IAEA Safety Standards

for protecting people and the environment

# Environmental and Source Monitoring for Purposes of Radiation Protection

Safety Guide

No. RS-G-1.8

IAEA
International Atomic Energy Agency

# IAEA SAFETY RELATED PUBLICATIONS

## IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety, and also general safety (i.e. all these areas of safety). The publication categories in the series are **Safety Fundamentals, Safety Requirements** and **Safety Guides**.

Safety standards are coded according to their coverage: nuclear safety (NS), radiation safety (RS), transport safety (TS), waste safety (WS) and general safety (GS).

Information on the IAEA's safety standards programme is available at the IAEA Internet site

http://www-ns.iaea.org/standards/

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at P.O. Box 100, A-1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by e-mail to Official.Mail@iaea.org.

## OTHER SAFETY RELATED PUBLICATIONS

The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety and protection in nuclear activities are issued in other publications series, in particular the **Safety Reports Series**. Safety Reports provide practical examples and detailed methods that can be used in support of the safety standards. Other IAEA series of safety related publications are the **Provision for the Application of Safety Standards Series**, the **Radiological Assessment Reports Series** and the International Nuclear Safety Group's **INSAG Series**. The IAEA also issues reports on radiological accidents and other special publications.

Safety related publications are also issued in the **Technical Reports Series**, the **IAEA-TECDOC Series**, the **Training Course Series** and the **IAEA Services Series**, and as **Practical Radiation Safety Manuals** and **Practical Radiation Technical Manuals**. Security related publications are issued in the **IAEA Nuclear Security Series**.

# ENVIRONMENTAL AND SOURCE MONITORING FOR PURPOSES OF RADIATION PROTECTION

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The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

IAEA SAFETY STANDARDS SERIES No. RS-G-1.8

# ENVIRONMENTAL AND SOURCE MONITORING FOR PURPOSES OF RADIATION PROTECTION

SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
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# FOREWORD

## by Mohamed ElBaradei
## Director General

The IAEA's Statute authorizes the Agency to establish safety standards to protect health and minimize danger to life and property — standards which the IAEA must use in its own operations, and which a State can apply by means of its regulatory provisions for nuclear and radiation safety. A comprehensive body of safety standards under regular review, together with the IAEA's assistance in their application, has become a key element in a global safety regime.

In the mid-1990s, a major overhaul of the IAEA's safety standards programme was initiated, with a revised oversight committee structure and a systematic approach to updating the entire corpus of standards. The new standards that have resulted are of a high calibre and reflect best practices in Member States. With the assistance of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its safety standards.

Safety standards are only effective, however, if they are properly applied in practice. The IAEA's safety services — which range in scope from engineering safety, operational safety, and radiation, transport and waste safety to regulatory matters and safety culture in organizations — assist Member States in applying the standards and appraise their effectiveness. These safety services enable valuable insights to be shared and I continue to urge all Member States to make use of them.

Regulating nuclear and radiation safety is a national responsibility, and many Member States have decided to adopt the IAEA's safety standards for use in their national regulations. For the Contracting Parties to the various international safety conventions, IAEA standards provide a consistent, reliable means of ensuring the effective fulfilment of obligations under the conventions. The standards are also applied by designers, manufacturers and operators around the world to enhance nuclear and radiation safety in power generation, medicine, industry, agriculture, research and education.

The IAEA takes seriously the enduring challenge for users and regulators everywhere: that of ensuring a high level of safety in the use of nuclear materials and radiation sources around the world. Their continuing utilization for the benefit of humankind must be managed in a safe manner, and the IAEA safety standards are designed to facilitate the achievement of that goal.

# IAEA SAFETY STANDARDS

## SAFETY THROUGH INTERNATIONAL STANDARDS

While safety is a national responsibility, international standards and approaches to safety promote consistency, help to provide assurance that nuclear and radiation related technologies are used safely, and facilitate international technical cooperation and trade.

The standards also provide support for States in meeting their international obligations. One general international obligation is that a State must not pursue activities that cause damage in another State. More specific obligations on Contracting States are set out in international safety related conventions. The internationally agreed IAEA safety standards provide the basis for States to demonstrate that they are meeting these obligations.

## THE IAEA STANDARDS

The IAEA safety standards have a status derived from the IAEA's Statute, which authorizes the Agency to establish standards of safety for nuclear and radiation related facilities and activities and to provide for their application.

The safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment.

They are issued in the IAEA Safety Standards Series, which has three categories:

**Safety Fundamentals**

— Presenting the objectives, concepts and principles of protection and safety and providing the basis for the safety requirements.

**Safety Requirements**

— Establishing the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements, which are expressed as 'shall' statements, are governed by the objectives, concepts and principles of the Safety Fundamentals. If they are not met, measures must be taken to reach or restore the required level of safety. The Safety Requirements use regulatory language to enable them to be incorporated into national laws and regulations.

**Safety Guides**

— Providing recommendations and guidance on how to comply with the Safety Requirements. Recommendations in the Safety Guides are expressed as 'should' statements. It is recommended to take the measures stated or equivalent alternative measures. The Safety Guides present international good practices and increasingly they reflect best practices to

help users striving to achieve high levels of safety. Each Safety Requirements publication is supplemented by a number of Safety Guides, which can be used in developing national regulatory guides.

The IAEA safety standards need to be complemented by industry standards and must be implemented within appropriate national regulatory infrastructures to be fully effective. The IAEA produces a wide range of technical publications to help States in developing these national standards and infrastructures.

## MAIN USERS OF THE STANDARDS

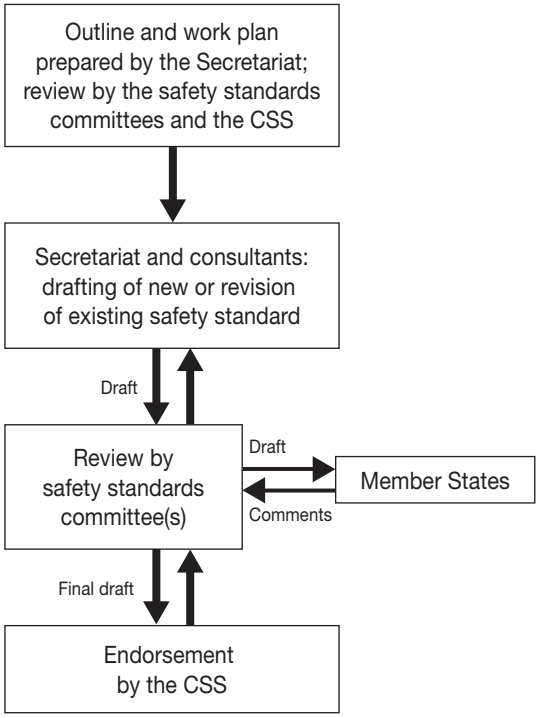
As well as by regulatory bodies and governmental departments, authorities and agencies, the standards are used by authorities and operating organizations in the nuclear industry; by organizations that design, manufacture and apply nuclear and radiation related technologies, including operating organizations of facilities of various types; by users and others involved with radiation and radioactive material in medicine, industry, agriculture, research and education; and by engineers, scientists, technicians and other specialists. The standards are used by the IAEA itself in its safety reviews and for developing education and training courses.

## DEVELOPMENT PROCESS FOR THE STANDARDS

The preparation and review of safety standards involves the IAEA Secretariat and four safety standards committees for safety in the areas of nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS), which oversees the entire safety standards programme. All IAEA Member States may nominate experts for the safety standards committees and may provide comments on draft standards. The membership of the CSS is appointed by the Director General and includes senior government officials having responsibility for establishing national standards.

For Safety Fundamentals and Safety Requirements, the drafts endorsed by the Commission are submitted to the IAEA Board of Governors for approval for publication. Safety Guides are published on the approval of the Director General.

Through this process the standards come to represent a consensus view of the IAEA's Member States. The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the standards. Some standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the International




*The process for developing a new safety standard or revising an existing one.*

Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

The safety standards are kept up to date: five years after publication they are reviewed to determine whether revision is necessary.

## APPLICATION AND SCOPE OF THE STANDARDS

The IAEA Statute makes the safety standards binding on the IAEA in relation to its own operations and on States in relation to operations assisted by the IAEA. Any State wishing to enter into an agreement with the IAEA concerning any form of Agency assistance is required to comply with the requirements of the safety standards that pertain to the activities covered by the agreement.

International conventions also contain similar requirements to those in the safety standards, and make them binding on contracting parties. The Safety Fundamentals were used as the basis for the development of the Convention on Nuclear Safety and the Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management. The Safety

Requirements on Preparedness and Response for a Nuclear or Radiological Emergency reflect the obligations on States under the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency.

The safety standards, incorporated into national legislation and regulations and supplemented by international conventions and detailed national requirements, establish a basis for protecting people and the environment. However, there will also be special aspects of safety that need to be assessed case by case at the national level. For example, many of the safety standards, particularly those addressing planning or design aspects of safety, are intended to apply primarily to new facilities and activities. The requirements and recommendations specified in the IAEA safety standards might not be fully met at some facilities built to earlier standards. The way in which the safety standards are to be applied to such facilities is a decision for individual States.

## INTERPRETATION OF THE TEXT

The safety standards use the form 'shall' in establishing international consensus requirements, responsibilities and obligations. Many requirements are not addressed to a specific party, the implication being that the appropriate party or parties should be responsible for fulfilling them. Recommendations are expressed as 'should' statements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures) for complying with the requirements.

Safety related terms are to be interpreted as stated in the IAEA Safety Glossary (http://www-ns.iaea.org/standards/safety-glossary.htm). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard within the Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the main text (e.g. material that is subsidiary to or separate from the main text, is included in support of statements in the main text, or describes methods of calculation, experimental procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the standard. Material in an appendix has the same status as the main text and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. An annex is not an integral part of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material published in standards that is under other authorship may be presented in annexes. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

# CONTENTS

# 1. INTRODUCTION

## BACKGROUND

1.1. The controlled release of radionuclides to the atmospheric and aquatic environments is a legitimate waste management practice in the nuclear industry and its related facilities [1]. Typically, controlled discharges of gaseous and particulate material containing radionuclides are made through stacks, although for small facilities they may be made through discharge vents or working hoods, for example. Controlled liquid discharges are typically made via pipelines into rivers, lakes or the sea, but they may also be made via the normal sewer systems from small establishments. An important and essential element in the control of the discharges is regular monitoring — both at the source of the discharge and in the receiving environment — to ensure the protection of the public and the environment.

1.2. The uncontrolled release of radionuclides to the atmospheric, aquatic and terrestrial environments may occur as a result of a nuclear or radiological accident. Monitoring of the accidental release at its source, and especially the direct monitoring of the environmental contamination with radionuclides, is necessary for the assessment and execution of actions for public protection and longer term countermeasures as well as of emergency occupational radiation protection. In such cases individual monitoring may be justified. In areas historically contaminated with long lived radionuclides, monitoring is essential for the protection of the public and as a basis for restoration activities.

1.3. In 1995, the IAEA published a Safety Fundamentals publication on The Principles of Radioactive Waste Management [1]. This establishes principles, concepts and objectives for measures for the protection of human health and the environment, since the improper management of radioactive waste could lead to adverse effects on human health or the environment both in the short term and in the future.

1.4. In 1996, the IAEA, jointly with five other international sponsoring organizations,[1] published the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (hereinafter referred to as the Basic Safety Standards (BSS)) [2]. The BSS establish the requirements for protection against the risks associated with exposure to ionizing radiation and, in particular, they establish requirements for radiation monitoring in the context of discharge control to check for compliance with the authorized limits on discharges and to permit the estimation of the exposure of critical groups. The BSS also establish requirements for radiation monitoring and assessment in emergency exposure conditions, which are elaborated on in a separate Safety Requirements publication [3].

1.5. The safety requirements for the predisposal management of radioactive waste, including the discharge of radionuclides, are established in another safety standard [4]. The Safety Requirements on Near Surface Disposal of Radioactive Waste [5] include requirements for radiation monitoring for the purpose of demonstrating compliance with safety standards.

1.6. This Safety Guide elaborates on relevant requirements established in Refs [2–5]. It also takes account of the guidance of the International Commission on Radiological Protection on the issue of radiation monitoring [6]. It accompanies the Safety Guide on Regulatory Control of Radioactive Discharges to the Environment [7], which is mainly concerned with the considerations and the procedures to be followed in establishing authorizations for the discharge of radioactive material. The present Safety Guide supersedes two earlier Safety Guides.[2]

[1] The five other sponsoring organizations were the Food and Agriculture Organization of the United Nations (FAO), the International Labour Organisation (ILO), the Nuclear Energy Agency of the Organisation for Economic Co-operation and Development (OECD/NEA), the Pan American Health Organization (PAHO) and the World Health Organization (WHO).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Objectives and Design of Environmental Monitoring Programmes for Radioactive Contaminants, Safety Series No. 41, IAEA, Vienna (1975); Monitoring of Airborne and Liquid Radioactive Releases from Nuclear Facilities to the Environment, Safety Series No. 46, IAEA, Vienna (1978).

## OBJECTIVE

1.7. The purpose of this Safety Guide is to provide international guidance, coherent with contemporary radiation protection principles and accounting for experience gained since the previous publication of guidance (see footnote 2), on the strategy of monitoring in relation to: (a) the control of radionuclide discharges under the conditions of practices, and (b) situations requiring intervention, such as a nuclear or radiological emergency or the past contamination of areas with long lived radionuclides.[3] Three categories of monitoring are discussed: monitoring at the source of the discharge (hereinafter called 'source monitoring'), monitoring in the environment ('environmental monitoring') and monitoring of individual exposure ('individual monitoring').

1.8. The Safety Guide also provides general guidance on the assessment of the doses to critical groups of the population due to the presence of radioactive material or due to radiation fields in the environment, which may arise both from the normal operation of nuclear and other related facilities (practices) or from a nuclear or radiological emergency or the past contamination of areas with long lived radionuclides (interventions). The dose assessment is based on the results of source monitoring, environmental monitoring or individual monitoring or on combinations of these.

1.9. This Safety Guide is primarily intended for use by national regulatory bodies that have responsibilities for regulating the introduction and conduct of any practice involving sources of radiation and for appropriate radiation monitoring procedures. It will also be valuable to other agencies involved in national systems for radiation monitoring as well as to operators of nuclear installations and other facilities in which natural or human made radionuclides are treated and monitored.

[3] In the context of this Safety Guide, which concerns the radiation protection of the public against both present and future exposure, the term 'long lived radionuclide' is applied to radionuclides with half-lives of 30 years or more (e.g. $^{137}Cs$), in contrast to the usual terminology in waste safety, where this term is usually used for radionuclides with half-lives of 1000 years or more.

## SCOPE

1.10. This Safety Guide is primarily concerned with source monitoring and environmental monitoring of discharges from authorized (registered or licensed) practices under normal operating conditions and during the decommissioning of facilities. The practices considered in this Safety Guide include the operation of nuclear power plants and research reactors, reprocessing plants and nuclear fuel production plants, uranium and thorium mining and milling facilities, near surface disposal facilities for radioactive waste, and facilities of other types where natural or human made radionuclides are used (medical, radiopharmaceutical, research, educational and others).

1.11. The guidance presented here applies for planning monitoring during waste emplacement in surface (uranium and thorium ore mining and milling sites) or near surface (for low and intermediate level waste) disposal facilities and for borehole and deep underground (geological) waste disposal facilities, and specifically for post-closure monitoring — although radionuclide releases would not be expected from such facilities under normal circumstances.

1.12. General issues of emergency monitoring in the aftermath of a radiation accident are also considered in this publication. More detailed information on monitoring during emergencies is presented in Refs [8–12].[4]

1.13. This Safety Guide also addresses general aspects of monitoring for long lived radionuclides widely dispersed in the environment following a radiation accident, or as residual waste from past practices. This includes monitoring of the content of natural and human made radionuclides in commodities, especially in foodstuffs and drinking water.

1.14. This Safety Guide does not address the monitoring of workers and the workplace, although its recommendations and guidance may be useful for the occupational protection of emergency workers in the event of an accident

[4] The references cited supersede the following IAEA safety standards: Techniques and Decision Making in the Assessment of Off-site Consequences of an Accident in a Nuclear Facility, Safety Series No. 86, IAEA, Vienna (1987); Response to a Radioactive Materials Release Having a Transboundary Impact, Safety Series No. 94, IAEA, Vienna (1989); Emergency Planning and Preparedness for Accidents Involving Radioactive Materials Used in Medicine, Industry, Research and Teaching, Safety Series No. 91, IAEA, Vienna (1989).

accompanied by the release of radionuclides to the environment. More detailed guidance on the occupational monitoring of workers and the workplace is provided in Refs [13–16]. Neither does the Safety Guide address monitoring for research purposes, which is not for the purposes of radiation protection, or monitoring of the global fallout of radionuclides released during past nuclear weapon tests, which are unamenable to control.

1.15. A general surveillance and monitoring programme for the release to, or the presence of toxic chemicals in, the environment is not addressed in this Safety Guide, which is devoted to the monitoring of radionuclides only. However, operators and other responsible organizations may find it convenient to combine chemical and radiological monitoring programmes.

### STRUCTURE

1.16. Section 2 discusses some general international guidance for monitoring radionuclides in the environment. Section 3 outlines the responsibilities of registrants, licensees and regulatory bodies with regard to monitoring. Most generic aspects of monitoring programmes are discussed in Section 4, and detailed objectives and different types of design of monitoring programmes for practices and interventions are presented in Section 5. Section 6 addresses some specific technical features of monitoring procedures. In Section 7 dose assessment methods as they relate to different types of monitoring programmes are discussed. Section 8 contains guidance on the interpretation of monitoring results. Section 9 describes the appropriate quality assurance programme. Section 10 is devoted to the recording of monitoring results and Section 11 specifies requirements for education and training.

## 2. MEETING REGULATORY REQUIREMENTS FOR MONITORING IN PRACTICES AND INTERVENTIONS

### LEGAL CONTEXT

2.1. Exposures of members of the public from a controlled discharge in a practice, an uncontrolled release or past area contamination may arise from the direct emission of radiation at the source of the discharge or from the dispersal

of radionuclides in the environment. For the latter case the more likely pathways are external exposure due to radionuclides in a plume and on the ground as well as the ingestion of contaminated food. The inhalation of airborne radionuclides in a plume or from the resuspension of ground deposits may also be of importance. In the case of practices, the monitoring of radiation dose rates around the source, of discharge levels and of the levels of radionuclides in the environment is necessary to verify compliance with authorized limits on discharges and to facilitate the assessment of radiation dose to members of the public. In case of interventions, monitoring of a release source and of environmental contamination is necessary for decision making on protective actions and longer term countermeasures in an emergency, or on remedial actions in areas contaminated with long lived radionuclides.

2.2. The concepts underlying the requirements for monitoring are set out in Refs [2, 3, 5, 7, 17].

2.3. With regard to the monitoring of controlled discharges in practices, the BSS require that "Registrants and licensees shall be responsible… for the establishment, implementation, and maintenance of appropriate monitoring equipment and surveillance programmes to assess public exposure to the satisfaction of the [regulatory body]" (Ref. [2], para. III.2(f)). In particular, according to the Basic Safety Standards (Ref. [2], para. III.13), "Registrants and licensees shall, if appropriate:

"(a) establish and carry out a monitoring programme sufficient to ensure that the requirements of the Standards regarding public exposure to sources of external irradiation be satisfied and to assess such exposure;
"(b) establish and carry out a monitoring programme sufficient to ensure that the requirements of the Standards for discharges of radioactive substances to the environment and the requirements established by the [regulatory body] in granting the discharge authorization be satisfied and that the conditions assumed in deriving the authorized discharge limits remain valid and sufficient to enable the exposures to critical groups to be estimated;
"(c) keep appropriate records of the results of the monitoring programmes;
"(d) report a summary of the monitoring results to the [regulatory body] at approved intervals;
"(e) report promptly to the [regulatory body] any significant increase in environmental radiation fields or contamination that could be attributed to the radiation or radioactive discharges emitted by sources under their responsibility;

"(f) establish and maintain a capability to carry out emergency monitoring, in case of unexpected increases in radiation fields or radioactive contamination due to accidental or other unusual events affecting sources under their responsibility; and
"(g) verify the adequacy of the assumptions made for the prior assessment of radiological consequences of the discharges."

2.4. With regard to assessment and monitoring in emergency exposure situations the BSS (Ref. [2], paras V.23–V.25) require that:

"V.23. All reasonable steps shall be taken to assess exposure incurred by members of the public as a consequence of an accident, and the results of the assessments shall be made publicly available.

"V.24. The assessments shall be based on the best available information, and shall be promptly updated in the light of any information that would produce substantially more accurate results.

"V.25. Comprehensive records shall be maintained of assessments and their updates, and of monitoring results for workers, the public and the environment."

2.5. For the purpose of assessment and monitoring in emergency exposure situations, the Safety Requirements on Preparedness and Response for a Nuclear or Radiological Emergency [3] further require that:

(a) In response to the initial phase of the emergency, "Radiation monitoring and environmental sampling and assessment shall be carried out in order to identify new hazards promptly and to refine the strategy for response." (Ref. [3], para. 4.67.)
(b) To ensure preparedness to respond to the initial phase of the emergency, "arrangements shall be made for promptly assessing any radioactive contamination, releases of radioactive material and doses for the purpose of deciding on or adapting the urgent protective actions to be taken following a release." (Ref. [3], para. 4.71.)
(c) To ensure preparedness to take agricultural countermeasures and longer term protective actions, "arrangements shall include… timely monitoring for ground contamination in the field; the sampling and analysis of food and water." (Ref. [3], para. 4.89.)

2.6. In order to ensure proper monitoring and assessment during the operation of near surface waste disposal facilities and after their closure, the Safety Requirements publication on Near Surface Disposal of Radioactive Waste [5] requires that:

"(a) The design of a near surface repository shall allow for implementation of a monitoring programme to verify the containment capability of the disposal system during operation and, as necessary, after closure of the repository. Arrangements for monitoring shall not compromise the long term performance of the disposal system." (Ref. [5], para. 7.5.)
"(b) The regulatory body shall provide guidance necessary to establish an environmental monitoring programme, including monitoring of releases and external exposure, and to assess the environmental impact of operations." (Ref. [5], para. 9.3.)
"(c) The operator shall be responsible for ensuring the provision and maintenance of adequate monitoring to measure radioactive releases during repository operation, and shall take necessary actions to ensure that the requirements established by national authorities are met." (Ref. [5], para. 9.12.)
"(d) The responsible organization shall implement an appropriate post-closure monitoring programme, which shall be approved by the regulatory body. This programme shall deal with radiological and other monitoring of the repository and its surrounding area in order to verify the absence of unacceptable radiological impacts (for example, with respect to the leachate limits, if appropriate), and to confirm, as far as possible, the assumptions made in the safety assessment." (Ref. [5], para. 11.8.)

2.7. The Safety Requirements publication on Safety of Nuclear Power Plants: Design [18] specifically requires that at the stage of nuclear power plant design, "arrangements shall also be made to determine radiological impacts, if any, in the vicinity of the plant, with particular reference to:

"(1) pathways to the human population, including the food-chain;
"(2) the radiological impact, if any, on local ecosystems;
"(3) the possible accumulation of radioactive materials in the physical environment; and
"(4) the possibility of any unauthorized discharge routes." (Ref. [18], para. 6.106.)

2.8. For the stage of nuclear power plant operation, the Safety Requirements publication on Safety of Nuclear Power Plants: Operation [19] specifically requires that:

"(a) The operating organization shall establish and implement procedures for monitoring and controlling discharges of radioactive effluents. A copy of these procedures shall be made available to the regulatory body.
"(b) If required by the regulatory body, the operating organization shall establish and implement a programme for monitoring the environment in the vicinity of the plant in order to assess the radiological impacts of radioactive releases on the environment." (Ref. [19], paras 8.11 and 8.12.)

## GENERAL CONDITIONS FOR MONITORING

2.9. The type of monitoring programme, as well as its scale and extent, should be commensurate with the source characteristics at the expected or current discharge rates, the radionuclide composition, the comparative significance of different exposure pathways, and the magnitudes of expected and potential doses to individuals. Some practices and sources (e.g. hospitals or research institutes using short lived radionuclides) may not require a monitoring programme for the environment; some (e.g. small nuclear installations or nuclear medicine departments using radionuclides for diagnostic purposes) may require routine monitoring at the source but only occasional checks on environmental levels; and others (e.g. most nuclear installations, large nuclear medicine departments) require continuous and comprehensive monitoring of both source and environment. Every facility should be prepared to conduct emergency monitoring at an appropriate level.

### Conditions for monitoring in practices

2.10. The requirements for the monitoring of discharges in a practice should be directly related to the regulatory situation applying to the sources in question. The international requirements as they relate to monitoring actions are described in the following paragraphs.

2.11. Monitoring is not required at the source or in the environment for sources that give rise to exposures that are 'excluded' from regulatory control because their magnitude or likelihood is essentially unamenable to control through the requirements of the BSS [2]. A relevant example in the context of this

publication is the gaseous discharge through a building ventilation system of radon and its decay products arising from the underlying soil.

2.12. Practices and sources can be exempted or materials cleared from the requirements for regulatory control if the associated radiation risks to individuals and populations are low enough to be of no regulatory concern and the exempted practices or sources are inherently safe [2]. For exempted practices and sources or cleared materials that include discharges, there is no requirement for monitoring. An example of exemption is a small laboratory that utilizes amounts of radionuclides for which either the total activity of a given radionuclide or the activity concentration is below the exemption level [2].

2.13. Sources or practices for which neither exclusion nor exemption is possible are required to be authorized by the regulatory body [2, 7]. The authorization takes the form of either a registration or a licence. Examples of registered practices are those at small research institutes and small hospitals, where the usage of short lived radionuclides and the corresponding discharges to the environment are low. Monitoring in the environment for registered practices of these types is usually not required by the regulatory body, while some degree of monitoring at the source may be required.

2.14. Finally, there are several types of source for which routine monitoring programmes are required. Most installations in the nuclear fuel cycle, some large research establishments and radioisotope production facilities fall under this category. Installations of this type are licensed by the regulatory body, have specific safety related requirements and conditions with which the licensee must comply, and are always subject to monitoring, both at the source and in the environment, as well as to public dose assessment. The routine monitoring programme may also form the basis for the emergency monitoring programme at facilities of these types, although not all of them require a full emergency monitoring capability. Table 1 summarizes a relationship between the types of source and the necessary types of monitoring.

**Conditions for monitoring in intervention situations**

2.15. Intervention situations requiring a response in order to reduce or avert exposures can be emergency exposure situations or situations of chronic (prolonged) exposure. Protective and remedial actions are not normally likely to be necessary unless intervention levels or action levels are or may be exceeded. The initial input for decision making with regard to protective or

TABLE 1. TYPES OF MONITORING AND DOSE ASSESSMENT REQUIRED FOR DIFFERENT TYPES OF SOURCE

| Exposure category | Type of source | Type of monitoring | | | |
|---|---|---|---|---|---|
| | | Source monitoring | Environmental monitoring | Individual monitoring | Dose assessment |
| Practice | Excluded, exempted or cleared | No monitoring required | | | |
| | Registered source | Required | Not required | | |
| | Licensed source | Required | | Not required | Required |
| | Multiple sources | Required | | Not required | As appropriate |
| Intervention | Emergency situation | Required | | As appropriate | |
| | Chronic (prolonged) exposure situation | As appropriate | Required | Not required | As appropriate |

remedial actions is usually based on monitoring. An overall monitoring strategy for emergencies and remedial actions should therefore be established; such a strategy should be site specific and should be based on detailed consideration of the sources and of possible pathways of human exposure.

*Emergency exposure situations*

2.16. Radiation monitoring should be performed in the event of any nuclear or radiological emergency. The strategy for emergency monitoring should be determined in accordance with the possible radiological consequences of the accident. The intended uses of the monitoring results should guide the selection of priorities in monitoring and the technical details of the type of monitoring that is to be performed.

2.17. Emergency exposure situations range from a spill of small amounts of radioactive material in a laboratory to a major reactor accident with loss of confinement. The methods and extent of emergency monitoring, including source monitoring, environmental monitoring, individual monitoring and appropriate dose assessment (see Table 1), should depend on the severity of the emergency and its potential or actual consequences.

2.18. With regard to the timing, number and methods for radiation measurements and environmental sampling, to ensure the timely execution of protective and remedial actions, the monitoring strategy should be selected for the early detection of any exposures of the general public or of emergency workers that are approaching the intervention levels or action levels.

2.19. In the development of a national strategy for emergency monitoring, both national and international aspects should be considered. Emergency monitoring should be aimed at receiving data relevant to the possible transfer of accidentally released radioactive material to other States and international waters. The national monitoring system should also be able to monitor environmental radioactive contamination originating from accidental releases that occur in other States.

2.20. Emergency monitoring may be terminated when control over the accidental source is restored or when radioactive conditions are not deteriorating and levels of human exposure and environmental contamination are substantially below the respective generic intervention levels and action levels [2] or the appropriate national levels.

*Situations of chronic (prolonged) exposure*

2.21. Situations of chronic (prolonged) exposure include exposure to radioactive residues from past events, such as radioactive contamination caused by radiation accidents (post-emergency exposure situations), as well as from the past conduct of practices and the use of sources not under the system of regulatory control (sites contaminated with natural long lived radionuclides).

2.22. There is no standard of radiation protection that is universally applied in all States for intervention in situations of chronic (prolonged) radiation exposure of populations. Appropriate intervention levels or action levels are established by national authorities, depending on the circumstances and generally based on existing or averted doses, dose rates in air and radionuclide concentrations. According to the International Commission on Radiological Protection (ICRP), intervention (remedial actions) is not likely to be justifiable if the existing annual effective dose from all the environmental radioactive sources does not reach 10 mSv [20].

2.23. Monitoring of environmental contamination with long lived radionuclides would generally be justified if the annual dose due to this source comprised a substantial fraction (one tenth or more, i.e. 1 mSv or above) of the generic level as given in para. 2.22 or the appropriate national intervention or action levels.

2.24. Monitoring of food contamination with long lived radionuclides for the purpose of the substantiation of protective actions would generally be justified if the radionuclide levels in food comprised a substantial fraction of the generic action levels for radionuclides in foodstuffs [2] or the appropriate national intervention or action levels.

# 3. RESPONSIBILITIES FOR MONITORING

## RESPONSIBILITIES OF THE OPERATOR

3.1. In relation to the control of discharge practices, operators should have the following general responsibilities:

(a) To prevent any unacceptable radiation or contamination hazard to the public resulting from a discharge practice;
(b) To comply with applicable regulatory requirements;
(c) To report to the regulatory body any changes to the discharge practice.

3.2. With regard to specific responsibilities in the area of monitoring, operators:

(a) Should perform all necessary pre-operational investigations (including, as appropriate, pre-operational monitoring);
(b) Should provide means and perform adequate source and environmental monitoring programmes during and after operation that will permit unexpected releases to be detected promptly and will provide the data to demonstrate that doses to the public are below the dose criteria established by the regulatory body;
(c) Should report to the regulatory body any significant changes in releases or increases in environmental radiation fields or contamination that could be attributed to releases from the sources under their responsibility.

3.3. On this basis, the responsibilities of operators for monitoring should be defined along the following lines[5]:

(a) Source monitoring referred to a specific practice or source within a practice that is under the responsibility of the particular operator (licensee or registrant) should be carried out by that operator in all phases of the programme, including monitoring in operational and post-operational stages and in the event of an emergency. The operator should have the responsibility of establishing, carrying out and maintaining the

[5] In some States, the main responsibility for environmental monitoring lies with the regulatory body or with other governmental agencies, in general agreement with IAEA guidance [21].

appropriate equipment and programmes for the monitoring of discharges.

(b) Environmental monitoring referred to a given practice or source within a practice is only necessary for major practices and sources warranting a licence. The licensees should be generally responsible for such environmental monitoring in all its phases, including the pre-operational, operational and post-operational stages. The licensees should also establish and maintain an adequate capability to carry out environmental monitoring in emergency situations.

(c) The licensees should periodically check the assumptions made for the prior assessment of the radiological impact of the discharges.

## RESPONSIBILITIES OF THE REGULATORY BODY

3.4. In relation to the control of discharge practices, the regulatory body has the following general responsibilities:

(a) Ensuring, by means of establishing and implementing appropriate regulations, that the public and the environment are protected;

(b) Ensuring that the operator complies with the appropriate regulations and regulatory requirements, including those in respect of carrying out such source and environmental monitoring as may be necessary;

(c) Providing assurance that judgements concerning the safety of the public are based upon valid information and sound methods.

3.5. With regard to specific responsibilities in the area of monitoring, the regulatory body:

(a) Should establish technical requirements for monitoring arrangements, including arrangements for emergency monitoring and quality assurance, and should regularly review them;

(b) Should check the monitoring data provided by operators;

(c) Should provide evidence that can satisfy the public that authorized sources of exposure are being suitably monitored and controlled.

3.6. On this basis, the allocation of responsibilities for the regulatory body should be along the following lines:

(a) Although the licensees should be generally responsible for source and environmental monitoring, in some cases (such as major practices or

sources) the regulatory body may carry out a limited confirmatory programme of environmental measurements to verify the quality of the results provided by the licensee and to confirm that the doses to members of the public are maintained below the constraints established in the licence [21].

(b) When several sources may have an impact on the same areas and population groups, an environmental monitoring programme should be carried out in order to assess the cumulative radiological impacts of these different sources. As it may be difficult for individual registrants or licensees to undertake such monitoring, since they may not have information about the radionuclide composition of materials discharged by other operators, this monitoring may be arranged or carried out by the regulatory body.

(c) If the potential exists for a large scale accident, the regulatory body must ensure that emergency preparedness arrangements are in place and are routinely tested. This should include the ability for rapid, large scale monitoring under emergency conditions, which may be performed by a designated responsible organization with the requisite capability or by the regulatory body itself. The required monitoring may include both environmental monitoring and individual monitoring.

3.7. In rare circumstances, if the assessed annual dose to the average individual member of the critical group arising from all relevant practices, estimated on the basis of environmental monitoring, is approaching the dose limit, a reassessment of the doses to the critical group should first be made by the registrant or licensee and then validated by the regulatory body. Table 2 outlines the major areas of responsibility for registrants, licensees and the regulatory body concerning the different types of monitoring.

## RESPONSIBILITIES OF OTHER AGENCIES

3.8. The government or the regulatory body may delegate specific responsibilities relevant to environmental monitoring to other agencies. The government may control this delegation through the regulatory body or directly. The delegation of authority may concern:

(a) Review, testing and calibration of monitoring equipment;
(b) Review of the quality assurance programme;

TABLE 2. RESPONSIBILITIES FOR ENVIRONMENTAL AND SOURCE MONITORING

| Exposure category | Type of source | Responsible body | | |
|---|---|---|---|---|
| | | Registrant | Licensee | Regulatory body or designated organization |
| Practice | Excluded, exempted or cleared | No monitoring required | | |
| | Registered sources | Source monitoring | *Not applicable* | Control measurements and review/verify dose assessments, as appropriate |
| | Licensed sources | *Not applicable* | Source and environmental monitoring; dose assessment | |
| | Multiple sources | Source monitoring | Source and local environmental monitoring | Environmental monitoring and dose assessment |
| Intervention | Emergency situations | Source monitoring | Source monitoring, near field environmental monitoring and individual monitoring of workers | Large scale and near field environmental monitoring; individual monitoring of the public as appropriate |
| | Chronic (prolonged) exposure situations | *Not applicable* | Source and local environmental monitoring | Large scale and near field environmental monitoring; dose assessment as appropriate |

(c) The design and regular performance of the confirmatory programmes of environmental measurements or release measurements to verify the quality of the results provided by the licensee;
(d) The confirmatory assessment of the doses to members of the public to warrant that they are maintained below the limits established in licences;
(e) The environmental monitoring programme carried out in order to assess the cumulative radiological impact of multiple sources when they have an impact on the same areas and the same population groups;
(f) Emergency response.

3.9. Other agencies may also be responsible for other domains relating to monitoring, such as:

(a) Collection and retention of data provided by operators, governmental or international agencies;
(b) Nationwide environmental monitoring;
(c) Establishing standards.

3.10. In deciding on the delegation of specific monitoring responsibilities to other agencies or companies, the regulatory body should pay due attention to the availability in these organizations of appropriate analytical techniques, equipment and qualified personnel, and of a quality assurance system.

3.11. As a general principle, the regulatory body, as well as any other agencies to which responsibilities have been delegated by the regulatory body, should remain independent of any government department and of any agencies 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 radiation facilities used in the practices being regulated.

## REPORTING OF MONITORING RESULTS

3.12. In accordance with the BSS, "Registrants and licensees shall, if appropriate:

"(d) report a summary of the monitoring results to the [regulatory body] at approved intervals;
"(e) report promptly to the [regulatory body] any significant increase in environmental radiation fields or contamination that could be attributed

to the radiation or radioactive discharges emitted by sources under their responsibility" (Ref. [2], para. III.13).

3.13. In addition, registrants and licensees should promptly report any discharges exceeding the authorized limits on discharges in accordance with criteria established by the regulatory body.

3.14. The periodic summary report of the monitoring results should include the results of both the source monitoring programme and the environmental monitoring programme. In all cases, results should be reported in a way that allows the verification of compliance with the limits on discharges authorized by the regulatory body. The way in which results are reported should be related to the objectives of the monitoring programme as defined by the regulatory body. In some circumstances it may be adequate to compare measured dose rates or activity concentrations with appropriate derived levels; in other cases, it may be necessary to evaluate the doses to critical groups. As specified by the regulatory body, these doses should be compared with the dose constraints attached to discharge authorizations; the results of the comparison and their interpretation should be reported to the regulatory body.

3.15. The periodic summary report should also include an interpretation of the results and an adequate explanation of their significance (e.g. with reference to appropriate models or standards or to the uncertainty of the results), especially for results that show significant variations in the releases or in the contamination of the environment. The summary should also include other useful information such as the weather conditions during the reported period and the net electrical energy production (for nuclear power plants) or the quantities of fuel produced (for a fuel fabrication facility) or reprocessed (for a fuel reprocessing plant) in the period concerned.

3.16. The registrant or licensee should present source and environmental monitoring data to the regulatory body at least annually, but other factors may necessitate more frequent reports. These factors could include the type of operation (e.g. registered or licensed sources or practices) and the time variability of the quantities and rates of the discharge. Licensed practices such as nuclear fuel cycle facilities should specify in their reporting the quantities of radionuclides discharged to the environment in accordance with the authorized limits established by the regulatory body.

3.17. The prompt report of a significant unplanned increase in environmental radiation fields or contamination should include a description of the

investigation that has been set up, its preliminary results if available, the immediate actions that have been taken in relation to discharge operations (e.g. stopping batch discharges) and the actions that are foreseen for the immediate future (e.g. resuming discharge operations).

3.18. In view of the increasing public awareness of environmental issues, the regulatory body together with the licensees and registrants should make available to the public summary information on environmental monitoring with an adequate explanation of its significance (e.g. with reference to standards or to the uncertainty of the results).

# 4. GENERIC ASPECTS OF MONITORING PROGRAMMES

## GENERAL

4.1. The general objectives of any monitoring programme for the protection of the public and the environment, as considered in this Safety Guide, are [6, 7]:

(a) To verify compliance with authorized discharge limits and any other regulatory requirements concerning the impact on the public and the environment due to the normal operation of a practice or a source within a practice;
(b) To provide information and data for dose assessment purposes and to assess the exposure or potential exposure of critical groups and populations due to the presence of radioactive materials or radiation fields in the environment from the normal operation of a practice or a source within a practice and from accidents or past activities;
(c) To check the conditions of operation and the adequacy of controls on discharges from the source and to provide a warning of unusual or unforeseen conditions and, where appropriate, to trigger a special environmental monitoring programme.

4.2. Some subsidiary objectives, which should usually be fulfilled by a monitoring programme, are [6, 7]:

(a) To provide information for the public;

(b) To maintain a continuing record of the impacts of an installation or a practice on environmental radionuclide levels;
(c) To check the predictions of environmental models so as to modify them as appropriate in order to reduce uncertainties in the dose assessment.

4.3. In accordance with general and subsidiary objectives, the monitoring programmes should include radiation measurements and the collection of relevant supporting information as well as the assessment of doses to critical groups and populations due to the presence of radioactive material in the environment from a practice or intervention and a demonstration of compliance with authorized limits on discharges within a practice.

## HUMAN EXPOSURE PATHWAYS

4.4. One important purpose of monitoring is to provide data that permit the analysis and evaluation of human radiation exposure. For this purpose, programmes for monitoring radionuclides in the environment should focus on pathways of human exposure. An exposure pathway defines routes from a source of radionuclides and/or radiation to a target individual or a population through media in the environment. There are two main categories of exposure pathway: external exposure pathways (the source of exposure remains outside the body) and internal exposure pathways (the source of exposure is incorporated into the body).

4.5. The main external exposure pathways considered in this Safety Guide are:

(a) *Source of radiation* → *human*: direct exposure from a source of ionizing radiation;
(b) *Source of radionuclides* → *atmosphere or water body* → *human*: exposure due to the plume of radionuclides in the atmosphere ('cloud shine') or water;
(c) *Source of radionuclides* → *atmosphere or water body* → *human skin*: contact exposure from radionuclides on the skin;
(d) *Source of radionuclides* → *atmosphere or water body* → *soil or sediment or building surface or vegetation* → *human*: exposure from the radionuclides deposited on the ground or on sediments (on the shores of rivers, lakes or the sea) or building surfaces (walls, roofs and floors) or vegetation (trees, bushes and grass).

4.6. The main internal exposure pathways considered in this Safety Guide are:

(a) *Source of radionuclides → atmosphere → human*: inhalation of radionuclides in the plume;
(b) *Source of radionuclides → atmosphere or water body → (soil or sediment) → vegetation and/or meat, milk, eggs or marine food → human*: ingestion of radionuclides in food or beverages;
(c) *Source of tritium → atmosphere → human*: for tritium oxide in the plume, absorption through the skin;
(d) *Soil or sediment → human*: inhalation of resuspended radionuclides.

4.7. Figure 1 illustrates the pathways by which an individual may be exposed following the discharge of radionuclides to the atmosphere and the surface water or groundwater, respectively.

4.8. The importance of the various exposure pathways depends on:

(a) The radiological properties of the material released (e.g. gamma emitters, beta emitters or alpha emitters; physical half-life);
(b) The physical (e.g. gas, liquid or solid) and chemical (e.g. organic or inorganic form, oxidation state, speciation, etc.) properties of the material and its migration characteristics;
(c) The dispersal mechanism and factors affecting it (e.g. stack height, meteorological conditions, etc.) and environmental characteristics (e.g. climate, type of biota, agricultural production, etc.);
(d) The locations, ages, diets and habits of the exposed individuals or population.

4.9. Under conditions of normal discharges the exposure pathways are usually permanent and well defined. In the case of emergency releases, the contributions via different pathways to the doses received by workers and the public may be different from the normal and transient. These differences should be considered when establishing the emergency monitoring programme. In order to protect the public and workers from deterministic health effects following major accidents, different radiological criteria may be applied in emergencies from those applied under conditions of normal discharges and, therefore, the collection of additional monitoring data may be necessary.

4.10. At different stages of an accident the exposure pathways may change and different monitoring data may be necessary to support decision making on protective actions. Thus, at an early stage of an accidental atmospheric release,

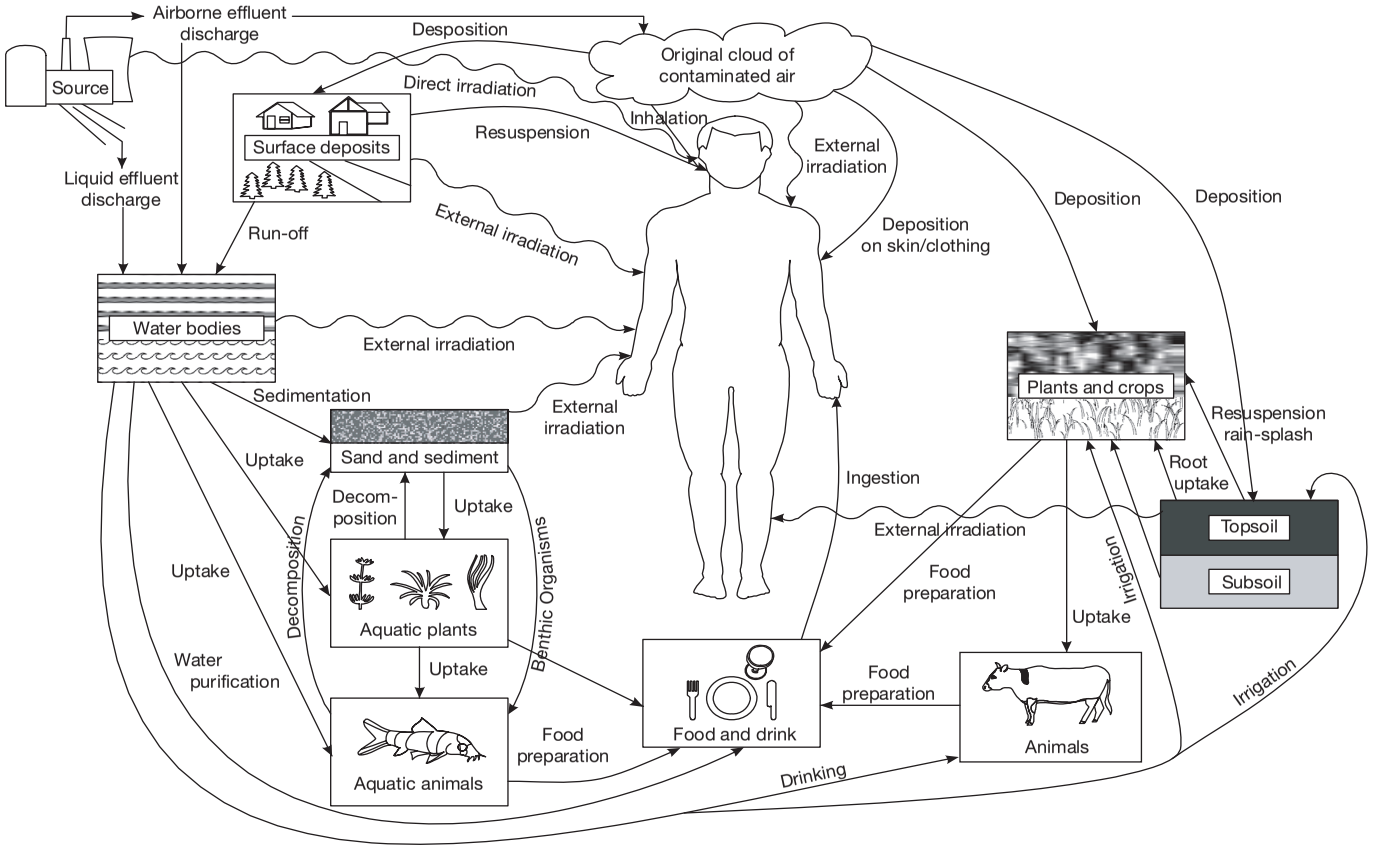



*FIG. 1. The possible pathways of exposure for members of the public as a result of discharges of radioactive material to the environment.*

the monitoring should be focused on measurements of cloud shine and on the sampling of radionuclides from the plume to assess the contributions of external exposure and inhalation to doses. Once the release has been terminated and the radioactive cloud has passed, monitoring should be refocused on 'ground shine' and food contamination to take into account the contributions of external exposure and ingestion to doses.

4.11. In situations of chronic (prolonged) exposure, exposure pathways are usually well defined and not likely to change rapidly. External exposure is determined by the radiation from radionuclides deposited on the ground or sediments, building surfaces or vegetation and not by cloud shine. The ingestion of agricultural and/or natural foodstuffs containing radionuclides may contribute substantially to doses. Because of the gradual penetration of long lived radionuclides into soil, the importance of resuspension and, therefore, of the inhalation pathway decreases with time.

## EXPOSURE GROUPS

4.12. One of the primary purposes of monitoring in the context of normal discharges is to provide information and data for assessing the exposure of members of the public and for verifying the doses anticipated at the licensing stage to occur as a consequence of discharges to the environment during normal operation.

4.13. An important concept for this purpose is that of the 'critical group'. The critical group is defined as a group of members of the public which is reasonably homogeneous with respect to its exposure for a given radiation source and is typical of individuals receiving the highest effective dose or equivalent dose (as applicable) from the given source because of their location, age, diet or habits [2]. Dose constraints or, in some circumstances, dose limits established by the regulatory body generally apply to the mean dose to this critical group. The ICRP has provided guidance to assist in the determination of critical groups [6]. This issue is discussed in more detail in Ref. [7].

4.14. The critical group for a particular set of circumstances should be selected carefully. Adequate attention should be paid to the habits of ethnic and cultural minorities as well as those of indigenous people where applicable. Their living patterns and habits of consumption of food and water could give rise to pathways and elevated exposure levels that are unanticipated by conventional analysis.

4.15. One of the major aspects of the selection is the size of the critical group, which is strongly influenced by the above mentioned requirement for homogeneity. In extreme cases, it may be convenient to define the critical group in terms of a single hypothetical individual. However, the critical group will not usually consist of a single individual, although it will rarely be a large group because homogeneity could then be lost. In practice, the size of the critical group is generally of the order of a few tens of individuals, except in cases in which a large population is homogeneously exposed, for example, through the ingestion of widely distributed foodstuffs or of drinking water from a large reservoir.

4.16. There may be different groups of the most exposed for different exposure pathways and some individuals may be members of more than one such group. In this situation, the critical group should be defined on the basis of the calculated sum of doses via all exposure pathways, which should be compared with the dose constraints or dose limits (e.g. in the case of multiple sources). Some population distributions or land use patterns near a facility may change with time, creating a new critical group or changing the relative importance of some exposure pathways.

4.17. Whereas in the case of normal discharges the doses calculated for the exposure groups are often conservative, the doses for exposure groups during emergencies and situations of chronic (prolonged) exposure should be defined according to 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 adequate allocation of resources. The exposure groups defined should be oriented on real individuals and on assumptions of real patterns of deposition and contamination of the environment and of the foodstuffs and feedstuffs that are produced and used by the population in the affected areas.

## TYPES OF RADIATION MONITORING

4.18. Monitoring for radiation protection of the public can be divided into three types: monitoring at the source (source monitoring), monitoring in the environment (environmental monitoring) and, in very rare cases, individual monitoring of members of the public. Source monitoring includes measurements of radiation levels and radionuclides from a particular source of radiation or from a practice, environmental monitoring is conducted outside

the site giving rise to the exposure and individual monitoring is concerned with measurements carried out directly on people [6].

4.19. Environmental monitoring can be further subdivided into two categories: source related environmental monitoring and person related environmental monitoring (see Fig. 2). Source related environmental monitoring concerns the measurement of absorbed dose rates in air or activity concentrations resulting from a defined source or practice; comparative measurements may be necessary to distinguish the contribution of the particular source or practice under investigation. Person related environmental monitoring is environmental monitoring in circumstances in which there may be several sources irradiating the same group of people; the main objective is to assess the doses deriving from all these sources [6]. The specific objectives and characteristics of the different types of monitoring are discussed below.

4.20. When both source and environmental monitoring or environmental and individual monitoring are required, there should be good liaison between the respective monitoring programmes, because information obtained from one programme may contribute to a better understanding of the other. In principle, it is preferable to base dose calculations on the results of individual monitoring rather than on environmental monitoring, and on environmental monitoring rather than on monitoring at source. This approach has the advantage of minimizing the modelling uncertainties involved in the dose calculations and could provide a firmer indication of the doses actually incurred by the critical group. However, low levels of activity and dose make individual monitoring

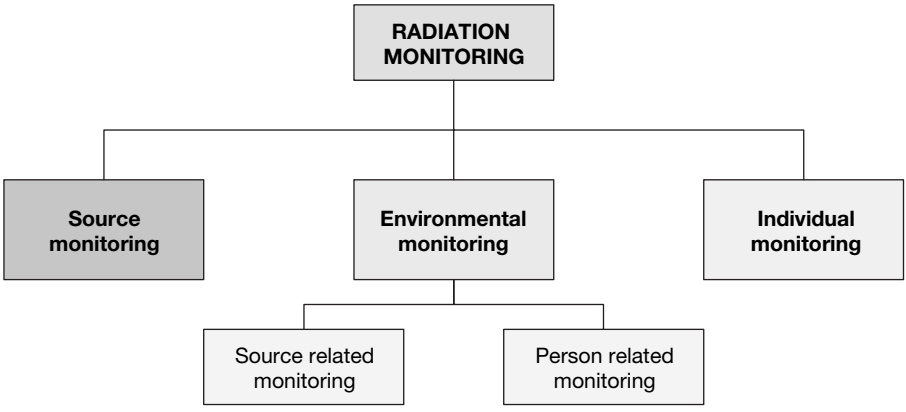



*FIG. 2. Types of monitoring for radiation protection of the public.*

and sometimes environmental monitoring impracticable for dose assessment purposes.

4.21. Individual monitoring for members of the public would only be necessary in the case of an intervention if the assessed average individual dose to members of a particular group of people is close to or could exceed a substantial fraction of an appropriate intervention level [2]. Such a situation is extremely rare.

4.22. The following conditions should be taken into account in the design of any monitoring programme:

— Radioactive inventory and radionuclide composition at the source;
— Space and time features of the radiation fields around the source;
— Authorized discharges and discharge rates;
— Possible contributions from any nearby practices or sources, discharge pathways, exposure pathways, environmental features at the site, and features and habits of the population involved;
— Significance of the annual average doses of the critical group(s) and the environmental radiation levels from planned radioactive releases and possible releases.

4.23. The routine monitoring programme should also be designed to provide a good basis for emergency monitoring in the event of an accident. This requires considerable flexibility in the monitoring arrangements (through the choice and the calibration of appropriate equipment, applicable in both routine and emergency monitoring, organizational provisions and personnel training) to allow a prompt shift from normal to emergency operation in the monitoring programme. Thorough preparation and planning for the monitoring relating to possible emergencies are essential.

**Source monitoring**

4.24. Source monitoring is the monitoring of a particular source of radiation or the discharge of radionuclides arising from a practice. The basic considerations in the design of source monitoring programmes are the same for all sources, but the scale and frequency of monitoring will differ. Source monitoring programmes are usually designed to measure dose rates at the source and/or the discharge rates of radionuclides. Dose rates will vary depending on the nature of the source and its condition. The mode of discharge will also vary: airborne effluents are most frequently discharged continuously during

operation, but the operation itself may be discontinuous, whereas liquid effluents may be discharged continuously or may be stored and subsequently discharged from tanks on a batch basis.

4.25. For each type of source and for each pathway of potential exposure it is necessary to consider the location of the measurement point, whether continuous monitoring is required, the frequency of sampling and/or measurement and the requirements for additional information. For discharges of radionuclides it may be necessary to obtain information on the chemical form, density and flow rate of the discharge, as well as meteorological and hydrological data and information relating to the receiving environment [6].

**Environmental monitoring**

4.26. Environmental monitoring is conducted both on and outside the site giving rise to exposure of the public and radionuclides in the environment. The environmental monitoring programmes include measurements of radiation fields and radionuclide activity concentrations in environmental samples relevant to human exposure, primarily in air, drinking water, agricultural produce and natural foodstuffs, as well as in bioindicators that concentrate radionuclides and provide a measure of trends in activity levels.

4.27. Source related environmental monitoring is carried out to assess the impact of a particular source of radiation and radionuclide discharge. To determine the environmental impact of a particular source, 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.

4.28. Although many sources giving rise to radionuclide releases or external dose rates are localized and environmental monitoring programmes can be focused on them, there are also sources that are multiple, widespread or diffuse, which cannot be treated in this way. The radionuclides released by such sources are mixed in the environment, and there is a need to monitor the total contribution from multiple or widespread sources. The person related environmental monitoring applied for these conditions is often characterized by a wide geographical coverage and by the capability of detecting most radionuclides found in the environment [6].

4.29. Environmental monitoring is always dependent on the site specific features of the environment to be monitored. The monitoring should be done

to detect changes in long term trends in activity concentrations or dose rates in the environment. The other objectives of environmental monitoring are to verify the results of source monitoring, and to confirm predictions of radionuclide transfer in the environment. The environmental monitoring programmes should be comprehensive and appropriate for the local area, rapid in response and capable of sampling and measuring dose rates or activity levels in emergencies.

**Individual monitoring**

4.30. Individual monitoring is concerned with measurements carried out directly on people. It is not normally used in routine monitoring programmes for public exposure but it could be employed following an accident to assess actual doses to individuals and to provide information to the public [6]. Special programmes of individual monitoring may be undertaken for scientific purposes such as the validation of models or the provision of information for public reassurance.

4.31. Individual monitoring includes measurements of external doses with dosimeters carried by individual members of the public and/or measurements of the quantities of radioactive substances in the body or in excreta, and the interpretation of such measurements in terms of individual dose.

# 5. PROGRAMMES FOR MONITORING IN PRACTICES AND INTERVENTIONS

## GENERAL

5.1. The programmes of radiation monitoring include measurements of radiation fields at the source and in the environment, radionuclide content in the media of release and in the environmental samples and, in very rare cases, in the human body. Supporting monitoring programmes should include other types of measurement and data collection activities, such as relevant general environmental characteristics (meteorological, hydrological, soil type, etc.), population characteristics (age distribution, food habits, occupation, etc.) and economic characteristics (land and water use, agricultural technologies, etc.).

5.2. The programmes of radiation monitoring substantially depend on the characteristics of the release source, release medium and release rate, radionuclide composition and physical and chemical form of the released radionuclides, and on environmental parameters in the area contaminated with radionuclides. They also depend on the possibilities of control of the release in cases of practices and interventions. Different techniques and programmes are applied for the monitoring of a release source (stack, discharge pipe, etc.) or radioactive contamination of the environment.

5.3. The monitoring objectives and programmes are different at the various stages of facility operation: the pre-operational stage, the operational stage, decommissioning (or closure) and post-closure. The possible contributions from any nearby practices or sources, discharge routes and the pathway(s) of human exposure, environmental features of the site, characteristics and habits of the relevant population and the likely magnitude of the annual average individual dose for the critical group from planned releases and potential releases should also be taken into account when monitoring programmes are designed.

5.4. The setup of a monitoring programme is the result of an optimization process in which the availability of measurement resources, the relative importance of different exposure pathways, and the levels of activity and dose in relation to the regulatory constraints are taken into consideration. Once a monitoring programme has been implemented, it should be reviewed periodically to ensure that it continually fulfils the objectives.

## MONITORING OF RADIOACTIVE DISCHARGES WITHIN PRACTICES

5.5. During safety assessments carried out as part of the licensing process, the operations of facilities that may possibly discharge radionuclides should be analysed and evaluated and the conditions of operation should be defined. In general, the following data are established as part of the licensing process:

- The spectrum of radionuclides expected to be released in different operational states, including abnormal states;
- Exposures via important pathways that contribute to the doses and the doses to be expected due to discharges;
- The discharge limits.

5.6. One of the main goals of the monitoring programme is to check the assumptions and validate the results of the safety assessment. Thus, the monitoring programme should pay particular attention to the critical pathways and the critical radionuclides.

5.7. The nature of the monitoring programme will change at different stages of operation of a facility. At the pre-operational stage, environmental monitoring is designed to establish existing activity concentrations and radiation dose rates in the environment. At this stage it is necessary to investigate local factors (e.g. meteorology, hydrology, hydrobiological characteristics in the aquatic environment, population distribution, consumption rates of foodstuffs, occupancy factors and land use) that might affect the doses received by individuals in the population. The monitoring network and the environmental sampling regime should be established on the basis of this information.

5.8. In the early stages of operation of a facility, frequent and detailed environmental measurements are necessary to confirm predictions of the behaviour and transfer of radionuclides in the environment. As experience is gained, it may be possible to reduce the scale of both source monitoring and environmental monitoring. Normal discharges may not lead to readily detectable levels of radiation or radionuclides in the environment, either in the early stage of operation or even after years of operation. Nevertheless, any decision to reduce the frequency of sampling or the scope of the environmental monitoring programme should be reviewed carefully and account should be taken of the potential for changing discharge regimes or unexpected releases, as well as any existing concerns raised by the public. The facility and/or the monitoring agency should consider involving the public in the design and review of monitoring programmes so as to help alleviate any concerns raised.

5.9. Generally, all monitoring programmes should be subject to periodic review to ensure that measurements continue to be relevant for their purpose and that no significant routes of discharge or environmental transfer or no significant exposure pathways have been overlooked. In the event of changes in the manner of operation of the source installation or in the nature of the discharges, the monitoring programmes should be reassessed to ensure their continuing validity. Significant changes in the local environment may also occur during the period of operation of the installation (e.g. biological changes in the aquatic ecosystem due to thermal discharges or general eutrophication of the entire water body, redistribution of the surrounding population or changes in

their habits), and these changes may significantly affect the routes of environmental transfer and exposure pathways.

5.10. Changes made to the discharge authorization by the regulatory body on the basis of its regular reviews may also have implications for the design of the monitoring programme. Finally, the environmental monitoring programme will need to be adapted when operations change or cease, during decommissioning of the source facility and in the post-closure period.

**Pre-operational studies**

5.11. Pre-operational studies should be performed for practices to establish 'baseline' environmental radiation levels and activity concentrations for the purpose of subsequently determining the impacts of the source. Pre-operational assessments should also be made of the expected inventories of radionuclides during operation of a facility, the possible discharge pathways and the likely amounts that will be discharged to the environment, with due consideration of the effluent treatment systems that will be installed. The pre-operational studies should also be such as to provide basic environmental data for use in the prediction of doses to the public and discharges to the environment. The first authorized limits on discharges and conditions of discharge to the environment should be established and the monitoring programme designed on the basis of these pre-operational studies.

5.12. For this purpose it is necessary to determine:

(a) The expected activity inventory and radiation characteristics of the source;
(b) The types and activities of radionuclides that will be discharged, their physical and chemical forms, the methods and routes of discharge and the rates of discharge;
(c) The mechanisms for the transfer of radionuclides through environmental media, including dispersion and reconcentration mechanisms, and their seasonal variation;
(d) The natural and artificial features of the environment that will affect this transfer (e.g. geological, hydrological and meteorological conditions, vegetation or the presence of reservoirs or harbours);
(e) The ecological characteristics of the water body planned to receive liquid discharges (e.g. its fauna and flora, annual variability, state of eutrophication and expected changes in ecosystems);

(f) The utilization of the environment for agriculture, the supply of water and food, industry, habitation and recreation;
(g) The density of population, its distribution according to age and to dietary, occupational, domestic and recreational habits;
(h) Possible critical groups;
(i) Existing levels of radionuclides in the environment and their variability;
(j) The existence of any physical or chemical pollutants that may affect the transfer of radionuclides.

5.13. A pre-operational programme might also identify suitable indicator organisms[6] or indicator materials for particular radionuclides. The pre-operational programme can also serve to train staff and to test the equipment, instruments and organization of the operational monitoring programmes. The pre-operational programme should be initiated in good time (2–3 years) before the commencement of operation so as to be able to study the annual variability in the local environment.

5.14. During the pre-operational period, arrangements for emergency preparedness should be considered carefully in terms of the source, environmental and individual monitoring that might be required in the event of any conceivable emergency. The basic intervention levels [2] should be understood by all responsible persons and organizations, and operational intervention levels (OILs)[7] should be established on a site specific basis. The OILs should refer to parameters which can be easily measured (e.g. dose rate in air or deposition density of radionuclides) so that an interpretation can be made rapidly if intervention is required.

[6] Indicator organisms are biota that may not be significant in relation to pathways of human exposure and are therefore not used for dose assessment purposes, but that concentrate radionuclides effectively and so can be utilized as sensitive indicators for assessing trends in environmental radiation levels and activity concentrations of radionuclides in the environment.

[7] OILs are typically expressed in terms of dose rates, activity of radioactive material released, time integrated air activity concentrations, ground or surface activity concentrations, or activity concentrations of radionuclides in environmental, food or water samples.

**Monitoring in the operational stage**

*Source monitoring*

5.15. Source monitoring in the context of this Safety Guide refers to the measurement of authorized discharges and of the radiation field around the source itself. The discharges to the environment may be in the form of gases, aerosols or liquids. The relative activity of the discharges may change in abnormal situations and the external radiation fields around the source may be increased.

5.16. The specific objectives of source monitoring within a practice are:

(a) To verify compliance with the authorized limits on discharges for airborne and liquid discharges;
(b) To provide information necessary for checking whether systems for effluent treatment and control are performing properly;
(c) To provide early warning of any deviations from normal authorized operation;
(d) To provide data on the discharge of radionuclides to the environment, as a basis for the estimation by predictive modelling of environmental radiation levels and activity concentrations and exposure of the public (e.g. rates of discharge and radionuclide compositions).

5.17. The design of the source monitoring programme should be such as to enable the verification of compliance with the authorized limits on discharges and the criteria for discharges specified by the regulatory body. The monitoring of radioactive discharges may entail measurements for specific radionuclides or gross activity measurements, as appropriate. Measurements should normally be carried out before dilution occurs or at the point of discharge (e.g. at the stack for atmospheric discharges or the discharge pipeline for a liquid discharge). In the case of batch discharges, the material for discharge is adequately characterized by the volume of the batch and the radionuclide composition of a sample taken at the reservoir from the homogenized batch prior to discharge.

5.18. For both airborne and liquid effluents three types of measurement are possible:

(a) On-line monitoring of discharges;
(b) Continuous sampling and laboratory measurements of activity concentrations in the sample;

(c) Intermittent sampling and laboratory measurements of activity concentrations in the sample.

5.19. The choice of the sampling and measurement procedures will depend on:

(a) The characteristics and amounts of discharged radionuclides and the sensitivity of the measurement system;
(b) The expected variation with time, if any, in the discharge rates of the radionuclides;
(c) The likelihood of unplanned discharges requiring prompt detection and notification.

5.20. In all situations, it will be necessary to make provisions 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 period can be computed on the basis of measurements of activity concentration. In order to calculate the radiation dose to the critical group resulting from the discharges, relevant meteorological and hydrological dispersion data will also be needed. Other parameters that might be helpful for evaluating the impact of the discharge include:

(a) The physical and chemical form and solubility of the radionuclide(s) discharged;
(b) The particle size distribution in the case of airborne discharges;
(c) The pH in the case of water based liquid discharges.

5.21. There should be good coordination between the source monitoring and the environmental monitoring programmes. In the case of normal discharges, the activity concentrations detected in environmental monitoring are usually very low, and consequently in most cases the dose calculations are based on source monitoring data and appropriate modelling.

5.22. In setting up the instrumentation and data handling requirements for the monitoring of normal discharges, possible abnormal discharges and accidental releases should also be considered to ensure that the range of the key instrumentation is sufficient, that alarm facilities are adequate and that data analysis for accidents can be carried out sufficiently rapidly to assist in guiding the environmental monitoring and the implementation of countermeasures. An important consideration is that the radionuclide composition and physical and chemical characteristics of a release resulting from an accident situation are likely to be different from those in normal situations, and this should be borne

in mind to achieve sufficient flexibility of response in designing the monitoring system for accidental releases [6].

*Environmental monitoring*

5.23. Environmental monitoring in the context of this Safety Guide refers to the measurements of external dose rates in the environment and radionuclide activity concentrations in air, water, soil, bottom sediments, vegetation, the bodies of animals and foodstuffs. It can be divided into two types: source related and person related environmental monitoring. A key feature in designing environmental monitoring programmes for major sources is the identification of potentially critical radionuclides, pathways and groups. On the basis of the identification and assessment of these, it is possible to select those radionuclides and pathways that make the major contributions to individual doses so that the monitoring programmes can be directed to the more important subjects.

5.24. The specific objectives of environmental monitoring within a practice are:

(a) To verify the results of source monitoring and the associated modelling to ensure that the predictions are consistent and that exposure limits are not exceeded;
(b) To check environmental radiation conditions for compliance with the authorized environmental limits, if applicable;
(c) To provide information to enable the assessment of actual or prospective doses to members of the critical group resulting from authorized practices or sources;
(d) To detect any unpredicted changes in activity concentrations and to evaluate long term trends in environmental radiation levels as a result of the discharge practice;
(e) To provide information for the public.

5.25. The design of an environmental monitoring programme should be consistent with the objectives of monitoring. The need for and the scale of an environmental monitoring programme will be determined primarily by the significance of the expected doses to the critical group. Measurements should be made and sampling carried out at appropriate locations accessible to the public outside the operations boundary of the facility. The measurements should include measurements of external radiation levels and of radionuclide concentrations in all relevant environmental samples, food products and drinking water. The locations for measurements and sampling should be

determined on a site specific basis with the aim of determining the highest radiation doses to the public and identifying the areas most contaminated with radionuclides.

5.26. The results of an environmental monitoring programme should enable the verification of the predictions made on the basis of the results of source monitoring and the assessment of doses to the public, when possible. For this purpose, samples should be taken and measurements should be made at a number of locations selected on the basis of the dispersion pattern of the discharges, including background areas. In addition, the most relevant sampling procedure should be determined on the basis of knowledge of the habits and consumption patterns of the critical group of the population.

5.27. In addition to measurements on direct pathways to humans, consideration should be given to the measurement of activity concentrations in natural or artificially added 'indicator' organisms or materials such as seaweeds, lichen or suspended particulate matter which are not always direct parts of food chains. Indicator materials are selected not because they represent a component of the human diet but because they concentrate radionuclides and provide a measure of trends in activity levels. Because of the concentration mechanism, radionuclides in indicator materials are usually more readily detectable than in foodstuffs, so the indicator organisms or materials provide a more sensitive indicator of environmental contamination [6].

5.28. When environmental monitoring is carried out to assess the impact of a particular practice or source, it is referred to as source related environmental monitoring. A source related environmental monitoring programme should be such as to enable the verification of the results of source monitoring by means of samples taken from and measurements made in carefully chosen locations in the vicinity of the facility, selected in view of their correlation with different discharges or accidental releases. It should also enable the assessment of the doses due to external exposure of members of the public outside the boundary of the facility.

5.29. Person related environmental monitoring should be carried out where there are several practices or sources giving rise to the potential exposure of the same group of individuals. An example of this type of monitoring would be when there are several licensees and/or registrants in proximity to one another that have been granted the authority to discharge liquid effluents to the same body of water. In this case, a person related environmental monitoring

programme involving the activities of a particular critical group of people specific to that area (see paras 4.12–4.17) should be carried out.

5.30. The design principles for person related monitoring programmes will be very similar to those for source related monitoring programmes. In the case of person related environmental monitoring, there will be a need to select sampling locations from which the aggregate effect of all discharges can be assessed; for example, in the case mentioned above, the confluence of surface waters or a water treatment facility. For the proper design of such a monitoring programme there is a need for information on the radiation emitted and the radionuclides discharged from each of the contributing sources, their chemical and physical forms and the intervals at which discharges are made, so that appropriate collection and measurement techniques can be employed.

**Monitoring during facility decommissioning**

5.31. Facilities subject to decommissioning at the end of their useful lifetimes include uranium mines and mills, uranium enrichment plants, fuel fabrication facilities, nuclear reactors [33, 34], nuclear fuel reprocessing plants and other radionuclide processing facilities. Spent fuel and other fissile materials and highly radioactive components are usually removed at an early stage, as part of operations, to reduce risk. Subsequently the decontamination, dismantling and removal of radioactive material, waste, structures and components take place, and some buildings and facilities within a site may be released as they are cleaned up. Finally, all materials exhibiting significant levels of activity [2] are removed and the site is released for unrestricted use. The duration of decommissioning may be deliberately protracted to allow for additional risk reduction through radioactive decay.

5.32. As decommissioning proceeds, the potential for impact on the surrounding public from direct irradiation and discharged radionuclides changes in relation to that for the operational stage. Once fissile materials are removed from reactors or reprocessing plants there is no potential for a nuclear accident or for the release of short lived fission products. Radioactive discharges in liquid form will be likely to change as a result of the decommissioning process and will eventually be eliminated. However, the decontamination and dismantling activities integral to decommissioning may result in radioactive releases through the creation, suspension and resuspension of contaminated aerosols. In the case of reactors in particular, activation products may be involved. Unless the contaminated air can be passed through filtered and monitored effluent points such as stacks, there is a

potential for diffuse releases which are difficult to monitor at the source. Consequently there are likely to be changes in the source term as decommissioning proceeds, so monitoring systems for the source and the environment that were in place during operation of the facility should be evaluated to determine whether changes are appropriate. Once determined, the requirements for source and environmental monitoring should be documented in the decommissioning plan [22].

5.33. Decommissioning is considered to be a practice rather than an intervention, and the standards for practices for radiation protection of the public are applicable during the process of decommissioning [22, 23]. Any residual contamination of the surrounding environment from the past operations of the facility being decommissioned is not considered to be part of the practice of decommissioning, but may be a candidate for intervention if warranted. Monitoring in this type of situation of chronic (prolonged) exposure is discussed in paras 5.118–5.132.

*Source monitoring*

5.34. As discussed for the operational stage, discharges to the environment during the decommissioning of facilities may be in the form of gases, aerosols or liquids. The relative activities of the discharges may be expected to change during decommissioning, and the external radiation fields around the sources may vary but will eventually become weaker. The specific objectives of source monitoring are essentially the same as for the operational stage; however, diffuse sources are more likely to be encountered. As the facility undergoes the transition to decommissioning, the existing monitoring programme should be reviewed and possibly adapted to the new situation to ensure that it still enables verification of compliance with the authorized limits and criteria for external radiation levels and discharges as specified by the regulatory body.

5.35. As discussed for the operational stage, the choice of procedures for sampling and measurement will depend on the characteristics of the effluents, the sensitivity of the measurement system, the expected variations and the likelihood that unplanned discharges would require prompt detection and notification. Possible accidental releases during decommissioning of the facilities (after spent fuel or other fissile material has been removed) are likely to be smaller than those that are possible during the operational stage, so the requirements for monitoring equipment to perform adequately over a wide

dynamic range[8] may be less stringent. Once decommissioning is complete, there should be no further need for source monitoring.

*Environmental monitoring*

5.36. Environmental monitoring during the decommissioning of a facility will be similar to that for the operational stage, modified to take account of changes in the source term and in critical radionuclides, pathways and groups. The measurement of external dose rates in the environment and radionuclide activity concentrations in air, water, soil, bottom sediments, vegetation, animals and foodstuffs should be considered for the environmental monitoring programme.

5.37. As for the operational stage, monitoring during decommissioning of a facility includes the objectives specified in para. 5.24. Because decommissioning activities will probably produce diffuse sources of emissions that are difficult to monitor, environmental monitoring assumes additional importance. Even though activity concentrations may be very small or even not measurable, the environmental measurements can be valuable in the assessment of the upper bounds on possible doses to populations.

5.38. The design of programmes for environmental monitoring during the decommissioning of a facility should be consistent with the objectives of monitoring and should accommodate altered source terms and the consequent changes in critical radionuclides, pathways and groups. Once the potential for nuclear fission has been removed, for example, the capability to measure short lived isotopes of iodine in ambient air, pasture and milk is no longer necessary. Similarly, once discharges of radioactive material in liquid form have been significantly reduced or eliminated, it may be possible to reduce and eventually eliminate the need for monitoring surface water. The programme for collecting aerosols that was established for the operational stage should be adequate for

[8] The dynamic range is the range of dose rates or radionuclide concentrations that can reliably be measured by an on-line monitoring system. The lower bound is determined by the detection limit and the upper bound by the acceptable limit on the reliable response of the system as a result of saturation of the pulse counting system of the detector. An on-line monitoring system is a device, usually for the measurement of airborne or water borne activity, that continuously measures emissions from radionuclides flowing through a counting chamber or collected by sampling media at the location.

monitoring aerosols which may be generated during decommissioning, on the assumption that the collecting stations have been sited appropriately.

5.39. Depending on the methods of decommissioning, some aspects of environmental monitoring may have to continue after decommissioning of the facility has otherwise been completed. An example is the situation in which groundwater has become contaminated as a consequence of operation of the facility. Monitoring may have to continue to ascertain whether dilution, dispersal, sequestration and radioactive decay reduce concentrations to acceptable levels [17] before the groundwater reaches points of withdrawal for consumption.

5.40. Several aspects of environmental monitoring that were discussed previously in the section on the operational stage have direct applicability to monitoring during the decommissioning of facilities, but they are not repeated here (see paras 5.26–5.30).

**Monitoring of radioactive waste disposal facilities after closure**

*General considerations*

5.41. This section covers the specific monitoring of facilities intended to confine and contain radioactive waste — mainly in the period after operations at the facility have ceased and the facility has been closed. During the operational phase the guidance given earlier applies; see the subsections on pre-operational studies (paras 5.11–5.14) and monitoring in the operational stage (paras 5.15–5.30). The waste disposal facilities considered include those at which waste is placed on the surface (for example, at some sites for waste from the mining and milling of uranium or thorium ore), near to the surface (low and intermediate level waste), in shallow or deep boreholes and deep underground (geological waste disposal facilities).

5.42. In these cases, the intent is that the waste is contained within the facility for a sufficient period of time until the activity of its radioactive content has reduced to acceptable levels or until the associated rate of release to the environment is low enough to ensure safety. In view of the long time-scales involved, however, a certain amount of migration of radionuclides away from the site may occur at some time after the facility's closure. Complete retention is very difficult to achieve for some mobile radionuclides such as tritium. In the case of geological disposal facilities, in which the waste is contained within several engineered barriers, the migration of radionuclides away from the

waste container may not occur for thousands of years after closure. For waste on or near to the surface, migration may occur substantially sooner.

5.43. The potential migration of radionuclides to the atmosphere and to the geological medium surrounding the closed facility should be considered and, as appropriate, arrangements for monitoring should be provided. It should be recognized, however, that the potential for release to the geological medium is normally likely to be the more important. Any monitoring system devised for use after the closure of the waste repository should not intrude into the barriers designed to contain the radionuclides.

5.44. The future behaviour of the waste in a facility should be assessed as part of the safety assessment process carried out under the licensing procedure [1, 5]. A condition for authorization of the disposal facility by the regulatory body should be the finding that any predicted migration of radionuclides from the facility will not result in the relevant dose criteria established by the regulatory body being exceeded. Reference levels of radionuclide concentrations in the media to be monitored should be established with due consideration of the dose constraints or other relevant dose criteria established by the regulatory body.

5.45. Thus, the main objectives of the post-closure monitoring of a radioactive waste disposal facility are:

— To show compliance with reference levels established by the regulatory body for the purposes of protection of human health and the environment;
— To confirm, as far as possible, the relevant assumptions made in the safety assessment;
— To provide indications of any malfunctioning of the containment leading to unpredicted releases of radionuclides;
— To provide reassurance to concerned persons living in the vicinity of the waste disposal facility.

5.46. Post-closure monitoring of radioactive waste disposal facilities should be carried out within the framework of the programme of active institutional control. The monitoring programme should be developed by the organization responsible for institutional control, and it should be approved and reviewed as necessary by the regulatory body.

5.47. In principle, monitoring should be continued after closure of the waste disposal facility for as long as the facility is deemed to remain a potential

hazard owing to its being a potential source of radionuclides that could be released to the environment. The regulatory body should determine this time period with due account taken of the physical decay of the radionuclide content of the waste and the results of the safety assessment and of monitoring.

*Near surface and on-surface waste disposal facilities*

5.48. Post-closure monitoring programmes aimed at confirming the safety of a disposal facility should include measurements of environmental radiation levels and of radionuclide concentrations in environmental samples collected, with due account taken of the guidance given in Section 6. The design of the monitoring programme should be based on the assumptions, modelling and findings of the safety assessment. Due account should be also taken of site specific[9] factors (e.g. climate, site location, geological and geomorphological conditions, the design of the facility and its barriers, the off-site environment and the population distribution) [24].

5.49. The media for post-closure environmental sampling, as in the operation of facilities, are mobile environmental media (mainly geological media) and biota through which radionuclides could migrate and reach the human habitat and thereby enter the human body. These are atmospheric air (in the case of radon emissions from uranium mining and milling waste sites), soil water and groundwater, surface water, sediments, biota and foodstuffs. Groundwater should be monitored through monitoring wells located at a sufficient depth around and downstream of the facility. Monitoring locations for surface water, sediment, biota and foodstuffs should be related to the potential migration pathways determined by pre-operational studies, and the frequencies of sampling and measurements should be specified with a view to the timely detection of significant changes in the release rates and concentrations of radionuclides and the associated levels of human exposure in accordance with monitoring objectives.

5.50. After the closure of a waste disposal facility, the characteristics of the source term (i.e. release pathways and release levels, and the chemical and physical composition of the released radionuclides) may change. Thus,

[9] Site specific data are data on important parameters used in assessment models that relate to the particular site of interest and that have been obtained for the purpose of the assessment. If site specific data are unavailable, generic estimates (default values) based on measurements made at other locations may be used.

although the surface closure of a sealed facility cover will prevent or minimize the atmospheric release of volatile radionuclides, subsurface leakage into the ground through the engineered barriers may still occur. This may result in a change to the possible human exposure pathways and levels of exposure in comparison with the operational period.

5.51. In the long term, changes in climatic and environmental conditions such as hydrological flows or groundwater chemistry, as well as societal changes such as changes in land use or food production technologies, may occur and may result in substantial changes in human exposure pathways and levels of exposure. The monitoring programmes in the environs of closed waste disposal or storage facilities should be reviewed to take into account any changes in human exposure conditions.

5.52. As discussed for the other stages of facility operation considered in this Safety Guide, the ambient radionuclide levels in all relevant media in the surroundings of the closed waste disposal facility should be compared with appropriate monitoring data collected during the operation of the facility and with pre-operational data to provide a basis for determining whether any significant changes or impacts have occurred or are likely to occur.

5.53. As most of the short lived radionuclides in disposal facilities will have decreased to almost zero activity at the time of closure, monitoring should focus on the medium and long lived radionuclides, and in the long term it should focus only on the long lived radionuclides. Post-closure monitoring should especially focus on the detection of radionuclides of the most mobile elements such as tritium oxide and $^{90}Sr$. The concentrations of these radionuclides in environmental samples should be interpreted both in radiological terms and as an early indication of any loss of integrity of the facility.

5.54. To provide support for the assumptions made in the safety assessment relevant to the post-closure period, the use of more sensitive measurement methods may be necessary. Since it is not to be expected that there would be any significant migration of radioactive material from the disposal facility, the support of the safety assessment on the basis of monitoring will be through the non-detection of some contaminants and the absence of statistically significant changes in the levels of others that are not unique to the disposal facility at that location. The monitoring should be so designed that the result ‘less than a given activity or concentration’ is sufficient to support the safety assessment.

5.55. The monitoring data should serve to indicate when the investigation of a possible inadequacy in the performance of the disposal facility in respect of providing protection against radiation exposure is warranted, and when remedial actions may be needed. The investigation undertaken to determine the reason for unexpected values may involve repeated or more extensive sampling. Analysis of the long term time variation of radionuclide concentrations in appropriate media may be useful. The investigation should be continued until an explanation is obtained that is satisfactory to both the responsible organization and the regulatory body. If necessary, the monitoring programme should be revised to adjust to changing release conditions and possibly migration conditions. The results of the modified or new safety assessment and the monitoring data should be taken into consideration in the decision making on any consequent remedial actions.

5.56. Many of the more common near surface waste disposal facilities were constructed and operated over decades when safety requirements were less stringent than at present. The leakage of more mobile radionuclides from some of these older facilities is more probable than for modern facilities, and more extensive monitoring efforts may be needed.

5.57. The distinction between source and environmental monitoring used elsewhere in this Safety Guide is difficult to make in the case of a waste disposal facility in the post-closure phase, except for some fully engineered near surface repositories where the radionuclides released are systematically collected. Therefore, with the exception of this case, no further attempt is made to draw the distinction between source and environmental monitoring in this context. For modern engineered near surface facilities, monitoring of leachate collected from underdrains offers the most sensitive method of detection of radionuclide leakage.

*Special case of on-surface disposal facilities: mine tailings*

5.58. Before closure of the on-surface waste repository, mining and milling tailings are usually covered with layers of soil, other barrier materials or water (impoundments), which may substantially change human exposure pathways and levels of exposure in comparison with the operational period. Thus the resuspension of particles decreases but the diffusion of radon through the cover may remain significant. The changes in human exposure pathways and levels of exposure should be taken into account in the post-closure monitoring programmes.

5.59. For this type of waste repository located on or close to the surface and being subject to natural (e.g. erosion, landslides and changes in surface water courses) and anthropogenic (e.g. construction work and drilling for mineral resources or water) impacts, changes in the conditions for the waste are possible in both the long and the medium term that may lead to unpredicted changes in the human exposure pathways and levels of exposure in comparison with the period of operation of the facility. Thus wind erosion or the seepage of water and subsequent contamination of both groundwater and surface water may increase over time because of reduced attention to barrier integrity in the post-closure period. Gradual deterioration in the conditions of the waste in relation to safety is more probable for facilities constructed in the past under less strict safety requirements than at present. The post-closure monitoring programmes should take into account changed conditions for the waste [25, 26].

5.60. Additionally, monitoring programmes for on-surface waste disposal facilities containing bulk amounts of mining ores should include monitoring of non-radioactive hazardous materials.

*Geological waste disposal facilities*

5.61. In view of the highly reliable nature of the containments featured in designs for geological waste disposal facilities and their non-accessibility for external natural and human influences, the long term safety of these facilities does not rely on continued active institutional control after closure, including monitoring.

5.62. After the closure of a geological disposal facility, it may be considered appropriate to continue monitoring the site and its surroundings with the aim of demonstrating radiation safety for the public and providing confirmation of the facility's integrity. There may also be continued surveillance of the facility in terms of nuclear safeguards. To facilitate future monitoring efforts, a comprehensive environmental monitoring database should be passed on to future generations [27].

5.63. As yet there is only limited operational experience with geological disposal facilities and closure of such facilities is not expected before several decades, by which time the development of more comprehensive guidance on environmental monitoring may be envisaged.

## MONITORING IN EMERGENCY EXPOSURE SITUATIONS

5.64. In emergency exposure situations, depending on the severity of an accident, all three types of radiation monitoring — source monitoring, environmental monitoring and individual monitoring — may be performed. The overall strategy for emergency monitoring should be preplanned to address the needs of assessors, decision makers and responders over time and geographical location, and as a function of the type of decision on protective actions and response actions that might be necessary to protect the public and responders or to mitigate the consequences of the emergency.

5.65. The specific objectives of emergency radiation monitoring in the environment are:

(a) To provide accurate and timely data on the level and degree of hazards resulting from a radiation emergency, in particular on the levels of radiation and environmental contamination with radionuclides;
(b) To assist decision makers on the need to make interventions and take protective actions;
(c) To provide information for the protection of emergency workers;
(d) To provide information for the public on the degree of the hazard;
(e) To provide information needed to identify any people for whom long term medical screening is warranted.

5.66. In emergencies the nature of key data and requirements for the emergency monitoring programme will evolve with time. For planning purposes emergency time phases can be specified, which are then used for guiding the prioritization of emergency monitoring actions. The phases used here are designated as the pre-release and early phase (release), the post-release or intermediate phase and the recovery or remediation phase. These time phase designations of an emergency correspond largely to those defined by the ICRP [28].

5.67. The scale of the emergency envisaged will determine the design of the environmental monitoring and sampling programme. While the nature and extent of an emergency cannot be anticipated, it is important that advance arrangements be made to prepare for a range of possible emergencies. Arrangements should be made for instrumental measurements, sample collection, sample analysis, dose assessment, interpretation of results, communication and the receipt of assistance from other organizations, if needed.

5.68. This guidance applies to those facilities at which there could be emergencies that result in releases warranting the implementation of protective actions off the site. This includes facilities in threat category I or II as defined in Ref. [3]. Facilities in threat category I, such as nuclear power plants, could give rise to releases that result in severe deterministic health effects off the site. Facilities in threat category II, such as research reactors, could give rise to releases resulting in doses to people off the site that warrant taking protective action in accordance with international standards [2].

5.69. During and immediately after a nuclear or radiological emergency, monitoring resources are likely to be heavily overtaxed, and it is essential to ensure that such resources are utilized as effectively and efficiently as possible until additional assistance can be secured. At the outset, all available meteorological information and modelling predictions should be used to determine the geographical area in which people could be affected by the release of radioactive material.

5.70. Data from source and environmental monitoring should be recorded and retained for use during an emergency, in post-emergency evaluations, and for the long term health monitoring and follow-up of emergency workers and members of the public who may be affected.

**Preparedness for emergency monitoring**

5.71. For planning purposes two areas should be specified in advance corresponding approximately to the zones for which different types of decisions may be necessary, and different monitoring data will be needed to support these decisions [3]:

(a) The urgent protective action planning zone, which is an area around a facility, for which arrangements have been made to take urgent protective actions in the event of a nuclear or radiological emergency to avert doses off the site in compliance with international standards. Protective actions within this area are to be taken on the basis of environmental monitoring or, as appropriate, prevailing conditions at the facility.
(b) The food and agricultural restriction area is the area in which it is likely that land contamination will occur but the need for urgent protective actions is less likely; contamination may result in the need to impose restrictions on the use of foodstuffs and water, and agricultural countermeasures would most probably be taken.

5.72. For emergency planning zones, arrangements should be made for promptly assessing any radioactive contamination, releases and doses for the purpose of determining or modifying protective actions following a release. This capability should include arrangements for promptly conducting environmental monitoring and monitoring of the contamination of people (e.g. evacuees) within the affected zones. The availability of instrumentation and trained personnel should be considered in the arrangements.

5.73. In a nuclear accident the prompt monitoring of a large area may be needed. For this reason, automatic measuring stations that will continuously measure and transmit to an emergency centre the dose rate in the environment should generally be installed around major facilities for the purposes of early monitoring and plume tracking. It is advantageous if the measuring stations are also capable of measuring concentrations of airborne particles, gaseous iodine and any other radionuclide of particular concern. For example, if a facility may contain large amounts of tritium, some special device to measure tritium may well be installed.

5.74. A map with preselected sampling locations should be prepared. Computer modelling of the dispersion of the radioactive plume with the source term, meteorological conditions and other factors taken into account can help to clarify monitoring priorities. The populated areas projected to be the most contaminated should have priority in the monitoring. Those responsible for assessments and management should be aware, however, that dose projections are uncertain. They should expect differences between the results obtained with different computer models and should not use these projections as the sole basis for protective actions.

5.75. Arrangements should be made for identifying the presence of gamma, beta and alpha emitting radionuclides and for delineating the areas in which different protective actions and countermeasures are warranted.

5.76. Within the emergency planning zones arrangements should be made for monitoring the contamination levels of vehicles, personnel and goods moving into and out of contaminated areas to control the spread of contamination. This should include the setting of operational criteria for the results of the monitoring that indicate the need for decontamination or controls in compliance with international standards [2, 3].

5.77. In addition, arrangements should be made for promptly assessing the results of environmental and individual monitoring so as to initiate protective

actions to protect emergency workers and the public. They should include observation in terms of default OILs, so that if an OIL is exceeded the intervention activities follow as automatically as possible. The OILs should generally be site specific or even emergency specific. A useful example of assessment procedures to be implemented in the case of a reactor accident is given in Ref. [10]; the same general method could be adapted for other types of facilities.

5.78. The effects of a protracted radioactive release and of the overwhelming of local resources for monitoring should be considered in relation to emergency preparedness. Thus arrangements should be made in the planning process for receiving help from other organizations if needed.

5.79. Environmental monitoring data should be analysed to produce information for supporting effective decision making (e.g. maps). The results from the different organizations (at facility, local, national and international levels) that conduct environmental monitoring and analysis should be presented in a compatible form.

5.80. In the event of a severe accident, provision should be made for the establishment of a radiological monitoring and assessment centre at which the efforts of all the groups conducting monitoring and assessment will be coordinated. The effectiveness of these arrangements should be evaluated in exercises that simulate response conditions.

**Source monitoring during an emergency**

5.81. The primary purpose of source monitoring under emergency conditions is to determine the magnitude of the releases that might occur, that are occurring or that have occurred. Such data, in combination with meteorological data and the results of predictive dose assessment models, would often be the first line of information available to intervention authorities.

5.82. If a facility might conceivably experience an accident that could give rise to doses over intervention limits, then the operator and the intervention authorities should be prepared to act immediately on the basis of early measurements and predictions. If emergency preparedness arrangements have been implemented appropriately, the responses should be automatic and should be based on a properly designed source monitoring programme.

5.83. Some accidental releases would occur through stacks or other discharge points that have been designed for use in normal operations. As such, a continuous or batch monitoring system with a sufficient dynamic range which can be used to define the release should be installed for all stacks and points of liquid discharge. For these predictable environmental release routes (atmospheric and water), methods to assess releases under emergency conditions should be developed in advance.

5.84. Once a release has occurred such information should be retrieved as rapidly as possible and used in conjunction with meteorological data and dose prediction models to define the geographical areas of concern and to make preliminary estimates of the projected doses. It should always be understood, however, that further releases may have occurred owing to building leaks or at locations not designed for the discharge of radionuclides.

5.85. If a release has occurred by an unanticipated means, such as an explosion, there may be no meaningful monitoring data to define the release. If that is the case, the release might only be inferred on the basis of what radioactive materials might be involved. If there is a continuing evolution of a release, then attempts to measure the release rate should be considered.

5.86. Under any emergency conditions for which the locations of the potential or actual releases can be identified, instrumental measurements should be used to define as well as possible the source related radiation fields associated with the emergency. Under most conditions this would amount to the use of beta–gamma survey instruments. However, it should be ensured that the types of instruments available for measurement purposes are suitable. For example, if the material released might consist of tritium or plutonium, then the usual beta–gamma survey instruments are not useful, and special instruments and/or monitoring techniques should be used.

5.87. Personnel conducting monitoring, sampling and assessments during an emergency should be designated as emergency workers and should be subject to the requirements for emergency workers established in Refs [2, 3]. Arrangements should be made to continually assess and record the doses received by emergency workers.

5.88. If attempts are made to perform source monitoring during any emergency the personnel involved should be equipped with appropriate self-reading dosimeters. Furthermore, each person should be completely familiar with a site defined emergency worker turnback dose (EWTD), which is the dose at which

the worker should no longer attempt to make any measurement or to take any remedial action (except perhaps for saving life) but should simply turn back and avoid the accumulation of a potentially harmful dose. The EWTD limits should be developed with due consideration of all exposure routes (e.g. inhalation), and they should be consistent with international guidance [2].

5.89. In a large scale accident, where the release is from an unmeasured point, or where emergency workers cannot access the site without exceeding the EWTD, it may not be possible to perform meaningful source monitoring. A minimum action should be to determine isodose-rate contour lines around the point of release, even if this can be done safely only from outside the facility.

**Environmental monitoring during an emergency**

5.90. Environmental monitoring will often be the most informative source of data under emergency conditions. In theory, source monitoring data would be more useful, but in practice the ability to perform meaningful source monitoring is often lost on the occurrence of an emergency.

5.91. In deciding on the priority for environmental monitoring (and sampling), the composition of the area should be taken into account, i.e. whether it is residential, agricultural, rural or commercial, and whether it features industrial activities, public services and infrastructural elements.

5.92. In the initial emergency response, the determination of which affected areas are significantly contaminated should take precedence over quantitative analyses, particularly when resources for response are limited. In this context, significantly contaminated areas would be those areas in which radiation levels are at or above the levels at which intervention is required to avoid the immediate potentially harmful exposure of people.

5.93. Of necessity, early measurements should be made with simple instruments and should be made rapidly with the purpose of defining the nature of the emergency. The locations for measurements should include some that have been predefined for that purpose on the basis of the expected locations of maximum impact. The area to be monitored would vary depending on the scale of the emergency, but it should include all locations where interventions might conceivably be needed. The site specific and emergency specific interpretation of these simple measurements should be considered in the process of developing emergency preparedness, so that any necessary interventions can be carried out rapidly. Thus, given a postulated emergency

specific mixture of radionuclides, it is possible to interpret a measured dose rate in air in terms of the likely integrated doses for members of the public who are exposed. This activity should be done in advance, so that any necessary interventions can be carried out on the basis of a comparison of the simple measurements with the site specific and/or emergency specific OIL.

5.94. In the early phase of a severe accident involving airborne contamination, the priorities for environmental measurement and sampling are as follows:

(a) Making measurements rapidly of external gamma dose rates in air over appropriate areas to define whether a predetermined OIL may have been exceeded. These measurements should be repeated on a frequent basis, at least hourly, at locations of possible intervention, and due consideration should be given to meteorological data and feedback from the previous surveys. For large installations at which major accidents might be anticipated, possible locations of substantial radionuclide deposition may be predefined and provisions made for performing such measurements from an aircraft.
(b) In-plume air sampling during a release for the measurement of concentrations and compositions of radionuclides, which provide necessary data for the evaluation of inhalation hazards. Whether such measurements can be made or not, the simple measurement of the external dose rate in air should also be made. Arrangements should be made to analyse these samples promptly for the purposes of revising the default OILs and the EWTD.
(c) Immediately after the release and deposition have stopped, measurements of the external dose rate in air due to ground deposition to detect any locations where the OILs for evacuation, relocation or restrictions on the consumption of foodstuffs are exceeded. In addition, field gamma spectrometry should be performed in the deposition area. This would provide an opportunity to define which gamma emitting radionuclides have been released to the area. The simultaneous measurement of the external gamma dose rate in air would provide an opportunity to estimate radionuclide specific deposition densities for other locations for which there were only the simple measurements of external gamma dose rate in air.
(d) The specification of some locations where continuous recordings of the external gamma dose rate in air can be made. This will be useful in projecting doses over time and in redefining OILs, if appropriate.
(e) Soil sampling after the end of the release or after passage of the plume for the measurement of radionuclide concentrations to give values for

ground deposition to supplement the deposition values determined by field gamma spectrometry. If there is a possibility that radionuclides were released that cannot be detected by means of field gamma spectrometry, these samples should be processed for the detection of pure beta (e.g. $^{90}Sr$) and alpha (e.g. $^{239}Pu$) emitters.

(f) Sampling of contaminated food, water and milk after the end of the release or after passage of the plume; measurements of radionuclide concentrations provide the input data necessary to assess the need for food restrictions and the possible disposal of foodstuffs.

*Monitoring at the pre-release and release stages*

5.95. If it appears that a release is probable but none has yet occurred, priority should be given to accessing information on the likely composition of the material that might be released and the meteorological data (including wind speed, wind direction and data on precipitation) that would indicate where contamination might occur. Depending upon the radionuclides which might be released, it should be ensured that the types of instrument available for making measurements are appropriate.

5.96. At the pre-release stage the environmental monitoring teams should be assembled and deployed in the populated areas. If the projected release is large, existing plans to request assistance from other organizations should be rehearsed in exercises.

5.97. If an instrumented aircraft is available to the facility or can be made available from another facility, arrangements should be put into effect to get the airborne platform into the air so as to provide data immediately on the external gamma dose rate in the plume and, if possible, to obtain a sample of the released material. Usually samples are collected by forcing air through a filter material such as glass fibre. However, if it is suspected that the plume contains radionuclides that are not trapped efficiently by glass fibre filters, then special samplers should be made available for use. For example, activated charcoal filters should back up the glass fibre filter to ensure the collection of radioiodines and special devices can be used to sample tritium.

5.98. Once a release has occurred the most useful measurements will typically be those of external gamma dose rates in the plume and external gamma dose rates in air arising from the deposition of radionuclides on the ground. Measurements of these types can be made most easily and rapidly from airborne platforms, if available. Otherwise, measurements of external gamma

dose rates in air can be made on the ground by teams equipped with the usual beta–gamma survey meters. An early goal should be to determine where the OILs might be exceeded and thus where protective actions should be taken.

5.99. An OIL should be established in advance that would allow dose rate measurements to be interpreted immediately in terms of the intervention needed. In accidents of some types the presence of short lived radionuclides may be very important in terms of the early doses to members of the public. When interventions are being considered, allowance should be made for these early doses due to short lived radionuclides.

5.100. Samples of pasture, milk and other foodstuffs and water should be collected and measurements should be made to assess the exposure of the population and for the purposes of the implementation of interventions such as the restriction of foodstuffs. Milk is especially important in the event of a reactor accident or criticality accident because of the associated releases of radioiodines. Recommended intervention levels for radionuclides in foodstuffs are provided in the Basic Safety Standards [2]. If it is suspected that releases of tritium have occurred, measurements of tritium in pasture vegetation should be made.

5.101. Depending on the nature of the release, it may be advisable to set up ground based air samplers after a release has occurred to monitor for the presence of fallout and resuspended radionuclides. The resuspension of radionuclides does not usually give rise to an important pathway of exposure; however, it can do so for plutonium or other actinides.

*Monitoring at the post-release stage*

5.102. Once a release has ceased and deposition levels have stabilized, further information can be acquired rapidly by the use of field gamma spectrometry (see para. 5.94(c)). This technique can identify the deposition densities of all gamma emitting radionuclides; such information can then be used to project integrated external doses to the affected population. If needed, the more detailed information can be used to derive revised OILs for the situation as better known. Successful field gamma spectrometry requires advance preparation and extensive calibration of the instruments used [11]. The information that can be obtained is valuable in determining any further actions that might be required.

5.103. The results of field gamma spectrometry should be supplemented as soon as possible by means of the collection of representative samples of soil from precisely specified and measured areas. These results can be used to confirm the field gamma spectrometry results but, more importantly, analyses should be undertaken to determine any suspected deposition of radionuclides (i.e. pure alpha or beta emitters) that could not be measured by field gamma spectrometry.

5.104. After the immediate situation has been determined and any necessary interventions have been performed, sampling programmes should be established to determine whether longer term interventions, such as temporary relocations and restrictions on foodstuffs, should be implemented. Vegetables and other locally grown produce, drinking water supplies and milk from local dairies need to be checked by comparison with the OILs. The extent and the nature of such sampling programmes will depend on the extent and the scale of the release and the demographics of the location in terms of local agricultural activities and the population distribution.

5.105. The public should be promptly provided with results of environmental monitoring or of other activities that directly involve them, their homes, their communities or their workplaces, as well as with interpretations of the results in terms of health risks and advice on protective actions, if any, on the basis of monitoring data and other relevant data.

**Individual monitoring**

5.106. Individual monitoring should be conducted together with source and environmental monitoring to determine whether decontamination or medical follow-up of people in the emergency zones is warranted.

5.107. Individual monitoring includes measurements of external dose with dosimeters carried by individual members of the public and/or measurements of the radionuclide activity in their bodies or individual organs or in excreta. The combined use of data from individual measurements and modelling is necessary for the purposes of dose assessment. Because individual measurements are expensive and difficult to perform, such measurements would usually be limited to a selected part of the exposed population, with special attention to critical groups.

5.108. In emergencies involving airborne releases, the prompt assessment of the external contamination of individuals with radionuclides might be useful

for a first screening to determine whether they are candidates for more rigorous surveillance (e.g. by internal dosimetry or medical inspection).

5.109. Individual measurements are only rarely practised in the context of monitoring of the public and they may be appropriate mainly in severe emergencies in which particular individuals are exposed at levels close to or exceeding the intervention levels. In these conditions, special programmes of individual monitoring may be undertaken for scientific purposes such as the validation of models, the provision of dosimetric data for future epidemiological studies, or the provision of information for reassurance of the public.

*External exposure*

5.110. Individual dosimeters should be used for measurements of individual external gamma dose for emergency workers and members of the public following a severe nuclear or radiological emergency. These dosimeters should be distributed to members of the more exposed population groups and should be worn throughout the prescribed time periods.

5.111. During emergencies, particular attention should be paid to the protection of the emergency workers themselves. Every emergency responder should have an appropriate self-reading dosimeter and in conditions of elevated exposure should check it regularly.

5.112. For radiation accidents involving an environmental release of radionuclides, the groups of the general public most exposed in their occupations are people working predominantly in the open air (e.g. agricultural workers and foresters). Such persons should generally receive priority for individual dose monitoring; the sensitivity of the dosimeter and the assigned time periods of wearing the dosimeter should be consistent with the projected dose and the specific objectives of the individual monitoring. Individual monitoring for the external exposure of members of the public is technically feasible if the dose rate due to the radioactive contamination or the loss of shielding substantially exceeds that due to the natural background level of radiation.

5.113. The results of selective measurements of individual external doses should be used both for the validation of the dosimetric models applied and for specification of the exposure levels of the critical group. The individual external doses obtained for time periods before individual monitoring was started

should be assessed with due account taken of dose rate dynamics during the early phase of the accident.

*Internal exposure*

5.114. Transportable and stationary whole body counters should be used for the measurement of the content of radionuclides distributed in the human body owing to a radioactive release in an emergency, for both the inhalation and the ingestion of radionuclides. The content of radionuclides that concentrate in specific organs and tissues (e.g. $^{131}$I in the thyroid gland and radionuclides with low solubility in the lungs) should be measured by means of collimated gamma radiation detectors. Spectrometric equipment should be used for measurements on individuals under emergency conditions, especially during the early stage of a nuclear accident. For the purpose of wide scale monitoring, simplified methods can be applied for the direct measurement of the $^{131}$I content in the thyroid gland or of $^{134}$Cs and $^{137}$Cs in the whole body by means of non-spectrometric devices [29].

5.115. Together with the direct measurement of the content of radionuclides in the body, radiometric analyses of excreta samples, mainly of urine and faeces, can be used for the monitoring of internal exposure for individuals. This indirect method should be applied in the event of accidental environmental contamination with radionuclides emitting beta and alpha radiation and not emitting significant gamma radiation.

5.116. Different age groups, including children and adolescents, should be monitored since, for some radionuclides, metabolic parameters vary significantly with the person's age. In radiation accidents involving an environmental release of radionuclides the most exposed social groups are people working in the open air (for inhalation) and/or people consuming local food products (for ingestion).

5.117. The results of selective measurements for individuals of the content of radionuclides in the body should be used both for validation of the dosimetric models applied and for specification of the exposure levels of the critical group. The individual internal doses should be assessed on the basis of data from measurements and modelling with account taken of the intake dynamics and the metabolic properties for the radionuclides concerned [30, 31].

## MONITORING IN SITUATIONS OF CHRONIC (PROLONGED) EXPOSURE

5.118. Sites with long lived radioactive residues include off-site areas with increased levels of natural radionuclides from uranium and thorium decay chains as a result of past industrial activities, and off-site areas contaminated with human made radionuclides ($^{137}$Cs, $^{90}$Sr, plutonium isotopes and others) as a result of radiation accidents and/or past radioactive releases. Such sites are the subject of environmental monitoring and sometimes individual monitoring. The ultimate goal of the radiation monitoring of sites contaminated with long lived natural or human made radionuclides is to aid decisions concerning remedial actions (intervention).

5.119. The specific objectives of monitoring sites contaminated with long lived radionuclides are:

(a) To check radiation conditions for accordance with radiological criteria and to identify areas in which detailed radiation monitoring is needed;
(b) To identify areas in which remedial actions are justified in radiological terms;
(c) To provide information for estimating actual or prospective doses to members of the critical group and of larger population groups;
(d) To detect changes and evaluate long term trends in environmental radiation levels as a result of natural processes and human activities, including remedial actions;
(e) To provide information for the reassurance of the public.

5.120. The need for and the scale of an environmental monitoring programme are determined primarily by the significance of the envisaged doses to the members of the critical group (see paras 2.15–2.24). The environmental media relevant to human exposure pathways and those media that are sensitive to early changes in radiation conditions should be monitored. Such monitoring will depend on the radionuclides concerned, the physical and chemical composition of the radioactive contamination at the site, the medium containing the radionuclides (e.g. soil or a water body) and practices relating to land and water use. The monitoring programme should include the measurement of external radiation levels and the measurement of radionuclide concentrations in relevant environmental media and food products. The locations for measurement and sampling should be selected on a site specific basis in such a way that the highest radiation doses to the exposure group can be assessed.

5.121. In accordance with the objectives mentioned above, initial monitoring should be carried out in areas that are suspected to be contaminated with long lived radionuclides. The objective of this initial (screening) monitoring is to decide whether intervention may be justified and whether further monitoring is necessary. If the results show that according to the intervention and action levels established by national authorities remedial actions may be required, adequate detailed monitoring should be carried out to help establish the appropriate actions. Monitoring should also be carried out during and after the taking of remedial actions to assess their effectiveness.

5.122. Where radiation conditions caused by long lived radionuclides are unlikely to change rapidly, periodic monitoring should be carried out only at a low frequency (i.e. annually or once every few years).

**External exposure**

5.123. Monitoring of human exposure due to external sources of gamma radiation should be carried out by measurement of dose rates in air at locations accessible to the public. To evaluate the contribution of the radioactive contamination at the site to the effective dose, the background dose rate should be estimated and subtracted from the measurement data. For areas uniformly contaminated with radionuclides, the measurement data on dose rates should be averaged across the monitored area. The results of the dose rate measurements should be used for dose assessments conducted with the aid of appropriate dosimetric models. Depending on specific monitoring objectives, account may be taken in these models of the occupations of different population groups in typical urban areas and their vicinity.

5.124. For screening purposes, the dose rate is usually measured above undisturbed soil for large scale radioactive contamination of the environment, and models applied for dose assessment for the critical group should be simple and conservative and no account should be taken of any reduction in the dose rate in urban areas or for occupation indoors.

5.125. When detailed monitoring of external radiation fields in inhabited areas is carried out, the dose rate should be measured in typical areas that are accessible to the public: in dwellings, public buildings, production areas, gardens and in recreation areas (beach, park, etc.). The appropriate models for external dose assessment in a critical group and for larger population groups should account for non-uniform distributions of radionuclides across the area monitored, seasonal reductions in the dose rate due to snow cover, the

reduction of dose rates in urban areas and typical occupation times indoors and outdoors of the critical group.

5.126. In areas significantly contaminated with radionuclides, external exposure of critical groups can be measured with individual gamma radiation dosimeters worn by group members for some days or weeks. The results of individual measurements should be used mainly for the validation of models used for the assessment of external doses.

**Internal exposure**

5.127. The data on radionuclide concentrations in environmental samples, drinking water and food products would be used for the assessment of the internal doses of a critical group and of larger population groups due to the inhalation and/or ingestion of radionuclides. The major pathways of human internal exposure should be identified at the initial stage of site specific monitoring. Different pathways should be investigated at the screening stage after both airborne and water borne releases because of the complexity of the environmental migration of radionuclides.

5.128. In unpaved areas, long lived radionuclides gradually penetrate into the soil, which prevents their resuspension in the air. In the long term the sampling and analysis of airborne radionuclides should therefore be regularly performed mainly in inhabited areas contaminated with plutonium and other actinides.

5.129. The accumulation of radionuclides in soil and sediments should be monitored regularly for the purposes of predicting radionuclide concentrations in biota, especially in food products. In the event of radioactive contamination of large areas with radioisotopes of mobile elements (i.e. caesium, strontium, radium and uranium), drinking water and all the major groups of food products should be regularly sampled and analysed for their radionuclide concentrations: agricultural vegetable and animal products and natural food products (such as fresh water fish, game, mushrooms and berries). Particular attention should be paid to monitoring the radioactive contamination of those food products, which are consumed in large amounts by some populations, and of those with elevated concentration of radionuclides. In rural areas, food products of local origin are usually sampled, and in towns and cities samples of food products should be collected from markets, shops and public catering facilities.

5.130. In some areas with poor sandy or organic soils (such as woodlands and arctic and tropical areas), the transfer of radionuclides from soil to plants and animals is substantially increased. This leads to increased internal exposure of the local population, which should be taken into account in monitoring programmes.

5.131. The internal doses for the critical group and for larger population groups should be assessed with the models for inhalation of airborne radionuclides and ingestion of contaminated drinking water and food on the basis of typical or site specific food rations. At the screening stage of monitoring programmes, simplified models for critical groups, in which no account is taken of any import of non-contaminated food or of culinary losses of radionuclides, should be applied for the purposes of dose assessment. The influence of these processes on internal doses can be taken into account in the detailed monitoring and dose assessment for the critical group and for larger population groups.

5.132. In areas that are significantly contaminated with radionuclides or in areas with elevated rates of transfer of radionuclides from soil to biota, whole body measurement techniques can be applied to determine the human body burden and to assess doses due to the internal exposure of critical groups. Seasonal variations in the content of some radionuclides in the human body should be taken into account when assessing annual doses on the basis of particular whole body measurements. The results of individual measurements should be used mainly for validation of the models applied for the purposes of internal dose assessment.

## SUPPORTING MONITORING PROGRAMMES

5.133. In addition to measurements of radiation and contamination levels, monitoring programmes should include other types of measurements and activities for data collection such as general monitoring of the environment as well as monitoring of characteristics of the population.

5.134. Climatological conditions (including wind speed, wind direction, stability of the mixing layer of the atmosphere, precipitation statistics, temperature and humidity) should be monitored, both in the pre-operational studies and during operation of the facility.

5.135. Hydrological characteristics of rivers (e.g. variations in water fluxes and characteristics of effluent mixing) into which liquid effluents are released

should also be monitored in the pre-operational studies and in the operational stage. When liquid effluents are released into a lake or sea, hydrodynamic characteristics (including those of water currents, tidal characteristics and currents, and characteristics of general circulation, thermocline evolution and mixing conditions) of the aquatic environment should be monitored in the pre-operational studies and periodically verified in the operational stage. The pre-operational studies should also include monitoring of the local hydrogeology and soils and of the topographical features that may influence the dispersion of airborne effluents. Tracer studies may be desirable in situations of complicated dispersion.

5.136. The distribution and characteristics (in particular the age distribution) of the population in the vicinity of the installation as well as occupations and habits, including food consumption rates and the origins of the food consumed as well as activities and the time periods allocated to them, should be monitored in the pre-operational studies and periodically verified during the operational stage. Periodic local investigations should be conducted to study the habits of the population around major sources. The characteristics of agriculture and aquaculture (including the species involved and agricultural habits and practices) as well as those of gardening should be monitored in the pre-operational studies and periodically verified during the operational stage. Uses of river water should be monitored in the vicinity of the source and as far downstream as might be subject to significant contamination.

5.137. In emergencies, knowledge of the weather and of hydrological conditions is essential to be able to predict or explain the dispersion of the radionuclides released. The wind speed, wind direction, stability of the mixing layer of the atmosphere and magnitude and extent of any precipitation should be monitored in the event of an airborne release. Hydrological characteristics of rivers and lakes should be monitored in the event of a release of radionuclides either into the atmosphere or into surface water bodies. The distribution and characteristics (in particular the age distribution) of the population in the vicinity of the installation should be known and recorded from previous monitoring.

5.138. Supporting monitoring programmes for sites contaminated with long lived radionuclides should be focused both on the terrestrial environment and on the description and habits of the population. The local water cycle should be monitored: precipitation and evaporation, local surface waters and groundwaters and their connections, and inputs and outputs by main rivers. Characteristics of soils should be studied. The descriptions and distributions of

populations should be monitored as well as their habits, in particular their rates of consumption of local foods. Agriculture and gardening habits in particular should be followed. The local and downstream uses of water should be carefully monitored. Particular attention should be paid to the characteristics of ethnic and cultural minorities and indigenous peoples.

# 6. TECHNICAL CONDITIONS FOR MONITORING PROCEDURES

## SAMPLING STRATEGY

6.1. The sampling strategy should be adapted to the situation that is to be monitored and should be consistent with the objectives and purpose of the specific monitoring. The sampling locations, frequencies and techniques will depend on the tasks, the types of release, the radionuclide compositions concerned and the exposures that are to be expected as a consequence of the releases.

### Sampling during normal discharges

*Source sampling*

6.2. Most of the data on the discharge of radionuclides from nuclear facilities are usually obtained by means of on-line measurements of the dose rate, activity concentration or total activity at the discharge point. Sampling and subsequent measurements of the air and water released, whether continuous or discontinuous, should be used mainly to determine the radionuclide composition of a discharge. If discharges are very low, on-line measurements may be insufficiently sensitive and sampling together with subsequent laboratory analysis may be necessary.

6.3. The frequency of sampling should be determined with account taken of the results of previous monitoring of the particular facility or similar facilities so as not to miss significant changes in the radionuclide composition of the discharges.

*Environmental sampling*

6.4. In the case of normal discharges from licensed facilities, environmental sampling and measurements should primarily be performed for proving the compliance of measured values with the established limits for or the predicted values of radionuclide concentrations in environmental samples. Sampling locations should therefore be selected close to points where the maximum exposure or deposition is expected, preferentially in the main wind direction for airborne discharges or downstream from the release point for aquatic discharges and at the site boundary for direct radiation from the source. Since atmospheric dispersion and water dispersion may very significantly from year to year, a significant part of the monitoring measurements should be performed at the same location for the year by year comparison of the results.

6.5. Additional environmental sampling and/or measurements should be conducted regularly in nearby population centres as well as in background areas (upwind or upstream of the source) to compare the results with those of the main monitoring programme.

6.6. Continuously produced agricultural food products such as leafy vegetables or milk should be sampled several times a year, or more frequently in the case of releases of short lived radionuclides such as radioiodines. Soil and products with one harvest per year should be monitored once a year.

6.7. The constituents monitored and the frequencies of sampling and measurement are summarized in Table 3. This should be considered a framework; the specific programme should be set up in consideration of the radionuclides involved, site specific considerations and the levels of discharges. The choice of food will depend on local agricultural practices and the food related habits of the population.

**Sampling in emergencies**

6.8. Sampling in an emergency is difficult to plan since its circumstances cannot be clearly foreseen and it therefore necessitates a high degree of flexibility, especially for environmental monitoring. In emergencies, the possibilities for comparing the results of environmental measurements with those obtained from source monitoring are limited, since the amount of radioactive material released, especially during the release phase, can usually be determined only with large uncertainties. Environmental monitoring should

TABLE 3. ENVIRONMENTALLY MONITORED CONSTITUENTS AND FREQUENCIES OF SAMPLING AND MEASUREMENT FOR NORMAL DISCHARGES OF RADIONUCLIDES TO THE ENVIRONMENT

| Discharge | Monitored constituents | Frequency |
|---|---|---|
| Airborne | *External radiation* | |
| | Gamma dose rate | Continuously |
| | Gamma dose — integrated | Twice a year |
| | Neutron dose rate (if neutron radiation is foreseen) | Continuously |
| | Neutron integrated (if neutron radiation is foreseen) | Twice a year |
| | *Air, deposition* | |
| | Air | Continuous collection, weekly to monthly measurement |
| | Rain | Continuous collection, monthly measurement |
| | Deposition | Continuous collection, monthly measurement |
| | Soil | Once a year |
| | *Foodstuff and/or ingestion* | |
| | Leafy vegetables | Each month during growing season |
| | Other vegetables and fruits | Selected samples, at harvest |
| | Grain | Selected samples, at harvest |
| | Milk | Each month when cows are on pasture |
| | Meat | Selected samples, twice a year |
| | Drinking water and/or groundwater | Twice a year |
| | *Terrestrial indicators* | |
| | Grass | Each month when cattle are on pasture |
| | Lichen, mosses, mushrooms | Selected samples, once a year |
| Liquid | *Aquatic dispersion* | |
| | Surface water | Continuous sampling, monthly measurement |
| | Sediment | Once a year |

TABLE 3. ENVIRONMENTALLY MONITORED CONSTITUENTS AND FREQUENCIES OF SAMPLING AND MEASUREMENT FOR NORMAL DISCHARGES OF RADIONUCLIDES TO THE ENVIRONMENT (cont.)

| Discharge | Monitored constituents | Frequency |
|---|---|---|
| | *Aquatic foodstuffs* | |
| | Fish | Selected samples, once a year |
| | Shellfish | Selected samples, once a year |
| | *Aquatic indicators* | |
| | Seaweeds, marine sponges | Selected samples, twice a year |
| | Benthic animals | Selected samples, twice a year |

therefore provide data for supporting actions that might be necessary to mitigate the radiological consequences.

*Source sampling*

6.9. Most data on increased amounts of radionuclides released from nuclear facilities in emergencies should be obtained by on-line measurements of the dose rate and/or the total beta activity at the release point. To assess the radiological consequences of an accident, the radionuclide composition of the associated release should be determined as often as possible. In the case of an airborne radioactive release in an emergency, a continuous filter system supplied with a high resolution spectrometer may be especially informative with regard to iodine and other aerosols. For reasons of personnel safety, the monitoring system should be installed.

*Environmental sampling*

6.10. In the event of an accident at a nuclear or other facility, environmental sampling and subsequent measurements should be performed to provide data on the levels, time dependence and spatial distribution of radionuclides in air, soil, plants, foodstuffs and feedstuffs so as to assess doses to critical groups of the population and to support decisions on mitigation and protective actions. Sampling should therefore be representative with regard to the exposure conditions of the critical group (see paras 6.18–6.22).

6.11. The sampling locations should be selected to give an overview of the entire vicinity of a facility from which radioactive material has accidentally

been released but also in the far field. At the early stage, sampling and measurements should be performed in all directions, but predominantly in the main wind direction for an airborne release or downstream for an aquatic release. However, the actual locations will be defined by the spatial distribution of the gamma dose rate in air. The monitoring should be focused on the areas with the potentially highest contamination with account taken of their patterns of land use.

6.12. As soon as the release and its associated fallout are terminated, foodstuffs and fodder should be measured within a short period of time. Measurements of plants after the termination of the deposition may give valuable information for estimating the activity in these products at harvest.

6.13. The environmental media that should be considered in emergency monitoring and the recommended frequency and location of sampling or measurement are summarized in Table 4. It should be regarded as a framework; the specific monitoring programme should be set up in consideration of the radionuclides involved, site specific considerations and the levels of the releases. For example, a long duration of releases might make it necessary to start earlier with measurements on soil, food and radiological indicators as indicated in Table 4.

6.14. The intensity and duration of the monitoring activities should be determined on the basis of the severity of the emergency. It may take from a few days to years; during this time the monitoring activities will be adapted to the actual radiological situation. Furthermore, the season in which the accident happens is very important with respect to the intensity of the monitoring programme. Outside the vegetation period only a few types of plant will be affected by foliar contamination, which will drastically reduce the necessity for food monitoring.

**Environmental sampling in conditions of chronic (prolonged) exposure**

6.15. As long as activity levels in the environment arising from emergencies or from practices such as uranium mining and milling remain close to the action levels, prolonged surveillance of the environment may be necessary to ensure that action levels are not exceeded and that necessary remedial actions are undertaken in time. During these periods, the main pathways that contribute to exposures are external exposure due to long lived radionuclides on the ground, ingestion of foods contaminated by root uptake and, in cases where

TABLE 4. ENVIRONMENTAL MONITORING OF RADIONUCLIDES TO BE PERFORMED FOLLOWING EMERGENCIES

| Release | Monitored constituents | Frequency | Remarks |
|---|---|---|---|
| Airborne | Measurements during the passage of a cloud | | |
| | *External radiation* | | |
| | Gamma dose rate | Continuously | Near and far field, external dose rate map |
| | Neutron dose rate (if neutron radiation is foreseen) | Continuously | Only near field, if neutrons are expected |
| | *Air* | | |
| | Air | Continuous collection, measurement every 2 h | Near and far field |
| | Rain | Continuous collection, measurement every 2 h | Near and far field |
| | Measurements after the passage of a cloud | | In contaminated areas |
| | *External radiation* | | |
| | Gamma dose rate | Continuously | External dose rate map |
| | *Deposition* | | |
| | Soil | Once | Contamination map for relevant radionuclides |
| | *Foodstuffs/ingestion* | | |
| | Leafy vegetables | Daily | Good indicator for plant food |
| | Milk | Daily | Good indicator for animal food |
| | Other vegetables and fruits | At harvest | |
| | Grain | At harvest | |
| | Meat | Representative samples | |
| | Drinking water and/or groundwater | Representative samples | |
| | *Terrestrial indicators* | | |
| | Grass | Daily | |
| | Lichen, mosses, mushrooms | At harvest | |

TABLE 4. ENVIRONMENTAL MONITORING OF RADIONUCLIDES TO BE PERFORMED FOLLOWING EMERGENCIES (cont.)

| Release | Monitored constituents | Frequency | Remarks |
|---|---|---|---|
| Liquid | After releases | | Affected areas and water bodies are limited |
| | *Aquatic dispersion* | | |
| | Surface water | Continuous sampling, daily measurement | |
| | Sediment | Weekly | |
| | *Aquatic foodstuffs* | | |
| | Fish | Selected samples | |
| | Shellfish | Selected samples | |
| | *Aquatic indicators* | | |
| | Seaweeds | Selected samples | |

contamination with alpha emitters is relevant, the inhalation of radon, actinides or contaminated soil particles that have been resuspended by wind.

6.16. For the purpose of assessing doses to critical groups of the population and supporting decisions on remedial actions, sampling should be representative with regard to the exposure conditions of the critical group (see paras 6.18–6.22).

6.17. Owing to the long half-lives of the radionuclides involved and to long term transfer processes, the annual decreases in dose rates and levels of food contamination are relatively small. Only seasonal factors such as increased resuspension in dry periods may cause larger fluctuations in contamination levels. Under these relatively constant conditions, the monitoring intensity can be reduced in comparison with that during an emergency. In general, monitoring should be more frequent in areas where radiation conditions are close to intervention levels or action levels.

**Sampling techniques**

6.18. Environmental monitoring is aimed at obtaining representative values. Representativeness in this context means that the sample should reflect the conditions in the environment from which it is taken. In general, activity levels in terrestrial samples are subject to spatial and temporal variability caused by

various factors such as inhomogeneous spatial distributions of the deposited radioactive material in soil, redistribution of radionuclides by wind or by water erosion, differences in soil conditions and agricultural practices and the superposition of different exposure pathways like foliar uptake and root uptake.

6.19. Measured activity levels in environmental samples are the result of the complex interactions of these factors which cannot be clearly foreseen. The variability in samples of soils, plants, animals and sediments causes uncertainties in the determination of activity levels in environmental samples.

6.20. The inherent variability of environmental samples necessitates careful design of sampling strategy. Since under monitoring conditions the reasons for the variability cannot be fully understood, a predefined sampling strategy should be used that is closely connected with an appropriate statistical evaluation of the measured activities. This is important since the comparison of activity levels in environmental samples with intervention levels or action levels may form the basis for decisions with long term consequences for health, society and the economy.

6.21. To provide for representative sampling, specific procedures for sampling have been suggested by the International Commission on Radiation Units and Measurements (ICRU) [32]. Although this may not eliminate the uncertainty associated with activity levels in environmental samples, it may reduce the uncertainty and enable it to be quantified by statistical means. Table 5 summarizes the main sampling techniques [32] and their features.

6.22. The sampling frequency will depend on the quantity that is to be estimated, the precision that is required, the time dependence and the variability of the quantity to be measured. In general, sampling should be more frequent in areas where radiation conditions are close to intervention levels or action levels. Sampling should also be more frequent for monitoring with increasing spatial and temporal variability, including the monitoring for radionuclides with short half-lives and monitoring of foodstuffs with a short duration between harvesting and consumption.

## STRATEGY FOR MEASUREMENTS

6.23. In the frame of monitoring programmes, radiation measurements are performed at the source, in the environment and in laboratories, under

TABLE 5. SAMPLING TECHNIQUES FOR ENVIRONMENTAL MONITORING

| Sampling technique | Description | Comment |
|---|---|---|
| Judgemental sampling | Sample is taken on the judgement of the sampling person | Increased probability of biased sampling; representativeness cannot be quantified; accuracy cannot be quantified |
| Simple random sampling | Any sample has the same probability of being included | Provides representativeness; problems may arise with inhomogeneous terrain |
| Stratified sampling | The sample in its entirety is divided into parts that are known to be more homogeneous; simple random sampling is then applied to the remaining subdivisions | Requires knowledge of the inhomogeneity of the entire sample; may lead to bias if the fractions of the samples 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 contamination patterns may be overlooked |

conditions of normal and emergency releases or in situations of chronic (prolonged) exposure. In this context, the technical requirements for radiation measurements are: selection of the media, locations and frequencies for measurements; selection of equipment for the detection of particular types of radiation and energies; and requirements for minimum and maximum detection levels for radiation or activity.

6.24. The equipment to be used for measurements should be selected in consideration of the purpose for which it is to be used. The range of radionuclides that might possibly be released from a facility, both in normal operation and in an emergency, should be taken into account. Whereas nuclear power plants may release a wide range of radionuclides with half-lives of seconds to thousands of years, fuel fabrication facilities release a much narrower range of radionuclides with no short lived radionuclides. The technical requirements of the measurement strategy will depend on the purpose of the monitoring.

6.25. Table 6 summarizes the sampling and measurement procedures for the determination of various quantities that may be important for various contexts

TABLE 6. MONITORING QUANTITIES AND MEASUREMENT GUIDANCE

| Quantity to be measured | Sampling/measurement | Application |
|---|---|---|
| | *Source monitoring* | |
| Gamma dose rate at the source | Stationary on-line equipment, continuous measurement | Practice, emergency |
| Gases in released air | Stationary on-line equipment, continuous measurement | Practice, emergency |
| Aerosols in released air[a] | On-line equipment and/or sampling; nuclide specific analysis, total alpha and total beta | Practice, emergency |
| Activity in released water[a] | On-line equipment and/or sampling; nuclide specific analysis, total alpha and total beta | Practice, emergency |
| | *Environmental monitoring* | |
| Gamma dose rate over ground | Field measurements; mobile or stationary devices | Practice, emergency, chronic (prolonged) exposure |
| Aerosol activity in air | Filter sampling; nuclide specific analysis | Practice, emergency, chronic (prolonged) exposure |
| Radioiodine in air | Sampling specific to physical and chemical form; nuclide specific analysis | Practice, emergency |
| Activity in rain | Sampling in rain collector; nuclide specific analysis | Practice, emergency |
| Deposited activity | In situ gamma spectrometry; planchet sampling and nuclide specific analysis | Practice, emergency |
| Activity in soil | In situ gamma spectrometry; field sampling and nuclide specific analysis | Practice, emergency, chronic (prolonged) exposure |
| Activity in foodstuffs and feedstuffs, waters, sediment | Field sampling; nuclide specific analysis | Practice, emergency, chronic (prolonged) exposure |

[a] If the discharge limits for a practice are given in terms of total alpha activity and/or total beta activity, and not for specific radionuclides, radionuclide specific measurements on a routine basis may not be necessary.

of monitoring. In general, radionuclide specific activity levels in environmental media should be measured. If the discharge limits for a practice are given in terms of total alpha activity and/or total beta activity, and not for specific radionuclides, radionuclide specific measurements on a routine basis may not be necessary.

6.26. The sampling frequency will depend on the item to be measured and the variations with time in the activity concentration in the media. During practices and chronic (prolonged) exposure, the temporal fluctuations are generally relatively low, so the frequency may consequently be low. The time intervals between measurements should reflect the half-lives of the radionuclides that are to be monitored. If the sampling time on a filter is long in comparison with the half-life of the radionuclide concerned, this radionuclide may not be detected and the purpose of the monitoring is missed.

6.27. For low level measurements in conditions of practices and chronic (prolonged) exposure, the minimum detectable activity of the equipment and the method applied should be such as to enable the measurement of radionuclide levels that are substantially lower, by one to two orders of magnitude, than established limits or action levels for radionuclides in the appropriate media. If the established limits are lower than the background levels, however, then a minimum detectable activity that enables the measurement of radiation levels or activity concentrations lower than background levels is sufficient.

6.28. When monitoring data are to be used to assess the annual doses for a critical group and to verify compliance with the dose constraints in the case of practices or to check against the intervention level, the minimum detectable activity of the equipment concerned should be selected so as to enable measurements to be made at levels that are substantially lower than the established reference dose levels, with account taken of multiple pathways of human exposure. For every pathway that has to be checked, a certain fraction of the reference dose should be allocated; the minimum detectable activities should be designed to guarantee the detection of these possible contributions to doses.

6.29. The equipment to be used in emergency conditions should be capable of measuring the high levels of radiation or high concentrations of radionuclides that are feasible under severe accident conditions. Since the derivation of a source term in such a situation is of vital importance for decisions on

countermeasures, such monitoring should at least be able to provide data on the most radiologically significant radionuclides in such an event.

## UNCERTAINTIES IN MONITORING DATA

6.30. Monitoring activities should be such as to provide the necessary data for the analysis and evaluation of environmental contamination. Monitoring, especially in emergencies, is an important information source for decision making and for the justification of countermeasures. However, as with any measurements, monitoring data have associated uncertainties that arise from technical uncertainties, the non-representativeness of samples and/or measurements, and human errors.

6.31. The technical uncertainties in the monitoring data arise mainly from:

— The spatial and temporal variability of the quantity monitored (e.g. dose rate and activity concentration);
— The variability of procedures for sampling, processing and measurement;
— The statistics of counting in the case of low level radionuclide activity.

6.32. These uncertainties cannot be eliminated but they should be reduced as far as possible by means of quality assurance procedures. Whereas incorrect calibration may be detected and corrected at a later stage, errors in the treatment of the samples cannot readily be detected and corrected. Furthermore, the storage of samples allows the repetition of measurements for the samples that are obviously not correct. Regular training and exercises should be conducted for the staff to maintain the experience of personnel as an important precondition for high quality work, especially under stress in emergencies.

6.33. Representativeness in sampling and/or in field measurements can be optimized by means of an appropriate sampling and measurement scheme as described above and by intensifying the monitoring activities.

6.34. Human errors are difficult to quantify. Stress and a heavy workload, especially in emergencies, may give rise to human errors leading to, for example, improper recording, loss of samples, incorrect labelling, cross-contamination during sample preparation and contamination of measurement devices. Since many human errors can be foreseen and simulated, adequate

training of personnel and quality assurance procedures should be used to reduce their number, even in emergency conditions.

6.35. The uncertainties in monitoring results should be determined with account taken of uncertainties in sampling and measurement procedures, including the uncertainties in sample processing parameters and equipment calibration, and they should be reported together with the monitoring results. The uncertainties in monitoring results should be taken into account in dose assessment procedures and in the interpretation of monitoring data.

# 7. CONSIDERATIONS IN DOSE ASSESSMENT

## GENERAL CONCEPTS

7.1. Information from monitoring programmes should be used to estimate radiation doses to members of the public for comparison with dose criteria established by the regulatory body. Such criteria are usually specified in terms of limits on the annual radiation dose (practice) or as intervention levels of the dose received by the critical group. This assessment is performed by calculating the doses that members of the critical group receive or could potentially receive. Results from source monitoring, environmental monitoring or individual monitoring, or from a combination of these, are used in these calculations.

7.2. None of the above mentioned monitoring methods directly gives the radiation doses received by members of the critical group; mathematical models are needed to convert results from monitoring programmes into dose predictions. The models to be used to calculate doses will depend on the exposure conditions, the available results of the monitoring, the purpose of the assessment and the magnitude of the doses. The models should simulate the major pathways contributing significantly to the exposure of the population groups under consideration (see paras 4.4–4.11).

7.3. The purpose of the dose assessment, the time dependence of exposure conditions and the radionuclide composition of the release and the deposition are different for practices (chronic long term discharge), emergencies (short term release) and chronic exposure situations (contamination with long lived

radionuclides). Different models of human exposure should therefore be used to assess doses in these exposure situations (see below).

7.4. When environmental monitoring provides results on the radiation levels and radionuclide content of air, water and foodstuffs, metabolic and dosimetric models should be used for the purposes of dose assessment, in conjunction with data on the time spent in different exposure conditions by individuals of the critical groups, the volume of air inhaled and their consumption rates of foodstuffs and beverages. When only the results of source monitoring are available or when environmental monitoring does not provide sufficient data on radiation levels and the contamination of air, water and food, the use of radionuclide transfer models for transfer through the environmental pathways of exposure and the food chains is also necessary.

7.5. Dose assessment should, if possible, involve measurements of environmental contamination in combination with environmental transfer models. The balance between measurements and models will depend on several criteria such as:

(a) The availability of environmental measurements directly relevant to individuals of the reference group,
(b) Whether the samples are representative,
(c) The accuracy of the measurements,
(d) The number of measurements under the detection limit for radionuclides that are released from sources,
(e) The degree of validation of models for site specific calculations.

7.6. Different models for radiological assessment with varying degrees of complexity exist. The level of detail and the complexity of the modelling needed should reflect the magnitude of the predicted doses [33].

## ASSESSMENT OF DOSES FROM NORMAL DISCHARGES

### External exposure

7.7. The assessment of external irradiation from the source is straightforward, at least in principle. When the source is discrete, the radiation fields in its vicinity may be measured (the natural background radiation should be estimated and subtracted from the results) or calculated using simple techniques. To determine the dose to the critical group, calculations should be

made to allow for the effects of distance, shielding and scattering and the proportion of the year that a member of the critical group is likely to spend in the area.

7.8. External exposure due to radionuclides present in the plume or on the ground is generally difficult to assess from direct radiation measurements because variations in the natural background radiation are usually larger. Nevertheless, in many cases such external exposure due to radionuclides can be derived from spectrometric measurements of air contamination and ground deposition using established contamination to dose conversion models and the proportion of the year that a member of the critical group is likely to spend in the area. Reductions in exposure due to shielding by building structures as well as increases in exposure due to deposition on the walls and roofs of buildings can be taken into account if data on building structures are available or by using published default shielding factors.

7.9. The most exposed group of the population for external exposure in conditions of chronic normal discharges may be represented by persons working mainly outdoors (such as field workers, herders and foresters). If a residential area is located in the vicinity of a nuclear facility, persons living in one storey houses constructed of light materials (e.g. wood) should be taken into account in the identification of the critical group.

**Internal exposure**

7.10. The pathways to be taken into account in the calculation of internal doses will depend on the purpose of the calculation (e.g. for screening purposes versus making a detailed assessment, or adopting a conservative approach to ensure compliance with limits versus a realistic approach for optimization studies) as well as the magnitude of the doses. The predominant exposure pathways should generally be taken into account: the inhalation of air contaminated by airborne discharges, the ingestion of foodstuffs and beverages (vegetables, fruit, meat and milk) contaminated by airborne releases, and the ingestion of fish, shellfish and seaweed products contaminated by liquid discharges.

7.11. The calculation of doses from inhalation requires data on the volume of contaminated air inhaled in a year by individuals of the critical groups. This volume will depend on their ages, the proportion of the year that members of the critical group are likely to spend in the area and their activities in the area. The ICRP has provided guidance in this matter [34].

7.12. The calculation of doses from ingestion requires data on the consumption rates of contaminated foodstuffs and beverages by individuals of the critical groups. The consumption rates of different types of foodstuff and beverage are usually region specific. It should be taken into account that subgroups of the population (e.g. fishermen) may have very specific consumption rates for certain categories of foodstuff or beverage [33]. The calculation of doses also requires data on the origin of the foodstuffs; generally only local foodstuffs are significantly contaminated by normal discharges and thus of the foodstuff and beverages consumed by individuals of the critical group only the fraction of local origin should be taken into account in the dose calculations.

7.13. When the contamination of foodstuffs and beverages has been assessed by means of models, calculation of the source related doses is straightforward. Modification of the contamination of foodstuffs due to food processing and cooking practices may be taken into account at this stage of the dose calculation, but cautious verification of data is necessary.

7.14. The calculation of doses from the results of environmental monitoring requires appropriate processing of the monitoring results. The background radiation, whether natural background radiation or that due to fallout from nuclear weapon tests, should be identified, generally by means of comparison with results from monitoring in an area that has not been contaminated (if such an area has been well characterized); for the calculation of doses due to releases from a source or a practice, these background radiation levels should be subtracted from the results for contamination. If the contamination is due to releases from several sources, the total dose should be calculated on the basis of environmental monitoring measurements, but it is generally difficult to attribute fractions of the dose to each source.

7.15. It should be emphasized that the calculation of doses on the basis of the results of environmental monitoring should be preferred when the contamination of air, water and foodstuffs has been readily measured and when the number of results allows significant statistics to be derived. Generally, only some of the discharged radionuclides can be measured above the detection limits in the relevant environmental media and foodstuffs. The calculation of doses on the basis of the results of environmental monitoring should therefore generally be complemented with calculations made on the basis of the results of source monitoring for those radionuclides that cannot be detected in the environment. Additionally, environmental monitoring during practices enables the verification of the assumptions, models and parameters that were used in the licensing process are consistent with the site specific conditions.

7.16. To be useful for the purposes of dose calculations, measurements of food contamination should relate to the edible portions, not to the entire organism or plant, and it should also be made clear whether the results are on the basis of wet weight or dry weight. The dose calculations made on the basis of the measurements of food contamination should use an average contamination level derived from at least several representative samples. Seasonal crops should be sampled near the time of harvest. Dose calculations should be made on the basis of measurements of the contamination of only those species that are actually consumed by individuals of the critical groups.

## DOSE ASSESSMENT IN EMERGENCIES

7.17. All appropriate arrangements should be made to assess the exposure incurred by emergency workers and members of the public as a consequence of a nuclear or radiological emergency. Such an assessment should be based on the best available information and should be promptly updated in the light of any information that would produce substantially more accurate results.

7.18. The dose assessment model to be used for emergencies should:

— Take into account factors that have a significant impact on off-site doses;
— Make use of readily available information;
— Be easy to use under stressful emergency conditions;
— Produce results that are easy to understand and that support the decision making process;
— Produce results in which the major uncertainties associated with such projections are take into account.

7.19. The methods and models [33, 35] used to assess doses to members of the public from normal discharges are not appropriate for emergency situations, in which the maximum use needs to be made of the available information, from a limited number of measurements, to estimate off-site consequences promptly. These methods should include provisions to project off-site consequences that could arise as a result of the conditions at the facility (e.g. in the case of unmonitored or possible future releases). These projected off-site consequences could be precalculated doses for different accident conditions, as provided in Ref. [10], or computer models such as INTERRAS [10]. The dose projections should be as realistic as possible, and in any case doses for situations in which persons might be in danger of being harmed should not be underestimated.

7.20. Those who are responsible for assessments and management should be aware that dose projections are uncertain and that for severe emergencies it may be impossible to make accurate projections of off-site doses. They should expect there to be differences in the results obtained from the models used by different organizations and they should not use such projections as the sole basis for deciding on protective actions.

7.21. During the emergency preparedness phase the models to be used during any conceivable emergency should be chosen, and persons who will use these models should be made thoroughly familiar with them in terms of the input data of various kinds that could be used to derive dose projections. The kinds of data that are likely to be available for input should be understood and the model should be capable of accepting these preferably simple forms of input. For example, if the relative mixture of radionuclides that are likely to be released is known, then even one simple measurement of the external gamma dose rate in air can be used to estimate doses at that particular location from both external and internal exposure. Later, as more measurements become available, the first early projections can be modified. Modifications to the projections can also be made if interventions such as sheltering have been implemented.

**External exposure**

7.22. The assessment of external exposure in an emergency situation will generally include assessments of exposure from the plume and from deposits on the ground and, in some circumstances in an emergency, possibly direct exposure from the source.

7.23. Direct exposure from the source may show high temporal variations and the assessment of doses would require very frequent monitoring of the radiation field. The radiation levels would generally be far in excess of the usual background radiation levels, which could therefore be neglected. Other components of the radiation fields, such as radiation from the plume, should be subtracted from the direct measurements of radiation from the source if this is feasible. The assessment of external irradiation from the source is straightforward; it may be calculated using simple techniques in which account is taken of the effects of distance and scattering and of the time that individuals (such as emergency workers) are likely to spend in the area. The effects of shielding should also be taken into account if relevant data are available. As a first approximation, in an emergency, measurements of the kerma in air (in Gy/h

or any equivalent) can be used in the same way as measurements of the ambient dose rate (in Sv/h or equivalent).

7.24. The external exposure due to radionuclides present in the plume can be derived from direct radiation measurements or from measurements of the concentrations of airborne radionuclides. Whereas these measurements are usually radionuclide specific or specific to the physical and chemical form of the radionuclides, it should be ascertained that the radiologically significant radionuclides present in the plume have been sampled and measured. Account should be taken in the calculations of the distance from the point of measurement to the plume axis so as to extrapolate the monitoring results to the most exposed populations, who are those situated in the main body of the plume. When the releases and release rates are estimated on the basis of data from source monitoring with good accuracy, which is generally difficult to ensure, external exposure due to radionuclides present in the plume can also be calculated from models of the dispersion of the releases. The effect of shielding by building structures may be taken into account provided that the necessary data are available and sheltering countermeasures have been effective.

7.25. External exposure due to the deposition of radionuclides on the ground can be derived from direct radiation measurements made after the plume has passed (when the dose rate is well above natural background levels) or when spectrometry has been performed. It can also be derived from measurements of radionuclide concentrations made on environmental samples (e.g. soil, grass and rain water). External doses due to the deposition of radioactive materials are generally calculated for a limited time period, typically of a day or a few days, that is consistent with the implementation of urgent protective actions (sheltering or evacuation). For such short periods, deposition can be assumed to be constant except for the radioactive decay of short lived radionuclides. The effect of shielding by building structures may be taken into account provided that data are available and that sheltering has been effective.

**Internal exposure**

7.26. In emergencies, for calculations of doses from internal exposure consideration should generally be directed first to inhalation, because this pathway is of paramount importance for the implementation of urgent protective actions (sheltering, evacuation and prophylaxis with stable iodine). As discussed for external exposure due to the radionuclides present in the plume, internal exposure due to the inhalation of radionuclides present in the

plume can be derived from the results of environmental monitoring or from model results based on source monitoring.

7.27. Resuspension of deposited radionuclides is generally not taken into account, as it is usually of less importance during the early phases of an emergency (with the possible exception of large scale dispersion of plutonium). The effect of sheltering may be taken into account provided that data are available and that sheltering countermeasures have been effective. The effects of prophylaxis with stable iodine may also be taken into account provided that the exact time of its application is available.

## DOSE ASSESSMENT FOR SITUATIONS OF CHRONIC (PROLONGED) EXPOSURE

7.28. People living in areas contaminated with natural or human made long lived radionuclides are usually subjected to exposure via multiple pathways. The contributions of external doses and internal (i.e. by ingestion and inhalation) doses depend on the isotopic compositions and the physical and chemical forms of the radionuclides, environmental conditions and the habits of the population.

7.29. In the case of long term public exposure with slowly changing radiation conditions, dose assessments should be based on the available data from environmental monitoring in combination with simple static or equilibrium models. For States with a temperate or polar climate, account should be taken in these models of seasonal changes in the exposure conditions (e.g. due to snow cover) and human habits. The possible influence of specific climate conditions (such as drought or optimum conditions for mushroom growth) on the accumulation of radionuclides by vegetation should also be taken into account.

7.30. The purpose of the dose assessment for the public living in conditions of chronic (prolonged) radiation exposure is usually the justification of remedial actions that involve considerable expense associated with them. The doses of critical population groups should therefore be estimated on the basis of realistic, not screening, dosimetric models. To the extent possible, available data from environmental measurements and selective data from individual measurements, such as data from whole body counting for internal dosimetry and individual doses for external dosimetry, should be used to validate these models.

7.31. To determine existing annual doses, all the components of both the external exposure and the internal exposure caused by the environmental radiation, including natural background radiation, should be accounted for. Special methods of measurement and data processing should be applied to identify the dose components contributed by particular environmental radiation sources.

**External exposure**

7.32. The external dose to the critical population group in conditions of chronic (prolonged) exposure should be determined on the basis of environmental monitoring data by the use of a simple calculation model in which account is taken of the partial shielding of the human environment in comparison with an open area, human occupation, the ratio between the dose in air and the effective dose, and the seasonal variation of relevant parameters.

7.33. The most exposed group of the population for external exposure in conditions of chronic (prolonged) exposure usually comprises those persons working mainly outdoors (such as foresters, herdsmen and field workers) and those persons living in one storey houses constructed of light materials (such as wood). Estimations of typical occupation time periods spent by such a group in living, working and rest areas, both indoors and outdoors, at various typical locations in the different seasons are best made by means of conducting personal interviews.

7.34. The set of measurements of dose rates performed at various locations where members of the critical group usually reside, both outdoors and indoors, can be used directly to assess the existing external doses. To define the contribution of a particular radiation source to the external dose, methods of field gamma spectroscopy should be applied with subsequent assessment of the dose due to particular radionuclides or subtraction of the background radiation as determined in similar conditions.

7.35. As an alternative source of data from environmental monitoring, the levels of soil deposition of particular radionuclides in the area assessed can be used for estimation of the external doses due to radionuclides. With the use of radionuclide specific conversion coefficients, these data should be converted into dose rate values above undisturbed ground (e.g. lawns), ploughed soil or solid surfaces (e.g. asphalt or concrete).

7.36. Model parameters accounting for the attenuation of dose rates in typical rural and urban locations relative to a reference surface (usually a lawn) should be determined prior to dose assessment by making a series of field measurements or by modelling radiation conditions in settlements, dwellings and other locations.

7.37. The uncertainties associated with the estimation of external doses can be substantially reduced if some crucial parameters are determined by measurements and the final result of the dose assessment is validated with the data from individual dose monitoring performed in particular time periods.

**Internal exposure**

*Ingestion*

7.38. The internal doses to a critical population group in conditions of chronic (prolonged) exposure due to the ingestion of contaminated food and/or drinking water should be determined on the basis of environmental monitoring data by the use of a simple calculation model in which account is taken of the origin and consumption rate of particular food products as well as seasonal variations in relevant parameters.

7.39. Persons consuming substantial amounts of locally produced food comprise the most exposed group of a population with regard to radiation exposure via the ingestion pathway. For long lived radionuclides with slight dependence of the dose coefficients on age (e.g. tritium and caesium), adults consuming both locally produced agricultural and natural food products will usually form the most exposed population group. For radionuclides whose dose coefficients depend strongly on age because of their specific metabolic properties (e.g. strontium, radium and polonium), infants or children usually form the most exposed population group.

7.40. The set of data that are regularly obtained on radionuclide concentrations in locally produced agricultural foodstuffs can be used directly to assess the annual intake and the associated committed dose. In regions where the inhabitants normally consume substantial amounts of natural food products (e.g. game, freshwater fish, forest mushrooms and berries) with elevated radionuclide concentrations, available data from measurements should also be used for the estimation of intakes of radionuclides.

7.41. If data from measurements on food are unavailable or insufficient, the concentrations of radionuclides in foodstuffs can be roughly estimated from data on soil deposition or water concentrations by using known coefficients of radionuclide transfer from soil or water to plants and animals. When transfer coefficients are selected, attention should be paid to the use of appropriate natural and climatic conditions, including the soil type and the mineral content of fresh water.

7.42. The ingestion model should include the major groups of foodstuff and drinking water as consumed by the critical group. The estimations of consumption rate to take into account the contributions of locally produced foodstuffs should be based on official production and trade statistics (for the general public) or should be obtained by means of personal interviews (for the critical group). The culinary losses of food mass and the associated reductions in intakes of radionuclides can additionally be used in estimating the ingestion of radionuclides.

7.43. The uncertainties in the modelling of internal doses can be substantially reduced when some crucial parameters are evaluated by measurement and some site specific corrections are introduced. The most reliable method of validation of an ingestion model is by comparing its predictions with internal dose assessments made on the basis of data from individual measurements of radionuclide contents in the human body performed by whole body counting or by analysis of the concentrations of radionuclides in excreta.

*Inhalation*

7.44. The contribution of inhalation to the internal doses to the critical group is substantial for radioactive gases and vapours (e.g. radon or tritium oxide) and for radionuclides with low solubility and low mobility in food chains (e.g. actinides and transuranics), especially for persons working in the open air and in dusty conditions. The special case is that of long term residence in areas with elevated concentrations of natural uranium and radium resulting in the emanation of radon.

7.45. The inhalation dose to the critical population group in conditions of chronic (prolonged) exposure should be determined on the basis of data from the monitoring of radionuclide concentrations in the above ground air with the use of a model in which account is taken of the breathing rate of persons of various ages in conditions of performing various physical activities as well as for seasonal variations in the relevant parameters.

7.46. The set of regularly obtained data on radionuclide concentrations in air can be directly used to assess the annual intake and the associated committed dose. If measurement data are unavailable or insufficient, radionuclide concentrations in air can be roughly estimated from soil deposition rates by using a resuspension model.

## UNCERTAINTIES IN DOSE ASSESSMENTS

7.47. The uncertainties in dose assessments made on the basis of monitoring results incorporate both uncertainties in monitoring data and uncertainties in dosimetric models. The largest uncertainty is usually that associated with the modelling performed using source monitoring data as the input because in this case the modelling includes the dispersion of radionuclides in the environment, which can be predicted only with significant uncertainty. The uncertainties in dose assessments are lower when data from comprehensive environmental monitoring are used and lowest when individual monitoring data are available.

7.48. In the conduct of practices, rates of release of radionuclides are generally low and the possibilities for a detailed analysis of exposure might be limited if, for example, the external dose rate attributed to releases is of the same order as the fluctuations in the dose rate due to background radiation. In this case, the dose can be assessed as a value less than the dose estimated with the minimum detectable activity for the measurement used as input data. This dose assessment can be assigned an estimated uncertainty that takes into account the uncertainties in the parameters of the dosimetric models.

7.49. For emergencies and situations of chronic (prolonged) exposure, dose assessments are necessary for the analysis and evaluation of the radiological situation, to provide the basis for making decisions on whether mitigatory and/or protective actions are necessary or not. Table 7 summarizes the types of data yielded by monitoring and used for dose assessments as well as the major sources of the associated uncertainties in modelling that contribute to uncertainties in dose estimations.

7.50. Besides the uncertainties associated with monitoring procedures, an important source of uncertainty arises from the modelling and especially from people's habits. Often only nationwide average values, if any at all, for the relevant parameters are known, which may deviate considerably from the values for specific persons in specific areas. For the conduct of practices and for chronic (prolonged) exposure, activity levels in the environment may be

TABLE 7. MAJOR SOURCES OF UNCERTAINTIES IN DOSE ESTIMATIONS MADE ON THE BASIS OF DATA FROM ENVIRONMENTAL AND INDIVIDUAL MONITORING

| Pathway of human exposure | Quantity monitored | Source of uncertainties in dose estimates |
|---|---|---|
| External exposure | Gamma dose rate in air as a function of time and space | Location and duration of stay of people in the area monitored |
| | External dose measured with a thermoluminescent dosimeter | Duration of stay at the location of the thermoluminescent dosimeter; little uncertainty, if the thermoluminescent dosimeter is worn continuously by the exposed person |
| Ingestion | Activity concentration in foods as function of time and space | Age dependent food intake; origin of food; seasonal variation of food intake |
| Inhalation | Activity concentration in air | Location of people; inhalation rate; dose coefficients |
| Internal exposure | Whole body activity | Limited to gamma emitters; variability of intake rate; requires metabolic data to convert activities to doses |
| | Bioassay of excreta | Variability of intake and excretion rate; requires metabolic data to convert activity concentrations to doses |

relatively stable and the use of averaged data on habits will give reasonable results. However, in emergencies more specific data are required that are relevant to the particular seasonal and social conditions prevailing when the accident occurred.

7.51. Uncertainties as to the origins of foods remain important contributors to the uncertainties in the assessment of ingestion doses. Although in rural areas a significant proportion of the diet may be produced locally, at least a part of the food consumed is produced elsewhere. Where there are usually no reliable data on this matter, it may be assumed that all the food consumed is produced locally, which gives a conservative bias.

7.52. The degree of conservatism in the internal dose assessment can be estimated by comparing dose calculations made on the basis of modelling with the results of whole body measurements. These considerations might be very useful for validating and calibrating dose assessments made on the basis of monitoring data. This method is limited to gamma emitters since pure alpha and beta emitters cannot be detected with sufficient accuracy by whole body counters.

7.53. Dose rates and activity levels may be expected to vary considerably in time and space during and after emergencies. The allocation of average values to real exposed persons under these circumstances introduces more uncertainties than under conditions in which activity levels in the environment show only relatively small fluctuations. Furthermore, people may tend to take spontaneous countermeasures of their own that decrease the doses to be expected on the basis of monitoring data even at dose levels that are far below any intervention level or action level.

7.54. Both uncertainties in monitoring data and major sources of uncertainties in dosimetric models as presented in Table 7 should be taken into account in determining the uncertainties in dose assessments made on the basis of monitoring results. When the uncertainties in all the components contributing to the estimated dose are small, the resulting uncertainty in the dose can be calculated analytically by the summation of the appropriate variances. However, if the uncertainty and the importance of one or more components are substantial, stochastic modelling should be performed to assess the resulting uncertainty in the dose.

7.55. The uncertainties in dose assessments should be taken into account in the interpretation of data from radiation monitoring.

# 8. INTERPRETATION OF MONITORING RESULTS

## GENERAL CONSIDERATIONS

8.1. The results of a monitoring programme, whether for source, environmental and/or individual monitoring, are presented in terms of:

— Radiation levels at the source of the release and radionuclide concentrations in the materials released;
— Radiation levels and radionuclide concentrations in the environment;
— The doses currently received by individuals of critical groups or given populations;
— The dose projected for individuals of critical groups (in emergencies).

8.2. For the conduct of a practice, the results of a monitoring programme for source, environmental and/or individual monitoring should be used to check for compliance of the actual radiation conditions with authorized limits by way of comparison with one of the following as reference values:

— Discharge limits;
— Environmental limits;
— Dose constraints for source related monitoring;
— Dose limits for individual related monitoring.

8.3. In emergencies, the data from the monitoring of radionuclides in the environment, including foodstuffs, should be used as an input to decision making for mitigatory and protective actions on the basis of comparison with:

— Generic or specific action levels of radionuclide concentrations in the environment or in foodstuffs;
— Generic or specific intervention levels of dose for individuals of critical groups.

8.4. In situations of chronic (prolonged) exposure, the monitoring data should be used to justify remedial actions and long term countermeasures on the basis of comparison with:

— Generic or specific action levels of radionuclide concentrations in the environment;
— Generic or specific intervention levels of dose for individuals of critical groups.

8.5. Both in emergencies and in situations of chronic (prolonged) exposure, the environmental monitoring data can also be employed as input data for optimization procedures used to justify and optimize countermeasures (i.e. protective or remedial actions), respectively.

8.6. Although methods and protection criteria for biota are still under development, the results of a source and/or environmental monitoring programme can also be interpreted in terms of the dose received by biota organisms.

8.7. Data from the monitoring of radionuclides in the environment can also be used for the following subsidiary purposes:

— To detect changes in conditions for the source, the environment or individuals;
— To determine long term trends for levels of radionuclides in the environment;
— To validate or update the radionuclide transfer model and dose models adopted in the pre-operational studies.

8.8. Environmental monitoring can be used as a means of performing an independent check on the operation of an installation and especially to detect any unplanned release, route of release or increase in radiation levels. Such departures from normal conditions are generally detected owing to significant unplanned increases or decreases in radionuclide concentrations or in radiation exposure. The interpretation of such variations generally requires a comparison with historical levels (which ought to be recorded) or with upwind and downwind (or upstream and downstream for flowing water) measurements (or other reference measurements) to determine whether the installation is the cause of the increase or decrease. The interpretation of measurements of radionuclide concentrations in bioindicators can be valuable in the early detection of small departures from normal conditions.

8.9. To avoid the misinterpretation of monitoring data, a thorough understanding of the conditions of sampling and measurement is necessary. The types of conditions include:

— The geographical location;
— The date and time;
— The duration of sampling;
— The procedures for sampling and measurement;
— A clear understanding of the physical quantities measured;
— The background radiation levels and radionuclide concentrations in the environment.

8.10. Due consideration should be given to the reliability of the data, with account taken of:

— The precision and accuracy of sampling and measurements;
— The variability of environmental factors and the representativeness of sampling and measurements;
— The measurement of gross activity which requires other assumptions to be made on the composition of radionuclides;
— The interpretation of measurements under the detection limit.

8.11. The assumptions used by the operator for interpreting the results of monitoring form a key part of that interpretation. The description of the interpretation of the results should document in an open and transparent manner the assumptions used in all aspects of carrying out the monitoring and in interpreting the results.

8.12. Environmental monitoring programmes generally include both inexpensive routine measurements of integrated parameters (e.g. gross alpha measurements) and periodic measurements of the concentrations of individual radionuclides (by means of spectrometry or radiochemical analysis) at the source and/or in some environmental compartments. For the interpretation of the measurements, every kind of correlation between different types of monitoring should be studied:

— Results of source monitoring and of environmental monitoring;
— Measurements of radiation levels and of radionuclide concentrations;
— Measurements of integrated parameters and of individual radionuclides;
— In situ gamma surveys and sample measurements;
— Routine and periodic measurements;
— Measurements of radionuclides and of other parameters (e.g. weather conditions).

## COMPLIANCE WITHIN PRACTICES WITH REFERENCE LEVELS AND CRITERIA FOR PUBLIC EXPOSURE

8.13. The reference levels and public exposure criteria to which reference is made in this section are internationally, regionally or nationally accepted standards. Internationally accepted standards established by the IAEA [2] require that the average doses to the relevant critical groups of members of the public that are attributable to practices not exceed an effective dose limit of

1 mSv in one year. Regional standards are expressed, for example, in the 1996 European Directive [36], which applies to member states of the European Union. National standards may include source related reference levels of dose (termed dose constraints) that are not to be exceeded. Typical national values of the dose constraints in different States range from a few tens of microsieverts to 0.5 millisievert in a year [7].

**Compliance with reference levels**

*Discharge limits*

8.14. Within a practice, usually annual discharge limits are granted to operators. Other discharge limits such as discharge limits for shorter periods may also be included in the permits. Measurements for source monitoring should be made to ensure that the actual discharges are below these limits.

8.15. Normally, time integrated measurements based on continuous radiation measurements or continuous sampling should be used to ensure that no unmonitored releases have occurred. For releases of radionuclides that are not discharged in large amounts and that are not radiologically significant, average values from periodic sampling or measurements may be acceptable provided that no wide variation in discharges is anticipated. If wide variations in discharges are anticipated, however, the variation should be periodically verified.

8.16. Procedures on how to take into account measurements that are under the detection limits should be made clear and unambiguous. Measurements under the detection limit for radionuclides that are likely to be present in the discharges should be taken into account on the basis of a fraction (e.g. 50%) of the discharge volume multiplied by the detection limit.

8.17. The uncertainties in discharge measurements should be taken into account in a conservative way to verify compliance with established discharge limits.

*Environmental limits*

8.18. Discharge permits may also include environmental limits, such as radiation levels at the site boundary or limits on the concentrations of radionuclides or particular categories of radionuclides in specific environmental compartments. Data from environmental monitoring should be

used to ensure that actual radiation levels and radionuclide concentrations are below these limits.

8.19. Data from environmental monitoring can also be used to ascertain whether the models employed to predict levels of environmental contamination and of human exposure are sufficiently conservative by comparing results from monitoring with those from modelling. Where the predictions made on the basis of the model differ substantially from those made on the basis of the monitoring data, this should be considered a reason to use a site specific structure and/or site specific parameters for the model.

8.20. When limits are established as mean values for particular areas and/or time periods, the appropriate monitoring data should be averaged and the standard errors in the mean values should be determined. The recommendations made in relation to discharge levels concerning measurements under the detection limit and means of accounting for uncertainties apply also to environmental levels.

**Compliance with criteria for public exposure**

8.21. The results of source monitoring and environmental monitoring in relation to a practice should be used to confirm that the actual doses which result from normal conduct of the practice comply with the criteria for public exposure.

8.22. Whereas discharge limits are established by means of dose modelling for a critical group, the compliance of source monitoring data with the discharge limits ensures the compliance of doses estimated on the basis of source monitoring data with the exposure criteria if the same or a similar model is used. In particular, as the doses assessed on the basis of source monitoring results are clearly attributable to the source, the results from source monitoring should be used specifically to verify compliance with the dose constraints.

8.23. When comprehensive environmental monitoring data relating to the major human exposure pathways are available, they should be directly used to assess the doses to critical groups and to ensure that discharges and radiation levels in normal conduct of the practice actually comply with the public exposure criteria. In the case of a single source of environmental discharges, the assessed dose should be compared with the appropriate dose constraint, and in the case of multiple sources of discharges of radionuclides the doses should comply with the 1 mSv per year limit.

8.24. The dose received by individuals in the population should be derived from the results of environmental monitoring, with the natural background taken into account. The background levels should be subtracted from the results of the measurements so as to assess the doses due to practices only. Both statistically significant measurement data (above the detection limit) and measurements under the detection limits can be used for dose assessment purposes with the associated uncertainties taken into account.

8.25. The source related doses can also be derived from the results of environmental monitoring by removing the base line, including natural background radiation and other sources. Such source related doses should nevertheless be interpreted cautiously since the fractions of radiation or radionuclide concentrations that are attributable to other sources may be subject to large uncertainties.

8.26. Uncertainties in monitoring results should be fully taken into account in the assessment of doses and their comparison with public exposure criteria. Uncertainties should be taken into account in a conservative way; in other words, the assessed doses should encompass the actual doses received by the individuals of the critical group:

— Both uncertainties in measurements above the detection limit and uncertainties in modelling should be taken into account to assess doses and their uncertainties;
— Measurements under the detection limit should be assumed in the dose assessment to be the value of the detection limit, unless there are convincing reasons to assume that undetected radionuclide concentrations and undetected radiation levels are actually negligible.

## ASSESSMENT OF PROTECTIVE ACTIONS IN SITUATIONS OF EMERGENCY EXPOSURE

8.27. In situations of emergency exposure, urgent protection actions, including sheltering, evacuation and iodine prophylaxis, should be taken on the basis of general assessment and modelling rather than monitoring data. However, decisions on the cessation of urgent protection actions and the application of longer term protection actions (e.g. agricultural countermeasures or temporary relocation) should be taken mainly on the basis of data from monitoring and dose assessment [2].

8.28. In situations of emergency exposure, data from source monitoring, if available, are used for making dose projections, which should be compared with appropriate intervention levels. The environmental monitoring data should be used both to determine whether generic or specific environmental action levels have been reached and to make dose projections. This recommendation applies to both nuclear and radiological accidents.

**Environmental contamination levels**

8.29. To make decisions on taking protective actions in a particular area, average radiation levels and/or activity concentrations in foodstuffs, drinking water, crops and other relevant materials should be determined. On the basis of the available preliminary monitoring data, areas with relatively uniform levels of radioactive contamination should be identified, and mean radiation levels and activity concentrations should be determined from measurements. These average values should be compared with appropriate generic [2, 37, 38] or specific action levels, including OILs [10].

8.30. Action levels are usually established for particular radionuclides or their groups, and appropriate monitoring data should be obtained for comparison with action levels. It should be confirmed that there has been adequate monitoring for every important radionuclide (e.g. in the event of a nuclear accident: $^{89}$Sr, $^{90}$Sr, $^{95}$Zr, $^{95}$Nb, $^{103}$Ru, $^{106}$Ru, $^{131}$I, $^{134}$Cs, $^{137}$Cs, $^{140}$Ba, $^{140}$La, $^{238}$Pu, $^{239+240}$Pu and $^{241}$Am). In the case of a nuclear accident, the decay of short-lived radionuclides and the consequent reduction of environmental radiation levels and activity concentrations should be taken into account. For radiological accidents, monitoring conditions are usually simpler because such accidents generally involve a limited number of known radionuclides.

8.31. The following information relevant to the assessment of protective actions should be documented and reported to the regulatory body when known:

— The uncertainties in measurements, in particular for results close to the action levels;
— The locations and origins of the sampled foodstuffs, drinking water, crops and other relevant material and the relative directions and distances of these locations from the zone of maximum impact;
— The amounts of foodstuffs, drinking water, crops and other relevant material that has been sampled.

**Dose assessment and criteria for public exposure**

8.32. In an emergency, criteria for public exposure for use in decisions on intervention under any circumstances are based on short term (i.e. less than two days) projected absorbed doses or dose commitments to organs and tissues: whole body, bone marrow, lung, skin, thyroid gland, lens of the eye and gonads. Other criteria for public exposure for use in decisions on urgent protective actions are based on short term avertable effective doses for the following periods: no more than two days for sheltering, no more than one week for evacuation and one month for temporary relocation. For iodine prophylaxis, the avertable committed dose to the thyroid gland due to radioiodine should be assessed [2].

*Source monitoring data*

8.33. The interpretation of the results of source monitoring in terms of doses requires the use of computational models for dose assessment that have been developed specifically for accident conditions. It should be noted however that adequate results from source monitoring are seldom available in emergencies. The first step in the interpretation of data from source monitoring should therefore be to verify the adequacy of the results, i.e. to verify that:

— No unmonitored releases of radionuclides (e.g. from leaks) or emissions of radiation are possible;
— Discharged radionuclides can be detected by the monitoring systems (e.g. releases from pure beta emitters or pure alpha emitters are monitored);
— Measurements are within the range of the measuring capacity of the monitoring system (e.g. where standard monitoring systems are used, their ability to measure much higher release levels);
— The uncertainties in the monitoring results remain reasonable.

8.34. Emergency plans may include estimates of the upper bounds for releases of radionuclides for accidents of various kinds, often as a fraction of the inventory, and these estimates should be regularly updated.

8.35. Provided that adequate results from source monitoring, computational models and other necessary data such as data on weather conditions are available, the following quantities should be calculated for areas affected by accidents:

(1) The projected absorbed doses or dose commitments to organs and tissues (whole body, bone marrow, lung, skin, thyroid gland, lens of the eye and gonads) for a period of two days in the event of a severe accident;
(2) Projected effective doses and avertable (by appropriate protective actions) effective doses for periods of two days, one week and one month;
(3) Committed thyroid doses due to radioiodine in the event of a nuclear accident or a release of radioiodine under other circumstances.

8.36. These doses estimated from the results of monitoring of the source term should then be assessed against the criteria for public exposure to determine whether protective actions should be implemented and, if so, which ones. One convenient form of presentation of doses is as an area map with isolines of projected dose levels.

*Data from environmental monitoring*

8.37. In emergencies, results from environmental monitoring should be used extensively for assessing projected and avertable external and internal doses since their interpretation is generally straightforward and does not require assumptions, which may be unreliable, to be made on the basis of source monitoring or assessment for use in modelling.

8.38. External gamma dose rate measurements, from the early phase of an accident to the post-release stage, should be used as input data for simple calculational models to assess the projected absorbed doses in organs and tissues (over two days) and, in conjunction with appropriate atmospheric sampling during the release phase, the projected and avertable effective doses for periods of two days, one week and one month. In the release phase of the accident, external gamma dose rate measurements include the contribution of radiation from the plume. In the post-release phase, external gamma dose rate measurements are attributable mainly to radiation from deposits on the ground. Close to the installation, these measurements may also include the contribution of radiation from the source.

8.39. The data on radionuclide concentrations in air at ground level collected by appropriate means of atmosphere sampling during the release phase and post-release phase, as appropriate, should be used as input data for simple calculational models used to assess absorbed doses due to inhalation to organs and tissues from two days' inhalation as well as projected and avertable effective doses from two days', one week's and one month's inhalation.

8.40. The estimated inhalation doses should be added to the corresponding projected external absorbed and avertable effective doses for short term periods that are derived from the measurements of external gamma dose rates. The total (external dose plus inhalation dose) doses should then be compared with the criteria for public exposure to determine whether sheltering, evacuation or temporary relocation should be recommended. Since measurements of the external gamma dose rate are inexpensive and are usually made for large areas, they should be interpreted to define the area in which such protective actions are necessary.

8.41. Since temporary relocation may involve large numbers of individuals and substantial time periods as well as large zones, large sets of results from environmental monitoring that yield adequate statistics should be obtained. Such large sets of data and the use of realistic site specific models rather than conservative generic models would enable the overall uncertainties in the dose assessment to be substantially reduced.

8.42. The data from the sampling of airborne radioiodine during the release phase should be used to assess the average avertable committed absorbed doses to the thyroid glands of the inhabitants of particular affected areas and to assess these doses against the criterion for stable iodine prophylaxis.

*Data from individual monitoring*

8.43. In emergency conditions, when the occurrence of substantial adverse health effects of radiation exposure can be envisaged, data from individual monitoring, of both external and internal exposure, should be used to specify human exposure levels, especially to avoid the underestimation of doses. Although methods of individual monitoring are sophisticated and expensive, they provide information that should be used to validate methods of dose assessment based on source monitoring and environmental monitoring.

8.44. Properly calibrated methods of individual monitoring, with the inherent uncertainties taken into account, provide the most precise data for use in dose assessment. The results of individual monitoring should be used to specify models for dose assessment by means of the comparison of appropriate radiological quantities (i.e. external doses for particular periods and/or radionuclide activity for the whole body at the time of individual measurements). If systematic discrepancies are identified, appropriate correction factors should be introduced into the dose assessment models.

8.45. Particular care should be taken not to underestimate doses in emergencies. Overestimation should be avoided also because there are risks associated with protective actions, especially with evacuation.

## ASSESSMENT OF REMEDIAL ACTIONS IN SITUATIONS OF CHRONIC (PROLONGED) EXPOSURE

8.46. For conditions of chronic (prolonged) exposure there are established generic and/or specific dose criteria and action levels for radionuclide content in foodstuffs and drinking water. At the international level, the ICRP has recommended annual existing (from all environmental sources, both natural and human made) effective doses for members of a critical group of 10 mSv as the generic dose criterion above which remedial actions may be necessary [20]. In some States, especially those affected by significant radioactive contamination, dose intervention levels or action levels for doses that can be attributed to specific chronic exposure conditions, as well as action levels of radionuclides in foodstuffs, are established nationally.

8.47. Since long term public exposure conditions change slowly with time, the assessment of the dose to members of the critical group should be based on the most recent environmental monitoring data available in combination with simple equilibrium models that are realistic rather than screening models[10]. To the extent possible, available environmental data and data on selective individual measurements should be used to validate these models.

8.48. The results of environmental monitoring and/or individual monitoring should be used for both steps of the application of remedial actions: first, as input data to determine the remedial actions that should be taken, and second, once the remedial actions have been taken, to determine their efficiency and the need for further measures.

[10] Screening (see Glossary) models are simple models that use conservative assumptions for the express purpose of identifying those radionuclides and exposure pathways that may be of negligible radiological significance in relation to public exposure due to a particular source in a particular environment.

**Environmental contamination levels**

8.49. The results of radionuclide measurements for substantial batches of foodstuffs should be compared immediately with generic or specific action levels, with account taken of uncertainties in sampling and measurement.

**Dose assessment and criteria for public exposure**

*Environmental monitoring data*

8.50. The results of environmental monitoring should be used primarily to assess, using simple models, the average annual effective doses (doses attributable to specific exposure conditions or existing doses, depending on national regulations and requirements) received by population groups and critical groups once the main exposure pathways and the radionuclides contributing predominantly to the total doses have been defined. The dose assessments that are relevant for the area where remedial actions may be required should be compared with the relevant dose criteria.

8.51. The benefits in terms of the reductions in doses that are to be expected from remedial actions are derived by using decontamination factors obtained by local experiments or other sources of information. Once the countermeasures have been taken, a confirmatory environmental monitoring programme should be conducted. The differences between the radiation levels or radionuclide concentrations in the same environmental compartments, as determined before and after the remedial actions have been taken and with the uncertainties in the measurements and the radioactive decay taken into account, indicate the efficiency of the measures.

*Data on individual monitoring*

8.52. In conditions of chronic (prolonged) exposure, there is usually no danger of deterministic health effects among the population, and therefore methods of dose assessment based on best parameter estimates should be employed, rather than conservative models as used in emergencies.

8.53. The results of monitoring for a number of selected individuals within a large area give an opportunity to validate widely applied dose assessment models that are based on data from environmental monitoring. Two sets of data should be used for the comparison of appropriate radiological quantities (i.e. external doses for particular periods and/or whole body radionuclide activity at

the time of individual measurements). If systematic discrepancies are identified, appropriate correction factors should be included in the dose assessment models.

8.54. The results of individual monitoring for the inhabitants of particular areas who are subjected to chronic (prolonged) exposure can be used immediately for the identification of critical groups by means of the direct comparison of average monitored values in different population groups selected according to age, gender, occupation and food habits.

# 9. QUALITY ASSURANCE[11]

## QUALITY ASSURANCE FOR MONITORING

9.1. The use of quality assurance is required by the BSS (Ref. [2], para. 2.29) and should be an integral part of programmes for source monitoring, environmental monitoring and individual monitoring. Quality assurance should be used to provide for a disciplined 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.

9.2. An adequate quality assurance programme should be designed to satisfy as a minimum the general requirements established by the regulatory body for quality assurance in the field of radiation protection.

9.3. Generally, the quality assurance programme should be designed to ensure that:

[11] The IAEA is revising the requirements and guidance in the subject area of quality assurance as established in Safety Series No. 50-C/SG-Q (1996) for new safety standards on management systems for the safety of nuclear facilities and activities involving the use of ionizing radiation. The term 'management system' has been adopted in the revised standards instead of the terms 'quality assurance' and 'quality assurance programme'. The new standards will integrate all aspects of managing a nuclear facility, including the safety, health, environmental and quality requirements, into one coherent system.

(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 management measures, including planning, scheduling and resource considerations, are addressed;
(c) Work processes and procedures are established and understood;
(d) The regulatory requirements relating to source monitoring, environmental monitoring and individual monitoring are met;
(e) Appropriate methods of sampling and measurement are used;
(f) The choices of environmental media, the locations for sampling and measurement and the associated sampling frequency are appropriate;
(g) Interlaboratory comparisons at the national or international level for methods and instruments are in place.

9.4. In this context the regulatory body should periodically perform an independent review of the licensees' or registrants' programmes of source monitoring and environmental monitoring.

9.5. More specifically, the quality assurance programme should cover:

(a) The design and implementation of monitoring programmes, including the selection of suitable equipment, sampling locations and procedures and their documentation;
(b) The proper maintenance, testing and calibration of equipment and instruments to ensure that they function correctly;
(c) The use of calibration standards that are traceable to national or international standards;
(d) Quality control mechanisms and procedures for reviewing and assessing the overall effectiveness of the monitoring programme [7] (any departures from normal procedures should be documented);
(e) Uncertainty analysis;
(f) Record keeping requirements;
(g) The adequate qualification and training of personnel for the facilities in which they are required to work.

## QUALITY ASSURANCE FOR DOSE ASSESSMENT

9.6. Appropriate quality assurance programmes should be established to provide confidence in the results of dose assessments. Such programmes should

satisfy as a minimum the general requirements established by the regulatory body for quality assurance in the field of radiation protection.

9.7. Measures to achieve specific goals should be incorporated into the quality assurance programmes. These measures include reviews to ensure that:

(a) The regulatory requirements relating to dose assessment are met;
(b) Appropriate results of source monitoring and environmental monitoring are used;
(c) Appropriate models and parameters are used for the dose assessment;
(d) Appropriate calibration, verification and validation procedures have been followed for the model;
(e) Dose calculations have been performed correctly;
(f) Appropriate documentation is available and maintained;
(g) Personnel are qualified and trained.

# 10. RECORDING OF RESULTS

## RECORDING MONITORING DATA

10.1. In accordance with the BBS [2], registrants and licensees are required:

(a) To "record the monitoring results and estimated exposures" (Ref. [2], para. III.11);
(b) To "keep appropriate records of the results of the monitoring programmes" (Ref. [2], para. III.13).

10.2. The recording of monitoring results and related information should be such as to satisfy the objectives of the monitoring programme, which include the requirement to carry out a comparison of measured values with appropriate derived levels and, where appropriate, to calculate the annual dose to the average individual of the critical group and the collective doses.

10.3. The interpretation of the results of monitoring procedures is taken to be an integral part of monitoring itself. The assumptions used in the derivation and interpretation of the monitoring results form a key part of the results themselves and they should be recorded.

10.4. The organization of records should be related to the objectives of the monitoring programme as defined by the regulatory body.

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

**Data from source monitoring**

10.6. Data from source monitoring should be recorded to document the amounts of radiation emitted and the rates of emission, as well as the types, quantities and release rates of the radionuclides discharged, for the purpose of demonstrating that radiation doses and discharge rates and the annual discharges comply with the appropriate authorization.

10.7. Detailed records of the measurements of radiation dose rates (including locations, times and instruments) and related information on the calibration of instruments should therefore be maintained. Similarly, detailed information about measurements of radionuclides in airborne and water-borne discharges should also be maintained. This includes information on discharge points, sampling periods, radioanalytical procedure(s) and instruments used and related data on instrument calibration. The details of measurements of the discharge flow rates that are correlated with the radionuclide measurements should also be retained, together with appropriate calibration data.

**Data on environmental monitoring**

10.8. Data from environmental monitoring should be recorded to document the environmental radiation levels and radionuclide concentrations around the facility. This information should be used to assess the annual dose to the average individual of the critical group and the collective doses, and to verify whether the annual doses comply with the dose limitations attached to the discharge authorization. Where appropriate, these measurements may also be used to demonstrate compliance with the environmental reference levels that are specified in the licence. The data are also used to indicate trends in environmental radiation levels over time and to confirm that environmental concentrations of radionuclides are consistent with those predicted on the basis of source monitoring.

10.9. The record keeping system should be designed to retain all relevant information about the collection of individual samples, measurements of samples, calibration procedures and uncertainties, as well as summaries of the results that are reported routinely. Similar information should be kept for samples collected for the purpose of determining the radiation background.

**Data from individual monitoring**

10.10. Data from individual monitoring should be recorded and documented for assessing the individual doses received in a particular time period and for confirming that the doses comply with the dose limitations attached to the discharge authorization. The record keeping system should be designed to retain as much basic information as necessary for the purposes of the assessment of individual doses.

10.11. Information on measurements of external doses for individuals should include personal information, dates and times of the issue and collection of the dosimeter, device readings, and procedures for calibration and for the determination of the radiation background. Information from in vivo measurements of radionuclide activity in the human body should include personal information, dates and times of the measurements, and the activity detected in the body.

## RETENTION OF RECORDS

10.12. The regulatory body should specify in its regulatory requirements the necessary retention period for the records from source monitoring, environmental monitoring and individual monitoring. In practice this retention period will usually be at least for the period of validity of the licence, including the decommissioning period for the facility, and for 30 years subsequently.

# 11. EDUCATION AND TRAINING

11.1. Regulatory bodies should ensure that qualification standards for jobs relating to source monitoring, environmental monitoring and individual monitoring as well as procedures for the assessment of qualification, the authorization of individuals and the accreditation of training courses are established. These standards should include the minimum qualification required, as appropriate, for sampling techniques, measurement techniques and the interpretation of monitoring results. Regulatory bodies should verify that qualified professionals and accredited courses comply with the requirements [39].

11.2. The operators should implement a strategy for building qualifications and competence in source monitoring, environmental monitoring and individual monitoring. The operators should ensure the education of the appropriate numbers of staff to the appropriate qualification levels.

11.3. The operators should develop training programmes that are consistent with the qualification standards required by the regulatory body. The training programmes should include courses on the necessary theoretical knowledge, on the principles of and requirements for radiation protection, on relevant legislation and regulations and on appropriate technological developments, as well as presentations on the practical experience gained by operators and on case studies. The training programmes should also include demonstrations of the devices used in monitoring, appropriate simulations of sample collection, measurements in situ and on samples and interpretation of the results, visits to see monitoring systems at various nuclear facilities, and job training under the supervision of senior professionals. The training programmes should be regularly updated to incorporate technological innovations and recent experience gained from the operation of monitoring systems and, in particular, from the analysis of malfunctions and human errors.

11.4. The operators should develop retraining programmes which should be attended by the staff on a periodic basis so that the operators can verify that the necessary level of expertise of the professionals involved in monitoring is maintained continuously.

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# GLOSSARY

**accident.** Any unintended event, including operating errors, equipment failures or other mishaps, the consequences or potential consequences of which are not negligible from the point of view of protection or safety.

**action level.** The level of dose rate or activity concentration above which remedial actions or protective actions should be carried out in chronic exposure or emergency exposure situations.

**background.** The dose or dose rate (or an observed measure related to the dose or dose rate), attributable to all sources other than the one(s) specified.

**calibration.** A measurement of, or adjustment to, an instrument, component or system to ensure that its accuracy or response is acceptable.

**contamination.** 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.

**countermeasure.** An action aimed at alleviating the radiological consequences of an accident. Countermeasures are forms of intervention. They may be protective actions or remedial actions.

**critical group.** A group of members of the public which is reasonably homogeneous with respect to its exposure for a given radiation source and is typical of individuals receiving the highest effective dose or equivalent dose (as applicable) from the given source.

**critical pathway.** The exposure pathway for the highest dose to a critical group.

**detection limit or minimum detectable activity.** The activity which, if present in a sample, produces a counting rate that will be detected (i.e. considered to be above background) with a certain level of confidence.

**discharge.** Planned and controlled release of (usually gaseous or liquid) radioactive material to the environment.

**dose.** A measure of the energy deposited by radiation in a target. Absorbed dose, committed equivalent dose, committed effective dose, effective dose, equivalent dose or organ dose, as indicated by the context.

**dose constraint.** A prospective restriction on the individual dose delivered by a source, which serves as an upper bound on the dose in optimization of protection and safety for the source.

**dose limit.** The value of the effective dose or the equivalent dose to individuals from controlled practices that shall not be exceeded.

**effluent monitoring.** See under 'source monitoring'.

**emergency.** A non-routine situation or event that necessitates prompt action, primarily to mitigate a hazard or adverse consequences for human health and safety, quality of life, property or the environment. This includes nuclear and radiological emergencies and conventional emergencies such as fires, release of hazardous chemicals, storms or earthquakes. It includes situations for which prompt action is warranted to mitigate the effects of a perceived hazard.

**emergency preparedness.** The capability to take actions that will effectively mitigate the consequences of an emergency for human health and safety, quality of life, property and the environment.

**environmental monitoring.** The measurement of external dose rates due to sources in the environment or of radionuclide concentrations in environmental media.

**exposure pathway.** A route by which radiation or radionuclides can reach humans and cause exposure. An exposure pathway may be very simple, e.g. external exposure from airborne radionuclides, or a more complex chain, e.g. internal exposure from drinking milk from cows that ate grass contaminated with deposited radionuclides.

**individual monitoring.** Monitoring using measurements by equipment worn by individual workers, or measurements of quantities of radioactive materials in or on their bodies.

**intervention.** Any action intended to reduce or avert exposure or the likelihood of exposure to sources which are not part of a controlled practice or which are out of control as a consequence of an accident.

**intervention level.** The level of avertable dose at which a specific protective action or remedial action is taken in an emergency exposure situation or a chronic exposure situation.

**licence.** A legal document issued by the regulatory body granting authorization to perform specified activities related to a facility or activity. The holder of a current licence is termed a licensee.

**member of the public.** In a general sense, any individual in the population except, for protection and safety purposes, when subject to occupational or medical exposure. For the purpose of verifying compliance with the annual dose limit for public exposure, the representative individual in the relevant critical group.

**model.** An analytical representation or quantification of a real system and the ways in which phenomena occur within that system, used to predict or assess the behaviour of the real system under specified (often hypothetical) conditions.

**model validation.** The process of determining whether a model is an adequate representation of the real system being modelled, by comparing the predictions of the model with observations of the real system.

**monitoring.** The measurement of dose or contamination for reasons related to the assessment or control of exposure to radiation or radioactive substances, and the interpretation of the results.

**nuclear or radiological emergency.** An emergency in which there is, or is perceived to be, a hazard due to: (a) the energy resulting from a nuclear chain reaction or from the decay of the products of a chain reaction; or (b) radiation exposure.

**operational intervention level (OIL).** A calculated level, measured by instruments or determined by laboratory analysis, that corresponds to an intervention level or action level.

**operator (operating organization).** Any organization or person applying for authorization or authorized and/or responsible for nuclear, radiation, radioactive waste or transport safety when undertaking activities or in relation to any nuclear facilities or sources of ionizing radiation. This

includes, inter alia, private individuals, governmental bodies, consignors or carriers, licensees, hospitals, self-employed persons, etc.

**practice.** Any human activity that introduces additional sources of exposure or exposure pathways or extends exposure to additional people or 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.

**protective action.** An intervention intended to avoid or reduce doses to members of the public in chronic exposure or emergency exposure situations.

**quality assurance.** Planned and systematic actions necessary to provide adequate confidence that an item, process or service will satisfy given requirements for quality, for example, those specified in the licence.

**radioactive discharges.** Radioactive substances arising from a source within a practice which are discharged as gases, aerosols, liquids or solids to the environment, generally with the purpose of dilution and dispersion.

**reference level.** An action level, intervention level, investigation level or recording level.

**registration.** A form of authorization for practices of low or moderate risks whereby the legal person responsible for the practice has, as appropriate, prepared and submitted a safety assessment of the facilities and equipment to the regulatory body. The practice or use is authorized with conditions or limitations as appropriate. The requirements for safety assessment and the conditions or limitations applied to the practice should be less severe than those for licensing. The holder of a current registration is termed a registrant.

**remedial action.** Action taken when a specified action level is exceeded, to reduce radiation doses that might otherwise be received, in an intervention situation involving chronic exposure.

**regulatory body.** An authority or a system of authorities designated by the government of a State as having legal authority for conducting the regulatory process, including issuing authorizations, and thereby regulating nuclear, radiation, radioactive waste and transport safety.

**screening.** A type of analysis aimed at eliminating from further consideration factors that are less significant for protection or safety, in order to concentrate on the more significant factors. This is typically achieved by consideration of very pessimistic hypothetical scenarios.

— Screening is usually conducted at an early stage in order to narrow the range of factors needing detailed consideration in an analysis or assessment.

**source.** Anything that may cause radiation exposure — such as by emitting ionizing radiation or by releasing radioactive substances or materials — and can be treated as a single entity for protection and safety purposes. For example, materials emitting radon are sources in the environment, a sterilization gamma irradiation unit is a source for the practice of radiation preservation of food, an X ray unit may be a source for the practice of radiodiagnosis; a nuclear power plant is part of the practice of generating electricity by nuclear fission, and may be regarded as a source (e.g. with respect to discharges to the environment) or as a collection of sources (e.g. for occupational radiation protection purposes). A complex or multiple installation situated at one location or site may, as appropriate, be considered a single source for the purposes of application of safety standards.

**source monitoring.** The measurement of activity in radioactive materials being released to the environment or of external dose rates due to sources within a facility or activity.

**source term.** The amount and isotopic composition of material released (or postulated to be released) from a facility. Used in modelling releases of radionuclides to the environment, particularly in the context of accidents at nuclear installations or releases from radioactive waste in repositories.

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**Mohamed ElBaradei**
**IAEA Director General**

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