IAEA Safety Standards

for protecting people and the environment

Remediation Strategy and Process for Areas Affected by Past Activities or Events

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General Safety Guide

No. GSG-15

IAEA
International Atomic Energy Agency

IAEA SAFETY STANDARDS AND 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. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

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

www.iaea.org/resources/safety-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: Vienna International Centre, PO Box 100, 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 email to Official.Mail@iaea.org.

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 in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

Other safety related IAEA publications are issued as **Emergency Preparedness and Response** publications, **Radiological Assessment Reports**, the International Nuclear Safety Group's **INSAG Reports**, **Technical Reports** and **TECDOCs**. The IAEA also issues reports on radiological accidents, training manuals and practical manuals, and other special safety related publications.

Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** comprises informational publications to encourage and assist research on, and the development and practical application of, nuclear energy for peaceful purposes. It includes reports and guides on the status of and advances in technology, and on experience, good practices and practical examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

REMEDIATION STRATEGY AND PROCESS FOR AREAS AFFECTED BY PAST ACTIVITIES OR EVENTS

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. GSG-15

REMEDIATION STRATEGY AND PROCESS FOR AREAS AFFECTED BY PAST ACTIVITIES OR EVENTS

GENERAL SAFETY GUIDE

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2022

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Marketing and Sales Unit, Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
fax: +43 1 26007 22529
tel.: +43 1 2600 22417
email: sales.publications@iaea.org
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FOREWORD

by Rafael Mariano Grossi
Director General

The IAEA's Statute authorizes it to "establish…standards of safety for protection of health and minimization of danger to life and property". These are standards that the IAEA must apply to its own operations, and that States can apply through their national regulations.

The IAEA started its safety standards programme in 1958 and there have been many developments since. As Director General, I am committed to ensuring that the IAEA maintains and improves upon this integrated, comprehensive and consistent set of up to date, user friendly and fit for purpose safety standards of high quality. Their proper application in the use of nuclear science and technology should offer a high level of protection for people and the environment across the world and provide the confidence necessary to allow for the ongoing use of nuclear technology for the benefit of all.

Safety is a national responsibility underpinned by a number of international conventions. The IAEA safety standards form a basis for these legal instruments and serve as a global reference to help parties meet their obligations. While safety standards are not legally binding on Member States, they are widely applied. They have become an indispensable reference point and a common denominator for the vast majority of Member States that have adopted these standards for use in national regulations to enhance safety in nuclear power generation, research reactors and fuel cycle facilities as well as in nuclear applications in medicine, industry, agriculture and research.

The IAEA safety standards are based on the practical experience of its Member States and produced through international consensus. The involvement of the members of the Safety Standards Committees, the Nuclear Security Guidance Committee and the Commission on Safety Standards is particularly important, and I am grateful to all those who contribute their knowledge and expertise to this endeavour.

The IAEA also uses these safety standards when it assists Member States through its review missions and advisory services. This helps Member States in the application of the standards and enables valuable experience and insight to be shared. Feedback from these missions and services, and lessons identified from events and experience in the use and application of the safety standards, are taken into account during their periodic revision.

I believe the IAEA safety standards and their application make an invaluable contribution to ensuring a high level of safety in the use of nuclear technology. I encourage all Member States to promote and apply these standards, and to work with the IAEA to uphold their quality now and in the future.

PREFACE

Requirements for the protection of people and the environment in existing exposure situations are established in IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. GSR Part 3 is jointly sponsored by the European Commission, the Food and Agriculture Organization of the United Nations, the IAEA, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization, the United Nations Environment Programme and the World Health Organization.

This Safety Guide provides recommendations on planning and implementing the remediation of sites and areas affected by past activities and events to meet the requirements established in GSR Part 3. It was prepared in consultation with the Food and Agriculture Organization of the United Nations, the IAEA, the United Nations Development Programme, the United Nations Environment Programme and the United Nations Office for the Coordination of Humanitarian Affairs.

The Food and Agriculture Organization of the United Nations is a specialized agency that leads international efforts to defeat hunger, achieve food security for all and ensure that people have regular access to enough high quality food to lead active, healthy lives. The United Nations Development Programme works in 170 countries and territories to help build integrated, lasting solutions in fighting to end the injustice of poverty, inequality and climate change. The United Nations Environment Programme is the leading global environmental authority that sets the global environmental agenda, promotes the coherent implementation of the environmental dimension of sustainable development within the United Nations system and serves as an authoritative advocate for the global environment. The United Nations Office for the Coordination of Humanitarian Affairs is responsible for bringing together humanitarian actors to ensure a coherent response to emergencies and also ensures that there is a framework within which each actor can contribute to the overall response effort.

The European Commission, the International Commission on Radiation Units and Measurements, the International Commission on Radiological Protection, the International Organization for Standardization and the OECD Nuclear Energy Agency have also made significant contributions to the drafting and review of this Safety Guide to ensure consistency in the guidance and recommendations provided by international organizations on the application of the system of protection and safety in remediation.

THE IAEA SAFETY STANDARDS

BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered ‘overarching’ requirements, are expressed as ‘shall’ statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and

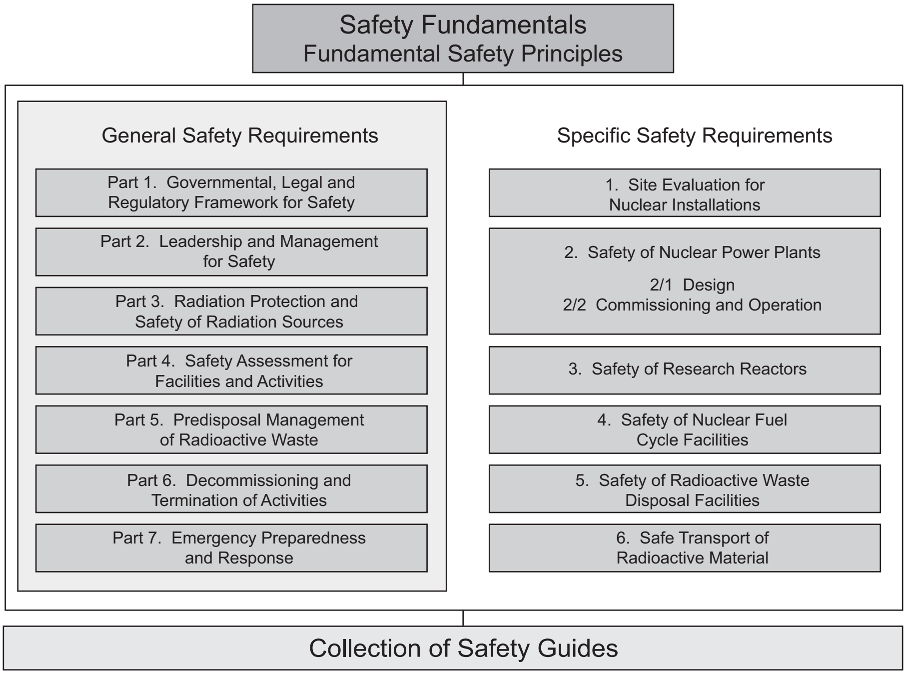

FIG. 1. The long term structure of the IAEA Safety Standards Series.

increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and five Safety Standards Committees, for emergency preparedness and response (EPReSC) (as of 2016), 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 IAEA safety standards programme (see Fig. 2).

All IAEA Member States may nominate experts for the Safety Standards Committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards. It articulates the mandate of the IAEA, the vision for the future application of

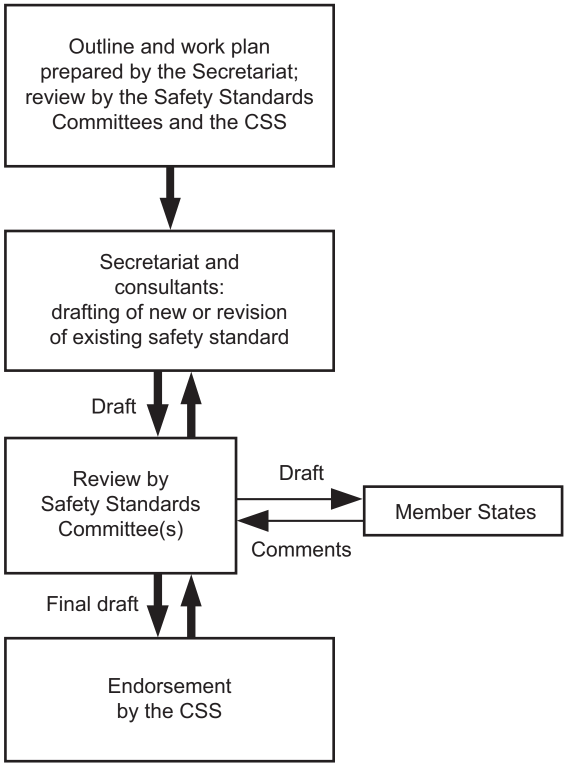

FIG. 2. The process for developing a new safety standard or revising an existing standard.

the safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

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 IAEA safety standards. Some safety 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 United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as defined in the IAEA Safety Glossary (see https://www.iaea.org/resources/safety-standards/safety-glossary). 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 in the IAEA 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 body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, 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 safety standard. Material in an appendix has the same status as the body 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. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. This publication is a revision of IAEA Safety Standards Series No. WS-G-3.1, Remediation Process for Areas Affected by Past Activities and Accidents[1], which it supersedes. WS-G-3.1 provided guidance on how to meet the requirements established in IAEA Safety Standards Series No. WS-R-3, Remediation of Areas Contaminated by Past Activities and Accidents[2]. WS-R-3 was superseded in 2014 by IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [1]. GSR Part 3 introduced three different types of exposure situation[3], taking into account International Commission on Radiological Protection Publication 103 [2]. In addition, since 2007 several other Safety Requirements publications have been revised and published (e.g. Refs [3–9]), necessitating a revision of WS-G-3.1.

1.2. A variety of past activities (including past practices[4]) and events have resulted in contamination of a large number of sites and areas by residual radioactive material[5]. In cases where relevant criteria are exceeded (see paras 3.17, 3.18 and 3.27–3.33), such sites and areas need to be remediated. Remediation is defined as any measures that may be carried out to reduce the radiation exposure due to existing contamination of land areas through actions applied to the contamination

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[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Remediation Process for Areas Affected by Past Activities and Accidents, IAEA Safety Standards Series No. WS-G-3.1, IAEA, Vienna (2007).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Remediation of Areas Contaminated by Past Activities and Accidents, IAEA Safety Standards Series No. WS-R-3, IAEA, Vienna (2003).

[3] GSR Part 3 [1] distinguishes between three different types of exposure situation: planned exposure situations, emergency exposure situations and existing exposure situations, which together cover all situations of exposure for which GSR Part 3 applies.

[4] For the purposes of this Safety Guide, a ‘past practice’ is a practice that was not carried out in accordance with current standards.

[5] The term ‘residual radioactive material’ is used in accordance with the meaning given in the definition of an ‘existing exposure situation’, that is an exposure due to residual radioactive material that derives from past practices that were never subject to regulatory control or exposure due to residual radioactive material deriving from a nuclear or radiological emergency after an emergency has been declared to be ended [10]. In this context, residual radioactive material is radioactive material remaining on a site or in an affected area due to a past activity or event.

itself (the source) or to the exposure pathways to humans. Complete removal of the contamination is not implied [10].

1.3. Sites and areas affected by residual radioactive material are considered within the requirements established for existing exposure situations [1] and are located in many regions of the world and in different types of environment. The types of past activities and events that have resulted in contamination include the following:

(a) Past activities that were never subject to regulatory control or that were subject to regulatory control but not in accordance with current requirements (e.g. GSR Part 3 [1]). Such past activities include the industrial processing of radioactive material, the mining and processing of uranium or thorium ores, the testing of nuclear weapons and the management of residual materials[6], including radioactive waste.
(b) Past activities undertaken on sites where regulatory control has evolved to meet current standards, but where contamination exists because of past activities, resulting in a need for decommissioning on part of the site and remediation of contaminated land on the same site. Such sites may include those affected by past activities that are considered existing exposure situations and that also contain facilities being operated in accordance with the requirements for planned exposure situations.
(c) Accidents during the conduct of activities that gave rise to an unplanned, uncontrolled release of radioactive material (e.g. releases of radioactive material during activities such as the transport of radioactive material, the decommissioning of facilities and radioactive waste management activities; releases of radioactive material from facilities such as nuclear installations, hospitals, industrial facilities and research facilities).
(d) Events involving the release of radioactive material owing to a malicious act.

1.4. Preparing for remediation following an event is undertaken as part of overall emergency preparedness in accordance with the recommendations provided in IAEA Safety Standards Series No. GSG-11, Arrangements for the Termination of a Nuclear or Radiological Emergency [11].

[6] Residual materials can include environmental media and debris that may be recycled or reused as well as radioactive waste and non-radioactive wastes that require proper interim storage and, ultimately, disposal in a facility that has been engineered for the type of waste to be disposed of.

1.5. In 2015, the IAEA published its report on the accident at the Fukushima Daiichi nuclear power plant [12], in which Technical Volume 5 on Post-accident Recovery [13] includes sections on remediation, the management of contaminated material and radioactive waste, community revitalization and stakeholder[7] engagement. Relevant lessons from the remediation carried out following the Fukushima Daiichi accident have been incorporated in this Safety Guide.

1.6. The legal and regulatory framework for remediation of affected areas is also subject to the requirements established in IAEA Safety Standards Series No. GSR Part 1 (Rev. 1), Governmental, Legal and Regulatory Framework for Safety [5], which defines the components of a comprehensive administrative and legal system and assigns responsibilities to the different national authorities involved. The requirements established in IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [7], are also applicable, with due application of the graded approach and in the context of existing exposure situations.

1.7. Requirements for the management of radioactive waste are established in IAEA Safety Standards Series No. GSR Part 5, Predisposal Management of Radioactive Waste [3], and IAEA Safety Standards Series No. SSR-5, Disposal of Radioactive Waste [4].

OBJECTIVE

1.8. The objective of this Safety Guide is to provide recommendations on the planning and implementation of remediation of sites and areas affected by past activities and events. It is intended to support the implementation of IAEA safety requirements, and in particular, Requirements 47–49 and 52 of GSR Part 3 [1] on existing exposure situations.

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[7] ‘Stakeholder’ has the same meaning as ‘interested party’, which is defined as “a person, company, etc., with a concern or interest in the activities and performance of an organization, business, system, etc.” [10]. Interested parties have typically included the following: customers, owners, operators, employees, suppliers, partners, trade unions; the regulated industry and professionals; scientific bodies; governmental agencies and regulatory body and other authorities (national, regional and local) whose responsibilities may cover nuclear energy; the media; the public (individuals, community groups and interest groups); and other States, especially neighbouring States that have entered into agreements providing for an exchange of information concerning possible transboundary impacts, or States involved in the export or import of certain technologies or materials [14].

1.9. This Safety Guide is intended to be used by governments, national authorities, regulatory bodies, operating organizations and other parties involved in the remediation of sites or areas and contributing to the recovery process for areas affected by past activities or events.

1.10. This Safety Guide covers a broad range of situations and circumstances for which remediation may be necessary. Implementation of the recommendations provided in this Safety Guide will need to take into account the specific characteristics of a given situation and the prevailing circumstances; for example, the circumstances in which remediation is being planned and implemented following an accident or event (e.g. a malicious act) can differ from the circumstances of remediation for an area affected by a past practice.

SCOPE

1.11. This Safety Guide covers all aspects of the remediation of sites and areas that have been affected as a result of past activities, accidents or unauthorized acts (malicious or non-malicious [10]) that could cause prolonged radiation exposure, and for which a decision on control needs to be taken. In the context of this Safety Guide, the term 'sites and areas' has a generic meaning relating to a geographical location or region, together with any buildings, structures, biota and ecological features contained within it. It may encompass urban and rural landscapes, industrial zones, agricultural areas, residential areas, water bodies and previously undisturbed natural areas, and may include features at, above or below the surface. 'Areas' are typically larger and are more geographically diverse than 'sites', which tend to be more localized. A 'site' could be considered a localized 'area'. The term 'area' includes 'sites' within its boundary. Sites and areas might or might not have been subject to past or current regulatory controls.

1.12. This Safety Guide does not cover situations of exposure to natural background radiation, other than from the perspective of characterization of baseline radiation.

1.13. Environmental restoration, which is an integral part of recovery along with remediation, is outside the scope of this Safety Guide.[8]

[8] In some contexts (e.g. the wider chemical industry), the terms 'remediation' and 'restoration' are used to describe different parts of overall recovery [10]. Both remediation and restoration could be relevant following a nuclear accident, for example.

1.14. This Safety Guide provides recommendations on remedial actions[9] and, as relevant, other protective actions[10] (in accordance with Principle 10 of IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [15]) that are intended to reduce or prevent prolonged exposures (or the likelihood of such exposures) that may occur from contamination. This includes remedial actions, such as the removal of the source of exposure, and protective actions that reduce the contribution from one or more identified exposure pathways, such as advisories about consumption and restrictions on the distribution and sale of contaminated foodstuffs produced in the area, and restrictions on access to affected areas or on land use.

1.15. This Safety Guide does not address the decontamination of areas carried out as part of the operation or decommissioning of facilities[11] [8] that have been continuously maintained under adequate regulatory control and in accordance with the conditions of an authorization. It also does not address the planned closure of disposal facilities, including those associated with authorized mining operations, nor does it address events that resulted in the contamination of localized areas within the site boundary of an authorized facility in the case that such events are covered as part of planned activities. In addition, this Safety Guide does not address upgrades of existing disposal facilities, as these situations are addressed in section 6 of SSR-5 [4].

1.16. This Safety Guide does not apply to the decommissioning of facilities. Decommissioning is an authorized process primarily concerned with the decontamination and dismantling of systems, structures and components of a facility and with the decontamination and demolition of buildings. Remediation

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[9] A 'remedial action' is defined as the removal of a source or the reduction of its magnitude (in terms of activity or amount) for the purposes of preventing or reducing exposures that might otherwise occur in an emergency or in an existing exposure situation. Remedial actions could also be termed protective actions, but protective actions are not necessarily remedial actions [10].

[10] A 'protective action' is defined as an action for the purposes of avoiding or reducing doses that might otherwise be received in an emergency exposure situation or an existing exposure situation [10].

[11] The term 'decommissioning' relates to planned exposure situations and is defined as the administrative and technical actions taken to allow the removal of some or all of the regulatory controls from a facility (except for the part of a disposal facility in which the radioactive waste is emplaced, for which the term 'closure' instead of 'decommissioning' is used) [8].

can entail activities[12] that are similar to decommissioning; both remediation and decommissioning activities are typically performed under an authorization. Abandoned and currently unauthorized industrial sites, such as former uranium mines and mills and former radium processing facilities, may have buildings and structures to be taken down by actions consistent with the decommissioning process (e.g. decontamination and dismantling); however, such activities are considered to be a part of site remediation and would typically be carried out as part of a site specific remediation plan[13]. Consequently, such activities are within the scope of this Safety Guide.

1.17. Sites may also exist where the regulatory control has evolved to a level that meets current standards, but on which contamination exists because of past activities. This could involve decommissioning activities to be undertaken on one part of the site and remedial actions to be undertaken on other parts of the same site. In such cases, some facilities may be managed within a planned exposure situation, for which dose limits and dose constraints are established and applied, but there may also be contaminated land that needs to be dealt with as an existing exposure situation[14], for which reference levels are established and applied. As such, the decommissioning is outside the scope of this Safety Guide, whereas the remediation is within the scope.

1.18. This Safety Guide does not apply to situations where a facility is subject to an event but is repaired and brought back into service.

1.19. This Safety Guide focuses on protection against radiation risks. In undertaking remediation, it is also appropriate to address non-radiological risks, including chemical and physical risks, and other factors (e.g. economic factors, social and psychological impacts on affected communities, environmental impacts), which will often have to be controlled under separate regulations. While non-radiological risks and such other factors are outside the scope of this Safety

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[12] Such activities might include the characterization of materials including waste, decontamination of contaminated structures for which there was no decommissioning plan, dismantling of buildings for which there was no decommissioning plan, and removal of contaminated soil from an area within the authorized boundary of a facility, but in this case, such removals are normally referred to as ‘cleanup activities’.

[13] A ‘remediation plan’ is a document setting out the various activities and actions and the timescales necessary to apply the approach and to achieve the objectives of the remediation strategy in order to meet the legal and regulatory requirements for remediation [10].

[14] Occupational exposures arising from the remediation process are required to be controlled in accordance with the requirements for planned exposure situations (see GSR Part 3 [1]; see also paras 8.14 and 8.15 of this Safety Guide).

Guide, some of the recommendations refer to non-radiological risks to the extent that consideration should be given to the interrelationships between the various control measures for different types of risk.

1.20. The recommendations in this Safety Guide do not address the overall planning for the emergency response or long term recovery following a nuclear or radiological emergency (e.g. Refs [12, 13, 16]). However, this Safety Guide supports the planning for remediation as part of overall emergency response efforts and long term recovery and is relevant to events resulting in the contamination of localized areas within the boundaries of an authorized facility that might not be covered as part of planned activities but where the facility is currently under regulatory control.

STRUCTURE

1.21. Section 2 addresses government responsibilities and the establishment of laws and regulations, and a strategic approach to remediation based on the principles of radiation protection. This includes recommendations on regulatory oversight, the funding and financing of remediation, and the involvement of interested parties. Section 3 provides recommendations on the application of the radiation protection principles that support remediation. Within Section 4, the remediation process is divided into five phases and recommendations on the first four phases are provided in subsequent sections: Section 5 deals with preliminary evaluation; Section 6 deals with detailed evaluation; Section 7 addresses the planning of remediation; and Section 8 covers implementation of remediation and verification monitoring. Section 9 provides recommendations on the management of residual materials generated during remediation, including those that have to be managed as radioactive waste. Section 10 provides recommendations on post-remediation management, the fifth and final phase of the remediation process.

1.22. Additional supporting information is provided in two appendices and seven annexes. Appendix I provides guidance on the assessment of public exposure for remediation purposes. Appendix II addresses self-help protective actions that can be advised by the party responsible for the remediation, the regulatory body and other authorities, or the government to members of the public who continue to live in affected areas. Annex I provides an example of a table of contents of a site or area specific remediation plan. Annex II addresses the practical aspects of optimization of protection and safety in remediation and provides an example of how to derive reference levels. Annexes III–VI provide example case studies of how to apply the remediation process for sites or areas affected by the Chernobyl accident, for sites or areas affected by the Fukushima Daiichi nuclear accident, for sites or areas affected by nuclear weapon testing, and for sites or areas affected by past mining practices. Annex VII provides a bibliography of relevant literature.

2. NATIONAL FRAMEWORK FOR REMEDIATION

2.1. A prerequisite for remediation at a national level, taking account of the United Nations' Sustainable Development Goals, is a well developed governmental, legal and regulatory framework. The basis of the national framework for remediation is a national policy and corresponding strategy, and the legal and regulatory framework necessary to implement the policy and strategy (see GSR Part 1 (Rev. 1) [5]).

2.2. Requirements on the governmental, legal and regulatory framework for the safety of facilities and activities are established in GSR Part 1 (Rev. 1) [5]. These requirements address the need to establish a national policy and strategy for safety and to promulgate the necessary laws and statutes. Requirement 1 of GSR Part 1 (Rev. 1) [5] states:

> "**The government shall establish a national policy and strategy for safety, the implementation of which shall be subject to a graded approach in accordance with national circumstances and with the radiation risks associated with facilities and activities**".

2.3. Requirement 2 of GSR Part 1 (Rev. 1) [5] states that "**The government shall establish and maintain an appropriate governmental, legal and regulatory framework for safety within which responsibilities are clearly allocated**." Furthermore, para. 2.5 of GSR Part 1 (Rev. 1) [5] states that "This framework for safety shall set out…[t]he safety principles for protecting people — individually and collectively — society and the environment from radiation risks, both at present and in the future".

2.4. With regard to remediation, Requirement 9 of GSR Part 1 (Rev. 1) [5] states:

> "**The government shall establish an effective system for protective actions to reduce undue radiation risks associated with unregulated sources (of natural or artificial origin) and contamination from past**

activities or events, consistent with the principles of justification and optimization."

2.5. A national framework for remediation should be established to avoid, to the extent possible, an ad hoc approach. The governmental, legal and regulatory framework should form the basis for defining the national strategy for remediation to address the health, safety and environmental aspects of areas affected by past activities or events. The government, the regulatory body and other relevant authorities, and other interested parties as appropriate, should be actively involved in the development of the national framework for remediation.

2.6. The national framework should be established to minimize the amount of residues, including radioactive waste, generated during remediation, for example by making provision for clearance, reuse and recycling of residual materials from remediation, to the extent possible (see Section 9). The national framework should also take account of the volumes and types of waste that might be generated in a nuclear or radiological emergency (see Requirement 15 of IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [9]). When a residual material that has been generated during remediation is designated as radioactive waste, it is required to be managed within the overall national framework for radioactive waste management (see Requirement 1 of GSR Part 5 [3]). The national framework for radioactive waste management is usually documented in the form of a national policy for radioactive waste management, together with a national strategy for radioactive waste management (see Requirement 2 of GSR Part 5 [3]). This strategy is required to address all classes of radioactive waste (see Requirement 9 of GSR Part 5 [3] and IAEA Safety Standards Series No. GSG-1, Classification of Radioactive Waste [17]) and serve as a means for achieving the national goals and requirements set out in the national policy for radioactive waste management. Waste management options that can be implemented in accordance with the IAEA safety standards and that are based on established, proven technologies, methods, techniques, equipment and processes should be identified and considered, to ensure that the management of radioactive waste is safe and cost effective. The management of residual materials generated during remediation should consider practical disposal options including the ability of local authorities to develop a suitable radioactive waste repository of the necessary capacity. Further requirements on the national policy and strategy for radioactive waste management are established in GSR Part 1 (Rev. 1) [5] and GSR Part 5 [3].

2.7. The national framework for remediation may be integrated into, for example, the existing national framework on decommissioning or radioactive waste management, or may be standalone.

2.8. The national framework for remediation should include provisions for the following:

(a) The national prioritization of sites and areas for remediation;
(b) Financing mechanisms to cover the costs of remediation of sites and areas prioritized for remediation;
(c) The establishment of radiological and non-radiological criteria to ensure and demonstrate protection of people and the environment;
(d) Radioactive waste management;
(e) Assignment of a responsible party[15] for remediation;
(f) Arrangements for responding to emergencies that occur during remediation;
(g) Mechanisms for consultations with interested parties, for example between the public and the regulatory body.

2.9. Planning for recovery operations to enable the transition from an emergency exposure situation to an existing exposure situation should be undertaken prior to any emergency (see GSG-11 [11]). This should include planning for remediation, including the management of radioactive waste and other residual materials and the development of predisposal management strategies and, to the extent possible, disposal strategies as well as other approaches to minimize the generation of large volumes of material containing radioactive substances, including material generated from the remediation itself. To the extent possible, this planning should be undertaken as part of emergency preparedness.

2.10. The national framework should address the issue of knowledge management for remediation, for example by acquiring and maintaining technical specialists, by reviewing current knowledge management capabilities, by encouraging organizations to develop training and knowledge management strategies in support of remediation roles and responsibilities, and by ensuring that knowledge is transferred, documented and maintained for an appropriate time period for future use.

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[15] The 'responsible party' is the person or organization with responsibility for establishing and implementing remediation.

NATIONAL POLICY FOR REMEDIATION

2.11. The national policy for remediation should establish the basic premises that guide the approach to remediation in the State and that should be addressed in the national strategy and the legal and regulatory framework for remediation (e.g. to help focus the investigations and analysis of remedial options[16]). The policy for remediation should include the following, which might also be embedded in law or regulations:

(a) The protection of human health and the environment as the overall safety objective;
(b) The prioritization of sites and areas for remediation to make the best use of available resources commensurate with the risks of each site or area;
(c) The approach to remediating existing exposure situations (e.g. former uranium mining and milling sites) where the party responsible for contamination cannot be identified or is no longer present;
(d) Compliance with all relevant laws and regulatory requirements;
(e) The adoption of a graded approach in which the remedial actions applied to a particular affected area, and the agreed remediation end state, are commensurate with the risks associated with that area;
(f) Ensuring that remediation is justified and optimized;
(g) Ensuring the optimization of protection and safety, including ensuring cost effectiveness;
(h) Establishment of a preference for technologies that take account of sustainability principles, for example in evaluating active and passive remedial options[17] to ensure that they utilize the best available technologies and consider the waste management hierarchy;
(i) The roles and responsibilities of the government, the regulatory body and other authorities, and the responsible party;
(j) Ensuring that there is an open and transparent process involving the public and other interested parties when decisions are made concerning remediation;

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[16] A ‘remedial option’ is a possible action or set of actions that might be undertaken to implement the remediation plan. Options that have been selected for implementation become remedial actions.

[17] Active remedial options involve earth moving or other physical work; passive options involve allowing natural dispersion and decay (e.g. natural attenuation) to reduce the hazards and include land use control. Both active and passive options involve monitoring and surveillance to verify that the option is performing as expected, in accordance with the remediation plan and the authorization.

(k) Funding and financing of remediation, and mechanisms for such when the party responsible for contamination cannot be identified or is no longer present;
(l) The identification of potential sites or areas where the government might become the responsible party.

NATIONAL STRATEGY FOR REMEDIATION

2.12. The national strategy for remediation should consider the safety objective of protecting people and the environment, present and future, against radiation risks [15]. The national strategy for remediation should provide a basis for the plan of action for implementing the national policy for remediation. The national strategy for remediation should include, for example, provisions for the following:

(a) Identifying and evaluating contaminated areas;
(b) Making decisions on the need for remediation;
(c) Where there are multiple contaminated areas within a State's boundaries, establishing an order of priority for action.

The national policy and national strategy should be reviewed and updated, as appropriate, on the basis of operating experience, successes and other lessons from remediation.

2.13. The national strategy should be taken into account when decisions are made on the need to involve, and ensure liaison between, various governmental agencies, the regulatory body and other authorities, and other interested parties such as landowners. The order of priority for remediation should take into account not only the risks from residual radioactive material but also non-radiological risks. Collaboration and exchange of information between the different competent authorities involved is a prerequisite for the establishment of such priorities. Prioritization should also consider environmental and socioeconomic impacts as well as other factors, as relevant.

2.14. The national strategy for remediation should also outline the approach to dealing with the remediation of affected areas following an emergency involving a significant release of radioactive material to the environment. Considering that remediation of areas affected by an event will start during the emergency exposure situation, remediation should be addressed within the national protection strategy for a nuclear or radiological emergency [1, 9, 11, 18]. While the remediation of affected areas should be implemented as early as practicable, the national strategy for remediation should acknowledge that remediation following an emergency with significant radioactive release to the environment can take several years or longer. The national strategy for remediation should consider how to maintain essential infrastructure and services in order to maintain normal living conditions in the affected areas.

2.15. The identification and prioritization process for the national strategy for remediation should, at the earliest opportunity, involve relevant national authorities, institutions, members of the public, industry and other relevant interested parties (e.g. scientific bodies, special interest groups, non-governmental organizations). The entire process should be properly recorded through the use of a transparent and traceable documentation system that is updated, as necessary, to take account of changing circumstances and new information.

2.16. The national strategy for remediation should take into account information from the identification and characterization of contaminated areas within the national boundaries. This should be followed by an evaluation of these areas and the setting of national priorities regarding remediation, considering potential risks as well as socioeconomic impacts. Neighbouring countries should coordinate their remediation efforts where there are transboundary impacts.

2.17. The identification and prioritization of multiple sites or areas needing remediation should also consider the overall effort needed for remediation of a particular site or area, and whether the amount of effort is commensurate with the potential reduction in radiation risks and non-radiological risks. In cases where there is high uncertainty or a lack of information, it can be difficult to evaluate risk, and additional characterization[18] and/or monitoring[19] should be undertaken to provide adequate information to plan for a possible need for remediation.

2.18. In the event of a nuclear or radiological emergency, remediation could constitute a part of the actions undertaken in the transition phase of the emergency

[18] ‘Characterization’ is defined as the determination of the nature and activity of radionuclides present in a specified place [10] and is conducted as part of preliminary and detailed evaluations and as needed throughout the remediation process.

[19] ‘Monitoring’ is defined as the measurement of dose, dose rate or activity for reasons relating to the assessment or control of exposure to radiation or exposure due to radioactive substances and the interpretation of the results [10]. The monitoring programme is re-evaluated over the lifetime of the remediation process and adjusted, as necessary, on the basis of the prevailing circumstances and conditions.

and after the termination of the emergency as part of long term recovery[20] (see Ref. [16]). Remediation of areas affected by an event should be initiated as early as practicable during the transition phase[21]. Remedial actions and, as relevant, protective actions, should be identified, justified and optimized once adequate characterization has been carried out, and their long term implications should be considered during remediation planning. The development of a strategy for the characterization of the exposure situation and for the delineation of areas in which habitation will need to be restricted is an important consideration during the transition phase. These considerations should be taken into account when developing the remediation plan. Further recommendations on the transition from an emergency exposure situation to an existing exposure situation are provided in GSG-11 [11].

2.19. For areas affected by an event, socioeconomic and political pressure might be substantial because the areas warranting remediation may be large and involve private and public lands that were previously inhabited. In situations where there are displaced populations, the perception of the affected people on resettlement and potential future land use may exert a large influence on remediation, for example on the time frame to implement remediation. By comparison, the schedule for remediation of areas affected by past activities could be more flexible because implementation could be less urgent compared with that after an emergency, although appropriate protective actions to protect the public should still be undertaken.

2.20. In areas affected by past activities (e.g. industrial areas), it is less likely that remediation will involve displaced populations (i.e. in comparison with areas affected by an event) and there may be less pressure to take prompt action. Nevertheless, an assessment of the need for protective actions should still be undertaken (e.g. in cases of contamination of the drinking water supply or imminent risk to the public). Maintenance of services (e.g. management of household wastes, sewerage, the drinking water supply, health services, education)

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[20] As described in GSG-11 [11], the term ‘recovery’ refers to actions undertaken to resume normal social and economic activity. Such actions may include those aiming to deal with residual contamination, accident damaged facilities and/or disrupted infrastructure and they encompass remediation, decommissioning and management of residual materials including waste [13].

[21] The ‘transition phase’ is defined as the period of time after the emergency response phase when (a) the situation is under control, (b) detailed characterization of the radiological situation has been carried out and (c) activities are planned and implemented to enable the emergency to be declared terminated [11]. The exposure situation in the transition phase is still an emergency exposure situation even though the emergency response phase is over [11].

is essential to maintain normal living conditions of the population in the affected areas. This should be taken into account in the national strategy.

2.21. The national strategy for remediation to address areas affected by past activities and events should be applied in remediation planning to ensure the following:

(a) The drafting or revision of national laws and regulations relating to remediation is facilitated.
(b) National laws and regulations can be applied in a coherent and timely manner.
(c) Duplication of effort among different authorities is avoided or minimized to the extent possible; this may involve allowing sufficient flexibility for local decision making when necessary.
(d) National priorities are set regarding areas that need remediation.
(e) Adequate human resource capacity and competence for remediation, including predisposal management and disposal of radioactive waste, is established (e.g. with respect to estimating costs).
(f) The authorities communicate and consult with interested parties in a coordinated and consistent manner (see IAEA Safety Standards Series No. GSG-6, Communication and Consultation with Interested Parties by the Regulatory Body [19]).
(g) Financing mechanisms are in place for ensuring that each authority can meet its particular responsibilities.
(h) The use of financial resources for remediation is in accordance with the principles of justification and optimization of protection and safety.

2.22. While the elements described in para. 2.21 are common to all remediation strategies, the approach to the remediation of areas affected by past activities may differ from that for the remediation of areas affected by an event. This reflects the differences in the location, type and number of areas affected and their characteristics, as well as the amounts and extent of contaminated material, the urgency of the need for remediation, and the level of disruption to daily life. The remediation of an area affected by an event is likely to be more complex in terms of social, economic and health issues, and in some cases, in terms of the environment and the nature and extent of the contamination, and it will be impacted by the protective actions implemented and restrictions imposed during the emergency response and the transition from an emergency exposure situation to an existing exposure situation (see GSG-11 [11]).

LEGAL AND REGULATORY FRAMEWORK FOR REMEDIATION

2.23. The legal and regulatory framework that is necessary to implement the national policy and national strategy for remediation should include laws and regulations that provide mechanisms for the following:

(a) For ensuring that activities are planned such that future situations that will later necessitate remediation are prevented.
(b) For identifying and evaluating areas affected by past activities and events.
(c) For deciding on and prioritizing the need for remediation, taking into account that the prioritization should be aided by the involvement of various governmental and non-governmental organizations and agencies as well as other interested parties including the public. The national strategy should make provision for their input into the process.
(d) For the regulatory body to review and approve proposed remediation plans submitted by organizations responsible for implementing the remediation of areas. The framework is required to include provision for the granting of any necessary authorizations (see para. 5.13 of GSR Part 3 [1]). The framework should also describe the system of regulatory control and enforcement necessary during the remediation process.
(e) For identifying the responsible party for establishing and implementing remediation programmes, including in cases for which such persons or organizations are no longer present or are unable to meet their liabilities (see Requirement 49 of GSR Part 3 [1]).
(f) For regular communication and consultation with interested parties regarding the development, implementation and verification of the remediation plan, and for the involvement of interested parties in the decision making process (see para. 5.12(e) of GSR Part 3 [1]).
(g) For ensuring that responsibility is allocated to the appropriate organization or authority to develop training and knowledge management strategies to support the regulatory body and other relevant authorities and the responsible party throughout remediation and into the future.

2.24. The legal and regulatory framework should also establish the basic premises and processes for remediation, including the following:

(a) Justification of remedial actions and optimization of protection and safety, with due consideration of the need to define reference levels and other criteria, as relevant (see paras 3.17, 3.18 and 3.27–3.33), taking into account other factors that need to be considered.

(b) The adoption of a graded approach in which the remedial actions applied to a particular affected area are commensurate with the risks associated with that area.
(c) Enabling an open and transparent process for making decisions concerning remediation plans.
(d) Assigning responsibilities for the development of remediation strategies; for the planning, implementation and verification of the results of remedial actions; for the provision of the necessary human and technical resources, equipment and supporting infrastructure; and for regulatory oversight of remediation and institutional controls, as appropriate.
(e) Ensuring that, for each authorized facility and activity, provisions are made to conduct remediation in the case of an accidental release.
(f) Ensuring that adequate funding and financing mechanisms are in place to implement the remediation in a safe and timely manner (e.g. through reporting requirements and/or regulatory requirements), that these mechanisms are manageable and economically sustainable, and that responsibilities are assigned for the financing of remedial actions (including any actions needed for post-remediation management) and the management of associated radioactive and non-radioactive residual materials.
(g) Providing for adequate funding to be available if organizations or individuals responsible for the contamination are unable to meet their liabilities for remediation (e.g. through the establishment of provisions to identify a responsible party).
(h) Providing for the safe management of residues, including radioactive waste generated by remedial actions, in accordance with the overall national policy and national strategy for protection in an existing exposure situation.
(i) Providing the basis for establishing any restrictions that may be placed on the use of or access to the affected area before, during and, if necessary, after remediation.
(j) Assigning responsibility for record keeping that covers the nature and extent of contamination; the decisions made prior to, during and after the implementation of remedial actions; and information on verification of the results of the remediation, including the results of all monitoring programmes after completion of the remedial actions. This is particularly important where restrictions are imposed on access to the area or the activities that may be conducted in these areas.

2.25. The legal and regulatory framework for remediation should ensure that responsibilities and arrangements for emergency preparedness and response, in accordance with GSR Part 7 [9] and associated Safety Guides [11, 18, 20], also form a basis for defining the national strategy for remediation.

2.26. The regulatory framework should also provide guidance on how remedial options are to be evaluated, in order to take into account technical feasibility and to find an appropriate balance between occupational exposure and public exposure, as well as between economic, environmental and social impacts, public acceptance, and other relevant factors.

SITE OR AREA SPECIFIC REMEDIATION STRATEGY AND PLANNING

2.27. In addition to the need for the government to establish a national strategy for remediation, which should include radiation protection, radioactive waste management and other aspects (see paras 2.12–2.22) and take into account the corresponding laws and regulations supporting its implementation (see paras 2.23–2.26), the responsible party should develop a site or area specific remediation strategy (referred to herein as the ‘remediation strategy’). Similar to the national strategy for remediation, the remediation strategy should take account of all relevant factors, including the safety objective of protecting people and the environment, present and future, against radiation risks. Such factors include the prevailing circumstances and conditions in the area to be considered in the planning and implementation of the remediation, as well as inputs from the public and other interested parties in the decision making process. Involvement of the public will, for example, help in correctly identifying relevant prevailing circumstances and conditions to be considered in developing the remediation strategy and the remediation plan (see paras 7.29–7.38 and Annex I).

GOVERNMENTAL AND REGULATORY OVERSIGHT OF REMEDIATION

2.28. Specific roles and responsibilities of the government, the regulatory body and other authorities, and other parties responsible for remediation are described in Requirements 47–49 and 52 of GSR Part 3 [1]. Requirement 47 of GSR Part 3 [1] states:

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

The government should prioritize which sites or areas affected by past activities or events need to be addressed first (see paras 2.12–2.22). The government may choose to delegate some or all of these responsibilities to the regulatory body.

2.29. Requirement 49 of GSR Part 3 [1] states that "**The government shall ensure that provision is made for identifying those persons or organizations responsible for areas with residual radioactive material**".

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

2.31. The responsible party is required to establish the necessary arrangements for the planning and implementation of remediation, and for post-remediation management (including monitoring and surveillance) to assess the efficiency and effectiveness of the remediation, including support for self-help protective actions, where such actions are considered necessary[22].

2.32. In accordance with Requirements 3 and 18 of GSR Part 1 (Rev. 1) [5], the regulatory body is required to have appropriate resources, including properly trained and experienced staff, facilities and committed financial resources.

2.33. Paragraph 5.13 of GSR Part 3 [1] states:

"The regulatory body…shall take responsibility…in particular for:

(a) Review of the safety assessment submitted by the responsible person or organization, approval of the remedial action plan and of any subsequent changes to the remedial action plan, and granting of any necessary authorization;
(b) Establishment of criteria and methods for assessing safety;
(c) Review of work procedures, monitoring programmes and records;
(d) Review and approval of significant changes to procedures or equipment that may have radiological environmental impacts or that may alter the exposure conditions for workers taking remedial actions or for members of the public;
(e) Where necessary, establishment of regulatory requirements for control measures following remediation."

[22] The government is required to establish infrastructure to support 'self-help protective actions' in areas where these are necessary (see para. 5.17 of GSR Part 3 [1]).

2.34. In addition to the requirements cited in paras 2.32 and 2.33, the responsibilities of the regulatory body should include the following:

(a) Deciding if regulatory control is necessary for a given situation and, if so, the appropriate scope of control, according to a graded approach;
(b) Identifying and quantifying potentially contaminated areas that need regulatory control and the associated responsible party;
(c) Prioritizing contaminated areas, for example in the public domain or in cases where a site that has been affected by past activities has been abandoned, to ensure that adequate controls are put into place in a timely manner to ensure protection;
(d) Reviewing and approving the management strategy submitted by the responsible party for residual materials, including radioactive waste, generated during remediation;
(e) Establishing or approving remediation criteria and the objectives of the remedial actions to ensure the protection of people and the environment (see paras 3.17, 3.18 and 3.27–3.33);
(f) Developing regulatory guidelines for the planning, approval and implementation of remedial actions;
(g) Making provision for preparedness and response for an emergency during remediation, if appropriate;
(h) Reviewing and approving the remediation strategy and remediation plan submitted by the responsible party;
(i) Verifying completion of remedial actions, in accordance with regulatory requirements and the remediation plan;
(j) Ensuring adequate regulatory oversight (including performing regulatory inspections (see Requirement 27 of GSR Part 1 (Rev. 1) [5])), and independent monitoring and measurements, where appropriate, to verify the protection of people and the environment, and to confirm that authorization conditions are being met, throughout all phases of the remediation (see IAEA Safety Standards Series No. RS-G-1.8, Environmental and Source Monitoring for Purposes of Radiation Protection [21]);
(k) Evaluating reports on unplanned events;
(l) Evaluating and authorizing revisions to the remediation plan and to post-remediation control measures, if compliance with the remediation end point criteria or end state criterion (see para. 3.27) is not achieved, such that the remediation process can be adaptively managed;
(m) Reviewing the report of the final radiological survey, which is to be conducted as part of the final remediation report (see para. 5.14(e) of GSR Part 3 [1]), upon completion of remediation and verifying that all final conditions, including the authorized remediation end point(s) (see para. 3.27), have been

met prior to terminating regulatory control or removing other restrictions over all or part of the site or area, as relevant;

(n) Authorizing termination of any regulatory or other governmental control over the area when the remediation process is satisfactorily completed, and stipulating monitoring, surveillance, restrictions or other institutional controls, as necessary;

(o) Ensuring that opportunities for the involvement of interested parties are available throughout the remediation process and that the decision making process is transparent to members of the public and other relevant interested parties.

2.35. The regulatory body is required to take appropriate enforcement actions whenever regulatory requirements or authorization conditions are not met (see Requirements 30 and 31 of GSR Part 1 (Rev. 1) [5]).

2.36. Requirement 7 of GSR Part 1 (Rev. 1) [5] establishes requirements for the "**Coordination of different authorities with responsibilities for safety within the regulatory framework for safety**". Depending on their particular responsibilities, various authorities, including the regulatory body, may have an interest in remediation. Some of these authorities, however, may be unfamiliar with the principles of radiation protection. In this regard, para. 2.18 of GSR Part 1 (Rev. 1) [5] states:

> "Where several authorities have responsibilities for safety within the regulatory framework for safety, the responsibilities and functions of each authority shall be clearly specified in the relevant legislation. The government shall ensure that there is appropriate coordination of and liaison between the various authorities
>
> …….
>
> "This coordination and liaison can be achieved by means of memoranda of understanding, appropriate communication and regular meetings. Such coordination assists in achieving consistency and in enabling authorities to benefit from each other's experience."

2.37. In the case of remediation following a nuclear or radiological emergency, those individuals and organizations having roles and responsibilities in relation to remediation as a part of the overall recovery should be identified at the preparedness stage and should be involved as early as practicable in the transition phase in accordance with the protection strategy [11]. This will allow for a smooth transition towards long term recovery in an existing exposure situation.

2.38. Many factors can influence the extent of the authorizations and approvals that need to be issued by the regulatory body to the responsible party. Such factors include the scope and complexity of the remediation and the range of regulatory bodies with jurisdiction over the area to be remediated. The responsible party is required to apply to the regulatory body for an authorization (e.g. registration, licensing), in accordance with Requirement 7 of GSR Part 3 [1]. Authorizations and other forms of approval issued by the regulatory body should aim to ensure the health and safety of the workers engaged in the remediation (including occupational radiation protection), the radiation protection of members of the public, the protection of the environment, and the safety and security of residual radioactive material (including waste). The regulatory body and other authorities concerned may provide advice on possible means to achieve compliance with regulatory requirements and authorization conditions, for example by means of guidance documents.

2.39. To meet Requirement 49 of GSR Part 3 [1], regulatory oversight of remediation is necessary before, during and, where appropriate, after remediation. This may include routine inspections during remediation to visually assess the state of the remediation area (including the compilation of photographic records), to check that remedial actions are consistent with the authorized site or area specific remediation plan (see paras 7.29–7.38), and to identify the need for any corrective actions or modifications to the remediation plan to address unforeseen changes. Annex I provides an example of the contents of a site or area specific remediation plan.

2.40. Depending on the conditions of the authorization, regulatory oversight might also be needed to verify the levels of education, training, certification and competence of radiation protection personnel and occupationally exposed workers, and to verify the accreditation of analytical laboratories.

2.41. For sites or areas subject to post-remediation management, the relevant authority is required to maintain an appropriate level of oversight (see para. 5.16 of GSR Part 3 [1]). This oversight should be designed to verify that the site or area remains safe and secure, that any access control measures have not been compromised, that new exposure pathways have not developed and that the remediation objectives and end state criterion continue to be met, and to ensure that a system of record keeping is established and maintained.

FUNDING AND FINANCING OF REMEDIATION

2.42. Paragraph 5.10 of GSR Part 3 [1] states:

> "For the remediation of areas with residual radioactive material deriving from past activities or from a nuclear or radiological emergency…the government shall ensure that provision is made in the framework for protection and safety for… [the] identification of those persons or organizations responsible for the contamination of areas and those responsible for financing the remediation programme, and the determination of appropriate arrangements for alternative sources of funding if such persons or organizations are no longer present or are unable to meet their liabilities".

2.43. In accordance with the 'polluter pays' principle[23], when the responsible party that has caused contamination or allowed it to occur can be identified, that party should be held responsible and accountable for financing the remediation and its funding.[24] However, in many instances the circumstances may be complex and it might not be possible to identify the responsible party, or the total remediation costs might be disproportionately high in comparison with the actions of the organization that is causing or has caused the contamination; for example, the contamination may have been caused by changes to exposure pathways that were unforeseen when a discharge authorization was given, or may be the result of an accident. The economic costs apportioned to an organization might also be such that they could lead to its bankruptcy and consequent inability to pay. In accordance with para. 5.10(a) of GSR Part 3 [1], the government is required to ensure that provision is made in the regulatory framework for appropriate arrangements for alternative sources of funding to cover situations where the responsible party is unable to meet its liabilities. Costs could fall wholly or in part on the original polluter, the current site owners, industry, developers or local communities, or on local, regional or national governments.

2.44. The government and the regulatory body should ensure that relevant laws and regulations also make provision for ensuring that adequate funding will

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[23] In environmental law, the 'polluter pays' principle is enacted to make the party responsible for producing pollution (i.e. causing contamination) responsible for paying for the damage done to the natural environment [22] (see also the Rio Declaration on Environment and Development from the United Nations Conference on Environment and Development [23]).

[24] 'Funding' is the money provided by operating organizations, the government or another party for a specific purpose, whereas 'financing' is a process of receiving capital or money for that purpose.

be available for remediation. The government should also make provision for adequate funding to the regulatory body or other authorities to enable the review and assessment of the remediation plan, and to verify that remedial actions are implemented in accordance with the national framework for remediation and in compliance with the authorization and the approved site or area specific remediation plan. The reliability of the funding sources should be verified by the government before any remedial actions are undertaken (see also para. 2.27 of GSR Part 1 (Rev. 1) [5]).

2.45. When remediation has been justified, it should normally be financed by the responsible party, which is required to ensure that sufficient resources have been allocated. In cases where it is not possible to identify a responsible party for the remediation, the government is required to assign a responsible party for the remediation in accordance with para. 5.10(b) of GSR Part 3 [1]. In doing so, care should be taken to ensure that there is a clear assignment of the responsibility for estimating the cost of the remediation.

2.46. The apportionment of liabilities to the responsible party might be contentious, particularly when large sums of money are involved or when designating an area as requiring remediation affects the value of surrounding properties. Therefore, the responsible party should engage and communicate with relevant interested parties as early in the remediation process as practicable, for example to clarify factors that can affect liabilities, such as the scope and timeline of the remediation, the short term risks during remediation and long term risks that might arise during post-remediation management (see Section 4).

2.47. If adequate funding for the implementation of an approved site or area specific remediation plan cannot be ensured, the relevant authority should not authorize the initiation of any remediation. Nevertheless, if current conditions are anticipated to cause significant risk to the public or the environment, certain restrictions — such as site access controls, physical barriers (e.g. fencing), specific security controls, land use restrictions, transfer of deeds or urgent arrangements for short term remedial actions — may be necessary.

2.48. In cases where post-remediation control measures are necessary, the responsible party should ensure that adequate funding is available for relevant activities, such as the establishment of restrictions, site characterization, surveillance and monitoring, as appropriate.

2.49. Financing mechanisms for any necessary remedial actions, including the management of residual materials, including radioactive waste, generated by the remediation process, should be established by the responsible party.

2.50. The relevant authority should review the financial arrangements on a regular basis to ensure that adequate financing will continue to be available, taking account of any changes in the remediation plan resulting from new information generated during the course of remediation.

INVOLVEMENT OF INTERESTED PARTIES

2.51. The involvement of interested parties is essential to the success of any remediation and should be sustained throughout the remediation process, from the initial preliminary evaluation to the completion of remedial actions and, where appropriate, the transition to post-remediation management (including institutional control). The amount and types of involvement will change depending on the interested party and during the various steps in the remediation process. The consequences of insufficient involvement could strongly affect individuals (e.g. stress, depression, failure to return following evacuation or voluntary displacement of the population), communities and industries (e.g. potentially causing adverse impacts on economic and social activities).

2.52. The requirements for communication and consultation with, and involvement of, relevant interested parties, including the public, are established in Requirements 34 and 36 of GSR Part 1 (Rev. 1) [5], paras 5.3(d), 5.12(e) and 5.17 of GSR Part 3 [1] and recommendations are provided in GSG-6 [19].

2.53. Interested parties should have a role in contributing knowledge and information to the remediation process. The role of interested parties — such as members of the public, the responsible party, the regulatory body and other relevant authorities involved in the remediation — is to exchange information in an ongoing dialogue to help ensure that well informed decisions are made. Representatives of interested parties should have the opportunity to express and discuss their positions, expectations and views regarding the remediation. This will facilitate the development of mutual understanding and meaningful involvement in the decision making process regarding the planning and implementation of remedial actions.

2.54. The involvement of interested parties that started during the development of the national strategy for remediation should continue during the development of the site or area specific remediation strategy and throughout the remediation process. The involvement of the public and other interested parties as early as practicable in the remediation process (see Section 4) will allow them to play a meaningful role in the decision making process (e.g. in identifying remedial actions). The types of involvement, the roles of different parties, and the communication and consultation strategies should be established as soon as possible, and these could vary over the course of the remediation process. Further recommendations regarding the involvement of interested parties, as well as example templates for a communication strategy and a communication plan, are provided in GSG-6 [19].

2.55. Paragraph 4.67 of GSR Part 1 (Rev. 1) [5] states:

> "The regulatory body, in its public informational activities and consultation, shall set up appropriate means of informing interested parties, the public and the news media about the radiation risks associated with facilities and activities, the requirements for protection of people and the environment, and the processes of the regulatory body. In particular, there shall be consultation by means of an open and inclusive process with interested parties residing in the vicinity of authorized facilities and activities, and other interested parties, as appropriate".

2.56. The government is required to make provision for the involvement of interested parties (see paras 5.3(d) and 5.17 of GSR Part 3 [1]), and the responsible party is required to provide a mechanism for the planning, implementation and verification of remedial actions (see para. 5.12(e) of GSR Part 3 [1]). As part of meeting these requirements, the regulatory body with lead responsibility for oversight of the remediation, and other relevant authorities with interest in the remediation, should engage with interested parties. The relevant authorities should be clear about who is responsible for providing which type of information and to whom, as documented in communication and consultation strategies for the remediation. Efforts should be made to coordinate information dissemination to avoid contradictory messages to the public. At an early stage, the relevant authorities should reach an agreement with the responsible party with regard to consultation and information sharing with interested parties, including the broader public. A clear statement of the actions to be taken by each party, and the timing of such actions, helps to ensure that harmonized public relations are established and conflicting messages are avoided. Such an approach is instrumental in building confidence and trust between all parties. In addition, the appropriate authority should reach a tentative decision regarding land use and the end state criterion in consultation with the public and other interested parties.

2.57. The responsible party should inform the public and other interested parties of planned and ongoing activities relating to the remediation. Relevant interested parties could include those responsible for the contamination, the regulatory body and other authorities, local authorities, property owners, tenants, local businesses, potential developers, liability insurance companies, nearby communities, technical experts, those responsible for funding and financing remediation, and environmental groups.

2.58. The 2012 UNSCEAR Report to the UN General Assembly [24] provides the basis for communication with the public on issues relating to the attribution of health effects to radiation exposure and inferring risks. Radiation protection professionals should refer to the conclusions of the 2012 UNSCEAR Report [24] when explaining the sources of radiation to which the public are exposed, the magnitude of these exposures, the associated health risks, the uncertainties in the risk estimates and the system that is in place to protect against these risks. Information should be communicated in plain language that is understandable to the public and other interested parties. Both actual risks and perceived risks should be addressed.

2.59. Important issues that may be raised in consultation with interested parties, for which the conclusions of the 2012 UNSCEAR Report [24] may be useful, include the following:

(a) The need to clarify and delineate concepts such as the retrospective attribution of radiation health effects to past radiation exposures and the prospective inference of health risks from exposures that have occurred or are expected to occur, especially in relation to the prediction of theoretical health effects, taking into account the underlying assumptions and their uncertainties (e.g. appropriate and inappropriate uses of collective dose).
(b) The need to communicate issues clearly and unambiguously, consistent with the requirements and recommendations of the IAEA safety standards. This is particularly important in situations where decisions have to be taken urgently and where they will have long term consequences. The lessons from the Fukushima Daiichi accident highlight the following:

   "**The risks of radiation exposure and the attribution of health effects to radiation need to be clearly presented to stakeholders, making it unambiguous that any increases in the occurrence of health effects in populations are not attributable to exposure to radiation, if levels of exposure are similar to the global average background levels of radiation.**" [16]

(c) The need for robust assessments of and clear communication on radiation risks and other safety issues associated with the following:
   — The site or area prior to remediation;
   — The actual remediation work;
   — The management and disposal of radioactive waste generated by the remediation;
   — The site or area after remediation.
(d) The need for a graded approach to protection and safety.
(e) The importance of not creating unnecessary anxiety, while appropriately recognizing relevant inferred risks and detriments, in order to enable people to make their own informed decisions (see also Appendix II on self-help protective actions).
(f) The need to explain the ‘linear no-threshold’ dose response hypothesis, which underpins the ICRP Recommendations [2] and provides the basis for the IAEA safety standards and national legal and regulatory frameworks, and which is a prerequisite for the application of radiation protection principles in practice.

2.60. Interested parties should be encouraged to contribute to the decision making process through formal and/or informal input[25] throughout the remediation process (see Section 4). Such input can be directed to the government, the regulatory body and other authorities, and/or the responsible party. In the decision making process, the needs, wishes and requests of interested parties should be taken into account and evaluated against the regulatory requirements, scientific and technical aspects, financial constraints and other relevant factors, as applicable. To ensure transparency and accountability, the following elements should be clearly explained to interested parties in a timely manner:

(a) Justification of the remediation plan;
(b) A description of how relevant factors were taken into account to select the remedial options through application of the process of optimization of protection and safety;
(c) The basis for the selected remediation decisions.

[25] Examples of formal input include written requests for information, submission of comments during formal consultation processes, involvement in public hearings and written reporting of concerns or issues. Examples of informal input include telephone calls, discussions and information sharing.

3. APPLICATION OF THE PRINCIPLES OF RADIATION PROTECTION

3.1. SF-1 [15] states:

> “**Principle 7: Protection of present and future generations**
>
> “**People and the environment, present and future, must be protected against radiation risks.**
>
> “3.27. Radiation risks may transcend national borders and may persist for long periods of time. The possible consequences, now and in the future, of current actions have to be taken into account in judging the adequacy of measures to control radiation risks.”

Further, Principle 10 of SF-1 [15] states that “**Protective actions to reduce existing or unregulated radiation risks must be justified and optimized.**” Requirements in support of these principles are set out in paras 2.9 and 2.10 of GSR Part 3 [1] on justification and optimization of protection and safety, respectively. SF-1 [15] and related requirements in GSR Part 3 [1] address the application of a graded approach to protection and safety. Paragraph 2.12 of GSR Part 3 [1] states that “The application of the requirements for the system of protection and safety shall be commensurate with the radiation risks associated with the exposure situation.” The graded approach applies to all types of exposure situation, including existing exposure situations, and should be adopted as part of the approach to remediation.

3.2. The requirements set out in GSR Part 3 [1] — many of which are applicable to remediation — include general requirements for protection and safety, together with more specific requirements for each of the following three types of exposure situation, as follows:

(a) A planned exposure situation is a situation of exposure that arises from the planned operation of a source or from a planned activity that results in an exposure due to a source. This includes planned decommissioning (including any necessary site decontamination) carried out after cessation of the operation of a facility and prior to release of the site from regulatory control [10].

(b) An emergency exposure situation is a situation of exposure that arises as a result of an accident, a malicious act or other unexpected event, and requires prompt action in order to avoid or to reduce adverse consequences [10].
(c) An existing exposure situation is a situation of exposure that already exists when a decision on the need for control needs to be taken. Existing exposure situations include situations of exposure due to residual radioactive material that derives from past practices that were not subject to regulatory control or that remains after an emergency exposure situation [10].

3.3. Remedial actions might be performed by occupationally exposed workers or, in some cases, by members of the public (e.g. volunteers) [12, 13].

3.4. The protection of workers is required to be optimized and their exposure is required to be subject to the dose limits and relevant dose constraints for occupational exposure (see para. 8.7 and GSR Part 3 [1]; see also IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [25]).

3.5. With regard to members of the public involved in remedial actions (e.g. volunteers), the regulatory body should issue guidance on the type of activity that such persons could carry out and on measures to be taken for their protection.

GRADED APPROACH

3.6. The graded approach described in para. 3.1 should be applied in the planning and implementation of remediation to determine the appropriate levels of analysis, documentation, actions and regulatory oversight such that the effort is commensurate with the risk associated with the affected site or area. Criteria relevant to the situation (e.g. the screening criterion, the reference level, end point criteria, the end state criterion) should then be set (see paras 3.17, 3.18 and 3.27–3.33). This process should consider the magnitude of the hazard involved and its duration, the characteristics of the site or area to be remediated, the relative importance of radiological and non-radiological impacts (e.g. impacts where a small number of people might be exposed to higher doses compared with those where a larger number of people are exposed at lower levels), and other relevant factors such as site or area access. A graded approach facilitates the identification of the key areas to be assessed — for example, areas where the highest contribution to doses and risk are to be expected — such that the effort can be directed to these specific areas to minimize the overall costs of the remediation.

3.7. If, during the site or area evaluation process (which includes a preliminary evaluation and a detailed evaluation; see Sections 5 and 6, respectively), a non-routine situation or event occurs that necessitates prompt action, primarily to mitigate a hazard or adverse consequences for human life, health, property and the environment due to the energy resulting from a nuclear chain reaction or from the decay of the products of a chain reaction or due to radiation exposure, a nuclear or radiological emergency should be declared. Protective actions and other response actions should then be implemented, as required by GSR Part 7 [9].

REFERENCE LEVELS

3.8. Paragraph 5.2 of GSR Part 3 [1] states that "The government shall ensure that, when an existing exposure situation is identified…appropriate reference levels are established."

3.9. Paragraph 5.22 of GSR Part 3 [1] states:

> "The regulatory body or other relevant authority shall establish specific reference levels for exposure due to radionuclides in commodities such as construction materials, food and feed, and in drinking water, each of which shall typically be expressed as, or be based on, an annual effective dose to the representative person that generally does not exceed a value of about 1 mSv."

3.10. A reference level is "the level of dose or the level of risk above which it is judged to be inappropriate to plan to allow exposures to occur, and below which the optimization of protection and safety is implemented" [1]. The range of recommended reference levels varies for different exposure situations. For emergency exposure situations, it is recommended that the reference level, specified in terms of residual effective dose, be set in the range 20–100 mSv, acute or annual, including dose contributions via all exposure pathways [9]. The recommended range of reference levels for existing exposure situations is 1–20 mSv [1, 2]. An annual effective dose of the order of 20 mSv indicates the point at which to consider whether transition from an emergency exposure situation to an existing exposure situation is appropriate [11]. For areas affected by an event, smooth continuation of remediation should be ensured, starting in the emergency exposure situation and continuing after the transition to an existing exposure situation.

3.11. For an area affected by past activities or an event, the reference level is the starting point for optimization of protection and safety through remediation. Reference levels should be used prospectively in remediation planning and in the optimization of protection and safety and, together with the end state criterion, retrospectively as a benchmark for evaluating the effectiveness of the overall remediation that has been implemented.

3.12. The reference level should be used as a boundary condition for the optimization of protection and safety to define the range of remedial options (see Section 6). The national strategy for remediation and the site or area specific remediation strategy should be developed such that their implementation will ensure the doses will not exceed the established reference level. For particular existing exposure situations, the reference level should be selected in such a way that within a reasonable period of time (e.g. of the order of some years), the residual dose to the public in all the areas considered would be below the reference level.

3.13. Paragraph 5.4 of GSR Part 3 [1] states that "The regulatory body or other relevant authority assigned to establish a protection strategy for an existing exposure situation shall ensure that it specifies…[a]ppropriate reference levels."

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

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

Reference levels for use in remediation are typically expressed in terms of annual effective dose (i.e. above any contributions from natural background radiation). For practicality, it might be beneficial to also establish derived criteria (see paras 6.11 and 6.12) that correspond to the reference level and that can be easily measured (e.g. activity per unit area, per unit weight or per unit volume; gamma dose rates at 1 m height for a defined surface).

3.15. Selection of a reference level involves making a judgement based on qualitative as well as quantitative factors. Care should be taken to set the reference level only after taking into account the prevailing circumstances and relevant factors, such as the levels of exposure due to residual radioactive material in the environment, environmental conditions, land use and the lifestyles of impacted communities (see paras 6.2 and 6.3). Doing otherwise could unnecessarily restrict the range of remedial options that can be considered.

JUSTIFICATION OF REMEDIATION

3.16. Remediation is required to be justified (see Requirement 48 of GSR Part 3 [1]). This justification involves a determination of whether the benefits of remediation (e.g. to individuals and society) outweigh any possible detriments from the remediation. Possible benefits of remediation include lower public exposure in the long term, employment and training opportunities during the planning and implementation of the remediation and enabling the future economic use of remediated areas. Possible detriments from remediation include increased occupational exposure and the exposure of workers to other hazards during the remediation, the generation of large volumes of radioactive waste that then has to be managed and regulated over potentially long time periods, and impacts on the local environment (such as habitat loss and impacts on specific species). Justification of remediation should consider different aspects, including the need for changes in lifestyles and traditional use of resources.

Relevant criteria for the justification of remediation

3.17. The reference level should be considered in the justification of remediation. During preliminary evaluation (see Section 5), the dose that would be expected to be received if planned remedial actions were not taken (i.e. the 'projected dose prior to remediation') should be compared with the screening criterion (e.g. the lower boundary of the reference level range, as established in the national strategy for remediation) that has been approved by the regulatory body or other relevant authority. This screening criterion should be used to determine whether remediation might be justified.

3.18. In cases where the projected dose prior to remediation exceeds the screening criterion, it is possible that remediation might be justified and more detailed evaluation (see Section 6) should be undertaken to determine whether remediation is justified. In such cases, it is necessary to establish a reference level for the affected site or area being considered for remediation, above which it is not appropriate to plan to allow exposures to continue to occur and below which optimization of protection and safety should be implemented (see paras 3.10–3.12). The projected dose prior to remediation should then be compared with this established reference level, or corresponding derived criteria, to determine whether remediation is justified (see Appendix I). If the projected dose prior to remediation exceeds the established reference level, remediation should be deemed justified.

Relevant factors in the justification of remediation

3.19. The justification of remediation can be achieved through the use of decision aiding techniques and processes, as necessary, taking account of all relevant factors that are to be considered in remediation planning and implementation, such that there is a net positive benefit. These factors include the following:

(a) Laws, regulations and other requirements that need to be complied with;
(b) Possible short term increases in public exposure during the remediation, and the long term reduction of public exposures due to the remediation;
(c) The occupational exposures and non-radiological risks to remediation workers during the remediation;
(d) The potential impacts on the environment caused by the remediation (positive and negative) and the reduction in long term impact (i.e. post-remediation);
(e) Risk perceptions of the local population, including expectations and views of interested parties;
(f) The potential impacts of the remediation (positive and negative), with consideration of aspects of the area that are valued by local residents (e.g. diet, traditional use of land and resources, recreational activities) and the maintenance of community cohesion;
(g) The financial cost of the remediation, including costs for possible waste management and disposal;
(h) The social benefits (e.g. improved public protection and safety, the possibility of displaced people returning home following remediation) and detriments (e.g. the need to finance the remediation of abandoned sites using public money, the displacement of people following an emergency) of the remediation;
(i) Options for the management of radioactive waste arising from remediation and the availability of facilities for waste processing, storage and disposal;
(j) The anticipated end use of the remediated area.

3.20. Balancing the factors relevant to remediation planning and implementation through the justification process might be complex and difficult. This complexity might increase when remediation is necessary following a nuclear or radiological emergency with significant release of radioactive material that affects the lives of the local population. In such cases, a decision to allow people to live permanently in the affected areas should be justified, as should any conditions that are attached to this decision.

3.21. The process of justification typically involves many more factors than just radiation protection, and therefore should involve all appropriate governmental agencies as well as other relevant interested parties. As part of the process of justification, consultation with relevant experts may also be necessary.

3.22. While in most cases the detriments associated with remediation (e.g. in terms of aspects such as disruption and inconvenience) will be borne by the present population, remedial actions taken to protect the present generation should be designed such that predicted impacts on the health of future generations will not be greater than the levels of impact that are currently regarded as acceptable.

OPTIMIZATION OF PROTECTION AND SAFETY IN REMEDIATION

3.23. Requirement 48 of GSR Part 3 [1] states that "**The government and the regulatory body or other relevant authority shall ensure that…protection and safety is optimized.**"

3.24. Once remediation and the associated remedial actions have been justified, the form, scale and duration of remedial actions or protective actions are required to be optimized, in order to make the best use of resources in reducing radiation risks. The process of optimization of protection and safety will be specific to the prevailing circumstances (e.g. environmental conditions, location of the area, surrounding population and land use, the availability of resources for remediation) and is a structured, iterative process that is applied to plan and implement remediation. In addition, the optimization of protection and safety should take into account the national policy and national strategy for remediation (see paras 2.11–2.22), for example with respect to remediation and radioactive waste management, including radioactive waste disposal options, waste minimization and other factors. The process of the optimization of protection and safety should be conducted in consultation with relevant interested parties.

3.25. The aim of optimization of protection and safety in remediation and the associated remedial actions is to ensure that the magnitude of individual doses, the number of individuals (workers and members of the public) subject to exposure, and the likelihood of exposure are as low as reasonably achievable, economic and social factors being taken into account [1]. In this process, the evaluation of doses should be as realistic as possible, and account should be taken of the quality and reliability of the available information. In practice, exposures can be influenced by human behaviour. There is, therefore, a need to consider a number of different exposed groups, including present and future generations, selected on the basis of the intended use of the area, and an analysis of exposure pathways.

3.26. The optimization of protection and safety entails the selection of the appropriate remedial action(s) from a set of justified remedial options, such that the form, scale and duration of the associated remedial actions provide the maximum net benefit. The optimization of protection and safety should be undertaken at relevant stages throughout the entire remediation process.

Relevant criteria for the optimization of protection and safety

3.27. A reference level is not a criterion that defines when remediation is complete (which is commonly referred to as the remediation 'end state') and should not be treated as a limit; rather, it is the level below which the optimization of protection and safety would continue to be implemented. The optimization of protection and safety is also undertaken to determine the optimum end state for the remediation of a site or area. Notwithstanding this, in practice, remedial actions can only be implemented if the criteria for completing such actions are known. As such, throughout the process of optimization of protection and safety, the end points of remedial actions should be defined. A given end point is relevant for a given individual remedial action or a group of related remedial actions and is "typically the level of *contamination* beyond which further *decontamination* or *remediation* is considered unnecessary" and is "often calculated on the basis of a level of *dose* or *risk* that is considered acceptable" [10]. One or more end point criteria should be established for each remedial action or group of related remedial actions to verify their completion in accordance with the remediation plan. In comparison, the end state is "the final status of a site [or area] at the end of *activities* for *decommissioning* and/or *remediation*, including approval of the radiological and physical conditions of the site and remaining *structures*" [10]. An end state criterion should be established for use in verification that the overall remediation plan and associated remedial actions have led to achieving the defined end state.

3.28. The end state criterion is a set of conditions that need to be met to verify that remediation has been completed and the defined end state has been achieved. The end state criterion can include a group of end point criteria relating to radiological and/or non-radiological conditions that must also be met to verify that the defined end state has been achieved. Reaching the end state ultimately leads to the release of part or all of a site or area from regulatory control or other restrictions and subsequent post-remediation management (see Section 10).

3.29. The end state criterion should be considered in the optimization of protection and safety, and the selection of remedial actions and, where appropriate, protective actions for remediation to achieve this criterion. The end state criterion for remediation, and corresponding end point criteria, should be defined in the environmental impact assessment for the remediation. The environmental impact assessment should also provide an estimate of the projected dose prior to remediation (see para. 3.17) and the dose expected to be incurred after remedial actions have been terminated or after a decision has been taken not to take protective actions (i.e. the residual dose; see Appendix I). The expected dose reduction due to the overall remediation and the individual remedial actions, and as relevant, protective actions relating to the remediation, should be documented in the environmental impact assessment.

3.30. Operational criteria that are measurable should be developed, and a monitoring programme that covers source monitoring, environmental monitoring and, as relevant, individual monitoring (see RS-G-1.8 [21]) should be established to verify that the remediation is being implemented in accordance with the approved remediation plan. Over the course of the remediation, monitoring should be conducted and the results should be evaluated to ensure that operational criteria are not exceeded. In cases where operational criteria are exceeded, the remediation plan and its implementation should be reviewed and adjusted, as appropriate, and an assessment should be undertaken to ensure that the relevant end point criteria are met. This should include a dose assessment to ensure that the residual dose is acceptable, as set out in the approved environmental impact assessment or regulatory conditions relating to the remediation.

3.31. Upon completion of each action or set of actions, the projected dose prior to remediation should be compared with the residual dose estimated following completion of a given action or set of actions to determine the effectiveness of remediation and to verify that the remediation is being implemented as planned. Such comparisons of projected doses prior to remediation and residual doses after remediation should be documented.

3.32. In cases where the remediation is not being implemented as planned, the remediation plan should be reviewed and adjusted, as appropriate, and an assessment should be conducted to verify that any adjustments to the remediation plan will lead to the planned end state of remediation, including a reduction in residual dose, as set out in the approved environmental impact assessment or regulatory conditions relating to the remediation.

3.33. The end point criteria and end state criterion that have been developed will not necessarily be those that provide the lowest residual dose, since dose reduction is only one of several attributes considered as part of the optimization of protection and safety. During optimization of protection and safety, other radiological and non-radiological factors should also be considered, with an aim to optimize below the reference level (see para. 3.11). The optimum option might result in extensive remediation but not the restoration of the initial conditions that existed before a site or area was affected. In some cases, restrictions on access to or use of certain resources (e.g. land, drinking water, food, other commodities) might be the outcome of the process of optimization of protection and safety.

4. OVERVIEW OF THE REMEDIATION PROCESS

4.1. The remediation process should be based on a stepwise approach, applying the principles of radiation protection, including justification, the optimization of protection and safety, and dose limitation.

4.2. The remediation process can be broadly described in terms of five phases, as follows:

(1) Preliminary evaluation;
(2) Detailed evaluation;
(3) Planning of remediation;
(4) Implementation and verification monitoring;
(5) Post-remediation management.

This process can be applied to the planning and implementation of the remediation of sites and areas affected by past activities or events. The remediation process is shown schematically in Fig. 1.

4.3. The responsible party should ensure that the processes for communication and consultation with and involvement of interested parties are determined as part of preparing for remediation. Active communication and involvement should commence prior to the preliminary evaluation of the site or area and should continue through the entire remediation process. The involvement of interested parties should be continued in the post-remediation phase.

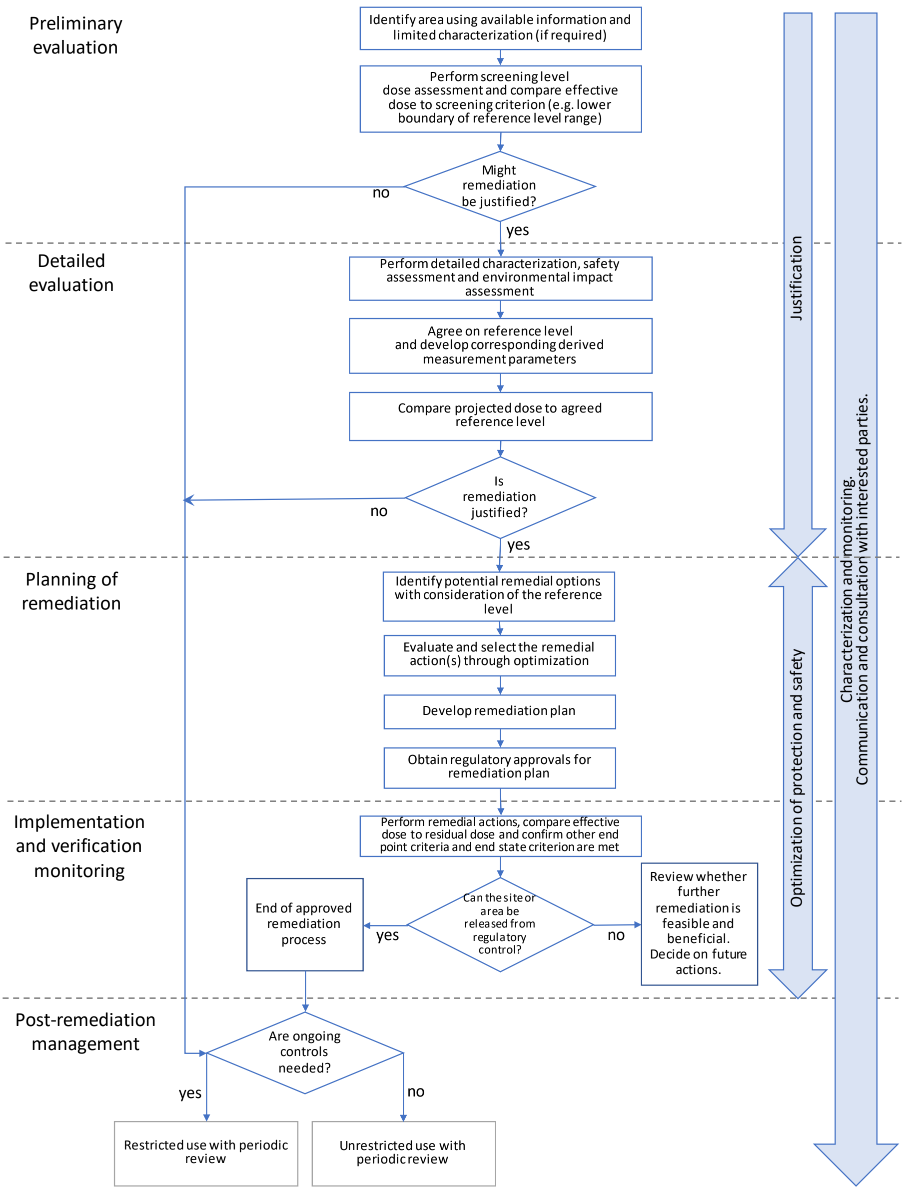

FIG. 1. Representative scheme for the phases involved in the remediation of a contaminated area.

4.4. The preliminary evaluation phase (see Section 5) includes the assessment of available information about the site or area under consideration to gain an understanding about the types, levels and distribution of contaminants; the relevant exposure pathways; the history of the site or area; the lifestyles of residents; and other prevailing circumstances. In cases where little information is available, further characterization of the site or area (e.g. through field surveys) may be necessary.

4.5. The information from the preliminary evaluation should be used to conduct a preliminary dose assessment. The projected doses prior to remediation should be compared against the relevant screening criterion (e.g. the lower level of the reference level range, as established in the national strategy for remediation) that has been approved by the regulatory body, in order to determine whether or not remediation might be justified (see para. 3.17). The screening criterion should be conservative and can be established by the responsible party or the regulatory body, depending on the legal and regulatory framework. In cases where the screening criterion is established by the responsible party, it should be subject to approval by the regulatory body.

4.6. If the comparison of the projected doses prior to remediation and the screening criterion indicates that remediation could be justified (i.e. the projected doses are above the screening criterion), the detailed evaluation phase should be initiated (see Section 6). In doing so, a detailed survey should be undertaken to further characterize the affected site or area. The detailed evaluation phase also involves the establishment of a reference level (see paras 3.8–3.15) and the corresponding derived criteria for individual remedial actions. The reference level should be selected taking account of the prevailing circumstances (e.g. the potential for dose reduction, costs, technical feasibility, societal factors) and making use of experience from similar situations. At the end of the detailed evaluation phase, a decision should be made as to whether or not remediation is justified.

4.7. If remediation is justified, the next phase of the remediation process is the planning of remediation (see Section 7). The remediation planning phase involves the identification and evaluation of various remedial options, each of which should be justified (see paras 3.16–3.22). A process to optimize protection and safety should then be conducted (see paras 3.23–3.33). The feasibility, availability and practicability of individual remedial options should be considered as part of this process. An optimum remedial option should be identified. In some cases — for example, where there is high uncertainty — it might be necessary to also identify an alternative remedial option that can be implemented if the optimum remedial option is subsequently found not to be feasible or cannot be effectively implemented. In cases where there is high uncertainty, or where insufficient information is available about an affected area, it may be necessary to identify a number of potentially feasible remedial options that could be undertaken pending further information. This may include a combination of active and passive measures. In such situations, a schedule should be developed which identifies key decision points by which missing information will be collected in order to ensure that sufficient information is available to select the final remedial action. The remedial actions being considered for implementation should then be included in the site or area specific remediation plan (see Annex I).

4.8. The site or area specific remediation plan, once developed, is required to be submitted by the responsible party to the relevant authority for approval (see para. 5.12(a) of GSR Part 3 [1]).

4.9. The concentration and distribution of radionuclides in the environment can change over time, for example owing to radioactive decay, ingrowth of radioactive progeny, natural processes (such as natural attenuation and contaminant migration) or human actions. Owing to this variation over time, the sequencing and scheduling of remedial actions may also need to be taken into account in the site or area specific remediation plan, with consideration of the available monitoring and characterization data. This time dependence, especially the possibility of migration of radionuclides, should also have been taken into account in the detailed evaluation phase. A time frame for the detailed evaluation and for the establishment of controls (e.g. institutional control) following remediation should be defined as part of the remediation process and approval by the regulatory body should be sought.

4.10. The next phase of the remediation process is the implementation of remediation and verification by means of monitoring (see Section 8). In the implementation phase, remedial actions are required to be carried out in accordance with the approved remediation plan (see para. 5.14(a) of GSR Part 3 [1]). The step by step approval of remedial actions by the regulatory body, along with the assessment and evaluation of feedback and lessons from the previous phases of remediation, can be an effective approach to verifying that the remediation is being progressively implemented as planned. Remediation is an iterative process and the outcome of each step is assessed against remediation end point criteria (see paras 3.27 and 3.28) and decisions are made regarding further actions until the end state criterion has been met (see paras 3.27 and 3.29). The outcome and effectiveness of the remediation are then required to be assessed (see para. 5.14(d) of GSR Part 3 [1]), and decisions should be made regarding further actions and, as appropriate, the release of part or all of the site or area from regulatory control.

4.11. The final phase of the remediation process is post-remediation management (see Section 10). The need for any post-remediation control measures is required to have already been identified as part of the remediation plan (see para. 5.15(a) of GSR Part 3 [1]). The effectiveness of the implementation of this plan will be a factor in determining where the site or area is suitable for unrestricted or restricted use. In accordance with para. 5.16 of GSR Part 3 [1], monitoring and surveillance are also required to be continued as necessary (e.g. if engineered structures or systems were put into place as part of the remediation).

4.12. In cases where both radiological and non-radiological hazards are present (e.g. at former uranium mining and milling sites), an integrated approach to the national strategy for remediation (see paras 2.12–2.22) should be considered in the preliminary evaluation and the detailed evaluation (see Sections 5 and 6) to evaluate the potential impacts of the hazards. The regulatory body, other authorities and other interested parties should be involved in this process. It is useful to compare the process shown in Fig. 1 with the commonly adopted phases used in remediation in the chemical industry, as follows:

(a) Phase I of an environmental site assessment (ESA) for remediation in the chemical industry corresponds to the 'preliminary evaluation' phase presented in Fig. 1. A Phase I ESA is, in general, a desk based historical investigation to assess the possible impacts of past activities at and around a site, and to identify areas of the site that might be contaminated. Where the Phase I ESA indicates that screening criteria for chemical contaminants have been exceeded, a Phase II ESA should then be conducted.
(b) Phase II of an ESA for remediation in the chemical industry corresponds to both the 'detailed evaluation' phase and the first part of the 'planning of remediation' phase (i.e. the identification of potential remedial options) in Fig. 1. A Phase II ESA involves detailed site characterization, including the establishment of a sampling plan to evaluate the extent of contamination and to determine remedial options.
(c) Phase III of an ESA for remediation in the chemical industry corresponds to the remainder of the 'planning of remediation' phase and the first part of the 'implementation and verification monitoring' phase (i.e. the implementation of remedial actions) in Fig. 1. A Phase III ESA includes the detailed planning and execution of remediation of an affected site. A Phase III ESA also involves the development of an environmental remediation strategy and a work plan, as well as their execution.
(d) Phase IV of an ESA corresponds to the remainder of the 'implementation and verification monitoring' phase and the 'post-remediation management' phase in Fig. 1. A Phase IV ESA is sometimes referred to as 'validation' or

‘record of site condition’ and can include confirmation based on monitoring and assessment that the remedial actions undertaken have achieved their stated aim; a summary of the remediation done at the site, which forms the basis for communicating with interested parties that the appropriate standard of work has been completed; and a means for archiving appropriate documentation.

4.13. In accordance with Requirement 6 of IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [6], the remediation process is required to be developed and implemented in the context of a management system that “**shall integrate its elements, including safety, health, environmental, security, quality, human-and-organizational-factor, societal and economic elements, so that safety is not compromised.**” The management system should allow for a continuous review and analysis of the site or area specific remediation plan, as needed, to facilitate any necessary changes to this plan over the lifetime of the remediation process. This could include reconsideration of the end point criteria, the end state criterion or other criteria, as relevant, and changes in the needs and conditions of those living in the area.

4.14. Throughout the remediation process, characterization of the site or area is required to be undertaken (see para. 5.14(c) and (d) of GSR Part 3 [1]). This includes the design and implementation of an appropriate monitoring programme (see para. 5.12(f) of GSR Part 3 [1]) and use of appropriate monitoring equipment. The monitoring programme should be considered a key element of the management system. Comprehensive guidance on monitoring programmes and systems is given in RS-G-1.8 [21] and Ref. [26]. This includes guidance on the selection and calibration of suitable monitoring instruments, the use of appropriate sampling and measurement techniques, and the recording of data.

4.15. Site or area characterization and surveys (e.g. involving measurements of ambient gamma dose rate as well as sampling and analysis of air, surface and subsurface soil, water, flora and fauna) should be supported by the necessary data collection techniques, including quality assurance and quality control processes as part of the integrated management system.

5. PRELIMINARY EVALUATION

5.1. Sites and areas with residual radioactive material from past activities or events should be identified and prioritized for remediation, consistent with the national strategy for remediation (see Section 2). The process for identifying and prioritizing sites and areas for remediation should consider any information already available from previous site or area evaluations.

5.2. The preliminary evaluation should be undertaken by the responsible party, with the following objectives:

(a) To determine whether a site or area is contaminated and, if so, to what extent;
(b) To identify and document the possible causes of the contamination on the site or in the area;
(c) To identify and document the source of contamination[26] and the possible extent and characteristics of radiological and non-radiological contamination and other hazards through characterization;
(d) To identify the relevant exposure pathways and receptors of exposure[27];
(e) To develop a conceptual site model[28] to describe the key sources of contamination and exposure pathways;
(f) On the basis of the available information, to evaluate the extent to which the site or area poses a risk to human health or the environment and, as

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[26] A ‘source of contamination’ is anything that may cause exposure — such as by emitting ionizing radiation or by releasing contamination, radioactive substances or radioactive material — and can be treated as a single entity for the purposes of protection and safety.

[27] A ‘receptor of exposure’ is the entity exposed to the stressor of concern. This term may refer to humans, flora and fauna (including endangered and threatened species), habitats or ecosystems.

[28] The ‘conceptual site model’ provides a qualitative overview of the key aspects for consideration during remediation and the connection of these aspects to the site or area being considered for remediation. The conceptual site model identifies relevant sources of contamination, contaminant transport pathways, receiving environments and receptors of exposure (e.g. human populations) to facilitate a broad estimation of the possible activity concentrations of radionuclides in the environment and the associated levels of exposure of persons. This model synthesizes and confirms what is known about a site in support of decision making. Development of the conceptual site model is an iterative process. For screening purposes (e.g. during preliminary evaluation), the assessment of impacts typically involves conservative assumptions, for example to estimate doses to the public. In cases where detailed evaluation is necessary, the radiological environmental impact assessment incorporates site or area specific data, and the conceptual site model is reviewed and updated, as necessary, to capture the site or area specific conditions.

appropriate, to prioritize the need for implementing remedial actions and/or protective actions;
(g) To provide input into the design of a detailed site evaluation, in particular, to establish the types of data and associated measurement uncertainty that will be needed in order to make decisions regarding the source and the extent of the contamination;
(h) To assess the possible migration of contaminants into surrounding areas;
(i) To identify the party or parties that may have been responsible for the contamination;
(j) To determine whether remediation could be justified and, therefore, whether a detailed evaluation is necessary.

5.3. The first step of a preliminary evaluation is to undertake a desk based assessment using information that is readily available for the site or the area under consideration. All relevant information, both current and historical, should be compiled. This may include information on the following:

(a) The location and boundaries of the site or area;
(b) The nature and extent of the activities carried out (including the past and present owners and tenants);
(c) Buildings, buried structures and materials (including any waste), and physical barriers;
(d) General meteorological conditions for the site or area;
(e) Geological and hydrogeological characteristics, including types of soil;
(f) Nearby water resources and their use by the public;
(g) Human activities on the site or in the area and in the vicinity;
(h) The environmental conditions on the site or in the area and in the vicinity, including the presence of protected or endangered species;
(i) Data and information from characterization and monitoring activities undertaken at the affected site or in the area (e.g. quantification of sources, measurement of activity concentrations in the environment, characterization of exposure pathways).

For remediation following an event, some of this information might have been collected as a part of the emergency response and should be considered in the preliminary evaluation.

5.4. The information should be collected from various sources, including historical operational records (e.g. from former uranium mining and milling operations), past radiological and non-radiological surveys, and local government records. Information may also be obtained through site visits (involving the gathering of

GPS data and photographic information) as well as through consultations with past and present owners, employers and employees, local industry, local residents and government officials.

5.5. In cases where there is not adequate information available to conduct the preliminary evaluation, it may be necessary to conduct targeted field studies or surveys to collect additional information or data. The historical use of the site, and the materials used and produced on the site, will guide the planning and type of sampling and analysis to be done during the preliminary evaluation. In some cases, it may be determined that active remedial actions — involving, for example, source removal — are not necessary and that passive remedial actions, with restrictions on access, can be implemented instead.

5.6. If there is only very limited information available for the site or area being considered for remediation, it may be necessary to undertake a field visit and to conduct further characterization and/or a survey to collect additional information.

5.7. The characterization should include an assessment of the estimated levels of exposure and the corresponding projected dose prior to remediation. The characterization should also include an assessment of environmental impacts, including potential effects on neighbouring States, and other factors such as socioeconomic considerations, and the availability of funding, feasible remediation techniques and equipment, and relevant scientific data.

5.8. Before a visit is made to an affected site or area (e.g. a site affected by a past practice, a property affected by an accident), the purpose of the visit should be discussed with any relevant interested parties. Access to local knowledge, where available, is important, particularly if the team visiting the site is not familiar with the site and its surrounding area. It is important to identify individuals with knowledge of the area who may be consulted or employed as guides during field visits and surveys, particularly where there is a lack of maps or local records or data.

5.9. An initial characterization, as part of the preliminary evaluation, may include limited measurements (e.g. of ambient dose rates) and sampling of materials for analysis. Any preliminary sampling programme should be planned in advance and should focus on sampling in areas identified as affected, especially those where people spend their time. A safety assessment and environmental impact assessment may be required to cover the collection of samples from contaminated areas (see Requirement 13 of GSR Part 3 [1] and GSR Part 4 (Rev. 1) [7]). Such activities may require regulatory authorization (see Requirement 7 of GSR Part 3 [1]).

5.10. The information collected in the preliminary evaluation should be used in a preliminary screening analysis involving a comparison of the estimated projected doses prior to remediation against the screening criterion (see para. 3.17). If the screening analysis suggests that there might be significant impacts on people and the environment, further characterization and assessment should be undertaken, as part of detailed evaluation (see Section 6), to develop the scope of remediation and to identify people, flora and fauna that might be at risk. The information gathered in the preliminary evaluation phase should also be used to determine the type, quality and quantity of the measurements that will be necessary for deciding on the full nature and extent of the remediation required.

5.11. If the preliminary evaluation confirms the presence of contamination on a site or in an area, it is important to also consider the area adjacent to the site or area, as contamination may have migrated.

5.12. Consistent with the best available information at the time, a preliminary estimate of the potential types and volumes of residual material, including waste, that could be generated during remediation, its handling and storage, as well as its ultimate use or disposal, should be produced. This estimate should be revisited at different phases during remediation, such as during the selection of remedial options and during the implementation of remedial actions to verify the estimates of the types and amounts of material, residue and waste generated.

5.13. Decision making at this step may need to be done in the context of incomplete information. Future plans, actions and communication based on such information should be presented in terms of estimates, approximations or ranges, but actions should not be deferred pending more information.

5.14. Data gathered in the preliminary evaluation phase should be used to make informed decisions regarding the justification for remediation, and also regarding any further characterization and/or monitoring that may be needed. Care should be taken to ensure that data are of sufficient quality and quantity and meet relevant data quality objectives, as specified in the management system. Data should be collected by trained and qualified individuals using, as appropriate, calibrated instruments of a suitable type.

5.15. A system for collecting and maintaining records of the actions taken during the initial site or area evaluation should be developed and documented, consistent with the national strategy, laws and regulatory requirements (see Section 2).

5.16. This information gathered in the preliminary evaluation should be documented in an inventory of affected areas and should then form the basis of the site or area specific remediation plan. A site or area specific remediation plan (see paras 7.29–7.38) that is consistent with the national policy and national strategy and that complies with legal and regulatory requirements should be developed by the responsible party to plan and implement the remediation, taking account of the site or area specific remediation strategy and the assessment of site or area characterization data.

5.17. On the basis of the preliminary evaluation, it should be determined whether or not remediation might be justified. There are some instances where the information on the history of the site or area, the characterization data and the survey data, and the conceptual site model indicate a clear need to remediate without further justification. In addition, there may be reasons not relating to radioactive contamination that might justify the implementation of remedial actions.

5.18. Areas where the estimated dose to members of the public is less than the screening criterion (see para. 3.17) that has been approved by the regulatory body might be released for unrestricted use (see para. 8.32). In areas where the estimated dose to members of the public exceeds the approved screening criterion, remediation might be justified. Detailed evaluation is then needed to determine whether remediation is justified.

6. DETAILED EVALUATION

6.1. If the preliminary evaluation indicates that remediation might be justified, a detailed evaluation of the site or area should be undertaken by the responsible party to determine whether remediation is, in fact, justified and, if so, to provide necessary information for remediation planning. The detailed evaluation should include the following:

(a) Characterization[29] of the local environment, including the compilation of weather data for the area of interest, surveys to measure ambient radiation

[29] Results from characterization undertaken prior to remediation can be compared with results from characterization undertaken following remediation to determine the effectiveness of the remediation.

levels, and sampling and analysis of soil, groundwater, surface water and sediment, as appropriate;
(b) Determination of the nature and extent of the contamination;
(c) Identification of exposure pathways and receptors of exposure, and provision of input to a quantitative site or area model[30] to mathematically describe the conceptual model using site or area specific data (see para. 5.2), in support of the dose assessment or risk assessment models;
(d) Assessment of occupational health and safety, including occupational radiation protection;
(e) Assessment of public exposures associated with the contaminated site or area;
(f) A prior assessment of environmental issues that could occur during the remediation of the site or area;
(g) A decision on whether or not the remediation is justified.

6.2. The design of surveys should be determined by the conditions in the site or area, the type, nature and extent of the contaminants, and the available resources. Building on the objectives of the preliminary evaluation, special consideration should be given to conducting further characterization and surveys to obtain more detailed information on the following:

(a) The arrangements for the management of the site or area, including site or area access controls to prevent, for example, inadvertent access or unauthorized intruders and thereby minimize exposure;
(b) Persons living or working in the contaminated area and other interested parties;
(c) Usage of surface water or groundwater downstream of the contaminated area;
(d) Current and possible future land uses;
(e) The type of ecosystem and the flora and fauna in and around the contaminated area;
(f) The use of contaminated materials from the area (e.g. in local dwellings);
(g) Site and area specific environmental conditions, such as the local climate, physicochemical conditions, hydrogeology and specific exposure pathways;

[30] The 'quantitative site or area model' is a representation that uses a mathematical formulation to describe the movement of radionuclides in the environment and to estimate the resulting exposures. The development of the quantitative site or area model is an iterative process.

(h) Agricultural activities carried out in and around the contaminated area (e.g. crop growing, irrigation of crops with contaminated water, application of contaminated sewage sludge to crops, grazing of animals);
(i) The potential for the migration of contamination from the site or area.

6.3. The data gathered in the detailed evaluation (including its associated uncertainty) should be compiled into a report. The data gathered in the preliminary evaluation (see Section 5) and detailed evaluation provide a baseline for the pre-remediation conditions against which to compare conditions following remediation to evaluate the effectiveness of remedial actions. Characterization of the pre-remediation baseline should include sites and areas that are thought to be affected by the past activity or event being evaluated, as well as areas that are unaffected. These data should be used to estimate the projected dose prior to remediation (see para. 3.17) and should form the basis for establishing the reference level and corresponding derived criteria (see para. 3.14).

6.4. In the case of remediation following an event, protective actions and other response actions will have been taken in response to the emergency [9]. Therefore, the residual dose after protective actions were taken during the emergency should be considered in defining the pre-remediation baseline conditions and the corresponding projected dose prior to remediation (see para. 3.17) for comparison with the reference level for the site or area being considered for remediation.

ESTABLISHMENT OF REFERENCE LEVELS

6.5. Reference levels are typically established on a case-by-case basis, depending on the prevailing circumstances and conditions. When selecting the reference level and corresponding derived criteria (see paras 6.10–6.12), a number of factors might be considered, including the following:

(a) Radiological characteristics (e.g. radionuclide composition, physical and chemical properties, radionuclide deposition density, size of contaminated area);
(b) Site or area specific environmental attributes (e.g. soil types, relief, climate, presence of forests and/or water bodies, land use, agricultural practices and techniques, social and demographic characteristics such as settlement type and eating habits);
(c) The opinions of interested parties.

The selection of the reference level should be based on adequate characterization of the site or area. Annex II provides examples of how to take account of the prevailing circumstances and the various other factors in the selection of a reference level.

6.6. If the doses to the public in a settlement or area are represented by a frequency distribution, a priority of the remediation should be to reduce the proportion of the population that receives doses above the reference level. For the members of the public whose projected doses prior to remediation exceed the reference level, the regulatory body or other relevant authorities might decide on specific measures to reduce exposures (e.g. food advisories, restrictions). Appendix I provides guidance on how to conduct a dose assessment for the purposes of remediation.

6.7. When establishing reference levels, the principles of justification and optimization of protection and safety should both be considered. National authorities should consider the prevailing circumstances in determining the reference level, including past remediation experience and the availability of resources [27]. The optimization of protection and safety during remediation will then lead to a progressive reduction of exposure to below the reference level. In accordance with the recommendations in ICRP 103 [2], the distribution of individual doses may be moved downwards in a stepwise manner to progressively improve the situation. Reference levels are required to be periodically reviewed by the regulatory body and other authorities; see para. 5.9 of GSR Part 3 [1].

6.8. Consultation with interested parties should be undertaken in selecting an appropriate reference level. Clear communication of the rationale for the choice of the reference level to interested parties, such as local communities in the vicinity of the remediation area, is essential in building trust and increasing the possibility of acceptance by interested parties.

6.9. The selection of the reference level might impact the amount of waste generated during remediation. In general, the lower the reference level, the higher the volume of waste generated (e.g. because a larger area is remediated). Paragraph 3.29 of SF-1 [15] states that “The generation of radioactive waste must be kept to the minimum practicable level”. This should be a consideration in the selection of an appropriate reference level.

6.10. In practice, reference levels can be converted, as appropriate, to corresponding derived criteria (e.g. in terms of becquerels per gram) to aid in the application of the reference levels and to guide the planning, implementation and verification of remedial actions.

6.11. For operational remediation purposes, derived criteria[31] might be calculated by means of realistic dosimetric models for a representative person (see paras I.11–I.14) residing in an existing exposure situation. These derived criteria are measurable quantities, such as ambient dose rate, activity concentration in foods or other environmental media.

6.12. When selecting reference levels and derived criteria, it is important to take account of uncertainties associated with, for example, sampling and measurements, environmental modelling, the estimated (distribution of) doses to the public, and the effectiveness of the proposed remedial actions.

6.13. Selection of the reference level involves judgement of qualitative and quantitative factors and calls for wide and informed communication and consultation; it may be aided by techniques such as multi-attribute decision analysis. Care should be taken to avoid setting the reference level at a value that is too low (as it may be difficult to increase it in the future) and/or at too early a stage in the detailed evaluation process (i.e. when the available information is inadequate).

6.14. In cases of severe contamination, or lack of resources to carry out full remediation immediately, it may be considered advantageous to select an intermediate or short term reference level and then, on the basis of the experience gained and the availability of further resources, revise this downwards so as to progressively improve the situation until the long term reference level can be met.

6.15. The radiation risks and non-radiological risks in the site or area being considered for remediation should be identified in a safety assessment[32] (see GSR Part 3 [1], GSR Part 4 (Rev. 1) [7]), a safety case[33] (see GSR Part 5 [3],

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[31] The term ‘derived criteria’ is related to the concept of ‘derived reference levels’ established in the publication ICRP 126 [28]. According to ICRP 126, a ‘derived reference level’ is defined as a “Numerical value expressed in an operational or measurable quantity, corresponding to the reference level set in dose.” A derived criterion is more generic than a derived reference level and refers to a numerical value expressed in an operational or measurable quantity, corresponding to a given criterion, such as a reference level, screening criterion, end point criterion or end state criterion (see paras 3.17, 3.18 and 3.27–3.33).

[32] A ‘safety assessment’ is defined as an assessment of all aspects of a facility or activity that are relevant to protection and safety [10].

[33] A ‘safety case’ is defined as a collection of arguments and evidence in support of the safety of a facility or activity. This will normally include the findings of a safety assessment and a statement of confidence in these findings [10]. A safety case is prepared to ensure that remediation is undertaken in a safe manner.

SSR-5 [4], and IAEA Safety Standards Series No. SSG-23, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste [29]) and an environmental impact assessment[34] (see paras 6.16–6.24). The arrangements for submitting these assessments to the regulatory body (i.e. for the purpose of authorization) should be established in the legal and regulatory framework (see paras 2.23–2.26). These assessments should cover all the proposed remedial actions and should consider the potential impacts on workers, the public and the environment from the remediation itself, as well as public exposures before and after remediation. Assessments should address potential events, including accidents, that might occur during remediation. Based on these assessments, the site or area specific remediation plan should detail the measures that will be taken to ensure the health and safety of workers, protection of the public and protection of the environment.

SAFETY ASSESSMENT AND ENVIRONMENTAL IMPACT ASSESSMENT

6.16. Information obtained from the remediation safety assessment, the environmental impact assessment and the safety case can aid in identifying remedial actions and determining whether these actions are justified and optimized (e.g. in terms of form, scale and duration).

6.17. Estimates of present and future doses to individuals, the number of exposed individuals and the likelihood of exposure are key inputs to the processes of justification and optimization of protection and safety. The radiological impact on flora and fauna is an additional factor that should also be considered within the processes of justification and optimization of protection and safety. A dose assessment, including the calculation of doses to the representative person, should be performed and then updated, as appropriate, throughout the remediation process, and remedial actions should be modified, as needed, to ensure that protection and safety remains optimized. Non-radiological impacts should also be considered in the safety assessment and environmental impact assessment.

6.18. In addition to the dose to the representative person, the dose distribution in the overall affected population may also be an important parameter (see Annex II).

[34] An 'environmental impact assessment' refers to "a procedure within a governmental decision making process for identifying, describing and assessing prospectively the effects and the risk of effects of a particular proposed activity or facility on aspects of environmental significance" [30]. Remediation is a planned activity.

Both the exposure of the representative person and the dose distribution in the affected population should be considered in the optimization of protection and safety. Appendix I provides a further description of dose assessment as an input to the remediation process.

6.19. The regulatory body should consider issuing guidance on undertaking safety assessments and environmental impact assessments for remediation. Such guidance may be specific to certain types of site or may be more generic.

6.20. Both internal exposure (e.g. through ingestion of contaminated foodstuffs, ingestion of contaminated drinking water and/or inhalation of contaminated dust) and external exposure should be assessed. Doses to workers and the public (i.e. projected doses prior to remediation for conditions before remediation, and residual doses during and after remediation) need to be estimated on the basis of model predictions, assuming realistic exposure scenarios. Model predictions should provide a holistic assessment of the exposure situation in terms of the numbers of people affected, timescales and locations. Where possible, such predictions of residual doses following implementation of remedial actions and other protective actions relating to the remediation should be supported by site and area specific characterization data and the results of radiological monitoring programmes. In some cases, the distribution of doses could be uneven, and the representative person in such cases should be chosen with care.

6.21. Where possible, radiation doses should be estimated on the basis of the results of measurements and using models that take account of site or area specific conditions (while also noting any assumptions made in the modelling). Calculation of projected doses prior to remediation requires modelling in the context of a conceptual site or area model that depicts key sources, exposure pathways and their connections with receptors of exposure, as appropriate, and in the context of a corresponding quantitative site or area model that takes into account site and area specific factors and parameters. In general, the models used should be as realistic as possible and should be tailored to the specific needs at each phase in the remediation process. Incorporating excessive conservatism can result in a significant overestimation of radiological impacts, leading to the implementation of remedial options that are not justified and/or where protection and safety is not optimized (e.g. unnecessary resettlement of people, unnecessary restrictions on the use of resources such as water). In addition, such overstatement of risk could create unwarranted concerns and unrealistic expectations among interested parties, particularly those living in areas close to a remediation site or in an area affected by an event. Therefore, the model that is applied should be fit for purpose and capable of addressing all relevant sources and exposure pathways, using site or area specific data wherever possible. Application of a conservative screening criterion can, however, be useful as part of the preliminary evaluation phase (see Section 5), as it allows sites and areas for which remediation is not justified to be effectively screened out. Models should be tested and validated, as appropriate, taking account of variability and uncertainty (e.g. through sensitivity analysis). Particular attention should be paid to ensuring that model assumptions are relevant to the circumstances under consideration. Appendix I provides a more detailed description of dose assessment.

6.22. At the end of the detailed evaluation phase, a decision should be taken on whether remediation of the site or area is justified. Decisions on remediation should be based on the estimated long term projected dose to the public prior to remediation compared with the agreed reference level for the site or area (see paras 3.8–3.22). If the projected dose prior to remediation exceeds the reference level, then remediation is likely to be justified. The views of interested parties should be taken into account before any decisions on whether to remediate are finalized.

6.23. The information on the decision made regarding the justification of remediation should be documented (see para. 5.16) such that it can be used to support future remediation decisions and help in the identification of remedial options, as appropriate.

6.24. The results of the site or area evaluation should be submitted to the regulatory body for review. The conclusion of this regulatory review constitutes a key step in the decision making process.

7. PLANNING OF REMEDIATION

7.1. The third phase of the remediation process is planning, as shown in Fig. 1. The planning of remediation should be initiated as soon as it is decided that remediation is justified, on the basis of the detailed evaluation phase of remediation (see Section 6).

7.2. The graded approach described in para. 3.1 should be applied in the planning and implementation of remediation to determine the appropriate levels of analysis, documentation, actions and regulatory oversight such that the effort is commensurate with the risk associated with the contaminated site or area. Criteria relevant to the situation (e.g. reference level, end point criteria, end state criterion) should then be set. This process should consider the magnitude of the hazard involved and its duration, the characteristics of the site or area to be remediated, the relative importance of radiological and non-radiological impacts, and other relevant factors such as security. A graded approach facilitates the identification of the key areas to be assessed — for example, where the highest contribution to doses and risk are to be expected — such that the effort can be directed to these specific areas to minimize the overall costs of the remediation.

7.3. A systematic approach is needed to ensure that decisions regarding the appropriate remediation strategy and remedial options for the prevailing circumstances are made in a timely manner. This systematic approach should be developed in the context of the management system described in para. 4.13. The management system is required to cover the entire lifetime of the remediation (see para. 1.13 of GSR Part 2 [6]).

7.4. Remediation should be focused on the optimization of protection and safety for the public and the environment in the long term, for example, through the selection of relevant remedial options. In addition, consideration should be given to the protection strategy for a nuclear or radiological emergency [1, 9, 11], as applicable, and the remediation strategy to be implemented.

7.5. Financial resources for remediation are often limited, the work can be labour intensive and equipment costs can be high. In addition, it might be necessary to make decisions (e.g. on appropriate remedial actions to be undertaken on a site affected by a past activity) in the absence of adequate information (e.g. incomplete historical records). Therefore, the work needs to be scheduled as efficiently and effectively as possible and in a manner that avoids the need for corrective action at a later stage. Careful remediation planning helps to ensure the best use of limited available funding, especially when dealing with complex remediation situations such as those for which there is high uncertainty, a complex environment, inadequate information and/or a large number of interested parties with diverse expectations.

7.6. Early planning ensures timely identification and consideration of the many factors that might have an impact on the final outcome of remediation, such as the following:

(a) The type and extent of contamination (e.g. in groundwater, soil or surface water);
(b) The types and quantities of waste and other residual material generated;

(c) Options for the management of residual materials, including radioactive waste (see Section 9);
(d) The adequacy of financial provisions;
(e) Public opinion;
(f) Regulatory compliance;
(g) The availability of a radioactive waste disposal option;
(h) The availability of proven technologies.

7.7. Optimization of protection and safety should include the evaluation of the various factors considered for remediation within the context of the prevailing circumstances for the site or area. Timely attention to actual and perceived issues can often prevent deterioration of the situation, avoid unforeseen consequences, and allow better and more sustainable decisions to be made as the remediation proceeds, while maintaining the confidence and trust of interested parties.

7.8. In areas contaminated by past activities, it may be better to first remove localized areas of relatively high levels of contamination (e.g. discrete spots or patches of contamination; specific materials such as leaves, organic debris or dust, where contamination has concentrated) to quickly reduce the associated radiation exposures. This should be done in consultation with interested parties. Remediation strategies involving the extensive removal of materials generate large volumes of debris (such as soil and vegetation) that then need to be characterized, classified and managed accordingly (see Section 9). In comparison, remediation strategies for areas affected by an event might rely more on protective actions that are targeted at reducing the contribution of relevant exposure pathways (e.g. agricultural countermeasures[35], food restrictions, drinking water restrictions). Agricultural countermeasures might produce large volumes of biodegradable waste requiring disposal. Food restrictions will require a waste management strategy to be in place. The remediation strategy that is adopted should form the basis of the remediation plan (see para. 2.27).

7.9. Remediation planning should be based on clearly defined remediation objectives. The overall objective is to ensure the optimization of protection and safety; normally this is achieved by transitioning the site or area into a state such that the potential impacts on the public and the environment are reduced to an acceptable level. The remediation objective can be expressed both in terms of the residual dose to the public after remediation and in terms of the end

[35] A 'countermeasure' is an action aimed at alleviating the radiological consequences of an accident. Countermeasures are forms of intervention. They may be protective actions or remedial actions [10].

state, taking into account the quality of life of local residents and any eventual restrictions regarding the use of the site or area. For areas affected by an event, the remediation objective might be expressed as resumption of normal social and economic activity.

7.10. More specifically, the objective of remediation is to reduce risks until they are commensurate with the intended use of the site or area (taking into account other risks and social and economic factors). Therefore, when considering remedial options, it might not always be necessary to undertake significant remediation if the desired remediation objectives can be largely achieved through a sustainable approach involving a more moderate degree of remediation. A compromise may sometimes have to be accepted between what would otherwise have been the optimum remedial option and the option that is possible within the funding that is actually available. It is necessary to determine the best option for the available resources. This may result in a site or area requiring the imposition of restrictions, or additional institutional controls, beyond those originally envisaged.

7.11. Remediation objectives should be carefully considered, practical and achievable (in the short and long term), with consideration of potential impacts during and after remediation. Remediation objectives should be focused on the protection of humans and the environment (including flora and fauna) against radiation risks and non-radiological risks. This includes the health and safety of workers while they undertake the remediation and protection of members of the public during and after remediation. The impact on community cohesion from extended evacuation and other protection countermeasures should be considered. From an environmental protection perspective, impacts on surface water, groundwater, soil, air, flora and fauna should also be considered.

7.12. In the case of remediation following a nuclear or radiological emergency, data collected throughout the emergency exposure situation should be used, as appropriate, to develop the remediation strategy and the remediation plan.

7.13. Establishing remediation objectives is the responsibility of the persons or organizations responsible for the planning, implementation and verification of remedial actions. The responsible party should seek the early involvement of relevant interested parties (in particular, local residents); this is important in order to ensure a successful outcome.

7.14. Remediation objectives and their priority may differ depending on the origin of the contamination. For example, in a situation following a nuclear or radiological emergency, the return of the land to its previous use may be one of the most important objectives. In comparison, for areas contaminated by past activities, especially areas that are relatively remote from inhabited areas, the use of the area for economic benefit may be a more important consideration. Possible regional development planning may also have to be taken into account.

7.15. The remediation plan (see paras 7.29–7.38) should be reviewed periodically in order to take account of the actual progress and effectiveness of the remediation and any new information that has become available.

IDENTIFICATION OF REMEDIAL OPTIONS

7.16. If on the basis of the results of the detailed evaluation (see Section 6), it is determined that remediation is justified, appropriate remedial options should be identified by the responsible party.

7.17. A study to ensure the optimization of protection and safety should be performed by the responsible party to compare the respective benefits and impacts of each remedial option as part of remediation planning. This study should include the following:

(a) An assessment of available technologies and the technical feasibility of the remedial options being considered;
(b) A review of the potential safety issues (radiological and non-radiological) during and after remediation;
(c) An environmental impact assessment to assess impacts on the public and the environment;
(d) An assessment of doses to workers before, during and after remediation, as appropriate;
(e) Characterization, monitoring and sampling;
(f) The types and amounts of residual material (including radioactive waste) that will be generated;
(g) The processing, storage, transport and disposal of radioactive waste and non-radioactive waste and other residual materials (see Section 9);
(h) Estimates of the costs and other resources associated with the design and implementation of each possible remedial option;
(i) Controls that may be required after remediation (see para. 5.15 of GSR Part 3 [1]), as applicable.

7.18. Remedial options should be relevant to the prevailing circumstances and should be based on a set of credible exposure scenarios. Non-radiological risks should be taken into account, as appropriate. In some cases, non-radiological considerations might be the driving factor in the remediation process.

7.19. Input from interested parties should be sought and considered in order to identify possible remedial options.

7.20. Remedial actions might result in additional exposure of members of the public during the implementation phase of remediation, and the possibility of this should be taken into account in the process of identification of remedial options.

EVALUATION AND SELECTION OF REMEDIAL OPTIONS

7.21. Other factors that should be considered by the responsible party when undertaking evaluation, justification and optimization of protection and safety of remedial options include the following:

(a) Compliance with national laws, regulations and requirements (e.g. conditions in authorizations);
(b) The time frame for remediation and the potential for exposure to the contaminants to change during this time frame (see para. 4.9);
(c) The effectiveness of actions in the short term and in the long term, including the permanence of remedial actions;
(d) Whether actions result in a reduction in radiological, chemical and biological toxicity of waste (e.g. through radioactive decay, packaging and/or incineration);
(e) Whether actions reduce the mobility of radionuclides and other contaminants;
(f) Whether actions result in a reduction in the volume of waste generated during remediation;
(g) The availability of waste storage facilities and waste disposal facilities;
(h) Access to land and availability of resources to undertake remediation;
(i) The feasibility of remediation and the ease with which individual remedial actions can be performed;
(j) The disturbance caused to local residents during the implementation of remediation;
(k) Societal factors and the views of interested parties.

7.22. The process of undertaking the evaluation and optimization of protection and safety of remedial options is likely to involve a combination of qualitative and quantitative assessments. Where quantitative assessment is appropriate (e.g. for complex remediation), the use of tools, such as a multi-attribute decision analysis tool that weights criteria according to what is most important to interested parties, should be considered.

7.23. The living conditions of persons already residing and/or working in contaminated areas should be taken into account when considering remedial actions. Issues such as the consumption, use and trade of materials, food and commodities, and the management of residual materials, including waste (see Section 9), should also be considered.

7.24. The types and amounts of residual material (including debris and radioactive and non-radioactive waste) that could potentially be generated as a result of each remedial option should be assessed during the planning phase and taken into account in the selection of remedial options. Throughout the remediation process, the generation of large volumes of residual material (including waste) should be avoided to the extent possible.

7.25. Remedial options that result in the generation of waste with no available route for disposal or that give rise to a significant risk of unplanned release of radioactive material to the environment (e.g. liquid waste that could be spilled or that could leak into the environment when stored) should be avoided. When evaluating remedial options in terms of their potential for waste generation, the full range of residue management strategies should be evaluated, including waste minimization (see paras 9.3 and 9.4), reuse (see paras 9.22–9.24), recycling (see paras 9.22–9.24), clearance[36] (see para. 9.17) and specific clearance (see paras 9.18 and 9.19).

7.26. The optimum option (i.e. one which may involve a series of remedial actions whose form, scale and duration are optimized) should be selected on the basis of the evaluation of the remedial options and the optimization of protection and safety. It can also be beneficial to identify alternative options for implementation in the event that it is not possible to implement the optimum option.

7.27. In considering the long term effectiveness of remediation, the influence of physical, chemical, geological, climatic and other factors on the environment should be evaluated. Contamination of groundwater might not become apparent for a long time and might result in contamination being transferred a long way from the site or area. Such considerations should be documented in the site or area

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[36] Remediation is an authorized activity, and regulatory control might be removed from radioactive materials and objects located on work sites during the implementation of the remediation.

specific remediation plan, in the final remediation report and in any programme of post-remediation control measures (see Section 10).

7.28. The decision making process to select appropriate remedial options should be transparent. To build and maintain trust with interested parties (including any affected populations), the roles of different parties (e.g. the regulatory body and other authorities, the responsible party) should be clearly identified, together with the aims and objectives of the remediation plan and a process for the continued involvement of interested parties. The degree to which the results of this involvement are to be taken into account in decision making should be clearly stated in the site or area specific remediation plan.

SITE OR AREA SPECIFIC REMEDIATION PLAN

7.29. Remediation is required to be undertaken in accordance with a remediation plan[37] (see paras 5.12 and 5.14(a) of GSR Part 3 [1]). In developing the remediation plan, the reference levels established by the regulatory body or other authorities need to be taken into account. A site or area specific remediation plan should be developed by the responsible party.

7.30. The remediation plan should be based on the site or area specific remediation strategy (see para. 2.27) and should take into account the results of the preliminary evaluation phase (see Section 5) and the detailed evaluation phase (see Section 6). In the case of remediation after an event, it is important to ensure coordination as early as possible between the emergency response organizations and the responsible party for remediation.

7.31. The site or area specific remediation plan should include consideration of the following aspects:

(a) Assignment of responsibilities for all aspects of the remediation process.
(b) Selection of remedial actions applying the principle of optimization of protection and safety (e.g. ensuring that their form, scale and duration are optimized).
(c) Protection against non-radiological hazards and identification of the relevant regulatory body and other authorities for controlling these hazards.

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[37] A ‘remediation plan’ is a document setting out the various activities and actions and the timescales necessary to apply the approach and to achieve the objectives of the remediation strategy in order to meet the legal and regulatory requirements for remediation [10].

(d) Site or area security (e.g. to restrict access or unauthorized intruders, to secure residual radioactive material left on a site).
(e) Preparedness and response for an emergency during remediation.
(f) Analysis and interpretation of historical records from past activities and events, including records of inspections, as well as data on the physical and environmental conditions of the site or area.
(g) Selection and achievement of a remediation end state that provides for sustainable long term protection, while balancing any short term impacts.
(h) A formal process for the involvement of interested parties throughout the remediation process.
(i) Adoption of a graded approach such that the level of effort applied to the remediation process is commensurate with the magnitude and likelihood of exposures.
(j) A means for evaluating a range of possible remediation technologies and waste minimization technologies that might be applied.
(k) The basic approach to dose reduction — for example, the choice between actions to remove contaminated material (e.g. soil) and actions to modify the contribution of exposure pathways (e.g. through placement of engineered covers or the establishment of restrictions) — taking into account factors such as occupational exposures and public exposures, short term impacts relative to long term benefits, and the volume of radioactive waste generated.
(l) Protective actions such as access controls to prevent further exposure and to prevent the spread of contamination outside the remediation area.
(m) Any arrangements necessary, in the interests of public safety, for obtaining access to private property.
(n) The process for communication with and involvement of interested parties in decision making before and during remediation.
(o) The availability of adequate funding for the remediation, including funding for the management of residual materials, which include waste generated during remediation.
(p) Minimizing the generation of radioactive waste and managing such waste in accordance with the national framework for radioactive waste management. As part of this, use should be made of clearance levels to facilitate the reuse and recycling of remediation residues (see paras 9.17–9.24).
(q) Formal arrangements for record keeping and communication during all phases of remediation, specifying who is responsible for performing these functions at each stage, which records should be kept, to whom they should be submitted and communicated, and for how long they should be retained.
(r) Monitoring and verification of the effectiveness of the remediation plan by comparing source monitoring data and environmental monitoring data with the results of the quantitative site model.

(s) Where appropriate, a mechanism for ensuring that the approval of the regulatory body is sought prior to the implementation of each step of the remediation plan, once completion of the previous step has been verified. This mechanism should be part of a stepwise process for approval, verification and financing of the remediation, with the flexibility to review past decisions and to adjust the remediation plan, as appropriate.
(t) Provision for information and knowledge management throughout remediation and after completion of the remediation.
(u) Post-remediation monitoring, surveillance and institutional controls (e.g. access restrictions, restrictions on land use).

7.32. More detailed information should be provided in supporting documents (e.g. characterization report, safety assessment, environmental impact assessment, study evaluating remedial options with regard to optimization of protection and safety).

7.33. The process of developing a site or area specific remediation plan should take advantage of lessons from similar remediation completed in the past, whether in the State or in another State. This emphasizes the importance of establishing and maintaining a system of record keeping (see paras 8.44–8.48).

7.34. The responsible party should ensure that interested parties have a clear understanding of the remediation objectives and that these are central to any successful remediation. The means for determining when these objectives have been met should be clearly stated so that remediation is not unnecessarily continued beyond the point at which it is justified and protection and safety has been optimized.

7.35. The remediation plan should include the remediation and the necessary actions for post-remediation management, such as maintenance, monitoring and controls to enforce restrictions on land use and buildings, if applicable. Although these controls might be implemented over a very long timescale, they are part of post-remediation management and should be included in the site or area specific remediation plan.

7.36. The site or area specific remediation plan should be prepared in accordance with regulatory requirements and should demonstrate that remediation can be safely implemented. Paragraph 5.12 of GSR Part 3 [1] states:

> "The persons or organizations responsible for the planning, implementation and verification of remedial actions shall, as appropriate, ensure that…[a] remedial action plan, supported by a safety assessment, is prepared and is submitted to the regulatory body or other relevant authority for approval."

7.37. Once the regulatory body has approved the site or area specific remediation plan, the plan should be implemented as soon as practicable.

7.38. The remediation plan and supporting documents should be updated, as needed, in an iterative manner over the course of the remediation, such as when new information becomes available and in cases where the remediation is not progressing as anticipated. As the remediation progresses, the plan should be updated to reflect any significant changes relating to the implementation and progress of the remediation. Any changes to the remediation plan are subject to approval by the regulatory body (see para. 5.13(d) of GSR Part 3 [1]). However, modifications to the remediation plan should not be necessary for every operational decision (e.g. changes in the timing or implementation of remedial actions that do not change the overall outcome of the remediation plan), as this would unduly hinder the remediation progress.

EMERGENCY PREPAREDNESS

7.39. As part of the safety assessment for the remediation, the responsible party is required to identify the possible radiation risks resulting from accident conditions (see GSR Part 4 (Rev. 1) [7]) and to assess potential consequences of an emergency during the remediation (e.g. an accident during transport of radioactive material; breach of a structure, such as a dam or vessel holding radioactive material; fire). The results of this assessment should be used to identify measures for preventing accidents and to develop necessary arrangements for emergency preparedness and response as required by GSR Part 7 [9] and in accordance with the recommendations provided in IAEA Safety Standards No. GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [18], IAEA Safety Standards Series No. GS-G-2.1, Arrangements for Preparedness for a Nuclear or Radiological Emergency [20], and GSG-11 [11]. These emergency arrangements should be elaborated in the site or area specific remediation plan, which should include plans, procedures, tools, equipment, training programmes, drills and exercises, as appropriate. The responsible party for remediation should ensure that relevant procedures for responding to any emergency that might occur during the remediation are established and that all relevant personnel are aware of their assigned response functions and are trained in their fulfilment.

8. IMPLEMENTATION AND VERIFICATION MONITORING

8.1. When the site or area specific remediation plan has been approved by the regulatory body, the implementation of the selected remedial actions should be initiated to achieve a timely and progressive reduction of radiation risks. The steps to implement the remediation are as follows:

(1) Execution of the site or area specific remedial actions, including a confirmation of whether controls are required to be put into place for the remediated area (e.g. to confirm whether it is suitable for restricted use or for unrestricted use);
(2) Completion of "a final radiological survey after completion of remedial actions to demonstrate that the end point conditions, as established in the remedial action plan, have been met" (para. 5.14(d) of GSR Part 3 [1]);
(3) Verification that the remediation has been completed in accordance with the remediation plan;
(4) Preparation of a final remediation report to document the current conditions on the site or in the area following remediation to demonstrate that the end state criterion has been met;
(5) When the site or area meets the end state criterion for unrestricted use, requesting the regulatory body to approve the release of the site or area from regulatory control (see para. 3.139 of IAEA Safety Standards Series No. GSG-13, Functions and Processes of the Regulatory Body for Safety [31]).

8.2. Other considerations during this phase include the following:

(a) The management of residual materials, including radioactive waste, non-radioactive waste and materials that can be cleared for recycling or reuse (see Section 9);
(b) Assessment of the effectiveness of remedial actions and verification of the results;
(c) Involvement of interested parties.

8.3. Remedial actions should be implemented within an integrated management system (see para. 4.13). Activities for remediation, transport and waste management should be performed by properly trained and qualified individuals, in accordance with working procedures that have been established by the responsible party for remediation. Working procedures for each activity should be prepared by the responsible party in the context of the overall site or area specific remediation plan. In the development of the integrated management system, the need for the acquisition and retention of records and information relevant to the area being remediated should be emphasized.

8.4. Implementation of the remediation plan should be conducted in accordance with regulatory requirements and any conditions in the authorization granted by the regulatory body or other authorities.

8.5. The responsible party should have, or should have access to, competent staff or individuals to adequately address the following areas:

(a) Compliance with regulatory requirements and other conditions (e.g. in authorizations) specified by the regulatory body;
(b) Site and area characterization;
(c) Environmental impact assessment (including environmental modelling) and safety assessment;
(d) Radiation protection, including the integration of occupational radiation protection with other areas of occupational health and safety including industrial safety;
(e) Data collection and interpretation, uncertainty analysis and record keeping;
(f) Source monitoring, environmental monitoring and individual monitoring (see RS-G-1.8 [21]);
(g) The management system (see IAEA Safety Standards Series No. GS-G-3.1, Application of the Management System for Facilities and Activities [32]);
(h) Geological and hydrogeological processes and dynamics;
(i) Management of residual material, including radioactive waste management (see IAEA Safety Standards Series No. GSG-3, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste [33] and SSG-23 [29]);
(j) Security of the site or area;
(k) Project management;
(l) Communication and consultation with, and involvement of, the public and other interested parties;
(m) Other areas of knowledge or expertise relevant to the safe implementation of the remediation plan.

8.6. Throughout the implementation of remedial actions, the responsible party for remediation has the primary responsibility for the health and safety of workers, including any contractors engaged to perform specific tasks and functions. Non-radiological risks are likely to be present; appropriate arrangements for control, supervision and training should be provided to ensure the health and safety of workers with respect to all occupational hazards and risks.

8.7. Paragraph 5.26 of GSR Part 3 [1] states that “Employers shall ensure that the exposure of workers undertaking remedial actions is controlled in accordance with the relevant requirements on occupational exposure in planned exposure situations”. As such, the protection of workers is required to be subject to the dose limits for occupational exposure, and protection and safety is required to be optimized (e.g. through the setting of dose constraints) [1]. Recommendations on meeting the requirements for occupational radiation protection are given in GSG-7 [25].

8.8. With regard to members of the public involved in remediation activities (‘volunteers’), the regulatory body should issue guidance on the types of activity that such persons could carry out and on measures to be taken for their protection.

8.9. Persons involved in the remediation should be made familiar with the affected area, the hazards and corresponding risks that might be present, and the relevant procedures for the safe and effective performance of their duties. Specialized training may be needed in certain areas of work. For some activities, the use of training models and scenarios for training can enhance safety and efficiency. Training of all workers is an essential element of the site or area specific remediation plan.

8.10. The remediation plan may also involve self-help protective actions by affected communities [34]. For example, this could include initiatives by local residents to assist with remediation of public spaces or their own gardens, and/or with radiation monitoring, provided that adequate training is given.

8.11. The government is required to provide support for self-help protective actions (see para. 5.17(b) of GSR Part 3 [1]); this should include training in how to implement self-help protective actions and in how to make use of information about protection (e.g. on how to interpret the outcomes of self-help protective actions), and in some cases might include the provision of appropriate equipment and training in its use. Measures should also be taken to facilitate dialogue between qualified experts and the public to provide specific advice to ensure that self-help protective actions do not unnecessarily increase individual doses to participants. Self-help protective actions are addressed further in Appendix II.

8.12. Verification of the effectiveness of the remediation strategy and remediation plan is important throughout the remediation process. This involves comparison of the residual doses with the projected dose determined prior to remediation during the detailed evaluation phase of remediation (see Section 6), and verification of the measures established for their control. If the actual exposure differs significantly from the initial estimate, the plan should be revised to account for the actual conditions being experienced and mitigative measures should be put into place, as needed, to gain control over radioactive releases and to reduce exposure. In cases where the actual exposures exceed those initially estimated[38], or if there is an increasing trend in exposure, an investigation should be undertaken to improve understanding of the situation, and to prevent actual doses that are higher than anticipated or that increase over time (indicating a possible loss of control of radioactive material).

8.13. Verification is needed with respect to both occupational exposure and public exposure.

Occupational exposure

8.14. Paragraph 8.7 covers the dose limits for occupational exposure and the requirement for optimization of protection of workers.

8.15. If, during the course of remediation, unexpected radiation levels are detected, appropriate measures should be taken to ensure the health and safety of workers. Appropriate measures may include securing the area, safely stopping work as necessary, modifying plans and procedures as needed, and evaluating the new conditions. Once the new conditions have been understood, it may be necessary to revise the site or area specific remediation plan accordingly and to obtain approval from the regulatory body to restart remedial actions.

Public exposure

8.16. Any increased public exposure as a result of the implementation of remedial actions should be justified on the basis of the long term net benefit resulting from remediation. The control of exposures of members of the public resulting from

[38] The exposure initially estimated is related to the residual dose, which is the dose expected to be incurred after protective actions have been terminated (or after a decision has been taken not to take protective actions) [10].

remedial actions, including suitable monitoring, should be an integral part of the remediation plan.

MONITORING AND ONGOING SURVEYS DURING REMEDIATION

8.17. During the implementation of remedial actions, monitoring (e.g. source monitoring, environmental monitoring) will be necessary within and around the site or area being remediated to confirm that the work is proceeding in a safe manner, consistent with the remediation plan and the authorization (see RS-G-1.8 [21]). Monitoring should be undertaken to verify that remedial actions are not causing significant contamination to migrate into or out of the area where work is being conducted, that any changing or unexpected conditions are identified and addressed in a timely manner and, overall, that the regulatory requirements are being met.

8.18. Monitoring of workers and the work environment, as appropriate, to assess occupational exposure will also be required as part of the radiation protection programme (see Requirements 20 and 24 of GSR Part 3 [1]). In addition to meeting the requirements for the control of occupational exposure (see paras 8.14 and 8.15), the data collected will benefit the wider monitoring programme.

8.19. The nature and the extent of the monitoring programme should be determined during the planning of remediation (see Section 7) on the basis of the specific conditions on the site or in the area (e.g. the characteristics of the contamination, the physicochemical attributes of the site or area, the nature of the environment on and around the site or area, the local meteorological conditions) as well as the planned remedial actions.

8.20. The monitoring programme should address all potential hazards, risks and exposure pathways, and should be modified, as necessary, over the course of the implementation of remediation (e.g. on the basis of characterization and monitoring results). Examples of what should be covered by the monitoring programme include the mechanical stability of tailings dams, the release of radiological and non-radiological contaminants in the environment, the migration of contaminants in the environment (e.g. groundwater, surface water), the erosion of contaminated soil, wind-blown migration of contaminated dust and potentially many other aspects. The monitoring performed before and during remediation should be designed to provide continuity with post-remediation monitoring activities. Appropriate modelling may help in establishing an effective and cost-efficient monitoring programme.

8.21. Monitoring data should be recorded, validated and evaluated to verify compliance with regulatory requirements and the remediation objectives, and should be archived for traceability and to facilitate the analysis of trends over the longer term. This will allow an evaluation of the effectiveness of remediation, which is necessary for the management of the remediation plan and for the termination of regulatory control or other restrictions. Verified monitoring data should be used in communication with interested parties and, in conjunction with other information in support of data interpretation, for the ongoing optimization of protection and safety and updating of planned remedial actions. Several types of survey, with different objectives, may be necessary during the remediation process (e.g. detailed area characterization surveys, surveys during remediation, surveys to confirm that the objectives of the remediation have been achieved). The type, frequency, detection limit and acceptable uncertainty of each survey should be described in the site or area specific remediation plan. Provision should be made for changes in the monitoring programme in the case of a change in radiological conditions (e.g. a reduction in monitoring if the situation is stable or has improved owing to the effectiveness of remedial actions) or in cases where radiological conditions are not as anticipated (e.g. an increase in monitoring to gain additional understanding of a situation).

8.22. Procedures should be established to ensure that abnormal conditions relevant to protection and safety are reported to the regulatory body and, as appropriate, to other interested parties. Reporting levels should be developed using a graded approach in consultation with interested parties. During the implementation of remedial actions, unexpected situations may arise that necessitate adjustment of the planned activities and, in some cases, modification of the site or area specific remediation plan (subject to the approval of the regulatory body (see para. 5.14(c) of GSR Part 3 [1])).

8.23. Where self-help protective actions are to be carried out (see paras 8.10, 8.11 and 10.12), there may be a need for an ongoing evaluation of the effectiveness of such actions through a monitoring programme.

8.24. To implement a monitoring programme and ongoing surveys, suitable, functioning and calibrated equipment and trained staff to operate it and to interpret the results need to be available (see Requirements 14 and 32 of GSR Part 3 [1]). Calibration procedures for sampling and measurement equipment, developed as part of the management system, and calibration records should be maintained to ensure and to demonstrate the integrity of monitoring data.

EMERGENCY RESPONSE

8.25. The responsible party for remediation should ensure that relevant procedures to respond to any emergency that occurs during remediation are implemented in accordance with the emergency preparedness plan (see para. 7.39). In the case of such events happening during remediation, the responsible party for remediation should without delay notify the regulatory body and other relevant contact points, and, where appropriate, the public and other interested parties.

ACCESS CONTROLS TO THE SITE OR AREA

8.26. Appropriate access controls, commensurate with the identified risks, should be established and maintained in order to restrict access to the site or area throughout the remediation and in the post-remediation phase, as applicable [35, 36].

CONSIDERING THE NEED FOR FURTHER REMEDIATION

8.27. If, after the remedial actions in the remediation plan have been carried out, the established end state criterion has not been met, the responsible party should determine the next actions (e.g. additional monitoring; modification of the remediation strategy and/or remediation plan). Such options may include evaluation of whether further remediation is appropriate or whether the area should be released with restrictions. Once the next course of action has been decided, the responsible party should submit a proposal on how to proceed to the regulatory body for approval. If conditions have changed or additional information has been collected to demonstrate that further remediation is justified, the remediation process illustrated in Fig. 1 should again be followed, starting at the stage at which the remedial options are to be identified (see paras 7.21–7.28). The government should consider the review and update of the national policy and national strategy as appropriate, based on operating experience, successes and other lessons from remediation.

RELEASE OF REMEDIATED AREAS FROM REGULATORY CONTROL

8.28. Paragraph 5.14 of GSR Part 3 [1] states:

> "The person or organization responsible for carrying out the remedial actions…[s]hall perform a radiological survey after completion of remedial actions to demonstrate that the end point conditions, as established in the remedial action plan, have been met".

These end point conditions should be related to corresponding end point criteria, and ultimately to the end state criterion, to verify the effectiveness of remedial actions. The results of this survey should also be used to decide whether the established objectives of the remediation have been achieved or if additional actions are needed (see para. 10.6).

8.29. The results of the final remediation survey should be reviewed by the regulatory body to determine whether it is appropriate to release the site or area from regulatory control or from other restrictions; however, there are also other factors to consider, such as arrangements for managing the site or area, characteristics of residual materials (including radioactive waste), site and area characteristics, demographics, types of activity being undertaken on the site or in the area (e.g. an abandoned site versus a site with operating facilities where the site had not been regulated in accordance with current standards), future land uses, expectations and perceptions of interested parties, the permanence of remedial actions and the risk of non-compliance with future standards or restrictions.

8.30. The final decision by the regulatory body on how to proceed should also be based on an assessment of the future exposure of the public and a demonstration that protection and safety is optimized (i.e. further remedial actions are not required) (see para. 5.8 of GSR Part 3 [1]).

8.31. There are different possible outcomes of the remediation process:

(a) Access to and use of the site or area is unrestricted;
(b) Use of some or all of the site or area needs to be restricted and then controlled;
(c) Access to the site or area needs to be restricted and arrangements need to be put into place to enforce this.

UNRESTRICTED USE

8.32. If the objective of the remedial plan was to enable the unrestricted use of the site or area and the final remediation report demonstrates that these conditions have been met, then the site or area can be released without restrictions.

RESTRICTED USE

8.33. In cases where remediation cannot be justified, or where remediation is justified but the optimum remedial option does not produce the conditions necessary for unrestricted use, specific restrictions on the future use of the affected areas may need to be put into place. These restrictions should include controls on the removal of residual materials from the area and on the use of such materials for other purposes (e.g. use as backfill material on the remediation site or elsewhere).

8.34. A decision to impose restrictions is required to be made by the regulatory body or other authorities (see para. 5.15(c) of GSR Part 3 [1]) and should be based on an assessment of public exposures, as well as an evaluation of the justification of the restrictions being considered.

8.35. The term 'restricted use' refers to "The use of an *area* or of materials subject to restrictions imposed for reasons of *radiation protection and safety*" [10]. Some types of use may be allowed, while others are not; for example, in certain cases, the use of an area for forestry might be permitted but its use for agriculture might be prohibited. Similarly, the use of an area for recreational, industrial or certain agricultural purposes might be appropriate, but its residential use might not be.

8.36. Where a significant part of the exposure due to residual contamination arises via the food chain, the use of agricultural countermeasures, restrictions aimed at preventing fish and seafood from entering the food supply chain, drinking water advisories and/or other similar measures should be considered. The impact of the residual contamination on aquifers should also be considered. Advisories on the use of such water for the production of food or animal feed should be considered.

8.37. If remediation objectives have been met after modification or reduction of the contribution of an exposure pathway (e.g. through the installation of an impermeable barrier), the area should be released only with appropriate restrictions. These restrictions would be in the form of controls on the use of the area (e.g. to prevent activities that could affect the long term effectiveness of the remediation).

8.38. In cases of restricted use, further surveillance and monitoring may be necessary to confirm the long term effectiveness of the remediation, and controls may need to be imposed or relaxed on the basis of the monitoring results (see Section 10).

RESTRICTED ACCESS

8.39. In accordance with para. 5.15(c)(i) of GSR Part 3 [1], specific restrictions to control access by unauthorized persons to remediated areas may need to be continued after remedial actions have been completed. This would be the case, for example, where an exposure deemed significant by the regulatory body could be received over a relatively short period. The degree of any such restriction is required to be determined by the regulatory body or other authorities and will depend on the types and levels of residual contamination.

8.40. Access control measures may vary — from the placement of warning signs to the establishment of fencing or barriers of various types with controlled access points. Area control personnel, if these are considered necessary, should have the legal authority to deny access to the area.

8.41. Paragraph 5.15 of GSR Part 3 [1] states that "the regulatory body or other relevant authority…[s]hall periodically review conditions in the remediated area and, if appropriate, shall amend or remove any restrictions." These periodic reviews should also verify compliance with requirements and make amendments or changes to the authorization, as necessary, for implementation by the responsible party.

FINAL REMEDIATION REPORT

8.42. In accordance with para. 5.14(e) of GSR Part 3 [1], the responsible party is required to submit a final remediation report to the regulatory body or other relevant authority. This report should include the results of the final radiological survey in order to demonstrate that the end point criteria and end state criterion for the remediation have been met.

8.43. The regulatory body or other relevant authority should review the final remediation report and use the information that has been provided to verify the nature, extent, effectiveness and duration of any necessary post-remediation control measures.

8.44. The responsible party is required to ensure that a system for collecting and maintaining records of the actions taken for protection and safety is in place (see para. 5.12(g) of GSR Part 3 [1]). This system should be documented in the site or area specific remediation plan and implemented in accordance with the approved remediation plan.

8.45. In accordance with para. 5.10(d) of GSR Part 3 [1], the government is required to make provision for keeping records of the following:

> "[T]he nature and the extent of contamination; the decisions made before, during and after remediation; and information on verification of the results of remedial actions, including the results of all monitoring programmes after completion of the remedial actions."

8.46. The regulatory body or other authority should specify the content and retention period of records. Such records should include the following:

(a) The basis for the justification and optimization of protection and safety, and the associated decisions and selection of one or more remedial options.
(b) A description of each action carried out during the remediation.
(c) Identification of areas that were remediated and those with residual levels of contamination remaining, including the nature and extent of any remaining contamination.
(d) Specifications of any areas that remain restricted, their zoning and the restrictions that apply.
(e) Data (including the associated uncertainties) from the monitoring and surveillance programmes.
(f) Documentation of the types and quantities of residual material (including radioactive waste) that was produced during remediation, and information regarding its management and disposition. Records should include information on where the residual material was produced and the date of production, how it was treated or handled, and where and when it was stored and/or disposed of. Residual materials that were cleared (conditionally or unconditionally) from regulatory control should also be documented.
(g) Occupational health and safety records for remediation workers.
(h) Information on the methods used to verify the effectiveness of remedial actions, including the results of any monitoring undertaken for this purpose.
(i) Records of remediation costs and financial guarantees.
(j) Records of the involvement of interested parties.

(k) Documentation of the decision making process, including who was involved and the outcomes of any conflict resolution processes.
(l) Information on any continuing responsibilities for the site.
(m) A summary of the lessons identified from the remediation.

8.47. Accurate and complete information concerning the locations, configurations, types and amounts of radionuclides remaining in the area after remediation is essential and should be acquired and maintained. These records may be used to demonstrate that the remediation objectives have been met, and as a baseline for the situation post-remediation, against which to compare future surveillance records and monitoring data. The records should be made available to interested parties, as appropriate.

8.48. The regulatory framework should make provision for appropriate record keeping and maintenance of records to capture relevant information regarding the exposure situation, the remediation process and its result. This is particularly important where restrictions are imposed on access to areas and on the activities that may be conducted in such areas. A complete set of records should be maintained, so that interested parties can, in future, access information to aid any subsequent actions necessary for the removal of any restrictions imposed or to undertake additional activities in the area in a safe manner.

9. MANAGEMENT OF RESIDUAL MATERIALS GENERATED DURING REMEDIATION

9.1. In addition to the residual materials that might already be present on a site or in an area (e.g. tailings or waste rock at a uranium legacy site), the remediation of a site or area affected by a past activity or event might lead to the generation of large amounts of diverse residual materials, some or all of which might be contaminated with radionuclides. Residual materials might be generated during the different phases of the remediation process and could include the following:

(a) Residual industrial process materials such as sediments, scale, water treatment resins, mineral tailings, mineralized rock and ash from incineration;
(b) Soil and vegetation from the site or area being remediated;
(c) Contaminated liquids such as water used for decontamination, contaminated surface water and contaminated groundwater;

(d) Surface contaminated objects such as piping, tanks, heavy equipment, structural steel, buildings, tools and swabs;
(e) Contaminated clothing and personal protective equipment;
(f) Liquid and solid residues from hygiene and changing facilities;
(g) Liquid and solid residues from analyses of samples from the impacted site or area.

Residual materials, including waste, that are already present on a site or in an area, in addition to those generated during remediation, need to be managed in accordance with legal and regulatory requirements and good practices.

9.2. Radioactive waste containing high activity concentrations or nuclear material may require nuclear security measures [35, 36]. When identifying management options for such waste, the aim should be to arrange for final disposal at the earliest opportunity. This includes the identification of suitable storage and/or disposal sites and adequate financial arrangements.

9.3. Paragraph 3.131 of GSR Part 3 [1] states that “Registrants and licensees, in cooperation with suppliers, as appropriate…[s]hall ensure that any radioactive waste generated is kept to the minimum practicable in terms of both activity and volume”. All residual materials generated during remediation should be managed in accordance with a waste management hierarchy in which waste prevention is the preferred option, followed by reuse, recycling, recovery and (as a last option) safe disposal. Paragraph 1.3 of GSR Part 5 [3] states:

> “Measures to prevent or restrict the generation of radioactive waste have to be put in place in the design of facilities and the planning of activities that have the potential to generate radioactive waste. Radioactive waste may be cleared from regulatory control if it meets clearance criteria, and effluents produced during operations may be discharged if this is authorized by the regulatory body. The reuse and recycling of material is sometimes carried out as a means of minimizing the amount of radioactive waste from an activity or facility. The remaining radioactive waste from all sources that is not cleared, discharged or reused needs to be managed safely over its entire lifetime”.

9.4. Not all residual material generated during remediation will be contaminated such that it meets the definition of radioactive waste[39]. Furthermore, para. 3.29 of SF-1 [15] states that "The generation of radioactive waste must be kept to the minimum practicable level by means of appropriate design measures and procedures, such as the recycling and reuse of material". In accordance with this principle, the following step by step approach should be adopted:

(a) The need to minimize the amount of potentially hazardous residual materials generated during remediation should be recognized as an important factor to be considered when optimizing protection and safety in the design of the remediation process. This can be achieved by, for example, applying appropriate criteria (e.g. reference level, end state criterion) so the amount of material generated, and therefore requiring management, is minimized.
(b) Any material meeting the criteria for clearance, conditional use, unconditional use, disposal or release from regulatory control should be identified and managed accordingly.
(c) Any radioactive material that does not meet the criteria for clearance should be investigated for possible recycling, reuse or disposal in landfill sites, as appropriate, possibly in the affected area, if necessary, by establishing specific clearance levels (see paras 9.18 and 9.19).
(d) Any radioactive material that does not meet the criteria for clearance or specific clearance, or for which recycling, reuse or disposal landfill sites are not appropriate, should be classified as radioactive waste and managed accordingly.
(e) Management strategies for residual materials should be consistent with the national policy and strategy for radioactive waste management (see para. 2.6) and should take account of constraints on radioactive waste management in the selection of an appropriate remedial option. For example, both storage and disposal options, as well as the possible existence of different types of residual material that require different management solutions, should be considered in establishing management strategies.

9.5. Planning for remediation should take an integrated approach to the management of residual materials, including radioactive waste, throughout all phases of remediation through to disposal. This should include consideration of a range of options for materials management, including storage and disposal of residual materials on the remediation site.

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[39] 'Radioactive waste' is defined for legal and regulatory purposes as material for which no further use is foreseen that contains, or is contaminated with, radionuclides at activity concentrations greater than clearance levels as established by the regulatory body [10].

9.6. In the event of a nuclear or radiological emergency, residual materials, some of which might be contaminated and recognized as radioactive waste (see para. 9.1), might be generated from the event itself and/or the emergency response actions. Arrangements are required to be put in place for the safe and effective management of such radioactive waste arising in a nuclear or radiological emergency as part of the overall emergency preparedness (see Requirement 15 of GSR Part 7 [9]). More detailed guidance on such emergency arrangements is given in GSG-11 [11]. The long term management of residual materials arising in a nuclear or radiological emergency should be considered in the remediation plan (see Section 7).

9.7. The management of residual materials, including radioactive waste, should ensure the short term and long term protection of human health and the environment. Risks to human health and impacts on the environment arise not only from radioactive material but also from a variety of non-radiological hazards, all of which need to be taken into account in an integrated approach to protection and safety. In many cases, non-radiological hazards may be dominant, for example in the case of asbestos waste with low level tritium contamination or of phosphogypsum containing high levels of heavy metals.

9.8. Safety and security (including site security and nuclear security, as relevant) of residual materials (including radioactive waste) should be ensured during all stages of their management, using a graded approach that takes into account the radiation risks and, where appropriate, non-radiological risks [3, 4].

9.9. The volumes and characteristics of the residual materials and the feasibility of different management options should be considered. Some of these materials could be reused on-site as part of the remediation, while others would need to be disposed of (e.g. on-site, in the case of tailings on a legacy site) or safely stored (on-site or off-site, depending on the circumstances) until disposal. In some cases, it might not be possible for the material to be stored, used, processed or disposed of on-site. In such cases, it would be necessary to characterize, screen and transport the material elsewhere for recycling or reuse, or for temporary storage or disposal at a suitably authorized facility. Requirements for the transport of radioactive material are established in IAEA Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition [37].

In some cases, radioactive material might need to be transported under a special arrangement[40] (see Refs [10, 37]).

CLASSIFICATION OF RESIDUAL MATERIALS, INCLUDING RADIOACTIVE WASTE

9.10. Residual materials, including radioactive waste, should be classified and categorized to optimize protection and safety in the waste management process, with possible reuse or recycling (conditional and unconditional), predisposal management and disposal options being taken into account. The material classification scheme should take into account the levels of radionuclides in the material and their half-lives, as well as the physicochemical properties of the material and any other hazardous properties. The material should be segregated according to its classification in order to facilitate its safe management. In the case of radioactive residues, this should include arrangements for temporary storage, characterization, clearance or specific clearance (as appropriate), and disposal. The classification scheme provided in GSG-1 [17] should be considered when managing radioactive waste arising from remedial actions.

MANAGEMENT OPTIONS FOR RESIDUAL MATERIALS, INCLUDING RADIOACTIVE WASTE

9.11. The reuse or recycling of residual materials should be considered during the development of the remediation plan. A comprehensive and area-wide approach to managing residual materials (e.g. the use of materials in road construction or recovering metals for recycling) can reduce the overall costs of remediation.

9.12. The management of residual materials, including radioactive waste (e.g. for waste generated during decontamination or remediation), should take into account the available capacities for waste storage and for waste disposal. Wherever possible, the generation of waste should be minimized; however, the possibility of generating large volumes of waste can be anticipated and addressed in the strategy for waste management [12, 38].

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[40] A ‘special arrangement’ is defined as those provisions, approved by the competent authority, under which consignments that do not satisfy all the applicable requirements of SSR-6 (Rev. 1) may be transported [10, 37].

9.13. Radioactive waste should be safely stored (if needed, in the short term) and then disposed of in facilities authorized for the category of waste in question. Decisions on waste management options should be made in advance of generating residual materials. In cases where this is not possible, the decision should be made as soon as possible after the waste has been generated.

9.14. The segregation of residual materials should be based on characterization data of sufficient accuracy to permit the proper classification of the materials for clearance or specific clearance for recycling, reuse or disposal in landfill sites; this serves to minimize the amount of radioactive waste generated.

9.15. Residual materials should be sampled and characterized in terms of their physical, mechanical, chemical, radiological and biological properties, as appropriate. On the basis of this characterization, residual materials should be segregated for future management, such as treatment or disposal. The volumes and characteristics of the different types of residual material generated should be recorded to facilitate their further management.

9.16. Segregation of residual materials on the basis of characterization data is particularly important for maximizing the amount of material that can be reused or recycled, or disposed of in landfill sites. This then minimizes the volume of material to be managed as radioactive waste and helps to identify appropriate management options (see GSG-1 [17]). For example, the segregation of small volumes of contaminated soil from much larger volumes of uncontaminated soil with similar physical characteristics will allow large volumes of soil to be reused on or off the site.

CLEARANCE OF RESIDUAL MATERIALS

9.17. ‘Clearance’ is defined as the removal of regulatory control by the regulatory body from radioactive material or radioactive objects within notified or authorized facilities and activities [10]. Schedule I of GSR Part 3 [1] defines the general criteria for clearance that allow material to be released from regulatory control. The general criteria are expressed as values of individual dose, from which clearance levels, in terms of radionuclide specific activity concentrations, have been derived for the clearance of solid material without further consideration.

9.18. Paragraph I.13 of GSR Part 3 [1] allows for specific clearance to be granted by the regulatory body for specific situations. Such values are derived on the basis of the general (individual dose) criteria, taking into account the physical and chemical form of the material and its envisaged future use or means of disposal. In such cases, clearance criteria may be specified in terms of either activity concentration per unit mass or activity per unit surface area. To ensure that as much material as possible can be released from regulatory control, it may be appropriate for the regulatory body to define clearance on a case-by-case basis using the general (dose) criteria.

9.19. The concept of specific clearance[41] of a material by the regulatory body could be applied to a specific use (e.g. use of material containing low levels of radioactivity in the construction of engineered structures such as dams, berms and roads), which might necessitate ongoing surveillance of the area, restrictions on future land use and/or post-remediation controls to mitigate the risks of intrusion.

9.20. Where practicable, surface contaminated objects should be decontaminated to enable them to be approved for clearance. This should preferably be carried out at or near the remediation site or area to minimize any spread of contamination. Contamination that has been removed should be managed as radioactive waste arising from the remediation process.

9.21. Clearance of residual materials and equipment from a remediation site or area should be performed in accordance with clear, detailed and rigorous procedures under the supervision of a radiation protection officer to ensure that the material has been properly checked for compliance with the relevant clearance criteria. This process should be subject to regulatory oversight.

RECYCLING, REUSE OR LANDFILL DISPOSAL OF RESIDUAL MATERIALS IN THE AFFECTED AREA

9.22. The recycling, reuse or landfill disposal[42] of residual materials generated during remediation should be in compliance with the relevant national policies and regulatory requirements.

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[41] The concept of 'specific clearance' may be used in categorizing materials generated during remediation for recycling, reuse or disposal (e.g in landfills). For example, specific clearance levels may be developed for metals, rubble from buildings and waste for disposal in landfill sites (footnote 65 in GSR Part 3 [1]). Some Member States use the term 'conditional clearance', which is equivalent to 'specific clearance'.

[42] Landfill disposal, in this context, is different from final disposal (see paras 9.32−9.34). The former refers to disposal of non-radioactive material for which the requirements for radioactive waste management are not relevant, whereas the latter refers to the disposal of radioactive waste.

9.23. To minimize the amounts of residual material generated during remediation that require management as radioactive waste, all reasonable options that ensure an adequate level of safety to reuse or recycle these materials, or to dispose of them in landfill sites, should be investigated. If their nature allows it, residual materials may be sorted according to their radiological, chemical and/or physical properties, and decontamination could be performed wherever possible. For example, metal objects could be dismantled, segregated and decontaminated. In such a case, contaminated components should be managed as waste and components that meet clearance criteria could then be cleared and/or reused, in accordance with national regulations.

9.24. Mixing or blending of certain residual materials, as part of a processing operation, with other materials of similar characteristics (e.g. as part of construction materials for dams, roadbeds or engineered disposal facilities on the remediation site, or during ploughing of soil in agricultural fields in affected areas) might be considered, for example to minimize the generation of low level radioactive waste. This could be managed as a process of specific clearance. Such an approach could be considered when and where there is a clear benefit in enabling residual materials to be safely recycled or reused and when it is done within the context of the optimization of protection and safety.

PREDISPOSAL MANAGEMENT

9.25. 'Predisposal management' is defined as any waste management steps carried out prior to disposal, such as processing (i.e. pretreatment, treatment and conditioning), storage and transport activities [10]. Predisposal management should be carried out in accordance with the requirements established in GSR Part 5 [3], and should follow the recommendations and guidance provided in IAEA Safety Standards Series Nos SSG-40, Predisposal Management of Radioactive Waste from Nuclear Power Plants and Research Reactors [39]; SSG-41, Predisposal Management of Radioactive Waste from Nuclear Fuel Cycle Facilities [40]; SSG-45, Predisposal Management of Radioactive Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education [41]; GSG-11 [11]; RS-G-1.7, Application of the Concepts of Exclusion, Exemption and Clearance [42]; WS-G-6.1, Storage of Radioactive Waste [43]; SSG-60, Management of Residues Containing Naturally Occurring Radioactive Material from Uranium Production and Other Activities [44]; and GS-G-3.1 [32], taking account of the situation. For transport, the regulations established in SSR-6 (Rev. 1) [37] apply.

9.26. The storage of radioactive waste may be necessary in different phases of remediation, either between waste management steps or within them. In the case of very large quantities of radioactive waste, costs, logistical aspects and potential health, safety and environmental impacts often deter the transport of such waste. Consequently, such waste is often stored at the site of generation, for example in engineered surface facilities.

9.27. Moderate to large quantities of radioactive waste, with possibly high activity concentrations, might be stored at the site where the waste was generated or at another suitable site (see WS-G-6.1 [43]), in accordance with the conditions of an authorization issued by the regulatory body, until final disposal.

9.28. If radioactive waste is to be stored for significant periods of time, consideration should be given to the possibility of degradation of the waste or the waste packaging during the period of storage [43]. For example, the prolonged storage of organic material from remediation of residential or agricultural areas could create the potential for spontaneous combustion and/or the generation of flammable gases. In addition, weather conditions (e.g. heavy rain and wind, flooding, landslides), deterioration of cover sheets or bags where waste is being stored due to exposure to ultraviolet light, disruptive events (such as earthquakes), wild animals and vandalism can lead to damage to or loss of confinement of the waste. Although storage of radioactive waste may expedite the remediation process, the implications of having to move the waste to and from the storage facility should be evaluated early in the planning process.

9.29. Storage should not be considered the ultimate solution for the management of radioactive waste, for which final disposal is necessary to ensure safety and security. However, radioactive waste containing radionuclides with relatively short half-lives may be stored in a safe manner until the radioactivity has decayed to a level at which the material may either be cleared for reuse or recycling, or be disposed of as non-radioactive waste, in accordance with the national regulatory framework. In the mining context, well designed tailings management facilities might be appropriate for the long term management of high volume, low activity waste, subject to a safety assessment [44].

9.30. The processing of radioactive waste is an integral part of radioactive waste management. If waste minimization technologies or decontamination technologies are practicable, these should be applied. Further information is provided in Ref. [13].

9.31. For materials that are to be managed as radioactive waste, characterization provides assurance that the material meets the relevant waste acceptance criteria corresponding to the waste disposal options chosen and will assist in defining the proper waste management activities.

DISPOSAL

9.32. Disposal is the final step in the management of radioactive waste. The requirements for disposal are established in SSR-5 [4]. The management of most types of radioactive waste involves the concentration and/or confinement of the waste. The waste is then placed in a disposal facility with an acceptable assurance of safety and security, without the intention of retrieval. When identifying the most appropriate type of disposal facility, account should be taken of the volume, physical form, chemical characteristics and radionuclide content of the radioactive waste. In the case of remediation, the necessary disposal options might not be immediately available; however, a lack of immediate disposal options should not be the primary reason for postponing the commencement of remediation, especially for sites or areas that have been prioritized for remediation. The availability and timing of disposal and storage options should be taken into account when optimizing the remediation strategy.

9.33. It is preferable to minimize the overall 'waste disposal footprint', for example in terms of the size and number of disposal sites used. Consideration should be given to the consolidation of waste to the extent possible in order to facilitate disposal in a single disposal facility rather than in multiple facilities at various locations. Consideration should also be given to issues such as the availability of a suitable disposal facility and to the overall national framework for the long term management of radioactive waste, as set out in the national policy for radioactive waste management. Accurate records of the location and capacity of the disposal facilities used should be maintained.

9.34. The involvement of interested parties in decisions on the management of remediation residues is essential in gaining wide acceptance of the final outcome of the remediation. Local residents (including landowners) may have concerns if residual materials are left on the site or in the area, and measures should be taken by the regulatory body or other relevant authority and the responsible party to address such concerns through communication and consultation.

10. POST-REMEDIATION MANAGEMENT

10.1. Planning for post-remediation management should be initiated at the commencement of the planning of the remediation itself.

10.2. The post-remediation management phase (see Fig. 1) addresses how the remediated area should be managed once the remediation has been completed for a site or an area. The complexity of this phase will depend on whether restrictions on use or access need to be imposed and what those restrictions are. Even where there are no restrictions in place, some level of surveillance and monitoring and of involvement of interested parties may be necessary. It is important that this phase not be neglected, otherwise the full benefits of remediation might not be realized.

10.3. Post-remediation management includes the justification and implementation of any post-remediation controls, and the periodic re-evaluation of the effectiveness and robustness of the remedial actions taken. If a determination is made during re-evaluation that the action is less effective than anticipated, additional actions may be necessary.

10.4. Post-remediation controls should be implemented, where appropriate, to verify the effectiveness of remediation over time. For example, arrangements should be made by the responsible party for a qualified person to routinely inspect and sign-off on the integrity of engineered structures. Future monitoring and surveillance should be appropriate to the future land use.

10.5. Paragraph 5.17 of GSR Part 3 [1] states:

> "For those areas with long lasting residual radioactive material, in which the government has decided to allow habitation and the resumption of social and economic activities, the government, in consultation with interested parties, shall ensure that arrangements are in place, as necessary, for the continuing control of exposure with the aim of establishing conditions for sustainable living".

REMOVAL OF RESTRICTIONS

10.6. If the post-remediation control measures (in particular, the monitoring and surveillance programme) have verified the long term effectiveness of the remedial measures and that unacceptable risks to human health and unacceptable impacts on the environment have been eliminated, the regulatory body or other authority should consider removing some or all of the restrictions that have been applied to the area. This could involve a reduction of monitoring and/or surveillance, recognizing that some activities (such as the periodic inspection of engineered structures by a qualified person) will need to be carried out to perpetuity. If the option of ending or reducing these control measures is considered, the value of the monitoring and/or surveillance in gaining and maintaining public confidence should be taken into account.

10.7. Following remediation, restoration is the enhancement, creation or re-creation of environmental and community habitats. In short, the process of recovery (comprising remediation and restoration) restores a healthy and safe environment in which people can live and work.

RECORDS

10.8. Paragraph 5.10 of GSR Part 3 [1] states:

> "[T]he government shall ensure that provision is made in the framework for protection and safety for...[a]n appropriate system for maintaining, retrieval and amendment of records that cover the nature and the extent of contamination; the decisions made before, during and after remediation; and information on verification of the results of remedial actions, including the results of all monitoring programmes after completion of the remedial actions."

10.9. The records collected should be stored for a period of time as deemed appropriate by the regulatory body. This will ensure that the decisions and actions taken, as well as the results achieved, can be reviewed as needed in the future.

COMMUNICATION WITH AND INVOLVEMENT OF INTERESTED PARTIES

10.10. Communication and consultation with interested parties should continue in the post-remediation phase.

10.11. Where there are restrictions placed on the use of or access to land, communication with and involvement of interested parties will need to be ongoing. There should be a commitment documented in the site or area specific remediation plan to involving interested parties in a review of the need for restrictions and monitoring in the future, and to reviewing and amending the plan to reflect current conditions.

10.12. In some circumstances, local interested parties might adopt self-help protective actions (see paras 8.10 and 8.11) as a way of reducing radiation doses (e.g. washing crops that have been grown in their gardens, not growing certain crops). The need for and the effectiveness of these actions will need clear and careful explanation by the regulatory body or other authorities or the party responsible for remediation, depending on the prevailing circumstances. This might involve provision of training and further education to such interested parties. Too much reliance on self-help protective actions is inappropriate, given that the acceptance and implementation of these measures cannot be guaranteed, regardless of the level of interaction with interested parties. Further information on self-help protective actions is given in Appendix II.

MONITORING AND SURVEILLANCE PROGRAMME

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

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

10.14. An appropriate monitoring and surveillance programme should also be established for remediated areas in which no controls are required, to verify the long term effectiveness of remediation.

10.15. The monitoring and surveillance programme should be subject to periodic review and to approval by the regulatory body (see RS-G-1.8 [21] and GSG-13 [31]).

10.16. The extent of monitoring and surveillance should be based on the risks relating to the situation, on the associated degree of uncertainty, and on the need to verify the long term stability of radiological conditions and other relevant conditions [21]. Monitoring and surveillance programmes should be tailored to the specific situation and can include the sampling and analysis of soil, water, air, flora and fauna, including foodstuffs, for radiological and non-radiological contaminants, as well as measurement of gamma dose rates and, in some cases, individual (e.g. whole body) monitoring, if this is considered appropriate.

10.17. Decisions regarding the monitoring and surveillance programme should be documented in the site or area specific remediation plan, and the results from the programme should be documented and made readily available to interested parties to assist in gaining and maintaining public confidence (see para. 5.12(e) of GSR Part 3 [1]).

Appendix I

ASSESSMENT OF PUBLIC EXPOSURE FOR REMEDIATION PURPOSES

I.1. The contents of this appendix are partially based on the recommendations in section 7 of RS-G-1.8 [21].

I.2. The purpose of the assessment of public exposure is to decide on the necessity of remediation in areas that contain residual radioactive material due to past activities or events. The assessment of public exposure also provides information on the relative importance of the exposure pathways, which provides input for the justification of remedial actions and optimization of protection and safety in remediation planning and implementation. To avoid inappropriate allocation of resources, the estimated doses to the 'representative person' (see paras I.11–I.14) — both projected and residual doses — should be estimated as realistically as possible.

I.3. To determine annual radiation doses due to residual radioactive material, external exposures and internal exposures should be taken into account. In using the results of environmental monitoring, the pre-remediation radiation levels should be subtracted to ensure that the estimated doses are only from the residual radioactive material (i.e. from the past activity or event).

I.4. Radiation doses received by the representative person can be estimated using mathematical models that convert monitoring results into dose estimates. The models should simulate the main pathways contributing significantly to the exposure of the public.

I.5. Different models for radiological assessment, with varying degrees of complexity, exist. The level of detail and complexity of the model used should reflect the magnitude of the estimated doses, the complexity of the environment, the level of uncertainty in model predictions, the available data or the data that could reasonably be obtained, and the level of perceived risk by interested parties. The bibliography provides a list of publications with examples of the application of modelling in support of remediation planning and implementation.

I.6. To the extent possible, data from measurements of activity concentrations in environmental media (e.g. air, soil, vegetation, crops, foodstuffs, water, sediments), and from individual measurements (e.g. from whole body counting for internal dosimetry, from personal dosimeters for external dosimetry) should be used to validate model predictions.

EXPOSURE PATHWAYS

I.7. An exposure pathway defines a route of exposure from a source of radionuclides and/or radiation to a target individual (i.e. the representative person) or population through media in the environment. The main exposure pathways considered in this Safety Guide are as follows:

(a) External exposure from radionuclides deposited on the ground or other surfaces (e.g. walls, roofs and floors of buildings) and/or vegetation (e.g. trees, bushes, grass);
(b) Ingestion of radionuclides through food and drinking water;
(c) Inhalation of resuspended radionuclides deposited on the ground or other surfaces (e.g. building surfaces) that have become incorporated into the matrix of soils and dusts, or of radon emanating from such contamination.

I.8. The importance of the various exposure pathways depends on factors such as the following:

(a) The radiological properties of the material released (e.g. alpha, beta or gamma emitters; half-life);
(b) The physical and chemical properties of the radioactive material and its migration characteristics;
(c) The site specific mechanisms for dispersion and migration, and influencing factors such as meteorological conditions and environmental characteristics (e.g. climate, type of vegetation);
(d) Places of residence (which could be indoors or outdoors) and the lifestyle of the exposed individuals or population groups.

I.9. In existing exposure situations, exposure pathways are usually relatively well defined and unlikely to change rapidly. External exposure and the ingestion of agricultural and wild foodstuffs and/or drinking water containing radionuclides are typically the main contributors to public exposure.

I.10. The levels of ambient dose rate decline over time owing to the processes described in para. I.15(c). Additionally, the importance of resuspension — and therefore of the inhalation pathway — decreases with time. However, attention should be given to possible future land uses for the site, which could change the conditions of exposure and the magnitude (and relative importance) of the different pathways.

EXPOSURE GROUPS

I.11. Paragraph 5.8 of GSR Part 3 [1] states that “Reference levels shall typically be expressed as an annual effective dose to the representative person”. The representative person is an individual receiving a dose that is representative of the doses to the more highly exposed individuals in the population [10]. The ICRP has provided guidance to assist in the determination of the representative person [45].

I.12. The representative person for the remediation of a particular site or area should be selected carefully. Adequate attention should be paid to population groups with special habits, as appropriate. Their lifestyle and habits (e.g. in terms of consumption of food and drinking water) could give rise to exposure pathways and exposure levels that are unanticipated in a preliminary evaluation.

I.13. There may be different groups of ‘more highly exposed’ people for different exposure pathways, and some individuals may be members of more than one such group. In this situation, the representative person should be defined on the basis of the calculated sum of doses via all exposure pathways, which then should be compared with the reference level.

I.14. In estimating doses to representative persons, realistic lifestyle and habit data should be used in order to provide a realistic dose assessment that can be used as a basis for making decisions on remedial actions and to enable an unbiased process of optimization of protection and safety that will ensure adequate and appropriate allocation of human and financial resources. The habits used to define the representative person should be those that have recently been or are currently observed in the population, or that could reasonably be expected to be present given how the land is expected to be used in the foreseeable future. All age groups actually or likely to be present on the land should be considered when defining the habits of the representative person.

External exposure

I.15. The dose from external exposure of the representative person in existing exposure situations normally should be determined on the basis of ambient dose rate measurement data (obtained through site or area characterization and monitoring) and a simple calculation model [21]. Such calculations should consider the following:

(a) Human activities (e.g. patterns of human behaviour, including seasonal variations);
(b) Shielding from buildings;
(c) The reduction of ambient dose rates through radioactive decay, radionuclide migration into deeper soil layers and the loss of activity from surfaces through weathering;
(d) The relationship between the measured gamma dose in air and the effective dose;
(e) The seasonal variation of relevant parameters.

I.16. The more highly exposed members of the population incurring doses from external exposure in existing exposure situations usually include persons working mainly outdoors (e.g. persons working as foresters or herders and in fields) and persons living in one or two storey houses constructed of light materials (such as wood). Estimates of the typical occupancy time spent by such persons, both indoors and outdoors at various locations at different times of the year, should be obtained by conducting personal interviews.

I.17. The results of measurements of dose rates, both outdoors and indoors at various locations where a representative person would usually be, can be used directly to assess doses from external exposure. To determine the contribution of a particular radiation source or radionuclide to the dose from external exposure, in situ gamma spectroscopy can be undertaken.

I.18. As an alternative to measurement data, the levels of ground deposition of particular radionuclides can be used to estimate doses from external exposure. Through the use of radionuclide specific conversion coefficients, these data can be converted into ambient dose rate values above undisturbed ground (e.g. lawns), ploughed soil or solid surfaces (e.g. asphalt, concrete), as appropriate. Doses incurred indoors from external exposure can be estimated using shielding factors.

I.19. Model parameters accounting for the attenuation of dose rates in typical rural and urban locations (i.e. relative to a reference surface such as an infinite planar area (usually a lawn)), should be determined prior to the dose assessment, either by making a series of field measurements or by modelling the radiation attenuation conditions in settlements, dwellings and other locations, as relevant.

I.20. The uncertainties associated with the estimation of doses from external exposure can be substantially reduced if important parameters are determined through measurements and surveys, such as the shielding provided by the buildings in a specific area and the time people spend outdoors. Confidence in the dose assessment will be improved if the results can be validated through comparison with the results of individual monitoring campaigns.

Internal exposure

Ingestion

I.21. The doses to a representative person in an existing exposure situation due to the ingestion of contaminated food or drinking water can be determined on the basis of characterization data and environmental monitoring data through the use of a simple calculation model that takes account of the origin and consumption rate of food and drinking water, as well as seasonal variations in relevant parameters.

I.22. Persons consuming substantial amounts of locally produced food represent the most exposed group of a population with regard to the ingestion pathway. Monitoring data on radionuclide activity concentrations in locally produced agricultural foodstuffs can be used directly to assess the annual intake of radionuclides and the associated committed dose. In regions where the inhabitants normally consume substantial amounts of wild foodstuffs (e.g. game, fish, seafood, forest mushrooms, berries), measurements of the radionuclide activity concentrations in these foodstuffs are also needed for the estimation of intakes of radionuclides.

I.23. If data from measurements on food are unavailable or of poor quality, the activity concentrations of radionuclides in foodstuffs can be estimated approximately from data on soil deposition or radionuclide activity concentrations in water, using transfer coefficients. When transfer coefficients are used, they should be appropriate to the natural and climatic conditions, including the soil type and the mineral content of fresh water. The presence of contamination on the surface of plants, including from the interception of dusts by leaves and from the attachment of soil, should also be considered.

I.24. The ingestion model should include the major groups of foodstuffs and the drinking water expected to be consumed by the representative person. The estimated consumption rate of locally produced foodstuffs should be determined using methods to determine the total diet. For example, such methods could include the evaluation of official production and trade statistics (for the public), national dietary surveys, market basket studies and/or personal interviews (for modelling the habits of the representative person). The effects of food preparation and cooking (e.g. methods that reduce the intake of radionuclides) should also be used in estimating the doses from ingestion.

I.25. The uncertainties in the modelling of doses from internal exposure can be substantially reduced when crucial parameters are evaluated through measurements and relevant site specific corrections are introduced. The most reliable method of validation of an ingestion model is through the comparison of model predictions with an assessment of the dose from internal exposure made on the basis of data from individual measurements of radionuclide contents in the human body. Such information can be gained through performing whole body counting or analysis of the activity concentrations of radionuclides in excreta.

Inhalation

I.26. The contribution of inhalation to the dose to the representative person can be substantial for radioactive gases and vapours (e.g. tritium oxide) and for radionuclides with low solubility and low mobility in food chains (e.g. actinides, transuranic elements), especially for persons working in the open air in dusty conditions. In closed spaces with elevated concentrations of natural uranium and/or radium and inadequate ventilation, a significant dose can also be incurred due to inhalation of radon.

I.27. The dose to the representative person due to inhalation should be determined on the basis of data from the monitoring of radionuclide activity concentrations in the near surface air, if detectable, together with the use of a model that takes account of the breathing rate of persons of various ages performing various physical activities as well as seasonal variations in relevant parameters. If radionuclide activity concentrations are not detectable, then it might be necessary to estimate values or to use the lower limit of detection to estimate the dose due to inhalation.

I.28. The results of monitoring radionuclide activity concentrations in air can be used to directly assess the annual intake and the associated committed dose. If monitoring data are unavailable or insufficient, an approximate estimate of the radionuclide activity concentrations in air can be obtained from soil deposition rates using a resuspension model or dust loading measurements to determine the resuspension dose.

EVALUATION OF LONG TERM ANNUAL EFFECTIVE DOSES AFTER THE CHERNOBYL AND FUKUSHIMA DAIICHI NUCLEAR POWER PLANT ACCIDENTS

I.29. The most important radionuclide for the long term exposure of the public in areas affected by the Chernobyl accident and the Fukushima Daiichi accident is ^{137}Cs.

I.30. The deposition of ^{137}Cs results in both internal and external exposure. The contributions of these two pathways depend on many factors, such as the following:

(a) The shielding characteristics of buildings;
(b) The time people spend indoors and outdoors;
(c) The level of ^{137}Cs in crops and animal products, which is influenced by the soil characteristics (e.g. organic matter, pH value, clay content, exchangeable potassium in soil) in an affected area and by agricultural practices (e.g. use of potassium fertilizer) and animal husbandry practices;
(d) The fraction of food consumed that is produced in affected areas.

The Chernobyl accident in 1986

I.31. Following the Chernobyl accident, ^{137}Cs contributed to both internal and external exposure. The relative importance of internal and external exposure depended on the local conditions. Typically, the contribution of ingestion to the total dose tended to increase under the following circumstances:

(a) High fractions of acid soils, high in organic matter, low in clay content and low in potassium;
(b) Little or no application of potassium fertilizer;
(c) Close proximity of settlements to forest areas, leading to increased collection of mushrooms and berries, which are known to take up ^{137}Cs at higher rates;
(d) Predominant intake of locally produced foodstuffs.

I.32. Comprehensive investigations were undertaken to estimate doses to the public using modelling and individual monitoring (e.g. whole body counting, personal dosimeters). These studies covered a wide range of environmental conditions; the results provide an overview of the spectrum of annual effective doses per unit deposition. The results of these studies, for external and internal exposure, are summarized in Table I.1 and Table I.2, respectively. These tables show the estimated doses in various time periods after the accident for rural areas.

TABLE I.1. ANNUAL EFFECTIVE DOSES PER UNIT DEPOSITION DENSITY (ACTIVITY PER UNIT SURFACE AREA) OF Cs-137 FOR EXTERNAL EXPOSURE IN RURAL SETTLEMENTS OF BELARUS, UKRAINE AND THE RUSSIAN FEDERATION

Location	Year	Annual effective dose per unit deposition density for external exposure (μSv per kBq/m^2)[a]	Remark	Reference
Belarus	1995	3.5 (3.3–3.9)	Rural, official estimate, results for 24 settlements	[47]
Ukraine	1996	2.1 (2.0–2.2)	Rural, official estimate, results for 24 settlements	[47]
Russian Federation	1996	1.4 (0.7–2.7)	Rural, official estimate, results for 26 settlements	[47]
	1996	0.8 (0.3–1.7)	Rural, individual dosimetry, results for 5 settlements	[48]
Area in what is now the Russian Federation	1986	14	Estimate for adults in rural settlements	[46]
Area in what is now Ukraine	1986	24	Estimate for adults in rural settlements	[46]

[a] Median annual effective dose per unit deposition density for external exposure (range is given in parentheses).

I.33. The estimated effective doses from internal exposure are higher than the doses from external exposure in the first 10 years. Approximately 70% of the dose from external exposure was received after the first year. The proportion of the mean dose from internal exposure for residents of rural settlements received after the first year is highly dependent on the soil type, as shown in Table I.2.

TABLE I.2. ANNUAL EFFECTIVE DOSES PER UNIT DEPOSITION DENSITY (ACTIVITY PER UNIT SURFACE AREA) OF Cs-137 FOR INTERNAL EXPOSURE IN RURAL SETTLEMENTS OF BELARUS, UKRAINE AND THE RUSSIAN FEDERATION

Location	Year	Annual effective dose per unit deposition density for internal exposure (μSv per kBq/m²)[a]	Remark	Reference
Belarus	1995	0.8 (0.2–2.59)	Rural, official estimate, results for 24 settlements, predominantly consumption of locally produced foodstuffs	[47]
Ukraine (excluding Rivne region)[b]	1996	2.3 (0.7–7.1)	Rural, official estimate, results for 24 settlements, predominantly consumption of local foodstuffs	[47]
Ukraine (Rivne region)[b]	1996	9.8 (0.7–49)	Rural, official estimate, results for 24 settlements, predominantly consumption of local food stuffs	[47]
Russian Federation	1996	1.2 (0.1–4.3)	Rural, official estimate, results for 24 settlements, predominantly consumption of local foodstuffs	[47]
Area in what is now the Russian Federation	1986	10–90	Estimate for adults in rural settlements for different soil types	[46]
Area in what is now Ukraine	1986	19	Estimate for adults in rural settlements for different soil types	[46]

[a] Median annual effective dose per unit deposition density for internal exposure (range is given in parentheses).

[b] The Rivne region is characterized by a number of factors that result in high intake of Cs-137 through ingestion, such as a high fraction of acid organic soils with little potassium supply, and proximity to forests; therefore, this region is considered separately.

I.34. The variation of the dose per unit deposition density for external exposure is generally lower than for internal exposure. The values based on individual dosimetry, illustrated for rural settlements in the Russian Federation in 1996 (Table I.1), are lower, as model calculations usually apply deliberately conservative assumptions. Lower values might also be due to difficulties in obtaining realistic information on actual diets and occupancy. The values for dose per unit deposition density for internal exposure vary more widely, reflecting the influence of the environmental conditions. Doses from internal exposure estimated from whole body measurements for children showed that their long term doses from ingestion of food are usually 10–50% lower than those to adults and adolescents [46].

The Fukushima Daiichi accident in 2011

I.35. In contrast with the situation following the Chernobyl accident, where both external and internal pathways contributed significantly to the total dose, in the aftermath of the Fukushima Daiichi accident, the dose from external exposure was substantially more important than the dose from internal exposure [12]. Doses from internal exposure were largely prevented through widespread restrictions on the sale and distribution of contaminated food, supported by comprehensive monitoring of foodstuffs. Agricultural products were intensively inspected, and foodstuffs containing contamination above permissible levels were removed from sale.

I.36. The results of personal dosimetry to assess doses from external exposure of members of the public in 2012 are shown in Table I.3, along with projected effective doses from external exposure from deposition measurements in 2011 using the methodology applied in the UNSCEAR assessment of the radiological consequences of the accident [49]. The measurements are more indicative of typical exposures, while the model predictions are intended to be more representative of people who are likely to receive higher doses (i.e. the representative person). However, the doses are generally in good agreement.

I.37. Doses due to consumption of food were estimated by UNSCEAR on the basis of measurements in the environment in 2011, both with food restrictions and without, and are shown in Table I.4 [16]. The estimated doses from internal exposure include a contribution from ^{131}I in the first four months after the accident.

I.38. Whole body measurements were made of over 15 000 people in 18 municipalities between June 2011 and January 2012 [16]. The estimated radiocaesium doses from internal exposure derived from these measurements were reported to be less than 1 mSv for 99% of the people monitored.

TABLE I.3. ANNUAL EFFECTIVE DOSES FROM EXTERNAL EXPOSURE IN FUKUSHIMA PREFECTURE: COMPARISON BETWEEN PERSONAL DOSMETRY AND MODEL PROJECTIONS
(modified from table 4.2–9 in Ref. [16])

Location	Year	Annual effective dose from external exposure (mSv)	
		Measured mean[a]	Projected dose[b]
Fukushima City	2012	1.2	1.8
Fukushima City	2013	0.3	1.0
Iwaki City	2012	0.34	0.2
Tamura City	2012[c]	0.5	0.28
Tamura City	2012	0.28	0.28

[a] Extrapolated from personal dosimetry measurements made during periods of between 1 and 3 months.
[b] Projected additional dose to the representative person based on environmental measurement data from 2011.
[c] Measurement period August 2011 to January 2012.

TABLE I.4. ANNUAL EFFECTIVE DOSES FROM INTERNAL EXPOSURE OF ADULTS IN FUKUSHIMA PREFECTURE ESTIMATED BY UNSCEAR
(modified from table C17 in Ref. [49])

Time, (years)	Annual effective dose from internal exposure (mSv)		Remark
	With food restrictions	Without food restrictions	
0–1	0.06	2.0	25% of food locally produced in Fukushima Prefecture
0–10	0.14	2.1	

I.39. A survey of the radionuclide content of foods distributed nationally was carried out in Japan by purchasing foods representative of the total diet and measuring the radiocaesium content in this diet, taking into account the typical consumption rates of each food. This is known as a market basket survey. The estimated annual doses from food were in the range of 0.001–0.004 mSv/a in a study in 2012 [50] and 0.0006–0.001 mSv/a in a study in 2017 [51]. These doses are lower than a few per cent of the 1 mSv/a dose criterion on which the regulation values were based.

FLORA AND FAUNA

I.40. In the context of the remediation of areas with residual radioactive material from past activities or events, consideration should be given to the likely consequences of radiation exposure of flora and fauna. The aim is for the overall outcome to do more good than harm; for example, destroying a habitat to reduce radiation exposure does not usually provide a justified outcome. Such decisions should be made within a holistic context, as radiation exposure is often not the dominant factor in terms of the impact of remediation on flora and fauna [52].

I.41. The use of the concepts of reference animals and plants and derived criteria (see Refs [29, 53]) should be considered in circumstances where there is, or might be, an exposure that could have an impact on the structure of a population of an individual species.

I.42. The impact on the environment should be considered as one of the elements in the process of optimization of protection and safety [29]. The radiological and non-radiological impacts on the environment from remedial actions that are intended to reduce public exposure should be considered in order to determine the overall benefits gained from the remediation [53].

Appendix II

SELF-HELP PROTECTIVE ACTIONS

II.1. Paragraph 5.17 of GSR Part 3 [1] states:

> "For those areas with long lasting residual radioactive material, in which the government has decided to allow habitation and the resumption of social and economic activities, the government, in consultation with interested parties, shall ensure that arrangements are in place, as necessary, for the continuing control of exposure with the aim of establishing conditions for sustainable living".

II.2. Worldwide experience following nuclear accidents and other types of accident shows that individuals are often very unwilling to leave affected areas. In general, while authorities might want individuals to leave the affected areas to avoid excessive levels of exposure, the authorities will aim for the recovery of these areas to allow further human activities.

II.3. The involvement of people from the affected communities in remediation and recovery is a specific example of the involvement of interested parties. Referred to as 'self-help protective actions', these are actions that the public can undertake themselves (e.g. dietary changes, monitoring, decontamination), following advice by the responsible party, the regulatory body and other authorities, or the government. Such actions provide a means by which individuals can have some control over their radiation exposure, and these actions could make an important contribution to the overall success of remediation.

II.4. Self-help protective actions are more likely to be effective in situations where individuals' lifestyles are a significant factor in the exposures received. Typical self-help protective actions include limiting time in certain areas, no longer consuming certain locally produced foodstuffs (or reducing the amount consumed) and initiatives by local residents to assist with remediation of public spaces or their own gardens [13]. There are a number of approaches that can help promote such actions, including the following:

(a) Developing situation specific strategies for providing information on how people can reduce their own exposures;
(b) Providing access to personal dosimeters or other monitoring equipment and training on their use, as needed;
(c) Involving the public in decision making.

II.5. While self-help protective actions can facilitate a degree of personal control over the radiation exposures received, such actions can also disrupt normal lifestyles, and their effective implementation depends on all individuals being fully aware of the situation and well informed about the actions and the benefit they produce. If equipment is provided by the authorities, individuals should be trained in its use. This necessitates an ongoing evaluation of the effectiveness of self-help protective actions carried out at local or individual levels, in order to provide adequate support for the continuation of such actions (see para. 5.17(b) of GSR Part 3 [1]).

II.6. In the remediation of areas containing residual radioactive material from past activities or events, justification is required for all actions in the remediation plan. This includes those actions implemented by the party responsible for remediation and the regulatory body and other authorities, and self-help protective actions implemented by individuals with the support of the authorities. The remediation strategy should take into account both categories of actions and should enable affected individuals to take self-help protective actions, where these are considered appropriate.

II.7. Self-help protective actions also need coordination and human resource capacity to help people understand the radiological situation and to provide adequate training and information about protective actions. Resources need to be allocated to support self-help protective actions to ensure adequate information exchange, dialogue and community support. This helps to foster communication and facilitate active involvement by affected communities in remediation efforts, which can build trust.

II.8. Not all people will want to be involved in implementing self-help protective actions. However, such people might still want to be informed about the actions being taken to control exposures. Therefore, multiple channels and levels of communication should be employed.

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Annex I

EXAMPLE OF A TABLE OF CONTENTS FOR A SITE OR AREA SPECIFIC REMEDIATION PLAN

I–1. An example table of contents for a remediation plan (see para. 5.12 of GSR Part 3 [I–1]) is provided below. This might be used as a template for developing a site or area specific remediation plan, with appropriate modification. Headings can be deleted, or additional headings inserted, to suit the type and condition of the site or area for which the remediation is being planned.

1. Introduction
    - 1.1. Scope of remediation
    - 1.2. Remediation objectives
    - 1.3. Organization and management
        - 1.3.1. Staffing resources
        - 1.3.2. Roles and responsibilities
        - 1.3.3. Time schedule
        - 1.3.4. Coordination expectations with other organizations
2. Regulatory requirements
    - 2.1. Reference level
    - 2.2. End point criteria
    - 2.3. End state criterion
    - 2.4. Site or area security
3. Site or area history
    - 3.1. Past operations
    - 3.2. Ownership records
    - 3.3. Production and disposal records
4. Site or area characteristics
    - 4.1. Location and key features, including utilities and services above ground and below ground
    - 4.2. Local and regional demographics, current and future land uses, current and future land users
    - 4.3. Geology, seismicity and hydrogeology of site or area
    - 4.4. Surface water features and characteristics, such as wetlands, streams, rivers, lakes, ponds
    - 4.5. Groundwater features and characteristics
    - 4.6. Type of climate, meteorological conditions, seasonal characteristics, precipitation

4.7. Maps and plans (may need multiple maps and plans at various scales and aerial photos)

5. Site or area evaluation
   5.1. Detailed description of the site or area
   5.2. Review of previous site and area data
   5.3. Preliminary evaluation of data and identification of hazards
   5.4. Preliminary screening assessment of radiation exposures to compare historical and newly collected data
   5.5. Evaluation of uncertainties
   5.6. Identification of data gaps and the proposed strategy to fill gaps, as necessary
6. Site and area contamination survey
   6.1. Survey strategy
   6.2. Survey methods
   6.3. Sample analysis
   6.4. Determination of radionuclides of interest
   6.5. Determination of non-radiological contaminants of interest
   6.6. Presentation of data
7. Dose assessment
   7.1. Estimated doses to members of the public (before, during and after remediation)
   7.2. Estimated doses to remediation workers
   7.3. Radiation protection programme
      7.3.1. Protection of the public during remediation
      7.3.2. Protection of remediation workers
   7.4. Prioritization of areas for remediation
8. Assessment of non-radiological risks
   8.1. Table of non-radiological risks
   8.2. Evaluation and prioritization of risks
   8.3. Risk management strategies
   8.4. Residual risk after implementation of risk management strategies
9. Assessment of environmental impacts
10. Identification of remedial options and selection of remedial actions
   10.1. Overall objectives of the options analysis
   10.2. General approach to identifying and evaluating options
   10.3. Preliminary identification of possible remedial actions and available remediation technologies
   10.4. Screening of options
   10.5. Detailed evaluation of options
   10.6. Identification of optimum remedial option(s) (including interim actions)

10.7. Development of specific site or area work plans, including, if appropriate, emergency arrangements for dealing with any events during remediation

11. Management plan for residual materials (including radioactive waste)
    11.1. Identification and characterization of residues
    11.2. Opportunities for minimization of residues
    11.3. Residues to be cleared from regulatory control, including residues to be reused or recycled
    11.4. Residues to be disposed of in landfill sites (e.g. municipal landfills)
    11.5. Residues to be managed as conventional waste
    11.6. Residues to be managed as radioactive waste
    11.7. Processing (pretreatment, treatment, conditioning)
    11.8. Storage
    11.9. Transport
    11.10. Disposal
12. Communication and consultation with interested parties
    12.1. List of interested parties identified
    12.2. Communication and consultation
    12.3. Record of communications, consultations and involvement
    12.4. Issues and concerns raised and how these have been addressed
13. Integrated management system
    13.1. Responsibilities
    13.2. Goals, strategies, plans and objectives
    13.3. Documentation
    13.4. Management of resources
    13.5. Management of processes and activities
    13.6. Management of the supply chain
14. Preparation of final report
15. Post-remediation planning
    15.1. Long term care and maintenance, institutional control
    15.2. Monitoring and surveillance
    15.3. Monitoring schedule
    15.4. Monitoring of performance criteria
    15.5. Responsibilities for assessing monitoring data
16. Costs and financing plan

REFERENCE TO ANNEX I

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Annex II

EXAMPLES OF OPTIMIZATION OF PROTECTION AND SAFETY IN REMEDIATION AFTER THE CHERNOBYL AND FUKUSHIMA DAIICHI NUCLEAR POWER PLANT ACCIDENTS

OPTIMIZATION OF PROTECTION AND SAFETY IN REMEDIATION AFTER THE CHERNOBYL ACCIDENT

Setting reference levels

II–1. After the Chernobyl accident, reference levels[1] were chosen for each affected area. The selected value of the reference level was between the projected dose prior to remediation (i.e. the dose that would be received if planned protective actions relating to remediation were not taken) and the residual dose (i.e. the dose that would be received following the application of such actions). The projected doses prior to remediation and the estimated residual doses expected following remediation were assessed prior to the implementation of remedial actions (see, e.g., Refs [II–1 to II–5]) and also in the year that followed (to assess the effectiveness of these actions). Once the reference levels were established, they then served as a benchmark for the subsequent process of optimization of protection and safety.

II–2. The procedure used after the Chernobyl accident to determine reference levels included the following steps:

(a) For the area under consideration, the projected doses from external and internal exposure of the representative person were assessed using radiation measurements (e.g. radionuclide deposition density, dose rate, activity concentration in foods) and modelling of each significant exposure pathway (see Appendix I).
(b) For the same area, the residual doses from external and internal exposure of the representative person were assessed for each remedial option (see Appendix I). In addition, the total residual dose following the implementation of all feasible remedial actions was assessed.
(c) A reference level in terms of annual dose from external exposure was then selected within the range between the projected dose and the residual

[1] Although the term ‘reference level’ was not in use at the time of the Chernobyl accident, a similar concept was referred to as an ‘action level for intervention’.

dose from external exposure. Within this range, the actual value of the reference level was selected by taking account of the prevailing social and economic conditions (i.e. the availability of funding, public perception and other factors). A reference level in terms of annual dose from internal exposure was selected in a similar way. For affected settlements in which the reference level for the dose from external exposure exceeded 1 mSv, a reference level for the dose from internal exposure of not more than 1 mSv was selected. Both the reference level for the dose from external exposure and the reference level for the dose from internal exposure were used in the calculation of derived criteria in terms of measurable quantities, such as dose rate or activity concentration.

(d) The reference level value for the total annual dose (the sum of selected reference levels for the doses from external exposure and internal exposure) was used for the optimization of protection and safety in remediation in each affected settlement under consideration.

II–3. The procedure used to determine reference levels after the Chernobyl accident, where there was non-uniform radioactive contamination of the area and correspondingly heterogenous dose distributions, was similar to that described in paras II–14 to II−18. The projected and residual doses were assessed for each settlement under consideration, a histogram depicting the number of settlements within respective dose bands was produced, and the 95th percentiles of the projected doses prior to remediation and residual doses following remediation were defined. The reference level for the area was then selected from between the 95th percentiles of the projected and residual doses, taking account of the prevailing social and economic circumstances. In cases where the number of residents in the various settlements inside the area differed substantially from each other, population weighting was applied to take account of their population sizes.

II–4. Radiological conditions and the associated radiation doses to the public change with time owing to natural processes (e.g. radionuclide decay, migration and complexation of radionuclides in environmental media) and anthropogenic activities (e.g. agricultural activities), as well as to changes in social, economic and demographic characteristics (e.g. land use). Consequently, the exposure of the population was to be reviewed every 1–10 years, depending on the anticipated rate of change in the radiological conditions and associated doses.

Derived criteria

II–5. For operational remediation purposes, a number of derived criteria were established following the Chernobyl accident. These levels were defined in terms of measurable quantities that were relevant to the public exposure pathways — such as ambient dose rate and activity concentration in main foodstuffs and other commodities — and were calculated by means of realistic dosimetric models for a representative person residing in an affected area.

II–6. The values of the derived criteria were selected in such a way that compliance with these derived criteria would give a high probability of compliance with the reference level defined in terms of annual dose.

II–7. Derived criteria for external exposure to gamma radiation were established in terms of the ambient dose rate at a height of 1 m above the ground; these were applied in locations where people received a substantial fraction of their dose from external exposure and where the dose rate was expected to change following remediation. For example, in urban areas that were impacted by the Chernobyl accident, the rooms in single storey or two storey residential houses were used for this purpose. These derived criteria were established in terms of the measured ambient dose rate after the baseline dose rate had been subtracted.

II–8. For radionuclides in commodities (e.g. food, animal feed, construction materials), derived criteria (see paras 6.11 and 6.12) were established based on a specific reference level of 1 mSv/a. The approach that was adopted is consistent with para. 3.99 of IAEA Safety Standards Series No. GSG-8, Radiation Protection of the Public and the Environment [II–6], which states:

> "The regulatory body or other national authority should establish a process to evaluate the levels of radionuclides in food grown in the State in areas that may be affected by past activities or by a nuclear or radiological emergency, and in food imported into the State that may incorporate radionuclides arising from residual radioactive material deriving from a nuclear or radiological emergency after it has been declared ended. This process should identify radionuclides that may be of concern and should include a methodology for developing guideline levels of activity concentration for these radionuclides in food, on the basis of the specific reference level for food that does not exceed a value of about 1 mSv established by the regulatory body. While in most instances a reference level of 1 mSv or less is appropriate, there may be special circumstances where consideration of a higher value for the reference level may be appropriate, owing to local societal and economic circumstances."

II–9. After the Chernobyl accident, for ingestion of radionuclides in food, derived criteria were calculated for various International Commission on Radiological

Protection (ICRP) age groups using simple models. These models took into account the specific reference level (1 mSv/a), age dependent food consumption rates and ICRP dose coefficients for ingestion. The minimum calculated values of the radionuclide activity concentrations in food for various age groups were selected as derived criteria.

II–10. Caesium radionuclides tend to concentrate in wild foods (e.g. forest mushrooms, berries, game), and derived criteria were established for these foods; these criteria were approximately one order of magnitude higher than the derived criteria for agricultural foods because of the low consumption rate of wild foods.

II–11. Derived criteria for the inhalation of radionuclides were calculated using appropriate models.

The approach taken in the Bryansk Oblast of the Russian Federation

II–12. The procedure that was used in 2001 for determination of the reference level for the public residing in the Bryansk Oblast of the Russian Federation, an area that was severely contaminated with radionuclides following the Chernobyl accident, was based on dosimetric data obtained from extensive monitoring and modelling [II–3].

II–13. A handbook [II–7] was produced containing lists of the affected settlements, estimates of the projected doses from external exposure prior to remediation and projected doses from internal exposure prior to remediation, and the total projected doses prior to remediation for the settlements. Internal exposure was predominantly due to the consumption of local agricultural and wild foods containing ^{137}Cs. In 2001, the projected dose from both internal and external exposure exceeded 1 mSv in 445 settlements and exceeded 5 mSv in 55 settlements. The maximum dose was 11 mSv in the village of Sankovo, Zlynka district [II–3]. The ^{137}Cs contamination in the area was substantially non-uniform; the dose distribution is presented in Table II–1 and Fig. II–1 for a number of these settlements.

II–14. In the selection of the reference level and associated derived criteria, the doses to the representative person for each settlement where the projected dose prior to remediation exceeded 1 mSv were considered. The projected doses prior to remediation were taken from Ref. [II–3], and the residual doses following remediation were calculated as described in Appendix I.

II–15. For conditions in the Bryansk Oblast, for the dose from external exposure, the reduction factor (i.e. the ratio between the projected dose prior to remediation and the residual dose following remediation) due to potential decontamination was calculated to be 1.2 for settlements that had been decontaminated previously and 1.5 for other settlements [II–4]. For the dose from internal exposure, the reduction factor due to the potential application of efficient agricultural countermeasures (e.g. radical improvement of meadows and pastures) was calculated to be in the range 1.5–9, depending on the soil type, the countermeasure technologies and other factors [II–4]. Based on experience following the Chernobyl accident, for conditions in the Bryansk Oblast, the optimum remedial option corresponded to a reduction factor of 3 for the dose from internal exposure.

II–16. The dose distributions in the 445 settlements in the Bryansk Oblast with a projected dose prior to remediation of 1 mSv or higher are presented in Fig. II–1. Table II–1 presents the statistical parameters of these distributions.

TABLE II–1. STATISTICAL PARAMETERS OF THE DOSE DISTRIBUTIONS IN SETTLEMENTS OF THE BRYANSK OBLAST IN 2001

Exposure pathway	Dose category	Dose distribution (mSv)			
		Mean	Median	95th percentile	Reference level range
External	Projected[a]	0.77	0.61	1.70	1.1–1.7
	Residual[b]	0.52	0.41	1.13	
Internal	Projected[a]	1.95	1.32	4.74	1[c]
	Residual[b]	0.65	0.44	1.6	
Total	Projected[a]	2.73	2.00	6.80	2.1–2.7[c]
	Residual[b]	1.17	0.88	3.2	

[a] The projected dose category is the projected dose prior to remediation.
[b] The residual dose category is the residual dose following remediation.
[c] The maximum reference level for the dose from internal exposure was set at 1 mSv/a.

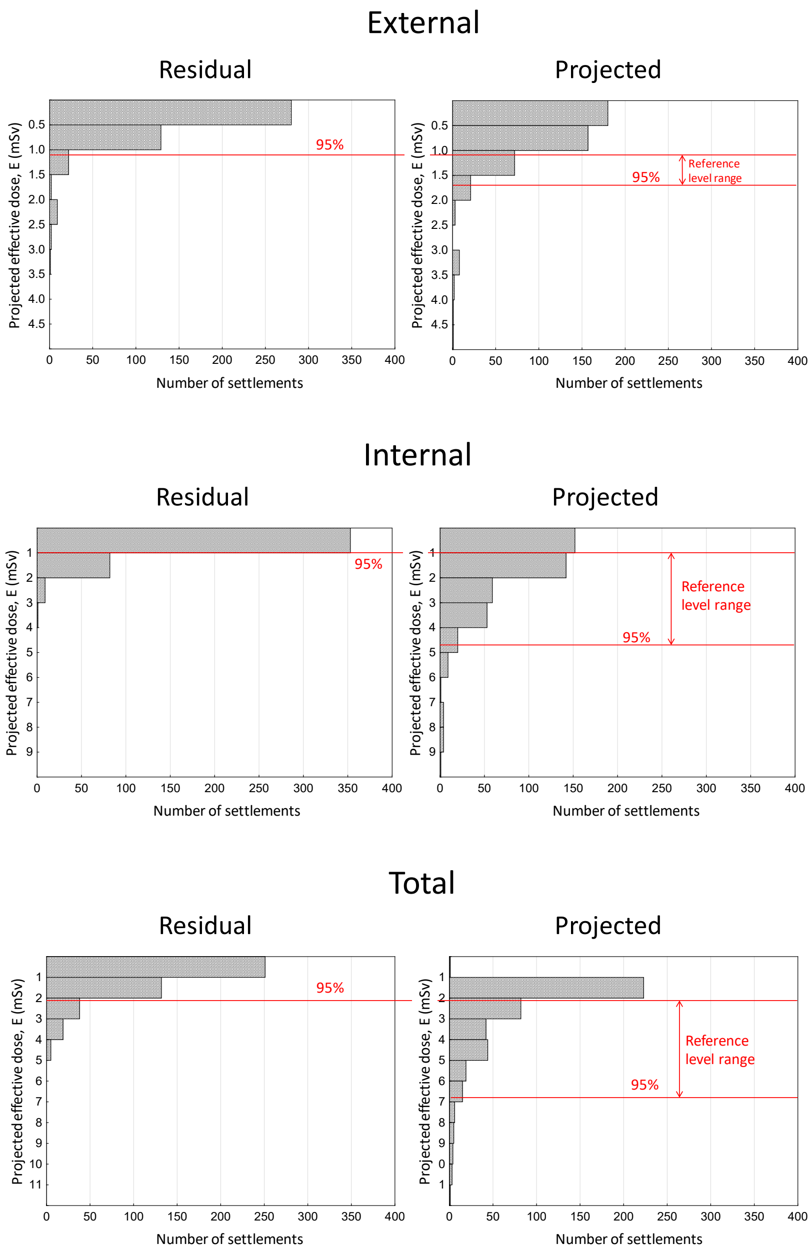

FIG. II–1. Distributions of the number of settlements in the Bryansk Oblast with projected effective dose (external, internal and total) prior to remediation in 2001 of 1 mSv or higher, based on the annual projected dose prior to remediation and annual residual dose following remediation (mSv)(adapted from Ref. [II–8]).

II–17. In Table II–1, the reference level range for the dose from external exposure was derived from the 95th percentile of the relevant dose distributions. The reference level selected for internal exposure (1 mSv/a) was consistent with the recommendations of the ICRP [II–9, II–10] and the IAEA [II–11], because the 95th percentile of the residual dose from internal exposure was substantially larger. Reference levels for external and internal exposure were used as a basis for determination of relevant derived criteria (i.e. in terms of measurable quantities).

II–18. The particular value of the reference level was selected within the range of 2.1–2.7 mSv/a on the basis of the prevailing social and economic conditions. These reference levels were used for optimization of protection and safety during remediation in the area under consideration.

OPTIMIZATION OF PROTECTION AND SAFETY IN REMEDIATION AFTER THE FUKUSHIMA DAIICHI ACCIDENT

Setting reference levels for food and drinking water

II–19. For the case of a nuclear or radiological emergency involving food and drinking water, in March 2011, Japan had developed criteria for activity concentrations in food (provisional regulation values) based on a dose of 5 mSv/a; however, these had not been implemented as regulatory limits [II–12, II–13].

II–20. Immediately after the Fukushima Daiichi accident in March 2011, as a matter of urgency, the Ministry of Health, Labour and Welfare decided, as an interim measure, to maintain the provisional regulation values for radionuclides in food and drinking water[2] [II–13].

II–21. In October 2011 the provisional regulation values for radionuclides in food were revised on the basis of the results of a health risk assessment. The dose criterion on which these derived criteria were calculated was reduced from 5 mSv/a to 1 mSv/a, taking into account the long term effects of radiation exposure from the relatively long lived radionuclides released during the accident. The revised regulation values[3] were adopted in April 2012.

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[2] The provisional regulation values for radionuclides in food are equivalent to derived criteria expressed as activity concentrations based on an annual dose criterion of 5 mSv.

[3] The revised regulation values that were adopted in April 2012 are called ‘standard limits’ in Japan. They are values for radionuclides in food and are equivalent to derived criteria expressed as activity concentrations based on an annual dose criterion of 1 mSv.

II–22. The provisional regulation values were classified into five categories (drinking water, milk and dairy products, vegetables, cereals and meat, fish and others). The revised regulation values are for four food categories: drinking water, milk, general foods and infant foods. The choice of this grouping takes into account consumption rates, the susceptibility of children to intakes of radionuclides and ease of explanation to members of the public.

II–23. The regulation values in food are set for radiocaesium, taking into account a contribution from ^{90}Sr, plutonium and ^{106}Ru. Radiocaesium accounts for the largest contribution to the dose, is most easily measured and is used as an indicator of the total dose from all the radionuclides released into the terrestrial environment. The regulation values ('standard limits') are shown in Table II–2.

II–24. The regulation value for general foods was set to be the minimum activity concentration in food that could lead to 1 mSv/a, considering the resulting doses from the consumption of food and drinking water for all age groups. Details of how the regulation values for food were set are given in Ref. [II–13].

II–25. The regulation values for foods are based on the annual dose limit of 1 mSv in line with the dose criterion underlying the Joint FAO/WHO Codex Alimentarius Commission's 'guideline levels' which apply to radionuclides contained in foods destined for human consumption and traded internationally, which have been contaminated following a nuclear or radiological emergency [II–14]. The regulation values are also intended to reduce radiation exposure to as low as reasonably achievable.

TABLE II–2. REGULATION VALUES ('STANDARD LIMITS') FOR FOOD [II–13]

Food category	Regulation value (Bq/kg radiocaesium)
Drinking water	10
Milk	50
General foods	100
Infant foods	50

Setting a reference level for the remediation of inhabited areas

II–26. An Intensive Contamination Survey Area (ICSA) was identified to include those municipalities where, in autumn 2011, the ambient dose rate in some areas exceeded 0.23 μSv/h (equivalent to a dose from external exposure of over 1 mSv/a) [II–15]. By December 2014, this designation had been lifted for 5 of the 104 designated municipalities within the ICSA owing to the reduction in dose rate from natural weathering and radioactive decay.

II–27. The ambient dose rate criterion 0.23 μSv/h was used to designate the ICSA but was not established as a target dose rate for remediation. As noted in Ref. [II–15], "an individual annual dose in addition to background of less than 1 mSv is the long term goal of the [Japanese] national Government".

II–28. The Basic Principles for Environmental Remediation contain the objectives of reducing additional annual doses to the general public and children by 50% and 60%, respectively, by August 2013 [II–16].

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Annex III

CASE STUDY FOR A POST-ACCIDENT SITUATION: REMEDIATION OF AREAS AFFECTED BY THE CHERNOBYL ACCIDENT

BACKGROUND

III–1. The accident in Unit 4 of the Chernobyl nuclear power plant was the most serious nuclear accident in history [III–1]. The accident resulted in the release of a mixture of radionuclides into the air over a period of approximately 10 days. The total release of radioactive substances was about 14 EBq[1] (as of 26 April 1986), including 1.8 EBq of ^{131}I, 0.085 EBq of ^{137}Cs and other caesium radioisotopes, 0.01 EBq of ^{90}Sr and 0.003 EBq of plutonium isotopes [III–2, III–3].

III–2. The radionuclides released were in the form of gases, condensed particles and fuel particles [III–1, III–2]. Fuel particles made up the most important part of the fallout in the close vicinity of the nuclear power plant. Radionuclides, such as ^{95}Zr, ^{95}Nb, ^{99}Mo, $^{141,144}Ce$, $^{154,155}Eu$, $^{237,239}Np$, $^{238–242}Pu$, $^{241,243}Am$ and $^{242,244}Cm$, were released in a matrix of fuel particles. More than 90% of the total activity of $^{89,90}Sr$ and $^{103,106}Ru$ released was in fuel particles [III–2, III–4, III–5].

III–3. Radiocaesium was the main contributor to radiation dose in the contaminated area around the Chernobyl nuclear power plant, except in the period during and immediately after the accident, when short lived[2] and intermediate lived[3] radionuclides were significant contributors to the exposure of the population. Therefore, the planning and implementation of remediation was based mainly on assessments of ^{137}Cs activity concentrations in the environment [III–6, III–7].

III–4. At a very early stage, on the basis of prior knowledge of radionuclide behaviour, the official demarcation of a ‘contaminated’ area was set at 37 kBq/m^2 of ^{137}Cs [III–8, III–9]. Areas with a contamination density of less than 37 kBq/m^2 were officially considered to be ‘uncontaminated’ [III–9].

III–5. Strontium-90 was the main contributor to radiation dose in the part of the 30 km exclusion zone around the Chernobyl nuclear power plant where

[1] 1 EBq is equal to 10^{18} Bq.

[2] Radionuclides with a half-life of up to 100 days.

[3] Radionuclides with a half-life of between 100 days and 10 years.

economic activities had been terminated, and in some surrounding areas of what are now Belarus and Ukraine where strict standards[4] for agricultural products were introduced [III–1]. Other radionuclides in the release did not influence the need for remediation of the contaminated areas because of their short radioactive half-life or low mobility in soil [III–6].

III–6. The areas most affected by the accident were those located in the European part of what is now the Russian Federation, and in Belarus and Ukraine. Of the total ^{137}Cs activity of approximately 64 TBq that was deposited on European territory in 1986, what are now the Russian Federation, Belarus and Ukraine received 30%, 23% and 18%, respectively. The highest levels of contamination were within 300 km of the Chernobyl nuclear power plant [III–2, III–10].

III–7. The largest areas with a deposition density above 37 kBq/m^2 were in what are now the Russian Federation (57 900 km^2), Belarus (46 500 km^2) and Ukraine (41 900 km^2). There were also some areas in Sweden, Finland, Austria, Norway, Italy, Greece, Romania and several other countries[5] where deposition densities were higher than 37 kBq/m^2 but lower than 185 kBq/m^2 [III–2, III–11, III–12].

DISCOVERY OF THE RELEASE

III–8. The release of radionuclides from the Chernobyl nuclear power plant was detected by national monitoring networks shortly after the accident commenced [III–2, III–13 to III–17]. The initial radionuclide activity concentrations in the air (e.g. radioactive isotopes of iodine) were a clear indication of a severe reactor accident and provided evidence that many areas would be contaminated by long lived radionuclides on a scale that would require remediation. This was confirmed by predictions from atmospheric dispersion modelling of radiocaesium, which took into account known information on the source term and the meteorological conditions [III–15, III–18].

[4] These included 3.7 Bq/kg dry mass or fresh mass and 5 Bq/kg being used as permissible levels for ^{90}Sr activity concentrations in bread in what are now Belarus and Ukraine, respectively.

[5] The countries mentioned are listed in order of decreasing affected area. The full list of countries can be found in Ref. [III–12].

PRELIMINARY EVALUATION

III–9. Within the first few days after the accident, emergency plans were introduced in most European countries. Airborne surveys were organized in the then Union of Soviet Socialist Republics (USSR) to identify deposition densities of gamma emitting radionuclides. Almost simultaneously, in May 1986, a large scale sampling campaign was started. This involved all the relevant national ministries, authorities and institutions that had the capability to undertake environmental sampling and radionuclide measurements [III–19].

DETAILED EVALUATION

III–10. Starting in 1986, a detailed survey[6] of the affected areas was conducted and was repeated at routine intervals thereafter to monitor any changes in the radioecological status over time in the most contaminated areas [III–19]. The sampling frequency was determined with consideration of changes in soil fertility and changes in the effectiveness of remedial options [III–20].

III–11. As early as the beginning of June 1986, maps of the density of radioactive deposition in the affected areas were prepared. It was determined that a total area of more than 150 000 km^2 had contamination densities of ^{137}Cs exceeding 37 kBq/m^2 [III–8, III–9].

III–12. In September 1986, each farm received a map of contamination levels (represented as deposition densities) on its land, with guidance on potential contamination of products, including instructions on the farming of land used by private farmers [III–19].

III–13. Based on a radiological survey performed from May to July 1986, approximately 130 000, 17 300 and 57 000 hectares of agricultural land were excluded from economic use in what are now Belarus, the Russian Federation and Ukraine, respectively [III–2, III–20, III–21]. The criterion used to define such land was that ^{137}Cs deposition exceeded 1480 kBq/m^2.

III–14. Subsequently, a detailed atlas of the ^{137}Cs deposition across Europe was produced as a product of a European Commission and Commonwealth

[6] This was a survey of every cultivated field and uncultivated meadow located in the areas contaminated above 37 kBq/m^2.

of Independent States collaboration, based on the information available in 1996 [III–12].

INVOLVEMENT OF INTERESTED PARTIES

III–15. The process of decision making for large scale remediation is extremely complex and involves many factors, such as the technical feasibility of remedial options, waste generation, costs, and ethical and ecological considerations. It was, therefore, considered appropriate to organize interactions between decision makers and other interested parties, including members of the public. The policy on the involvement of interested parties in decision making on remediation varied during different time periods following the accident [III–22]. For example, factors such as the public perception of the radiation risk or the economic situation led to changes in policy regarding the involvement of interested parties at different stages of the remediation.

III–16. The involvement of interested parties was considered at the global, national and local levels, with the involvement of relevant institutions, communities, public bodies and the media.

III–17. At the global level, four decision making conferences were organized: one in each of the affected Republics (now Belarus, Ukraine and the Russian Federation) and one at the level of the then USSR. At these conferences, relevant parties met to build a decision making model that covered the main issues and concerns of the public [III–22]. The main aims of these conferences were to identify the key socioeconomic and political issues influencing the protective actions and to illustrate the potential benefits of applying the theory of optimum management in the analysis and resolution of complex socioeconomic problems. The choice of participants was made by the then USSR and relevant Republic authorities. Each conference began with a general discussion of the key issues and concerns, a number of which were raised very often during these meetings, including those relating to the scale of the accident, health problems, stress, relocation, the lack of trust and understanding of the radiation protection authorities, and many other similar points.

III–18. Health effects originating from stress in the concerned populations and the public acceptability of remedial options were the driving forces considered in setting the main criteria to evaluate remedial strategies for the future [III–20]. Radiological consequences were found to be of secondary importance in setting criteria to evaluate remediation strategies compared with the public acceptance of remedial options.

III–19. The decision makers focused on gaining broad public acceptance of their decisions to address public concerns. In some cases, this approach led to the selection of inappropriate remedial options resulting in negligible reduction in exposures, even when decision makers were aware that these options were not justified and might have resulted in the misallocation of the scarce resources available for radiation protection [III–2, III–22]. It was, therefore, found to be very important for decision makers to inform the public of all aspects of their decisions, especially when the established levels at which actions were undertaken to reduce or avert exposure were based mainly on socioeconomic or political factors, rather than just radiation protection objectives. Without this information, the public could be misled and lose trust in radiation protection experts [III–22].

III–20. Several years after the Chernobyl accident, it was recognized that the involvement of local interested parties and the establishment of a clear and structured decision making process were needed to facilitate the selection of feasible remedial options during planning and a more effective implementation of remediation strategies and plans [III–2].

PLANNING OF REMEDIATION

Identification of remedial options

III–21. On the basis of prior information on factors governing the environmental behaviour of caesium, a wide list of possible protective actions and remedial options was developed and recommended for implementation under the environmental conditions specific to the situation following the Chernobyl accident [III–2, III–19, III–20, III–23 to III–26]. These options included a variety of decontamination techniques designed to reduce external exposure and involved the application of remedial options that were integrated with normal agricultural practices; this resulted in a reduction in external exposure. The most widespread options were normal ploughing (first year), skim and burial ploughing, liming, application of mineral fertilizers, application of organic fertilizers, radical improvement (e.g. soil removal), changes in crops used as animal feed, clean feeding, administration of caesium binders to animals, processing milk to butter and processing rapeseed to oil [III–20].

III–22. On the basis of the testing of potentially feasible protective actions and remedial options under varying environmental conditions, more than 100 remedial options were identified for possible implementation. In addition, a large amount of data on the anticipated effectiveness of the remedial options, along with information on ancillary factors such as resources, costs and technical feasibility, was derived, and the public was consulted to understand their perceptions of the remedial options [III–2, III–19, III–20, III–23 to III–26]. A summary of the estimated reduction factors for different remedial actions is provided in Table III–1.

Evaluation of remedial options

III–23. The experience gained during the first years after the Chernobyl accident has shown that remedial options need to be considered with respect to many aspects, including radiological, economic, environmental, societal and political aspects.

III–24. The evaluation of remedial options included consideration of the effectiveness of a given remedial option in reducing contamination, technical feasibility, the amounts and types of waste generated, the reduction in doses (from external and internal exposure and in total), the costs of implementation, communication and consultation needs, the possible side effects of the different options, perceptions of interested parties and constraints (e.g. legal, social, environmental) [III–27 to III–29].

III–25. There are economic and social consequences connected with the application of restrictions on access to contaminated forests, as well as the costs associated with the implementation of remedial actions [III–28].

Selection of the reference level

III–26. The distinguishing feature of the actions taken after the Chernobyl accident was the setting of a temporary dose criterion for whole body dose (which was termed a 'temporary limit of average equivalent whole body dose', in line with the terminology that was used in the then USSR at that time). This temporary dose criterion can be considered as being broadly equivalent to a reference level as currently defined (see para. 3.10). A temporary annual dose criterion of 100 mSv was set for the first year (from 26 April 1986 to 26 April 1987), followed by an annual dose criterion of 30 mSv for the second year, and of 25 mSv in 1988 and in 1989 [III–2]. These criteria were selected based on the assessments of the radiological conditions and on expert judgement.

III–27. The basic approach was to establish time dependent dose criteria that would be realistic but that also served as a driving force for remediation based on the principle of the optimization of protection and safety. Thus, the gradual reduction of these temporary dose criteria (in terms of dose) or temporary permissible levels (in terms of activity concentration) was used as a means of progressively limiting internal exposure of the public [III–2].

TABLE III–1. SUMMARY OF THE REDUCTION FACTORS OF DIFFERENT REMEDIAL ACTIONS USED IN FORMER USSR COUNTRIES [III–19]

Remedial action	Cs-137	Sr-90
Normal ploughing (first year)	2.5–4.0	—[a]
Skim and burial ploughing	8–16	—[a]
Liming	1.5–3.0	1.5–2.6
Application of mineral fertilizers	1.5–3.0	0.8–2.0
Application of organic fertilizers	1.5–2.0	1.2–1.5
Radical soil improvement		
First application	1.5–9.0[b]	1.5–3.5
Further applications	2.0–3.0	1.5–2.0
Surface soil improvement		
First application	2.0–3.0[b]	2.0–2.5
Further applications	1.5–2.0	1.5–2.0
Changes in crops used as animal feed	3–9	
Clean feeding	2–5 (time dependent)	2–5
Administration of Cs binders	2–5	—[a]
Processing milk to butter	4–6	5–10
Processing rapeseed to oil	250	600

[a] Data not available.

[b] An up to 15-fold reduction in the transfer of radiocaesium to grass occurs through the drainage of wet peat.

III–28. A long term remediation goal (equivalent to a reference level) of 1 mSv/a was set in 1990 [III–2, III–6].

III–29. A permissible level for ambient dose rate of 2.2 μSv/h, corresponding to a lifetime additional dose of 350 mSv, was implemented in 1989 to support the decontamination of rural settlements [III–30].

III–30. To support implementation of the temporary dose criteria, temporary permissible levels were also set for radionuclide activity concentrations in food and drinking water. The temporary permissible levels were approved on 30 May 1986 and were equivalent to a dose from internal exposure of 50 mSv or less. The temporary permissible levels approved in 1988 and 1991 were equivalent to doses from internal exposure of 8 mSv and 5 mSv, respectively [III–30].

III–31. The temporary permissible levels were set using expert judgement to consider the need to reduce the dose from internal exposure of the population against the need to sustain profitable agricultural production and forestry in the controlled areas (applying the principle of optimization of protection and safety). Even so, in many cases the approved levels led to high losses of foodstuffs and to a slowing down of the economic recovery in the affected regions [III–6].

III–32. Following the break-up of the USSR into different countries, including Belarus, the Russian Federation and Ukraine, each country developed its own radiation protection policy. In 1990, the ICRP recommended a dose limit of 1 mSv/a for exposure of the public [III–31]. This dose limit was recommended for practices (i.e. planned exposure situations) but was also adopted in the three most affected countries as representing a ‘safe level’ in post-emergency conditions. This level is still in use in Belarus, the Russian Federation and Ukraine, where it is defined as an ‘action level’[7] for the implementation of remediation, including long term remedial actions.

III–33. The national temporary permissible levels for food products, drinking water and wood that are applied in the three countries are comparable to each

[7] At the time of the Chernobyl accident, the setting of criteria was based on the now superseded publication INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANISATION, OECD NUCLEAR ENERGY AGENCY, WORLD HEALTH ORGANIZATION, Basic Safety Standards for Radiation Protection, Safety Series No. 9, IAEA, Vienna (1982) and on Ref. [III–32]. ‘Action level’ in this context is equivalent to the current concept of ‘reference level’ (see paras 3.10–3.15).

other and all are substantially lower than the European Union maximum permitted levels of radioactive contamination of food and feed; see Table III–2 [III–2].

Development of the remediation strategy and plan

III–34. Owing to the complicated nature of the release from the Chernobyl accident, the deposition of radionuclides was highly heterogeneous. Therefore, the classification and zoning of areas based on the deposition density (i.e. 37–185 kBq/m^2, 185–555 kBq/m^2 or 555–1480 kBq/m^2) was used to determine whether remediation was necessary and to identify the range of possible remedial options that could feasibly be implemented [III–1].

TABLE III–2. CURRENT TEMPORARY PERMISSIBLE LEVELS (Bq/kg) FOR CAESIUM IN FOOD PRODUCTS, ESTABLISHED AFTER THE CHERNOBYL ACCIDENT [III–2]

Food product	Country/region (year of adoption)			
	European Union[a] (1986)	Belarus (1999)	Russian Federation (2001)	Ukraine (1997)
Milk	370	100	100	100
Infant food	370	37	40–60	40
Dairy products	370	50–200	100–500	100
Meat and meat products	600	180–500	160	200
Fish	600	150	130	150
Eggs	600	—[b]	80	6 Bq/egg
Vegetables, fruits, potatoes, root crops	600	40–100	40–120	40–70
Bread, flour, cereals	600	40	40–60	20

[a] European Union values are levels at which actions were undertaken to reduce or avert exposure (previously called ‘intervention levels’), not temporary permissible levels [III–33].
[b] Data not available.

III–35. During the first years after the accident, the main remedial options considered were those that could be used to reduce contamination levels in animal feed. In Ref. [III–34], it was reported that 70–90% of the annual intake of ^{137}Cs could be attributed to the ingestion of milk and meat. Therefore, priority was given to the remediation of land that was used to produce animal feed, with special attention to land used for grazing.

III–36. By 1996, it was recognized that owing to the large variety of environmental conditions and exposure pathways, which depended on soil properties and agricultural practices, it was inappropriate to use identical remediation strategies for each contamination zone. This led to a need to develop economically viable, site specific, long term approaches to remediation, which are referred to here as the ‘remediation strategy’ [III–19].

III–37. Between 1996 and 2000, the European Commission supported two projects dealing with the optimization of protection and safety in remediation strategies in the long term after the Chernobyl accident. The main aim was to develop new, economically viable policies. The approach involved the classification of affected settlements into categories with similar site specific factors governing the contamination of agricultural products and the exposure of the population [III–35] (see Table III–3).

TABLE III–3. CLASSIFICATION OF AFFECTED SETTLEMENTS [III–35]

Annual dose from internal exposure (mSv/a)	Cs-137 activity per unit surface area (kBq/m^2)			
	37–185	185–370	370–555	≥555
	Annual dose from external exposure (mSv/a)			
	0.06–0.4	0.3–0.8	0.6–1.2	≥0.9
	Total annual dose (mSv/a)			
<0.5	—[a]	<1.3	0.6–1.7	≥0.9
0.5–1	0.56–1.4	0.8–1.3	1.1–2.2	≥1.4
≥1	≥1.06	≥1.3	≥1.6	≥1.9

[a] This was not included in the categories because settlements in this range could not be considered as affected so there was no need for remediation.

III–38. As shown in Table III–3, settlements were classified into 11 categories on the basis of the total annual dose (i.e. the sum of the annual dose from external exposure (contamination) and the annual dose from internal exposure). Affected settlements were further classified according to their proximity to a forest.

III–39. The effectiveness of protective actions and remedial actions was assessed with respect to their dependence on soil type and contamination level, and on the degree of previous implementation of remediation.

III–40. Further developments were based on information from the national radiological monitoring networks and an internationally agreed method for optimizing protection and safety in remediation strategies for affected areas [III–36].

III–41. Using the approach described in paras V–37 to V–40, the software tool ReSCA (Remediation Strategies after the Chernobyl Accident) for optimizing protection and safety in remediation strategies for the affected areas was developed and validated [III–37]. The tool used the most recent ICRP recommendations on radiation protection, including the concept of the representative person [III–38]. In this case, the representative person was defined on the basis of the sum of the averages of the upper 10% of the effective dose distributions from external exposure and from internal exposure. The dose estimates were validated using extensive monitoring data for soil, vegetation, agricultural products, dose rates from external exposure and whole body measurements.

III–42. The radiological effectiveness of remedial actions, expressed as a contamination reduction factor[8], was quantified. Any side effects of a given remedial option or set of options were subjectively evaluated in terms of the 'degree of acceptability'. The degree of acceptability of each remedial option was assessed on the basis of the outcome of a questionnaire sent out by the IAEA during 2003 and 2004 to the affected regions of Belarus, the Russian Federation and Ukraine. The questionnaire was distributed to interested parties, ranging from individuals living in contaminated settlements to the persons responsible for remediation planning and implementation in the affected regions.

III–43. For each affected settlement, calculations were performed to estimate the annual effective dose to the representative person. The results were then

[8] The 'contamination reduction factor' is the ratio of the concentrations of ^{137}Cs in the products of concern before and following application of the remedial option.

provided for individual farms, districts and regions, and for the area affected by the Chernobyl accident as a whole.

III–44. The efficiency of remedial options was expressed as the cost per unit of averted dose, whereas public attitude was expressed in terms of the degree of acceptability of a given remedial option. To identify priorities in the selection of remedial options and to develop a remediation plan, an optimization parameter (α) was used, as follows:

$$\alpha = \beta \frac{\min(CD)}{CD} + (1-\beta) DA_{\mathrm{r}} \quad \text{(III–1)}$$

where

β is a factor to weight preferences based on economic or social benefits (dimensionless). For a value of β equal to 1, the remedial options were ranked according to the cost per unit of averted dose, whereas for the minimum β equal to 0.01, the ranking was based mainly on the degree of acceptability of a given remedial option or set of options.
CD is the cost per unit of averted dose (euros per person-Sv).
min(CD) is the minimum cost per unit of averted dose (euros per person-Sv).
DA_{r} is the degree of acceptability (dimensionless).

The remediation plan prioritized the individual remedial options by ranking them according to the optimization parameter, α.

III–45. The remediation strategy was built sequentially as a list of separate remedial options to be considered until one of the following occurred: there were no more settlements with annual doses exceeding the annual dose criterion of 1 mSv; there were no more possible remedial actions to undertake; or the remaining possible remedial options were too costly (typically, more than €100 000 per person-Sv).

III–46. For a given input and set of model parameters, several strategies could be generated by varying the amount of available funding and/or user priorities, as expressed using parameter β to balance the cost effectiveness and the acceptability of remedial options to interested parties.

Development of remediation plans and gaining funding approvals

III–47. Remediation plans were prepared for each year following the accident on the basis of recommendations from relevant institutions (e.g. the Research Institute of Radiology in Homyel' (Belarus), the Russian Institute of Radiology and Agroecology in Obninsk, the Ukrainian Institute of Agricultural Radiology in Kyiv), and by the regional and district centres for agrochemistry and radiology. These remediation plans considered every cultivated field and uncultivated meadow within the affected territories with respect to contamination levels, land use, soil properties, and environmental and legal constraints.

III–48. The remediation plans were reviewed by the expert groups from the relevant ministries (i.e. those responsible for health and welfare, agriculture and forests) and approved by relevant governmental bodies and ministries, which were coordinating the remediation of the affected territories. The necessary funding was also reviewed and approved by the relevant governmental bodies and ministries responsible for finance and economic development.

International initiatives

III–49. Several international initiatives were taken to support the recovery of the affected territories [III–39 to III–42]. In particular, to understand the priorities of local and regional interested parties regarding the application of different remedial options, inhabitants of rural settlements and local interested parties from the most contaminated areas of what are now Belarus, the Russian Federation and Ukraine were interviewed.

III–50. In spite of some variation in the feedback from interested parties, including the affected population, it was found that options involving decontamination and ongoing restrictions were not suitable in the long term after the Chernobyl accident and that more attention needed to be given to options that promoted the local economy, which had a high acceptability to the public.

III–51. A number of European Commission and United Nations projects have applied similar considerations in trying to provide appropriate information to and interaction with people in contaminated areas. The intention of these projects was to involve people in making decisions in relation to the control of exposures and in determining what could be done to live sustainably in contaminated areas. These projects introduced the principle of self-help (see Appendix II) and provided an opportunity for people to decide for themselves whether they wished to modify their behaviour to reduce their doses, and in which ways.

III–52. The European Commission’s ETHOS project [III–39, III–40] identified the dissemination of information to foster a practical awareness of radiation protection within the population, especially among professionals in the public health area, as a prerequisite for safe living.

III–53. Between 2008 and 2010, the United Nations Cooperation for Rehabilitation (CORE) programme considered the long term sustainable development of the Brahin, Chachersk, Slawharad and Stolin districts of Belarus [III−41].

III–54. The CORE programme was focused on health care, radiation safety, information and education at the level of individual communities. Social and economic constraints were also addressed, with special attention given to the provision of a microcrediting system for small businesses and farmers, the cost effective production of ‘clean’ products, and the promotion of community economic initiatives.

III–55. The ETHOS project and CORE programme were presented to the population affected by the Chernobyl accident and other local interested parties — such as representatives of local communities, hospitals, schools and the media — as part of the communication and consultation processes. The outcomes of these initiatives, in terms of community feedback, income generation, health and well-being, can provide an indication of which approaches have proven or are proving successful, and to what extent. The holistic philosophy of these projects, considering both environmental and social issues, is in line with the United Nations initiative on a ‘Strategy for Recovery’ [III–42].

Funding and financing

III–56. Funding for remediation in the areas affected by the Chernobyl accident was entirely based on State financing through a set of USSR State programmes and, after 1990, through national State programmes on overcoming the consequences of the Chernobyl accident. These programmes included financial support for the inhabitants of the affected settlements, a variety of health programmes, improvement of the infrastructure of the affected regions and the remediation itself.

III–57. The provision of funding for remediation has been quite different in Belarus, the Russian Federation and Ukraine. In Belarus, this programme is still in force, although it is being revised each year. In the Russian Federation, support for the remediation programme at the governmental level was completed in 2015, and in Ukraine, remediation was ceased in 1991 and has not been resumed.

IMPLEMENTATION OF REMEDIATION

III–58. Since the Chernobyl accident, many remedial options have been tested and implemented. In the first 10 years after the accident, the remediation of contaminated areas was primarily focused on the amelioration of soil (through the application of 'soil based options'), aimed at reducing the transfer of radionuclides to plants, particularly those used for animal feed [III–7].

III–59. In the 37–185 kBq/m^2 zone, all previous agricultural practices were carried out without restrictions, except in areas with peat soils, which showed a high mobility of ^{137}Cs. In such cases, radical soil improvement with liming and fertilization was implemented, even where the deposition density was only 37 kBq/m^2 [III–19].

III–60. In the 185–555 kBq/m^2 zone, plant production on arable soils continued without restrictions. Soils were treated with fertilizers, which resulted in a 1.5-fold increase in the application rate of potassium and phosphorus [III–19].

III–61. Radical soil improvement on land used to produce animal feed was a key aspect of remediation after the Chernobyl accident. All natural meadows on sandy, sandy-loam and peat soils were subjected to radical soil improvement, with a 1.5-fold increase in the application rate of potassium and phosphorus fertilizers [III–19].

III–62. In the 555–1480 kBq/m^2 zone, large scale application of a wide variety of remedial options was implemented in what are now Belarus and the Russian Federation to support agricultural production (see Table V–1); however, in Ukraine, such lands were abandoned.

III–63. The use of agricultural lands in the most contaminated zone (>1480 kBq/m^2) has been prohibited in Belarus, the Russian Federation and Ukraine [III–1].

III–64. By 1994, the proportion of unacceptably contaminated agricultural products had decreased owing to the implementation of remedial actions and the effect of natural factors, and there had been a corresponding significant reduction in the internal exposure of people living in the contaminated areas [III–43].

At that time, changes were made from the temporary dose criteria (temporary dose levels and/or temporary permissible levels; ‘accident related’) to more stringent (‘routine’) dose criteria in terms of the permissible radionuclide activity concentrations in foodstuffs [III–1].

III–65. After 1994, the application of different caesium binders was found to be very effective and became one of the most widespread remedial actions taken. This then allowed animal products to be produced in highly contaminated areas. The extent to which each remedial action was applied varied between Belarus, the Russian Federation and Ukraine. The recommendations regarding the implementation of remedial actions were repeatedly revised and updated depending on changes in the radiological status of contaminated areas, economic constraints and the perceptions of interested parties, including the inhabitants of the affected settlements [III–19].

ASSESSMENT OF THE RESULTS OF REMEDIATION

III–66. As part of the justification of the remediation, preliminary assessments of the expected effectiveness and impacts of remediation were undertaken during the planning phase. Monitoring data that were collected during the implementation of the remediation were then compared with the anticipated effectiveness and impacts of remediation, and the reasons for deviations (if any) were analysed. Measures were then taken, as needed, to increase the effectiveness of further remedial actions.

III–67. Environmental monitoring during and shortly after remediation was undertaken to assess the local impacts of the remediation and the actual effectiveness of the remedial actions taken. Monitoring data were also used to identify the needs for further remediation.

III–68. In the first few years, on-site (i.e. on collective farms, at food processing plants, at markets) inspection of foodstuffs was carried out. Subsequently, areas requiring continued inspection were defined and a monitoring programme was established that defined the number, type, frequency and quantity of samples at all relevant facilities. In addition, quality management systems for both sampling and measurements were put into place.

III–69. The assessment of the effectiveness of remediation was based on a stepwise approach. First, the effectiveness of a given soil based remedial option was verified on the basis of data indicating changes in the radionuclide distribution in the topsoil. The effectiveness of remediation was then estimated on the basis of the radionuclide activity concentrations in animal feed. In the next phase, the assessment involved evaluation of the radionuclide activity concentrations in milk. Finally, whole body measurements were carried out to assess the overall effectiveness of the remediation in reducing doses from internal exposure of the public.

III–70. The post-remediation assessment of the decontamination of settlements was based on measurements of the dose rate from external exposure, performed at a minimum of five locations in each settlement.

POST-REMEDIATION ASSESSMENTS: IDENTIFICATION OF THE NEED FOR FURTHER REMEDIATION

III–71. The effectiveness of remediation was a focus of concern and was, therefore, periodically assessed by the regional centres responsible for remediation planning and for the implementation of the remediation programmes.

III–72. Soils on the agricultural land affected by the accident were periodically surveyed for levels of radionuclides. In Belarus and in the Bryansk Oblast of the Russian Federation, such surveys were conducted every 4–6 years. In Ukraine, repeated soil surveys were not performed owing to a lack of funding. Monitoring data on ^{137}Cs activity concentrations in agricultural produce and selected foods from individual settlements were also used for post-remediation assessments.

POST-REMEDIATION MANAGEMENT

III–73. The effectiveness of remediation was and remains the main focus of the appropriate authorities. The post-remediation monitoring system includes soil surveys and monitoring of agricultural products for some years after the termination of the application of remedial actions.

III–74. In Belarus, remediation was considered to be complete in a given settlement if, during the five years following the termination of the remediation, there were no instances where permissible radiation dose criteria were exceeded for agricultural products. In the Russian Federation, every five years since the completion of remediation, a new soil survey has been performed to determine whether further remediation may be needed. In addition, monitoring of agricultural products has been performed annually in the remediated settlements to make a judgement on the effectiveness of remediation [III–20].

LESSONS FROM THE REMEDIATION

III–75. The effectiveness of remediation depends on the amount of time that has passed since the deposition. The earlier the remediation strategy is developed and implemented, the more effective the results, although it is necessary to take some time to adequately characterize the situation and the prevailing circumstances to allow an informed decision to be made.

III–76. Setting achievable temporary dose criteria (broadly equivalent to reference levels) on the basis of realistic assessments of the radiological status of areas affected by an accident was an effective way to encourage the remediation of these areas.

III–77. The selection of remedial actions needs to be based not only on radiological criteria, but also on the technical feasibility and acceptability of a given action, on ethical and environmental considerations, and on the need for effective public communication and consultation (e.g. as input into the decision making process) [III–27 to III–29]. If radiological factors and socioeconomic aspects are taken into account, greater acceptability of remedial actions by the public can be achieved.

III–78. In a case of a large scale radiation accident, rural populations can receive higher radiation doses compared with populations in cities and towns because of the lower shielding factors for dwellings and the larger fraction of locally produced food that is typically consumed.

III–79. For long term remediation following a large scale nuclear accident, remediation of agricultural systems has been a more practical measure to reduce doses to the public than the decontamination of settlements aimed at reducing external exposure. This has particularly been the case owing to the importance of locally produced foods in the diet.

III–80. Even in the long term after an accident, costs per unit of averted dose are still low, representing less than €10 000 per person-Sv for the majority of the recommended remediation strategies, and it can be considered cost effective to continue applying the principle of optimization of protection and safety throughout remediation.

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Annex IV

CASE STUDY FOR A FORMER WEAPONS TESTING SITE: THE MARALINGA REMEDIATION

BACKGROUND

IV–1. Maralinga in Australia is a former military nuclear test site now under civilian control. Between 1952 and 1957, the United Kingdom (UK) conducted 12 atmospheric nuclear weapon tests — known as 'major trials' — at three sites in Australia. Of these 12 weapons, 7 were exploded at Maralinga from 1956 to 1957 and ranged in size from 1 to 25 kT. In addition, more than 600 'minor trials' were conducted on the site, resulting in the dispersal of long lived radionuclides (in excess of 8 tonnes of natural and depleted uranium and 24 kg of plutonium and associated americium from radioactive decay of ^{241}Pu) to the local environment [IV–1, IV–2].

IV–2. The 12 major trials produced contamination, in the form of fallout and neutron activation products in the immediate vicinity of the trial site. However, by 2030, the radionuclides present in the most contaminated area of the Maralinga site will have decayed to levels acceptable for permanent occupancy. The fact that the residual contamination had a radioactive half-life of 30 years or less justified the option of conducting minimal remediation while waiting for radioactive decay. Controls to restrict unsupervised access needed to be established, as appropriate, during this period and re-evaluated and adjusted, as necessary, during post-remediation management (see para. IV–33).

IV–3. The hundreds of minor trials resulted in the dispersal of highly radioactive and long lived contamination in the local environment. This contamination ranged in size from inhalable dust to collectible fragments. The land was subsequently ploughed to reduce the activity concentration by mixing in clean soil.

IV–4. In 1964, activities at the Maralinga range were suspended, pending a final decision about the site's future use, and various remedial actions were conducted, including Operation Brumby in 1967, which at the time was considered the 'final remediation' by the UK and Australian Governments. In this operation, the highest levels of plutonium contamination were found close to the firing pads at the Taranaki test site, which contained unknown quantities of plutonium. The contaminated material from this area was bulldozed into shallow pits. The highly contaminated surrounding surface areas were treated by mixing contaminated materials with uncontaminated materials to reduce the average contamination levels. Other areas that were affected by deposition from plumes were ploughed. In 1979, a discrete package of 0.4 kg of plutonium was retrieved from a burial pit and repatriated to the UK.

IV–5. Even 30 years later, beyond the ploughed area the plutonium contamination tended to remain on the surface. Within 500 m of the 12 firing pads, there were still many thousands of plutonium contaminated fragments that were large enough to attract the attention of scavengers as potential souvenirs. The types of fragment included wire, rusty steel plate, lead, pieces of a grey metal alloy of low density, bitumen and yellow Bakelite.

DISCOVERY OF THE ISSUE

IV–6. The contaminated land at Maralinga belonged to Aboriginal people who wished to resume possession and full use of the land. The Australian Government had no knowledge of any remaining problem with residual radioactive material until large numbers of particles and fragments highly contaminated with uranium, plutonium and americium were discovered on and close to the surface over a wide area during a scientific site survey in May 1984.

IV–7. As soon as the residual radioactive material was discovered, the local Aboriginal people were fully informed of the nature of the discoveries and the potential impacts [IV–3]. This was an important step, to ensure transparency and to build trust and confidence in the relevant scientific, regulatory and policy arms of the Australian Government.

IV–8. There were three important factors that encouraged action:

(a) Lifestyle issues: The local Aboriginal people had a strong desire to resume possession and full use of the contaminated lands.
(b) Political resolve: Australia established the Royal Commission into the British Nuclear Tests in Australia During the 1950s and 1960s.
(c) The radiation protection mandate of the Australian Radiation Laboratory: The Australian Radiation Laboratory had a responsibility to ensure the health and safety of the Australian population with regard to exposure to ionizing radiation. Prior to the remediation, it was determined that the possibility existed for an individual to be inadvertently exposed to enough plutonium to ultimately cause death.

PRELIMINARY EVALUATION AND DETAILED EVALUATION

IV–9. Large scale site surveys were conducted with the following objectives:

(a) To determine the nature of the hazard. Scientific studies determined the types of radionuclide present, the dose rates from external exposure, inhalation risks and the presence of contaminated particles.
(b) To characterize the contamination by means of field and laboratory studies to determine the particle size distributions, dust loadings, solubilities and chemical properties of the radionuclides present.
(c) To map the spatial extent of the contamination by means of aerial and ground based surveys.
(d) To determine the effects on the environment, including studies to examine uptake by flora and fauna.

It was determined that inhalation of plutonium was the primary radiological hazard at Maralinga.

INVOLVEMENT OF INTERESTED PARTIES

IV–10. Important steps for involving interested parties included the following:

(a) Consultation with the local population and landowners, involving local and national governments, particularly with regard to the development of the remediation reference level and the extent of remediation;
(b) Open and frank communication using non-technical but clear and easily understood language;
(c) Lifestyle (anthropological) studies to inform the modelling of exposure scenarios;
(d) Discussion with local population about their expectations for the future;
(e) Adjustment of the remediation plan on the basis of feedback from interested parties on specific aspects of the remediation;
(f) Ongoing consultation prior to, during and after the remedial actions.

PLANNING OF REMEDIATION

Identification and evaluation of remedial options

IV–11. A range of remedial options with cost estimates and timescales were defined for the remediation of Maralinga.

IV–12. A Technical Assessment Group was formed by the Australian Government to report in detail on the remedial options and associated costs. The Technical Assessment Group was not asked to recommend a particular remedial option. Rather, its task was to propose and estimate the costs of a range of remedial options — from doing nothing (apart from maintaining the existing security and surveillance) to conducting large scale remediation such that all the Maralinga lands could be permanently occupied.

IV–13. The Technical Assessment Group considered 9 main options and 26 suboptions [IV–4]. A summary of the broad scope of remedial options considered is as follows:

(a) Fencing off all plutonium contaminated areas and providing capital investment for maintaining a security presence in perpetuity.
(b) Maintenance of intrusion resistant fences; providing a warning fence around the areas of plume deposition; and either excavating, extracting and reburying the contents of the shallow disposal pits or using a variety of treatments for in situ stabilization of the pits.
(c) Fencing off the plume deposition areas, collecting and burying the soil from the heavily contaminated treated areas or implementing a remediation process to remove and concentrate the contamination for burial, together with a range of treatments for the burial pits.
(d) Minimizing the need for fencing and surveillance by mixing the contaminated surface soil in plume deposition areas with uncontaminated soil below the surface layer, thereby diluting the levels of surface contamination, or collecting and burying the contaminated soil. The cost estimate for this option also incorporated cost estimates for previously evaluated options for the creation of burial pits and the treatment of heavily contaminated areas.

IV–14. In November 1990, the Technical Assessment Group report was presented in the Commonwealth Parliament, together with a ministerial paper outlining issues the Government considered significant in identifying an optimum remedial option [IV–1].

IV–15. The Australian Government agreed, in consultation with the South Australian Government and Maralinga Tjarutja (which represented the traditional owners), on the following possible remedial options for further consideration:

— Option 1: Surrounding of the 120 km^2 contaminated area with a high chain-link fence at a cost of 13 million Australian dollars.
— Option 2: Burial of all contaminated soil collected from a 120 km^2 area at a cost of 650 million Australian dollars.
— Option 3: Combination of parts of options 1 and 2.
— Option 4: In situ vitrification or pressure grouting of the plutonium contaminated waste that was buried in shallow pits, to isolate it from the biosphere, at a cost of 20–30 million Australian dollars.

Selection of the reference level

IV–16. The prevailing circumstances in the areas of contamination at Maralinga meant that two radiation protection criteria needed to be determined on the basis of the scientific studies and agreed with the Aboriginal landowners:

(a) Dose criteria for exposures due to inhalation and due to external radiation;
(b) A practical rationale for the removal of contaminated particles.

IV–17. The criterion for remediation (also referred to as 'rehabilitation' with respect to the work conducted at the Maralinga site) established on the basis of the radiation protection system in 1990 was that, after remediation, the annual risk of fatal cancer following the inhalation and ingestion of contaminated soil was not to exceed 1 in 10 000 by the 50th year of exposure. This level of risk equated to an annual dose of 5 mSv for 50 years from birth. For earlier years (i.e. before 50 years would have elapsed), the annual risk associated with an annual dose of 5 mSv was less than 1 in 10 000 [IV–1, IV–4].

IV–18. Studies of dust resuspension and particle sizes showed that the expected dose to the critical group[1] (Aboriginal children living a semi-traditional lifestyle) from inhalation assuming 100% occupancy would not exceed 5 mSv/a for soil contamination below 3 kBq/m^2 of ^{241}Am under highly conservative assumptions (^{241}Am was used as a proxy for plutonium). By limiting occupancy factors to those typical of hunting activities in a particular location, the maximum doses would not exceed 5 mSv/a for soil contamination levels of up to 40 kBq/m^2 of

[1] The term 'critical group' was the common terminology during the time of remediation at Maralinga. This term has since been superseded by 'representative person' (see paras I.11–I.14).

^{241}Am. This soil contamination level became the important ‘remediation action level’[2] guiding the day-to-day remedial actions at Maralinga.

IV–19. The pragmatic criteria that were agreed for removal of radioactive particles and fragments were as follows:

(a) No particles or fragments with an ^{241}Am activity exceeding 100 kBq were to remain.
(b) Remaining particles with an ^{241}Am activity exceeding 20 kBq were not to exceed a surface density of 1 particle per 10 m^2.

IV–20. During consultation with interested parties on the remediation criteria, the following issues were raised:

(a) The area of 120 km^2 is contaminated to the extent that it exceeds the 5 mSv/a criterion, but only on the assumption of 100% occupancy.
(b) Remedial actions need to take account of the cost.
(c) A strong message from the Aboriginal landowners was that complete removal of vegetation and soil was to be avoided because of the environmental damage.
(d) Only the areas with the highest levels of contamination were to be treated by soil removal; the remaining 120 km^2 area was to be designated for restricted use as a ‘non-residential area’ and marked at regular intervals with signs to indicate that the area was suitable for hunting but not for camping.

Development of the remediation strategy and remediation plan

IV–21. For the agreed remediation strategy, the elements of the adopted remediation plan [IV–5] at a cost of 110 million Australian dollars included the following:

(a) A 120 km^2 non-residential area:
    (i) A non-residential area was established comprising those areas in which the expected annual dose via inhalation to the representative person — Aboriginal children living a semi-traditional lifestyle (assuming 100% occupancy at Maralinga) — exceeded 5 mSv/a.
    (ii) Within this non-residential area, transitory activities, such as hunting and travel, are permitted; however, routine use is discouraged through

[2] The term ‘remediation action level’ is equivalent to the term ‘derived criterion’ in this Safety Guide. See also para. 3.27.

the removal of some defined access routes and by revegetation of some areas. Alternative routes, passing around the area, were improved to encourage their use.

(b) Soil and particle removal:

(i) Within the non-residential area, close to the Taranaki test site, short duration visits prior to the remediation, particularly if they involved dust resuspension and high breathing rates, could still have given rise to unacceptably high doses. Moreover, the presence of highly active fragments and particles increased the likelihood of the intentional collection of plutonium and made the contamination of wounds, by either deliberate or inadvertent contact, a potentially significant exposure pathway. Such hazards are difficult to quantify.

(ii) It was agreed that the contaminated soil, along with contaminated debris, from areas where ^{241}Am activities exceeded 40 kBq/m^2 (averaged over one hectare) would be removed. Areas at Maralinga totalling approximately 2.3 km^2 were treated by removal of surface soil[3]. The need to satisfy the criteria relating to contaminated particles and fragments (see para. IV–19) meant that the maximum dose due to inhalation of contaminated dust would, in fact, be lower than otherwise expected at the largest contaminated area and the site with the highest levels of plutonium contamination at Maralinga (the Taranaki test site).

(iii) With regard to dispersed activity, contaminated soil at the Taranaki test site was removed to achieve contamination densities of less than 3 kBq/m^2 (averaged over one hectare). One reason for this approach was that if lower levels for the remediation boundary were recommended in future, it would be unlikely that further removal of soil from the area already remediated would be necessary.

(c) Burial pits and disposal trenches:

(i) Half the legacy disposal pits at the Taranaki test site were treated by in situ vitrification and the other half were excavated and the contents buried on the site in a purpose-built trench.

(ii) A near surface disposal trench was constructed on the Taranaki test site to dispose of contaminated surface soil. The trench dimensions were 140 m × 200 m, with a depth of 15 m. A minimum depth of 5 m of clean fill was placed on top of the contaminated soil. The volume used for disposal of contaminated soil was approximately 263 000 m^3.

[3] Surface soil was collected from a minimum depth of 100 mm, to an average depth of 150 mm [IV–6].

Obtaining regulatory and landowner approvals for the remediation strategy and the remediation plan

IV–22. The process of obtaining regulatory and landowner approvals for the remediation strategy and the remediation plan included obtaining agreement on and approvals for the following:

(a) The overall dose criterion (i.e. 5 mSv/a, assuming 100% occupancy at Maralinga);
(b) The means of meeting the overall dose criterion (e.g. soil removal and disposal, detection and removal of contaminated particles and fragments, restrictions on land use);
(c) Verification and sign-off of cleared areas;
(d) Disposal options for contaminated soil;
(e) Protection of remediation workers, including mechanisms for dust suppression during soil removal.

Obtaining funding and financing

IV–23. The process for the establishment of financing arrangements included the following:

(a) Negotiations with the UK Government, which resulted in a payment of approximately 35 million Australian dollars towards remediation;
(b) The decision for the remainder of the cost of the remediation (109 million Australian dollars) to be paid by the Australian Government;
(c) The decision for Australia to compensate the Maralinga Tjarutja with 13.5 million Australian dollars for the restrictions placed on the use of their land;
(d) The settlement of compensation claims by individuals for harm associated with the nuclear weapon tests.

IMPLEMENTATION OF REMEDIATION

IV–24. In line with the agreed remediation criteria, remediation boundaries were determined as follows:

(a) The boundaries for soil removal were determined by measuring the levels of relevant radionuclides by ground and aerial surveys [IV–7].

(b) Contaminated particles and fragments with an ^{241}Am activity exceeding 100 kBq were detected using a vehicle fitted with an array of radiation detectors and using analysis software. The locations of detected particles were logged using the GPS.
(c) The surface density of particles with an ^{241}Am activity exceeding 20 kBq was determined by using an approach similar to that used to determine the presence of contaminated particles and fragments.

IV–25. Remedial actions included the following:

(a) Zoning of the soil removal areas into individual areas of 3–4 hectares;
(b) Removal of surface soil using heavy duty scrapers;
(c) Collection of soil and contaminated fragments, which were then placed in the excavated disposal trench.

ASSESSMENT OF THE RESULTS OF REMEDIATION

IV–26. Monitoring for purposes of verification [IV–8] was performed on remediated areas, which included the following:

(a) A search for highly localized contamination (including contaminated fragments) using hand-held monitoring equipment and, if necessary, removal of such contamination;
(b) Surveys of remediated areas of land by high resolution gamma ray spectrometry measurements taken on a square grid with approximately 35 m spacing.

IV–27. The measurements taken at the Taranaki test site indicated that any remaining contamination would be less than 3 kBq/m^2 averaged over one hectare to meet the remediation criterion for release from regulatory control.

IV–28. Any remaining contaminated particles and fragments exceeding the remediation criteria were removed before a given area was issued a ‘clearance certificate’[4] by the regulatory body.

[4] The ‘clearance certificate’ was the written authority given to the soil removal operator by the auditor (an independent environmental monitor) as a guarantee of the effectiveness of the soil removal operation. These certificates indicated that the area met the remediation criteria and were to be classed as cleared. Access to cleared areas was restricted during subsequent remediation to limit the potential for recontamination.

POST-REMEDIATION DOSE ASSESSMENT

IV–29. The purpose of the comprehensive post-remediation dose assessment was to verify that the area had been made safe; that is, it was in accordance with the agreed dose criteria, following work undertaken during the 1994–2000 Maralinga Rehabilitation Project [IV–1]. This assessment was also used to determine where further remediation could be beneficial.

IV–30. The estimates of projected dose prior to remediation indicated that certain areas could give rise to doses due to inhalation that were too high to be considered acceptable except under the most rigorously controlled circumstances. Following the removal and burial at depth of contaminated surface soil, the remediated areas at Maralinga were shown by the post-remediation dose assessments [IV–5] to give rise to doses that were well within acceptable dose criteria for all envisaged land uses.

IV–31. The post-remediation outcomes were as follows:

(a) The restriction on occupancy within the boundary of the area of ‘restricted land use’ (non-residential) was considered to be a purely precautionary measure, as doses due to inhalation for permanent occupancy of all but a few areas (essentially within the untreated plume deposition areas) were well below 1 mSv/a.
(b) The restrictions on land use in the central part of the Taranaki test site also restricted access to the new burial trenches and, therefore, discouraged intrusion.
(c) Restrictions on access reduced the probability of contact with any undiscovered contaminated particles or fragments remaining in the plume deposition areas adjacent to the soil removal areas.
(d) Use of the most recent International Commission on Radiological Protection dosimetry model of the human respiratory tract [IV–9] decreased the estimated doses due to inhalation of plutonium and americium by approximately 75%.
(e) Owing to the combined effects of the revised International Commission on Radiological Protection dosimetry model and the better than expected effectiveness of remediation, the maximum estimated dose due to inhalation was 3.6 mSv/a. On this basis, it was concluded that a restricted area was not strictly necessary to meet the 5 mSv/a regulatory objective for the inhalation pathway.
(f) Casual visitors making occasional visits to the area who do not engage in activities resulting in abnormal dust resuspension or large scale soil

disturbance activities are now expected to receive a committed effective dose via inhalation of well below 1 mSv. Such visitors include tourists, geological prospectors and surveyors.

(g) The estimated doses received during ambient (calm) conditions are expected to be very low, and even temporary exposure to the substantial dust loadings observed during severe dust storms also results in negligible doses.

(h) In the future (e.g. when the current 'boundary' signs need replacing), consideration could be given to decreasing the size of the restricted area to only include the burial trenches and inner plume deposition areas, on the basis of an updated dose assessment.

POST-REMEDIATION MANAGEMENT

IV–32. In the future, there are a number of effects that might affect public exposure, as follows:

(a) Radioactive decay might affect public exposure, although this is only significant over timescales of thousands of years for the plutonium at Maralinga. Over the next hundreds of years, the estimated doses will remain approximately the same, assuming that the contamination remains in its present location.

(b) Weathering will, over time, reduce the contamination deposited on the surface owing to transport by various processes, including saltation and resuspension.

(c) The migration of the plutonium deeper into the soil, without migration off the site will lead to lower doses due to inhalation.

(d) Lifestyle changes could significantly affect the estimated doses. For example, if over time extensive areas of Maralinga were covered by concrete, tarmac, brick buildings and lawns, the dust levels, and hence, doses due to inhalation, would be much lower.

IV–33. An ongoing programme of monitoring of relevant parameters (including radionuclide levels and dose assessments for Aboriginal landowners and visitors to the area) was implemented to determine changes over time.

LESSONS FROM THE REMEDIATION

IV–34. The Maralinga remediation confirmed that every remediation project is unique owing to differences in the prevailing circumstances, including the following:

(a) The local environmental and sociological aspects;
(b) The radionuclides present, which affect the exposure pathways and doses, and ease of detectability;
(c) Site or area specific conditions, such as the availability of technologies, availability of resources, economic factors and political factors;
(d) Site factors that can affect a cost–benefit analysis, for example the value of land and disposal options and costs.

IV–35. At the time the contamination occurred, the land at Maralinga was considered worthless and uninhabitable. As a result, actions had been taken that made remediation more difficult and costly than it would otherwise have been; these included indiscriminate and undocumented burials in shallow pits and ploughing of surface contamination. Forty years later, the views of society had completely changed and there was a resolve to return the land — now highly valued — to its Aboriginal owners.

IV–36. It is important to keep abreast of advances in technology with respect to the planning and implementation of remediation. In the case of Maralinga, technology had advanced over time, making remediation more feasible.

IV–37. The steps taken in planning and implementing remediation at Maralinga (see paras IV–11 to IV–31) worked well, and the results exceeded expectations. For example, the amount of contamination removed (including contaminated fragments) and the potential doses averted were higher than initially anticipated. In addition, the traditional owners (represented by the Maralinga Tjarutja) were satisfied and were able to resume possession and full use of previously restricted land.

IV–38. The remedial actions that were implemented were as follows:

(a) Removal of contaminated soil to minimize inhalation of plutonium;
(b) Removal of highly active particles to prevent deliberate collection of and incidental or inadvertent exposure to contaminated fragments and particles;
(c) Prevention of access to buried debris contaminated with plutonium through in situ vitrification and by excavation of debris and reburial at depth.

IV–39. The importance of consultation with interested parties, and of following up these discussions, was identified, not only to build trust and confidence, but also to inform the decisions made on the selection of remedial options.

IV–40. There is a need for scientific expertise to be made available to both the remediation manager and the regulatory body in support of determining appropriate remediation strategies and criteria, and for informing regulatory decisions.

IV–41. There is a need for support by qualified professionals, including engineers and technical support staff (e.g. for specialized monitoring equipment and software development).

IV–42. There is a need to establish efficient and effective regulatory processes, while recognizing the following issues:

(a) The focus of the regulatory body is on ensuring the protection and safety of people and the environment, and thus priority also needs to be given to ways in which the regulatory body can expedite the remediation.
(b) Inadequate information and/or uncertainty about the potential consequences of remediation can impede authorization by the regulatory body.
(c) There is a need for clear and defensible terminology; for example, in many societies, 'radioactive waste' has a negative connotation, whereas 'residual radioactive material' is something that needs to be treated or addressed.
(d) It is important to encourage flexibility with respect to the development of a remediation strategy and a remediation plan, without introducing an unacceptable reduction in safety. Such flexibility will likely facilitate timely authorization and approvals.
(e) In identifying possible disposal options, it is important that there be no unacceptable reduction in safety. Also, it is important to be flexible when identifying disposal options for radioactive waste generated during the remediation of existing exposure situations. For example, this could include options that incorporate strong elements of reversibility and retrieval, and innovative means of information preservation (which is essential if long lived contamination is to be disposed of in situ). Such flexibility will also likely facilitate timely authorization and approvals.

IV–43. During the technical assessment phase (which involved preliminary and detailed evaluation, communication and consultation with interested parties, and planning of remediation to establish remediation criteria, strategies and plans), there were clear benefits from ensuring cooperation between the regulatory body and the party responsible for remediation, while recognizing the need to maintain the independence of the regulatory body. In the Maralinga remediation, it was found important to balance the requirement for independent regulatory decisions with scientific and technical cooperation, wherever possible, to aid in meeting the common remediation goals as efficiently as possible. Such cooperation is especially important following a nuclear or radiological emergency (i.e. when rapid decision making may be necessary).

IV–44. In the testing of new technologies (e.g. in situ vitrification), it is necessary to be prepared with a plan to abandon a given technology, if necessary, and move to an alternative option.

IV–45. It is beneficial to be pragmatic and to divide the remediation into manageable steps. For example, such steps could include the following:

(a) The establishment of a clear and defensible reference level;
(b) The establishment of practical remediation criteria for guiding remedial actions (i.e. derived criteria in terms of soil contamination levels and criteria for contaminated particles);
(c) The systematic characterization of the average contamination levels over realistic areas;
(d) Zoning of the total area into smaller areas, each of which can be treated individually.

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Annex V

CASE STUDY FOR REMEDIATION OF A NORM SITE: THE TAPARURA PROJECT AT SFAX, TUNISIA

BACKGROUND

V–1. Until recently, in most countries, facilities and activities for practices involving naturally occurring radioactive material (NORM) did not fall within the scope of radiation protection regulations (i.e. except in cases where NORM was processed for its fissile, fertile or radioactive properties, such as uranium mining and processing) [V–1 to V–3]. Because many NORM practices have a long history, in many cases the decision on regulatory control for radiation protection purposes is made long after these practices were started. As a result, facilities and activities relating to NORM have not necessarily met current radiation protection standards.

V–2. In many cases, in the planning and implementation of the remediation of NORM sites, radiation protection aspects are not the driving factors in the remediation process. As a result, the environmental authority, rather than the regulatory body for safety, can play the leading role in regulatory oversight of the remediation process.

V–3. There are many examples of successful remediation of sites that have been affected by past activities involving NORM. Safety Reports Series No. 78 on Radiation Protection and Management of NORM Residues in the Phosphate Industry [V–4] describes in detail the remediation of the phosphogypsum stack and coastal area of Sfax in Tunisia. This annex reproduces the main elements of that report, following the structure of Fig. 1.

V–4. A phosphate plant (Taparura) started operations in 1952 in the harbour of Sfax, Tunisia. Phosphogypsum and other residues were released directly onto the beaches and into shallow offshore areas, and a large phosphogypsum stack was accumulated close to the harbour and town. The plant was closed down in 1991 [V–5].

DISCOVERY OF THE ISSUE

V–5. The phosphogypsum stack, which covered an area of approximately 50 hectares and reached a height of up to 8 m above sea level, was surrounded by a crusty layer of phosphogypsum with an area of 90 hectares and a depth of up to 3 m.

V–6. The contamination from the Taparura facility and from the phosphogypsum stack was found to be detrimentally impacting the beaches and coastal waters of Sfax, resulting in the need to prohibit swimming in those waters and to prevent access to the beaches [V–5]. The contamination was also hampering further development and economic growth, such as tourism.

V–7. In 1985, a decision was made to redevelop the zone affected by the releases of phosphogypsum into the area surrounding the Taparura site.

PRELIMINARY EVALUATION

V–8. The phosphogypsum residue contained heavy metals, such as cadmium, arsenic and nickel, as well as radionuclides in the uranium decay chain and, to a lesser extent, the thorium decay chain.

V–9. The ^{226}Ra activity concentration in the residue was approximately 0.4 Bq/g (dry mass), and public exposure could occur through the inhalation of radon gas released from the phosphogypsum stack and through the migration of radionuclides into groundwater and surface water bodies, including the sea.

V–10. Several studies (e.g. Refs [V–6, V–7]) indicate that the release of phosphogypsum into surface water bodies can result in significantly elevated levels of radionuclides such as ^{210}Po in water, sediments and biota.

V–11. Exposures of members of the public were estimated to typically fall within the range of 2–10 μSv/a, with maximum values of up to 150 μSv/a. These estimates did not include exposures due to radon emanation from phosphogypsum, which can be significant where dwellings are constructed on soil contaminated with phosphogypsum and no prevention measures against the ingress of radon are implemented.

DETAILED EVALUATION

V–12. Several comprehensive studies were undertaken to determine the extent of the contaminated area (both on land and in the shallow sea surrounding the phosphogypsum stack) and to estimate the quantities of material to be removed. In 1997, the Tunisian Government decided to start the first phase of the Taparura remediation project, which consisted of taking control of all sources of pollution [V–8].

V–13. For the radiological characterization, gamma radiation surveys, dust monitoring, and measurements of indoor and outdoor radon were performed.

INVOLVEMENT OF INTERESTED PARTIES

V–14. At all stages of the remediation, communication with the public and other interested parties was organized through a variety of mechanisms, such as meetings, workshops, the internet and the media. The Tunisian National Radiation Protection Centre played a prominent role in addressing concerns regarding radiation issues.

PLANNING OF REMEDIATION

Identification and evaluation of remedial options

V–15. Once the extent of the contaminated area and the degree of contamination had been defined, different remedial options and technologies were investigated. The selection of the remedial option was based on the following priorities:

(a) Minimizing the size of the contaminated area, which involved the removal of significant quantities of material from land and sea;
(b) Ensuring the long term physical stability of the confinement area;
(c) Minimizing the transport of contaminants from the confinement area to the surrounding groundwater.

Selection of the reference level

V–16. The Tunisian National Radiation Protection Centre decided that a dose criterion (equivalent to the end state criterion) for public exposure of less than 1 mSv/a (above background) would be applied to the future use of the remediated sites.

Development of the remediation plan

V–17. The remedial option that was selected involved the excavation of the contaminated material and, after dewatering, disposal of this material on the original phosphogypsum stack. Work on the original stack also had to be carried out, including the reshaping of the slopes, the installation of a vertical barrier around the perimeter of the stack to create a stable confined area, the installation of a cover layer of uncontaminated sand and the application of a new topsoil layer.

V–18. The design studies that were conducted indicated that a minimum thickness of 30 cm of uncontaminated cover was needed to adequately attenuate gamma radiation and the emanation of radon gas from the phosphogypsum in the stack.

Funding and financing

V–19. The remediation was carried out by an autonomous Government company (Société d'Etudes et d'Aménagement des Côtes Nord de la Ville de Sfax) under the supervision of the Ministry of Housing. The project cost of €75 million was financed through taxes and through loans from the European Investment Bank and financial institutions in Belgium and France.

Gaining approval

V–20. The evaluation studies and the selection of the remedial option were approved by the competent Tunisian authorities, including the Ministry of Equipment, Housing and Territory Planning, the Ministry of Environment and Sustainable Development, the National Environmental Protection Agency (which approved the various impact studies), and the Coastal Protection and Planning Agency (which, among other organizations, defined the programme for monitoring water for swimming) [V–9].

IMPLEMENTATION OF REMEDIATION

V–21. The rectangular phosphogypsum stack was converted into a circular, terraced structure with a diameter of approximately 0.9 km. The stack is surrounded by a 12 m deep barrier embedded in a bentonite and concrete foundation. This barrier prevents the lateral movement of contaminated water from the stack into the surrounding groundwater.

V–22. Around 1.7 million m^3 of various materials were excavated. The modification of the stack shape from a square to a circular geometry involved the excavation and relocation of 0.787 million m^3 of material, while a further 0.465 million m^3 of phosphogypsum was dredged from the sea and incorporated into the stack.

V–23. Backfilling of the remediated areas and the creation of new beaches involved the excavation and relocation of approximately 8 million m^3 of material (essentially, uncontaminated sand).

ASSESSMENT OF RESULTS OF REMEDIATION

V–24. Several radiological surveys were performed following the remediation, including measurements of the gamma dose rate after the backfilling of the remediated areas and a radon measurement campaign [V–8, V–10]. In addition, a system to control groundwater and to collect seepage water from the stack was established (see para. V–26). Prior to the remediation process, the seepage water had a high acidity. After remediation, its pH increased and is now neutral.

POST-REMEDIATION MANAGEMENT

V–25. The remediation of the area was only the first phase of a large project focused on urban and economic redevelopment. One of the objectives of the project was to restore beach facilities close to the town and to reclaim additional land from the sea for urban expansion and tourism [V–5, V–9].

V–26. Post-remediation measures included the following:

(a) Monitoring of the groundwater level below the stack using automated systems and automatic pumping out of water whenever the level approaches a height of 10 cm below that of the groundwater outside the water barrier;
(b) Collection and pumping of seepage water under the stack;
(c) Collection of surface runoff and redirection into the flood control channels that discharge into the harbour;
(d) Maintenance of the stack cover and of the discharge channels [V–5];
(e) Prohibition of the construction of buildings on the remediated stack, unless preventive measures against radon ingress are incorporated [V–5].

LESSONS FROM THE REMEDIATION

V–27. Radiation protection aspects are part of a broader environmental impact assessment. A holistic approach with consideration of all contaminants and environmental stressors is needed for the development of a meaningful remediation plan. Such an approach facilitates the application of the principles of justification and optimization of protection and safety.

V–28. The remediation process is not a stand-alone process. Within the Taparura project, the remediation of the contaminated area was only the first phase of a broader project aimed at urban and economic development. The embedding of the remediation in a broader economic development project allowed the acquisition of adequate funding. As a result, a sustainable model for remediation was achieved.

V–29. Remediation is a multidisciplinary process involving, for example, the application of environmental sciences, engineering, dredging skills, project management, financial planning and many other fields of expertise. Radiation protection expertise is only one of the many disciplines involved.

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Annex VI

CASE STUDY FOR POST-ACCIDENT REMEDIATION OF AREAS AFFECTED BY THE FUKUSHIMA DAIICHI ACCIDENT

BACKGROUND

VI–1. On 11 March 2011, the Great East Japan Earthquake occurred, and the tsunami that followed damaged the facilities of the Fukushima Daiichi nuclear power plant, operated by the Tokyo Electric Power Company (TEPCO). This led to a nuclear accident and large amounts of radioactive material were released from the plant to an extensive area, of both land and sea, in the eastern part of Japan.

VI–2. No similar accidents with widespread release of radioactive material to areas off-site of a nuclear facility had been experienced in Japan, and the Chernobyl nuclear accident in 1986 was the only the comparable situation in the world. Moreover, regulations and rules did not exist to deal with such a situation. Before the accident at the Fukushima Daiichi nuclear power plant, separate arrangements had been in place for natural disasters and nuclear emergencies at the national and local levels. However, these arrangements did not cover situations involving a response to a nuclear emergency occurring at the same time as a natural disaster [VI–1].

VI–3. On 30 August 2011, the Act on Special Measures concerning the Handling of Environmental Pollution by Radioactive Materials Discharged by the Nuclear Power Station Accident Associated with the Tohoku District — Off the Pacific Ocean Earthquake That Occurred on March 11, 2011 [VI–2] (hereinafter referred to as the 'Act on Special Measures') was promulgated. The Act fully came into force on 1 January 2012; however, remediation activities were launched immediately following the accident at the Fukushima Daiichi nuclear power plant, before the Act on Special Measures was promulgated.

VI–4. After the Act on Special Measures was enacted, various types of remediation activities were systematically initiated on a large scale. These included the implementation of remedial actions relating to the following:

— Decontamination (e.g. wiping of walls and roofs of buildings, washing roads);
— Other types of remedial action (e.g. removal of topsoil, processes for the treatment of soil and waste generated through remedial actions, such as through incineration; treatment of residual materials not related to the accident, such as tsunami debris and sewage sludge).

VI–5. The Act on Special Measures defined the Special Decontamination Area (SDA) and the Intensive Contamination Survey Area (ICSA) (see Fig. VI−1). The SDA is the area where the decontamination and other remedial actions have been implemented mainly by the national Government. The ICSA is the area where the decontamination and other remedial actions have been implemented mainly by each municipality, with support from the national Government.

DISCOVERY OF THE ISSUE

VI–6. The release of radionuclides was detected at an early stage after the accident by public authorities and at monitoring stations [VI–4]. A large amount of radioactive material, including ^{131}I and ^{137}Cs, was released into the atmosphere, dispersed and deposited on the ground, and contamination was detected over an extensive area around eastern Japan, especially in Fukushima Prefecture [VI–4].

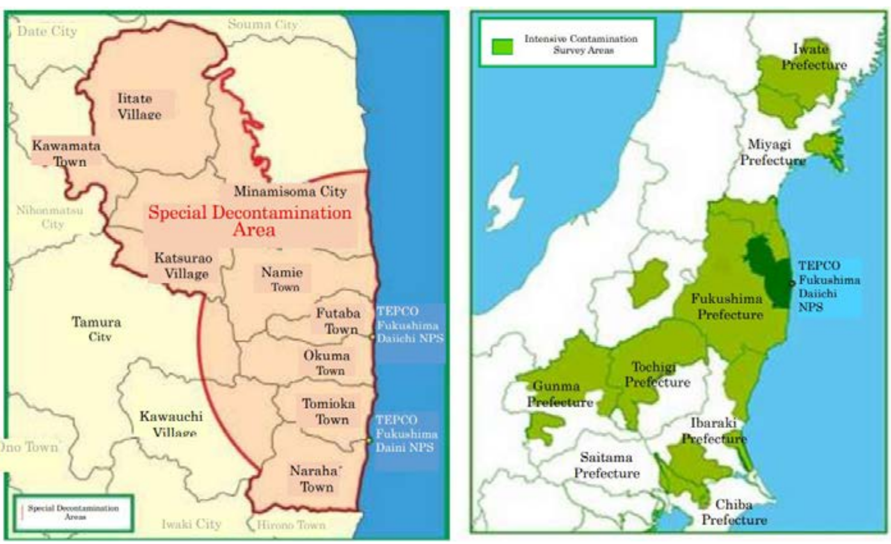

FIG. VI−1. Maps depicting the Special Decontamination Area (SDA) (left) and Intensive Contamination Survey Area (ICSA) (right) in Fukushima Prefecture, Japan [VI−3].

PRELIMINARY EVALUATION

VI–7. Following the accident, on 11 March 2011, the Prime Minister of Japan declared a nuclear emergency and established the Nuclear Emergency Response Headquarters (NERHQ) in the Prime Minister's Office. The NERHQ issued orders to the Governor of Fukushima and other municipal Governments in charge of the evacuation of residents living within a 3 km radius of the Fukushima Daiichi nuclear power plant and issued instructions to residents living within a 10 km radius to shelter indoors. Further instructions were issued on 12 March 2011 to evacuate all residents living within a 20 km radius of the Fukushima Daiichi nuclear power plant, which was later designated the 'Restricted Area' (see Fig. VI−2).

VI–8. On 22 April 2011, specific areas beyond a 20 km radius of the Fukushima Daiichi nuclear power plant with an estimated cumulative dose of above 20 mSv/a for a one year period after the accident were designated the 'Deliberate Evacuation Area' (see Fig. VI–2 and Table VI–1) and residents in this area were instructed to evacuate within approximately one month [VI–5]. In addition, an area known as the 'Evacuation-Prepared Area in Case of Emergency' was established between 20 and 30 km of the Fukushima Daiichi nuclear power plant, which included areas where the need for indoor sheltering or evacuation could not be ruled out (see Fig. VI–2). Afterwards, the national Government reviewed the designation of the evacuation areas several times, and the 'Restricted Area' and 'Deliberate Evacuation Area' laid the basis for the 'Countermeasure Area' [VI–6] and the SDA.

DETAILED EVALUATION

VI–9. Owing to the disruption of the lives of residents caused by the evacuation, it was deemed appropriate to review the evacuation areas, taking into account what were considered significant changes in the situation, such as the progress in ensuring the safety of the damaged Fukushima Daiichi nuclear power plant and the reduction of the air dose rate as a result of remediation activities, as confirmed through continuous monitoring.

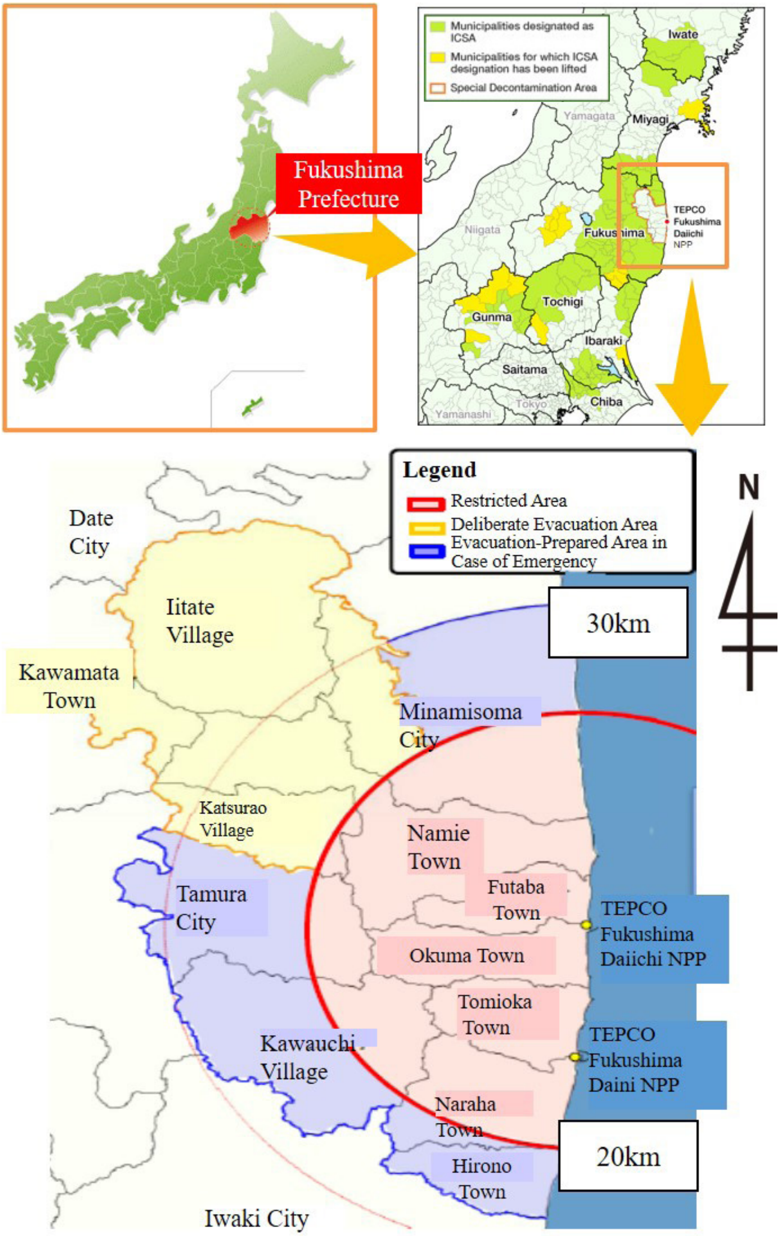

FIG. VI−2. Established evacuation areas in Fukushima Prefecture (as of 22 April 2011) [VI–3].

TABLE VI–1. TYPES OF EVACUATION AREAS ESTABLISHED IN FUKUSHIMA PREFECTURE (AS OF 22 APRIL 2011) [VI−3]

Type of evacuation area	Description
Restricted Area	Areas within a 20 km radius of TEPCO Fukushima Daiichi nuclear power plant. Other than persons engaged in emergency response measures, entry to this area is prohibited or evacuation orders have been issued, with the exception of cases where temporary entry has been permitted by the mayor of a relevant municipality.
Deliberate Evacuation Area	Areas where the cumulative dose during a one-year period after the Fukushima Daiichi accident could reach 20 mSv/a. Residents are required to engage in deliberate evacuation to another location within roughly one month.
Evacuation-Prepared Area in Case of Emergency	Areas within a radius of between 20 km and 30 km from TEPCO Fukushima Daiichi nuclear power plant. These areas are in a situation where the possibility cannot be ruled out that sheltering indoors or evacuation may be required in an emergency and residents are required to make preparations so that they can shelter indoors or evacuate in an emergency.

VI–10. On 17 April 2011, TEPCO issued the Roadmap towards Restoration from the Accident at Fukushima Daiichi Nuclear Power Station [VI–7], which consisted of two conditions, as follows:

(1) The first condition (Step 1) of the ‘cold shutdown state’ was defined in the Roadmap as a situation where ‘radiation dose is in steady decline’.
(2) The second condition (Step 2) was defined as a situation where ‘release of radioactive materials is under control and radiation dose is being significantly held down’.

VI–11. On 16 December 2011, the NERHQ confirmed the completion of Step 2 of the Roadmap, stating that the release of radioactive materials had been brought under control and the radiation dose was significantly suppressed, thus achieving the ‘cold shutdown state’ of the damaged reactors [VI–8].

VI–12. On 26 December 2011, the NERHQ published the Basic Concept and Future Tasks in Review of the Restricted Area and Areas Under Evacuation Orders After the Completion of Step 2 [VI–9]. The basic concept was to review the Restricted Area and the areas under evacuation orders, with a plan to lift evacuation orders in areas with low dose rates by implementing further remediation activities.

VI–13. In line with this basic concept, the areas under evacuation orders were to be reorganized into the following categories on the basis of radiation dose (see Fig. VI–3 and Table VI–2):

— Difficult-to-Return Zone;
— Habitation Restricted Areas;
— Preparation Areas for Lifting of Evacuation Orders.

Areas were categorized as being within the Difficult-to-Return Zone if the annual cumulative doses exceeded 50 mSv at that time and would highly likely exceed 20 mSv six years after the accident. Areas were categorized as Habitation Restricted Areas if the annual cumulative doses exceeded 20 mSv at that time. Areas were categorized as Preparation Areas for Lifting of Evacuation Order if the annual cumulative doses reached 20 mSv or less [VI–6].

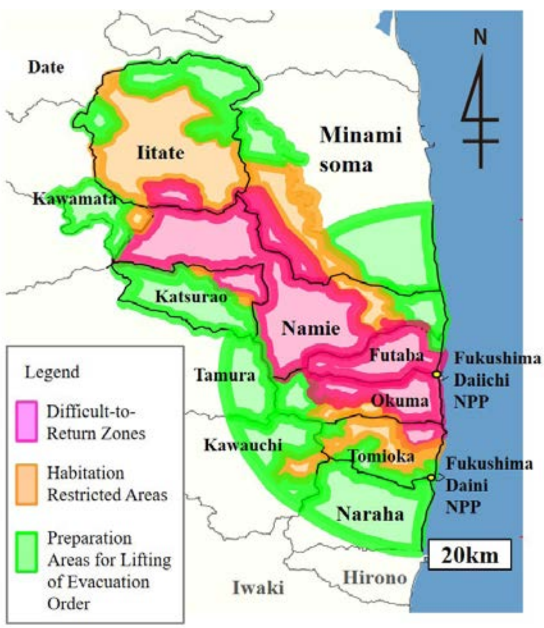

FIG. VI–3. Established areas under evacuation orders (August 2013, following revision to areas) [VI–3].

TABLE VI–2. TYPES OF AREAS ESTABLISHED UNDER EVACUATION ORDERS (AUGUST 2013, AFTER THE REVISION OF EVACUATION AREAS) [VI–3]

Type of area	Description
Difficult-to-Return Zones	Areas where the annual cumulative radiation dose might not fall below 20 mSv/a even five years after the accident and areas where the annual cumulative radiation dose exceeds 50 mSv/a. In principle, habitation will be restricted in the future and the designation of this area will be fixed for five years.
Habitation Restricted Areas	Areas where as of 26 December 2011 the annual cumulative radiation dose might exceed 20 mSv/a and where it is therefore necessary to maintain the evacuation from the perspective of reducing residents’ exposure to radiation. With the aim of realizing the return of residents and the rebuilding of communities in the future, decontamination and infrastructure recovery are to be implemented systematically.
Preparation Areas for Lifting of Evacuation Order	Areas that as of 26 December 2011 have been confirmed as having an annual cumulative radiation dose that is clearly less than 20 mSv/a. Although evacuation orders will remain in place, support measures for recovery and reconstruction, including decontamination, infrastructure recovery, and employment measures will be expedited, with the aim of achieving the return of residents as soon as possible.

VI–14. Three criteria were established for lifting the evacuation order [VI–8]:

(1) Confirmation that the annual effective dose due to radiation will be 20 mSv or less;
(2) Confirmation that sufficient progress has been made in the general restoration of essential infrastructure, especially with regard to children’s living environments;
(3) Confirmation that extensive talks have been held with the prefectural and local governments and with residents.

INVOLVEMENT OF INTERESTED PARTIES

VI–15. The Ministry of the Environment (MOE) had primary responsibility for the risk communication within the SDA, while the municipalities were responsible for this task within the ICSA.

VI–16. Explanatory meetings for local residents were held regularly at each stage of the decontamination and other remedial actions to discuss the following:

- Selection of temporary storage sites;
- Pre-decontamination monitoring;
- Decontamination and other remedial actions;
- Management of removed soil and waste;
- Verification of the effectiveness of decontamination and other remedial actions;
- Other relevant topics.

Depending on the level of contamination within each municipality, explanatory meetings, as well as round-table meetings and workshops (i.e. direct dialogues) for residents, were held, sometimes more than once a week and up to more than 100 times a year, during weekday evenings as well as weekends [VI–3].

VI–17. In addition to the direct dialogues with local interested parties, the Decontamination Information Plaza (now called the Environmental Regeneration Plaza) was established in January 2012 and became a source of information on radiation levels and on the progress of decontamination and other remedial actions. In addition, information centres were established for other recovery activities, such as the Landfill Facility for Specified Waste[1] in 2018 and the Interim Storage Facility (ISF)[2] in 2019.

VI–18. The information for dissemination to interested parties has been updated over time (between the time of the accident in March 2011 and the present) to reflect the changes in circumstances and in understanding and anxiety about

[1] This is the site for final disposal of waste generated through recovery activities such as the treatment of tsunami debris, dismantled houses and general waste that had been stockpiled in the Countermeasure Area, and for treatment of designated waste in Fukushima Prefecture.

[2] The ISF is the facility in which the contaminated soil and waste generated mainly through the remedial actions within Fukushima Prefecture are being temporarily stored.

radiation. The information updates can be divided on the basis of the progress of the remediation activities [VI–3] as follows:

- Emergency Response Period to Preparation Period for Decontamination (March 2011 to December 2011): Basic information on radiation levels was provided to reduce anxiety because evacuation orders had been issued.
- Decontamination Initial Period to Decontamination Promotion Period (January 2012 to December 2013): After the Act on Special Measures came fully into force in January 2012, basic information relevant to the implementation of full scale remediation — including details on the specific remedial actions taken (e.g. methods to remediate residences, schools, farmlands and forests), the effectiveness of decontamination and other remedial actions, and the safety of the temporary storage sites — was provided to residents, mainly in explanatory meetings.
- Early Decontamination Acceleration Period (January 2014 to September 2015): In addition to basic information regarding the remediation, it was important to communicate information on the safety of these activities because in the SDA the implementation of remediation activities peaked in this period and a large number of workers, instruments and vehicles were involved in remediation throughout the area. In this period, the evacuation orders were lifted for the first time after the accident and an explanation of the new and long term activities was gradually provided, including information on life after the lifting of the evacuation order and transport of removed soil and waste to the ISF.
- Later Decontamination Acceleration Period (October 2015 to March 2017). The information on the return of evacuees and recovery activities, such as the rebuilding of infrastructure, public services and businesses, began to attract the attention of the public, with a focus on remediation activities being reduced as the evacuation orders were sequentially lifted. Full scale remediation was completed in March 2017 in the SDA; however, concerns relating to the other remediation activities remained (e.g. relating to the management of soil and waste generated during remediation, the transport of waste and the restoration of the temporary storage sites).
- Supplementary Period after Decontamination (April 2017 to the time of writing). In March 2018, full scale remediation was also completed in the ICSA. After the completion of full scale remediation, information on supplementary decontamination and other remedial actions was provided to the residents to reduce their anxiety. In addition, most of the Difficult to Return Zone remained unremediated, although construction of the Specified Reconstruction and Revitalization Base had already been launched, which aimed at lifting the evacuation orders and allowing people to live within the Difficult to Return Zone.

VI–19. The amount of soil and waste transported from the temporary storage sites and on-site storage to the ISF has increased significantly since the start of storage of soil and waste in 2015, and the safety of the transport of this material has drawn the keen attention of local interested parties. In addition, decision making on the final disposal of the waste and soil stored in the ISF was under discussion, because Japanese law stipulated that this soil and waste must be brought from the ISF and finally disposed of outside Fukushima Prefecture within 30 years of the start of temporary storage in March 2015.

PLANNING OF REMEDIATION

Development of the remediation strategy

VI–20. Initial findings regarding remediation were summarized and evaluated and were taken into account in the development of remediation planning.

VI–21. After the Act on Special Measures was promulgated on 30 August 2011, it took time to designate the SDA and the ICSA and to establish technical standards before undertaking the more practical implementation. Remediation was, however, identified as an urgent issue to be initiated immediately. Therefore, in parallel with the discussion in the National Diet concerning the Act on Special Measures, on 26 August 2011, the NERHQ adopted the Basic Policy for Emergency Response on Decontamination Work [VI–10], which was to be used until the Act on Special Measures fully came into force. On the same day, the NERHQ released the Guidelines for Municipal Decontamination Work to enable municipalities to formulate and implement remediation plans [VI–11]. Furthermore, on 30 September 2011 the NERHQ announced plans to develop two sets of guidelines covering the decontamination and other remedial actions for forests and farmland, respectively, following the implementation of decontamination and other remedial actions in some municipalities in Fukushima Prefecture.

VI–22. In response to the establishment of the Act on Special Measures, in August 2011, the MOE launched the Committee on Environmental Remediation and held the first meeting on 14 September 2011, where they started to examine mainly technical issues, including the preparation of the basic policy for the Act on Special Measures and corresponding technical guidelines.

VI–23. On 11 November 2011, the Basic Policy for the Act on Special Measures concerning the Handling of Environmental Pollution by Radioactive

Materials [VI–12] was endorsed by the Cabinet. In this basic policy, by incorporating the concept of the Basic Policy for Emergency Response on Decontamination Work, an annual effective dose of 1 mSv or less was stipulated as the long term goal in the area in which the annual effective dose was predicted to be in the range of 1–20 mSv (see para. V1–25).

VI–24. To ensure the full coming into force of the Act on Special Measures, on 14 December 2011 the MOE promulgated a Ministerial Ordinance stipulating the designation requirements for the municipalities designated as part of the SDA and those designated as part of the ICSA. Under this Ministerial Ordinance, 11 municipalities were designated as part of the SDA and 102 municipalities were designated as part of the ICSA on 28 December 2011 and 2 more municipalities were designated as part of the ICSA on 28 February 2012 (4 municipalities contain areas that are part of the SDA and areas that are part of the ICSA).

Reference level

VI–25. The Nuclear Safety Commission stated in The Basic Idea on Radiation Protection for the Future Lifting of Evacuation Orders and Reconstruction [VI–13] (issued on 19 July 2011) that a lower dose in the range of 1–20 mSv/a would be chosen for the reference level to be applied for existing exposure situations. Furthermore, it stated that this intermediate reference level could possibly be adopted and later reviewed, but as a long term goal, 1 mSv/a was to be selected for the reference level.

VI–26. An annual effective dose of 1 mSv for the reference level was specified in the subsequent Basic Policy for Emergency Response on Decontamination Work [VI–10] (issued on 26 August 2011) and in the Basic Policy for the Act on Special Measures concerning the Handling of Environmental Pollution by Radioactive Materials [VI–12] (issued on 11 November 2011). This long term target was intended to be achieved not only by remediation but also by other factors influencing the reduction of dose rates with time, for example, through the physical decay of radionuclides, weathering effects, understanding and managing individual exposures and food safety management.

Development of remediation plans

VI–27. The MOE has largely been responsible for the planning and implementation of remediation in the SDA, while each municipality has been responsible for the ICSA, with the support of the national Government in terms of funding and techniques.

VI–28. Regarding the SDA, on the basis of the Act on Special Measures [VI–2], the MOE formulated a remediation plan for each of the 11 municipalities and set out basic policies concerning the implementation of remediation with necessary remedial actions to achieve the plans.

VI–29. The circumstances in each municipality were different, and the remediation plans were established by the MOE on different timescales (between April 2011 and July 2014). The remediation activities were initiated and conducted by the MOE according to these remediation plans.

VI–30. In formulating the plans, the MOE listened carefully to the opinions of each municipality and their mayors and the Fukushima Prefectural Government and its Governor. Before the announcement of the plans, residents were consulted on a number of subjects, such as radiation protection, decontamination and other remedial actions and their effectiveness.

VI–31. Each municipality designated as falling within the ICSA — which extends from the northern Tohoku area to the Kanto area — monitored the contamination level and judged the necessity of decontamination and other remedial actions according to the relevant guidelines. On the basis of the results of these surveys, each municipality formulated a remediation plan specifying the area where remediation was to be carried out, the implementation methods, the implementing bodies, the priority for the implementation of remediation and the timescale for implementation of the plan. The plan was then approved by the MOE. Within each municipality, responsibilities were assigned to the national Government, the prefecture, the independent administration agencies and the national universities with respect to conducting decontamination and other remedial actions on the properties managed by each authority.

VI–32. A 'derived reference level'[3] of 0.23 μSv/h for the air dose rate was set for the ICSA to meet the annual effective dose criterion of 1 mSv, on the basis of the assumed habits of the population. In some municipalities, no areas were found in which 0.23 μSv/h was exceeded. Therefore, on the basis of the air dose rates, decontamination and other remedial actions were only undertaken in 93 municipalities of the 104 municipalities designated as part of the ICSA.

[3] The 'derived reference level' is equivalent to a 'derived criterion' as used in this Safety Guide (see paras 6.11 and 6.12).

Identification and evaluation of remedial options

VI–33. On 14 December 2011, the MOE released the Decontamination Guidelines [VI–14], which describe the specific decontamination methods, along with the procedures to be followed regarding the monitoring, implementation, transport and storage of waste. The Decontamination Guidelines were revised in May 2013 to incorporate additional knowledge gained during the actual remediation activities, as well as new techniques, and input from experts and local governments. In order to promote remediation more effectively, supplements were added in December 2013, December 2014, September 2016 and March 2018.

VI–34. A significant volume of residual material was generated through activities relating to the overall recovery from the earthquake and tsunami, in addition to remedial actions, including the management of tsunami debris, dismantled houses, incineration ashes and sewage sludge. Guidelines for Waste Treatment [VI–15] were published on 27 December 2011 to cover the storage and treatment of radioactive waste generated by such activities. For the management of localized contamination not covered by the Act on Special Measures, Guidelines on Handling Local Areas Contaminated by Radioactive Materials [VI–16] were published on 12 March 2012 by the MOE.

VI–35. More detailed guidelines were also developed by other authorities, the Fukushima Prefectural Government and the Ministry of Agriculture, Forestry and Fisheries for different technical perspectives.

Classification of residual materials, including radioactive waste

VI–36. The Act on Special Measures [VI–2] defines five categories of residual material within Fukushima Prefecture [VI–6]:

(1) Waste within the Countermeasure Area (formerly the Restricted Area and Deliberate Evacuation Area, which almost overlaps the SDA; see paras VI–5, VI–7 and VI–8). This consisted of debris from the tsunami, demolition debris from houses hit by the disaster and waste from the decontamination of houses following long term evacuation.
(2) Designated waste, which was waste (e.g. sewage sludge, incineration ash) that was contaminated above an activity concentration of 8000 Bq/kg.
(3) A combination of (1) and (2), which was referred to as ‘specified waste’.
(4) Low level contaminated waste other than specified waste, which had an activity concentration of 8000 Bq/kg or less and which did not originate

from within the Countermeasure Area. This category of waste was subject to the Waste Management and Public Cleansing Law [VI–17].

(5) Soil and waste arising from the decontamination activities, which included materials such as soil, grass, leaves, branches and surface sediments.

VI–37. Residual materials from Fukushima Prefecture were also characterized in accordance with the following criteria, as defined in the Act on Special Measures [VI–2]:

— The area where residual material was generated (e.g. the SDA, the ICSA; see para. VI–5);
— Activity concentration of ^{134}Cs and ^{137}Cs in the residual material (<8000 Bq/kg, <100 000 Bq/kg or >100 000 Bq/kg);
— Type of residual material (combustible material, non-combustible material, soil);
— Origin of the residual material (remediation activities, demolition of houses damaged by earthquakes, waste generated during decontamination of houses in the evacuated areas).

Funding and financing

VI–38. As stipulated in Article 44, para. 1 of the Act on Special Measures [VI–2], costs of remediation taken under the act are to be borne by TEPCO, and the national Government has claimed compensation from TEPCO intermittently for expenditures for remediation (e.g. decontamination and other remedial actions, storage of soil and waste).

VI–39. In addition, the Act on Special Measures for the Reconstruction and Restoration of Fukushima was amended in May 2017 [VI–18] to address the reconstruction and rebuilding of the Difficult to Return Zone as quickly as possible. With this amendment, the remediation necessary for the reconstruction and revitalization of the Specified Reconstruction and Revitalization Base is regarded as remediation activities budgeted for by the national Government.

IMPLEMENTATION AND VERIFICATION MONITORING

The Special Decontamination Area

VI–40. The full scale remediation of the SDA on the basis of the remediation plans was completed at the end of March 2017. In the 11 municipalities in the

SDA, the cumulative number of workers was about 13.7 million persons (as of the end of March 2018) and the budget was about 1.5 trillion yen (as of the end of March 2019) [VI–19].

VI–41. A total of approximately 23 000 residential houses, 8700 hectares of farmland, 7800 hectares of forest and 1500 hectares of roadways had been remediated by the end of September 2017 [VI–20].

VI–42. Most of the soil and waste generated through the remedial actions in the SDA was transported to temporary storage sites, and then to the ISF; combustible waste was transported to incineration facilities. The ISF, located on the coast, near the Fukushima Daiichi nuclear power plant, is where the soil and waste generated through the remedial actions within Fukushima Prefecture are stored. In the ICSA, almost the same process is followed for managing the residual materials generated during remediation, but the soil and waste have sometimes been stored at sites where decontamination or other remedial actions were conducted (i.e. 'on-site storage'), before being transported to temporary storage sites.

VI–43. As of June 2019, removed soil and waste had been stored in 187 of the 324 temporary storage sites constructed in the SDA. Approximately 9.3 million m^3 of soil and waste had been generated, of which 4.0 million m^3 had been transported to the ISF or to incineration facilities [VI–21].

The Intensive Contamination Survey Area

VI–44. The full scale remediation of the ICSA in line with the remediation plans was completed in March 2018. In the 93 municipalities in the ICSA, the estimated total number of workers that participated in remediation was approximately 18.4 million persons (as of the end of March 2018) and the budget was approximately 1.4 trillion yen (as of the end of March 2019) [VI–19].

VI–45. A total of approximately 570 000 residential houses, 24 000 public facilities, 33 000 hectares of farmland, 4800 hectares of forest and 24 000 km of roadway had been remediated [VI–22].

VI–46. As of March 2019, removed soil and waste had been stored in 616 of the 997 temporary storage sites constructed in the ICSA in Fukushima Prefecture. In the ICSA in Fukushima Prefecture, approximately 6.9 million m^3 of soil and waste had been generated, of which 1.6 million m^3 had been transported to the ISF or incineration facilities. In the ICSA in Fukushima Prefecture, there were many on-site storage sites where the removed soil and waste was being stored at the remediated sites before being transported to the temporary storage sites. The number of on-site storage sites peaked in December 2016 at approximately 149 000 and decreased to approximately 86 000 by March 2019, according to the progress of transport of waste to the temporary storage sites and subsequently to the ISF [VI–21, VI–23]. There were also the temporary storage sites and on-site storage sites outside Fukushima Prefecture. As of March 2019, approximately 473 000 m^3 of soil and waste had been stored at 44 temporary storage sites and approximately 30 000 on-site storage sites [VI–24].

Assessment of results of remediation

VI–47. The air dose rate was monitored by survey meters before and after the decontamination, and other remedial actions were implemented to assess the effectiveness of the implemented decontamination and other remedial actions. In addition, approximately 6 months to 1 year after the decontamination and other remedial actions were implemented, monitoring was conducted to confirm the continued effectiveness of the decontamination and other remedial actions. According to the monitoring results, by August 2018 the average air dose rates in the SDA were approximately 30–60% lower after the decontamination and other remedial actions were performed on residential lands, farmlands, forests and roads. In addition, the air dose rate measured by subsequent monitoring was approximately 60–80% lower than the air dose rate measured before the decontamination and other remedial actions [VI–19]. Although it appears that the air dose rate has sometimes increased over time following remediation, owing to the migration of radionuclides, it has been concluded that the overall effectiveness of decontamination and other remedial actions has been maintained [VI–19]. There are a number of exceptions, however; for example, in some localized areas, further remedial actions have needed to be implemented, as described in paras VI–48 to VI–49.

Post-remediation verification of the need for further remediation

VI–48. After full scale remediation of the SDA and the ICSA (including the implementation of decontamination and other remedial actions), some areas were identified where the effectiveness of decontamination and other remedial actions was not maintained over time. To address this, the MOE developed the following strategy for supplementary decontamination in December 2015 [VI–25]:

(a) Full scale remediation would not be implemented again; however, if it was confirmed that there was an area where the effectiveness of decontamination was not maintained, the area would be further investigated. Such areas would be addressed on a case-by-case basis and supplementary decontamination and other remedial actions would be implemented, if justified and feasible.

(b) If it was confirmed that the annual effective dose is 1 mSv or less, it would be concluded that the Government's long term goal for radiation protection had been achieved and supplementary decontamination or other remedial actions would not be carried out (see para. VI–24).

(c) In the Habitation Restricted Areas, if it could not be ensured that the annual effective dose was 20 mSv or less (one of the criteria for lifting evacuation orders; see para. VI–14), even after full scale remediation, supplementary decontamination and/or other remedial actions would be carried out. In this case, the supplementary decontamination and other remedial actions would be implemented without waiting for subsequent monitoring, taking account of the prevailing circumstances at each site immediately after the full scale remediation.

In addition, for the decision on the implementation of (c), air dose rate monitoring would be conducted in residential areas with an average value exceeding 1 μSv/h over the area, and supplementary decontamination and other remedial actions would be considered in areas where the air dose rate might exceed 3.8 μSv/h within an area where there was comparatively homogeneous contamination. This dose rate was estimated to correspond to an effective dose of 20 mSv/a under the assumed habits of the population [VI–26].

VI–49. Supplementary decontamination had been carried out at approximately 10 000 residences (as of October 2017). The main targets for supplementary decontamination and other remedial actions were places where water collects or runoff occurs, such as slopes, rain puddles and roadside gutters; a reduction in air dose rate of approximately 50% was confirmed where such decontamination and other remedial actions were carried out [VI–27].

POST-REMEDIATION MANAGEMENT

VI–50. Monitoring of radioactivity in the environment and in commodities (e.g. foodstuffs) was carried out during full scale remediation of both the SDA and the ICSA, and has continued even after full scale remediation was completed.

Remediation activities for food and drinking water

VI–51. Regarding food, Japan has adopted an annual effective dose criterion of 1 mSv, as recommended by the Codex Alimentarius Commission, and has implemented a guidance level of 100 Bq/kg (total of ^{134}Cs and ^{137}Cs) [VI–28, VI–29] (see Annex II, paras II–19 to II–25).

VI–52. Regarding tap water, Japan has adopted an annual effective dose criterion of 0.1 mSv, as recommended by the World Health Organization for existing exposure situations, and has implemented a guidance level of 10 Bq/L (total of ^{134}Cs and ^{137}Cs). To date, inspections have been conducted by each water supplier, and in Fukushima Prefecture radiocaesium activity concentrations exceeding 10 Bq/L have not been detected in purified tap water since June 2011 or in raw water since May 2011 [VI–30].

VI–53. Regarding well water, according to a high priority survey of groundwater in the affected areas in Fukushima Prefecture, neither radioactive iodine (^{131}I) nor radiocaesium (^{134}Cs, ^{137}Cs) has been detected [VI–31]. In addition, monitoring of drinking water in wells in Minamisoma City and Tamura City between 1 April 2012 and 31 March 2013 radiocaesium exceeding a control value (10 Bq/L) was not detected [VI–32].

VI–54. According to the results of the inspection of more than 9 million bags of brown rice and approximately 2700 other foodstuffs in 2018 and 2019, there were no instances of exceedance of the regulatory standards, except for two cases of freshwater fishery products [VI–33].

VI–55. The setting of reference levels and derived reference levels (expressed in terms of activity concentrations in food) and their implementation is addressed in Annex II.

OBSERVATIONS AND LESSONS FROM THE REMEDIATION

VI–56. A detailed assessment of the causes and consequences of the accident at the Fukushima Daiichi nuclear power plant, and the observations and lessons from the accident, was undertaken and is documented in Ref. [VI–34]. This assessment included the documentation of observations and lessons relating to consequences for people and the environment associated with radioactivity and radiation from the accident [VI–35], and recovery activities undertaken following the accident, including those relating to remediation activities, such as decontamination and other remedial actions (see para. VI–4) [VI–6].

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Annex VII

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CONTRIBUTORS TO DRAFTING AND REVIEW

Asfaw, K.	International Atomic Energy Agency
Baines, K.	International Atomic Energy Agency
Balonov, M.	Consultant, Russian Federation
Batandjieva, B.	European Commission
Belencan, H.	Consultant, United States of America
Berkovskyy, V.	International Commission on Radiation Units and Measurements
Boyd, M.	Environmental Protection Agency, United States of America
Brown, J.	International Atomic Energy Agency
Chandler, S.	Consultant, United Kingdom
Charalambous, F.	Australian Radiation Protection and Nuclear Safety Agency, Australia
Crossland, I.	Consultant, United Kingdom
De La Vega, R.	International Atomic Energy Agency
Declercq, T.	United Nations Office for the Coordination of Humanitarian Affairs
Dercon, G.	Food and Agriculture Organization of the United Nations
Fan, Z.	International Atomic Energy Agency
Fesenko, S.	Russian Institute of Radiology and Agroecology, Russian Federation
Garamszeghy, M.	International Organization for Standardization
Geupel, S.	International Atomic Energy Agency
Grzechnik, M.	Australian Radiation Protection and Nuclear Safety Agency, Australia

Inoue, T.	Central Research Institute of the Electric Power Industry, Japan
Jova Sed, L.	International Atomic Energy Agency
Kiselev, S.	SRC Federal Medical Biophysical Centre, Russian Federation
Kouts, K.	International Atomic Energy Agency
Lazo, E.	Organisation for Economic Co-operation and Development
Michel, R.	Consultant, Germany
Mori, Y.	International Atomic Energy Agency
Mundigl, S.	European Commission
Oughton, D.	Norwegian University of Life Sciences, Norway
Pepin, S.	Federal Agency for Nuclear Control, Belgium
Perrin, M.-L.	Consultant, France
Proehl, G.	International Atomic Energy Agency
Ravishankar, B.R.	Consultant, Canada
Roberts, M.	International Atomic Energy Agency
Rowat, J.	International Atomic Energy Agency
Scott, T.	United Nations Development Programme
Seifert, R.	Department of Energy, United States of America
Shaw, P.	International Atomic Energy Agency
Thummarukudy, M.	United Nations Environment Programme
Vergichik, M.	United Nations Development Programme
Williams, G.	Australian Radiation Protection and Nuclear Safety Agency, Australia
Wright, R.	International Atomic Energy Agency
Wymer, D.G.	Consultant, South Africa

Yankovich, T.	International Atomic Energy Agency

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