IAEA Safety Standards
for protecting people and the environment

Predisposal Management of Radioactive Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education

Specific Safety Guide
No. SSG-45

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 on the IAEA Internet site

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

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at: 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.

PREDISPOSAL MANAGEMENT OF RADIOACTIVE WASTE FROM THE USE OF RADIOACTIVE MATERIAL IN MEDICINE, INDUSTRY, AGRICULTURE, RESEARCH AND EDUCATION

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

IAEA SAFETY STANDARDS SERIES No. SSG-45

PREDISPOSAL MANAGEMENT OF RADIOACTIVE WASTE FROM THE USE OF RADIOACTIVE MATERIAL IN MEDICINE, INDUSTRY, AGRICULTURE, RESEARCH AND EDUCATION

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2019

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FOREWORD

by Yukiya Amano
Director General

The IAEA's Statute authorizes the Agency to "establish or adopt… standards of safety for protection of health and minimization of danger to life and property" — standards that the IAEA must use in its own operations, and which States can apply by means of their regulatory provisions for nuclear and radiation safety. The IAEA does this in consultation with the competent organs of the United Nations and with the specialized agencies concerned. A comprehensive set of high quality standards under regular review is a key element of a stable and sustainable global safety regime, as is the IAEA's assistance in their application.

The IAEA commenced its safety standards programme in 1958. The emphasis placed on quality, fitness for purpose and continuous improvement has led to the widespread use of the IAEA standards throughout the world. The Safety Standards Series now includes unified Fundamental Safety Principles, which represent an international consensus on what must constitute a high level of protection and safety. With the strong support of the Commission on Safety Standards, the IAEA is working to promote the global acceptance and use of its standards.

Standards are only effective if they are properly applied in practice. The IAEA's safety services encompass design, siting and engineering safety, operational safety, radiation safety, safe transport of radioactive material and safe management of radioactive waste, as well as governmental organization, regulatory matters and safety culture in organizations. These safety services assist Member States in the application of the standards and enable valuable experience and insights to be shared.

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

Safety is not an end in itself but a prerequisite for the purpose of the protection of people in all States and of the environment — now and in the future. The risks associated with ionizing radiation must be assessed and controlled without unduly limiting the contribution of nuclear energy to equitable and sustainable development. Governments, regulatory bodies and operators everywhere must ensure that nuclear material and radiation sources are used beneficially, safely and ethically. The IAEA safety standards are designed to facilitate this, and I encourage all Member States to make use of them.

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[1] 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.

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[1] See also publications issued in the IAEA Nuclear Security Series.

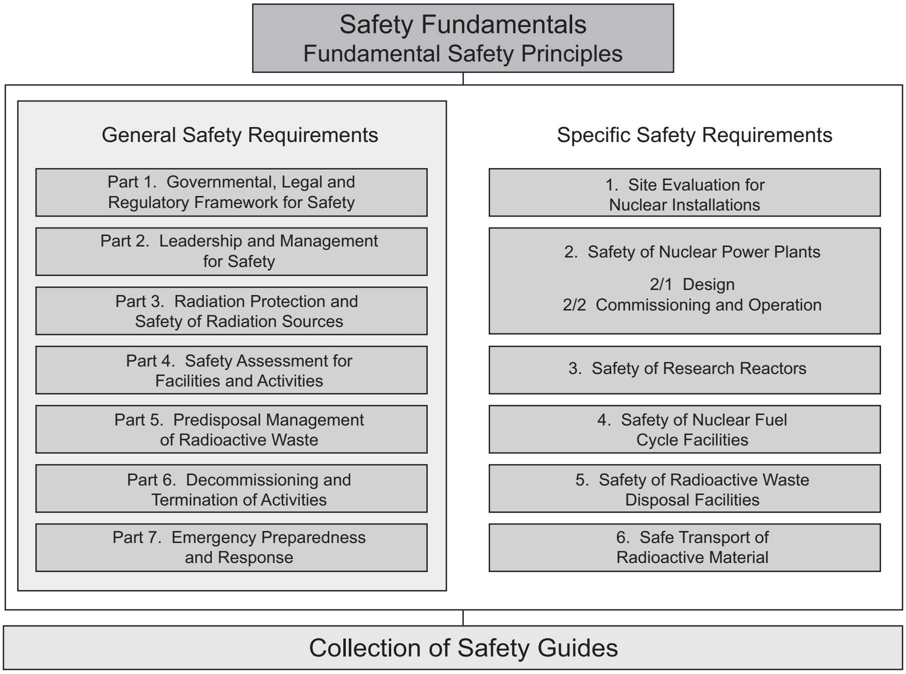

FIG. 1. The long term structure of the IAEA Safety Standards Series.

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 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

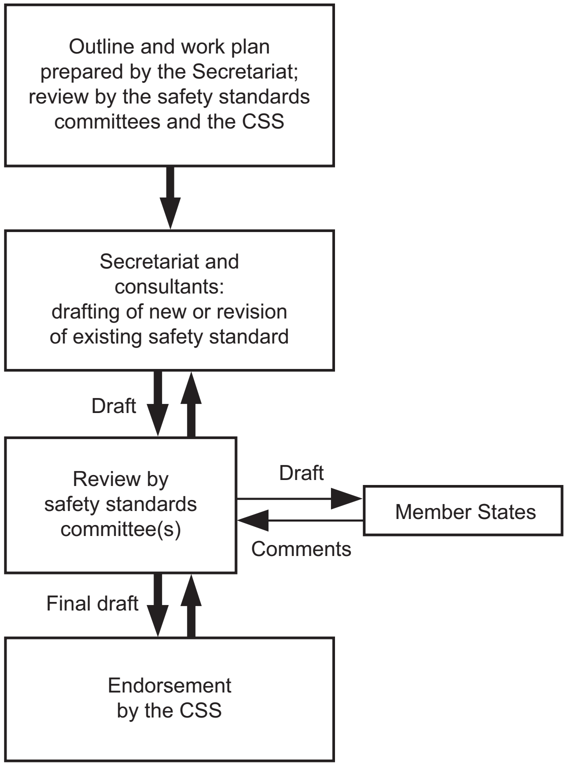

FIG. 2. The process for developing a new safety standard or revising an existing standard.

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

The background and context of each standard 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. Waste that contains or is contaminated with radionuclides arises from a number of activities involving the use of radioactive materials. Globally, significant amounts of radioactive waste are generated from a broad range of activities involving medical, industrial and research applications of radioactive materials. The nature of this radioactive waste is likely to be such that radiation protection considerations need to be taken into account for its safe management. The importance of the safe management of radioactive waste for the protection of human health and the environment has long been recognized, and considerable experience has been gained in this field.

1.2. Predisposal management of radioactive waste covers all the steps in the management of radioactive waste from its generation up to (but not including) its disposal, including processing (pretreatment, treatment and conditioning), storage and transport.[1]

1.3. The general principles of managing radioactive waste in a safe manner have been set out in IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [2] and the requirements to be met are established in the following IAEA Safety Requirements publications: IAEA Safety Standards Series Nos GSR Part 5, Predisposal Management of Radioactive Waste [3]; GSR Part 1 (Rev. 1), Governmental, Legal and Regulatory Framework for Safety [4]; and GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [5]. The Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management [6] is consistent with SF-1 [2]. The present publication is concerned with the application of these principles and requirements to the management of radioactive waste prior to disposal. Whilst the principles to be met [2] and the requirements to be applied [3] are the same for managing any amount of radioactive waste, there are a certain number of issues that have to be considered specifically for facilities and activities generating only small amounts of

[1] 'Predisposal' is a contraction of 'pre-disposal'; it is not a form of disposal. Terminology used in this publication is defined and explained in the IAEA Safety Glossary [1]. See www.iaea.org/resources/safety-standards/safety-glossary

waste. This is particularly so in respect of spent sources and disused sources[2]. For activities involving the generation and management of small amounts of radioactive waste, the types of facility concerned and the arrangements for waste management differ. Furthermore, the types of radioactive waste differ from facility to facility. Thus, the safe management of small amounts of radioactive waste needs specific consideration.

1.4. The radioactive waste in such facilities is varied and might be in the form of discrete sealed radioactive sources or unsealed radioactive material (including by-products of processes). Radioactive waste arises as a result of many activities, including: diagnostic, therapeutic and research applications in medicine; process control and measurement in industry; and many uses in academic and industrial research, teaching, agriculture, geological exploration, construction and other activities. Other applications include non-destructive testing (radiography and gauging), food irradiation (e.g. for pathogen control) and sterilization of other products (e.g. medical devices). The waste can be in solid, liquid or gaseous form. Solid waste can include: (a) spent or disused sealed sources; (b) contaminated equipment, glassware, gloves and paper; and (c) animal carcasses, excreta and other biological waste. Liquid waste can include: (a) aqueous solutions and organic solutions resulting from research and production processes; (b) excreta; (c) liquids from the decontamination of laboratory equipment or facilities; and (d) liquids from activity measurement systems (such as scintillation counting). Gaseous waste is generated at a number of facilities from the production and radiolabelling of chemical compounds and organisms and from the treatment of solid and liquid waste. A broader overview of waste arising from this range of applications is presented in Appendix I.

1.5. Because of the wide range of waste types encountered and the possibility for changes to occur in the ways in which waste is generated and then managed, particular attention has to be given to the safety issues that may arise in the management and regulatory control of waste. Both the operator and the regulatory body should take these factors into account.

1.6. In facilities in which only small amounts of waste are generated, staff might have limited knowledge about the safety of radioactive waste management. The safety culture in the organization might not be particularly focused on radioactive

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[2] Spent sources and disused sources are not considered as waste in certain States, but the safe management of such sources entails application of the requirements, and as such they are addressed in this Safety Guide.

waste management because of this limited knowledge and/or because insufficient importance is given to safety by senior management in the organization.

1.7. Good operating practice can significantly reduce the amount of radioactive waste generated, but, in general, waste cannot be fully eliminated. The waste may contain sufficient quantities of radionuclides that it has the potential to pose serious risks to human health and the environment if the radionuclides are not properly managed. Experience has shown this to be the case, particularly in respect of spent or disused sealed sources where poor practices in the past have resulted in radiation exposure of both operating personnel and members of the public and have, on occasion, caused extensive contamination of the environment. Instances have arisen where poor practices in the management of waste have resulted in radiation burns, deaths and considerable economic loss. A brief description of the general approach to and the technical steps in the predisposal management of radioactive waste is given in the following paragraphs. 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, and there is, therefore, a need for the establishment of a national policy and strategy for the safe management of radioactive waste [3].

1.8. Processing of radioactive waste includes its pretreatment, treatment and conditioning and is primarily intended to produce a waste form that is compatible with the selected or anticipated disposal option. Radioactive waste will also be handled and may be stored between and within the basic steps in its management and will also have to be in a form that is suitable for such handling and storage as well as for any transport.

1.9. It may be that not all processing steps are necessary for particular types of radioactive waste. The type of processing necessary depends on the particular type of waste, its form and characteristics, and the overall approach to its management, including consideration of the generation of secondary waste. Where appropriate, the waste material resulting from processing may be reused or recycled, or cleared from regulatory control in accordance with the regulations in place.

1.10. Radioactive waste is prepared for disposal by the means described in para. 1.8. However, in many instances no disposal facilities are available and storage may be necessary for considerable periods of time before disposal facilities become available.

1.11. In some instances, there are several potentially conflicting demands in the predisposal management of the waste that need detailed consideration to determine the optimal integrated solution. Such considerations include balancing occupational exposures and/or public exposures, the short term and long term risk implications of different waste management strategies, the technological options available and the costs.

1.12. To select the most appropriate type of pretreatment, treatment and conditioning for radioactive waste when no disposal facility has been established, assumptions have to be made about the likely disposal option. It is necessary to address the interdependences and the potential conflicts between the operational demands of each of the various steps in waste management, while ensuring that the waste is contained and stored in a passive, safe condition. In striking a balance between choosing an option and retaining flexibility, it is necessary to ensure that conflicts between operational demands that might compromise safety are avoided [2].

1.13. This Safety Guide supersedes IAEA Safety Standards Series No. WS-G-2.7, Management of Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education.[3]

OBJECTIVE

1.14. The objective of this Safety Guide is to provide recommendations on how to meet the requirements established in GSR Part 5 [3], GSR Part 1 (Rev. 1) [4] and GSR Part 3 [5] for the safe predisposal management of radioactive waste arising from the use of radioactive materials in medicine, industry, agriculture, research and education. The guidance is intended for use by organizations generating and managing radioactive waste, organizations handling such waste on a centralized basis and regulatory bodies responsible for regulating such activities.

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[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Management of Waste from the Use of Radioactive Material in Medicine, Industry, Agriculture, Research and Education, IAEA Safety Standards Series No. WS-G-2.7, IAEA, Vienna (2005).

1.15. This Safety Guide addresses the roles and responsibilities of the various organizations involved in predisposal management of radioactive waste generated in medicine, industry, agriculture, research and education and in the handling and processing of such radioactive waste.

1.16. This Safety Guide focuses on facilities with moderate sized inventories of radioactive waste, such as those in medicine, industry and research, and can also be applied to facilities with small inventories of radioactive waste using a graded approach.

SCOPE

1.17. This Safety Guide is applicable to all activities involving predisposal management of radioactive waste associated with the use of radioactive materials in medicine, industry, agriculture, research and education, including the management of disused sealed radioactive sources. The Safety Guide focuses on waste generated at small to moderate sized facilities, such as hospitals and research centres, where radioactive waste is not usually generated in bulk quantities. It covers both waste generated from the use of radioactive material in such facilities and waste generated from the decommissioning of such facilities. The Safety Guide covers the managerial, administrative and technical issues associated with the safe management of radioactive waste, from its generation to its release from further regulatory control or its acceptance at a disposal facility or a storage facility awaiting the availability of a suitable disposal option. It does not include detailed arrangements for the disposal of waste; safety requirements for the disposal of waste are established in IAEA Safety Standards Series No. SSR-5, Disposal of Radioactive Waste [7].

1.18. The management of spent sealed sources and disused sealed sources considered as radioactive waste is highlighted in this Safety Guide because of the propensity for accidents with such sources to have serious consequences. Further guidance on the safety and security of radioactive sources is given in the Code of Conduct on the Safety and Security of Radioactive Sources [8] and in IAEA Safety Standards Series No. RS-G-1.10, Safety of Radiation Generators and Sealed Radioactive Sources [9].

1.19. The predisposal management of radioactive waste may take place at the facility where the waste originated, or at a separate facility dedicated for waste management, for example, a national and/or regional facility where waste is collected and managed on behalf of a number of waste generators. In this Safety

Guide, the term ‘facility’ is used to refer to either of these possibilities. For large facilities operated for specific processes, such as nuclear power plants, reprocessing facilities or storage facility for spent fuel, predisposal management is typically conducted within the operational function of such facilities.

1.20. This Safety Guide does not cover the management of radioactive waste generated at nuclear fuel cycle research and development facilities, which is addressed in IAEA Safety Standards Series No. SSG-41, Predisposal Management of Radioactive Waste from Nuclear Fuel Cycle Facilities [10]. This Safety Guide also does not cover the management of radioactive waste generated at power reactors or research reactors, which is addressed in IAEA Safety Standards Series No. SSG-40, Predisposal Management of Radioactive Waste from Nuclear Power Plants and Research Reactors [11].

1.21. This Safety Guide is applicable to the management of limited quantities of waste containing radionuclides of natural origin from industrial and research activities (such as the use of uranium in universities or luminizing with radium). The management of larger quantities of waste containing radionuclides of natural origin from the mining and processing of ores is addressed in IAEA Safety Standards Series No. WS-G-1.2, Management of Radioactive Waste from the Mining and Milling of Ores [12].

1.22. Specific guidance on the storage of small amounts of radioactive waste at different stages of its management is provided in this Safety Guide. More detailed recommendations are provided in IAEA Safety Standards Series No. WS-G-6.1, Storage of Radioactive Waste [13].

1.23. This Safety Guide provides general guidance on the transfer of radioactive waste from the premises where the waste is generated to a centralized radioactive waste management facility. Requirements and guidance on the transport of radioactive material can be found in IAEA Safety Standards Series No. SSR-6 (Rev. 1), Regulations for the Safe Transport of Radioactive Material, 2018 Edition [14] and IAEA Safety Standards Series No. SSG-26, Advisory Material for the IAEA Regulations for the Safe Transport of Radioactive Material (2012 Edition) [15].

1.24. Reference is made in this Safety Guide to removal of regulatory control from materials and to the control of effluent discharges into the environment. Further details on these matters are given in GSR Part 3 [5], IAEA Safety Standards Series No. RS-G-1.7, Application of the Concepts of Exclusion, Exemption and Clearance [16] and IAEA Safety Standards Series No. GSG-9, Regulatory Control of Radioactive Discharges to the Environment [17].

1.25. Where decommissioning generates only small amounts of radioactive waste, the guidance in this Safety Guide is relevant. Further requirements and guidance on the management of waste from decommissioning are provided in IAEA Safety Standards Series No. GSR Part 6, Decommissioning of Facilities [18] and IAEA Safety Standards Series No. SSG-49, Decommissioning of Medical, Industrial and Research Facilities [19].

1.26. This Safety Guide provides recommendations on safety assessment relevant to the management of the radioactive waste described in paras 1.16 and 1.21. More detailed recommendations on the safety case and safety assessment for the predisposal management of radioactive waste are given in IAEA Safety Standards Series No. GSG-3, The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste [20].

1.27. There are often hazards of a non-radiological nature associated with radioactive waste due to the presence of other hazardous materials, such as pathogens and heavy metals. Some guidance is given on aspects to be considered in respect of these hazards, where this is related to radiation safety. In some cases, these hazards dominate the choice of available waste management options. Detailed recommendations regarding non-radiological hazards are beyond the scope of this Safety Guide.

1.28. The management of consumer products, such as ionization chambers, smoke detectors, gaseous tritium light devices and lightning rods, which are frequently used in and on homes and other buildings and which are exempted from the requirements of GSR Part 3 [5], is outside the scope of this Safety Guide. Guidance on the management of consumer products is provided in IAEA Safety Standards Series No. SSG-36, Radiation Safety for Consumer Products [21]. Many States place restrictions on the available disposal options for certain types of consumer product, in order to minimize the amount of radionuclides present in the environment and not under regulatory control or to encourage recycling. If, at the end of their useful lifetimes, consumer products are managed as radioactive waste, the guidance provided in this Safety Guide applies.

STRUCTURE

1.29. Section 2 provides recommendations on the protection of human health and protection of the environment in relation to the predisposal management of radioactive waste. Section 3 describes the roles and responsibilities of the regulatory body, users of radioactive material who generate radioactive waste and operators[4] of waste management facilities. Section 4 deals with the steps in the management of radioactive waste. Section 5 provides recommendations on safety case and safety assessment. Section 6 addresses the development and operation of facilities and activities. Section 7 deals with the management system, record keeping and reporting. Appendix I provides a general description of the waste arising from the production and use of sealed and unsealed sources in medicine, industry and research and includes lists of the main radionuclides used in these activities. Appendix II presents an example of a fault schedule for safety assessment and environmental impact assessment. Appendices III, IV and V provide examples of management flow diagrams for solid radioactive waste, for biological radioactive waste and for disused sealed sources, respectively. Annex I gives examples of disused sealed sources and techniques for their management. Annex II presents an example of a strategy for the identification and location of disused sealed sources.

2. PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

RADIOACTIVE WASTE MANAGEMENT

2.1. The safety objective and the fundamental safety principles established in SF-1 [2] apply for all facilities and activities in which radioactive waste is generated or managed, and for the entire lifetime of such facilities, including planning, siting, design, manufacturing, construction, commissioning, operation, shutdown and decommissioning. This includes the associated transport of radioactive material and the management of radioactive waste.

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[4] Generators of radioactive waste, including organizations carrying out decommissioning activities, and the operators of predisposal radioactive waste management facilities are considered to be engaged in the management of radioactive waste. In this Safety Guide, they are hereinafter referred to as ‘operator(s)’.

2.2. The main options for the management of radioactive waste are presented in Section 4. To meet the safety objective, in considering options for the management of radioactive waste, due consideration has to be given to the protection of workers, the public (including future generations) and the environment.

2.3. GSR Part 5 [3], GSR Part 1 (Rev. 1) [4] and IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [22] require both the regulatory body and the operator to establish a management system that addresses safety, health, environmental, security, quality, societal and economic requirements in an integrated manner so that safety is not compromised. A key component of such a system in each organization is a robust safety culture.

2.4. In controlling the radiological and non-radiological hazards associated with radioactive waste, the following aspects have also to be considered: conventional health and safety issues, radiation risks that may transcend national borders, and the potential impacts and burdens on future generations arising from long periods of storage of radioactive waste.

2.5. The safety requirements established in GSR Part 5 [3] and GSR Part 3 [5] for the protection of human health and the environment apply to the predisposal management of radioactive waste generated in medicine, industry and research and other activities in which the amount of radioactive waste generated is small. Waste is required to be managed so as to protect human health and the environment now and in the future, without imposing undue burdens on future generations [3]. This means that the radiation exposure of workers involved in the management of radioactive waste is required to be optimized and, under normal operational conditions, is required to be in compliance with the system of dose limitation specified in GSR Part 3 [5] and that the risk of accidental exposure of workers is required to be controlled. Public exposures that arise from materials removed from controlled environments, from the discharge of effluents containing radionuclides, from accidental releases and from the transport of radioactive waste in the public domain are also required to be controlled [5].

GRADED APPROACH

2.6. Paragraph 1.16 of GSR Part 5 [3] states:

> "The regulatory body has to consider a graded approach to the application of the requirements for the predisposal management of radioactive waste, depending on the hazards, the complexity of facilities and activities, and

the characteristics of the waste, and will have to apply the requirements as necessary and appropriate."

2.7. A graded approach is "a process or method in which the stringency of the control measures and conditions to be applied is commensurate, to the extent practicable, with the likelihood and possible consequences of, and the level of risk associated with, a loss of control" [1].

2.8. The graded approach should be applied in a way that does not compromise safety and that ensures compliance with all relevant safety requirements and criteria.

2.9. In the context of the predisposal management of radioactive waste from the use of radioactive materials in medicine, industry, agriculture, research and education, the application of the graded approach should take into account the following connected factors:

(a) The hazards and complexity associated with the facility or the conduct of the activity (waste processing, including pretreatment, treatment and conditioning, and storage of the waste);
(b) The inventory and the characteristics (radiological, physical, chemical and biological properties) of the waste (see table II-1 in annex II of IAEA Safety Standards Series No. GSG-1, Classification of Radioactive Waste [23]) and potential criticality hazards;
(c) Aspects of nuclear security (i.e. the threat, the nature of the waste, and the attractiveness of the material for use in a malicious act).

2.10. Recommendations on the application of a graded approach in the safety case and safety assessment for the predisposal management of radioactive waste are provided in GSG-3 [20].

RADIATION PROTECTION

2.11. Radiation protection considerations are governed by the principles of justification of facilities and activities, optimization of protection and limitation of individual dose and risk [2, 5]. In accordance with the recommendations of the International Commission on Radiological Protection [24] and with the requirements established in GSR Part 3 [5], the management of radioactive waste is considered part of the entire 'practice' giving rise to the waste, and as such does not require separate justification.

2.12. Requirements for radiation protection are established at the national level, with due regard to GSR Part 3 [5]. In particular, GSR Part 3 [5] requires protection and safety to be optimized for any persons who are exposed as a result of activities in the predisposal management of radioactive waste, with due regard to dose constraints, and requires the exposures of individuals to be kept within specified dose limits.

2.13. National regulations will prescribe dose limits for the exposure of workers and members of the public under normal conditions. Internationally accepted values for these limits are contained in Schedule III of GSR Part 3 [5]. The normal exposures of individuals, both workers and members of the public, are required to be restricted such that neither the effective dose nor the equivalent dose to tissues and organs exceeds any relevant dose limit specified in Schedule III of GSR Part 3 [5]. Additional restrictions may be applied to ensure that these dose limits are not exceeded owing to a possible combination of exposures from different authorized practices, including waste management.

2.14. In addition to the provisions for protection against exposures that arise from normal operations, provision is also required to be made for protection against potential exposure. Requirements for protection against potential exposure are also established in GSR Part 3 [5]. Management and technical requirements to prevent the occurrence of accidents and provisions for mitigating their consequences if they do occur are established in GSR Part 3 [5] and IAEA Safety Standards Series No. GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency [25].

2.15. Protection and safety is also required to be optimized, such that the magnitude of individual doses, the number of individuals exposed and the likelihood of exposure are all kept as low as reasonably achievable, economic and societal factors being taken into account, with the doses to individuals being subject to dose constraints [5]. For occupational exposure and public exposure, the operator is required to ensure, as appropriate, that relevant constraints are used in the optimization of protection and safety. Specifically, the benefits of choosing a particular strategic option in predisposal waste management (including minimization of waste in terms of its type, activity and volume, reuse, recycling, pretreatment, treatment and conditioning) should be optimized, bearing in mind any additional exposure to workers over and above the occupational exposures incurred in the original use of the radioactive material [3, 5]. The optimization of protection and safety for any particular facility or activity should be approached from a systematic point of view. Such an approach needs to balance safety considerations for the facility or activity as a whole, not simply within an individual activity, and as such needs to cover management of the waste generated. The process of optimization of protection and safety may range from qualitative analyses to quantitative analyses using decision aiding techniques.

2.16. The regulatory body should specify the value of dose constraints for public exposure that apply for the control of discharges from the facility. GSG-9 [17] provides recommendations on the application of the requirements established in GSR Part 3 [5] for the regulatory control of radioactive discharges to the environment. For occupational exposure, the operator should demonstrate that individual doses would remain below established constraints. Dose constraints set by the operator should be subject to regulatory approval.

2.17. When choosing options for the predisposal management of radioactive waste, consideration needs to be given to both the short term and the long term radiological impacts for workers and members of the public; for example, by balancing current exposures resulting from the dispersal of radionuclides in the environment against the exposures that could arise in the future from the disposal of radioactive waste [2, 26].

2.18. Doses and risks associated with the transport of radioactive waste are managed in the same way as those associated with the transport of any radioactive material. Safety in the transport of radioactive waste is ensured by complying with SSR-6 (Rev. 1) [14].

Radiation protection programme

2.19. A radiation protection programme is required to be put in place that ensures radiation safety and the control of access to areas where radioactive waste is managed [5].

2.20. All necessary provisions are required to be put in place to keep occupational exposures below the established dose limits, and as low as reasonably achievable to the extent warranted by the complexity of the operational activity [5]. Further recommendations are provided in IAEA Safety Standards Series No. GSG-7, Occupational Radiation Protection [26].

2.21. Appropriate workplace monitoring in the areas where waste is managed is required to be carried out and appropriate individual monitoring is required to be provided to workers who could incur occupational exposure whilst managing radioactive waste [5]. Material to be removed from controlled areas is required to be adequately monitored [5].

PROTECTION OF THE ENVIRONMENT

2.22. Requirements for environmental protection that are associated with predisposal management of radioactive waste are established by the relevant national regulatory bodies, with all potential environmental impacts that could reasonably be expected being taken into consideration [2, 5]. Detailed recommendations on assessing radiological environmental impacts are given in IAEA Safety Standards Series No. GSG-10, Prospective Radiological Environmental Impact Assessment for Facilities and Activities [27]. GSG-9 [17] provides recommendations and guidance on the control of radioactive discharges to the environment.

Environmental monitoring

2.23. Environmental monitoring is required to be a condition for authorization (see para. 3.135(a) of GSR Part 3 [5]) for any large waste management facility, but environmental monitoring might not need to be performed for smaller, less complex facilities. The need for monitoring should be closely linked to the possibility of significant radiation doses being incurred by the public: see IAEA Safety Standards Series No. RS-G-1.8, Environmental and Source Monitoring for Purposes of Radiation Protection [28]. A limited amount of monitoring may sometimes be adequate for purposes of public assurance. The scope of the monitoring programme, if it is necessary, should be established during the authorization process.

2.24. An environmental monitoring programme, if it is necessary, should be established in accordance with the risks posed by the waste management facility and the environmental characteristics of the surrounding area. The programme should involve the collection of environmental samples (for example from groundwater, air and dust) and measurement of radiation levels and contamination levels. When environmental monitoring is necessary, pre-operational monitoring should be carried out to establish the local background radiation level and concentration of radionuclides in environmental materials, which can vary from location to location [28].

3. ROLES AND RESPONSIBILITIES

GENERAL

3.1. The management of all radioactive waste is required to take place within an appropriate national legal framework that provides a clear allocation of responsibilities and that provides for effective regulatory control of activities generating waste and of facilities where such waste is managed [3]. Requirements on the allocation of such responsibilities, in particular those of the regulatory body, are established in GSR Part 1 (Rev. 1) [4] and GSR Part 3 [5]. Selected responsibilities of the various parties involved that are specific to the predisposal management of radioactive waste are outlined in the following paragraphs. The legal framework is also required to be compatible with other national and international laws and regulations. Although laws are normally of general application, national legal systems may have facility specific or site specific regulations on the management of waste generated from particular activities.

3.2. While safety is the prime responsibility of the operator, to whom the majority of the requirements apply, ensuring safety and developing a broader confidence in safety also requires the establishment of an effective regulatory process within a clearly defined legal framework [4]. This framework should ensure that there is a clear allocation of responsibilities for safety during the entire waste management process, including the transfer of such waste from one operator to another and the decommissioning of facilities where radioactive material has been used. This continuity of responsibility for safety should be ensured through specification of ownership and clarity of custodianship, enforced where necessary though authorizations and control by the regulatory body.

3.3. Regulatory responsibilities and responsibilities of the operator for radioactive waste management should be clearly delineated and should be functionally separated as far as possible in order to ensure effective and strict regulatory control over the different stages of waste management and the different organizations involved.

3.4. It is possible that the predisposal management of radioactive waste will involve the transfer of radioactive waste from one operator to another, or that radioactive waste may even be processed in another State. In such situations, continuity of responsibility for safety is necessary throughout the waste management process. In the event of the transfer of radioactive waste beyond national boundaries, article 27.1 of the Joint Convention on the Safety of Spent

Fuel Management and on the Safety of Radioactive Waste Management [6] applies to Contracting Parties to the Joint Convention, and compliance with this article is considered good practice for all States. This article concerns the need for the prior notification and consent of the State of destination, the need for adequate technical and administrative capacity in the State of destination, and the need to subject transboundary movement through transit States to the relevant international obligations.

3.5. The aim of predisposal radioactive waste management should be to minimize waste generation and to produce a waste form that conforms to the requirements for subsequent handling, processing, transport and storage, or meets the acceptance requirements for disposal. The waste management option selected may also result in a waste or material that is suitable for return to a manufacturer or supplier of radioactive material, to be recycled, for authorized discharge as liquid or gas to the environment [3, 5, 17], or for removal from regulatory control.

NATIONAL POLICY AND STRATEGY

Requirement 1 of GSR Part 5 [3]: Legal and regulatory framework

"The government shall provide for an appropriate national legal and regulatory framework within which radioactive waste management activities can be planned and safely carried out. This shall include the clear and unequivocal allocation of responsibilities, the securing of financial and other resources, and the provision of independent regulatory functions. Protection shall also be provided beyond national borders as appropriate and necessary for neighbouring States that may be affected."

Requirement 2 of GSR Part 5 [3]: National policy and strategy on radioactive waste management

"To ensure the effective management and control of radioactive waste, the government shall ensure that a national policy and a strategy for radioactive waste management are established. The policy and strategy shall be appropriate for the nature and the amount of the radioactive waste in the State, shall indicate the regulatory control required, and shall consider relevant societal factors. The policy and strategy shall be compatible with the fundamental safety principles [2]

and with international instruments, conventions and codes that have been ratified by the State. The national policy and strategy shall form the basis for decision making with respect to the management of radioactive waste.”

3.6. The government is responsible for establishing a national policy and corresponding strategies for the management of radioactive waste. The policy and strategy, and the legal framework, should cover all types and volumes of radioactive waste generated in the State, all waste processing and storage facilities located in the State, and waste imported or exported from it, with due account taken of the interdependences between the various stages of radioactive waste management, the time periods involved and the waste management options available.

3.7. Measures should be established within the legal framework to ensure compliance with other relevant international legal instruments, such as the Joint Convention [6] and the Code of Conduct on the Safety and Security of Radioactive Sources [8].

3.8. Where nuclear safety, environmental protection, industrial safety and occupational health aspects are separately regulated, the regulatory framework should recognize that safety as a whole is affected by the interdependences between radiological, industrial, chemical and toxic hazards. This should be taken into account in the regulatory framework, so that it delivers effective control.

3.9. It should be ensured within the legal framework that the construction of facilities for the predisposal management of radioactive waste adjacent to an existing facility that could affect the safety of either facility is monitored and controlled by means of planning requirements or other legal instruments.

3.10. The management of radioactive waste may entail the transfer of radioactive waste from one operator to another, or from one State to another. Such transfers create interdependences in legal responsibilities as well as physical interdependences in the various steps in the management of radioactive waste. The legal framework should include provisions to ensure a clear allocation of responsibility for safety throughout the entire waste management process, in particular with respect to the interface of waste management with the storage of radioactive waste and with respect to its transfer between operating organizations.

3.11. The extent to which on-site waste management is undertaken by an operator depends on the options available in terms of the national waste management strategy, the infrastructure of the operator and the technical competence available in relation to the management of the generated waste. On-site waste management can include a full range of operations, such as waste minimization, pretreatment (including segregation, characterization and chemical adjustment), treatment, conditioning and storage. However, as a minimum, waste minimization, segregation, basic characterization and associated storage should be undertaken on the site.

3.12. In many of the situations covered by this Safety Guide, a strategy involving a combination of on-site waste management and waste management at a centralized facility is appropriate. Thus, waste containing short lived radionuclides might be dealt with locally at the site where it is generated and waste with long lived radionuclides (as could be the case for the majority of disused sealed radioactive sources) might be dealt with at a national and/or regional facility.

3.13. The government is responsible for establishing a regulatory body independent from the owner of the radioactive waste or the operator managing the radioactive waste, with adequate authority, power, staffing and financial resources to discharge its assigned responsibilities [3, 4].

3.14. Responsibility for safety should be ensured by means of a system of authorization by the regulatory body. For transfers of radioactive waste between one State and another, continuation of responsibility is necessary throughout, and therefore there is a need for authorizations from the relevant national regulatory bodies of both States [3].

3.15. Interdependences exist between the various steps in the management of radioactive waste. The national and regulatory framework should set out clear definitions of the interdependences and the responsibilities for the management of the interdependences.

3.16. A mechanism for providing adequate financial resources is required to be established to cover any future costs, in particular the costs associated with the storage of radioactive waste, decommissioning of the predisposal waste management facility, and the costs of long term management of radioactive waste, if applicable. The financial mechanism should be established before licensing and eventual operation, and should be updated as necessary. Consideration is also required to be given to provision of the necessary financial resources in the event of a premature shutdown of the predisposal radioactive waste management facility or the early dispatch of waste to a disposal facility [18].

3.17. The government should consult interested parties (i.e. those who are involved in or are affected by radioactive waste management activities) on matters relating to the development of policies and strategies that affect the management of radioactive waste.

3.18. In order to facilitate the establishment of a national policy and strategy, the government should establish a national inventory of radioactive waste (both current waste and anticipated waste, including waste generated during the decommissioning and dismantling of facilities) and should update it at regular intervals. This inventory should take into account the guidance provided in GSG-1 [23].

3.19. Facilities at which waste from the use of radioactive materials in medicine, industry, agriculture, research and education is to be managed should have sufficient capacity to process all waste generated and the storage capacity should be sufficient to take account of uncertainties in the availability of facilities for treatment, conditioning and disposal.

3.20. The national policy and strategy should address the various waste classes, as identified in GSG-1 [23], and their long term management, from a technical point of view as well as to ensure adequate human resources and financial resources. It should take due account of societal and economic developments.

RESPONSIBILITIES OF THE REGULATORY BODY

Requirement 3 of GSR Part 5 [3]: Responsibilities of the regulatory body

“The regulatory body shall establish the requirements for the development of radioactive waste management facilities and activities and shall set out procedures for meeting the requirements for the various stages of the licensing process. The regulatory body shall review and assess the safety case[3] and the environmental impact assessment for radioactive waste management facilities and activities, as prepared by the operator both prior to authorization and periodically during operation. The regulatory body shall provide for the issuing, amending, suspension or revoking of licences, subject to any necessary conditions. The regulatory body shall carry out activities to verify that the operator meets these conditions. Enforcement actions shall be taken as

necessary by the regulatory body in the event of deviations from, or non-compliance with, requirements and conditions.

"[3] The safety case is a collection of arguments and evidence in support of the safety of a facility or activity. The safety case will normally include the findings of a safety assessment, and will typically include information (including supporting evidence and reasoning) on the robustness and reliability of the safety assessment and the assumptions made therein [1]."

3.21. Paragraph 3.7 of GSR Part 5 [3] states:

> "General requirements for the protection of human health and the environment are usually stated in national policy and set out in legislation. The regulatory body has to establish regulatory requirements specific to the predisposal management of radioactive waste, on the basis of national policy and legislation and with due regard to the objectives and principles set out in Section 2 [of GSR Part 5]."

3.22. To facilitate compliance with regulatory requirements, the regulatory body (see GSR Part 5 [3], para. 3.8):

(a) Provides necessary guidance on the interpretation of national standards and regulatory requirements that takes into consideration the complexity of the operations and the magnitude of the hazards associated with the facility and operations (the graded approach).
(b) Encourages dialogue between and participates in dialogues with the operator and other interested parties, and provides advice on development, interpretation and application of legislation and regulations.
(c) Ensures that the parties that generate or manage radioactive waste are assigned responsibilities for the preparation and keeping of relevant documents and records covering all the waste management steps, and ensures that that record keeping is properly carried out and that records are maintained for an appropriate period of time.
(d) Establishes an appropriate definition and/or classification of radioactive waste [23].
(e) Establishes criteria for the clearance of material from regulatory control, in accordance with national policy [5].
(f) Establishes and clarifies to the operator the processes used to evaluate safety and to review applications.
(g) Establishes and clarifies to applicants for a licence the requirements for licence application.

(h) Ensures that no activities generating radioactive waste commence without provision for the proper management of the radioactive waste and that adequate and suitable storage capacity is available.
(i) Documents the procedures that apply to the mechanisms for compliance verification and enforcement.
(j) Establishes a mechanism by means of which information on incidents significant to safety is disseminated to interested parties.
(k) Enters into agreement, where appropriate, with other governmental bodies responsible for regulation in related fields to delineate areas of responsibility or of cooperation.
(l) Ensures that requirements and criteria relating to the safety of facilities, processes and operations for radioactive waste management are established, including for the handling, processing, transport, storage and disposal of such waste. Such requirements and criteria should address acceptance of waste packages for disposal in existing and planned facilities.
(m) Establishes requirements for the decommissioning of facilities, including conditions on the end points of decommissioning.
(n) Establishes requirements for the removal of materials from regulated facilities or activities and provides guidance and regulatory agreement, as appropriate, for the authorized discharge of liquids and gases containing radionuclides.
(o) Defines the required time period for which records will be retained by the operator.
(p) Ensures that its own staff and the staff of the operator have the necessary expertise and competence to perform their functions adequately and, where necessary, ensures that adequate training is provided.
(q) Ensures that due consideration is given to non-radiological hazards throughout all steps in the predisposal management of radioactive waste.

3.23. The regulatory body will require the operator to submit safety documentation in support of an application for a licence or other type of authorization involving the management of radioactive waste. The safety case will include a supporting safety assessment commensurate with the complexity of the facility.

3.24. Paragraph 3.9 of GSR Part 5 [3] states:

> "The regulatory body has to carry out activities that are necessary to verify that requirements for safety and environmental protection are being met by the operator. These activities are required to be supported by an effective management system, including the establishment and maintenance of a strong safety culture [GSR Part 2 [22]]."

3.25. To fulfill its regulatory functions, the regulatory body, where appropriate, should undertake research, acquire independent assessment capabilities and participate in activities for international cooperation. The regulatory body should also ensure the interface between safety and security; and ensure that safety and security do not adversely affect each other.

RESPONSIBILITIES OF THE OPERATOR (INCLUDING THE GENERATOR OF THE WASTE)

Requirement 4 of GSR Part 5 [3]: Responsibilities of the operator

"Operators shall be responsible for the safety of predisposal radioactive waste management facilities or activities. ... The operator shall carry out safety assessments and shall develop a safety case, and shall ensure that the necessary activities for siting, design, construction, commissioning, operation, shutdown and decommissioning are carried out in compliance with legal and regulatory requirements."

3.26. Operators of facilities that handle, use or process radioactive materials have the primary responsibility for the safe management of any associated radioactive waste [3]. Ideally, this should include responsibility for disposal of the waste, but, where disposal facilities are not available, the operator has responsibility for the safe long term storage of the waste.

3.27. Before commencing construction or significant modification of a waste management facility or starting any activity that may generate radioactive waste, the operator should submit an application for a licence or other type of authorization to the regulatory body, which should include the information specified in para. 3.23. The application should identify the waste management steps to be followed, including arrangements for storage and disposal, should detail proposed design and operational practices, and should include an explanation of how safety requirements will be met.

3.28. Before commencing operations involving radioactive material, when necessary, the operator should carry out commissioning tests approved by the regulatory body, in order to demonstrate compliance with the design and safety requirements.

3.29. At the outset of planning for operations, the operator should prepare outline plans for eventual decommissioning activities [18, 19].

3.30. “Depending on the complexity of the operations and the magnitude of the hazards associated with the facility or the activities concerned, the operator has to ensure an adequate level of protection and safety by various means” (GSR Part 5 [3], para. 3.11). These means should include:

(a) Ensuring that the necessary activities for siting, design, construction, commissioning, operation, shutdown and decommissioning are carried out in compliance with legal and regulatory requirements.
(b) Demonstration of safety by means of the safety case and safety assessment, and for an existing facility or activity by means of periodic safety reviews (which should cover all stages of the projected lifetime of the facility, including decommissioning).
(c) Demonstration of environmental protection by means of a radiological environmental impact assessment, when required by national regulations.
(d) Establishment of a radioactive waste management strategy that includes all waste under the control of the operator, including waste that has arisen from past practices, taking into account interdependences among all steps in waste management, the available options and the national radioactive waste management policy and strategy, as far as applicable.
(e) Derivation of operational limits and conditions as well as administrative controls, including waste acceptance criteria, to assist with ensuring that the predisposal radioactive waste management facility is operated in accordance with the national regulations and the facility specific safety case.
(f) Ensuring that the generation of radioactive waste is kept to the minimum practicable, e.g. by using best available techniques.
(g) Ensuring that radioactive waste is managed by providing appropriate arrangements for the collection, segregation, characterization, classification, treatment, conditioning, storage and disposal of the waste, including the timely transfer of the waste among the various management steps.
(h) Ensuring that equipment and facilities are available to carry out the radioactive waste management activities safely.
(i) Preparation and implementation of appropriate operating procedures, including monitoring.
(j) Application of good engineering practice, maintaining an awareness of waste management practices and feedback from relevant operating experience.
(k) Ensuring adequate human resources and that staff are trained, qualified and competent, and, where applicable, licensed by the regulatory body, throughout the lifetime of the facility.
(l) Ensuring that there are no unavoidable delays in processing waste and transferring it to the next step as soon as practicable.
(m) Applying relevant international standards to ensure operations are safe.

(n) Establishment and implementation of an integrated management system [22] that ensures the safety and security of all authorized activities and compliance with regulatory requirements. The management system includes clear delineation of responsibilities, operating procedures and specifications for record retention, and makes provision for routine and non-routine reports that are required by the regulatory body.
(o) Maintenance of records and reports as required by the regulatory body, including those records and reports necessary to guarantee accountability for and traceability of radioactive waste throughout the different processes of radioactive waste management.
(p) Ensuring the monitoring, recording and reporting to the regulatory body of clearance of materials and of discharges of radionuclides, with sufficient detail and accuracy to demonstrate compliance with any regulatory requirements, limits and conditions established in the authorization, and reporting promptly to the regulatory body on any clearance of materials, discharges or releases exceeding the authorized amounts.
(q) Providing a record of the inventory of radioactive waste generated, held and stored, of discharges and of radioactive material removed from regulated facilities and activities or transferred to the responsibility of another operator. This record should be provided at such intervals, in such a form and containing such details as the regulatory body may require.
(r) Establishment and maintenance of a mechanism to provide and ensure adequate financial resources are available to the operator to discharge its responsibilities. All phases of the activity and/or stages of the lifetime of the facility, including end of life and decommissioning, should be covered by the financial assurance. The owner or operator of the radioactive waste management facility should provide proof that they will have sufficient funds available to pay for all stages of the activity and/or facility, including end of life and decommissioning of the facility. They also should demonstrate that they have sufficient funds to pay for decommissioning and for management of the associated radioactive waste.
(s) Assessment of the integrity of the waste control measures and facilities to ensure that they are tolerant to identified faults.
(t) Development of an emergency plan.
(u) Consideration of non-radiological hazards and conventional health and safety issues.
(v) Providing other information on radioactive waste management activities and facilities as required by the regulatory body.

3.31. The operator may use cost–benefit arguments to justify its proposed programme, as long as safety limits are respected.

3.32. The operator should handle, process and store the waste in an approved manner at its own facility or it may transfer the waste to the operator of an authorized waste management facility. The operator should ensure that radioactive waste is transferred only in accordance with waste acceptance criteria established by the radioactive waste management facility and that waste consignments are accompanied by the necessary information on the waste inventory.

3.33. Radioactive waste is required to be transported in accordance with SSR-6 (Rev. 1) [14].

3.34. The operator also has responsibility for ensuring that the waste packages comply with acceptance requirements for any long term storage or disposal of the waste or with requirements approved by or established by the regulatory body.

3.35. Sufficient financial and human resources should be made available by the operator to ensure that the waste management programme can be carried out safely and in accordance with conditions of authorization.

3.36. Staff with responsibilities for the management of radioactive waste should have appropriate qualifications, the appropriate scientific and/or technical knowledge and the appropriate level of experience to discharge their responsibilities competently.

3.37. The operator is responsible for the safety of all waste management activities, even if the work is contracted to a third party, until the waste becomes the responsibility of another authorized operator. "Where appropriate, the operator may delegate work associated with the aforementioned responsibilities to other organizations, but the operator has to retain overall responsibility and control" (GSR Part 5 [3], para. 3.14).

3.38. "The operator is responsible for implementing measures to ensure an appropriate level of security" (GSR Part 5 [3], para. 3.15).

3.39. "The operator is responsible for applying management systems to all steps and elements of the predisposal management of radioactive waste" (GSR Part 5 [3], para. 3.16). The operator is required to establish and maintain a strong safety culture by means of a demonstrated commitment to safety on the part of senior management [22, 29, 30].

3.40. Paragraph 3.17 of GSR Part 5 [3] states:

> "The operator is responsible for establishing and implementing the overall strategy for the management of the waste that is generated, and for providing the required financial securities, taking into account interdependences among all steps in waste management, the available options and the national radioactive waste management policy."

The overall waste management strategy should include and describe all the steps of the predisposal management of waste.

3.41. "Information about changes of ownership of waste or about changes in the relationship between owner and licensee has to be provided to the regulatory body" (GSR Part 5 [3], para. 3.18).

3.42. The operator should appoint an appropriately qualified person with overall responsibility for day to day control over the management of radioactive waste. This person may be the radiation protection officer, depending on the size and complexity of the organization. The appointed person should be given the specific responsibility of advising senior management on the implementation of all matters relating to the safe management of radioactive waste. Appropriate authority and resources should be provided to this person in order to ensure that the operator's obligations as specified in this section are carried out. This person may have the following responsibilities:

(a) To make and maintain contact with all relevant persons involved with radioactive waste and to provide an authoritative point of advice and guidance;
(b) To liaise, as necessary, with the radiation protection officer and with other radioactive waste management organizations;
(c) To establish and maintain a detailed record keeping system for all stages of radioactive waste management, including the inventory of radioactive waste;
(d) To ensure the proper conditioning of radioactive waste when appropriate;
(e) To ensure that on-site transfer of radioactive waste is carried out in accordance with written procedures;
(f) To ensure that waste packages for transport off the site are prepared to be in compliance with SSR-6 (Rev. 1) [14];
(g) To elaborate, review and update the safety case and safety assessment;
(h) To seek approval from the regulatory body for any new activity or facility dealing with radioactive waste management and transport of radioactive waste;
(i) To ensure appropriate shielding, labelling and integrity of waste packages;

(j) To ensure that any discharge of effluents is below the limits authorized by the regulatory body and is kept as low as reasonably achievable;
(k) To ensure that solid waste disposed of in a municipal landfill is in accordance with clearance levels, if such clearance levels have been established by the regulatory body;
(l) To report on incidents and inappropriate waste management practices to senior management of the operator;
(m) To keep his or her knowledge up to date and to maintain up to date records of the characteristics of discharges and of disposal options.

Emergency preparedness

3.43. The operator is required to establish and maintain an emergency plan commensurate with the hazards associated with the radioactive waste management facility and activities, and is required to report incidents significant to safety in a timely manner to the regulatory body and other interested parties, as appropriate [25].

3.44. The emergency plan should include, at a minimum, the training of staff to be competent to recognize and react to an accident or emergency, the assignment of responsibilities to the various parties involved and appropriate arrangements and equipment for the protection of emergency workers. Requirements for emergency preparedness and response are established in GSR Part 7 [25] and further guidance is provided in IAEA Safety Standards Series No. GS-G-2.1, Arrangements for Preparedness for a Nuclear or Radiological Emergency [31].

INTEGRATED APPROACH TO SAFETY

Requirement 5 of GSR Part 5 [3]: Requirements in respect of security measures

"Measures shall be implemented to ensure an integrated approach to safety and security in the predisposal management of radioactive waste."

Requirement 21 of GSR Part 5 [3]: System of accounting for and control of nuclear material

"For facilities subject to agreements on nuclear material accounting, in the design and operation of predisposal radioactive waste management facilities the system of accounting for and control of nuclear material

shall be implemented in such a way as not to compromise the safety of the facility [Refs [32–34]].”

3.45. Physical protection arrangements should be put in place at facilities where radioactive waste is generated or managed to ensure that radioactive waste is not accidentally or deliberately removed from its proper location without authorization. Particular attention should be given to materials or equipment of intrinsic value or that could pose a serious threat to human health or the environment if control were lost.

3.46. The operator should assess and manage the interfaces between nuclear security, safety and nuclear material accountancy and control activities in a manner to ensure that they do not adversely affect one another and that, to the extent possible, they are mutually supportive.

3.47. “Where security measures are necessary to prevent the unauthorized access of individuals and the unauthorized removal of radioactive material, both safety and security are to be approached in an integrated manner” (GSR Part 5 [3], para. 3.19).

3.48. When material needs to be accessed for purposes of waste management or for IAEA safeguards activities, all the requirements for radiation protection, waste management and nuclear security should be taken into account. Fundamentals and specific recommendations on nuclear security in the management of radioactive waste are provided in the IAEA Nuclear Security Series [35–37].

3.49. “The level of security is required to be commensurate with the level of radiological hazard and the nature of the waste” (GSR Part 5 [3], para. 3.20).

INTERDEPENDENCES

Requirement 6 of GSR Part 5 [3]: Interdependences

“Interdependences among all steps in the predisposal management of radioactive waste, as well as the impact of the anticipated disposal option, shall be appropriately taken into account.”

3.50. Interdependences exist among all steps in the management of radioactive waste, from the generation of the waste up to its disposal, discharge or, as far as practicable, removal of radioactive material within authorized practices from any further regulatory control. In selecting strategies and activities for the predisposal management of radioactive waste, planning should be carried out for all the various steps so that a balanced approach to safety is taken in the overall waste management programme and conflicts between the safety requirements and operational requirements are avoided. There are various alternatives for each step in the management of radioactive waste. For example, treatment and conditioning options are influenced by the established or anticipated waste acceptance criteria for disposal.

3.51. The following aspects, in particular, should be addressed:

(a) The identification of interfaces between each step and the definition of the responsibilities of the various organizations involved at these interfaces;
(b) The establishment of waste acceptance criteria, with approval of the regulatory body where necessary, and the confirmation of conformance with the waste acceptance criteria by means of verification tests or the examination of records.

3.52. The waste management programme should identify all relevant interdependences and should include arrangements to ensure that they are appropriately considered from the point of generation of the waste to the point of its disposal. For example, the waste acceptance criteria for disposal should be known and appropriately considered when the waste is generated, so that at the point of generation the controls and information associated with the waste will be aligned with the requirements for the next stage in the management of the waste and its disposal. Thus, the waste acceptance criteria for each step of predisposal management of radioactive waste should be aligned with the waste acceptance criteria for the next step of predisposal management of radioactive waste, ultimately up to the waste acceptance criteria for disposal. If a disposal facility is not yet available, reasonable assumptions are required to be made about the likely disposal option, including likely waste acceptance criteria (see GSR Part 5 [3], para. 1.8).

4. STEPS IN THE PREDISPOSAL MANAGEMENT OF RADIOACTIVE WASTE

GENERAL

4.1. Paragraph 4.4 of GSR Part 5 [3] states:

> "Various factors, including the nature and the amount of radioactive waste, occupational and public exposures, environmental effects, and human health, safety, and social and economic factors, are to be considered when deciding between options in the predisposal management of radioactive waste. However, the preferred option, as far as is reasonably practicable, is to concentrate and contain the waste and to isolate it from the biosphere."

4.2. Paragraph 4.5 of GSR Part 5 [3] states:

> "In the predisposal management of radioactive waste, decisions often have to be made at a time when no disposal facility is available and the waste acceptance criteria for disposal are unknown. A similar situation would arise if radioactive waste were to be stored over long periods of time for reasons of safety or for other reasons. In both cases, consideration has to be given to whether, for the purposes of safety, the radioactive waste will be stored in a raw, a treated or a conditioned form."

For example, in the case of disused sealed radioactive sources, preference is given to the conditioning option with the possibility of later retrieving the source for disposal. "The anticipated needs for any future steps in radioactive waste management have to be taken into account as far as possible in making decisions on the processing of the waste" (GSR Part 5 [3], para. 4.5).

4.3. The predisposal management of radioactive waste includes a number of processing activities which cover pretreatment, treatment, and conditioning. It also includes various storage and handling operations and transport to a centralized waste management facility and/or to a disposal facility. The management of lesser quantities of waste can be performed at the site of its generation (which may be a hospital, laboratory or research centre) and/or at a centralized waste management facility.

RADIOACTIVE WASTE MANAGEMENT AND CONTROL, INCLUDING MINIMIZATION OF WASTE

Requirement 8 of GSR Part 5 [3]: Radioactive waste generation and control

“All radioactive waste shall be identified and controlled. Radioactive waste arisings shall be kept to the minimum practicable.”

4.4. The regulatory body should require the operator to submit, as part of the authorization process, specific comprehensive information on the provisions adopted to minimize the amount of waste generated as far as practicable. Paragraph 4.6 of GSR Part 5 [3] states:

> “Measures to control the generation of radioactive waste, in terms of both volume and radioactivity content, have to be considered before the construction of a facility, beginning with the design phase, and throughout the lifetime of the facility, in the selection of the materials used for its construction, and in the control of the materials and the selection of the processes, equipment and procedures used throughout its operation and decommissioning. The control measures are generally applied in the following order: reduce waste generation, reuse items as originally intended, recycle materials and, finally, consider disposal as waste.”

4.5. Paragraph 4.7 of GSR Part 5 [3] states:

> “Careful planning has to be applied to the siting, design, construction, commissioning, operation, shutdown and decommissioning of facilities in which waste is generated, to keep the volume and the radioactive content of the waste arisings to the minimum practicable.”

4.6. The operator should adopt available provisions for avoiding the generation of radioactive waste, for example through the appropriate design and operation of the facility and using whenever possible radionuclides of relatively short half-life that will decay to insignificant levels within a short timescale. In addition, the operator should consider the recycling and reuse of radioactive material and of equipment to reduce the amount of radioactive waste to be managed and disposed of. Waste minimization is an important step in waste management and controlling risks. The implications of minimizing the amount of waste generated, for example, the implications for occupational exposure, should be assessed as part of the safety assessment and safety case.

4.7. Unnecessary materials should not be taken into controlled areas, in order to reduce the potential generation of radioactive waste and the spread of contamination.

4.8. Another essential aspect of waste minimization is to use the minimum quantity of radioactive material consistent with achieving the objective of the application. Consideration should be given to the need to control and optimize the procurement of radioactive materials.

4.9. Wherever possible, when purchasing sealed radioactive sources, contractual arrangements should be put in place that allow the return of sources to the manufacturer or to a predetermined waste management facility following use. This is particularly important for high activity sources from which regulatory control cannot be removed until after many years of decay storage and for sources containing long lived radionuclides (see IAEA Safety Standards Series No. SSG-19, National Strategy for Regaining Control over Orphan Sources and Improving Control over Vulnerable Sources [38]).

4.10. "The reuse and recycling of materials has to be applied to keep the generation of radioactive waste to the minimum practicable, provided that protection objectives are met" (GSR Part 5 [3], para. 4.8).

4.11. The reuse and/or recycling of radioactive materials should be considered as an alternative to disposal, if circumstances permit. The safety of reuse and/or recycling should be assessed before operations are started and, where additional risks could arise outside the authorized operations of the facility, approval from the regulatory body should be sought. Recycling and reuse can include the following activities:

(a) The reuse of sealed radioactive sources by the owner or by a new owner with appropriate authorization;
(b) The recycling of sealed radioactive sources by the manufacturer or by another authorized organization undertaking recycling;
(c) The decontamination and/or reuse of material, such as equipment and protective clothing;
(d) The recycling and reuse of materials that have met the conditions for the removal of regulatory control, as defined by the regulatory body.

4.12. Paragraph 4.9 of GSR Part 5 [3] states:

> "The authorized discharge of effluent and clearance of materials from regulatory control, after some appropriate processing and/or a sufficiently long period of storage, together with reuse and recycling of material, can be effective in reducing the amount of radioactive waste that needs further processing or storage. The operator has to ensure that these management options, if implemented, are in compliance with the conditions and criteria established in regulations or by the regulatory body. The regulatory body also has to ensure that the operator gives due consideration to non-radiological hazards in applying such options."

4.13. The operator, in order to keep the generation of radioactive waste to a minimum, in addition to the above mentioned recommendations, should adopt provisions such as the following:

(a) The careful control of the collection, segregation, packaging and handling of radioactive materials.
(b) Good waste segregation practices, including clearance of materials, at the point of generation of the waste.
(c) The efficient operation of the collection and processing systems for gaseous and liquid radioactive waste.
(d) The taking of precautions to avoid the contamination of materials, equipment and building surfaces in order to reduce the need for decontamination.
(e) Restrictions on taking packaging and other unnecessary material into controlled areas.
(f) The planning and performance of periodic surface monitoring and maintenance work with due care and with particular emphasis on precautions to avoid the spread of contamination.
(g) Establishing and maintaining a proper records management system that allows the periodic assessment of the effectiveness of measures adopted to minimize the generation of radioactive waste. The system should include the specification of measurable indicators for assessing the effectiveness of the applied system.

4.14. The non-radiological hazards of waste should also be considered. The mixing of radioactive waste with toxic or hazardous materials should be avoided. For example, it would be preferable to use a thermocouple for temperature measurement rather than a mercury glass thermometer to avoid the possible formation of a waste stream containing contaminated mercury.

CHARACTERIZATION AND CLASSIFICATION OF RADIOACTIVE WASTE

Requirement 9 of GSR Part 5 [3]: Characterization and classification of radioactive waste

"At various steps in the predisposal management of radioactive waste, the radioactive waste shall be characterized and classified in accordance with requirements established or approved by the regulatory body."

4.15. "Radioactive waste has to be characterized in terms of its physical, mechanical, chemical, radiological and biological properties" (GSR Part 5 [3], para. 4.10). Paragraph 4.11 of GSR Part 5 [3] states:

> "The characterization serves to provide information relevant to process control and assurance that the waste or waste package will meet the acceptance criteria for processing, storage, transport and disposal of the waste. The relevant characteristics of the waste have to be recorded to facilitate its further management."

4.16. Characterization of waste can be used for different purposes, such as the identification of the potential hazards associated with the particular types of waste; the designation of waste for decay; particular processing, storage or disposal options; and the planning and design of waste management facilities. Reference [39] provides information on waste characterization. The data from the characterization processes should be recorded and a record should be maintained for an appropriate period of time.

4.17. Classification of waste enables selection of the most appropriate waste management option and is often considerably influenced by the half-lives of the radionuclides contained in the waste. As a priority, waste containing radionuclides with short radioactive half-lives that can be managed by safe storage until decay to insignificant levels should be segregated from waste containing radionuclides with longer half-lives. In this context, due consideration should be given to impurities with long radioactive half-lives, which are not always detectable during the initial characterization of short lived waste. The most common classification is that made from the perspective of the future disposal option for the waste: see GSG-1 [23].

4.18. Radioactive waste generated from the use of radioactive materials can generally be categorized for operational purposes into the following main groups: solid waste, liquid waste and gaseous waste. The waste may contain radionuclides that are differentiated by activity (alpha, beta–gamma and neutron emitters) and half-life, and may further be differentiated by the physical, mechanical, chemical and biological properties of the waste matrix.

4.19. In order to ensure the proper interdependence among all steps in radioactive waste management and so that waste will be handled effectively when being transferred between operators, in the development of the categorization scheme the operator should take into account the acceptance criteria established for the subsequent handling, processing, transport, storage and disposal steps, within the overall waste management process.

PROCESSING OF RADIOACTIVE WASTE

Requirement 10 of GSR Part 5 [3]: Processing of radioactive waste

"Radioactive material for which no further use is foreseen, and with characteristics that make it unsuitable for authorized discharge, authorized use or clearance from regulatory control, shall be processed as radioactive waste. The processing of radioactive waste shall be based on appropriate consideration of the characteristics of the waste and of the demands imposed by the different steps in its management (pretreatment, treatment, conditioning, transport, storage and disposal). Waste packages shall be designed and produced so that the radioactive material is appropriately contained both during normal operation and in accident conditions that could occur in the handling, storage, transport and disposal of waste."

4.20. The regulatory body should establish requirements and criteria pertaining to the safety of all processes and operations encompassed in the predisposal management of radioactive waste.

4.21. The processing of radioactive waste can involve a number of operations that change the characteristics of the waste, including pretreatment, treatment and conditioning. Processing may be necessary for safety, technical or financial reasons. From a safety perspective, processing is necessary to eliminate or reduce associated hazards (e.g. radiological, physical, chemical and biological). Waste should be processed only after its precise characterization. Processed waste should then be further characterized, in order to supply the required data for the subsequent waste management steps. The methods for processing should be selected on the basis of the waste characteristics and the established national policy and strategy for radioactive waste management.

4.22. Paragraph 4.13 of GSR Part 5 [3] states:

> "The main purpose of processing radioactive waste is to enhance safety by producing a waste form, packaged or unpackaged, that fulfils the acceptance criteria for safe processing, transport, storage and disposal of the waste. Waste has to be rendered into a safe and passive form for storage or disposal as soon as possible."

"Radioactive waste has to be processed in such a way that the resulting waste form can be safely stored and retrieved from the storage facility up until its ultimate disposal" (GSR Part 5 [3], para. 4.16).

4.23. Paragraph 4.14 of GSR Part 5 [3] states:

> "Waste has to be processed in such a way that safety is appropriately ensured during normal operation, that measures are taken to prevent the occurrence of incidents or accidents, and that provisions are made to mitigate the consequences if accidents occur. The processing has to be consistent with the type of waste, the possible need for its storage, the anticipated disposal option, and the limits, conditions and controls established in the safety case and in the assessment of environmental impacts."

4.24. Paragraph 4.15 of GSR Part 5 [3] states:

> "Various methods are applied for processing radioactive waste of different types. Consideration has to be given to identifying suitable options and to assessing the appropriateness of their application. Decisions have to be taken within the overall approach to the predisposal management of radioactive waste on the extent to which the waste has to be processed, with account taken of the quantities, activity and physical and/or chemical nature of the radioactive waste to be treated, the technologies available, the storage capacity and the availability of a disposal facility."

4.25. If the waste contains fissile material, the potential for criticality should be evaluated and eliminated to the extent practicable by means of design features and administrative safety measures (see IAEA Safety Standards Series No. SSG-27, Criticality Safety in the Handling of Fissile Material [40]). Conditions of optimum moderation and reflection should be considered in the determination of safe configurations for the radioactive waste and in the development of operating procedures.

4.26. Paragraph 4.17 of GSR Part 5 [3] states:

> "Provisions have to be established by the operator for identifying, assessing and dealing with waste and/or waste packages that do not meet process specifications and requirements for its and/or their safe handling, transport, storage and/or disposal."

4.27. The generation of secondary radioactive waste should always be taken into account when selecting a processing method. "Consideration has to be given to the consequences of dealing with any secondary waste (both radioactive and non-radioactive) that is created during processing" (GSR Part 5 [3], para. 4.18). The implications of secondary waste arising should be taken into account in the safety assessment and environmental impact assessment. The generation of secondary waste is of particular concern for operations such as decontamination, sawing and cutting, shredding and crushing of solid waste for purposes of volume reduction. The processing of radioactive waste can also generate effluent that is suitable for authorized discharge or material that is suitable for authorized use or clearance from regulatory control.

4.28. In selecting the method for processing radioactive waste, due consideration should be given to the exposure of workers for each processing method, both in normal operation and due to potential incidents.

4.29. The regulatory body should be aware that other regulatory organizations, e.g. those responsible for transport, may be involved in the transfer of radioactive waste to a subsequent management step. Timely liaison with such organizations should be considered in order to avoid unnecessary delays or duplication of processes.

Pretreatment

4.30. Pretreatment of radioactive waste is the initial step in its management, and is carried out following generation. Pretreatment activities include collection, segregation, chemical adjustment and decontamination as defined in the waste management strategy. For this initial step, waste streams should be segregated at the source of generation and, as a prerequisite, the waste should be adequately identified and categorized in accordance with the categorization scheme in place. The operator of a centralized waste management facility receiving radioactive waste should verify the waste characteristics by routine measurements or random measurements or other means in order to confirm the information provided by the operator of the facility where the waste was generated and to facilitate the selection of suitable treatment and conditioning techniques. An updated record of the waste characteristics should be maintained as part of the management system. Further guidance on record keeping is provided in Section 7.

4.31. Generally, the collection and segregation of different types of radioactive waste should be undertaken in accordance with a defined waste management strategy and the available waste management infrastructure or the acceptance requirements of a radioactive waste management facility. The objective of waste segregation is to minimize the volume as well as the costs, complexity and risks associated with subsequent waste management steps. The operator should adopt provisions to ensure that after segregation each waste stream is kept in separate, appropriate and properly identified and labelled containers. Segregation of radioactive waste should be performed according to an appropriate categorization scheme to allow for the safe and adequate accomplishment of further predisposal steps. Particular attention should be given to the segregation of higher activity waste. This facilitates recycling within the process or disposal as non-radioactive waste when the quantities of radionuclides present in the waste are sufficiently low to enable it to be removed from a regulated facility or activity (cleared from regulatory control).

4.32. The containers used for collection and segregation of radioactive waste should be physically and chemically compatible with the waste and should provide adequate confinement of the material and provide protection for workers against any chemical, biological, physical or other hazards (such as injury from contaminated sharp objects). The container materials used should be mechanically robust and, where appropriate, such as for biological radioactive waste, use should be made of double wrapping or a suitable outer container.

4.33. Containers for solid waste should be lined with a durable plastic bag that can be sealed (tied with plastic adhesive tape or heat-sealed with a radio-frequency welder). Needles and other sharp objects should be collected separately and stored in rigid, puncture resistant containers (e.g. metal containers) that have been clearly labelled ‘sharps’. Damp solid waste and liquid waste should be collected in containers that are appropriate for the chemical and radiological characteristics of the waste and the volume of the waste and that meet handling and storage requirements. Normally, double packaging is used.

4.34. Disused sealed radioactive sources should be kept in their shielding. When the shielding is contaminated, it should be decontaminated or overpackaged to avoid the further dispersal of contamination.

4.35. The containers should be appropriately identified and labelled, and should be placed in relevant working places where the radioactive waste is expected to be generated. Consideration should be given to the safe use of the waste containers (for example, by providing refuse cans with foot pedals) and their handling in the next steps in the management of the waste. As soon as the accumulation of radioactive waste commences, information on the nature of the waste collected should be recorded by the operator. Containers should be checked for contamination and non-fixed surface contamination should be removed before reuse. The following information should be recorded for each waste container:

(a) Identification number;
(b) Radionuclides contained in the waste;
(c) Activity (measured or estimated) of the waste and date of measurement;
(d) Origin of the waste (e.g. room, laboratory);
(e) Non-radiological hazards (e.g. chemical hazards, infectious matter);
(f) Surface dose rate of the container and date of measurement;
(g) Quantity (weight or volume);
(h) Responsible person, group or organization.

4.36. Segregation of radioactive waste should be performed primarily on the basis of the following factors:

(a) The activity of the waste and the radionuclides present.
(b) The half-lives of radionuclides present, for example short lived radionuclides (e.g. half-lives not exceeding 100 days) suitable for decay storage or long lived radionuclides (e.g. half-lives exceeding 30 years).
(c) The physical and chemical form of the waste, such as:
    - Combustible or non-combustible waste;
    - Compressible or non-compressible waste;
    - Aqueous waste;
    - Organic waste;
    - Homogeneous or non-homogeneous waste (e.g. waste containing sludge or suspended solids);
(d) Non-radiological hazards posed by the waste (e.g. toxic, pathogenic, infectious, genotoxic, biological or pharmaceutical hazards or a mix of hazards).
(e) The intended processing, storage or disposal of the waste.

4.37. Decontamination should be carried out only if it is ensured that the following aspects have been evaluated:

(a) The presence of a removable layer of surface contamination;
(b) The extent and nature of the surface contamination;
(c) The volume, activity and characteristics of the estimated radioactive waste arising from the decontamination process;
(d) The potential hazards associated with the decontamination method to be used.

4.38. The operator should gather and record in a systematic manner information relating to the safety of the next waste management stage. Appropriate precautions should be taken (e.g. radiological monitoring or decontamination) before a radioactive waste container is transferred for further management.

Treatment

4.39. The treatment of radioactive waste includes those operations intended to allow safety, technical and financial considerations to be met by changing the characteristics of the radioactive waste. The basic treatment concepts applicable are reduction of the volume of the waste, removal of radionuclides from the waste and change of composition of the waste. The treatment process should be carried out in accordance with criteria derived from the national policy and strategy as well as the safety case and supporting safety assessment, and should be implemented through formally approved operating instructions. Adequate safety monitoring should also be provided.

Solid radioactive waste

4.40. A variety of options exists for the treatment of solid waste (see Appendix III). In general, none of these methods is applicable to disused sealed radioactive sources, with the exception of conditioning. Possible options for the treatment of solid waste and major safety considerations for each are as follows:

(a) Compaction should be carried out only if it is ensured that:
   - No waste is present that could damage the waste package;
   - No pyrophoric materials are present in the waste to be compacted;
   - Waste posing a non-radiological hazard is excluded to avoid its dispersion (or, in the case of infectious agents, it is disinfected);
   - Pressurized containers are excluded to avoid the uncontrolled release of gas or the dispersion of contamination;

- Liquids are excluded to avoid leakage from the package during compaction;
- Disused sealed sources are excluded to avoid high risks of contamination and exposure;
- Loose, active powders are excluded to avoid risks of contamination;
- Chemically reactive materials are excluded to avoid uncontrolled reactions.

(b) Incineration should be carried out only if it is ensured that:
- Disused sealed radioactive sources are excluded to avoid high risks of contamination;
- Pressurized containers are excluded to avoid uncontrolled release of gas or dispersion of contamination;
- Volatile toxic materials are excluded, if the incinerator is not designed for them;
- Materials with a high moisture content are controlled to ensure their complete combustion;
- There will be subsequent management of radioactive ash;
- Frozen materials are controlled to ensure complete combustion;
- No pyrophoric materials are present in the waste to be incinerated;
- Active dust control is applied, particularly for handling ash;
- Methods for the treatment and control of the generated exhaust gases are in place and gaseous effluents are discharged within the authorized limits.

(c) Thermal organic processes using pyrolysis and steam reforming are typically used, but are not limited to waste containing organic resins. Special attention should be paid to the following:
- Close monitoring for potential leakages;
- The need for organic residues to be characterized before disposition;
- The need for radionuclide emissions in vapor to be monitored;
- The need for solid residues to be characterized before disposition.

Liquid radioactive waste

4.41. A range of options exists for the treatment of liquid radioactive waste. Selection of the optimum treatment process for liquids depends on safety, technical and financial considerations. The treatment of liquids also depends on the type of liquid (aqueous or organic), the content of solid particles suspended in the liquid, the pH of the liquid, and the content of salts or acids in the liquid and the possibility for their removal.

4.42. Liquid radioactive waste streams should be segregated if they differ greatly in chemical or radionuclide content. For instance, solutions of different chemical properties should be stored separately if their immediate discharge is not possible.

Uncontrolled chemical reactions that may produce heat, aerosols or precipitates should be prevented. For example, acidic solutions should be segregated from alkaline solutions since a change of pH or redox conditions might lead, for instance, to a release of volatile radionuclides such as iodine.

4.43. The combining of liquid waste streams should be carried out only if the safety assessment has demonstrated the procedure to be acceptable, and if the process is performed in accordance with approved operating instructions. In general, mixing of dissimilar waste streams (such as aqueous liquids and organic liquids, waste containing short lived radionuclides and waste containing long lived radionuclides) should be avoided unless there is a specific reason for doing so (such as neutralization). In this way, the complexity and potential hazards of the waste streams are minimized.

4.44. Different processes may be applied for the treatment of aqueous waste streams and organic waste streams. For small amounts of aqueous radioactive waste, direct discharge to the sewerage system or to the receiving water body can be authorized by the regulatory body after this discharge has been justified in the safety assessment. Requirements are established in GSR Part 3 [5] and further guidance is provided in GSG-9 [17]. For other aqueous waste, the use of chemical precipitation, evaporation, ion exchange and ultrafiltration processes may be appropriate.

4.45. When making use of chemical precipitation, consideration should be given to the generation of secondary waste, the possibility of creating heterogeneous waste streams and the need for subsequent conditioning of the active precipitate. For evaporation, the following should be considered:

(a) The generation of secondary waste;
(b) The integrity of the evaporator (in terms of its resistance to corrosion);
(c) The potential fire risk if volatile organic materials are present;
(d) The confinement of radioactive spray;
(e) The subsequent conditioning of active concentrates.

4.46. When using an ion exchange process, consideration should be given to:

(a) The generation of secondary waste needing specialized conditioning;
(b) The reactivity of the resins with strong oxidants (such as strong nitric acid);
(c) The radiolytic degradation of resins;
(d) The spent resin produced that needs specialized conditioning.

The use of ultrafiltration necessitates consideration of the potential for leakage from high pressure systems possibly leading to the inadvertent dispersal of liquid waste and the subsequent need for conditioning of active solids or sludges.

4.47. For organic waste, incineration (with the exception of low flash point or volatile toxic materials), immobilization and absorption may be applied. When incineration is used, consideration should be given, at a minimum, to the possible environmental implications of discharging both gaseous and particulate matter and both the radioactive and non-radioactive components. Similarly, consideration should be given to minimizing the generation of airborne radioactive material, particularly in handling ash, as well as in the subsequent management of contaminated ash. In relation to immobilization and absorption, the long term stability of the final waste form should be evaluated.

4.48. Concentrates arising from the treatment of liquid radioactive waste (secondary waste) should be immobilized to produce a stable, solid waste form. Waste forms should be produced to be in accordance with criteria, established on the basis of the safety assessment, that take into account the requirements for transport, storage and eventual disposal.

Airborne discharges

4.49. For small amounts of gaseous effluents, direct discharge to the atmosphere is generally possible within the established licence conditions. In such cases, additional treatment of the gaseous effluents is unlikely to be necessary. This is often the case at medical laboratories and small research laboratories, where the amounts of radionuclides used are small and often have short half-lives.

4.50. Airborne discharge streams containing particulate radioactive material should, where necessary, be cleaned by means of filters or by other means prior to the release of such discharges to the atmosphere. Unless contaminated only with short lived radionuclides, the filter or other cleaning medium should be treated as solid radioactive waste. If only short lived radionuclides are deposited on the filter or other cleaning medium, these deposits can be allowed to decay without the need for further treatment and the filter or other cleaning medium can then be removed from regulatory control. Airborne discharges of radioactive effluents from incinerators or smelting facilities using recycled metals that have been cleared from regulatory control should be monitored to ensure that they remain within allowed limits.

Biological radioactive waste

4.51. Radioactive waste of a biological nature should be managed by taking into consideration the associated radiological and non-radiological hazards (biological hazards and/or infectious agents, physical, chemical, flammable and/or explosive hazards). For infectious biological waste from medical applications, pretreatment should be undertaken to eliminate all infectious agents before the waste is stored and/or disposed of. A flow diagram illustrating the management of biological waste is given in Appendix IV.

4.52. Practices for radioactive waste management are not usually appropriate or sufficient to control biological hazards. However, biological radioactive waste cannot always be treated using the same methods as for non-radiological biological waste. A number of options do exist for the processing of biological radioactive waste, such as steam sterilization, chemical disinfection, dry heat treatment and sterilization by irradiation. Thermal processes such as incineration, steam autoclaving, microwave processing and dry heat are used primarily to destroy organic material and to kill micro-organisms present in the waste. Chemical processes are used to disinfect biological waste.

Conditioning

4.53. Conditioning of radioactive waste involves those operations that convert the treated waste into a form that is suitable for handling, transport, storage and disposal. In selecting a conditioning process, depending on the type of waste and the national policy and strategy, the operator should consider the following aspects:

(a) Whether safety would be improved by the use of a matrix material and/or a waste container;
(b) Compatibility of the radioactive waste with the selected materials and processes;
(c) Minimization of the generation of secondary radioactive waste;
(d) The need for the result of the conditioning process to be compatible with the next step of waste management or the endpoint for the waste (e.g. long term storage versus disposal);
(e) The use of waste acceptance criteria (for disposal), which are developed by the operator and approved by the regulatory body.

4.54. Conditioning operations may include immobilization of the waste in a matrix, placing the waste into a container and providing additional packaging. In many instances, pretreatment, treatment and conditioning take place in close conjunction with one another.

4.55. The conditioning of radioactive waste should ensure:

(a) Compatibility between the waste, the matrix and the container;
(b) Homogeneity and stability of the waste form;
(c) Minimum content of liquid in the waste form;
(d) Minimum free space in the container;
(e) Durability of the container;
(f) Low leachability;
(g) Control over the complexing agents and organic compounds.

4.56. The operator should ensure that the waste packages are designed and produced so that radionuclides will be confined under both normal conditions and accident conditions that may occur during handling, storage, transport and disposal. The relevant acceptance criteria should be approved by the regulatory body. Reference [41] provides technical guidelines for the development of waste package specifications that comply with acceptance requirements for storage and disposal of radioactive waste. Consideration should be given in the safety assessment and safety case to the materials to be conditioned and the relevant acceptance criteria for storage and for the authorized disposal of the waste; both sets of criteria should be authorized by the regulatory body.

4.57. In conducting the safety assessment, it is useful to view the radioactive waste package as consisting of two principal components, that is, the waste form and the container. The nature of the waste form in the container has a significant effect on the properties of the overall waste package and can influence the performance of the package with respect to the relevant acceptance criteria.

4.58. The operator should ensure that each waste package is provided with a durable label bearing the identification number and relevant information and that a proper record of each waste package is kept as part of the management system. All records should be securely stored, easily accessible and capable of being retrieved over an extended period of time. Information should include, at a minimum, for each individual package the following:

(a) The origin of waste;
(b) The identification number of the package;

(c) The type and design details of the package and the associated transport documents;
(d) The weight of the package;
(e) The external size and/or volume of the package;
(f) The maximum dose rate in contact with and at a distance of 1 m from the external surfaces of the package (to derive the transport index) and the date of measurement;
(g) Results of the measurement of surface contamination and the date of measurement;
(h) The radionuclide(s) and activity content;
(i) The fissile material content, if applicable (such as for ^{239}Pu–Be sealed sources);
(j) The physical nature of the waste;
(k) The presence of pathogens, chemicals, asbestos, organic matter and other potentially hazardous materials.

4.59. The operator should ensure that each package of conditioned waste can be transported in accordance with national regulations and in compliance with SSR-6 (Rev. 1) [14].

4.60. Since the waste packages may be stored for a long time prior to disposal, quality control of the conditioning process and the waste packages produced is a key aspect to be considered by the operator. As part of the management system of the operator, measures for quality assurance and control should be implemented in respect of the packaging of waste to ensure compliance with the waste acceptance criteria for the selected or anticipated disposal option. The quality control measures should include, but are not limited to, the following:

(a) Specification of the quality standards applying to waste packages.
(b) The unambiguous specification of quality indicators for the conditioning processes as well as for the final packages. The quality indicators should be such that it can be demonstrated that the packages meet specified requirements and acceptance criteria.
(c) The development of a testing programme to verify the performance of the packages.
(d) Appropriate record keeping.
(e) Making available technical support for radiological and non-radiological measurements and procedures.

Discharge of radioactive material to the environment

4.61. Once the need for an authorization for the discharge of radioactive material is confirmed, the authorization process should be carried out with the following steps:

(a) The regulatory body should specify the relevant dose constraint for the facility or activity under consideration.
(b) The operator should characterize the discharges and the main exposure pathways identified, in order to assess adequately the exposure of the representative person.
(c) The operator should optimize the protection and safety of the public, considering measures to be used to keep the exposures due to discharges as low as reasonably achievable, and taking into account all relevant factors.
(d) The operator should assess the doses to the representative person (this may involve conducting a simple, cautious, generic assessment and, if required, following this with a more detailed and site specific study).
(e) The operator should submit the results of the assessment to the regulatory body. The regulatory body should evaluate whether the models and assumptions used by the operator are valid and whether the requirements for optimized protection of the public are met for the resulting doses.
(f) The regulatory body should set authorized discharge limits and should establish means by which compliance during operation is to be demonstrated, including requirements for source and environmental monitoring systems and programmes.

4.62. The discharge levels proposed by the operator should be based on an assessment of the radiological impacts of such discharges using appropriate modelling [22]. Expected doses to the more highly exposed individuals should be estimated. It may be necessary to conduct a survey of the habits of members of the public in order to determine the representative person, who is defined as "an individual receiving a dose that is representative of the doses to the more highly exposed individuals in the population" (GSR Part 3 [5]). The habits (e.g. consumption of foodstuffs, location, usage of local resources) used to characterize the representative person should be typical habits of a small number of individuals representative of those more highly exposed. Extreme or unusual habits, however, should not dictate the characteristics of the representative person considered. The representative person may be different for airborne discharges and for liquid discharges.

4.63. As part of the control of discharges the operator should establish and document technical procedures to carry out discharge operations, as well as specifying the individuals with responsibility for such operations.

4.64. Compliance with authorized discharge limits should be demonstrated either through the monitoring of discharges by approved methods of sampling and measurement or through the estimation of discharges by calculation, if approved by the regulatory body.

4.65. Consideration should be given to addressing discharges to the environment in the event of an accident in the appropriate emergency arrangements.

4.66. Further guidance on regulatory control of radioactive discharges can be found in GSG-9 [17].

4.67. During the operational stage, the operator:

(a) Should keep all radioactive discharges as far below the authorized limits as is reasonably achievable;
(b) Should not deliberately dilute material, other than the dilution that takes place in normal operations;
(c) Should monitor and record the discharges of radionuclides with sufficient detail and accuracy to demonstrate compliance with the authorized discharge limits and to permit estimation of the exposure of the representative person;
(d) Should maintain an appropriate management system for the activities relating to source monitoring or environmental monitoring;
(e) Should report discharges to the regulatory body at intervals as may be specified in the licence, and promptly notify the regulatory body if any discharges exceed the authorized limits.

4.68. The operator should review its operating experience with respect to discharges and, in agreement with the regulatory body, should adjust its measures for the control of discharges to ensure optimization of protection and safety.

Clearance of material from regulatory control

4.69. In an application for authorization, the operator should declare its intention to clear materials from the regulatory control in place during the operational stage (see RS-G-1.7 [16]).

4.70. With regard to the clearance of material from regulatory control, the operator should adopt provisions to ensure that:

(a) The clearance of radioactive waste complies with clearance levels established by the regulatory body;
(b) A formal mechanism is put in place, including rigorous control measures, to demonstrate compliance with regulatory requirements in respect of clearance;
(c) Deliberate dilution of material to make it suitable for clearance will not be carried out, other than the dilution that takes place in normal operations;
(d) Any radiation markings will be removed from any material for which regulatory controls no longer apply;
(e) Protection and safety are optimized before materials are cleared from regulatory control.

4.71. Information on material that has been removed from regulatory control should be recorded, retained within a management system and reported to the regulatory body, as required.

4.72. Control measures for the clearance of radioactive material from regulatory control may include the following:

(a) Determination of the activity concentration of the waste;
(b) Segregation of any such waste designated for storage for decay;
(c) Sampling of each batch of waste prior to its removal from regulatory control.

4.73. A graded approach consistent with the optimization of protection and safety can be taken when activity concentrations exceed generic clearance levels. The regulatory body should provide guidance on the content and scope of the information to be submitted by an operator seeking authorization to release material from regulatory control with radionuclide concentrations exceeding generic clearance levels. The regulatory body may decide (where the national regulatory framework so allows) that the optimum regulatory option is not to apply regulatory requirements to the legal person responsible for the material. The mechanism for giving effect to such a decision will depend on the national regulatory framework. In many cases, a decision will be made by the regulatory body on a case by case basis. General requirements and recommendations in this regard are provided in GSR Part 3 [5] and RS-G-1.7 [16].

4.74. Whenever activity concentrations exceed clearance levels and removal of regulatory control appears to be the optimum option for the management of radioactive material, the operator should apply for regulatory approval to release the material from regulatory control.

Disused sealed radioactive sources

4.75. Sealed radioactive sources have a wide range of activities depending on their originally intended use: from a few kilobecquerels for calibration sources up to many terabecquerels for external beam radiotherapy sources for medical applications. While disused sealed radioactive sources may represent only a small fraction of the volume of the radioactive waste generated by a particular operator, they may dominate in terms of the activity content of the radioactive waste generated. It is essential to note that, although the activity levels of teletherapy sources and other large sealed radioactive sources may have fallen below useful levels for their initial purposes, the potential for radiation induced injury from such sources remains substantial. External beam radiotherapy sources may contain caesium compounds (^{137}Cs) in a dispersible form and can represent a very significant hazard if their primary containment is breached.

4.76. The operator should review its inventory of radioactive sources at least annually to identify any sources that are not in routine use and have become disused. Disused sources should be included in the inventory of radioactive waste. The operator is responsible for meeting any regulatory requirements for reporting disused sources. Once radioactive sources have become disused, the operator should ensure the continuity of control. The operator should periodically review the status of control of such sources [42].

4.77. The following aspects should be considered in respect of the safe management of disused sealed radioactive sources (see also Appendix V):

(a) The further authorized use of the disused source by another licensed operator;
(b) The return of the source to the supplier;
(c) Temporary storage of the source in its original shielding for decay (e.g. for radionuclides with half-lives of less than 100 days);
(d) Conditioning and processing of the source (e.g. overpacking);
(e) Long term storage of the source (such as in a centralized storage facility) before conditioning and disposal;
(f) Disposal of the source.

4.78. The most sustainable option for managing disused sealed sources is further use by another authorized operator. If that is not possible, the preferred management option for disused sealed radioactive sources is the return of the source to its supplier. Unfortunately, this option is not always available for many old (legacy) sources, as the original supplier might not be known or no longer exist. For disused sealed sources with short half-lives (e.g. a half-life not exceeding 100 days) and of high activity (e.g. ^{192}Ir sources as used in medical applications and in gamma radiography), secure storage for decay may be the preferred option. If the clearance levels are met, the sources are managed as non-radioactive waste. The main steps in the management of disused sources are illustrated in Appendix V.

4.79. All disused sealed radioactive sources should be conditioned, unless the half-life of the radionuclides contained in them is short enough to enable their removal from regulatory control within a reasonably short period of time (e.g. two to three years). Long lived sources are generally conditioned in centralized radioactive waste management facilities by means of encapsulation in welded steel capsules to facilitate their future management. Conditioning methods should be subject to approval by the regulatory body (in accordance with the national policy for radioactive waste management).

4.80. In instances where the operator has neither adequate storage facilities nor facilities or expertise for the conditioning of spent and disused sealed sources by encapsulation, arrangements should be made to transfer the sources to another licensed operator with proper and adequate facilities (e.g. a centralized conditioning or storage facility). A centralized facility should be established for the safe long term storage of disused sealed radioactive sources containing ^{226}Ra, ^{241}Am and other long lived radionuclides.

4.81. The management of disused sealed radioactive sources can involve potentially serious hazards. Sealed sources are not subjected to compaction, shredding or incineration. As a general principle, the overriding need for safety means that sealed sources should not be removed from their primary containers, nor should the containers be physically modified. Peripheral components of large items of irradiation equipment (those not directly associated with the source) should be removed, monitored and disposed of appropriately. A safety assessment and an environmental impact assessment should be carried out before any operations are undertaken. For sources with a potential for leakage (such as disused radium sources), particular precautions in respect of radiation protection should also be taken during handling and storage. Special attention should be given to monitoring for surface contamination and airborne contamination. Sources with a potential for leakage should be stored in a dedicated area with appropriate ventilation and equipment (see Annex I).

4.82. The most important consideration in the management of sealed sources, once they are no longer useful, is the continuity of control. Provisions should be made by the operator and the regulatory body to maintain and to revisit periodically the status of control of disused sealed sources.

4.83. The regulatory body should give consideration to situations involving disused sealed sources that cannot be returned to the supplier or manufacturer. Such sources may require subsequent management, such as conditioning, for which the operator is neither qualified nor licensed. In such cases, the regulatory body should give consideration to the assignment and authorization of an appropriate organization that is better equipped to safely conduct the necessary operations.

Orphan sources

4.84. There have been many cases of sealed sources being acquired for specific purposes (such as for industrial process control) and then subsequently being lost because the operator has ceased operation and control over the sources has been lost. Many portable radiography devices contain valuable heavy metals and are attractive as scrap metal. These are some of the reasons why disused sealed radioactive sources are lost from regulatory control. In order to address the issue of such orphan sources, States should establish and implement an appropriate national strategy. An example of a strategy for the identification and location of orphan sources is presented in Annex II.

4.85. In all cases, the strategy should ensure that whenever an orphan source is identified, appropriate recovery measures are taken (see SSG-19 [38]). Such measures should include identification of the responsible organizations and of funding within the State to recover, handle, condition, store and, if necessary, dispose of the source as radioactive waste according to the national policy and strategy for radioactive waste management.

Generation of radioactive waste from accidents

4.86. The loss or unauthorized use of radioactive material (such as sealed sources) can give rise to accidents resulting in radiation exposure of workers, contamination of facilities and land, and exposure of members of the general public. This can lead to the unplanned generation of radioactive waste. Operators should take all appropriate measures to ensure that appropriate technical and organizational means are in place, including the necessary contingency arrangements for the processing and storage of any such radioactive waste generated in an accident (see GS-G-2.1 [31], IAEA Safety Standards Series No. GSG-2, Criteria for Use in Preparedness and Response for a Nuclear or Radiological Emergency [43] and Ref. [44]).

On-site handling

4.87. The handling of radioactive waste on the site includes all transfer (movement) operations from the place of generation of the waste to the location for processing, storage and/or disposal. This may include physical handling, process flow or on-site transport (including loading and unloading of packages from conveyances). Handling should be carried out:

(a) In containers or with overpacks that are easily decontaminated;
(b) With adequate provision for occupational radiation protection;
(c) With appropriate labelling of the radioactive waste package and the vehicles used for transferring the waste;
(d) In accordance with the radiation protection programme for the facility and the procedures for physical protection, safe transport and emergency planning at the site, as well as with national legislation.

4.88. A survey for non-fixed surface contamination should be conducted before the package is handled. This serves to protect workers handling the package, helps prevent the accidental spread of contamination and provides an independent check of the record keeping system. In addition, the radiation level should not exceed the maximum allowable radiation dose rate at the surface of each radioactive waste package, or at a specified distance from the surface, as defined as part of the package acceptance requirements for storage.

4.89. The unexpected presence of contamination on a radioactive waste package may be an indication that the package itself or a package nearby has been breached or physically damaged. Procedures should be established in advance and documented and should be followed in such an event. At a minimum, the area around the suspect package should be cordoned off, the person responsible for waste safety should be notified, and procedures should be applied to identify the source of contamination and to ensure that it is confined. The simplest means of confining the source of contamination is, if possible, to place it in a secondary overpack container.

Off-site transport

4.90. Transport of radioactive waste should be carried out in accordance with national regulations and in compliance with SSR-6 (Rev. 1) [14].

4.91. Prior to the transport of radioactive waste packages from the sites on which they are produced, the necessary confirmation should be obtained that the waste will be accepted at its intended destination. The operator of the facility to which the waste is being transported should clearly specify to the operator of the facility where the waste is generated the safety related information and formal documentation that is necessary for acceptance.

4.92. Paragraphs 4.58 and 4.59 provide recommendations on the information to be provided for each individual package, as a minimum, upon transfer of waste.

4.93. In the case of sealed sources, shielding is usually an integral part of the original storage and/or transport package. The dimensions and type of shielding depend on the activity and the radionuclides to be shipped. If possible, the original manufacturer's packaging should be used in transporting disused sealed radioactive sources. However, consideration should be given to whether the design of the original packaging is in compliance with SSR-6 (Rev. 1) [14] and whether the package continues to meet its design standard. If the original package is not available, the disused sealed radioactive sources should be repackaged in accordance with SSR-6 (Rev. 1) [14].

STORAGE OF RADIOACTIVE WASTE

> **Requirement 11 of GSR Part 5 [3]: Storage of radioactive waste**
>
> **"Waste shall be stored in such a manner that it can be inspected, monitored, retrieved and preserved in a condition suitable for its subsequent management. Due account shall be taken of the expected period of storage, and, to the extent possible, passive safety features shall be applied. For long term storage in particular, measures shall be taken to prevent degradation of the waste containment."**

4.94. Paragraph 4.19 of GSR Part 5 [3] states:

> "Within the context of radioactive waste management, storage refers to the temporary placement of radioactive waste in a facility where appropriate

> isolation and monitoring are provided. Storage has to take place between and within the basic steps in the predisposal management of radioactive waste. Storage is used to facilitate the subsequent step in radioactive waste management; to act as a buffer between and within waste management steps; to allow time for the decay of radionuclides prior to clearance or authorized discharge; or to hold waste generated in emergency situations pending decisions on its future management."

4.95. Prior to generating radioactive waste, the operator should ensure the availability of an appropriate storage facility within its own organization, or in another authorized facility. The operator should follow the national policy and strategy in determining which types of waste have to be stored for authorized discharge, authorized use or clearance or for processing and/or disposal at a later time.

4.96. The operator should put arrangements in place to verify whether the waste that has been collected or received in the storage facility under its responsibility meets the acceptance criteria approved by the regulatory body in the safety case for that facility. In defining criteria for acceptance of waste packages in a storage facility, the operator should take account of the known or likely requirements for subsequent disposal of the radioactive waste. In case the waste to be stored does not meet the acceptance criteria for storage, the operator should establish provisions that compensate for the non-compliance or should refuse to accept the waste.

4.97. Provision should be made for the regular monitoring, inspection and maintenance of the waste and the storage facility to ensure their continued integrity and the subsequent management of the radioactive waste packages. Due account should be taken of the anticipated period of storage, and, to the extent possible, passive safety features should be applied. For long term storage, in particular, measures should be taken to prevent the degradation of the waste form and its container.

4.98. The design of the storage facility depends on the type of radioactive waste, its characteristics and associated hazards, the radioactive inventory and the anticipated period of storage.

4.99. Storage is by definition an interim measure, but it can last for several decades. The intention in storing waste is that the waste can be retrieved for clearance, processing and/or disposal or, in the case of effluents, for authorized discharge.

4.100. The adequacy of the storage capacity should be periodically reviewed, with account taken of the predicted waste arisings, both for normal operation and for possible incidents, the expected lifetime of the storage facility and the availability of disposal options.

4.101. Consideration should be given to the protection of present and future generations in accordance with Principle 7 of SF-1 [2] when it is proposed that radioactive waste will be stored for a long period of time.

4.102. Radioactive waste should be stored in a manner that ensures isolation, protection of workers and the public and protection of the environment, and that enables the subsequent movement, handling, transport or disposal of the waste. Full traceability of the waste packages should be maintained during storage by means of record keeping and adequate labelling.

4.103. The safety of storage arrangements should be ensured for any radioactive waste management activity. On-site storage may be used to allow time for the decay of radionuclides to levels where regulatory control may be removed from the materials. Storage may be necessary for operational reasons (such as for unconditioned radioactive waste prior to its subsequent conditioning or transfer off the site). In general, the on-site storage period should be kept as short as practicable to ensure the long term safety of the waste. This is particularly so when the waste is to be transferred to a central storage facility for radioactive waste and when optimal longer term storage capabilities are not available at the facility where the waste is generated. Storage facilities may be necessary for untreated, treated and conditioned radioactive waste. Special attention should be paid to the storage of: (a) unconditioned radioactive waste, in order to limit any leakage from packages; and (b) fissile materials, in order to avoid storage configurations that could lead to criticality.

4.104. In considering arrangements for the storage of radioactive waste, a detailed evaluation should be made of the following:

(a) The type and characteristics of the radioactive waste;
(b) The original integrity of the waste packages and potential levels of surface contamination;
(c) The means of closure and/or sealing of the packages and the continued integrity of the packages under storage conditions;
(d) The anticipated storage period and the possibility of further extension;
(e) The capability of the waste to comply with handling, storage and physical protection criteria;

(f) The need for and type of monitoring, e.g. monitoring for airborne radioactive substances, in the storage facility;
(g) The possibility of identifying potential damage to waste packages and facilitating the respective corrective measures.

4.105. If, in accordance with the national policy and strategy, radioactive waste is to be stored in a centralized storage facility, the operator should adopt provisions to ensure the prompt transfer of waste and disused sources to that facility.

4.106. Detailed guidance on the design and operation of small storage facilities for radioactive waste is provided in WS-G-6.1 [13].

Storage prior to discharge or removal of regulatory control

4.107. Storage for decay is particularly important for the clearance of radioactive waste containing short lived radionuclides. As mentioned before, clearance is the removal of regulatory control from radioactive material, provided that the radionuclide concentrations are below radionuclide specific clearance levels. Many radionuclides in use, particularly in research and medical applications, have half-lives ranging from a few hours to a few months.

4.108. The decay storage period should be long enough to reduce the initial activity to levels lower than the clearance levels. The decay storage period strongly depends on the initial activity and the half-life of the radionuclide. Therefore, for every specific source, a calculation should be performed in order to determine the proper decay storage period. Practical experience has shown that storage for decay is usually suitable for all types of solid, liquid and gaseous radioactive waste containing radionuclides with half-lives of around 100 days or less. For example, radioactive waste from nuclear medicine, such as excreta containing ^{99m}Tc (half-life about 6 h), may be stored for decay and subsequent discharge. Waste containing radionuclides with longer half-lives may also be safely stored for decay to insignificant levels and consideration should be given on a case by case basis to the storage of such waste for decay. Generic clearance levels and guidance for the derivation of clearance levels are provided in GSR Part 3 [5] and RS-G-1.7 [16].

4.109. From a safety, technical and financial perspective, storage for decay, where appropriate, is the preferred management option for radioactive waste generated in medical, industrial and research activities. Relatively small volumes of radioactive waste, contaminated with short lived radionuclides, with suitable activity content or activity concentration, should be collected and stored safely for sufficient time until the waste meets the regulatory criteria for removal (clearance) of the material from a regulated facility or activity or for authorized discharge.

4.110. Rigorous control measures should be put in place for the storage of radioactive waste for decay and for its subsequent removal from regulatory control. The activity concentration of the waste should be carefully determined and such waste designated for decay should be segregated from other waste, from the point of generation up to the end of the decay storage period and its disposal. Representative measurements should be carried out on samples taken and analysed prior to the removal of regulatory control from each batch. In taking samples, workers should be protected against both radiological and non-radiological hazards.

4.111. While storage for decay is also the preferred option for biological radioactive waste and for other perishable waste such as animal carcasses, such wastes should be segregated and should be stored in a freezer or refrigerator cabinet to allow time for radioactive decay. Such waste should not be disposed of in a landfill site unless specific approval has been obtained from the regulatory body. Incineration of such waste is usually the preferred option; further guidance should be sought from the relevant authority concerning the conditions under which such waste can safely be incinerated.

4.112. Records should be kept and retained of any radioactive material that has been removed from regulatory control.

Storage prior to processing

4.113. Each waste package should be tracked while in storage to facilitate its retrieval for further processing. Adequate radiation protection controls and physical security measures should be provided and the storage period of unconditioned waste should be limited, as unconditioned radioactive waste might present unexpected hazards. The waste should be stored in a way that ensures the following:

(a) The storage of packages in specially designated areas or premises, or in specifically constructed facilities (on-site facilities or centralized facilities);
(b) Compliance with the acceptance criteria for waste storage;
(c) The control of packages on receipt (such as control of the integrity of the waste package, and monitoring for surface contamination and for compliance with the supporting documentation);

(d) Separate storage of different waste types (including mixed waste) in accordance with the presence of pathogens, organic matter, toxic material or other potentially hazardous materials;
(e) Reliable labelling of packages;
(f) Tracking of the current status of waste and the continued availability of supporting documentation.

Storage of radioactive waste prior to disposal

4.114. Treated and conditioned radioactive waste should be stored separately from unconditioned waste, inactive raw materials and materials and items to be used for maintenance. Waste packages should be stored in a manner that allows for efficiency, for example in bins or on racks, pallets or skids. Storage locations should be planned so as to minimize the need for handling and transport.

4.115. Conditioned radioactive waste should be stored in a safe and physically secure manner after processing, and prior to transfer to a disposal facility.

4.116. Proposed storage solutions should be considered in the safety assessment and environmental impact assessment to demonstrate the acceptability of the proposed design and operational arrangements. The safety measures applied for storage should ensure that stored waste will remain adequately confined, that radiation from the stored waste is adequately shielded and that the stored packages will not degrade and give rise to future problems in handling and disposal.

4.117. Detailed recommendations on the storage of radioactive waste are provided in WS-G-6.1 [13].

RADIOACTIVE WASTE ACCEPTANCE CRITERIA

Requirement 12 of GSR Part 5 [3]: Radioactive waste acceptance criteria

"Waste packages and unpackaged waste that are accepted for processing, storage and/or disposal shall conform to criteria that are consistent with the safety case."

4.118. The interdependence among the steps in the management of radioactive waste is required to be considered for achieving continuity in operations and consistency of the entire waste management process.

4.119. The operator of a particular waste predisposal management facility should define in the safety case its own waste acceptance criteria, bearing in mind the criteria established for other steps within the waste management process. Paragraph 4.24 of GSR Part 5 [3] states:

> "Waste acceptance criteria have to be developed that specify the radiological, mechanical, physical, chemical and biological characteristics of waste packages and unpackaged waste that are to be processed, stored or disposed of; for example, their radionuclide content or activity limits, their heat output and the properties of the waste form and packaging."

Each criterion established by the operator of a facility should be submitted to the regulatory body for review, assessment and approval as part of the safety case.

4.120. The operator of a waste management facility should establish specific acceptance criteria and procedures for different types of radioactive waste and package and should make them available to the operator of the facility where the waste is generated. The waste acceptance criteria should specify:

(a) The requisite stable form and container resistance as regards the extent of waste processing to be carried out;
(b) The maximum content of liquid (usually up to 1% of the total radioactive waste by volume);
(c) The requisite mechanical, chemical, structural, radiological and biological stability of the waste form;
(d) Activity limits (e.g. the maximum activity per package);
(e) The absence of a potential for criticality;
(f) The extent to which the waste should be non-pyrophoric, non-explosive and non-reactive;
(g) The potential for generation of toxic gases;
(h) The limitation of heat generation.

4.121. Paragraph 4.25 of GSR Part 5 [3] states:

> "Adherence to the waste acceptance criteria is essential for the safe handling and storage of waste packages and unpackaged waste during normal operation, for safety during possible accident conditions and for the long term safety of the subsequent disposal of the waste."

The operator is required to ensure that an appropriate management system is established to provide confidence that the waste under its responsibility meets the applicable acceptance criteria [3].

4.122. The operator should ensure that radioactive waste to be transferred to other facilities or waste management steps will meet the waste acceptance criteria established by the operator of the facility at the subsequent step.

4.123. “The operators’ procedures for the reception of waste have to contain provisions for safely managing waste that fails to meet the acceptance criteria; for example, by taking remedial actions or by returning the waste” (GSR Part 5 [3], para. 4.26).

4.124. The operator of the waste management facility should clearly identify the documentation to be provided by the operator of the facility where the waste is generated, as well as the relevant waste package records. Waste packages should be inspected in an appropriate manner both prior to the shipment to a waste management facility and on receipt at the waste management facility. Caution should be applied to the receipt of all packages, as the packages might not be in compliance with the agreed specifications and the associated documentation. Inspection should include verification of:

(a) The number of packages and their respective identification;
(b) The physical integrity of the packages;
(c) The surface contamination levels;
(d) The external dose rate from the packages;
(e) Completeness of the documentation.

4.125. Upon receipt, full confirmation of the content of the package should be carried out without compromising the integrity of the package. The information received from the operator of the facility where the waste is generated and the data obtained as part of the control of receipt should be recorded.

5. SAFETY CASE AND SAFETY ASSESSMENT

GENERAL

5.1. Paragraph 4.62 of IAEA Safety Standards Series No. GSR Part 4 (Rev. 1), Safety Assessment for Facilities and Activities [45] states:

> "The results and findings of the safety assessment shall be documented, as appropriate, in the form of a safety report that reflects the complexity of the facility or activity and the radiation risks associated with it. The safety report presents the assessments and the analyses that have been carried out for the purposes of demonstrating that the facility or activity is in compliance with the fundamental safety principles and the requirements established in [GSR Part 4 (Rev. 1)], and with any other safety requirements as established in national laws and regulations."

5.2. Paragraph 4.4 of GSG-3 [20] states:

> "Safety assessment is the main component of the safety case and involves assessment of a number of aspects…. The fundamental element of the safety assessment is the assessment of the radiological impact on humans and the environment in terms of both radiation dose and radiation risks. The other important aspects subject to safety assessment are site and engineering aspects, operational safety, non-radiological impacts and the management system."

5.3. Paragraph 4.7 of GSG-3 [20] states:

> "A specific role of the safety case in aiding decision making about treatment options is to ensure that suitable waste forms are produced. The safety case should provide an integrated consideration of safety for all waste management steps, and should address both the safety of operations at the individual facility and the interdependences with other waste management steps. The adequacy of waste forms produced should be judged on the basis of waste acceptance criteria for all subsequent waste management activities, in particular processing, storage, transport and eventual disposal of the waste. There are many aspects connected to these decisions, some of which will be based on quantitative assessments while others will be more qualitative in nature."

5.4. Paragraph 4.5 of GSG-3 [20] states:

> "The safety case is of particular importance and benefit for large predisposal waste management facilities, such as centralized facilities for the processing and storage of radioactive waste in States that have a nuclear power programme. For smaller scale facilities, such as storage facilities for disused sealed sources, the components of the safety case … are still relevant; however, the level of detail and the complexity and depth of the safety assessment are required to be commensurate with the potential hazard (Requirement 1, [GSR Part 4 (Rev. 1) [45]]). In addition, the actual process of developing the safety case and conducting safety assessment will be commensurately less demanding, and several of the aspects discussed below, such as development of the safety case in stages, will be less relevant for some types and sizes of facilities. … IAEA Safety Reports setting out examples of safety cases are under development to provide additional guidance on the level of depth and detail warranted for safety cases prepared for smaller facilities."

A detailed description of the safety assessment and safety case is given in GSG-3 [20].

APPROACH TO SAFETY

5.5. Any application for authorization is required to include a safety case and supporting safety assessment and an environmental impact assessment, as appropriate. The information that is supplied should reflect the requirements of the regulatory body and is required "to be commensurate with the complexity of the operations and the magnitude of the hazards associated with the facility and activities" (GSR Part 5 [3], para. 5.7).

5.6. Wherever practicable, waste management practices should be included in the authorization for a facility or activity that generates waste. For example, the management of radioactive waste at a nuclear medicine facility could be included in the authorization to conduct nuclear medicine activities.

PREPARATION OF THE SAFETY CASE AND SUPPORTING SAFETY ASSESSMENT

Requirement 13 of GSR Part 5 [3]: Preparation of the safety case and supporting safety assessment

"The operator shall prepare a safety case and a supporting safety assessment. In the case of a step by step development, or in the event of modification of the facility or activity, the safety case and its supporting safety assessment shall be reviewed and updated as necessary."

5.7. Paragraph 5.3 of GSR Part 5 [3] states:

> "The safety case has to be prepared by the operator early in the development of a facility as a basis for the process of regulatory decision making and approval. The safety case has to be progressively developed and refined as the project proceeds. Such an approach ensures the quality of the technical programme and the associated decision making."

"It is the operator's responsibility to compile the safety assessment as part of the safety case in accordance with the requirements of the regulatory body" (GSR Part 5 [3], para. 5.4).

5.8. According to para. 5.3 of GSR Part 5 [3], the safety case

> "provides a framework in which confidence in the technical feasibility and safety of the facility can be established at each stage of its development. This confidence has to be developed and enhanced by means of iterative design studies and safety studies as the project progresses. The step by step approach has to provide for the collection, analysis and interpretation of the relevant technical data, the development of plans for design and operation, and the development of the safety case for operational safety."

SCOPE OF THE SAFETY CASE AND SUPPORTING SAFETY ASSESSMENT

Requirement 14 of GSR Part 5 [3]: Scope of the safety case and supporting safety assessment

"The safety case for a predisposal radioactive waste management facility shall include a description of how all the safety aspects of the site, the design, operation, shutdown and decommissioning of the facility and the managerial controls satisfy the regulatory requirements. The safety case and its supporting safety assessment shall demonstrate the level of protection provided and shall provide assurance to the regulatory body that safety requirements will be met."

5.9. Paragraph 3.29 of GSR Part 3 [5] states:

"The regulatory body shall establish requirements for persons or organizations responsible for facilities and activities that give rise to radiation risks to conduct an appropriate safety assessment.... Prior to the granting of an authorization, the responsible person or organization shall be required to submit a safety assessment, which shall be reviewed and assessed by the regulatory body."

5.10. Paragraph 3.31 of GSR Part 3 [5] states:

"Safety assessments shall be conducted at different stages, including the stages of siting, design, manufacture, construction, assembly, commissioning, operation, maintenance and decommissioning (or closure) of facilities or parts thereof, as appropriate, so as:

(a) To identify the ways in which exposures could be incurred, account being taken of the effects of external events as well as of events directly involving the sources and associated equipment;
(b) To determine the expected likelihood and magnitudes of exposures in normal operation and, to the extent reasonable and practicable, to make an assessment of potential exposures;
(c) To assess the adequacy of the provisions for protection and safety."

5.11. Paragraph 5.6 of GSR Part 5 [3] states:

"The safety case has to address operational safety and all safety aspects of the facility and activities. The safety case has to include considerations for reducing hazards posed to workers, members of the public and the environment during normal operation and in possible accident conditions."

5.12. Paragraph 5.5 of GSR Part 5 [3] states:

"The design of the facility, the arrangements for operational management and the systems and processes that are used have to be considered and justified in the safety case. This has to involve the identification of waste arisings and the establishment of an optimal programme of waste management to minimize the amount of waste generated and to determine the design basis and operational basis for the treatment of effluents, the control of discharges and clearance procedures. The primary aim of the safety case is to ensure that the safety objectives and criteria set by the regulatory body are met."

5.13. Paragraph 3.32 of GSR Part 3 [5] states:

"The safety assessment shall include, as appropriate, a systematic critical review of:

(a) The operational limits and conditions for the operation of the facility;
(b) The ways in which structures, systems and components, including software, and procedures relating to protection and safety might fail, singly or in combination, or might otherwise give rise to exposures, and the consequences of such events;
(c) The ways in which external factors could affect protection and safety;
(d) The ways in which operating procedures relating to protection and safety might be erroneous, and the consequences of such errors;
(e) The implications for protection and safety of any modifications;
(f) The implications for protection and safety of security measures or of any modifications to security measures;
(g) Any uncertainties or assumptions and their implications for protection and safety."

5.14. Paragraph 3.33 of GSR Part 3 [5] states:

"The registrant or licensee shall take into account in the safety assessment:

(a) Factors that could give rise to a substantial release of radioactive material, the measures available to prevent or to control such a release, and the maximum activity of radioactive material that, in the event of a major failure of the containment, could be released to the environment;
(b) Factors that could give rise to a smaller but continuing release of radioactive material, and the measures available to detect and to prevent or to control such a release;
(c) Factors that could give rise to unintended operation of any radiation generator or a loss of shielding, and the measures available to detect and to prevent or to control such occurrences;
(d) The extent to which the use of redundant and diverse safety features that are independent of each other, so that failure of one does not result in failure of any other, is appropriate to restrict the likelihood and magnitude of potential exposures."

5.15. "The extent and detail of the safety case and the safety assessment have to be commensurate with the complexity of the operations and the magnitude of the hazards associated with the facility and activities" (GSR Part 5 [3], para. 5.7). The safety case process is comprehensive and contains numerous components and steps. Some of these steps could be omitted based on the limited or negligible risk associated with the predisposal management of radioactive waste (e.g. small inventories of waste, or waste containing limited radioactivity, or containing only short lived radionuclides) that does not require long term pretreatment or long term storage facilities. The safety case for the predisposal management of waste should address the following:

(a) The chemical, physical and radiological properties of the waste to be managed;
(b) The radioactive waste management strategy, which should include a description of proposed radioactive waste management activities relating to waste generation (anticipated waste quantities, provisions for waste minimization and control), waste processing (pretreatment, treatment, conditioning), storage and transport, and a description of facilities and their associated systems;
(c) The safety assessment for the waste management, which should demonstrate the integrity of the waste management facility and the associated waste control measures;
(d) A demonstration of compliance with established safety criteria and regulations in force;
(e) Storage arrangements;

(f) Arrangements for the removal of regulatory control from materials, activities and facilities (clearance), if permitted in national regulations;
(g) Arrangements for waste to be removed from the site for storage, processing or disposal at some other site;
(h) Proposals for the discharge of materials (points and method of discharge and related controls);
(i) Programmes for the monitoring of discharges and for environmental monitoring and proposals for safety assessment;
(j) Decommissioning plans and procedures;
(k) The radiation protection programme and evidence of the optimization of radiation protection;
(l) The management system, including operational procedures and record keeping;
(m) Staff competence and training provisions;
(n) The emergency plan for the facility.

5.16. The safety assessment should demonstrate that the performance objectives for the waste management facility and the processes used can be met, and that the overall system is acceptable for licensing or authorization. The resulting information should include predicted impacts on workers, the public and the environment. The quantities and concentrations of radioactive material or other hazardous materials that may be safely discharged from the facility should be determined and documented. Non-radioactive hazardous materials may be covered by other legislation in some States. In such cases, integration of the safety assessment with such other legislation is necessary. The extent of the safety assessment depends on the radiation risks to workers, the public and the environment that arise from the proposed operations. The focus of safety assessment for operators managing small quantities of waste should be on demonstrating compliance with regulatory requirements.

5.17. The safety assessment should be independently reviewed under the relevant management system.

5.18. A non-radiological environmental impact assessment is usually carried out in accordance with national environmental laws and regulations and is outside the scope of this Safety Guide.

5.19. A systematic and structured approach to the safety assessment should be demonstrated, with account taken of all stages in the waste management process, both as individual stages, and as a part of an integrated waste management system. For simpler and smaller operations this integrated waste management system may be fairly straightforward and brief. The assessment should address the interdependences between the steps in waste management and between the organizations involved. It should also consider normal operating conditions and abnormal operating conditions and should propose actions to reduce identified risks to an acceptable level, in compliance with the requirements of the regulatory body.

5.20. Where complex and elaborate waste management operations are proposed, it will generally be appropriate to apply sophisticated hazard analysis. However, for the majority of small waste management facilities, a simplified assessment approach will be adequate. An example of a fault schedule for such a simplified assessment is given in Appendix II. The purpose of a fault schedule is to identify hazards and to propose engineered, administrative and contingency controls to result in an acceptable risk. Both radiation risks and non-radiological risks should be addressed.

5.21. The results and findings of the safety assessment are required to be documented in the form of a safety report (para. 4.62 of GSR Part 4 (Rev. 1) [45]). The safety report should address both radiation risks and non-radiological risks that might arise under normal conditions and abnormal conditions, and actions to be taken to reduce these risks to acceptable levels. The arrangements for such actions, which include reference levels, conditions and practical and administrative procedures, should form the basis of operational documentation and should be followed by the operator of the waste management facility. Requirements on safety assessment are established in GSR Part 4 (Rev. 1) [45] and recommendations on safety assessment and content of the safety case for a predisposal waste management facility are provided in GSG-3 [20].

DOCUMENTATION OF THE SAFETY CASE AND SUPPORTING SAFETY ASSESSMENT

Requirement 15 of GSR Part 5 [3]: Documentation of the safety case and supporting safety assessment

"The safety case and its supporting safety assessment shall be documented at a level of detail and to a quality sufficient to demonstrate safety, to support the decision at each stage and to allow for the independent review and approval of the safety case and safety assessment. The documentation shall be clearly written and shall

include arguments justifying the approaches taken in the safety case on the basis of information that is traceable.”

5.22. “Justification has to involve explaining why particular choices were made and stating the arguments in favour of and against the decisions made, especially those decisions that relate to the main approaches taken in the safety case” (GSR Part 5 [3], para. 5.8).

5.23. Paragraph 5.9 of GSR Part 5 [3] states:

> “Traceability refers to the possibility of following the information that is provided in the documentation and that has been used in developing the safety case. For the purposes of both justification and traceability, a well documented record is necessary of the decisions and assumptions that were made in the development and operation of the facility, and of the models and data used in the safety assessment to obtain the set of results. Good traceability is important for the purposes of technical and regulatory review and for building public confidence.”

5.24. Paragraph 5.10 of GSR Part 5 [3] states:

> “Clarity refers to good structure and presentation at an appropriate level of detail such as to allow an understanding of the arguments included in the safety case. This necessitates that the documents present the work in such a way that the interested parties for whom the documents are intended can gain a good understanding of the safety arguments and their bases. Different styles and levels of documentation may be necessary, depending on the intended audience for the material.”

PERIODIC SAFETY REVIEWS

Requirement 16 of GSR Part 5 [3]: Periodic safety reviews

“The operator shall carry out periodic safety reviews and shall implement any safety upgrades required by the regulatory body following this review. The results of the periodic safety review shall be reflected in the updated version of the safety case for the facility.”

5.25. “The safety assessment has to be reviewed periodically to confirm that any input assumptions that need to be complied with remain adequately controlled within the overall safety management controls” (GSR Part 5 [3], para. 5.11).

5.26. Paragraph 5.12 of GSR Part 5 [3] states:

> “The safety assessment and the management systems within which it is conducted have to be periodically reviewed at predefined intervals in accordance with regulatory requirements. In addition to such predefined periodic reviews, the safety assessment has to be reviewed and updated:
>
> — When there is any significant change that may affect the safety of the facility or activity;
> — When there are significant developments in knowledge and understanding (such as developments arising from research or operational experience feedback);
> — When there is an emerging safety issue owing to a regulatory concern or an incident;
> — When there have been significant improvements in assessment techniques such as computer codes or input data used in the safety analysis.”

5.27. If, as a result of a safety assessment, or for any other reason, opportunities to improve protection and safety become available and improvement seems desirable, any consequential modifications should be made cautiously and only after favourable assessment of all the implications for protection and safety. The implementation of all improvements should be prioritized so as to optimize protection and safety.

6. DEVELOPMENT AND OPERATION OF PREDISPOSAL RADIOACTIVE WASTE MANAGEMENT FACILITIES AND ACTIVITIES

GENERAL

6.1. Paragraph 5.1 of GSR Part 5 [3] states:

> "The development of authorizations and of limits, conditions and controls for the predisposal management of radioactive waste benefits from close communication and cooperation between the operators, regulatory bodies and other interested parties."

6.2. Paragraph 5.2 of GSR Part 5 [3] states:

> "It is the responsibility of the regulatory body to derive and document in a clear and unambiguous manner the criteria on which the regulatory decision making process is based. It is important that any additional guidance provided by the regulatory body takes account of the wide range of predisposal radioactive waste management facilities that may be developed and the wide range of activities that may be conducted at these facilities."

6.3. The safety of a predisposal radioactive waste management facility is required to be ensured through application of good engineering practice and implementation of a management system (see Requirements 4 and 7 of GSR Part 5 [3]). In particular, the concept of defence in depth, providing for multiple levels of protection against failures for technical reasons or because of human errors, is required to be applied (see para. 3.40 of GSR Part 3 [5]). This should include:

(a) Systems of several physical barriers on the migration pathway of radionuclides to the environment;
(b) Technical and organizational means for protection of the integrity and efficiency of the barriers;
(c) Measures for protection of the public and the environment in case of failure of or damage to the barriers.

6.4. At all stages of the lifetime of a predisposal radioactive waste management facility (i.e. its siting, design, construction, commissioning, operation, shutdown and decommissioning), technical and organizational means to apply the concept of defence in depth are required to be provided for:

> "(a) Preventing accidents;
> (b) Mitigating the consequences of any accidents that do occur;
> (c) Restoring the sources to safe conditions after any such accidents" (GSR Part 3 [5], para. 3.40).

LOCATION AND DESIGN OF FACILITIES

Requirement 17 of GSR Part 5 [3]: Location and design of facilities

"Predisposal radioactive waste management facilities shall be located and designed so as to ensure safety for the expected operating lifetime under both normal and possible accident conditions, and for their decommissioning."

6.5. Paragraph 5.13 of GSR Part 5 [3] states:

> "The features to be incorporated in the design will depend largely on the properties, total inventory and potential radiological and non-radiological hazards associated with the radioactive waste that is to be managed, as well as on the requirements of the regulatory body."

6.6. "The need for operational maintenance, testing, examination and inspection has to be addressed from the conceptual design stage onward" (GSR Part 5 [3], para. 5.14).

6.7. In designing facilities for processing radioactive waste, consideration should be given to providing the following:

(a) Separation of the radioactive waste processing systems from the other systems in the facility, as well as from premises and facilities where other potentially hazardous materials are stored or handled;
(b) Auxiliary systems, for example, systems for sampling or decontamination;
(c) Control at all stages of the management of the waste, including control over waste receipt, and measures for protection of workers and for the safety of the working environment;
(d) Adequate confinement of radioactive material (e.g. fume cupboards, drip trays, sealed and recessed work benches) and shielding (e.g. lead or concrete blocks);
(e) Demarcation of the working premises according to their classification as controlled areas or supervised areas (e.g. by means of labels, rope or other barriers), as appropriate;
(f) Radiation monitoring (measurements of dose rate and surface contamination);
(g) Technological control, such as recording of the characteristics of the radioactive waste and control over the characteristics of the final product (the waste form);

(h) Arrangements for the location and layout of the equipment and systems in a way that provides ease of access for normal operation, maintenance and control;
(i) Appropriate handling equipment and the selection of short and uncomplicated routes to ensure safe handling of the waste;
(j) Surfaces that can be easily decontaminated;
(k) Adequate drainage and ventilation systems (e.g. air filtration, air pressure differentials and flow considerations);
(l) The normal electrical supply and an emergency electrical supply;
(m) Premises for storing emergency equipment;
(n) Fire protection systems;
(o) Measures for physical protection.

6.8. Depending on the quantities of radioactive waste, safety arrangements can range from processing and/or storage in a shielded cabinet to dedicated separate rooms or facilities. The specific arrangements depend largely on the activities and the chemical and physical characteristics of the radioactive waste and the amounts involved, as well as on the technologies available. The requirement to maintain radiation doses as low as reasonably achievable and the preference for maintaining working areas free of radioactive waste with long half-lives may mean that a separate room should be provided where the waste can be stored in an orderly way. However, where only very small amounts of radioactive waste are generated, even over many days of work, a local store or cabinet close to the workplace may be used.

6.9. In general, the container should be suitable for the safe management of the specific waste, and should be selected in accordance with the chemical and radiological characteristics of the waste, the volume, and the handling and storage specifications. Pressurization of containers due to the expansion of liquids and the generation of gases and vapours (mainly when handling organic fluids) should be avoided.

6.10. The design of storage facilities should allow for regular inspection and monitoring, including radiation monitoring (monitoring of dose rate and surface contamination) and visual examination of waste packages in order to obtain an early indication of any physical deterioration or leakage. The lifetime of the construction materials should correspond to the envisaged storage period and the storage conditions should be such as to maintain the characteristics of the waste packages for this storage period. The design of the storage facility should allow for the possible extension of the storage period into the future and the retrieval of the radioactive waste from the facility for subsequent processing or disposal.

CONSTRUCTION AND COMMISSIONING OF THE FACILITIES

Requirement 18 of GSR Part 5 [3]: Construction and commissioning of the facilities

“Predisposal radioactive waste management facilities shall be constructed in accordance with the design as described in the safety case and approved by the regulatory body. Commissioning of the facility shall be carried out to verify that the equipment, structures, systems and components, and the facility as a whole, perform as planned.”

6.11. “It is the responsibility of the operator to construct facilities in accordance with the approved design, including conducting any verification tests that need to be performed (e.g. the testing of welds or foundations)” (GSR Part 5 [3], para. 5.15). The regulatory body is responsible for ensuring that the operator constructs the facility in accordance with an approved design, and that activities conducted by the operator for verification and construction are approved.

6.12. “Commissioning may be carried out in several stages that are subject to the review and approval of the regulatory body” (GSR Part 5 [3], para. 5.16).

6.13. Paragraph 5.17 of GSR Part 5 [3] states:

> “Upon the completion of commissioning, a final commissioning report is usually produced by the operator. The report has to document the as-built status of the facility, which, in addition to providing information to facilitate operation, is important when considering possible future modifications to the facility and its shutdown and decommissioning. The report has to describe all the testing and provide evidence of the successful completion of testing and of any modifications made to the facility or to procedures in commissioning. The report has to provide assurance that all the conditions of authorization have been satisfied. This report has to be maintained with the operator as part of the documentation needed for operation and for the development of the decommissioning plan. The regulatory body has to assess this report to ensure that all conditions and requirements are satisfied before agreeing to the operation of the facility. The safety case has to be updated, as necessary, to reflect the as-built status of the facility and the conclusions of the commissioning report.”

6.14. “A modification of a facility with significant safety implications that requires a revision of the safety case has to be subject to the same regulatory controls and approvals as are applicable for the new facility” (GSR Part 5 [3], para. 5.18).

FACILITY OPERATION

> **Requirement 19 of GSR Part 5 [3]: Facility operation**
>
> **“Predisposal radioactive waste management facilities shall be operated in accordance with national regulations and with the conditions imposed by the regulatory body. Operations shall be based on documented procedures. Due consideration shall be given to the maintenance of the facility to ensure its safe performance. Emergency preparedness and response plans, if developed by the operator, are subject to the approval of the regulatory body.”**

6.15. The operator applying for a licence to operate any facility for predisposal management of radioactive waste should demonstrate to the regulatory body that the concept of the facility is consistent with the national policy and strategy.

6.16. Paragraph 5.19 of GSR Part 5 [3] states:

> “The operational limits, conditions and controls are not in all cases provided in the authorization document, but they may be given in a separate document (sometimes called the safety related technical specifications), referred to in the authorization document. All operations and activities important to safety have to be subject to documented limits, conditions and controls, and have to be carried out by trained, qualified and competent personnel.”

6.17. Paragraph 5.20 of GSR Part 5 [3] states:

> “All facility specific safety related criteria and documented operating procedures required by the regulatory body have to be submitted to the regulatory body for approval. Such procedures may include a programme of periodic maintenance, testing and inspection of systems that are essential to safe operation.”

Such systems include ventilation systems and sewage systems.

6.18. For a large and/or centralized storage facility, the operator applying for a licence should ensure in the design and construction of the facility that:

(a) There is sufficient storage capacity to account for uncertainties in the availability of facilities for treatment, conditioning and disposal. The design of the facility should take into account the possible need to process waste arising from incidents.
(b) The facility is suitable for the expected period of storage, preferably by using passive safety features, with account taken of the potential degradation of the waste and with due consideration of site characteristics that could impact performance, such as geology, hydrology and climate.
(c) The waste can be inspected, monitored and preserved in a condition suitable for release from regulatory control or transport, as appropriate.
(d) There is appropriate confinement of the waste; for example, the integrity of the facility's structures and equipment, as well as the integrity of the waste forms and containers should be ensured over the expected duration of storage. Consideration should be given to interactions between the waste, the containers and the storage environment (e.g. corrosion processes due to chemical or galvanic reactions).
(e) Provision is made for retrieval of the waste whenever necessary.

SHUTDOWN AND DECOMMISSIONING OF FACILITIES

Requirement 20 of GSR Part 5 [3]: Shutdown and decommissioning of facilities

"The operator shall develop, in the design stage, an initial plan for the shutdown and decommissioning of the predisposal radioactive waste management facility and shall periodically update it throughout the operational period. The decommissioning of the facility shall be carried out on the basis of the final decommissioning plan, as approved by the regulatory body. In addition, assurance shall be provided that sufficient funds will be available to carry out shutdown and decommissioning."

6.19. Paragraph 5.21 of GSR Part 5 [3] states:

> "Decommissioning of predisposal radioactive waste management facilities has to be considered in the design stage. The objective is to limit occupational exposures, the generation of waste and the potential for accidents during decommissioning."

6.20. Paragraph 5.23 of GSR Part 5 [3] states:

> "Facilities have to be shut down and decommissioned in accordance with the conditions set by the regulatory body. The objective is to facilitate the future dismantling activities by reducing occupational exposures, minimizing the generation of waste and reducing the potential for accidents during decommissioning. Particular consideration has to be given to any transfer of responsibility for the facility that may occur at this stage."

6.21. "The time periods between updates of the decommissioning plan will be dependent on the type of facility and the operational history and have to be agreed with the regulatory body" (GSR Part 5 [3], para. 5.22).

6.22. The operator should give consideration to aspects of decommissioning of the facility at every stage of the lifetime of the facility. This is particularly the case for the design of the facility and for any subsequent modification. Also, when decommissioning operations commence, it should be ensured that the necessary administrative and managerial controls will remain in place or will be changed to accommodate the new circumstances. In principle, dismantling of processing or storage facilities should commence only after:

(a) Radioactive waste and other potentially hazardous materials have been removed;
(b) The systems and components to be dismantled have been decontaminated.

However, acceptable safety cases may be envisaged where not all waste is removed before decontamination and dismantling.

6.23. There may be a need for extended storage of waste arising from decommissioning activities. Decommissioning activities could be carried out individually or in combination, depending on the type and scale of the processing or storage facility, the radioactive waste, and the national strategy and availability of centralized storage and disposal facilities. Further requirements and guidance are provided in GSR Part 6 [18] and in SSG-49 [19].

EXISTING FACILITIES

Requirement 22 of GSR Part 5 [3]: Existing facilities

"The safety at existing facilities shall be reviewed to verify compliance with requirements. Safety related upgrades shall be made by the operator in line with national policies and as required by the regulatory body."

6.24. The operator should cooperate with the regulatory body to establish a reasonable time frame within which the necessary measures to achieve compliance are to be taken.

6.25. The recommendations given in this Safety Guide are intended to apply to all facilities considered in the scope of this Safety Guide. Paragraph 5.25 of GSR Part 5 [3] states:

> "Since existing facilities might not be in compliance with all the requirements, decisions have to be taken, in line with national policies, with regard to the safety of these facilities. In such a case, a review initiated by the regulatory body has to be used to identify those facilities that are not in compliance with all the requirements and that need additional modifications or operational restrictions, or that need to be shut down."

7. MANAGEMENT SYSTEMS

GENERAL

Requirement 7 of GSR Part 5 [3]: Management systems

"Management systems shall be applied for all steps and elements of the predisposal management of radioactive waste."

7.1. Paragraph 3.24 of GSR Part 5 [3] states (citations omitted):

> "To ensure the safety of predisposal radioactive waste management facilities and the fulfilment of waste acceptance criteria, management systems are to be applied to the siting, design, construction, operation, maintenance,

> shutdown and decommissioning of such facilities and to all aspects of processing, handling and storage of waste. Features that are important to safe operation, and that are considered in the management system, are to be identified on the basis of the safety case and the assessment of environmental impacts. These activities are required to be supported by means of an effective management system that establishes and maintains a strong safety culture."

The management system covers all aspects of management, including arrangements for quality assurance and quality control (see also GS-G-3.3 [30]).

7.2. An effective management system is a prerequisite to ensure the safety of radioactive waste management and the protection of human health and the environment. Management and demonstration of quality in the waste management programme should be achieved by establishing and working within a formalized management system that has been approved by the regulatory body. The management system should be commensurate with the complexity of the activities undertaken, the waste generated and the waste management programme. The management system should ensure compliance of the activities in radioactive waste management with the conditions for authorization and should facilitate the provision of information to the regulatory body.

7.3. The requirements for the management system are to be applied by users of radioactive materials in medicine, industry, agriculture, research and education, operators of waste management facilities and the regulatory body.

7.4. For establishing and maintaining an integrated management system, the following long term aspects (with account taken of the duration of waste processing and storage periods) should be considered:

(a) The preservation of technology and knowledge and the transfer of such knowledge to individuals joining the organization in the future;
(b) The retention or transfer of ownership of the radioactive waste and of the waste management facility;
(c) Succession planning for technical human resources and managerial human resources;
(d) The continuation of arrangements for interacting with interested parties;
(e) The provision of adequate financial resources (the adequacy of resources for maintenance and eventual decommissioning of facilities and equipment may need to be periodically reviewed over operational periods that may extend over decades);

(f) The preservation and quality of records and information (e.g. details of radioactive waste inventories, records relating to the siting, design, commissioning, operation and decommissioning of the facility, and records relating to the development of the safety case);
(g) Provision for review to ensure that the goals of the management system can continue to be met.

7.5. Guidance on the detailed components of the management system as part of an overall approach to quality management is given in GS-G-3.1 [29] and GS-G-3.3 [30].

7.6. The operator should audit the implementation of the management system in its organization on a regular basis. Whenever deviations are identified, appropriate corrective actions should be proposed, taken and recorded.

7.7. The auditing should include revision of the quality assurance procedures to remove any procedures that do not contribute to the safety of the facility or activity.

RECORD KEEPING AND REPORTING

7.8. A suitable and comprehensive record system should be developed as part of the management system for radioactive waste management. Information on waste inventories should be properly recorded, updated (such as changes to waste characteristics during processing), transferred (between waste management stages or to another responsible organization) and retained in such a way as to ensure that relevant information is accessible in the future, as necessary.

7.9. The operator should review on a regular basis the proper functioning of the record system. Safety related details of the history of disused sealed sources considered as waste should be included in the inventory. The record system should allow for traceability of waste from the point of its collection through to its long term storage and/or disposal.

7.10. The operator should ensure that information relating to the main radioactive waste characteristics is adequately maintained and retained, in particular:

(a) The source of origin of the waste;
(b) The physical and chemical form of the waste;
(c) The amount of waste (volume and/or weight);

(d) Radiological properties (the activity concentration, the total activity, the radionuclides present and their relative proportions, including the date of measurement);
(e) Physical and chemical properties;
(f) Categorization of the waste in accordance with the categorization scheme for operational purposes;
(g) Classification of the waste in accordance with the national waste classification system;
(h) Thermal properties, when applicable;
(i) Any chemical, pathogenic or other non-radiological hazard associated with the waste and the concentration of hazardous material;
(j) Any special handling necessary owing to criticality concerns, the need for the removal of decay heat or significantly elevated radiation levels.

7.11. The operator of a facility generating radioactive waste, in order to ensure the proper control under waste management activities, should maintain records for:

(a) The radioactive waste generated (e.g. the date of generation, waste characteristics);
(b) The radioactive waste in storage (including the identification, origin, location, physical and chemical characteristics of the waste);
(c) Material from which regulatory control has been removed or that has been discharged to the environment (including data relating to the process of removal of regulatory control or of discharge to the environment);
(d) Disused sealed radioactive sources that have been returned to suppliers;
(e) Radioactive waste and disused sealed radioactive sources transferred to another waste management facility;
(f) Non-compliances and actions taken in response.

7.12. For processing and storage facilities for radioactive waste, the records concerning waste management activities should include the following:

(a) Data relating to the waste and any disused sealed radioactive sources collected or received;
(b) The data necessary for a national inventory of waste;
(c) The data necessary for waste characterization;
(d) The records from the processes for pretreatment, treatment and conditioning of the waste;
(e) Documents relating to the procurement of containers necessary to provide confinement for a certain period (e.g. in a disposal facility);

(f) The specifications for waste packages and audit records for individual containers and packages;
(g) Trends in operating performance;
(h) Non-compliances with the specifications for waste packages and the actions taken to rectify them;
(i) Data relating to materials that were cleared or discharged;
(j) Lessons from events and incidents.

7.13. The operator should ensure, where necessary, that site plans, engineering drawings, specifications and process descriptions as well as operating procedures and safety related operating instructions are maintained. The results from quality control activities as well as operating activities should be well documented and recorded.

7.14. The operator should also keep records of information relating to the safety of the predisposal radioactive waste management facility during commissioning, operation, modification or decommissioning.

7.15. The regulatory body should specify the timing, scope and content of periodic reports to be submitted by the operator and reports describing any non-compliance with safety requirements or unplanned situations. Reports may include the following:

(a) Details of materials from which regulatory control has been removed or that have been discharged to the environment;
(b) Details of disused sealed radioactive sources returned to suppliers;
(c) The current inventory of radioactive waste, including the identification, origin, location, physical and chemical characteristics of the waste, the radionuclide composition, the total activity or activity concentration (with the measurement or estimation date) and, as appropriate, a record of radioactive waste removed from the facility;
(d) Safety assessment methods used and results of safety assessments;
(e) Results from effluent monitoring and environmental monitoring;
(f) Results of internal audits and other findings by the operator;
(g) Emergencies, if any, occurring during processing of the waste, methods adopted for the handling of such situations and any lessons drawn.

7.16. If any radioactive waste has been lost or stolen, or effluent has been discharged above the established limits, the operator should promptly inform the regulatory body and should submit a written report on the matter and actions taken.

7.17. When waste is being transferred, the associated records should be made available to the operator of the subsequent step.

7.18. The regulatory body may also require the operator to submit on a regular basis a summary of the status of the waste generation and management.

SAFETY CULTURE

7.19. All the organizations involved with the generation and management of radioactive waste and its regulatory control should develop and maintain a strong safety culture [22, 30]. Safety culture includes individual and collective commitment to safety on the part of leadership, management and personnel at all levels of the organization. Efforts should be made to create the necessary awareness of the need for proper management of radioactive waste at all levels of the organization and should discourage complacency in any aspect of related operations (see para. 3.13 of SF-1 [2]).

7.20. All individuals should adopt a questioning and learning attitude with regard to the adequacy and effectiveness of radioactive waste management programmes and should seek at all times to make improvements in the arrangements for protection and safety.

Appendix I

TYPICAL RADIATION SOURCES USED IN MEDICINE, INDUSTRY AND RESEARCH AND THE ASSOCIATED RADIOACTIVE WASTE GENERATED

I.1. Sources of ionizing radiation are produced for a broad range of applications in medicine, industry, research and other areas. Many of the sources used in medical treatments are also used in pharmaceutical research or in the manufacture of radiopharmaceuticals. As a result of the initial production of radioactive materials and their subsequent use, radioactive waste in various forms is generated. In general, this waste comprises radioactive material that is no longer useful and is therefore considered waste; items that have become contaminated, such as paper, plastic gloves and covers; counting tubes and glassware; and washing liquids and excreta from patients to whom radionuclides have been administered. In addition to such routine waste, waste of variable composition may also arise from incidents involving radioactive material. The risks associated with the waste and thus the precautions that should be taken vary widely depending on the application, the radionuclides and the quantities.

I.2. Radioactive materials are used in two different forms. Sealed radioactive sources are used in a form for which the probability of dispersion of the radioactive contents is very low. Unsealed sources are dispersible, although combined with the chemical medium of which they are a part. Tables 1 and 2 provide information on the main unsealed radioactive sources and sealed radioactive sources used in medicine, industry and research.

Radionuclide production

I.3. Particle accelerators and nuclear reactors are used for the production of radionuclides. The radionuclides generated in particle accelerators and reactors are produced in targets and capsules, which are removed for processing and purification. Small volumes of liquid waste with relatively high activities and larger volumes of dry, low level solid waste are generated.

Medical applications

I.4. Radioactive materials are used in medicine for diagnosis, therapy and research, including in the following applications:

(a) In vitro radioassay for clinical diagnosis and research using unsealed radionuclides;
(b) In vivo use of radiopharmaceuticals for clinical diagnosis, therapy and medical research using unsealed radionuclides;
(c) Radiotherapy using sealed sources that are either implanted inside the patient or used in an external device.

I.5. Commercially available kits containing only kilobecquerel quantities of radionuclides are used for in vitro radioassay. In many States, this activity is not controlled by the regulatory body because the used kits are eligible for exemption. ^{125}I is the main radionuclide, with each assay usually involving a very small amount of activity. Following each individual assay and after the expiry date of the kit, the radioactive material and contaminated items are normally disposed of as conventional waste.

I.6. For the main in vivo applications, the particular organ to be studied or treated governs the type of radiopharmaceutical used and the quantity administered to the patient. Of the radionuclides in use for imaging work, ^{99m}Tc is the most common, having a radioactive half-life of 6 hours. It is normally eluted in a sterile environment from a commercially supplied generator containing a core of ^{99}Mo. Since the half-life of ^{99}Mo is 66 hours, generators need to be replaced at approximately weekly intervals. The waste arising from the preparation of ^{99m}Tc labeled agents, such as discarded vials, syringes and swabs, is potentially contaminated with the radionuclide, but the radioactivity decays rapidly owing to the short half-life, so that regulatory control can be removed and the waste disposed of as conventional waste. However, when applying decay storage for large amounts of ^{99m}Tc it should be noted that the decay product of ^{99m}Tc, namely ^{99}Tc, is radioactive and has a very long half-life.

I.7. Radionuclides such as ^{131}I, ^{32}P, ^{90}Y, ^{192}Ir and ^{89}Sr are administered to patients in activities ranging from 200 MBq to 11 GBq for therapeutic purposes. In therapeutic applications, due attention should be paid to the radioactive contaminants contained in waste from patients, such as excreta and soiled linen.

I.8. Sealed radioactive sources containing other radionuclides such as ^{60}Co, ^{192}Ir and ^{137}Cs are used for patient therapy as temporary implants, for external beam therapy and for irradiation of blood products. Detailed guidance on radiation protection in medical uses of radiation, including the safe handling of waste from medical applications, is provided in IAEA Safety Standards Series No. SSG-46, Radiation Protection and Safety in Medical Uses of Ionizing Radiation [46].

TABLE 1. TYPICAL UNSEALED RADIOACTIVE SOURCES USED IN MEDICINE AND BIOLOGICAL RESEARCH

Radionuclide	Half-life	Principle application	Typical activity per application	Waste characteristics
^{3}H	12.3 a	Radiolabelling Biological research Organic synthesis	Up to 50 GBq	Solvent, solid, liquid
^{11}C	20.4 m	Positron emission tomography Lung ventilation studies	Up to 2 GBq	Solid, liquid
^{14}C	5730 a	Medical diagnosis Biological research Labelling	Up to 1 MBq Up to 50 GBq Up to 50 GBq	(Exhaled CO_2) Solid, liquid Solvent
^{15}O	122 s	Positron emission tomography Lung ventilation studies	Up to 2 GBq	Solid, liquid
^{18}F	1.8 h	Positron emission tomography	Up to 500 MBq	Solid, liquid
^{24}Na	15.0 h	Biological research	Up to 5 GBq	Liquid
^{32}P ^{33}P	14.3 d 25.4 d	Therapeutic nuclear medicine Biological research	Up to 200 MBq Up to 50 MBq	Solid, liquid
^{35}S	87.4 d	Medical and biological research	Up to 5 GBq	Solid, liquid
^{36}Cl	3.01×10^{5} a	Biological research	Up to 5 MBq	Gaseous, solid, liquid
^{45}Ca	163 d	Biological research	Up to 100 MBq	Mainly solid, some liquid
^{46}Sc	83.8 d	Medical and biological research	Up to 500 MBq	Solid, liquid
^{51}Cr	27.7 d	Diagnostic nuclear medicine Biological research	Up to 5 MBq Up to 100 MBq	Solid Mainly liquid effluent
^{57}Co ^{58}Co	271.7 d 70.8 d	Diagnostic nuclear medicine Biological research	Up to 50 MBq	Solid, liquid effluent

TABLE 1. TYPICAL UNSEALED RADIOACTIVE SOURCES USED IN MEDICINE AND BIOLOGICAL RESEARCH (cont.)

Radionuclide	Half-life	Principle application	Typical activity per application	Waste characteristics
^{59}Fe	44.5 d	Diagnostic nuclear medicine Biological research	Up to 50 MBq	Solid, mainly liquid
^{67}Ga	3.3 d	Diagnostic nuclear medicine	Up to 200 MBq	Solid, liquid
^{68}Ga	68.2 m	Positron emission tomography	Up to 2 GBq	Solid, liquid
^{75}Se	120 d	Diagnostic nuclear medicine	Up to 10 MBq	Solid, liquid
^{81m}Kr	13.3 s	Lung ventilation studies	Up to 6 GBq	Gaseous
^{85}Sr	64.8 d	Biological research	Up to 50 MBq	Solid, liquid
^{86}Rb	18.7 d	Medical and biological research	Up to 50 MBq	Solid, liquid
^{82m}Rb	6.2 h	Diagnostic nuclear medicine	Up to 50 MBq	Solid, liquid
^{89}Sr	50.5 d	Therapeutic nuclear medicine	Up to 300 MBq	Solid, liquid
^{90}Y	2.7 d	Diagnostic nuclear medicine Therapeutic nuclear medicine	Up to 300 MBq	Solid, liquid
^{95}Nb	35.0 d	Medical and biological research	Up to 50 MBq	Solid, liquid
^{99m}Tc	6.0 h	Diagnostic nuclear medicine Biological research Nuclide generators	Up to 100 GBq	Solid, liquid
^{111}In	2.8 d	Clinical measurements Biological research	Up to 50 MBq	Solid, liquid
^{123}I ^{125}I ^{131}I	13.2 h 60.1 d 8.0 d	Medical and biological research Diagnostic nuclear medicine Therapeutic nuclear medicine	Up to 500 MBq Up to 11 GBq	Solid, liquid, occasionally vapour

TABLE 1. TYPICAL UNSEALED RADIOACTIVE SOURCES USED IN MEDICINE AND BIOLOGICAL RESEARCH (cont.)

Radionuclide	Half-life	Principle application	Typical activity per application	Waste characteristics
^{113}Sn	155.0 d	Medical and biological research	Up to 50 GBq	Solid, liquid
^{133}Xe	5.3 d	Diagnostic nuclear medicine	Up to 400 MBq	Gaseous, solid
^{153}Sm	1.9 d	Therapeutic nuclear medicine	Up to 8 GBq	Solid, liquid
^{169}Er	9.3 d	Therapeutic nuclear medicine Diagnostic nuclear medicine	Up to 500 MBq	Solid, liquid
^{198}Au	2.7 d	Therapeutic nuclear medicine Diagnostic nuclear medicine	Up to 500 MB	Solid, liquid
^{201}Tl	3.0 d	Diagnostic nuclear medicine	Up to 200 MBq	Solid, liquid
^{203}Hg	46.6 d	Biological research	Up to 5 MBq	Solid, liquid

TABLE 2. SEALED RADIOACTIVE SOURCES USED IN MEDICINE, INDUSTRY AND RESEARCH

Application	Radionuclide	Half-life	Source activity	Comments
Bone densitometry	^{241}Am ^{153}Gd ^{125}I ^{239}Pu–Be	433.0 a 244.0 d 60.1 d 2.41×10^4 a	1–10 GBq 1–40 GBq 1–10 GBq Various	Mobile units
Manual brachytherapy	^{198}Au ^{137}Cs ^{226}Ra ^{32}P ^{60}Co ^{90}Sr ^{103}Pd ^{125}I ^{192}Ir ^{106}Ru	2.7 d 30.0 a 1600 a 14.3 d 5.3 a 29.1 a 17.0 a 60.1 d 74.0 d 1.01 a	50–500 MBq 30–300 MBq 50–500 MBq Various Various 50–1500 MBq 50–1500 MBq 50–1500 MBq 200–1500 MBq Various	Small portable sources
Remote after-loading brachytherapy	^{137}Cs ^{192}Ir	30.0 a 74.0 d	0.03–10 MBq 200 TBq	Mobile units
Teletherapy	^{60}Co ^{137}Cs ^{226}Ra	5.3 a 30.0 a 1600a	50–1000 TBq 500 TBq Various	Fixed installations
Whole blood irradiation	^{60}Co ^{137}Cs	5.3 a 30.0 a	50–1000 TBq 2–100 TBq	Fixed installations
Research	^{60}Co ^{137}Cs	5.3 a 30.0 a	Up to 750 TBq Up to 13 TBq	Fixed installations
Sterilization	^{60}Co	5.3 a	Up to 40 PBg	Fixed installations
Calibration sources, anatomical markers, sources as standards in instruments	^{63}Ni ^{137}Cs ^{57}Co ^{226}Ra ^{147}Pm ^{36}Cl ^{129}I	100 a 30.0 a 271.7 d 1600 a 2.62 a 3.01×10^5 a 1.57×10^7 a	<4 MBq <4 MBq Up to 400 MBq <10 MBq <4 MBq <4 MBq <4 MBq	Fixed installations in instruments or mobile sources

TABLE 2. SEALED RADIOACTIVE SOURCES USED IN MEDICINE, INDUSTRY AND RESEARCH (cont.)

Application	Radionuclide	Half-life	Source activity	Comments
Thickness gauges, density gauges, well logging, moisture detectors, X ray fluorescence	^{22}Na	2.6 a	Various	
	^{55}Fe	2.6 a	Up to 5 GBq	
	^{85}Kr	10.7 a	Up to 100 GBq	
	^{90}Sr	28.1 a	Up to 10 GBq	
	^{109}Cd	1.27 a	Various	
	^{134}Cs	2.1 a	Up to 20 GBq	
	^{137}Cs	30.0 a	Up to 10 GBq	
	^{147}Pm	2.62 a	Up to 2 GBq	
	^{241}Am–Be	433 a	Up to 500 GBq	
	^{238}Pu	87.7 a	Up to 5 GBq	
	^{252}Cf	2.6 a	Up to 10 GBq	
Static eliminators	^{210}Po	138 d	Up to 20 GBq	Mobile equipment
Electron capture detectors	^{3}H	12.3 a	Up to 10 TBq	Mobile equipment
	^{63}Ni	100 a	Up to 50 GBq	
Industrial radiography	^{169}Yb	32 d	Up to 1 TBq	Mobile equipment
	^{170}Tm	128.6 d	Up to 1 TBq	
	^{60}Co	5.3 a	Up to 15 TBq	
	^{75}Se	120 d	Up to 2 TBq	
	^{137}Cs	30.0 a	Up to 3 TBq	
	^{192}Ir	74.0 d	Up to 5 TBq	

Research applications

I.9. Research using radionuclides may involve the following:

(a) The production and labelling of compounds, resulting in waste containing radionuclides with megabecquerel activities, such as tritium, ^{125}I, ^{14}C or ^{32}P. The range of radionuclides used in such applications is normally fairly restricted and the activity content of the labelled compounds is low.

(b) The study of metabolic, toxicological or environmental pathways associated with a large range of compounds such as drugs, pesticides, fertilizers and minerals. Work may be related to areas such as the manufacture of new drugs, crop production and environmental studies. Animals may also be involved, resulting in radioactive excreta, carcasses and bedding. The radionuclides most commonly employed in studying the toxicology of many chemical compounds and their associated metabolic pathways are ^{14}C

and tritium, as they can be readily incorporated into complex molecules, while ^{33}P is widely used as a tracer in genetics.

(c) The development of clinical processes and applications of prepared compounds (such as pharmaceuticals) for work involving humans as well as animals.

(d) Research relating to the nuclear fuel cycle that is not carried out at a commercial nuclear fuel cycle facility. The research is usually conducted in laboratories, using a small amount of fissile material (uranium, plutonium) and relatively long lived fission products, mainly ^{137}Cs and ^{90}Sr. The waste generated includes solid materials and liquids containing fission products and fissile material.

(e) Basic research in the fields of physics, materials and biology (e.g. the use of ^{57}Co in Mössbauer spectroscopy and the use of tritium as a tracer in hydrology).

Industrial applications and other applications

I.10. Sealed radioactive sources are used extensively for various industrial applications. Such applications include non-destructive testing (radiography and gauging) and the sterilization of food and other products. Sealed radioactive sources are also used for process control and for calibration of laboratory equipment. The dominant radionuclide is present in a very concentrated form with the total activity depending on the application and the nature of the emission from the sources. Operators consider sealed radioactive sources to be waste when they have decayed to the extent that they are no longer useful for their original purpose, or because the equipment in which they are housed has become outdated, or because routine tests have indicated that the source is leaking.

I.11. An example of the industrial use of unsealed radioactive sources as a tracer is the evaluation of wear and corrosion of key components in plant and machinery, such as the wear of engine components, furnace linings and metallic surfaces. Other applications involving unsealed sources include monitoring of sewage treatment works and studying the performance of landfill disposal sites, the movement of groundwater, and the dispersion and dilution of cooling water or gaseous effluents. In most cases, short lived radioactive tracers are used. The industrial applications of radioisotope tracer techniques are often of greater magnitude than those on a laboratory scale. Waste can be generated from radionuclides used in certain consumer products such as smoke detectors (^{241}Am), exit signs (tritium) and static eliminators (^{210}Po). Attention should be given to the need to manage large quantities of waste generated from these sources.

I.12. Both sealed and unsealed radioactive sources are also used in teaching students and in training emergency planners and members of the civil defence forces. All these applications generate waste with activities that are normally very low.

WASTE TYPES

I.13. Radioactive waste can be liquid, solid or gaseous. Liquid waste may be further subdivided into aqueous waste and organic waste, while solid waste may be subdivided into compressible waste and non-compressible waste and combustible waste and non-combustible waste.

Aqueous radioactive waste

I.14. At radioisotope production facilities, aqueous waste results from chemical processing, mainly the etching and dissolving of target materials. The solution, which is of small volume, is normally contaminated with radionuclide impurities. Depending upon the chemical processes used, the aqueous waste may be chemically very reactive.

I.15. In hospitals, the types of aqueous waste depend on the techniques used in therapeutic and diagnostic nuclear medicine. Most of the radionuclides used for diagnosis are very short lived (half-life less than 10 days).

I.16. Studies of metabolic pathways may involve laboratory animals. The animals may be involved at various stages of the work, resulting in contaminated excreta, blood, carcasses and bedding. Some of this material may become part of the conventional aqueous waste stream, thereby creating a potential biological hazard. In some cases, longer lived radionuclides are used to label microspheres for such studies. While these microspheres are solid, they may easily become suspended in the liquid waste. Small animal carcasses may also be macerated to a liquid form to make them suitable for discharge as aqueous waste.

I.17. Aqueous waste also arises from radiochemical neutron activation analysis. Such waste can be extremely varied in chemical composition but the radionuclides are often relatively short lived. In small nuclear research centres, liquid waste may be contaminated with both short lived radionuclides and longer lived radionuclides such as ^{14}C and tritium. The volume of liquid waste produced by individual users of radioactive materials is not likely to be large. However, the waste from radiolabelling processes may have a relatively high activity concentration and should generally be kept separate from lower activity wash solutions. It is unlikely that alpha emitting radionuclides (other than uranium and thorium compounds) or relatively long lived gamma emitters such as ^{137}Cs and ^{60}Co will be used.

I.18. Irrespective of the field of work, contaminated equipment and facilities may need to be cleaned, decontaminated and/or disinfected, resulting in radioactive aqueous waste which may have associated biological hazards. This waste may contain large quantities of complexing agents used to solubilize the radioactive contaminant.

Liquid organic radioactive waste

I.19. Liquid organic radioactive waste typically includes vacuum pump oil, lubricating oil and hydraulic fluids, scintillation solutions from analytical laboratories, solvents from research on solvent extraction and uranium refining, and miscellaneous organic solvents. Most waste of these types arises from work in nuclear research centres. Depending on the origin, the waste contains relatively small quantities of beta and gamma emitting radionuclides. The volume of liquid organic waste produced from nuclear applications of radionuclides is generally small compared with the other categories of radioactive waste generated.

I.20. Organic scintillation liquids normally result from measurements of low energy beta and gamma emitters in samples consisting of aromatic organic compounds, and the material under investigation. The most common radionuclides contained in the waste are tritium and ^{14}C, with ^{125}I and ^{35}S less common.

I.21. A number of non-water-miscible organic solvents may arise in a variety of operations. Such solvents include carbon tetrachloride, trichloroethane and perchloroethylene. Where small quantities of water miscible organic solvents are used (acetone, alcohol), they are typically treated as conventional aqueous waste.

I.22. In nuclear research centres, the solvent most commonly used for extraction of uranium and plutonium is tributyl phosphate. For the extraction process, tributyl phosphate is diluted, usually with a liquid such as paraffin. Sometimes other organic compounds are used for the extraction of heavy metals, including tri- and tertiary amino-compounds, though the volumes are usually very small in comparison with tributyl phosphate.

Solid radioactive waste

I.23. Most solid waste generated in medical and research laboratories falls into the category of combustible waste. This includes paper towels, swabs, paper, cardboard, plastics, rubber gloves, protective clothing and masks, animal carcasses and biological material.

I.24. Non-combustible waste includes glassware, scrap metal and waste from the decommissioning of facilities in which radionuclides were used.

I.25. The categories in paras I.23 and I.24 are not mutually exclusive. This categorization, which should be employed for segregation of solid waste, is based on the degree of volume reduction that may reasonably be expected by compaction or incineration. The waste generated in medical, industrial, research and teaching activities is predominantly of a combustible nature and may also be categorized as compressible, provided that there is no biological hazard.

I.26. Solid waste includes protective clothing, plastic sheeting and bags, rubber gloves and mats, shoe covers, wipe rags and towels. Frequently, such material is only slightly contaminated and possibly exhibits no measurable contamination but is initially classified as radioactive waste purely because it arose in controlled areas. It may be possible to remove such materials from regulatory control and dispose of them as industrial waste. However, certain individual items may be significantly contaminated, particularly if they have been directly involved in procedures or experiments involving unsealed radioactive sources of high activity.

I.27. Disused sealed radioactive sources may have a wide range of activities depending on their original use: this varies from a few kilobecquerels for check sources up to many terabecquerels for external beam radiotherapy sources. While disused sealed radioactive sources are usually a small fraction of the volume of radioactive waste generated by a particular operator, they may dominate the activity content of the waste arisings. Although the activity of external beam radiotherapy sources and other large sources may have fallen below useful levels, the potential for injury from such sources remains substantial. In particular, external beam radiotherapy sources normally contain caesium compounds (^{137}Cs) in dispersible form and present a severe hazard if their primary containment is breached [45].

I.28. Contaminated material and equipment may be generated in medical activities and research activities and may consist of components of dismantled experimental rigs or surgical implants. Such material and equipment may be made of glass, metal or plastic, and their activity differs widely according to use (see Tables 1 and 2).

I.29. Activated materials may include shielding materials (e.g. depleted uranium) and isotope containers from isotope production or materials testing in research reactors. The highest activities are normally those of ^{60}Co and other activated impurities in steel. For cyclotron based production, the radionuclide with the highest activity is normally ^{65}Zn, produced from copper. The residual activity of such materials is a function of both irradiation and period of decay. Such items are unlikely to be either combustible or compressible.

I.30. Animal carcasses have activity concentrations that depend on the species of the animal and the experimental procedures that have been applied. Carcasses may present biological and chemical hazards if they decompose to any significant extent prior to disposal. Carcasses contaminated with long lived radionuclides necessitate particularly careful consideration, especially when incineration is not an available management option.

I.31. Decommissioning of predisposal waste management facilities may result in solid waste comprising construction materials, equipment components and soil. The main features of waste from decommissioning are the relatively large size of the waste items and the presence of long lived radionuclides.

Gaseous or airborne waste

I.32. Gaseous or airborne radioactive waste may be generated from a range of nuclear applications. A specific medical application involves the use of radioactive gases such as ^{133}Xe, ^{81m}Kr or ^{99m}Tc, and short lived positron emitters such as ^{18}F and ^{11}C used for investigating the ventilation of the lungs.

Appendix II

FAULT SCHEDULE FOR SAFETY ASSESSMENT AND ENVIRONMENTAL IMPACT ASSESSMENT

TABLE 3. FAULT SCHEDULE SETTING OUT A SIMPLIFIED APPROACH TO SAFETY ASSESSMENT AND ENVIRONMENTAL IMPACT ASSESSMENT

Process stages	Hazard	Control measures		Mitigated risk	Contingency arrangements
		Engineered measures	Administrative measures		
Identify all stages and interfaces in the waste management decision making process as related to safety and environmental impacts	Identify hazards for each stage of decision making for normal and abnormal conditions, including external events (e.g. flood, fire, earthquakes, tsunamis)	Provide information on engineered control measures. Examples include, but are not limited to: protection devices, containment, shielding, thermal and/or electrical insulation	Provide information on administrative control measures. Examples include, but are not limited to: operating instructions, procedures, limits, conditions, requirements	Quantify the mitigated (controlled) risk for each stage under normal and abnormal conditions once control measures have been taken into account	Provide information on contingency measures. Examples include, but are not limited to: personal protective equipment, power shut off devices, external supporting safety arrangements

Appendix III

FLOW DIAGRAM FOR THE MANAGEMENT OF SOLID RADIOACTIVE WASTE

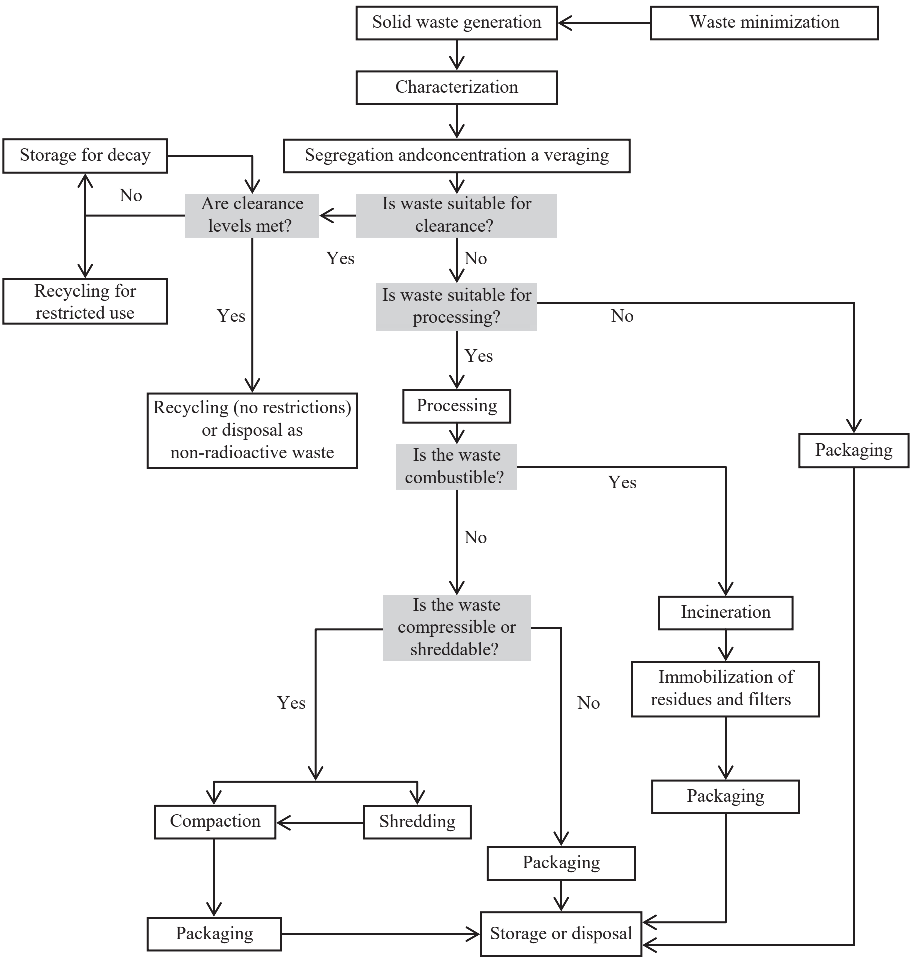

FIG. 1. Flow diagram illustrating the main steps in the management of solid radioactive waste.

Appendix IV

FLOW DIAGRAM FOR THE MANAGEMENT OF BIOLOGICAL RADIOACTIVE WASTE

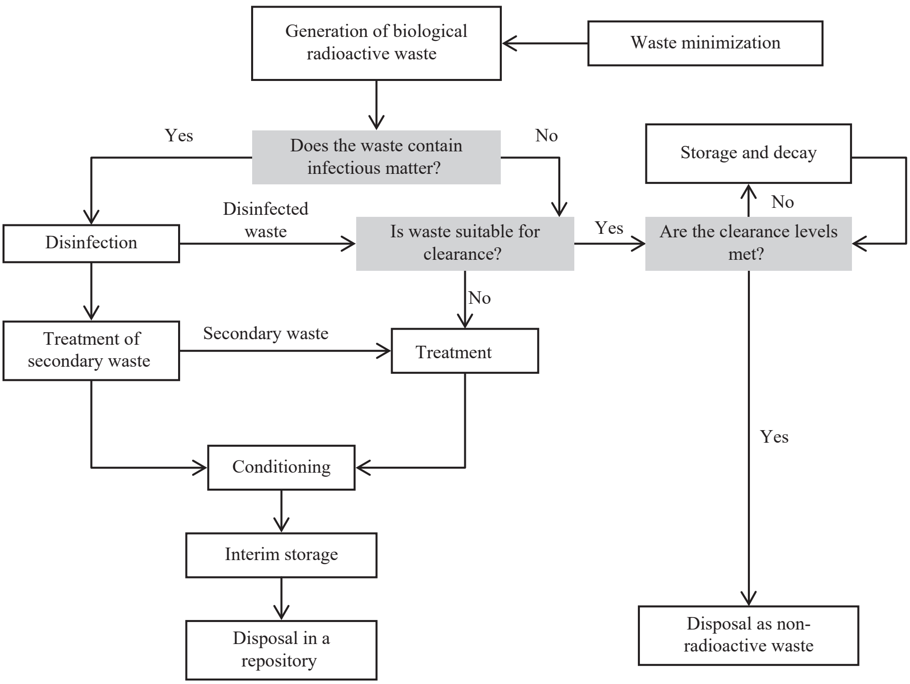

FIG. 2. Flow diagram illustrating the main steps in the management of biological radioactive waste.

Appendix V

FLOW DIAGRAM FOR THE MANAGEMENT OF DISUSED SEALED SOURCES

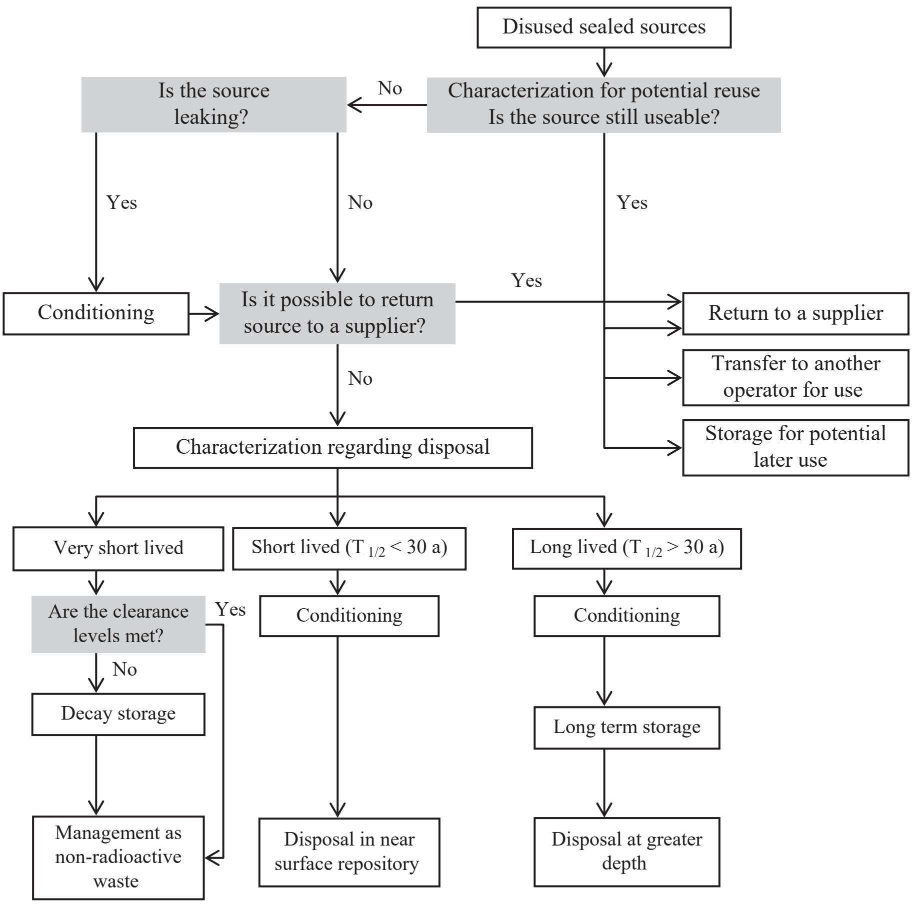

FIG. 3. Flow diagram illustrating the main steps in the management of disused sealed sources.

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Annex I

EXAMPLES OF DISUSED SEALED RADIOACTIVE SOURCES AND IDENTIFICATION OF TECHNIQUES FOR THEIR MANAGEMENT

TABLE I–1: EXAMPLES OF COMMON DISUSED SEALED SOURCES AND THE TECHNIQUES AND EQUIPMENT USED FOR THEIR SAFE MANAGEMENT

Isotope	Half-life	Applications	Handling equipment	Monitoring	Packaging	Storage container
α source (low activity)						
^{241}Am	432.2 a	Smoke detectors Lightning rods Static eliminators	Glovebox Latex gloves	α detection	Stainless steel internal drum	Drum with concrete
^{210}Po	138.38 d	Static eliminators	Latex gloves			
^{238}Pu	87.74 a	X ray fluorescence analyser	Glovebox		Tight container	Drum with concrete
^{239}Pu	24 181 a	Smoke detectors	Glovebox		Tight container	
α and γ sources (low activity)						
^{241}Am	432.2 a	Gauges X ray fluorescence analyser Bone densitometry	Tongs	α detection	Stainless steel internal drum	Drum with concrete

TABLE I–1: EXAMPLES OF COMMON DISUSED SEALED SOURCES AND THE TECHNIQUES AND EQUIPMENT USED FOR THEIR SAFE MANAGEMENT (cont.)

Isotope	Half-life	Applications	Handling equipment	Monitoring	Packaging	Storage container
β and γ sources (low activity) long or short half-life						
$^{90}Sr/^{90}Y$	28.2 a	Gauges Brachytherapy	Rubber gloves	β detection		
^{147}Pm	2.6 a	Gauges	Rubber gloves			
^{63}Ni	100 a	Electron capture detectors	Rubber gloves			
^{109}Cd	462.6 d	X ray fluorescence analyser	Rubber gloves	γ detection		
^{60}Co	5.3 a	Gauges Calibration	Shielded screen Tongs	β, γ detection	Lead shielded pot	Drum with concrete + Pb
^{137}Cs	30.2 a	Gauges Calibration	Shielded screen Tongs		Lead shielded pot	Drum with concrete + Pb

TABLE I–1: EXAMPLES OF COMMON DISUSED SEALED SOURCES AND THE TECHNIQUES AND EQUIPMENT USED FOR THEIR SAFE MANAGEMENT (cont.)

Isotope	Half-life	Applications	Handling equipment	Monitoring	Packaging	Storage container
β and γ sources (high activity) short half-life						
^{192}Ir	73.8 d	Industrial radiography	Lead hot cell Manipulators	β, γ detection	Lead shielded pot	Drum with concrete
^{170}Tm	134 d	Industrial radiography	Shielded screen Tongs		Stainless steel basket	
^{169}Yb	32 d	Industrial radiography	Shielded screen Tongs			
^{75}Se	120 d	Industrial radiography	Shielded screen Tongs			
β and γ sources (high activity) long half-life						
^{60}Co	5.3 a	Industrial radiography	Lead hot cell Manipulators	β, γ detection	Lead container	400L drum with concrete or concrete container
^{60}Co	5.3 a	Teletherapy	Concrete hot cell Manipulators		Lead container	
^{60}Co	5.3 a	Irradiators	Concrete hot cell Manipulators		Specific, to be defined	Specific, to be defined
^{137}Cs	30.2 a	Irradiators	Concrete hot cell Manipulators		Specific, to be defined	Specific, to be defined

TABLE I–1: EXAMPLES OF COMMON DISUSED SEALED SOURCES AND THE TECHNIQUES AND EQUIPMENT USED FOR THEIR SAFE MANAGEMENT (cont.)

Isotope	Half-life	Applications	Handling equipment	Monitoring	Packaging	Storage container
Special sources						
^{226}Ra	1600 a	Lightning rods Static eliminators	Glovebox Tongs	γ detection	Tight container	Lead shielded container
^{85}Kr	10.7 a	Gauges Lightning rods Krypton gas penetrant Imaging	Glovebox Tongs	^{85}Kr detection		
^{3}H	12.3 a	Electron capture detectors X ray fluorescence analyser	Glovebox Tongs	^{3}H detection	Stainless steel	Drum with concrete
Neutron sources						
$^{241}Am/Be$	432.2 a	Moisture detectors Well logging	Neutron protection	α and neutron detection		Neutron protection
^{252}Cf	2.65 a	Moisture detectors Well logging Brachytherapy	Neutron protection			Neutron protection
$^{226}Ra/Be$	1600 a	Moisture detectors Well logging	Neutron protection			Neutron protection
$^{238}Pu/Be$	87.74 a	Moisture detectors Calibration instruments	Neutron protection			Neutron protection

Annex II

EXAMPLE OF A STRATEGY FOR THE IDENTIFICATION AND LOCATION OF DISUSED SEALED RADIOACTIVE SOURCES

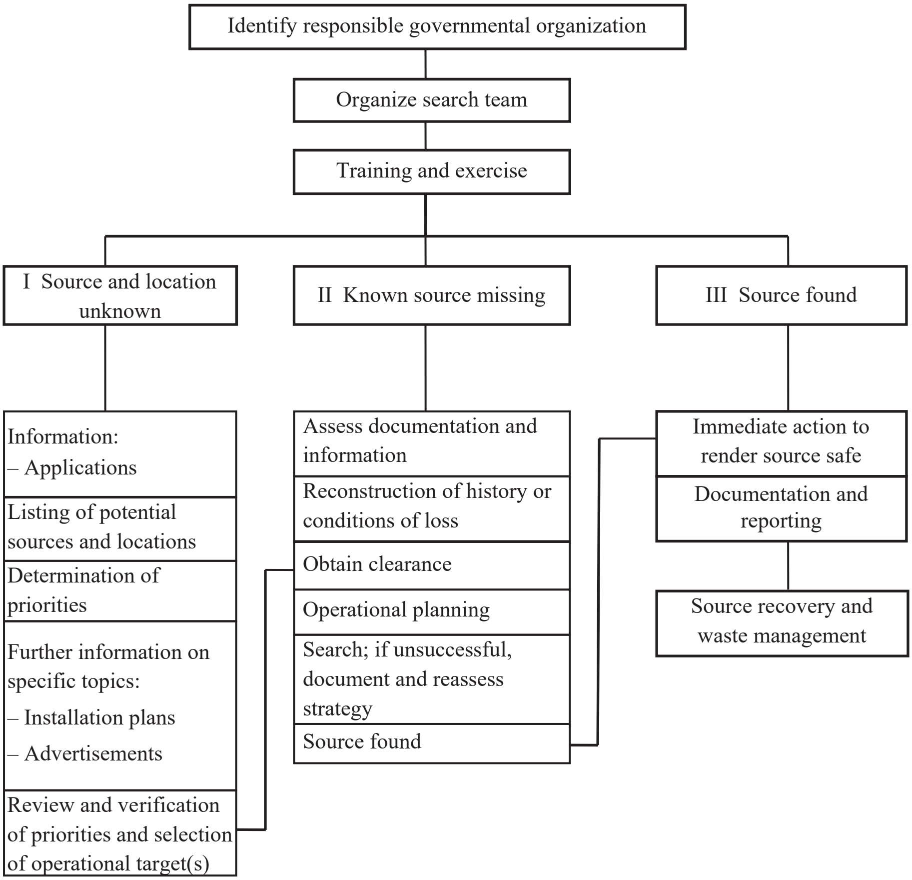

FIG. II–1. An example of a strategy for the identification and location of disused sealed radioactive sources.

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