should anticipate such situations and, when necessary, include pre-signed agreements and training.

6.19. The effects of a protracted release of radioactive material on the available resources for emergency monitoring should be considered when developing the monitoring strategy. The environmental monitoring strategy should, as necessary, include arrangements for assistance from other organizations and other States, if deemed necessary.

6.20. For facilities that could warrant urgent protective actions or early protective actions and other response actions, environmental monitoring systems, consisting of fixed remote stations at designated locations and mobile resources for environmental monitoring under emergency conditions should be established and deployed in accordance with the provisions included in the emergency plan.

6.21. The arrangements for environmental monitoring should take into account that, large amounts of monitoring data — for example, dose rates, activity concentrations and deposition of radionuclides in relevant media — will need to be collected in an evolving situation, often over a large area, and that these data should be made available in a timely manner in order to compare them to operational criteria and to estimate doses to make prompt decisions about the implementation of appropriate protective actions.

Individual monitoring

6.22. Individual monitoring of the public may be considered appropriate in the context of an emergency exposure situation: if so, such monitoring should be appropriately justified and should focus on individuals that could have received doses close to or exceeding the generic

criteria for protective actions and other response actions to avoid or minimize severe deterministic effects or to reduce the risk of stochastic effects (see Appendix II of GSR Part 7 [5]). Individual monitoring should be conducted if deemed necessary to determine whether protective actions such as decontamination, medical care or follow-up is warranted. Individual monitoring may also be useful as a means of reassuring individuals and to verify the dose assessments that have been made [42].

6.23. In establishing the individual monitoring strategy, it should be considered that measurements of external exposure of members of the public are only technically feasible if the dose rate in the area significantly exceeds the natural background level, for example three times. Selected representative members of the public may be provided with individual dosimeters and receive instructions on their use.

6.24. Measurements of quantities of radionuclides incorporated or deposited on individuals should provide input for the assessment of the committed dose and may help to reassure members of the public, for example, who have been evacuated. Measurements of iodine isopotes in the thyroid, other gamma emitters (such as cobalt and caesium isotopes), beta emmiters (such as tritium and strontium-90) and alpha emitters (such as radium, uranium and plutonium isotopes) should be considered in accordance with the radiological characteristics of the emergency [23].

6.25. Results of individual monitoring and related information should be carefully managed since they contain personal information. Permission should be sought from each person before performing individual measurements, and the nature and purpose of the measurements, and the planned use and protection of the information obtained, should be explained to the persons that are monitored.

6.26. The arrangements for individual monitoring should take into account the urgency needed to detect short lived radionuclides, such as ^{131}I, in the body.

PUBLIC DOSE ASSESSMENT IN AN EMERGENCY EXPOSURE SITUATION

6.27. The doses to the members of the public and emergency workers may be derived from source monitoring, environmental monitoring or individual monitoring data, or from a

[23] The measurement procedure will depend on the emitter. Monitoring of radioiodine content in thyroid glands should be undertaken with an appropriately calibrated gamma detector. The direct measurement of other gamma emitting radionuclides may be made by whole body counters. The doses due to incorporated beta emitters are usually estimated by bioassay [38, 41].

combination of these. Data from monitoring should be combined with supporting information — such as data on meteorological and hydrological conditions — and appropriate environmental dispersion and transfer models, and dose coefficients [43], to assess doses to members of the public and emergency workers. Best available monitoring data should be considered when performing the dose assessment.

6.28. During an emergency careful consideration should be given to the methods and models selected to assess doses to members of the public. Models used for dose assessment from discharges in planned exposure situations might not be appropriate to estimate doses for emergency exposure situations.[24]

INTERPRETATION, REPORTING AND COMMUNICATION OF MONITORING RESULTS FOR AN EMERGENCY EXPOSURE SITUATION

6.29. Monitoring data should be interpreted and presented to the regulatory body and other governmental organizations in a way that facilitates well-informed decision making (e.g. tables, maps, indications of time evolution, appropriate and consistent units). The monitoring results and related analysis from different organizations (at local, national and international levels) conducting monitoring should be presented in a pre-arranged compatible format[25]. The regulatory body or other competent authority should establish the format, content and frequency of reporting the results by organizations conducting source and environmental monitoring activities in an emergency exposure situation. A centralized system to collect, maintain and share this information with different users, in accordance with pre-established agreements on the level of access, should be developed.

6.30. The government is required to ensure that arrangements are in place to provide the public with information that is necessary for their protection (see Requirement 10 of GSR part 7 [5]). This should include arrangements for the regulatory body to promptly provide the public with clear information based on the results of monitoring and additional analysis and interpretation. The information should include understandable interpretations in terms of health risks and advice on protective actions and other response actions. IAEA Safety Standards Series No. GSG-14, Arrangements for Public Communication in Preparedness and Response for a Nuclear or Radiological Emergency provides further recommendations [45].

[24] Models in planned exposure situations are designed to deal with steady state long-term conditions rather than the variable short-term dispersion that occurs in emergency situations.

[25] Information on the content and format of reports of measurement results for record keeping and information exchange is provided in Ref. [4].

6.31. When the results of monitoring programmes indicate that the information is relevant outside national boundaries, this information should be shared with the States concerned[26] [5]. The State where the emergency occurred should arrange with the States concerned the means for exchange of information and consultations, as appropriate [44].

[26] See the Early Notification Convention (https://www.iaea.org/topics/nuclear-safety-conventions/convention-early-notification-nuclear-accident).

7. MONITORING IN AN EXISTING EXPOSURE SITUATION

7.1. Monitoring programmes for the existing exposure situations addressed in this Safety Guide include those for sites with residual radioactive material as a result of past activities that were not subject to effective regulatory control, areas with residual contamination as a consequence of a nuclear or radiological emergency.

7.2. Monitoring in existing exposure situations primarily relates to verifying the radiological conditions and comparing these conditions with reference levels for existing exposure situations. The monitoring can also be used to identify areas in which further, more detailed radiation monitoring is needed.

7.3. A monitoring programme for an existing exposure situation should be justified, and the type and extent of the monitoring programme should take into account the characteristics of the affected area or site, the number of people exposed, and the access to the site or area, in order to focus efforts on the highest radiological hazard.

7.4. Monitoring should be performed to identify areas in which remedial actions may be necessary and to aid decisions concerning the justification of remedial actions. If a decision for remediation is made, monitoring should be performed to verify that remedial actions or protective actions have been optimized.

7.5. Monitoring should be undertaken prior to and during the remediation of an area, and where required by the regulatory body or other authority, as part of post-remediation control. The concept of clearance also applies to the management of material originating from remediation activities[27] and, as for in planned exposure situations (see para. 5.4), for cleared materials there are no further requirements for monitoring.

RESPONSIBILITIES FOR MONITORING IN EXISTING EXPOSURE SITUATIONS

7.6. The government is required to ensure that responsibilities to assess and manage existing exposure situations that have been identified are assigned (see para. 5.2 of GSR Part 3 [1]). This should include the responsibilities for monitoring. The identification of the responsible party in

[27] The same qualitative and quantitative criteria as for clearance of materials from planned exposure situations apply to the management of material originating from remediation activities. GSG-18 [31] provides recommendations on the application of the screening values for recycling or disposal of materials and waste generated during remediation actions after a nuclear or radiological emergency. GSG-15 provides [16] recommendations on the management of residual materials generated during remediation.

an existing exposure situation is not always straightforward[28]. In cases where it is not possible to identify a responsible party, the responsibility should remain with the government.

7.7. Where an existing exposure situation results from a practice where the operating organization has been identified, this organization should have the responsibility to assess and manage that situation, including performing the appropriate monitoring. Where an existing exposure situation has been identified where there is no current responsible party, the government should assign a responsible body to ensure that the public and the environment are protected, including responsibilities for monitoring, as necessary.

7.8. In relation to monitoring of areas with residual radioactive material, the responsible party should undertake the following actions, as relevant:

(a) Obtain data and conclusions from preliminary studies where available;

(b) Conduct detailed monitoring for radiological evaluation of the area[29].

In the case where remedial actions have been justified, the following actions should be undertaken by the responsible party:

(c) Conduct characterization and monitoring to provide basic information for the purposes of developing a remediation strategy, planning the remediation programme and identifying appropriate remedial actions.

(d) Conduct monitoring throughout the implementation of the remediation plan.

(e) Conduct monitoring and verification of the effectiveness of the remediation by comparing source monitoring and environmental monitoring data with the results of the quantitative site model (see para 7.31(r) of GSG-15 [16]).

(f) Keep records of all the results from the monitoring programmes, including after the completion of the remedial actions.

7.9. The regulatory body should review monitoring programmes and perform confirmatory monitoring, as appropriate (see para 2.33(c) and 2.34(j) of GSG-15 [16].

[28] For sites with residual radioactivity, the responsible party may be the organization with responsibility for planning and implementing the remediation [16].

[29] This might include characterization of the local environment, including compilation of meteorological data for the area of interest, surveys of ambient radiation levels, and sampling and analysis of soil, groundwater, surface water and sediment, as appropriate [16].

OBJECTIVES FOR MONITORING IN EXISTING EXPOSURE SITUATIONS

7.10. The objectives of a monitoring programme for the radiological protection of the public and the environment in an existing exposure situation related to areas with residual radioactive material should include the following:

(a) To evaluate the radiological conditions and to provide information for estimating doses to members of the public.

(b) To compare with the reference levels and other radiological criteria and to identify areas where more detailed radiation monitoring is needed.

(c) To identify areas in which remedial actions or protective actions are justified;

(d) To support identification and justification of appropriate remedial actions, and as appropriate, other protective actions;

(a) To evaluate and verify the effectiveness of remedial actions, and as relevant, other protective actions;

(e) To detect changes and evaluate long term trends in radiological conditions in the environment as a result of natural processes and human activities, including remedial actions;

(f) To provide information to build trust with and for the reassurance of interested parties, including local communities and members of the public.

(b) To provide information to support decisions related to release of contaminated land from regulatory control and application of restrictions and institutional controls, as relevant[30].

The objectives of monitoring might be different at the various phases of remediation, as defined in GSG-15 [16].

[30] Considerations for environmental survey, surveillance and monitoring related to the release of remediated areas from regulatory control are provided in Ref. [16], including conditions for restricted and unrestricted release.

SOURCE MONITORING AND ENVIRONMENTAL MONITORING IN AN EXISTING EXPOSURE SITUATION

Source monitoring

7.11. In many existing exposure situations, the source is the radioactive contamination being evaluated and can be spread across a large area. Source monitoring in such situations can be similar to environmental monitoring.

7.12. Monitoring should assist in the delineation of areas requiring evaluation or remediation. Within the source area, the monitoring could include sampling and analysis to support the estimation of the migration of the contaminant outside the source area, as action might be needed to control such migration [16].

Environmental monitoring

7.13. Information on the radioactive contamination is essential to develop an environmental monitoring programme for areas with residual radioactive material. Where information is available on the source, the monitoring programme should consider that information. Where information about the source term is absent, or such information is insufficient and needs to be supplemented, historical records and local surveys could be considered to inform the design of an initial screening programme.

7.14. To develop an effective environmental monitoring programme for sites or areas with residual radioactive material, the most significant exposure pathways should be characterized to identify whether or not they are likely to evolve rapidly. Changes in exposure pathways, for example, in cases where remedial actions alter the structure of the environment are taken (e.g. remedial actions involving tree removal, excavation, blasting, diversion of water courses) or where groundwater contamination reaches surface waters, should be taken into account in the monitoring programmes. A periodic evaluation of the monitoring programme may be needed to verify that the exposure pathways and magnitude of the risks have not changed.

7.15. Areas with residual radioactive material could involve sites with multiple contaminants (such as chemicals and biological). In these cases, coordination with other competent authorities should be considered to obtain a common understanding of the situation and harmonize monitoring activities.

7.16. In those areas where a remediation programme has been conducted, the effectiveness of the remediation actions should be verified by environmental monitoring and a programme for monitoring and surveillance should continue after remediation has finished, as necessary.

External exposure

7.17. Where large areas are required to be evaluated, large-scale measurements of external dose rates should be considered. Ideally, different monitoring methods should be used in parallel, in accordance with the level of radiological contamination to provide comprehensive information on the situation. For example, aerial monitoring can be used to cover wide areas in a short time; measurements at fixed locations or walking surveys can provide a more precise measurement of dose rates at specific locations. All the data obtained using different methods should be integrated to provide a complete picture of the contamination.

7.18. In areas where the contamination is uneven, dose rates can vary greatly from one location to another. The monitoring programme should take into account the non-uniform distributions of radionuclides across the area monitored, seasonal changes in the dose rate due to weather conditions (e.g. snow cover or precipitations) and the reduction of dose rates in urban environment due to paved areas and to shielding provided by the buildings.

Internal exposure

7.19. In areas with residual radioactive material, the inhalation of resuspended radionuclides from the ground can cause a significant exposure. In these cases, sampling and analysis of airborne radionuclides should be regularly performed. Measurements should also be taken to determine the amount of dust generated by wind or by human activities, such as agricultural activities or traffic. If measurement data are unavailable or insufficient, radionuclide concentrations in air can be estimated from concentrations in soil by using a resuspension model. In areas with significant existing contamination, resuspension of radionuclides, such us those due to wild fires should be considered. In the case of areas contaminated with NORM, public exposure to radon indoors can be an exposure pathway of concern and should also be considered. Ref. [21] addresses the protection of the public against exposure indoors due to radon.

7.20. If the radioactively contaminated area extends to agricultural land, samples of all major animal products and crops grown in the area should be regularly collected and analyzed for their radionuclide concentrations (e.g. vegetables and milk and meat). The environmental

monitoring should also include wild food products (game, mushrooms and berries) from the contaminated area, if it is known that these foods are typically consumed. Drinking water should also be monitored if a source of drinking water is present in the contaminated area. Further information on the assessment of public health risks from radionuclides in drinking water is provided in Ref. [47]. Further guidance on monitoring of radionuclides in the diet is given in Ref. [18] and in Safety Reports Series No. 114, Exposure due to Radionuclides in Food Other Than During a Nuclear or Radiological Emergency. Part 1: Technical Material [48]. Activity concentrations of radionuclides in soil and sediments could also be monitored to estimate the migration and accumulation of radionuclides in these environmental media, which could be used to predict radionuclide concentrations in food products. The design of the environmental monitoring programme should ensure that important routes of radionuclide migration are considered, such as migration of radioactivity through the soil, groundwater or biomass.

7.21. In areas with significant radioactive contamination, particularly naturally occurring radionuclides, radionuclide activity concentrations in environmental matrices should be measured at an adequate sampling frequency to establish whether the activity concentrations comply with the reference levels established for the existing exposure situation (see paras 5.2, 5.4, 5.8 and 5.9 of GSR Part 3 [1]).

PUBLIC DOSE ASSESSMENT IN AN EXISTING EXPOSURE SITUATION

7.22. For normal discharges, the doses calculated for representative persons are often conservative. In contrast, the doses for representative persons in existing exposure situations should be defined on the basis of realistic habits so as to provide realistic dose assessments that can be used as a basis for making decisions on protective actions and remedial actions and to ensure an appropriate allocation of resources. In particular, where the purpose of the dose assessment is to determine if remedial actions are justified, the doses to the representative person should be estimated avoiding overconservative assumptions. In sites with highly heterogenous contamination, the dose assessment could also consider potential exposures[31].

[31] Sometimes, the estimated doses resulting from contaminated areas may be low when the decision to manage the situation is taken. Nevertheless, depending on the situation, potential transport and special characteristics of the source (for example, in cases of heterogeneous contamination, such as discrete particles) could lead in the future to higher exposures. These exposures are not certain to occur, so they are called 'potential exposures'. These potential exposures from contaminated areas should be assessed to define an appropriate remediation process. It is important in these cases to identify the potential exposure pathways and to determine the probability of exposures that could occur.

7.23. When transfer factors and concentration factors are selected, they should preferably be site specific and appropriate to the local food pathways and environmental conditions, including the soil type, soil chemistry, and the mineral content of fresh water [49].

7.24. The local food consumption rates and fractions should preferably be obtained by means of site specific studies. The effects of water treatment and food processing on reducing radionuclide concentrations should be considered in estimating the dietary intakes. Additonal recommendations on undertaking dose assessment from monitoring results are provided in Section 9.

INTERPRETATION, REPORTING AND COMMUNICATION OF MONITORING RESULTS FOR AN EXISTING EXPOSURE SITUATION

7.25. The monitoring results should be compared to relevant radiological criteria for the existing exposure situation. The estimated dose to the representative person should be compared to the reference level established for the existing exposure situation. In all such comparisons, uncertainties in sampling, measurements and calculations should be taken into account.

7.26. For practicality, derived criteria[32] that correspond to the relevant dose criteria and that can be easily measured (e.g. activity per unit area, per unit weight or per unit volume; gamma dose rates at 1 m height for a defined surface) may be established when deemed necessary [16].

7.27. Reports of the results of the source monitoring and environmental monitoring programmes should be produced at periodic intervals by the responsible party to monitor the evolution of radiological conditions and, in situations when remediation was justified and implemented, to verify the effectiveness of the of remedial actions. These reports should describe the monitoring results and the associated dose assessment to inform conclusions with respect to protective actions or remedial actions, as appropriate.

7.28. Estimated doses to the public after remediation has been completed should be compared to reference levels or other relevant end-point criteria in the approved remediation plan to determine if additional actions to restrict public exposure are necessary, and to demonstrate if land can be released from regulatory oversight.

[32] The term ‘derived criteria’ is related to the concept of ‘derived reference levels’ established in Ref. [46]. A derived reference level is “a numerical value expressed in an operational or measurable quantity, corresponding to the reference level set in dose”.

8. DESIGN AND IMPLEMENTATION OF A MONITORING PROGRAMME

DESIGN OF A MONITORING PROGRAMME

8.1. A monitoring programme should be designed using a systematic approach. The characteristics of the exposure situation (planned, existing or emergency), and the aspects of relevance that may impact the monitoring activities, including prior knowledge of the site and background monitoring data[33], should be taken into account.

8.2. The radiation monitoring programme should follow a graded approach and the types of monitoring should be appropriate to the expected level of anticipated risk associated with the source based on the likelihood of exposure and possible radiological consequences to the public[34] [2, 16] and the environment. Table 2 summarizes the relationship between the types of exposure situation and the types of radiation monitoring required.

TABLE 2. TYPES OF MONITORING RECOMMENDED FOR DIFFERENT EXPOSURE SITUATIONS

Exposure situation		Type of monitoring		
		Source monitoring	Environmental monitoring	Individual monitoring
Planned	Exempted or cleared	Not required	Not required	Not required
	Registered practices/sources	Required	Not required	Not required
	Licensed practices/sources	Required	Required	Not required
	Multiple sources	Required	Required	Not required
Emergency		Required	Required	As appropriate
Existing	Areas with residual radioactive material	Required	Required	Not required

8.3. Although the objectives of a monitoring programme are expected to vary between planned exposure situations, emergency exposure situations and existing exposure situations, in all cases, monitoring should provide information and data for assessing the radiological impact to the public and the environment. The following elements should be taken into account in the design of any monitoring programme:

[33] Background monitoring is the investigation done to establish baseline levels of radiations and/or radionuclides concentration to be compared against subsequent conditions.

[34] In all exposure situations, conceptual and quantitative site models need to be developed, as relevant, to provide an understanding of important radionuclides and pathways of exposure [2, 16].

(a) Radioactive inventory and radionuclide composition of the source.

(b) Spatial and temporal characteristics of the radiation fields around the source.

(c) Release rates.

(d) Exposure pathways[35]. Figure 1 illustrates the pathways by which an individual may be exposed following the discharge of radionuclides to the atmosphere and the surface water or groundwater, respectively.

(e) Possible contributions from other surrounding facilities or activities to environmental radioactivity.

(f) Geographic characteristics at the site, presence and characteristics of receptors (e.g. demography, living habits and conditions, flora and fauna), and the uses of the land;

(g) Significance of the calculated dose(s) to the representative person(s);

(h) Longevity of the contamination creating radiological risks.

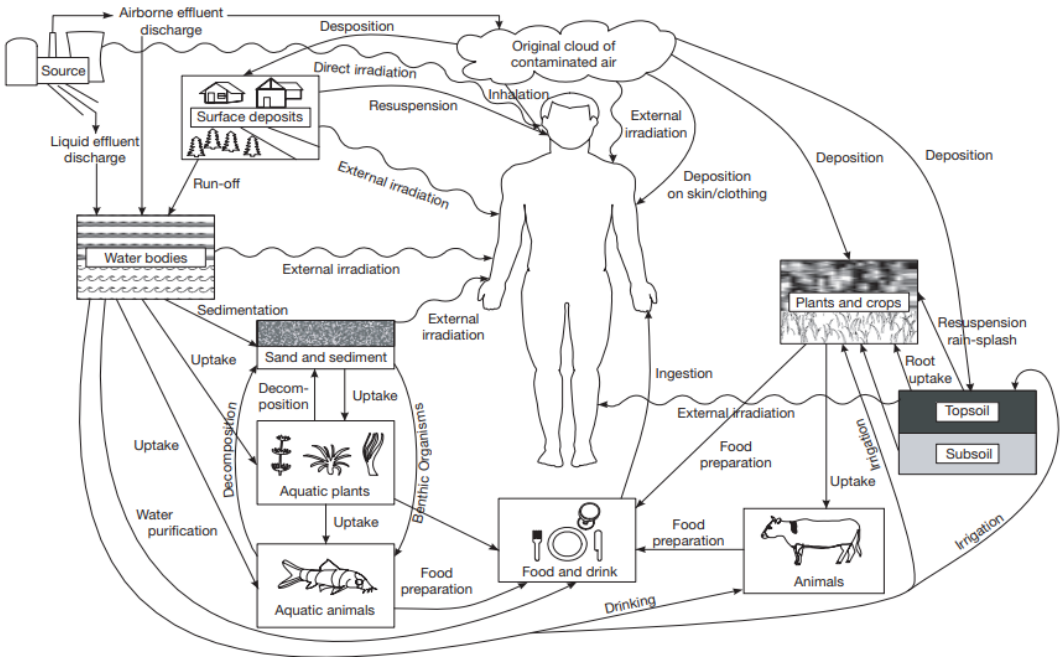

FIG. 1. The possible pathways of exposure for members of the public as a result of releases of radioactive material to the environment.

[35] Exposure pathways by which releases could give rise to exposure of members of the public are listed in GSG-10 [2]. Depending on the exposure scenarios and the site characteristics, not all the exposure pathways listed in GSG-10 [2] may need to be considered in the design of the monitoring programme. Therefore, some exposure pathways may be excluded from the design of the monitoring programme on the grounds that the doses associated with them are evaluated to be non-existent or negligible.

8.4. Information on the characteristics of the radioactive source(s) (in planned exposure situations), potential accidental radioactive releases (in emergency exposure situations), and historical information on the source (in existing exposure situations) should be obtained and considered in the design of monitoring programmes.

8.5. The scale and extent of monitoring programmes should take into account the information from safety assessments[36] (for planned exposure situations) and also from the hazard assessment (for emergency exposure situations) which can assist in defining the areas of the environment potentially impacted, the radionuclides involved, and the dose to the representative person in each area. This helps to ensure that the design of the monitoring programme is commensurate with the level of risk.

8.6. The characteristics of the monitoring programme (for example, the frequency of the collection of samples) should consider the expected seasonal variations in the environmental matrices and the resulting variation in the associated exposure. Non-homogeneous distribution of radionuclides should also be considered. Non-normal distribution of monitoring data should trigger a review of the sampling frequency. Further recommendations on the design of monitoring programmes for planned, emergency and existing exposure situations are presented in Sections 5, 6 and 7, respectively.

Design of source monitoring programmes

8.7. Source monitoring programmes should be designed to monitor a particular source of radiation or the release of radionuclides arising from a facility or activity.

8.8. The characteristics of the source and the mode of any release into the environment should be considered in the design of a monitoring programme. For example, in planned exposure situations, airborne effluents are often discharged continuously; in contrast, liquid effluents might be stored and subsequently discharged from tanks in batches. In the case of emergency exposure situations, in which a loss of control of the source may result in an unplanned and uncontrolled release of radioactive material to the environment, direct monitoring of the source may be difficult (or even impossible) and the magnitude of the release may have to be estimated by using measurements in the environment. Source monitoring in

[36] The safety assessment can assist in defining the extent of the impacted area in which monitoring should be conducted in a planned exposure situation. For emergency exposure situations, the hazard assessment can provide information to define the area to be monitored. For existing exposure situations, the characterization can provide such information.

areas with residual radioactive material should take into account that the source of radiation can either be a local source or be diffused over a large area in the environment, uniformly or heterogeneously.

8.9. Additional supporting information that should be considered in the design of a source monitoring programme includes information on the chemical form (i.e. which can affect the migration of radionuclides), temperature and flow rates of the release, as well as meteorological and hydrological data and information on the receiving environment.

Design of environmental monitoring programmes

8.10. Environmental monitoring programmes should take into account features of the environment to be monitored, such as the characteristics of the site that might affect the dispersion of radionuclides in the environment (e.g. geology, hydrology, meteorology, morphology, biophysical characteristics), as well as demography, living habits and conditions, land use and other activities, including agriculture, food production and other industries.

8.11. When monitoring of external radiation levels in inhabited areas is performed, the dose rate should be measured in typical areas that are accessible to the public, such as dwellings, public buildings, production areas, gardens and recreation areas (e.g. beaches, parks).

8.12. When designing the monitoring programme, the shielding provided by buildings[37] in the area contaminated with radioactivity should be taken into account and detailed data on dose rates in living environments should be considered, wherever possible, for the accurate assessment of the external dose to the public. This could be achieved by measuring dose rates both outside and inside dwellings, giving special attention to those individuals who, because of their habits may receive the highest dose.

8.13. The results of the environmental monitoring programme should enable the verification of the predicted doses to the public (and, as necessary, exposures to flora and fauna) using dispersion models and data from source monitoring. For this purpose, environmental samples should be taken, and measurements of the radionuclides that are expected to provide significant contributions to doses should be made at a number of locations selected on the basis of the dispersion pattern of the discharges and on the relevant exposure pathways. In addition, the

[37] Shielding is relevant for radiation from anthropogenic sources, while the natural background can be different in- and outdoors. In some cases, for example, dose rates indoors due to building materials may become higher than outdoors.

sampling of food products should be determined on the basis of knowledge of the habits and consumption patterns of the representative person.

Design of individual monitoring programmes for the public

8.14. Individual monitoring for members of the public may be appropriate in certain emergency exposure situations (see paras 6.22–6.27). When properly justified, individual monitoring for internal exposure may include measurements of radionuclides in individual organs or in the whole body using in-vivo or in-vitro bioassay techniques and analysis . Individual monitoring for external exposure should be based on measurements using individual dosimeters.

INFORMATION TO SUPPORT THE DESIGN OF A MONITORING PROGRAMME

8.15. Baseline monitoring data and data from control measurements, as appropriate, should be collected over a period as deemed necessary by the regulatory body or other relevant authority to enable the understanding of spatial and temporal trends (e.g. over at least two years). The information should be documented and should be updated as necessary if changes due to other sources affecting the area under consideration (e.g. other facilities and activities or accidental releases) are expected.

8.16. For planned exposure situations and existing exposure situations, the hydrological characteristics[38] of the aquatic environment and the meteorological characteristics of the atmosphere into which radionuclides are expected to be released should be monitored in the pre-operational stage (or during characterization studies) and periodically verified in the operational stage and while the exposure situation remains. For emergency exposure situations, studies performed in the operational stage should be used to identify the general characteristics of the environment that might affect accidental releases and which should be considered in the monitoring programme.

8.17. The local water cycle should be monitored: precipitation and evaporation, local surface waters and groundwaters and their connections, and inputs and outputs by main rivers. Characteristics of soils such as texture, structure, porosity, chemistry and colour should also be

[38] Examples of hydrological characteristics that might be considered in monitoring programmes are water fluxes, water depths, turbulence and other features that affect the mixing of radioactive releases in the receiving environment, including seasonal and inter-annual variations.

studied to predict any spatial and temporal changes in the radionuclide transfer and migration through the soil.

8.18. Environmental monitoring programmes should take account of the distribution and habits of the population in the vicinity of the site or area, and other factors that may be relevant to estimate doses, such as age distribution, food consumption rates and the fractions locally obtained, location of drinking water sources, and human activities. Land and water use, such as local practices of agriculture, and aquaculture should be considered as well as agricultural practices. Particular attention should be paid to the characteristics of ethnic and cultural minorities and indigenous peoples that may reside in the area.

8.19. In an emergency exposure situation, knowledge of the meteorological and, in some scenarios, the hydrological conditions that might be present during a radioactive release are essential to estimate or predict the dispersion of radionuclides. Parameters such as the wind speed, wind direction, stability of the mixing layer of the atmosphere and magnitude and extent of any precipitation should be measured in the event of an airborne release: this type of information is useful to predict the dispersion of radionuclides and to understand the extent of potential future impacts.

CONTENT OF A MONITORING PROGRAMME

8.20. Monitoring programmes should describe the basis for their design including the rationale for the matrices to be sampled, sampling locations, sampling strategy and analytical methods. The monitoring programme should include the specification of the following:

(a) Parameters to be measured;

(b) Environmental media to be monitored (in case of environmental monitoring);

(c) Locations of in-situ measurements and sampling;

(d) Frequency and timing of the measurements or sample collections;

(e) Sampling procedures, sample preservation, sample pre-treatment and sample analysis techniques;

(f) Equipment used;

(g) The personnel responsible for each task;

(h) Quality assurance procedures.

8.21. The monitoring programme should also provide information on procedures for managing and interpreting the data, assessing data quality, and reporting the results. It should include a process for ongoing programme evaluation, a process to revise and modify the monitoring programme as needed, and a process for ensuring qualifications and training of personnel.

TECHNICAL CONDITIONS FOR MONITORING PROCEDURES

Sample collection

8.22. Source monitoring and environmental monitoring should be aimed at obtaining representative values. Representativeness in this context means that the sample should reflect the conditions of the source or the environment from which it is taken. In general, activity levels in discharges or in the environment are subject to spatial and temporal variability and the sampling procedures should be formulated to consider such variabilities [50].

8.23. The sampling frequency should be established based on the quantity that is to be measured, the precision that is needed, the time dependence and the variability of the quantity to be measured[39]. In general, sampling should be more frequent for monitoring with increasing spatial and temporal variability, for example the monitoring for radionuclides with short half-lives and monitoring of food with a short time lapse between harvesting and consumption.

8.24. To provide for representative sampling in the environment, various methods could be used. Specific procedures are suggested in Ref. [51]. Although these procedures might not eliminate the uncertainty associated with activity levels in environmental samples, they may reduce the uncertainty and enable it to be quantified by statistical means. Table 3 summarizes the main sampling approaches [51] and their features.

TABLE 3. SAMPLING APPROACHES FOR ENVIRONMENTAL MONITORING [51]

Sampling Approach	Description	Comment
Judgmental sampling	Sample is taken based on the understanding of the environment and exposure pathways	Increased probability of biased sampling; representativeness cannot be quantified
Simple random sampling	Any sample has the same probability of being included	Provides samples that are representative of the sampling area;

[39] Data on variability in the discharges from planned exposure situations can be obtained from the facility safety assessment report or operating information, data on environmental variability can be obtained from prior studies, including pre-operational and early operational monitoring.

		problems might arise if the area is not homogeneous
Stratified sampling	The sampling area is divided into parts (strata) that are known to be more homogeneous; simple random sampling is then applied to the strata	Requires knowledge of the inhomogeneity of the sampling area; might lead to bias if the strata are not properly estimated
Systematic sampling	Starting from a randomly selected point, sampling follows a strict predefined sampling grid	In comparison with random sampling, easier to implement in practice; spatial pattern, spatial trends or correlation ranges of contamination data might be unnoticed

8.25. Sampling procedures should be developed to ensure that each sample is representative of the sampled medium, collected samples are spatially independent, the sampling procedure is reproducible, and that sample integrity is maintained. Procedures should be included for addressing the quality assurance in sampling and analysis of uncertainties originated from sampling in reported results (e.g. split samples, field replicates, field blanks), and for proper sample tracking through a 'chain-of-custody' process. Technical considerations for sampling that might apply to facilities in planned exposure situations are presented in the annex.

Measurements

8.26. As part of monitoring programmes, measurements may be performed at the source, in the environment and in laboratories. Monitoring at the source can be performed through on-line monitoring or sampling and laboratory measurements. On-line monitoring should provide a continuous indication of the activity of radionuclides in the discharge in real time or near real time and typically involves the measurements of dose rate or gross activity. Continuous flow measurement should be performed to estimate the release rates of significant radionuclides. Procedures for continuous measurement systems should include a regular schedule for instrument calibration and maintenance, as well as performance checks on the analysis systems.

8.27. Field measurements may include measurements performed in-situ by gamma spectrometry; measurements of aerosols or gases at fixed monitoring stations with or without gamma spectrometry capabilities; measurements with alpha and beta monitors; measurements of dose rates; and surface contamination. Field measurement procedures should be established and validated to ensure that they are reproducible and representative of conditions at the time of sampling.

8.28. Measurements of samples in laboratories should be used to characterize the activity concentration of radionuclides in the source and the environment. For the assessment of individual doses, dosimetry laboratories should assess individual dosimeters and/or bioassay samples (see Table 4).

8.29. If monitoring data are used to verify compliance with a dose limit or a dose constraint, or compared to an operational limit or reference level, the minimum detectable activity of the analytical procedure and equipment should be selected so as to enable measurements to be made at levels that are substantially lower than the limits or levels against which the results are to be compared. This could, for example, involve collecting a statistically significant number of samples, improving measurement statistics and/or increasing counting times. The contribution of multiple radionuclides to the total dose to the public should also be considered in the determination of a fit-for-purpose detection limit.

8.30. The equipment to be used for measurements should be selected taking into account the purpose for which it is to be used. In particular, it should take into account the specific radionuclides that might be released from a facility, both in normal operation and in accident conditions. For example, nuclear power plants may discharge a large number of radionuclides with half-lives ranging from seconds to thousands of years, whereas fuel fabrication facilities discharge a much narrower range of radionuclides with no short lived radionuclides.

8.31. Table 4 presents examples of monitoring parameters and their respective sampling and measurement techniques that should be considered for different types of monitoring. Technical considerations for measurements that might apply to facilities in normal operation are presented in the annex.

TABLE 4. EXAMPLES OF MONITORING PARAMETERS AND APPROACHES TO SAMPLING OR MEASUREMENT

Monitoring Parameter	**Sampling/Measurement**
	Source monitoring
External dose rate at the source [a]	Stationary on-line equipment, continuous measurement
Radionuclide activity concentrations of gases in released air	Stationary on-line equipment, continuous measurement
Radionuclide activity concentrations of aerosols in released air [b]	Stationary on-line equipment and/or aerosol filter sampling; continuous measurement and analysis for specific radionuclides and/or total alpha or total beta
Radionuclide activity concentrations in released water [b]	Stationary on-line equipment and/or sampling; continuous measurement and analysis for specific radionuclides and/or total alpha or total beta

Monitoring Parameter	Sampling/Measurement
	Environmental monitoring
External dose rate over ground [c]	Mobile or stationary equipment; discrete or continuous measurement
Radionuclide activity concentrations of aerosols in air above ground	Discrete or continuous air filter sampling; analysis for specific radionuclides
Radioiodine activity concentration in air	Discrete or continuous air filter sampling; activated charcoal filters
Radionuclide activity concentrations in dry/wet deposition	Planchette sampling; collector for dry/wet deposition; analysis for specific radionuclides
Radionuclide activity concentrations in soil	Surface soil sampling; analysis for specific radionuclides and/or in-situ gamma spectrometry
	Vertical soil sampling at specified depths; analysis for specific radionuclides
Radionuclide activity concentrations in food and feed, biota, water, sediment	Field sampling; analysis for specific radionuclides
Surface contamination	Mobile equipment; discrete measurements by surface contamination monitors and/or in-situ gamma spectrometry
	Individual monitoring
Radionuclide activity concentrations in human organ or body	In-vivo or in-vitro bioassay; analysis for specific radionuclides
External dose	Individual dosimeters

[a] External dose could result from different penetrating radiations, such as photons, neutrons and high-energy charged particles.

[b] If discharge limits are for gross alpha/beta activity, then routine analysis for specific radionuclides might not be necessary.

[c] Typically measured 1 m above ground

QUALITY ASSURANCE

8.32. A quality assurance programme as part of the management system [52] should be an integral part of monitoring programmes for protection of the public and the environment. Quality assurance should be used to provide for a consistent approach to all activities affecting quality, including, where appropriate, verification that each task has met its objectives and that any necessary corrective actions have been implemented.

8.33. An adequate quality assurance programme should be designed to satisfy as a minimum the general requirements established by the regulatory body for quality assurance in the field of radiation protection. Generally, the quality assurance programme should be designed to ensure that:

(a) The organizational structure, functional responsibilities, levels of authority and interfaces for those managing, performing and assessing the adequacy of work are defined;

(b) All measures to manage the monitoring programme, including planning, scheduling and resource considerations, are implemented;

(c) Work processes and procedures are established and understood;

(d) Regulatory requirements relating to source monitoring, environmental monitoring and individual monitoring are met;

(e) Appropriate methods of sampling and measurement are used;

(f) Selection of environmental media, the locations for sampling and measurement and the associated sampling frequency are appropriate;

(g) Interlaboratory comparisons at the national or international level for methods and instruments are in place;

(h) Quality control mechanisms and procedures for reviewing and assessing the overall effectiveness of the monitoring programme are in place.

8.34. The quality assurance programme should cover:

(a) The design and implementation of monitoring programmes, including the selection of suitable equipment, sampling locations and procedures, and their documentation;

(b) The maintenance, testing and calibration of equipment and instruments;

(e) The uncertainty analysis;

(f) The requirements for record keeping;

(g) The qualification and training of personnel, including the necessary theoretical knowledge, the relevant legislation and regulations, and the appropriate technological tools to perfom tasks related to the monitoring programme.

8.35. Analytical laboratories performing sample measurements should be qualified to make the measurements assigned and have the capacity to report the results within the specified time and budget.

Data quality

8.36. Data should be of sufficient quality to meet the objectives of the monitoring programme and the specific purpose of the measurement. Data quality should be evaluated against

predefined data quality objectives[40], as specified in the programme design. These objectives might include detection limits, or limits on precision and accuracy as determined from results for associated quality control samples such as blanks, duplicates, certified reference materials, if available, and matrix spikes.

PROGRAMME EVALUATION AND REVIEW

8.37. Monitoring programmes should be evaluated and reviewed regularly to ensure that they are producing data that are sufficient to meet the objectives of the programme and that no significant routes of discharge or environmental transfer or no significant exposure pathways have been overlooked. If this is the case, causes should be identified, and changes in the monitoring programme should be implemented.

8.38. The monitoring objectives may change over the lifetime of a facility in planned exposure situations or as an emergency exposure situation or an existing exposure situation evolves, and the monitoring programmes should also change to reflect these modifications.

8.39. If significant changes occur in operational conditions, environmental conditions, or regulatory requirements, which may have an impact on the monitoring programmes, these changes should trigger their reevaluation and review. Any changes made to the monitoring programme should be documented to provide a record of decisions and evidence it continues to be fit for purpose.

[40] Data quality objectives are a set of programme performance or data acceptance criteria used to evaluate the quality of a set of data or of individual data values. Data quality objectives might include targets for detection limits, precision, and accuracy of measurement [50]. Quality control samples (such as blanks, duplicates and matrix spikes) and external quality control (such as intercomparison, participation in proficiency tests) should be included in the monitoring programme and used to assess whether the data meet pre-determined data quality objectives.

9. DATA MANAGEMENT, ANALYSIS, INTERPRETATION AND REPORTING OF MONITORING RESULTS

DATA MANAGEMENT FOR MONITORING PROGRAMMES

9.1. A data management system should be established to ensure the integrity of the monitoring data, to facilitate assessment of data quality, the interpretation of results and traceability of data over time (e.g see Ref. [53]). Measured values should be recorded with their units, including an indication of fresh or dry weight for mass-based measurements[41].

9.2. Detailed records of the measurements of radiation dose rates, measurements of radionuclide activity concentrations in gaseous and liquid releases and measurements of other physical and chemical parameters or quantities that are correlated with the radionuclide measurements should be retained. Metadata to be recorded should be based on the specific requirements of the monitoring programme and should include locations and times of measurements and sampling; discharge points, sampling periods, radioanalytical procedures and instruments used, instrument calibration data, and measurement uncertainties.

9.3. The data recorded should also include information on the data quality that are associated with the sample, such as detection limits, data for blanks, duplicates, matrix spikes, instrument calibration data, background counts for background correction and results of intercomparisons.

9.4. To allow auditing of the monitoring data, records should be kept of all relevant intermediate observations in the course of the analysis and of the parameters used for the calculation of the data reported. Records should also be kept of any investigations concerning unusual environmental occurrences.

DATA ANALYSIS AND INTERPRETATION

9.5. Data analysis and interpretation should be consistent with the objectives that were specified in the programme design. The data analysis might include, for example, comparison of individual results (or calculated means values) with relevant criteria, comparison of mean values between affected areas and other areas (e.g. areas used for control measurements), or evaluation of trends for temporal and spatial variations.

[41] In bulk soil sediments, units are typically on a dry mass basis, whereas for food, units are typically on a fresh mass basis. For these media, moisture content is a useful measurement, which enables data conversion from one mass basis to another. In cases where samples are incinerated, the dry mass-to-ash mass conversion coefficient is also useful to convert data from one mass basis to another.

9.6. A preliminary evaluation should be undertaken to ensure that the data are suitable for the planned data analysis. Graphical presentations of data are also useful for identification of outlier values. An investigation of the quality of data not meeting expectations should also be performed[42].

Data interpretation

9.7. The results of a monitoring programme, whether for source, environmental and/or individual monitoring, should be presented in terms of the following:

(a) Radiation levels at the source of the release, and activity concentrations of radionuclides in the release;

(b) Radiation levels in the environment and activity concentrations of radionuclides in environmental media;

(c) The doses received by the public derived from a dose assessment based on the measurement data, such as the annual doses received by the representative person living in the vicinity of a nuclear facility from routine discharges, or the projected doses received by individuals due to an accidental release.

9.8. The interpretation of the results of monitoring should be an integral part of the monitoring programme. The assumptions used in the processing and interpretation of the monitoring results, and the uncertainties in the results, should be part of the information collected and recorded. The description of the interpretation of the results should be documented in an open and transparent manner, including the assumptions used in interpreting the results.

9.9. For the interpretation of the measurements, correlation between different types of monitoring should be studied, for example:

(a) Results of source monitoring and of environmental monitoring;

(b) Results of individual monitoring, if applicable;

(c) Measurements of radiation levels and of radionuclide concentrations;

[42] The preliminary evaluation of the data can be helpful in selection of statistical tests that are appropriate to the data (e.g. parametric or non-parametric hypothesis testing) or in selecting appropriate data transformations to meet the assumptions of the statistical method.

(d) Measurements of integrated parameters and of individual radionuclides;

(e) In situ gamma surveys and sample measurements;

(f) Routine and periodic measurements;

(g) Measurements of other parameters relevant for dose assessment (e.g. meteorological and hydrological conditions).

9.10. When different types of monitoring (source, environmental or individual) are performed, there should be an effective liaison between the respective monitoring programmes,: information obtained from one programme may contribute to a better understanding of the other.

Dose assessment from monitoring results

9.11. Information from monitoring programmes should be used to assess radiation doses to members of the public for comparison with criteria established by the regulatory body. Such criteria are usually specified in terms of annual dose limits or dose constraints (for planned exposure situations) or as reference levels (for emergency and existing exposure situations). This dose assessment should include a calculation of the dose to the representative person (see paras 3.6 and 3.7). GSG-10 [2] provides recommendations on the assessment of the dose to the representative person.

9.12. Retrospective assessment of the radiological impact to the public due to radioactive releases or residual radioactivity in the environment can be done using mathematical models to convert data of source or environmental monitoring (or their combination) into calculated doses. The results of such retrospective assessments should be used with careful consideration, taking into account the cautious nature of models used for environmental dispersion and transfer; that measurements in the environment may be below detection limits; or might be not representative because of the limited frequency and spatial coverage inherent to the sampling technique.

9.13. The assessment of the dose to the representative person should consider the predominant pathways of exposure. External exposure (e.g. irradiation from radioactivity in the air, deposited on the ground or in water and sediments) and internal exposure (e.g. inhalation, ingestion of food and drinking water) should be considered. Where the dose for the representative person is

of concern, in principle, dose calculations should be based on the results of environmental monitoring rather than on monitoring at the source[43].

9.14. Doses from external exposures from radionuclides in the plume or deposited on the ground can be estimated either directly using measurements of dose rates or indirectly using measurements of the activity deposited on the ground or the activity concentrations in air. For direct measurements of dose rates, account should be taken of the natural background and distance between where the measurement was taken and the location of the representative person. For indirect measurements, dose coefficients that relate the measured or estimated activitity concentration to a dose rate should be used [1, 43].

9.15. Dose assessment for internal exposure pathways may be based on measurements of activity concentrations of radionuclides in environmental media in combination with environmental transfer models and dosimetric models. The balance between measurements and models should depend on several criteria such as the following:

(a) The availability of environmental measurements directly relevant to the representative person;

(b) Whether the samples are representative;

(c) The accuracy and precision of the measurements;

(d) The number of measurements under the detection limit for radionuclides that are released from sources;

(e) The degree of validation of models for site specific calculations.

9.16. When environmental monitoring provides results on the radiation levels and activity concentrations of radionuclides in air, water and food, dose coefficients should be used for the purposes of dose assessment, in conjunction with habit data[44]. When only source monitoring results are available or when environmental monitoring does not provide sufficient data on radiation levels and activity concentrations in air, water and food; models for transfer of radionuclides through the environment and the food chains could be used.

[43] This approach has the advantage of minimizing the modelling uncertainties involved in the dose calculations and could provide a firmer indication of the actual doses incurred by the public. However, low levels of activity sometimes make environmental monitoring impracticable for dose assessment purposes.

[44] Habit data includes the time spent in different exposure conditions by individuals of the public and their consumption rates of foodstuffs and beverages.

9.17. When environmental monitoring data are used to estimate doses due to the ingestion of food and/or drinking water, account should be taken for the origin, consumption rate, and seasonal variation. Data on radionuclide concentrations in locally produced agricultural foodstuffs and wild food, when appropriate, should be used to assess the annual intake of radionuclides and the associated dose.

9.18. The calculation of doses from the results of environmental monitoring requires appropriate processing of the monitoring results. The background radiation, whether natural background radiation or that due to fallout from nuclear weapon tests, should be identified, generally by means of comparison with results from monitoring in an area that has not been contaminated, and should be subtracted from the results.

Consideration of uncertainties in monitoring data and dose assessment

9.19. Monitoring data have associated uncertainties that arise from technical uncertainties, the non-uniformity of samples and/or measurements, and human errors. Uncertainties in the monitoring data should be considered when interpreting monitoring data, in particular, when estimating public doses that are used in the decision making process to protect the public and/or the environment (e.g. decisions about implementation of protective actions or remedial actions).

9.20. The uncertainties in monitoring results should be estimated taking into account any uncertainties in sampling and measurement procedures, including, the uncertainties in sample processing and equipment calibration. Uncertainties should be reported together with the monitoring results.

9.21. Uncertainties cannot be eliminated but they can be reduced and controlled by use of appropriate standard procedures in the field and in the laboratory, and by use of a quality assurance programme to verify that these procedures are followed. Uncertainties in monitoring data can also be reduced through using appropriately calibrated instruments, performing regular intercomparison measurements amongst organizations involved in monitoring and participating in proficiency tests.

REPORTING

9.22. Results from the monitoring programmes should be reported to the regulatory body, or other competent authority, at a frequency required by the regulatory body or other authority, in accordance with the approved monitoring programme.

9.23. Monitoring results should be reported in a way that allows the comparison with the relevant criteria, such as the following:

(a) For planned exposures, limits on discharges or other criteria for operation specified in authorizations issued by the regulatory body, the dose constraint for the facility, the public dose limits, and, where specified, any derived levels for flora and fauna [19];

(b) For emergency exposures, operational intervention levels or emergency action levels,

(c) For existing exposures, dose reference levels, screening criteria[45] for remedial actions, end state criteria[46];

9.24. Monitoring reports should present the data obtained for the monitoring period, along with an interpretation of the data that addresses the objectives of the monitoring programme.

9.25. Monitoring reports should also contain an adequate interpretation of the radiological significance of monitoring data with reference to relevant standards or criteria. Particular attention should be given to monitoring data that show significant increase, or trends, in the releases or in the contamination of the environment.

9.26. Monitoring reports should also include a discussion of the uncertainty in the monitoring data, and, to the extent possible, of the uncertainty in calculated doses.

9.27. The regulatory body is required to publish or make available on request, results from monitoring programmes and related dose assessment to the public (see para. 3.136 of GSR Part 3 [1]). The regulatory body should define the content and characteristics of the reports on source and environmental monitoring to be made available to the general public and other interested parties. The basis for such reports should be the results on the monitoring programme by the operating organization and the independent monitoring by the regulatory body or the delegated party (see para. 4.4). The regulatory body should provide well documented and transparent information, taking into account that some interested parties might not have high specialized expertise. Information should be made available in an appropriate understandable form and include the key findings in a language (or languages) accessible for all the interested parties.

[45] Screening criteria are used to indicate if remediation could be justified. The projected doses prior to remediation should be compared against the relevant screening criterion (e.g. the lower level of the reference level range, as established in the national strategy for remediation) that has been approved by the regulatory body, in order to determine whether or not remediation might be justified [16].

[46] End state is a predetermined criterion defining the point at which a specific task or process is to be considered completed. It is used in relation to remediation as the final status of a site at the end of the activities for remediation [4].

The regulatory body might consider the need to include general information on aspects of radiation protection of the public of the environment, as a complement of the technical data.

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Annex

TECHNICAL CONSIDERATIONS FOR SAMPLING AND MEASUREMENTS FOR ROUTINE DISCHARGES IN PLANNED EXPOSURE SITUATIONS

A–1. The technical considerations presented in this Annex might not be applicable in all situations and need to be adapted, as appropriate, to the facility or activity.

SOURCE MONITORING DURING NORMAL OPERATION OF FACILITIES

A–2. Most of the data on the discharge of radionuclides are generally obtained by means of on-line measurements of the dose rate, measurements of activity concentration or total activity at the discharge point, or by effluent sampling in tanks before discharges with subsequent laboratory analysis. Sampling and subsequent monitoring of the air and water released, whether continuous or discontinuous, are used mainly to determine the radionuclide composition of a discharge.

A–3. If the activity concentrations in the discharged effluents are very low, on-line measurements might be insufficiently sensitive and sampling with subsequent laboratory analysis may become necessary. Continuous sampling is preferred when discharges are continuous. When discharges are made from tanks, samples of the effluent in each tank or composite samples of several tanks are obtained, after an efficient mixing of the effluents in the tanks in order to ensure samples are representative of the whole volume of the tanks.

A–4. When the radionuclide composition of the discharges is known and does not vary significantly, measurements of gross alpha, gross beta or gross gamma activity may be sufficient to characterize the radioactive discharges. When the radionuclide composition may vary, spectrometric measurements are needed; pure beta emitters need special consideration as chemical preparation is necessary. When discharges include radionuclides with short half-lives, prompt analysis is needed to avoid losses from rapid decay of the nuclides in the samples.

A–5. As appropriate, on-line measurements are complemented with an alarm which warns the operating organization when a predefined threshold is exceeded, and with automatic devices which stop the current discharges from tanks. For large facilities, the main monitoring systems might be equipped with alarms to warn the operating organization of any malfunctioning of the device; the main monitoring systems might also be duplicated in order to avoid any lack of monitoring during maintenance or failure of the systems.

A–6. As generally the concentrations of radionuclides are measured in the discharged effluents, an accurate measurement of the volume of discharged effluent is needed to derive the radionuclide quantities discharged into the environment. The diffuse discharges might be assessed from various parameter measurements, including parameters of the industrial processes, or from environmental measurements in the vicinity of the facility. The procedure to estimate diffuse discharges will normally be specified or approved by the regulatory body.

A–7. Diffuse sources might not be amenable to on-line monitoring. For example, radon gas (^{222}Rn) is released from some mining operations through multiple mine vents, and from tailings and waste rock storage areas. While continuous radon monitors are available to measure radon concentrations, on-line systems are not practical for large source areas. Retrospective detectors, such as alpha track detectors, collected for measurement and replaced periodically, might be more practical. In either case, monitoring is expected to cover all seasons in order to reflect the seasonality of radon emanation. Estimates of radon discharge can be made from measured concentrations and air flow or wind data. Recommendations on suitable monitoring methods are provided in Ref. [1].

ENVIRONMENTAL MONITORING IN NORMAL OPERATION OF FACILITIES

A–8. The main objectives of environmental monitoring during normal operation are the verification of compliance of measured values with environmental limits, or the comparison of measured values with predicted values of dose rates or radionuclide concentrations in environmental samples. Sampling locations are therefore selected close to points where the maximum exposure or deposition is expected for airborne discharges, or downstream from the release point for aquatic discharges, where the representative person lives or gets food, where sensitive biota or species at risk have been identified, or (for direct radiation from the source) at the site boundary. Since atmospheric dispersion and water dispersion might vary significantly from year to year, a part of the monitoring measurements need to be performed at the same location for the year by year comparison of the results.

A–9. Additional environmental sampling and/or measurements need to be conducted regularly in areas used for control measurements to compare the results with those in potentially affected areas.

A–10. Continuously produced agricultural food products such as leafy vegetables or milk are normally sampled several times a year, or more frequently in the case of releases of radionuclides, such as radioiodines that do not persist long in the produce, or such as tritium

that is highly mobile resulting in the possibility for rapid changes in activity concentrations in the environment. Sediment, soil and products with one harvest per year are monitored once a year at the time of harvest.

A–11. Typical constituents monitored, the frequencies and locations of sampling, and the measurements on the samples are presented in Tables A-1, A-2 and A-3. This is a generic framework; the site specific monitoring programme is expected to be established in consideration of the radionuclides involved, site specific considerations and the magnitude of discharges. The choice of foodstuffs will depend on local agricultural practices and the food related habits of the local population.

A–12. For large facilities, site characterization work to support the monitoring programme might include on-site automated weather observing systems (to monitor wind speed and direction, atmospheric stability and precipitation) and river flow or lake current monitoring systems.

A–13. The analysis systems for measurement of low-level environmental samples is expected to be physically separated from the systems for measurement of higher level effluent samples, to avoid cross contamination.

TABLE A–1. EXAMPLE OF TYPICAL ENVIRONMENTAL MONITORING FOR AN AIRBORNE DISCHARGE

Monitored constituent	Frequency of monitoring	Monitoring location	Measurement (as appropriate to the source)
External radiation			
External radiation	Continuously On-line, as appropriate	Several azimuths (e.g. 4) and several distances (e.g. fence, 1 km, 5km, 10 km) around the facility	Gamma dose rate Neutron dose rate at fence (if neutron radiation foreseen)
External radiation – integrated	Monthly to twice a year	Several locations at the fence (e.g. 10)	Gamma dose rate Neutron dose rate (if neutron radiation foreseen)
Air and deposition			
Air: -aerosols -gases including noble gases, tritium and iodine	Continuous collection	Several azimuths (e.g. 4) including downwind prevailing wind -Near areas with sensitive biota	Daily to monthly measurements: -Gamma and alpha spectrometry -Gross beta -Gross alpha -Tritium
Rain	Continuous collection	Downwind the wet prevailing wind	Monthly measurements: -Tritium -Gross beta -Gross alpha
Deposition	Continuous collection	-Downwind the prevailing wind -Near areas with sensitive biota	Daily to monthly measurements: -Gamma and alpha spectrometry -Gross beta -Gross alpha
Soil	Annually	-Downwind the prevailing wind -Near areas with sensitive biota	-Gamma and alpha spectrometry
Groundwater	Monthly to annually	Several locations around the facility	-Tritium -Gross beta (+ potassium) -Gross alpha
Food and drinking water			
Leafy vegetables	Monthly during growing season	Downwind the prevailing wind	-Tritium (HTO and OBT as appropriate) -Gamma spectrometry
Other vegetables and fruits	At harvest	Downwind the prevailing wind	-Tritium (HTO and OBT as appropriate) -Gamma spectrometry
Grain	At harvest	Downwind the prevailing wind	-Tritium (HTO and OBT as appropriate) -Gamma spectrometry
Milk	Monthly to annually, when cows on pasture	Pasture downwind the prevailing wind	-Tritium (HTO and OBT as appropriate) -Gamma spectrometry -Carbon-14 -Strontium-90

Monitored constituent	Frequency of monitoring	Monitoring location	Measurement (as appropriate to the source)
Meat	Annually	Animals on pasture downwind the prevailing wind	-Gamma spectrometry
Drinking water	Quarterly to annually	-Tap water and private wells near the facility	-Tritium -Gamma spectrometry -Gross alpha
Terrestrial pathways			
Grass	Monthly	Pasture downwind the prevailing wind	-Tritium (HTO) -Gamma spectrometry -Alpha spectrometry
Lichen, mosses, mushrooms	Annually	Selected samples downwind the prevailing wind	-Gamma spectrometry

Notes:

1. Tritium, carbon-14 and alpha emitters are to be measured only when these radionuclides are discharged from the facility.

2. Alpha spectrometry for the aerosols might be performed on a grouping of filters to enhance detection capability.

3. Potassium can be measured in order to derive the potassium-40 content. Alternatively, K-40 can be measured directly by gamma spectrometry to be subtracted from gross beta measurements.

4. Large volume samples (e.g. 20 L) may be needed to reach reasonable detection limits for radionuclides in water.

TABLE A–2. EXAMPLE OF TYPICAL ENVIRONMENTAL MONITORING FOR A LIQUID DISCHARGE TO FRESHWATER

Monitored constituent	**Frequency of monitoring**	**Monitoring location**	**Measurement (as appropriate to the source)**
Aquatic dispersion			
Surface water	Continuous sampling	Downstream	Monthly measurement: -Tritium -Gross beta (+potassium) -Gross alpha -Gamma spectrometry -Alpha spectrometry -Strontium-90 -Uranium
Sediment	Annually	Downstream	-Gamma spectrometry -Alpha spectrometry -Uranium
Aquatic foodstuffs			
Fish	Annually	Selected samples downstream	-Tritium (OBT) -Carbon-14 -Gamma spectrometry
Aquatic pathways			
Aquatic flora	Annually	Downstream	-Gamma spectrometry

Notes:

1. Tritium, carbon-14, strontium-90, uranium and other alpha emitters are to be measured only when these radionuclides are discharged from the facility.

2. Potassium can be is measured in order to derive the potassium-40 content. Alternatively, K-40 can be measured directly by gamma spectrometry to be subtracted from gross beta measurements.

3. When other discharges occur upstream, surface water and sediment should be also collected upstream of the point of discharge, as a baseline prior to discharge and during facility operation.

TABLE A–3. TYPICAL ENVIRONMENTAL MONITORING FOR A LIQUID DISCHARGE TO SEAWATER

Monitored constituent	**Frequency of monitoring**	**Monitoring location**	**Measurement (as appropriate to the source)**
Aquatic dispersion			
Surface water	Continuous sampling	Downstream	Monthly measurement: -Tritium -Gross beta (+potassium) -Gross alpha -Gamma spectrometry -Alpha spectrometry -Strontium-90
Sediment	Annually	Downstream	-Gamma spectrometry -Alpha spectrometry -Strontium-90
Aquatic foodstuffs			
Fish	Annually	Selected samples downstream	-Tritium (OBT) -Carbon-14 -Gamma spectrometry
Molluscs	Annually	Selected samples downstream	-Tritium (OBT) -Carbon-14 -Gamma spectrometry
Crustacean	Annually	Selected samples downstream	-Tritium (OBT) -Gamma spectrometry
Aquatic pathways			
Seaweed	Annually	Downstream	-Gamma spectrometry

Note:

1. Tritium, carbon-14, strontium-90 and alpha emitters are to be measured only when these radionuclides are discharged from the facility.

2. Potassium can be is measured in order to derive the Potassium-40 content. Alternatively, K-40 can be measured directly by gamma spectrometry to be subtracted from gross beta measurements.

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