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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. During normal operation, some facilities and activities may generate gaseous and liquid effluents containing small amounts of radionuclides, which could expose the public and the environment to very low levels of radiation[1]. Essential elements in controlling these releases and the associated exposures include assessing their radiological impact, regulating them through a process of authorization of discharges, and conducting monitoring at the source (source monitoring, see para. 3.12), monitoring in the environment (environmental monitoring, see para. 3.12) and, as necessary, monitoring of members of the public (individual monitoring, see para. 3.14).

1.2. Monitoring programmes are required to verify compliance with the safety requirements related to the control and assessment of public exposure (see para. 3.127(f) of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [3]). 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 involved in such monitoring have different responsibilities, ranging from the definition of the policies to the implementation of such programmes.

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 and submit the results of such evaluations to the regulatory body as an input for authorization and establishment of discharge limits (see paras. 3.123 and 3.132 of GSR Part 3 [3]). Recommendations on authorization of discharges, demonstration of compliance, and enforcement of authorization are provided in GSG-9, Regulatory Control of Radioactive Discharges to the Environment [4]. Recommendations on a general framework for conducting prospective radiological impact assessments for facilities and activities, to estimate and control the radiological effects on the public and the environment are provided in IAEA Safety Standards Series Nos GSG-10, Prospective Radiological Environmental Impact Assessment for

[1] The use of criteria at very low doses to control environmental releases, such as those at or below 1 mSv per year, is well established in radiation protection and is consistent with internationally accepted principles, including those of the ICRP and IAEA safety standards. At these levels, effects on health cannot be attributed to radiation exposure, reinforcing that such criteria are precautionary and appropriate for ensuring the higher standards for protection and safety. For further discussion on the concept of ‘very low doses’ (see Ref. [1] and Ref. [2]).

Facilities and Activities [5]. Unlike occupational exposure, where individual doses can be directly measured, public dose assessment relies primarily on modelling and results of monitoring. Retrospective dose assessment to the public involves, effluents and environmental measurements, habit data of the population under consideration and modelling of envionmental tranfer and dosimetry, rather than direct measurements of individual exposures [6].

1.4. The regulatory body may establish requirements for monitoring the impact of discharges using a graded approach, commensurate with the level of radiation risk associated with the source based on the likelihood of exposure and possible radiological consequences to the public. 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 applying a graded approach within the licensing process are provided in IAEA Safety Standards Series No. GSG-8, Radiation Protection of the Public and the Environment [7].

1.5. Despite measures to prevent accidents and mitigate harmful consequences, uncontrolled releases of radionuclides to the environment might still occur. Monitoring of an accidental release at its source, and of the resulting radioactive contamination[2] in the environment is necessary for the assessment and implementation of actions for protection of the public and the environment. In some cases, individual monitoring of members of the public may be appropriate. The requirements for 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 [9].

1.6. In areas contaminated with radionuclides from past activities that were not subject to appropriate regulatory control, or as a result of a nuclear or radiological emergency after its termination, monitoring may be needed to aid decisions on the protection of the public and the environment, including for implementing practical measures to reduce the exposures to the population, including remedial actions, where justified.

1.7. The IAEA safety standards, which are based on specific considerations of human exposure, generally provide for appropriate protection of the environment from harmful effects

[2] 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 [8].

of radiation[3]. However, GSR Part 3 [3] does not establish specific requirements for the explicit assessment of the exposure (and hence the level of protection) of flora and fauna. GSR Part 3 [3] identifies the protection of the environment as an issue usually necessitating assessment, while allowing for flexibility in incorporating into decision making processes the results of environmental assessments that are commensurate with the radiation risks. Demonstrating the protection of both humans and non-human species in planned exposure situations can be integrated in a relatively simple manner (see GSG-10[5] and Ref. [10]). The usual environmental monitoring programmes for the protection of the public, as described in this Safety Guide, are generally adequate to support 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[4], 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, in particular IAEA Safety Standards Series No. SF-1, Safety Fundamentals [11], GSR Part 3 [3] and GSR Part 7 [9].

OBJECTIVE

1.9. The objective of this Safety Guide is to provide recommendations on implementing the requirements established in GSR Part 3 [3], GSR Part 7 [9] and other IAEA Safety Requirements publications (see para. 2.7) relevant for source, environmental and individual monitoring for the protection of the public and the environment. This applies to planned, emergency, 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 members of the public. This Safety Guide also provides recommendations for those responsible for developing and implementing monitoring strategies and programmes.

[3] Protection of the environment includes the protection and conservation of: non-human species, both animal and plant, and their biodiversity; environmental goods and services, such as the production of food and feed; resources used in agriculture, forestry, fisheries and tourism; amenities used in spiritual, cultural and recreational activities; media, such as soil, water and air; and natural processes, such as carbon, nitrogen and water cycles GSR Part 3 [3].

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

1.11. This Safety Guide provides recommendations for two situations where monitoring programmes should be conducted by the regulatory body (or by another organization on behalf of the regulatory body, see para. 4.4): confirmatory monitoring programmes in relation to the operation and decommissioning of facilities and the conduct of activities; and monitoring programmes carried out when no responsible operating organization can be identified, for example an existing situation resulting from a past non-regulated practice.

1.12. This Safety Guide also provides recommendations on the interpretation of monitoring results, including for use in dose assessment, as well as recommendations on data management, recording and reporting for the provision of information to interested parties, including the 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 takes into account changes in monitoring requirements over the different stages in 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 the monitoring of radioactivity in the environment for nuclear installations is given 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. This Safety Guide applies to nuclear fuel cycle facilities, including facilities for the mining and processing of uranium and thorium ores. This Safety Guide does not cover monitoring in other industries that process materials with elevated concentrations of natural radioactivity, including the mining and milling of metalliferous and non-metallic ores, the production of coal, oil and gas, the extraction and purification of water, the generation of geothermal energy, and the production of industrial minerals, including phosphate, clay and

building materials. However, certain technical aspects of this Safety Guide may be helpful for monitoring in such industries.

1.17. General aspects of monitoring performed in all phases of a nuclear or radiological emergency are 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 source and environmental monitoring for facilities and activities in emergency situations where an off-site release has occurred or is foreseen to occur.

1.18. This Safety Guide addresses general aspects of monitoring associated with existing exposure situations 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 IAEA Safety Standards (see para. 5.1 of GSR Part 3 [3]). More detailed recommendations on monitoring related to the remediation processes and to the management of residual material generated during remediation are provided in IAEA Safety Standards Series No. GSG-15, Remediation Strategy and Process for Areas Affected by Past Activities or Events [16].

1.19. This Safety Guide considers the analysis of the content of radionuclides in food and drinking water only where this food and water is considered environmental media (see para. 3.3) 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] and [19].

1.20. Monitoring explicitly related to the assessment of exposures to flora and fauna is not covered in this Safety Guide. In planned exposure situations, the measurements of radiation levels and radionuclide concentrations in the environment for the purpose of members of the

public protection, would generally be adequate to support generic assessments for radiological protection of flora and fauna [10]. The government or the regulatory body should determine the need for specific monitoring requirements for protection of flora and fauna based on regulatory objectives and/or the outcomes of a generic assessment. The decision to implement specific monitoring could be influenced by factors such as the presence of endangered and threatened species, protected areas, particular flora and fauna that might be at high risk, or the need to provide public assurance. If deemed necessary, a generic methodology as described in Annex I of GSG-10 [5] can be used for assessing exposures of flora and fauna.

1.21. This Safety Guide does not cover the protection of workers against radon which is addressed in IAEA Safety Standards Series No. SSG-91, 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 which are provided in IAEA Safety Standards Series No. SSG-32, Protection of the Public against Exposure Indoors due to Radon and Other Natural Sources of Radiation [21].

1.22. This Safety Guide does not provide recommendations on monitoring for the purpose of assessing planned or accidental exposures from the transport of radioactive material. This is addressed in IAEA Safety Standards Series No. SSG-86, Radiation Protection Programmes for the Transport of Radioactive Material [22] and SSG-65 [15].

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

1.24. This Safety Guide does not address the monitoring of workers or the workplace, recommendations on which are provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [24] and in SSG-91[20] .

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

1.26. This Safety Guide does not address the monitoring of non-radiological contaminants or physical stressors (e.g. temperature), even though the chemical and physical properties relevant for the assessment of radiological impacts need to be considered in a monitoring programme for radiological protection of the public and the environment.

STRUCTURE

1.27. Section 2 of this Safety Guide 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 the government, regulatory body, operating organizations (i.e. registrants, licensees) and other parties 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 a monitoring programme 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 of uncertainties.

1.28. 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 [11] 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[5] that can reasonably be achieved, measures have to be taken, among others, to control the radiation exposure of people and the release of radioactive substances 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 need to establish a national policy and strategy for safety and to promulgate the necessary laws and statutes. Paragraph 2.5(5) of GSR Part 1 (Rev. 1) [25] states that the legal and regulatory framework is required to include "Provision for the involvement of interested parties and for their input to decision making". In addition, Requirement 13 states that: "**The government shall make provision, where necessary, for technical services in relation to safety, such as services for personal dosimetry, environmental monitoring and the calibration of equipment**."

2.3. GSR Part 3 [3] 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 [3] also 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 the monitoring in emergency exposure situations are established in GSR Part 7 [9].

2.4. Paragraph 2.23 of GSR Part 3 [3] states that:

> "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."

[5] In the context of the IAEA safety standards 'safety' and 'nuclear safety' are interchangeable according to Ref. [8].

2.5. Paragraph 1.20 of GSR Part 3 [3] distinguishes between three different exposure situations: planned exposure situations, emergency exposure situations and existing exposure situations. The paragraph states[6]:

"(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."

[6] The term 'practice' is defined in GSR Part 3 [3] as "Any human activity that introduces additional sources of exposure or additional exposure pathways, or that modifies the network of exposure pathways from existing sources, so as to increase the exposure or the likelihood of exposure of people or the number of people exposed." In accordance with the IAEA Nuclear Safety and Security Glossary [8], the term 'activities' is intended to provide an alternative to the terminology of practices (or interventions) to refer to general categories of situations. Terms such as 'authorized practice', 'controlled practice' and 'regulated practice' are used to distinguish those practices that are subject to regulatory control from other activities that meet the definition of a practice but do not need or are not amenable to control.

2.6. The responsibilities and requirements for monitoring vary depending on the exposure situation. Recommendations on the responsibilities specific to each of the three exposure situations indicated in para. 2.5 are provided in Sections 5, 6 and 7 of this Safety Guide.

REQUIREMENTS FOR MONITORING IN PLANNED EXPOSURE SITUATIONS

2.7. 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 [26]. 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 [27]. 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 [28]. 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 [29], and SSR-2/2 (Rev.1) Safety of Nuclear Power Plants: Commissioning and Operation [30]. Requirements for monitoring in relation to all stages of the life cycle of fuel cycle facilities are established in IAEA Standards Series No. SSR-4 Safety of Nuclear Fuel Cycle Facilities [31].

2.8. Requirement 14 of GSR Part 3 [3] 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 [3] 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 [3] states:

> "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 [GSR Part 3];
>
> (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 [GSR Part 3];

(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 [3] establishes the responsibilities of relevant parties related to public exposure in planned exposure situations. 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 [3] 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 [3] establish the responsibilities for monitoring programmes for planned exposure situations. Paragraph 3.135 of GSR Part 3 [3] 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 [GSR Part 3] for the control of public exposure."

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

"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."[7]

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

"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.

[7] In support of this requirement, para. 4.30 of IAEA Safety Standards Series No. GSG-6, Communication and Consultation with Interested Parties by the Regulatory Body [32] 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...publish or make available on request, as appropriate, results from source monitoring and environmental monitoring programmes and assessments of doses from public exposure."

(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.

(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.

…….

(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. Paragraph 3.43 of GSR Part 3 [3] states (reference 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."

2.17. Paragraph 3.137 of GSR Part 3 [3] states:

"Registrants and licensees shall, as appropriate:

…….

(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."

2.18. Requirement 43 of GSR Part 3 [3] states that "**The government shall ensure that an integrated and coordinated emergency management system is established and maintained.**" Related to this requirement, para. 4.5 of GSR Part 3 [3] states:

"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".

2.19. Requirement 5 of GSR Part 7 [9] states that: "**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. In addition, GSR Part 7 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.

2.21. Paragraph 6.24 of GSR Part 7 [9] 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."

2.22. Paragraph 5.40 of GSR Part 7 [9] 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."

2.23. Once the emergency is terminated, monitoring is subject to the requirements for planned exposure situations or existing exposure situations, as appropriate (see para. 5.101 of GSR Part 7 [9]).

REQUIREMENTS FOR MONITORING IN EXISTING EXPOSURE SITUATIONS

2.24. The requirements in GSR Part 3 [3] 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, as presented in paras 2.25–2.34.

2.25. Requirement 47 of GSR Part 3 [3] 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.**"

2.26. Requirement 48 of GSR Part 3 [3] 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.**"

2.27. Paragraph 5.8 of GSR Part 3 [3] 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."

2.28. Requirement 49 of GSR Part 3 [3] establishes the responsibilities for remediation of areas with residual radioactive material. Related to this requirement, paras 5.10, 5.12, 5.13, 5.16 and 5.17 of GSR Part 3 [3] establish the responsibilities for monitoring before and during remediation, for post-remediation and monitoring for public information.

2.29. Paragraph 5.10 of GSR Part 3 [3] states:

"For the remediation of areas with residual radioactive material deriving from past activities or from a nuclear or radiological emergency …, the government shall ensure that provision is made in the framework for protection and safety for:

…….

(d) 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."

2.30. Paragraph 5.12 of GSR Part 3 [3] 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."

2.31. Paragraph 5.13 of GSR Part 3 [3] states:

"The regulatory body … or other relevant authority shall take responsibility, in particular for:

…….

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

2.32. Paragraph 5.14 of GSR Part 3 [3] 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 approval by the regulatory body or other relevant authority".

2.33. Paragraph 5.16 of GSR Part 3 [3] 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."

2.34. Paragraph 5.17 of GSR Part 3 [3] 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 infrastructure to support continuing 'self-help protective actions' in the affected areas, such as by the provision of information and advice, and by monitoring[8]."

TRANSBOUNDARY IMPACTS

2.35. There are no specific provisions covering monitoring associated with transboundary impacts in GSR Part 3 [3] or GSR Part 7 [9], but there are requirements for transboundary impacts that are relevant to monitoring. For example, para. 3.124 of GSR Part 3 [3] states:

"[T]he 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."

[8] Ref. [33] mentions that self-help protection actions may include measurements made by interested parties assisted by local laboratories or universities that may be complementary to those carried out by the organizations responsible for managing emergencies.

2.36. Requirement 22 of GSR Part 7 [9] 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**".

2.37. Paragraph 6.13 of GSR Part 7 [9], 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

2.38. GSR Part 1 (Rev. 1) [25], GSR Part 3 [3] and IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [34] establish specific requirements for the implementation of a graded approach[9]. The type of monitoring programme for protection of the public and the environment, as well as its scale and extent, should take into account the characteristics of the practice or the source. This programme should also be commensurate with the magnitude of the radiation risk and the extent to which the exposure is amenable to control, consistent with the graded approach.

[9] For a system of control, such as a regulatory system or a safety system, graded approach is a process or method in which the stringency of the control measures and conditions to be applied is commensurate, to the extent practicable, with the likelihood and possible consequences of, and the level of risk associated with, a loss of control [8].

3. CONCEPTS AND TERMS RELEVANT TO MONITORING

3.1. This section provides an explanation of some of the concepts and terms used in this Safety Guide. Unless otherwise mentioned, concepts or terms are consistent with the definitions found in GSR Part 3 [3] or in the IAEA Nuclear Safety and Security Glossary [8].

DISCHARGES AND ENVIRONMENTAL RELEASES

3.2. A discharge is a planned and controlled release of radioactive substances to the environment [8]. 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 substances to the environment in an emergency and the migration of radioactive substances through the environment in an existing exposure situation are referred to as a 'release' or 'environmental release'. Discharges and releases may include gases, aerosols, liquids and solids.

ENVIRONMENTAL MEDIA

3.3. 'Environmental media' 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 or, in specific cases, to non-human species exposures, such as air; surface water and groundwater; soil; sediments; drinking water; crops; animals and vegetables in the human food chain and other foodstuffs; as well as bioindicators[10].

EXPOSURE AND EXPOSURE PATHWAYS

3.4. GSR Part 3 [3] 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" [3].

3.5. An exposure pathway is defined in GSR Part 3 [3] as "a route by which radiation or radionuclides can reach humans and cause exposure". Typical pathways for external exposures are direct irradiation from the source or from radionuclides in an atmospheric plume or

[10] Bioindicators are organisms that may not be significant in relation to pathways of human exposure and are therefore not used for dose assessment purposes, but can be utilized as sensitive indicators for assessing trends in environmental radiation levels and activity concentrations of radionuclides in the environment. Examples of bioindicators are mussels, insects, lichen, and seaweed.

deposited on different surfaces such as the soil, water bodies, crops and forests (see Fig. 1). Typical pathways for internal exposures are inhalation and ingestion of food and drinking water (see Fig. 1).

3.6. In the context of this Safety Guide, an exposure pathway can be described more specifically as a route 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.

MEMBER OF THE PUBLIC AND THE REPRESENTATIVE PERSON

3.7. GSR Part 3 [3] defines a member of the public, for the purposes of protection and safety, as "any individual in the population except when they are subject to occupational exposures or medical exposure". For the purpose of verifying compliance with dose constraints, dose limits and reference levels, as relevant in planned, existing and emergency exposure situations, it is necessary to identify the 'representative person', who is an individual receiving a dose that is representative of the doses to the more highly exposed individuals in the population [8]. The representative person is generally a hypothetical construct and not an actual individual. Factors such as the relevant exposure pathways, spatial distribution of radionuclides in the environment, use of local resources, age, diet, and habits of the population group to which the representative person belongs, as relevant, should be considered when defining the representative person and estimating the dose received. The habit data and characteristics of the environment to estimate doses to the representative person should be chosen based on reasonably conservative and plausible assumptions, avoiding the inclusion of extreme conditions. More information on assessing the dose of the representative person for the purpose of radiation protection is provided in GSG-10 [5] and in Ref. [35].

3.8. The concept of 'representative person' applies not only to planned exposure situations, but also to existing exposure situations and emergency exposure situations [35]. However, the particular characteristics of the representative person in each situation, such as location, habits and age group, may be different. For emergencies, the operational criteria[11] (e.g. operational intervention levels) need to be derived for a representative person with account taken of those

[11] GSR Part 7 [9] 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 and emergency action levels.

members of the public that are most vulnerable to radiation exposure, in particular children and pregnant women.

MONITORING STRATEGY AND MONITORING PROGRAMME

3.9. ‘Monitoring strategy’ in the context of this Safety Guide refers to the national approach for establishing the objectives and scope of monitoring programmes, as well as identifying the responsibilities of and interactions among the organizations that conduct activities related to monitoring[12]. It includes considerations for long-term monitoring, emergency monitoring, data management, and integration with decision-making processes.

3.10. ‘Monitoring programme’ in the context of this Safety Guide refers to a set of activities designed to measure radiological parameters, such as dose rates, radionuclide concentrations, or other relevant parameters in the source and the environment, to assess the radiological conditions and potential impacts. The monitoring programme includes, for example, sampling locations and frequency, types of environmental media, sampling and measurement techniques and the interpretation of the data obtained.

SOURCE

3.11. 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 [8]. If a facility or activity, releases radioactive substances into the environment, that facility or activity as a whole may be regarded as a source; if radioactive substances are already dispersed in the environment, such as those resulting from past practices that were not subject to regulatory control or that remain after an emergency exposure situation, the portion of the radioactive substances to which people are exposed to may be considered as a source.

TYPES OF MONITORING

3.12. ‘Source monitoring’ refers to the measurement of activity of radionuclides being released to the environment or external dose rates due to sources within a facility or activity [8].

[12] For emergency exposure situations, the monitoring strategy is related to the monitoring arrangements that form part of the protection strategy (see Section 6). Paragraph 4.27 of GSR Part 7 [9] states that: “protection strategies are developed … at the preparedness stage for taking protective actions and other response actions effectively in a nuclear or radiological emergency”.

3.13. ‘Environmental monitoring’ refers to the measurement of external dose rates due to sources in the environment or of radionuclide concentrations in environmental media [8]. Environmental monitoring is the monitoring conducted outside a site that gives rise to exposure. An environmental monitoring programme includes measurements of radiation fields and radionuclide activity concentrations in environmental media relevant to human exposure (primarily air, drinking water, sediments, soils, agricultural produce and foodstuffs, and aquatic foods), as well as in bioindicators that can provide a measure of trends in activity levels. An environmental monitoring programme may also include descriptions of the physical, chemical and biological features of the environment that might affect the behaviour of radionuclides in the environment (see para. 8.10).

3.14. ‘Individual monitoring’[13] 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 [8]. Individual monitoring for members of the public is necessary for certain emergency exposure situations (see paras 6.21–6.24), and existing exposure situations resulting from emergencies in which health follow-up was recommended (see paras 7.23–7.24).

4. RESPONSIBILITIES FOR MONITORING

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

4.1. The government or the regulatory body is expected to 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 (see GSR Part 1 [25] and GSR Part 3 [3]). 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 [9]).

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

[13] Individual monitoring can be performed for workers, patients, or members of the public.

4.3. With regard to planned exposure situations, the regulatory body is required to review and approve, as appropriate, 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 [3]). The regulatory body, or other appropriated authority, 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 tasks related to monitoring to other parties. These parties should possess sufficient technical capability and should remain independent 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 authority for these tasks directly, or through the regulatory body. The tasks might include the following:

(a) Selection of appropriate monitoring equipment;

(b) Testing and calibration of monitoring equipment;

(c) Review of quality management systems;

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

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

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

(g) Environmental monitoring and individual monitoring (see paras 3.13 and 3.14, respectively) and dose assessment in emergency exposure situations or existing exposure situations, as appropriate;

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

(i) Countrywide or subnational environmental monitoring.

4.5. The operating organization or another party[14] responsible 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. Depending on national arrangements, environmental monitoring conducted by operating organizations may complement the programmes of the government or the regulatory body.

4.6. The responsibilities of the government, regulatory body, operating organization, and other parties (e.g. response organizations) may differ depending on the exposure situation. Table 1 presents an indication of the main 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.

[14]Other parties with a role in monitoring might include technical support organizations, non-governmental organizations, food safety authorities, water authorities, public health authorities, and emergency preparedness and response organizations.

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

Exposure Situation		Operating organization[a]	Regulatory body	Government
Planned	Exempted, cleared and notified practice or source	No monitoring required	No monitoring required	No monitoring required
	Registered practice or source	Conduct source monitoring[b]	Review and approve monitoring programmes of registrants and licensees, as appropriate Review periodic reports on public exposure including dose assessments, as appropriate[c] Conduct limited confirmatory environmental monitoring, as appropriate[c,d]	Ensure arrangements are in place for monitoring
	Licensed practice or source	Conduct source and environmental monitoring and dose assessment		
	Multiple sources	Conduct source monitoring of its own facility, site specific environmental[c] monitoring, and dose assessment for its own facility[c]	Review monitoring data and prepare dose assessments cumulative over the relevant period, as appropriate Conduct environmental monitoring to assess cumulative radiological impact[d]	Ensure arrangements are in place for management of countrywide surveys
Emergency	–	Conduct source monitoring and site specific environmental monitoring[c]	Coordinate large scale and/or local environmental monitoring, as appropriate[d,e] Coordinate individual monitoring of the public, as appropriate[d,e]	Ensure resources and capabilities are available to respond to emergencies Ensure arrangements are in place for management of countrywide monitoring networks Assign responsibilities to the regulatory body or other response organizations depending on the national arrangements
Existing	Areas with residual radioactive material	Conduct source monitoring, site specific environmental monitoring and dose assessment[f]	Review monitoring data and dose assessments Conduct local environmental monitoring, as appropriate Coordinate individual monitoring of the public, as appropriate[d,g]	Screen areas where the radiological impact is of potential concern and a radiological survey is considered necessary Decide on the need for monitoring Ensure arrangements are in place for management of existing exposure sites, including monitoring, as the sites are identified

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

[b] For registered practices, the regulatory body might require source monitoring to be performed.

[c] Only for licensed practices or sources (see Table 2 in Section 8).

[d] The regulatory body can perform activities related to monitoring itself or delegate their implementation (see para. 4.4).

[e] The government can assign this responsibility to other response organizations rather than the regulatory body, depending on the national arrangements.

[f]In the cases in which remediation has been determined to be justified, the operating organization is the responsible party authorized to conduct remediation (see GSG-15 [16]). If the operating organization is not present, the government should assign a responsible body.
[g] For existing exposure situations in which health follow-up was recommended.

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 [3]. Examples of excluded exposures are provided in IAEA Safety Standards Series No. GSG-17, Application of the Concept of Exemption [36] 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 [3]). 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 [3]. For practices for which notification alone is sufficient, there is no requirement for monitoring (see GSR Part 3 [3]).

5.4. Material in which activity concentrations are below the clearance levels[15] is no longer considered radioactive material and can be used, recycled or disposed of without further regulatory consideration regarding the radiological aspects. 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[16] [3], routine monitoring programmes are required (see para. 3.127(f) of GSR Part 3 [3]). Nuclear installations, large research establishments and radioisotope production facilities typically have specific license conditions and are expected to have in place source and environmental monitoring programmes in support of verification of regulatory

[15] Radioactive material or radioactive objects within notified or authorized practices can be cleared of regulatory control. IAEA Safety Standards Series No. GSG-18, Application of the Concept of Clearance [37] provides recommendations 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.

[16] Sources or practices for which neither exclusion nor exemption is appropriate are required to be notified or authorized by the regulatory body (see GSR Part 3 [3]). Authorization can take the form of registration or licensing. Examples of licensed practices are the operations of nuclear power plants and of 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.

compliance. These monitoring programmes might also contribute to maintaining competences for emergency monitoring and provide a baseline for assessing the radiological impact of emergencies, 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 granting authorization[17]. 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 radioactive material to the environment, which are related to the management of gaseous, airborne and liquid effluents, should be defined by the regulatory body. In general, the following data should be established as part of the authorization process[18]:

(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 discharge limits, specified for different radionuclides, or groups of radionuclides.

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

RESPONSIBILITIES FOR MONITORING IN A PLANNED EXPOSURE SITUATION

5.8. Operating organizations have primary responsibility for performing 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 at 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. The operating organization should also be responsible for

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

[18] GSG-9 [4] provides recommendations on the establishment and authorization of discharge limits and the related operational conditions.

conducting environmental monitoring and performing dose assessment in accordance with the regulatory requirements (see Table 1 and paras 5.5–5.6).

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

5.10. The regulatory body is required, as appropriate, to make arrangements for an independent monitoring programme to verify the quality of results provided by the operating organization and to confirm that the doses to members of the public are below the dose limits (see para. 3.135(c) of GSR Part 3 [3]). The regulatory body may implement this independent programme itself or delegate implementation 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, as appropriate, 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 [3]). 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 addressed.

OBJECTIVES OF MONITORING IN A PLANNED EXPOSURE SITUATION

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 collect and provide accurate data from actual measurements to demonstrate compliance of the facility or activity with the authorized discharge limits, dose limits and constraints, and operational conditions, and verify the level of radiological protection of the public and the environment;

(b) To provide information and data for the radiological environmental impact assessment (see GSG-10 [5]), 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 anticipated operational occurrences[19], which might trigger the need for additional monitoring, mitigation and corrective actions for the facility or activity;

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

(e) To detect unexpected or unauthorized releases;

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

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

(h) To check that the results obtained with the environmental models used for dose assessment in the prospective radiological environmental impact assessment are accurate;

(i) To provide information for interested parties[20];

(j) To evaluate long term trends.

5.13. Dose rates to the reference animals and plants may also be evaluated with a methodology as described in annex I of GSG-10 [5], based on the ICRP approach for the protection of the environment (see Refs [38,39]). 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 (see para. 3.2) and associated transfer factors taking account of relevant exposure pathways.

[19] Examples of anticipated operational occurrences are loss of normal electrical power and faults such as a turbine trip, malfunction of individual items of a normally running plant, failure to function of individual items of control equipment, and loss of power to the main coolant pump [8].

[20] GSR Part 3 [3] uses the term 'interested party' to mean, in a broad sense, a person or group having an interest in the performance of an organization. Interested parties have typically included customers, owners, operators, employees, suppliers, partners and trade unions; the regulated industry or professionals; scientific bodies; governmental agencies or regulatory bodies; the media; the public (individuals, community groups and interested groups). The term could also include other States (e.g. neighboring States for which there are possible transboundary impacts).

MONITORING AT THE DIFFERENT STAGES IN THE LIFETIME OF A FACILITY

5.14. For certain facilities, for example, nuclear power plants and other nuclear installations, there are generally multiple stages throughout the lifetime of the facility (see IAEA Safety Standards Series No. SSG-12, Licensing Process for Nuclear Installations) [40]. Changes that occur across these stages can alter the impacts on the public and the environment, therefore, the nature of the monitoring programme should be appropriate for the characteristics of these different stages, and aspects such as the extension, scope and frequency of the sampling and the type of environmental media to be monitored should be taken into consideration to reflect any changes in the facility at the different stages. The allocation of resources for monitoring programmes at 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 are often needed to characterize the local spatial and temporal variation in environmental concentrations of radionuclides. These measurements can be used to verify the predictions of environmental models used to estimate the transfer of radioactivity through the environment and refine the assumptions and parameters considered in the prospective assessment of the impact of radioactive discharges. When more information and experience has been gained from such characterization, the scale and extent of both source and environmental monitoring can be reduced. Any decision to reduce the frequency of sampling or the scope of the environmental monitoring programme should be justified and documented. 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 with the frequency established by the regulatory body or in the following cases:

(a) When changes are anticipated in the operation of the facility or conduct of the activity, which affect the radionuclides composition or magnitude of the discharges and might lead, for example, to a modification of the discharge authorization;

(b) When significant changes in the demographics, local environment or habits of the local population are observed.

It is advisable to communicate the changes in the monitoring programmes to the public, as appropriate.

Pre-operational stage

5.17. For facilities and activities for which a site evaluation is part of the authorization process, pre-operational studies should be performed in planned exposure situations to establish baseline environmental radiation levels and activity concentrations for the purpose of subsequently determining the radiological impact of the source. The results from the baseline characterization studies should be used for evaluating the impact of facility operation on the site and the surrounding area, determining the acceptability of proposed decommissioning options, establishing end state criteria and demonstrating compliance with the proposed end state (see IAEA Safety Standards Series Nos GSR Part 6, Decommissioning of Facilities [41], SSG-47, Decommissioning of Nuclear Power Plants, Research Reactors and Other Nuclear Fuel Cycle Facilities[42] and SSG-49, Decommissioning of Medical, Industrial and Research Facilities [43]). Pre-operational studies should also provide information for use in the prospective assessment of doses to the public (see GSG-10 [5]), such as information on the expected inventories of radionuclides during normal operation of a facility, the possible discharge routes and the likely amounts that will be discharged to the environment, with consideration of the effluent treatment systems that will be installed. Pre-operational studies should include the monitoring of environmental media in order to provide accurate baseline values for the measurements to be taken during the operational stage. The prospective assessment of doses to the public should be evaluated by the regulatory body before issuing an authorization for discharges to the environment (see GSG-9 [4]).

5.18. The pre-operational monitoring programme should include an evaluation of the need to identify suitable bioindicators or inert indicator materials (e.g. water catchment soils, marine and riverine sediments) for particular radionuclides. The pre-operational monitoring programme should also serve to train staff, verify adequacy of the analytical capacity initially stablished, test instrumentation, and ensure effective organization of the monitoring programmes for the operational stage.

5.19. The pre-operational monitoring programme should be initiated sufficiently 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. For nuclear power plants a pre-operational environmental monitoring programme should be implemented two to three years before the planned commissioning of the plant. This pre-operational programme should provide for the measurement of background radiation levels in the vicinity of the site and their variation over and between the seasons. It should also provide the basis for the operational programme

of environmental monitoring and should include the routine collection and radionuclide analyses of various samples, such as samples of air, soil, water, sediments, foodstuff and other environmental media collected from several fixed and identified locations outside the site. The results of this pre-operational 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, at least one area that can be assumed to be unaffected by the facility or activity should be identified. If such areas are not already included in existing environmental monitoring programmes, pre-operational monitoring should also be conducted in these areas to provide control measurements for comparison with impacted areas.

Operational stage

Source monitoring at the operational stage

5.21. The design and implementation of a source monitoring programme in the operational stage should enable verification of compliance with the authorized discharge limits and operational conditions specified by the regulatory body. For licensed facilities, particularly for nuclear installations, periodic monitoring of the direct radiation[21] in the immediate vicinity of the facility and monitoring of discharges should be considered.

5.22. Direct radiation from the source should usually be measured at the boundaries of the controlled and supervised areas and at the boundaries of the facility. The monitoring of direct radiation can be performed using off-line integrating passive devices (such as thermoluminescent dosimeters), by periodic surveys using portable radiation meters or through an on-line network of dose rate meters. In cases in which the implementation of an on-line network is justified, some dose meters can be placed in nearby populated areas. The on-line network might also be useful to detect an unplanned significant increase in direct radiation from the source or an unplanned release of radioactive material (see Ref.[44]).

5.23. The monitoring of radioactive discharges may entail measurements of specific radionuclides or total activity measurements, as appropriate. If the discharge limits are given for 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

[21] Direct radiation exposure can be a non-negligible exposure pathway if a facility is storing spent fuel in an above-ground interim storage facility on site.

of the radionuclide composition in the discharges should be performed at least once, or at the intervals approved by the regulatory body, and whenever there might be changes in the radionuclide composition of releases.

5.24. Monitoring of discharges 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 effluents should be adequately characterized by the volume of the batch and the radionuclide composition either of a sample taken from the homogenized batch prior to discharge, or of a proportional flow sample taken during discharge. For continuous discharges, time integrated or continuous measurements should be used to ensure a correct assessment of the release.

5.25. In selecting the sampling and measurement procedures, the following should be taken into consideration:

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

(b) The expected variation over time in the discharge rates, in the composition of radionuclides and in the volume of effluent involved;

(c) The likelihood of abnormal or unexpected releases needing prompt detection and notification, and possible protective actions.

5.26. 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. To assess the radiological impact of the discharges, other physical and chemical parameters should also be considered.[22]

5.27. In selecting the instrumentation for source monitoring, possible abnormal releases should also be considered to ensure that the measurement range is sufficient and that alarm levels are adequately set. In designing the monitoring system, there should be sufficient flexibility of response for accidental releases, taking into consideration that the radionuclide

[22] These parameters include the physical and chemical form and solubility of the radionuclide(s) discharged; the particle size distribution in the case of airborne discharges; the pH in the case of water based liquid discharges; the temperature of the effluent; and the volatility of the substances in the discharges.

composition and physical and chemical characteristics of an accidental release are likely to be different from the discharges in normal operation.

Environmental monitoring at the operational stage

5.28. Measurements should be made, and sampling performed, at appropriate locations outside the boundary of the facility. The measurements should include, as appropriate, external radiation levels and radionuclide activity concentrations in all relevant environmental media. The locations where measurements and sampling are to be performed 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 should be considered in nearby populated areas, as appropriate, for public assurance, as well as in unaffected areas for comparison.

5.29. In addition to measurements that directly relate to exposure pathways to humans, the measurement of activity concentrations in bioindicators or inert indicator materials should be considered. This could include measurement of seaweed, lichen or suspended particulate matter that are not direct parts of the food chain but can provide data on trends and the buildup of radionuclides in the environment.

5.30. When environmental monitoring is performed to assess the impact of a particular facility or activity, measurement points and sampling points should be selected and analytical methods should be applied that allow the detection of radiation and radioactive contamination arising from the source under consideration.

5.31. Where there are several facilities or activities giving exposure to the same group of individuals, there may be a need to select sampling locations where the aggregate effect of all discharges can be assessed. In designing the monitoring programme in this case, information on the direct irradiation and the radionuclides discharged from each of the contributing sources is 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.

Decommissioning stage

5.32. During decommissioning, the monitoring programme should reflect changes in the characteristics of the discharges (e.g. radionuclide composition, magnitude of discharge, release rate). 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.[23] The monitoring programme for the source and the environment that were in place during operation of the facility should be re-evaluated whenever dynamic changes in the site occur to determine whether they remain appropriate. Any changes in the arrangements for source and environmental monitoring should be documented in the decommissioning plan and implemented, as appropriate.

Source monitoring at the decommissioning stage

5.33. The objectives of source monitoring at the decommissioning stage should be essentially the same as those at the operational stage. When designing a source monitoring programme for the decommissioning stage, possible changes in the quantities, radionuclide composition and physicochemical characteristics of the releases should be considered, as well as changes in the external radiation fields around the facility. As the facility undergoes 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 or approved by the regulatory body.

5.34. 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 need prompt detection and notification.

Environmental monitoring at the decommissioning stage

5.35. The environmental monitoring programme during the decommissioning of a facility might be initially similar to that for the operational stage but should be modified to take account of changes in the source term, the exposure pathways and the representative person. 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 and reviewed as decommissioning progresses. The

[23] Radioactive discharges in liquid and airborne form are likely to change as a result of the decommissioning process and will eventually cease. However, the decontamination and dismantling activities integral to decommissioning might result in increased radioactive releases through the creation, suspension and resuspension of contaminated aerosols. For a nuclear power plant, once reactor operations have ceased, short lived fission products in the discharges rapidly decline; however, the occurrence and resuspension of aerosols might increase the discharges of activation products. In addition, as decommissioning progresses, area sources become more likely to occur, whereas the potential for large emergency releases becomes less likely [42].

measures established to minimize the spread of residual radioactivity to the environment resulting from decommissioning activities, should be reviewed, and modified as appropriate.

Release from regulatory control

5.36. Prior to the release of sources or sites from regulatory control, monitoring should be conducted to verify compliance with the authorized end state criteria[24]. Recommendations for monitoring at this stage are provided in IAEA Safety Standards Series DS542, Release of Sites from Regulatory Control on Termination of Practices [45].

PUBLIC DOSE ASSESSMENT FOR A PLANNED EXPOSURE SITUATION

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

5.38. When sufficient results of measurements of the activity concentration of radionuclides in air, water and food are available, the calculation of doses on the basis of these measurement results is preferable to modelled assessments, which may contain significant statistical uncertainties. In many cases, only some of the radionuclides in the discharges can be measured in the relevant environmental media above the detection limits.[25] 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. Additional recommendations on dose assessment from internal exposure pathways are provided in paragraphs 9.16 – 9.18.

5.39. When possible, the models used for the prospective radiological impact assessment should be checked for accuracy through a comparison of the results predicted with the actual data from measurements. Data from environmental monitoring at the operational stage of a facility or during the conduct of an activity can be used as an input to verify compliance with

[24] End state criteria are predetermined criteria defining the point at which a specific task or process is to be considered completed. These criteria are used in relation to decommissioning activities as the final state of decommissioning of a facility [8].

[25] Both measurement results above the detection limits and measurement results below the detection limits can be used for dose assessment purposes. However, it should be noted that, in cases when measurements are below the detection limits, the use of detection limits as substitutive values might lead to a substantial overestimate in the estimated dose. Radionuclide concentrations that cannot be measured above the detection limits can be computed using scaling factors. It is an accepted practice to derive the activities from a fraction of the detection limit to avoid unrealistic dose estimation.

any applicable derived limits on the radionuclide concentration in the environment and dose limits and constraints (see GSG-10 [5]).

5.40. Doses from external exposures should include, as relevant, the external irradiation from sources within the facility and the external irradiation from radionuclides in an atmospheric plume or deposited on surfaces. The assessment of doses from external irradiation from a source within the facility using direct dose rate measurements is straightforward: the radiation field in the vicinity of the source may be measured using simple radiation detectors or calculated using radiation exposure mathematical methods. The results of source monitoring within a facility can be extrapolated to provide estimations on locations outside the facility. Additional recommendations on retrospective dose assessment from monitoring results are provided in Section 9.

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

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

(a) Discharge limits for the facility or activity;

(b) Environmental limits, as appropriate (see para. 5.44);

(c) Dose constraints for the facility, activity or site;[26]

(d) Dose limits for members of the public.

5.42. 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.

5.43. Discharge limits should include a margin of flexibility to provide for operational variability and for anticipated operational occurrences (see para. 5.67 of GSG-9 [4]).

[26] Recommendations on dose constraints for sites with multiple facilities or for facilities and activities where more than one source is present, which could contribute to the exposure of the representative person, are provided in GSG-9 [4].

5.44. 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 media. Data from environmental monitoring should be used to ensure that actual radiation levels and radionuclide concentrations are below these limits.

5.45. The operating organization is required to report promptly to the regulatory body whenever discharge limits have been exceeded (see para. 3.137(d) of GSR Part 3 [5]). The report should include the circumstances of the release, the results of any additional monitoring and estimation of doses to the public from the release. Operating organizations should also report promptly to the regulatory body a substantial[27] unexpected increase in environmental radiation fields or activity concentrations, or an unplanned release of a substantial 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 or reducing the level of discharges) and the actions that are anticipated for the immediate future, including corrective actions and plans for the resumption of discharges.

5.46. The operating organization is required to report the results of the monitoring programme for a facility or activity to the regulatory body at approved intervals (see para. 3.137(c) of GSR Part 3 [2]). This should include, as applicable, the results of dose assessments derived from the source monitoring or the environmental monitoring data and other data (e.g. meteorological) that are relevant to the dose assessment. A comparison with dose limits and dose constraints should also be presented. The analysis should present any trends and variations observed in comparison with previous results.

[27] 'Substantial' is used to convey the idea of a real, meaningful increase rather than just a fluctuation within the usual deviations

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 a radioactive release and assist in decision making on, or adjustment 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 [9]). These should include the responsibilities for monitoring in accordance with the possible radiological consequences of the emergency.

6.2. Depending on the severity of a nuclear or radiological emergency, all three types of monitoring (i.e. source monitoring, environmental monitoring and individual monitoring) should be performed, in accordance with a graded approach.

6.3. Monitoring during an emergency may be undertaken by several organizations (e.g. operating organization, regulatory body, technical support organizations, response organizations). The coordination between these organizations in relation to monitoring should be established by the government 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, emergency workers[28] and helpers, and the environment. The protection strategy should provide information necessary to make decisions on protective actions[29] and other response actions (see GSR Part 7 [9], GS-G-2.1 [13] and IAEA Safety Standards Series No. GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [46]), and should either be included in the emergency plan, or issued as a standalone document, as appropriate. The monitoring strategy should be established on the basis of the hazard assessment, and should follow a graded approach, as requested by the government (see Requirement 4 of GSR Part 7 [9]) and should be adjusted on the basis of the prevailing circumstances during the emergency.

[28] An emergency worker is a person having specified duties as a worker in response to an emergency. Emergency workers may or may not be designated as such in advance of an emergency. Emergency workers not designated as such in advance of an emergency are not necessarily workers prior to the emergency [8].

[29] Protective actions may include on-site and off-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, primarily based on monitoring, and can be taken within days or weeks (see GSG-11 [14]). The emergency planning and response requirements are established in GSR Part 7 [9], and detailed recommendations are provided in GSG-11 [14] and Refs [47,48].

6.5. The monitoring strategy for an emergency exposure situation should take into account both national and transboundary impacts. States should establish national strategies to respond 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 monitoring activities. For those States that do not need extensive emergency monitoring capability, monitoring to provide a baseline for assessing the radiological impact of emergencies in neighbouring countries should be considered. This monitoring might also contribute to maintaining competences for emergency monitoring in the event of an emergency that has transboundary consequences. The national monitoring strategy could include the establishment of a network of monitoring stations for early warning and to follow the evolution of environmental conditions at the regional scale.

RESPONSIBILITIES FOR MONITORING IN AN EMERGENCY EXPOSURE SITUATION

6.6. In preparation for any emergency, as part of the protection strategy based on the hazards identified, the government should ensure that a monitoring strategy is developed. The monitoring strategy should take account of the type of emergency and the resources needed to undertake monitoring, and should stipulate priorities for the different phases of the emergency[30], in accordance with the protection strategy.

6.7. The regulatory body or other competent authorities[31] should ensure that arrangements for monitoring on the site and in its vicinity during an emergency are established by the operating organization and are routinely tested. This should include ensuring the capacity and capability for rapid monitoring during an emergency.

6.8. The operating organization should establish and maintain an adequate capability to conduct monitoring on the site and in the vicinity of a practice or source for which authorization has been granted, in accordance with an emergency plan approved by the regulatory body.

6.9. The government is required to ensure that there is coordination between all the organizations involved in emergency preparedness and response at the local, regional, national levels, and, where appropriate, at the international level (see Requirement 22 of GSR Part 7 [9]

[30] GSG-11 [14] proposes a sequence of phases of a nuclear or radiological emergency, as follows: the urgent response phase, with a typical duration of hours to days from the onset of the emergency; the early response phase, with a typical duration of days to weeks from the onset of the emergency; and the transition phase, with a typical duration of days to a year from the onset of the emergency.

[31] Although the term ‘competent authority’ is generally used in the context of transport and nuclear security [8], it is used in this Safety Guide to refer to any body or authority designated by the government as having responsibility in an emergency situation.

and Ref. [49]). This should include establishing a coordinating mechanism to identify responsible organizations and coordinate all the monitoring activities involved in emergency preparedness and response.

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

OBJECTIVES OF MONITORING IN AN EMERGENCY EXPOSURE SITUATION

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

(a) To guide decision makers on the need to take protective actions and other response actions (e.g. see Refs [47, 48, 50]);

(b) To contribute to dose assessment and provide information for the protection of the public, emergency workers and helpers;

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

(d) To provide information on the efficacy of the protection strategy;

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

(f) To provide technically correct information to keep the public informed and maintain public trust;

(g) To facilitate the coordination and consistency of national emergency arrangements with international emergency agreements under the relevant instruments (Ref.[49]).

Source monitoring in an emergency exposure situation

6.12. 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 results of environmental monitoring. Source monitoring should be conducted to provide information for emergency classification[32] and to facilitate the assessment of the magnitude of the radiological hazard and the possible development of conditions throughout a nuclear or radiological emergency. This will allow the prompt initiation of an effective response and, where apppropiate, revision of the protection strategy (see GS-G-2.1 [13]). Source monitoring can be used to obtain information for the estimation of the accident source term and to assist in the implementation of environmental monitoring.

6.13. For facilities that might experience an accidental release that requires urgent protective actions, early protective actions or other response actions, a continuous or batch monitoring system that can measure the potential range of activity concentrations should be established at all potential release points (e.g. stacks and discharge points of radioactive liquid effluents). Additional technical information about source monitoring in emergency exposure situations is provided in Ref. [44].

6.14. The arrangements for source monitoring should consider that for certain accidents, further releases might 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, information related to source terms can also be derived from other measurement devices on site or at the boundaries of the facility.

Environmental monitoring in an emergency exposure situation

6.15. Environmental monitoring in an emergency exposure situation should provide information on the need and extent of protective actions and other response actions, and should facilitate the following:

(a) Identification of areas in which urgent or early protective actions or other response actions

[32] Emergency action levels are predefined criteria for the classification of an emergency. In the case of an emergency at a nuclear facility, they are on-site observables that can relate to abnormal conditions, security related concerns, releases of radioactive material, environmental monitoring, and other observable indications (see GSG-2 [46]).

need to be implemented;

(b) Confirmation of whether the urgent and early protective actions implemented (e.g. evacuation, sheltering, relocation, iodine thyroid blocking) are appropriate;

(c) Estimation of the accident source term;

(d) Assessment of doses to members of the public, emergency workers and helpers;

(e) Provision of information to identify any need for individual monitoring;

6.16. Depending on the duration of the release[33], environmental monitoring may include measurements of dose rates and the sampling of radionuclides from the plume to compare with operational criteria for emergency preparedness and response (see GSR Part 7 [9]). 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 and drinking water contamination, taking into account the pathways of radiation exposure and the protection and safety of the individuals taking the measurements. Additional technical information about environmental monitoring during and after the passage of the plume is provided in Ref. [44].

6.17. During and immediately after the onset of a nuclear or radiological emergency, the available monitoring resources might be insufficient to meet all the monitoring requirements, particularly after a severe nuclear accident. The available resources should be utilized as effectively and efficiently as possible, by setting priorities that take into account aspects such as the population distribution and land and water use in the emergency planning zones, the distances involved, the available infrastructure, and the prevailing meterorological conditions. It might be necessary to request support from other organizations including those that do not normally have responsibility for monitoring; in this case, it should be ensured that the monitoring capabilities of these organizations are adequate and that their personnel are capable of performing the necessary monitoring tasks. The monitoring strategy should anticipate such situations, including the signing of agreements and provision of training in advance of an emergency.

6.18. The effects of a protracted release of radioactive material on the available resources for emergency monitoring should be considered when developing the monitoring strategy.

[33] In many cases the significant release will be over by the time the results of environmental measurements are available; it might also be difficult to take samples and analyse air concentrations in a timely manner [47].

6.19. For facilities that could warrant urgent protective actions or early protective actions and other response actions (see table 1 of GSR Part 7 [9]), 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.

6.20. The arrangements for environmental monitoring should take into account that a large volume of monitoring data (including dose rates, activity concentrations and deposition of radionuclides in relevant media over large areas, meteorological conditions) needs to be collected and made available in a timely manner to reflect the evolving situation. The arrangements should also allow for comparison of these data with the operational criteria and for the fast estimation of doses so that prompt decisions can be made about the implementation of appropriate protective actions (see Ref. [47]).

Individual monitoring in an emergency exposure situation

6.21. Individual monitoring of members of the public may be appropriate in the context of an emergency exposure situation. Such monitoring should be appropriately justified and implemented effectively, efficiently and in a timely manner, by setting priorities. Permission should be sought from each person before performing individual monitoring, and the nature and purpose of the measurements, and the planned use and protection of the information obtained, should be explained to the persons being monitored.

6.22. Monitoring 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 [9]). 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 verifying the dose assessments that have been made (see Refs [44, 33]).

6.23. In establishing the individual monitoring strategy, it should be considered that the interpretation of measurements of external exposure for the purpose of dose assessment might be limited as the dose might fall within the range of the natural background radiation level. Therefore, individual monitoring of the external dose rate is only of value if the dose rate in the area significantly exceeds the natural background level. Selected representative members of the public may be provided with individual dosimeters along with instructions for their use.

6.24. Measurements of quantities of radionuclides taken into the bodies of individuals should provide input for the assessment of the committed dose and may help to reassure members of the public, for example, those who have been evacuated. The decision to conduct individual monitoring should be balanced against causing unnecessary alarm to the potentially affected population. Measurements of iodine isotopes in the thyroid, other gamma emitters (e.g. cobalt and caesium isotopes), beta emitters (e.g. tritium and ^{90}Sr) and alpha emitters (e.g. radium, uranium and plutonium isotopes) should be considered in accordance with the radiological characteristics of the emergency[34]. The arrangements for individual monitoring should take into account the urgency with which short lived radionuclides such as ^{131}I need to be measured in order to be detected in the body (see Refs [44, 33]).

PUBLIC DOSE ASSESSMENT IN AN EMERGENCY EXPOSURE SITUATION

6.25. 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 combination of these. Data from monitoring should be combined with supporting information (e.g. data on meteorological and hydrological conditions, data on habits) appropriate assumptions, environmental dispersion and transfer models, and dose coefficients (see Refs [51, 52]), to assess doses to the representative person[35] and emergency workers.

6.26. For identification of the representative person in emergency situations, different exposed population groups should be considered, depending on the characteristics of the emergency, for example the prevailing meteorological or hydrological conditions, possible temporary occupancy and seasonal variations in habits and in consumption of food products (see para. 5.63 of GSG-10 [5]).

6.27. 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 assessment of doses from discharges in planned exposure situations might not be appropriate to estimate doses in emergency exposure situations.[36]

[34] The measurement procedure depends on the emitter. Monitoring of radioiodine content in thyroid glands is undertaken with an appropriately calibrated gamma detector. The direct measurement of other gamma emitting radionuclides may be performed using whole body counters. The doses due to incorporated beta emitters are usually estimated by bioassay (see GSG-2 [46] and Ref. [50]).

[35] The representative person identified for potential exposures may be different from the representative person for exposures in normal operation.

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

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

6.28. Monitoring data should be interpreted and presented to governmental organizations with responsibility in decision making in a form (e.g. using tables, maps, indications of time evolution, appropriate and consistent units) that facilitates well-informed decisions. The monitoring results and related analysis by different organizations (at the local, national and international levels) conducting monitoring should be presented in a pre-arranged compatible format[37]. The regulatory body or other competent authority should establish the format, content and frequency of reports by organizations conducting source and environmental monitoring activities in an emergency exposure situation. Systems to collect, maintain and share this information with different users, in accordance with pre-established agreements on the level of access, should be developed, as appropriate.

6.29. The government is required to ensure that arrangements are in place to provide the public with information that is necessary for their protection (see Requirements 10 and 13 of GSR Part 7 [9]). This should include arrangements for the regulatory body or other response organizations to promptly communicate to the public clear information, including in the languages spoken by the locals. The information communicated should be based on the results of monitoring and additional analysis and interpretation by specialists. The information should use understandable terminology to convey health risks and practical advice on protective actions and other response actions. Communication should assist in preventing the spread of misinformation. Further recommendations are provided in IAEA Safety Standards Series No. GSG-14, Arrangements for Public Communication in Preparedness and Response for a Nuclear or Radiological Emergency [54].

6.30. When the results of monitoring programmes indicate that some information is relevant outside national boundaries, this information should be shared with the States concerned in accordance with the Convention on Early Notification of a Nuclear Accident [49]. The State where the emergency occurred should provide such information to the States concerned using the agreed means for exchange of information and consultations (see Ref. [53]).

[37] Information on the content and format of reports of measurement results for record keeping and information exchange is provided in Ref. [53].

7. MONITORING IN AN EXISTING EXPOSURE SITUATION

7.1. The monitoring programmes for 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 (see Ref. [16]) and 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 (see para. 5.8 of GSR Part 3 [3]). It can also be used to identify areas in which further, more detailed monitoring is needed. In areas with residual contamination as a consequence of a nuclear or radiological emergency, the monitoring conducted, and the protective actions implemented, during the emergency response should be considered in the development of the monitoring programme for the existing exposure situation.

7.3. A monitoring programme for an existing exposure situation should be justified, and should follow a graded approach. The type and extent of the monitoring programme, including the monitoring frequency, should take into account the characteristics of the affected area or site, the nature of the contamination, the number of people exposed, and the access to the site or area, in order to focus efforts on the highest radiological risk.

7.4. Characterization[38] should be conducted to assess radiological conditions and identify areas where remedial actions may be necessary. Monitoring should then be performed to support decisions on the justification of remedial actions. If a decision for remediation is made and remediation is initiated, monitoring should be performed to verify the effectiveness of remedial and protective actions and to confirm that they have been optimized (see GSG-15 [16]).

7.5. Monitoring should be undertaken prior to and during the remediation of an area, and when required by the regulatory body or other responsible authority, as part of post-remediation control. The concept of clearance applies to the management of material originating from remediation activities, with the same qualitative and quantitative criteria as for the clearance of material in planned exposure situations (see para. 5.4). Likewise, for cleared materials originating from remediation activities, there are no further requirements for monitoring. GSG-

38 Characterization is defined as the determination of the nature and activity of radionuclides present in a specified place [8] and is conducted as part of preliminary and detailed evaluations and as needed throughout the remediation process see GSG-15 [16].

18 [37] provides recommendations on the application of the screening values for recycling or disposal of materials and waste generated during remedial actions after a nuclear or radiological emergency. GSG-15 [16] provides recommendations on the management of residual materials generated during remediation.

7.6. For existing exposure situations resulting from emergencies or past activities in which health follow-up was recommended, the need for individual monitoring should be considered, as appropriate.

RESPONSIBILITIES FOR MONITORING IN AN EXISTING EXPOSURE SITUATION

7.7. 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 [3]). This should include the responsibilities for monitoring. The identification of the responsible party in an existing exposure situation is not always straightforward.[39] In cases where it is not possible to identify a responsible party, the responsibility should remain with the government.

7.8. If the operating organization of a past practice that resulted in an existing exposure situation has been identified, this organization should have the responsibility to assess and manage that situation, including performing the appropriate monitoring. If 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.

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

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

(b) Conduct appropriate monitoring to allow the radiological evaluation of the area[40].

In addition, if remedial actions have been justified, the responsible party should also take the following actions:

[39] For example, for sites with residual radioactivity, the responsible party may be the organization with responsibility for planning and implementing the remediation (see GSG-15 16).

[40] 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 (see GSG-15 [16]).

(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.

And finally, once remedial actions have been completed, the responsible party should take the following actions:

(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 programme, including after the completion of the remedial actions.

7.10. The regulatory body is required to review the monitoring programme (see para. 5.13(c) of GSR Part 3 [3]) and should perform confirmatory independent monitoring, as appropriate (see para. 2.34(j) of GSG-15 [16]).

OBJECTIVES OF MONITORING IN AN EXISTING EXPOSURE SITUATION

7.11. The objectives of a monitoring programme in an existing exposure situation involving 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 assist in the establishment of reference levels (see para. 5.8 of GSR Part 3 [3]);

(c) To compare measurements with the reference levels and other radiological criteria and to identify areas where more detailed monitoring is needed;

(d) To identify areas in which remedial actions or protective actions may be justified;

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

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

(g) 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;

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

(i) To provide information to support decisions related to release of contaminated land from regulatory control and application of restrictions and institutional controls, as relevant[41].

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

SOURCE, ENVIRONMENTAL AND INDIVIDUAL MONITORING IN AN EXISTING EXPOSURE SITUATION

Source monitoring in an existing exposure situation

7.12. In many existing exposure situations, the source is the radioactive contamination being evaluated and it might be spread across a large area that changes over time due to natural processes or disruptive events, which can be either natural or man-made. Source monitoring in such situations can be similar to environmental monitoring.

7.13. Monitoring should assist in the delineation of areas needing 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 (see GSG-15 [16]).

Environmental monitoring in an existing exposure situation

7.14. 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 take that information into consideration. Where information about the source term is absent, incomplete or insufficient and needs to be supplemented, historical records and local surveys could be used to inform the design of an initial screening programme. Results of this initial screening could be compared to the background levels to identify and differentiate the radionuclides present in the environment due to the past activities or emergencies.

[41] Recommendations on environmental survey, surveillance and monitoring related to the release of remediated areas from regulatory control, including conditions for restricted and unrestricted release, are provided in GSG-15 [16].

7.15. To develop an effective environmental monitoring programme for sites or areas with residual radioactive material, the most significant exposure pathways should be characterized and any likely changes in their significance in the future identified. Changes in the most significant exposure pathways, for example, in cases where remedial actions alter the distribution of radionuclides in the environment (e.g. tree removal, excavation, blasting, diversion of water courses) or where groundwater contamination reaches surface water over a period of time, 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.

7.16. Areas with residual radioactive material might include sites with multiple contaminants (e.g. chemical and biological contaminants). For these sites, coordination with other responsible authorities should be considered to obtain a common understanding of the situation and harmonize monitoring activities.

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

External exposure

7.18. Where large areas need 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.

7.19. 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 distribution of radionuclides across the area monitored, seasonal changes in the dose rate due to weather conditions (e.g. snow cover, precipitation) and the reduction of dose rates in urban environments due to paved areas and to shielding provided by the buildings.

Internal exposure

7.20. In areas with residual radioactive material, the inhalation of resuspended radionuclides from the ground might cause 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, the resuspension of radionuclides (e.g. as a result of wild fires) should be considered. In the case of areas contaminated with natural radionuclides, such as naturally occurring radioactive material (NORM) legacy sites, public exposure due to radon indoors can be an exposure pathway of concern and should also be considered. SSG-32 [21] addresses the protection of the public against exposure indoors due to radon.

7.21. If the radioactively contaminated area extends to agricultural land, samples of all major animal products and crops (e.g. vegetables, milk, meat) produced in the area should be regularly sampled and analysed for their radionuclide concentrations. The environmental monitoring should also include wild food products (e.g. game, mushrooms, berries) where it is known they are consumed. Drinking water should be monitored if a source of drinking water is present in the contaminated area or could be contaminated by the migration of radionuclides. Further information on the assessment of public health risks from radionuclides in drinking water is provided in Ref. [55]. Further information on the monitoring of radionuclides in the diet is given in Refs [18, 19]. 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 through soil or groundwater, or into biological matrices.

7.22. In areas with significant radioactive contamination, radionuclide activity concentrations in environmental media 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 [3]).

Individual monitoring in an existing exposure situation

7.23. Individual monitoring of the public may be considered appropriate in the context of an existing exposure situation resulting from an emergency or past activities: if so, such monitoring should be appropriately justified. Individual monitoring should be conducted if medical follow-up is necessary and may also be useful as a means of reassuring individuals and verifying the dose assessments that have been made (see Ref. [44]).

7.24. Individual monitoring in an existing exposure situation should consider the need for measurements of internal and external exposures of individuals (see Ref. [33]) and should provide input for assessing the committed dose. Individual monitoring should take into account the presence of long lived radionuclides and their possible build up in the environment.

PUBLIC DOSE ASSESSMENT IN AN EXISTING EXPOSURE SITUATION

7.25. For routine discharges, the doses calculated for the representative person as part of the authorization process are often conservative. In contrast, the doses calculated for the representative person 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 areas where there is significant variation in the contamination distribution, exposures that are not certain to occur should be assessed, as appropriate. [42]

7.26. 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 (see Ref. [56]).

7.27. 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. Additional

[42] In certain situations, (e.g. in cases of heterogeneous contamination, such as discrete radioactive particles) the transfer and characteristics of the source could potentially lead to higher exposures. These exposures are not certain to occur, however. It is important in these situations to identify the exposure pathways and to determine the probability of exposures that could occur, together with the magnitude of the detriment.

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

7.28. 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 (see paras 9.20–9.22).

7.29. For practicality, derived criteria[43] 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 as necessary (see para. 3.14 of GSG-15 [16] and Ref. [39]).

7.30. Reports of the results of the source monitoring and environmental monitoring programmes should be produced at periodic intervals, at least once per year, 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 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.

7.31. 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 if the area can be released from regulatory oversight.

[43] The term ‘derived criteria’ is related to the concept of ‘derived reference levels’, defined in Ref. [39] as 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, emergency or existing), and the aspects of relevance that may impact the monitoring activities, including prior knowledge of the site and background monitoring data, should be taken into account. Background monitoring includes the investigation done to establish baseline levels of radiation and/or radionuclide concentration to be compared against subsequent conditions.

8.2. The 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 for the public[44] and the environment. Table 2 summarizes the relationship between the types of exposure situation and the types of monitoring recommended.

TABLE 2. TYPES OF MONITORING RECOMMENDED FOR DIFFERENT EXPOSURE SITUATIONS

Exposure situation		Type of monitoring		
		Source monitoring	Environmental monitoring	Individual monitoring[a]
Planned	Exempted, cleared and notified practices or sources	Not recommended	Not recommended	Not recommended
	Registered practices or sources	Recommended	Not recommended	Not recommended
	Licensed practices or sources	Recommended	Recommended	Not recommended
	Multiple sources	Recommended	Recommended	Not recommended
Emergency		Recommended	Recommended	As appropriate
Existing	Areas with residual radioactive material	Recommended	Recommended	As appropriate

[a]For members of the public.

8.3. Although the objectives of a monitoring programme are expected to vary between planned exposure situations, emergency exposure situations and existing exposure situations,

[44] In all exposure situations, conceptual site models, and where relevant, quantitative models need to be developed to understand how important radionuclides may move through the environment and potentially lead to radiation exposures (see GSG-10 [5] and GSG-15 [16]). Conceptual site models are often diagrams that illustrate the relationships between sources, transport mechanisms, exposure routes, and receptors. Quantitative elements can be added into conceptual models that then evolve into more detailed mathematical models, supporting radionuclide transport modelling and dose calculations.

in all cases, monitoring should provide information and data for assessing the radiological impact on the public and the environment. The following elements should be taken into account in the design of any monitoring programme:

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

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

(c) Radionuclide activities being released per unit of time (i.e. release rates);

(d) Exposure pathways[45] (Fig. 1 illustrates the pathways by which an individual might be exposed following the discharge of radionuclides to the atmosphere, surface water or groundwater);

(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) Magnitude of the estimated dose to the representative person;

(h) Longevity of the contamination creating radiological risks.

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[46] (for planned exposure situations) and also from the radiological hazard assessment (for emergency exposure situations). This information 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 expected radiation risk.

[45] Exposure pathways by which releases could give rise to exposure of members of the public are listed in GSG-10 [5]. Depending on the exposure scenarios and the site characteristics, not all the exposure pathways listed in GSG-10 [5] 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.

[46] 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.

8.6. The design of the monitoring programme (e.g. frequency of sample collection) should take into consideration expected seasonal variations in the environmental media and the resulting variation in the associated exposure. Non-homogeneous distribution of radionuclides should also be considered. Reporting of any unusual 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 the direct radiation from a particular source and the release of radioactive material to the environment.

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) so the magnitude of the release may have to be estimated by using measurements in the environment. Source monitoring in 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 physical and chemical form (which can affect the migration of radionuclides), temperature and flow rates of the release, as well as meteorological, geological and hydrological data and information on the environment.

Design of environmental monitoring programmes

8.10. Environmental monitoring programmes should take into account the characteristics of the source and the mode of any release into the environment together with 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 external radiation levels in inhabited areas, the dose rate should be measured in the zones that are accessible to the public, such as close to 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[47] 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,

8.13. The accuracy of the environmental models used to predict doses should be checked through comparison with the measured data from the environmental monitoring programme. Environmental samples should be taken, and measurements made of the radionuclides that are expected to provide significant contributions to doses at a number of locations selected on the basis of the predicted dispersion pattern of the discharges and on the relevant exposure pathways. In addition, the sampling of food products should be decided 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 6.21–6.24) and in existing exposure situations in which health follow-up is recommended (see paras 7.23–7.24). 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 or external contamination monitoring. Individual monitoring programmes should be adapted to the situation, in particular to the size of the population to monitor.

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

8.15. Baseline monitoring data and data from control measurements, as appropriate, should be collected over a period 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 data 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, accidental releases) are expected.

8.16. For planned exposure situations (and existing exposure situations), the hydrological characteristics[48] 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, where possible, studies performed in the operational stage should be used to identify the general characteristics of the environment that might affect the behaviour and trajectory of accidental releases and that should be considered in the monitoring programme.

8.17. The local water sources and water cycle (including precipitation and evaporation, local surface water and groundwater flow regimes and their interconnections) should be monitored. Characteristics of soils and sediments such as texture, structure, porosity, chemistry, mineralogy and colour can also be studied to assist evaluating spatial and temporal changes in the radionuclide transfer and migration through the soil and sediment to groundwater or vegetation.

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, food consumption rates and the fractions locally obtained, location of drinking water sources, and human activities. Land and water use, such as local agriculture and aquaculture practices should be considered. Particular attention should be paid to individuals who might receive higher dose, because of their habits, or are more sensitve (e.g. farmers, infants, pregnant women). The characteristics of ethnic and cultural minorities and indigenous peoples that may reside in the area should also be considered.

[48] 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.

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 in the event of an airborne release; and surface water and groundwater flow regimes in the event of an aquatic release, should be measured. 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. A monitoring programmes should describe the basis for its design, including the rationale for the media to be sampled, sampling locations, sampling strategy and analytical methods. The following should be specified in a monitoring programme:

(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 measurements or sample collections;

(e) Sampling procedures, sample preservation, sample pretreatment and sample analysis techniques, including reporting values.

(f) Equipment used;

(g) Personnel responsible for each task;

(h) Investigation levels to detect unusual values in the monitoring data;

(i) 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, including uncertainties. It should include a process for ongoing programme evaluation, a process for revising and modifying the programme as needed, and a process for ensuring appropriate qualifications and training of personnel undertaking the monitoring.

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 (see, e.g., Ref. [57]).

8.23. The sampling frequency should be established on the basis of the quantity to be measured, the precision needed, the time dependence and the variability of the quantity[49]. In general, sampling should be more frequent the higher the spatial and temporal variability. For example, more frequent sampling is needed for monitoring radionuclides with short half-lives and food for which there is a short time period between harvesting and consumption.

8.24. To enable representative sampling in the environment, various methods and statistical schemes can be used. Specific procedures are suggested in Ref. [58]. 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 analysis. Table 3 summarizes the main sampling approaches and their features.

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 sample integrity is maintained. Procedures should be in place for quality assurance in sampling and the analysis of uncertainties originating 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.

TABLE 3. SAMPLING APPROACHES FOR ENVIRONMENTAL MONITORING [58]

Sampling approach	Description	Comment
Judgmental sampling	Sample is taken based on the understanding of the environment and	Increased probability of biased sampling; representativeness

[49] 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 preoperational and early operational monitoring.

	exposure pathways	cannot be quantified
Simple random sampling	Any sample has the same probability of being included	Provides samples that are representative of the sampling area; problems might arise if the area is not homogeneous; samples are not reproducible
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

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 measurement 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 measurements of 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 and deliver the necessary accuracy and precision.

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 use measurements from 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 are compared to an operational limit or reference level, the detection limit of the analytical

procedure and equipment should be selected so as to enable measurements to be made at levels that are lower than the limits or levels against which the results are to be compared. This could involve, for example, using more sensitive equipment, collecting a statistically significant number of samples, improving measurement statistics and 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 present, both in operational states and in accident conditions. For example, nuclear power plants might 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. Monitoring systems should have sufficient measurement range, appropriate alarm levels, and flexibility to handle differences in the magnitude of the releases and the radionuclide composition.

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 approach
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 activity
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 activity
Environmental monitoring	
External dose rate above 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	Planchette sampling; discrete or continuous sampling[d]; collector for

Monitoring parameter	Sampling/measurement approach
in dry or wet deposition	dry or 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 (surface water, groundwater and drinking water) and sediment	Field sampling; analysis for specific radionuclides
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 total alpha/beta activity, then routine analysis for specific radionuclides might not be necessary.
[c] Typically measured 1 m above ground
[d] For discrete samples, the sampling interval is determined on a case-by-case basis.

QUALITY ASSURANCE

8.32. A quality assurance programme as part of the management system (see IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [59]) should be an integral part of a monitoring programme 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. A quality assurance programme should, as a minimum, meet the requirements established by the regulatory body or other relevant authority for quality assurance in the field of radiation protection. 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) Appropriate environmental media, locations for sampling and measurement and sampling frequency are selected;

(g) Interlaboratory comparisons of methods and instruments are conducted at the national or international level;

(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 the following:

(a) Design and implementation of monitoring programmes, including the selection of suitable equipment and of sampling locations and procedures, and the documentation of the selection process;

(b) Maintenance, testing and calibration of equipment and instruments;

(c) Uncertainty analysis;

(d) Record keeping;

(e) Chain of custody;

(f) Data management system;

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

8.35. Analytical laboratories performing sample measurements should be qualified to perform the measurements assigned and have the capability to report accurate results.

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[50], as specified in the programme design. These objectives might include targets for detection limits, or limits on precision and accuracy of measurement

[50] 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.

(see Ref. [57]). Quality control samples (e.g. blanks, duplicates, certified reference materials, and matrix spikes) and external quality control (e.g. intercomparison, participation in proficiency tests) should be included in the monitoring programme and used to assess whether the data meet the pre-determined data quality objectives.

MONITORING PROGRAMME EVALUATION AND REVIEW

8.37. Monitoring programmes should be evaluated and reviewed regularly, with the frequency established by the regulatory body or, in the case of planned exposure situations, when changes are anticipated in the operations of the facility or conduct of the activity, which affect the radionuclide composition or magnitude of the discharges. This evaluation and review should ensure that the monitoring programme is producing data that are sufficient to meet the objectives of the programme and that no significant routes of discharge or environmental transfer, and no significant exposure pathways, have been overlooked. If they have, the 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 be updated to reflect these changes.

8.39. If there are significant changes in the operational conditions, environmental conditions or regulatory requirements, which may have an impact on the monitoring programme, the programme should be reviewed. Any decision to make a change to the monitoring programme should be documented, and approved by the regulatory body, as appropriate, along with evidence that the programme continues to be fit for purpose.

9. DATA MANAGEMENT, ANALYSIS AND 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, and to facilitate assessment of data quality, the interpretation of results and traceability of data over time (e.g see Ref. [60]). Measured values should be recorded with their units, including an indication of fresh or dry weight for mass-based measurements.[51]

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 with a specified confidence level.

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

9.4. The government or the regulatory body should specify a retention period for monitoring data. Records, including records of all relevant observations in the course of the analysis and of the parameters used for the calculation of the data reported should be kept for the established period.

9.5. Results of individual monitoring and related information should be carefully managed since they contain personal and health related information.

[51] 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. Data analysis and interpretation should be consistent with the objectives that were specified in the programme design. Data analysis might include, for example, comparison of individual results (or calculated mean 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. Unexpected results should be investigated to determine if any changes in the monitoring programme are needed, and reported, as appropriate.

9.7. 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.[52]

Data interpretation

9.8. The results of a monitoring programme, whether for source, environmental or individual monitoring, or a combination thereof, 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.

9.9. 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

[52] A preliminary evaluation of the data can be helpful in selecting 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.

documented in an open and transparent manner, including the assumptions used in interpreting the results.

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

(a) Results of source monitoring, of environmental monitoring and of individual monitoring, if applicable;

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

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

(d) In situ gamma surveys and sample measurements;

(e) Routine and periodic measurements;

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

9.11. When different types of monitoring (i.e. source, environmental and individual) are performed, there should be effective coordination between the respective monitoring programmes. Information obtained from one programme may contribute to a better understanding of the another.

Dose assessment from monitoring results

9.12. 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 or other authority. 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). These retrospective dose assessments should include a calculation of the dose to the representative person (see paras 3.7–3.8). GSG-10 [5] provides recommendations on the assessment of the dose to the representative person.

9.13. In some cases, retrospective assessment of the radiological impact on the public from radioactive releases or residual radioactivity in the environment cannot rely solely on the results of monitoring programmes. In such cases mathematical models[53] can be used to calculate

[53] The IAEA issued a Safety Report on methods and models that can be used to assess the impact of releases of radioactive substances to the environment [61] and Technical Reports relating to environmental transfer parameters [55, 62].

doses from data acquired from source or environmental monitoring (or a combination of both). The results of such retrospective assessments should be used with careful consideration, taking into account both the cautious nature of models used for environmental dispersion and transfer and that the results of the measurements in the environment might be below detection limits or might not be representative because of the limited frequency and spatial coverage inherent to the sampling technique.

9.14. The assessment of dose to the representative person should be based on the predominant exposure pathways. 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 to the representative person is of concern, dose calculations might initially be based on the results of environmental monitoring rather than source monitoring.[54]

9.15. 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 the 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 activity concentration to a dose rate should be used (see Ref. [33]).

9.16. 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 depends on several factors, including 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;

A revision of Safety Reports Series No. 19 [61] is in preparation and will cover screening assessments of public exposure, generic models and parameters for use in assessing the impact of radioactive discharges, and generic models and parameters for assessing exposures of flora and fauna due to radioactive discharges from facilities and activities.

[54] 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.

(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.

9.17. 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[55]. 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 dispersion and transfer of radionuclides through the environment and the food chains could be used..

9.18. When environmental monitoring data are used to estimate doses due to the ingestion of food and/or drinking water, account should be taken of its origin and consumption rate, including seasonal variation in consumption. 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.

9.19. The calculation of doses from the results of environmental monitoring involves 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 by means of comparison with results from monitoring in an area that has not been contaminated, and should be subtracted from the results. In emergency exposure situations and in some existing exposure situations, the background radiation might, in some cases, be negligible compared to the projected doses and may then be ignored in the calculations.

Consideration of uncertainties in monitoring data and dose assessment

9.20. Monitoring data have associated uncertainties that arise from technical uncertainties, the non-uniformity of samples and/or measurements, and human errors. 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), uncertainties in the monitoring data and in any environmental and dosimetric models being used, should be considered.

[55] Habit data include the time spent in different exposure conditions by members of the public and their consumption rates of food and drink water. Shielding factors from structures might affect the exposure conditions of the population.

9.21. The uncertainties in monitoring results should be estimated taking into account any uncertainties in sampling and measurement procedures, including uncertainties in sample processing and equipment calibration. Uncertainties should be reported together with the monitoring results. Additional technical information about estimation and control of uncertainties can be found in Ref. [44].

9.22. The acceptable level of uncertainty should be commensurate with the magnitude of the quantity being measured and the relevant criteria for making decisions. For example, high uncertainty may be acceptable where measured concentrations result in trivial doses, whereas more precise measurements are needed for doses of significance. Uncertainties cannot be eliminated but they should 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 OF MONITORING RESULTS

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

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

(a) For planned exposure situations, 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 (see Ref. [38]);

(b) For emergency exposure situations, operational intervention levels or emergency action levels;

(c) For existing exposure situations, dose reference levels, screening criteria[56] for remedial actions or end state criteria[57];

9.25. 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.

9.26. 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 increases or trends in releases or in the contamination of the environment.

9.27. Monitoring reports should also indicate uncertainties in the monitoring data and, to the extent possible, uncertainties in the calculated doses.

9.28. The regulatory body is required to publish or make available on request, as appropriate, results from monitoring programmes and assessments of doses to the public (see para. 3.136 of GSR Part 3 [3]). The regulatory body should define the content and characteristics of the reports on source and environmental monitoring to be made available to the public and other interested parties. The basis for such reports should be the results of the monitoring programme by the operating organization, and the independent monitoring by the regulatory body or the delegated party (see para. 4.4). The regularory body can consider including in the reports additional information in consultaion with appropriate interested parties. 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. 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 to the technical data. In existing and emergency exposure situations other organizations may have these resposibilities, depending on the national arrangements.

[56] Screening criteria are used to indicate if remediation could be justified. This can be done by comparing the projected dose prior to remediation with 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 (see GSG-15 [16]).

[57] The 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 [8].

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Annex
TECHNICAL CONSIDERATIONS FOR SAMPLING AND MEASUREMENTS FOR ROUTINE DISCHARGES IN OPERATIONAL STATES OF FACILITIES

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

SOURCE MONITORING IN OPERATIONAL STATES OF FACILITIES

A–2. Most data on the discharge of radionuclides are obtained by means of on-line (real time) 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 analysis of the airborne and liquid releases, whether continuous or discrete, 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, making subsequent laboratory analysis 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 homogenization 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; in this case, 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 that warns the operating organization when a predefined threshold is exceeded, and with automatic devices that 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 a 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 the concentrations of radionuclides are generally 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.

A–7. 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 is normally specified or approved by the regulatory body.

A–8. 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. Integrating detectors (e.g. alpha track detectors) that are periodically collected for measurement and replaced, 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 IAEA Safety Standards Series No. SSG-32, Protection of the Public Against Exposure Indoors due to Radon and Other Natural Sources of Radiation [A–1].

ENVIRONMENTAL MONITORING IN OPERATIONAL STATES OF FACILITIES

A–9. The main objectives of environmental monitoring during operational states are the verification of compliance of measured values with environmental limits, and 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, or at the site boundary (for direct radiation from the source) (see Ref. [A-3]). In special cases when the specific monitoring of endangered species or protected areas is needed, samples can also be taken in or close to the relevant area(s). Since atmospheric dispersion and aquatic dispersion might vary significantly from year to year, some of the monitoring measurements need to be performed at the same location for the year-by-year comparison of results.

A–10. 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–11. Continuously produced agricultural food products (e.g. leafy vegetables, milk) are normally sampled several times a year, or more frequently in the case of releases of radionuclides such as radioiodine, which do not persist long in the produce, or tritium, 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 (see Ref. [A–2]).

A–12. The typical aspects monitored, the frequencies and locations of sampling, and the measurements taken on the samples for different types of discharges are presented in Tables A-1, A-2 and A-3. These tables provide a generic framework; a site specific monitoring programme is expected to be established, taking into consideration the radionuclides involved, site specific considerations and the magnitude of discharges. The choice of foodstuffs depends on local agricultural practices and the food related habits of the local population (see Ref. [A–2]).

A–13. For large facilities, site characterization work to support the monitoring programme might include on-site automated weather observation systems (e.g. to monitor wind speed and direction, atmospheric stability and precipitation) and river flow or lake current monitoring systems.

A–14. The analysis systems for measurement of low-level environmental samples are expected to be physically separated from the systems for measurement of higher level effluent samples, to avoid cross contamination. It is advisable to have separate laboratories for performing low-level measurements and effluent analyses. When possible, it is advisable to allocate the laboratory for low-level measurements outside of the facility.

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

Monitoring	**Frequency of monitoring**	**Monitoring location[a,b]**	**Measurement (as appropriate to the source)**
External radiation			
External radiation	Continuously On-line, as appropriate	Several locations (e.g. four) and several distances (e.g. at the site boundary, at 1 km, 5 km and 10 km) around the facility	Gamma dose rate Neutron dose rate (if neutron radiation is foreseen)
External radiation – integrated	Monthly to semiannually	Several locations (e.g. ten) at the site boundary	Gamma dose rate Neutron dose rate (if neutron radiation is foreseen)
Air and deposition			
Air: - Aerosols - Gases - Moisture condensate	Continuously	Several locations (e.g. four) including downwind of the prevailing wind direction Near areas with receptors of concern	Gamma spectrometry Alpha spectrometry Gross alpha, gross beta[c] Tritium[d]
Rain	Continuously	Downwind of the prevailing wind direction Near areas with receptors of concern	Tritium[d] Alpha spectrometry Gross alpha, gross beta[c]
Deposition	Continuously	Downwind of the prevailing wind direction Near areas with receptors of concern	Gamma spectrometry Alpha spectrometry Gross alpha, gross beta[c]
Soil	Annually	Downwind of the prevailing wind direction Near areas with receptors of concern	Gamma spectrometry
Groundwater	Monthly to annually	Several locations around the facility where groundwater is present	Tritium[d] Alpha spectrometry Gross alpha, gross beta[c]
Food and drinking water[e]			
Leafy vegetables	Monthly during growing season	Downwind of the prevailing wind direction Near areas with receptors of concern	Tritium[d] Gamma spectrometry Carbon-14[d]
Other vegetables and fruits	At harvest	Downwind of the prevailing wind direction Near areas with receptors of concern	Tritium[d] Gamma spectrometry Carbon-14[d]
Grain	At harvest	Downwind of the prevailing wind direction Near areas with receptors of concern	Tritium[d] Gamma spectrometry Carbon-14[d]

Monitoring	Frequency of monitoring	Monitoring location[a,b]	Measurement (as appropriate to the source)
Milk	Monthly to annually	Local farms	Tritium[d] Gamma spectrometry Carbon-14[d] Strontium-90
Meat	Annually	Local farms	Gamma spectrometry Carbon-14[d]
Drinking water	Quarterly to annually	Public and private water suppliers near the facility	Tritium[d] Gamma spectrometry Carbon-14[d] Gross alpha, gross beta[c]
Terrestrial pathways			
Grass	Monthly	Pastures downwind of the prevailing wind direction	Tritium[d] Gamma spectrometry
Lichen, mosses, mushrooms	Annually	Selected samples downwind of the prevailing wind direction	Gamma spectrometry Tritium[d] Carbon-14[d]

[a]In addition to the locations indicated in the table, sampling and analyses in unaffected areas is advisable for comparison purposes.

[b]Sampling in areas with endangered species or protected areas is only applicable if specific monitoring for this purpose is required by the regulatory body.

[c]If measurements of gross alpha or gross beta exceed the established screening levels, specific radionuclide analysis to identify the radionuclides is advisable. Potassium-40 can be measured directly by gamma spectrometry to be subtracted from gross beta measurements.

[d]Tritium, carbon-14 and alpha emitters are only required to be measured when they are present in the radioactive inventory and specified in the authorization of discharges.

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

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

Monitoring	**Frequency of monitoring**	**Monitoring location[a,b]**	**Measurement (as appropriate to the source)**
Aquatic dispersion			
Surface waters[c]	Continuous or discrete sampling	Downstream[d]	Tritium[e] Alpha spectrometry Gross alpha, gross beta[f] Gamma spectrometry
Sediment	Annually	Downstream[d]	Gamma spectrometry
Aquatic foodstuffs			
Fish	Annually	Downstream[d]	Tritium[e] Carbon-14[e] Gamma spectrometry Gross alpha, gross beta[f]
Bioindicators			
Aquatic organisms	Annually	Downstream[d]	Gamma spectrometry

[a]In addition to the locations indicated in the table, sampling and analyses in unaffected areas is advisable for comparison purposes.

[b]Sampling in areas with endangered species or protected areas is only applicable if specific monitoring for this purpose is required by the regulatory body.

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

[d]When other discharges occur upstream, surface water and sediment should be also collected upstream of the point of discharge.

[e]Tritium, carbon-14 and alpha emitters are only required to be measured when they are present in the radioactive inventory and specified in the authorization of discharges.

[f]If gross alpha or gross beta exceed the established screening levels, specific radionuclides analysis to identify the radionuclides is advisable. Potassium-40 can be measured directly by gamma spectrometry to be subtracted from gross beta measurements.

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

Monitoring	**Frequency of monitoring**	**Monitoring location[a,b]**	**Measurement (as appropriate to the source)**
Aquatic dispersion			
Surface water[c]	Continuous or discrete sampling	Downstream[d]	Tritium[e] Gross alpha, gross beta[f] Alpha spectrometry Gamma spectrometry
Sediment	Annually	Downstream[d]	Gamma spectrometry
Aquatic foodstuffs			
Fish	Annually	Selected samples downstream[d]	Tritium[e] Carbon-14[e] Gamma spectrometry Strontium-90
Molluscs	Annually	Selected samples downstream[d]	Tritium[e] Carbon-14[e] Gamma spectrometry Strontium-90
Crustaceans	Annually	Selected samples downstream[d]	Tritium[e] Gamma spectrometry Strontium-90
Bioindicators			
Seaweed	Annually	Downstream[d]	Gamma spectrometry

[a]In addition to the locations indicated in the table, sampling and analyses in unaffected areas is advisable for comparison purposes.

[b]Sampling in areas with endangered species or protected areas is only applicable if specific monitoring for this purpose is required by the regulatory body.

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

[d]When other discharges occur upstream, surface water and sediment should be also collected upstream of the point of discharge.

[e]Tritium, carbon-14 and alpha emitters are only required to be measured when they are present in the radioactive inventory and specified in the authorization of discharges.

[f]If measurements of gross alpha or gross beta exceed the established screening levels, specific radionuclides analysis to identify the radionuclides is advisable. Potassium-40 can be measured directly by gamma spectrometry to be subtracted from gross beta measurements.

REFERENCES TO THE ANNEX

[A–1] INTERNATIONAL ATOMIC ENERGY AGENCY, WORLD HEALTH ORGANIZATION, Protection of the Public Against Exposure Indoors due to Radon and Other Natural Sources of Radiation, IAEA Safety Standards Series No. SSG-32, IAEA, Vienna (2015).

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