This publication has been superseded by SSG-45.

IAEA Safety Standards

for protecting people and the environment

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

Safety Guide

No. WS-G-2.7

IAEA

International Atomic Energy Agency

IAEA SAFETY RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

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

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

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

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

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

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

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

OTHER SAFETY RELATED PUBLICATIONS

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

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

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

MANAGEMENT OF 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".

This publication has been superseded by SSG-45.

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

SAFETY GUIDE

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

by Mohamed ElBaradei
Director General

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

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

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

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

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

IAEA SAFETY STANDARDS

SAFETY THROUGH INTERNATIONAL STANDARDS

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

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

THE IAEA STANDARDS

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

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

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

Safety Fundamentals

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

Safety Requirements

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

Safety Guides

—Providing recommendations and guidance on how to comply with the Safety Requirements. Recommendations in the Safety Guides are expressed as 'should' statements. It is recommended to take the measures stated or equivalent alternative measures. The Safety Guides present international good practices and increasingly they reflect best practices to help users striving to achieve high levels of safety. Each Safety Requirements publication is supplemented by a number of Safety Guides, which can be used in developing national regulatory guides.

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

MAIN USERS OF THE STANDARDS

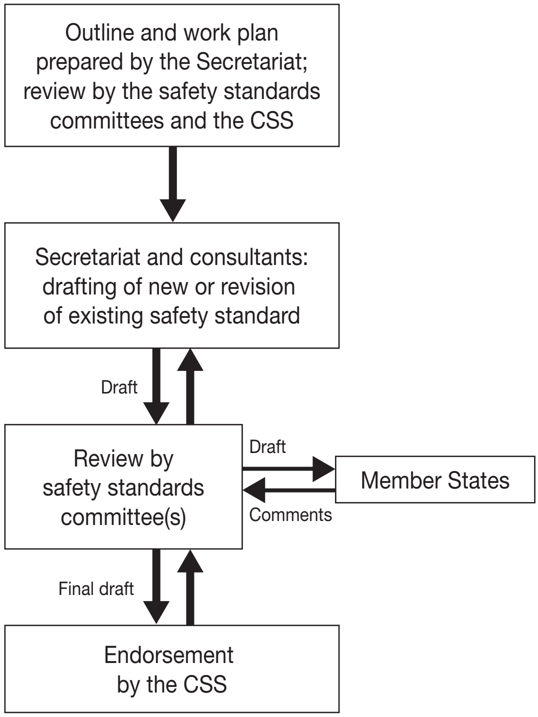
As well as by regulatory bodies and governmental departments, authorities and agencies, the standards are used by authorities and operating organizations in the nuclear industry; by organizations that design, manufacture and apply nuclear and radiation related technologies, including operating organizations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

DEVELOPMENT PROCESS FOR THE STANDARDS

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

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

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



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

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

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

APPLICATION AND SCOPE OF THE STANDARDS

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

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

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

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

INTERPRETATION OF THE TEXT

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

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

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

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

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

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1. INTRODUCTION

BACKGROUND

1.1. Radioactive waste is generated in a broad range of activities involving the use of radioactive material in medicine, industry, agriculture, research and education. The amounts of waste generated from these activities are often limited in volume and activity; however, they have to be managed as radioactive waste.

1.2. While the principles [1] and safety requirements [2] are the same for managing any amount of radioactive waste, a number of issues have to be considered specifically in organizations conducting activities in which only small amounts of waste are generated. This is the case in particular in respect of spent and disused sealed radioactive sources.[1] For activities involving the generation and management of small amounts of radioactive waste, the types of facilities concerned and the arrangements for waste management vary considerably. Furthermore, the types of radioactive waste differ from facility to facility. The safe management of small amounts of radioactive waste should therefore be given specific consideration.

1.3. The nature of the radioactive waste generated in the various activities under consideration also varies greatly. It may be in the form of discrete sealed or unsealed radiation sources or process materials or consumable materials. Waste arises as a result of many activities, including: diagnostic, therapeutic and research applications in medicine; process control and measurement in industry; and numerous uses of radioactive material in agriculture, geological exploration, construction and other fields. The radioactive waste under consideration can be in solid, liquid or gaseous form. Solid waste can include: spent or disused sealed sources; contaminated equipment, glassware, gloves and paper; and animal carcasses, excreta and other biological waste. Liquid waste can include: aqueous and organic solutions resulting from research and production processes; excreta; liquids arising from the decontamination of laboratory equipment or facilities; and liquids from activity measurement systems (such as those employing liquid scintillation counters). Gaseous waste

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[1] Spent or disused sealed sources are not considered waste in certain States but the safe management of such sources is achieved by compliance with the requirements for radioactive waste, and as such they are included in this Safety Guide.

is generated at a number of facilities in the production and radiolabelling of chemical compounds and organisms and in the treatment of solid and liquid waste. A broader overview of waste arising from this range of applications is presented in Appendix I.

1.4. In view of the variable range of waste types encountered and the possibility of changes occurring in the ways in which the waste is generated and then managed, particular attention should be paid to the safety issues that may arise in their management and regulatory control. Regimes for both management and regulatory control should be sensitive and responsive to these factors.

1.5. In facilities in which only small amounts of waste are generated, there may be limited knowledge among the staff of the safety issues relating to radioactive waste management. The safety culture among the staff may not be particularly focused on radioactive waste management because of this limited knowledge and/or because insufficient emphasis is placed on the related issues by the operating organization.

1.6. Good operating practice can significantly reduce the amounts of radioactive waste generated but in general such waste cannot be entirely eliminated. The waste may contain sufficient quantities of radionuclides that it has the potential to present serious risks to human health and the environment if it is not managed properly. Experience has shown this to be the case in particular for spent or disused sealed radiation sources. Poor practices with such sources 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. There have been instances where lack of control over such sources resulted in considerable economic loss, serious health effects due to radiation exposure and even death [3–5].

1.7. This Safety Guide provides recommendations and guidance on the fulfilment of the safety requirements established in Ref. [2]. It covers the roles and responsibilities of different bodies involved in the predisposal management of radioactive waste and in the handling and processing of radioactive material. Other IAEA safety standards, in particular the Safety Guide on Predisposal Management of Low and Intermediate Level Waste [6], are also applicable where relevant.

OBJECTIVE

1.8. The objective of this Safety Guide is to provide recommendations and guidance on how to meet the objectives, principles and requirements established in Refs [1, 2] for the safety of radioactive waste management for waste arising from the use of radioactive material in medicine, industry, research, agriculture and education. It is intended for organizations generating and handling radioactive waste or handling such waste on a centralized basis and the regulatory body responsible for regulating such activities.

SCOPE

1.9. This Safety Guide is applicable to all activities involving radioactive waste, including spent and disused sealed sources, associated with the use of radioactive material in medicine, industry, research, agriculture and education. The Safety Guide covers waste generated in small to medium sized facilities such as nuclear medicine departments in hospitals and research centres, where waste is not usually generated in bulk. This includes waste generated from the use of radioactive material and waste generated by organizations carrying out decommissioning activities in such facilities. The Safety Guide covers the managerial, administrative and technical steps associated with the safe handling and management of radioactive waste, from its generation to its acceptance at a disposal facility or at a storage facility pending the availability of a suitable disposal option or its release from further regulatory control through a clearance mechanism. It does not specifically include detailed arrangements for the disposal of the waste. Requirements for the disposal of waste at near surface disposal facilities are established in Ref. [7].

1.10. The management of spent and disused sealed sources is emphasized in this Safety Guide because of the possibility of accidents having serious consequences.

1.11. This Safety Guide covers the safe management of radioactive waste generated at various facilities involving medical, industrial and research applications and at centralized national and/or regional facilities where radioactive waste may be collected and managed on behalf of a number of waste generators.

1.12. This Safety Guide is applicable to the management of limited quantities of waste containing naturally occurring radionuclides that arises from industrial and research activities (such as the use of uranium in university laboratories or radium luminizing). Recommendations and guidance on the management of large quantities of radioactive waste arising from the mining and processing of ores are given in Ref. [8].

1.13. Guidance is provided on the storage of small amounts of radioactive waste at different stages of its management. Further details are to be given in a Safety Guide on the safe storage of radioactive waste.

1.14. This Safety Guide provides guidance on the transfer of radioactive waste from the premises of a waste generator to a centralized management facility for radioactive waste. Requirements for the transport of radioactive waste are established in Ref. [9] and related recommendations and advisory material are provided in Ref. [10].

1.15. Reference is made in this Safety Guide to the removal of regulatory control from radioactive material and to the control of discharges of effluents to the environment. Further details on such discharges are given in Ref. [11].

1.16. Where decommissioning produces only small amounts of waste, the guidance given in this Safety Guide is relevant. Recommendations on the management of waste arising from the decommissioning of medical, industrial and research facilities are provided in Ref. [12].

1.17. This Safety Guide provides guidance on safety assessment relevant to the management of radioactive waste that falls within its scope.

1.18. Hazards of a non-radiological nature are often associated with radioactive waste owing to the presence of other hazardous materials such as pathogens or heavy metals. Some guidance is given here on aspects to be considered with regard to these hazards, where these are related to radiation safety. In some cases these hazards will determine the choice of available waste management options. Recommendations concerning non-radiological hazards are outside the scope of this Safety Guide.

1.19. Consumer products such as smoke detectors used in homes that are exempted from the requirements of the Basic Safety Standards (BSS) [13] are outside the scope of this Safety Guide. If such products are collected for treatment and disposal as radioactive waste, the recommendations and guidance provided here are applicable.

STRUCTURE

1.20. Section 2 addresses the protection of human health and the environment in waste management. Section 3 describes the roles and responsibilities of the regulatory body, the users of radioactive material who generate radioactive waste (users) and the operators of waste management facilities (operators). Section 4 deals with general safety considerations. Section 5 outlines specific safety features in design and operation. Section 6 addresses aspects of waste disposal. Sections 7 and 8 deal with record keeping, reporting and management systems. Appendix I provides a general description of the waste arising from the production and use of sealed and unsealed sources and includes a list of the main radionuclides used in these activities. In cases where larger quantities of radioactive waste arise in association with the production of radiation sources, Ref. [6] is applicable. Appendix II presents an approach to safety assessment in the form of a fault schedule. Appendices III, IV and V provide typical management flow diagrams for solid radioactive waste, biological radioactive waste, and spent and disused sealed sources, respectively. Appendix VI gives typical examples of spent and disused sealed sources and techniques for their management. Appendix VII presents a strategy for the identification and location of spent and disused sealed sources.

2. PROTECTION OF HUMAN HEALTH AND THE ENVIRONMENT

GENERAL

2.1. The safety requirements established in Section 2 of Ref. [2] in respect of the protection of human health and the environment apply to the management of radioactive waste generated in medicine, industry, agriculture, research and education and other small uses. Radioactive waste is required to be managed in a manner that protects human health and the environment, now and in the future, without imposing undue burdens on future generations [1, 2]. The radiation exposure of workers involved in the management of radioactive waste is required to conform for normal operation to the system of dose limitation laid down in the BSS [13], and the risk of accidental exposure of workers is required to be controlled. Control is required to be exercised over the removal of radioactive material from controlled environments, the discharge of effluents containing radionuclides, activities that may give rise to accidental releases, and the transport of radioactive waste in the public domain, so as to ensure compliance with the system of radiation dose limitation and optimization in relation to members of the public.

DOSE LIMITATION

2.2. The normal exposure of individuals, both workers and members of the public, is required to be restricted so that neither the total effective dose nor the total equivalent dose to relevant organs and tissues caused by the possible combination of exposures arising from authorized practices, including waste management, dealt with in this Safety Guide exceeds any relevant dose limit specified in Schedule II of the BSS [13].

OPTIMIZATION OF PROTECTION AND SAFETY

2.3. In relation to any source within a practice, it is required to optimize protection and safety so that the magnitude of individual doses, the number of persons exposed and the likelihood of exposure are all optimized, economic and social factors being taken into account, within the restriction that the doses to individuals delivered by the source be subject to dose constraints (Ref. [13], paras 2.24–2.26). Specifically, the choice of particular waste management options (including treatment, waste minimization, packaging and conditioning) should be optimized with any additional exposure to workers taken into consideration [6].

2.4. The process of optimization of protection and safety may range from intuitive qualitative analyses to quantitative analyses using decision aiding techniques, but is required to be sufficient to take all relevant factors into account in a coherent way so as to contribute to achieving the following objectives:

“(a) to determine optimized protection and safety measures for the prevailing circumstances, with account taken of the available protection and safety options as well as the nature, magnitude and likelihood of exposures;

“(b) to establish criteria, on the basis of the results of the optimization, for the restriction of the magnitudes of exposures and of their probabilities by means of measures for preventing accidents and mitigating their consequences” (Ref. [13], para. 2.25).

DOSE CONSTRAINTS

2.5. The optimization of protection and safety for any particular source or facility considered in this Safety Guide should be performed systematically for the entire practice, not simply within an individual activity, and should cover all activities involving radioactive material, including waste management. It should be demonstrated that individual doses would remain below established dose constraints, which should have regulatory approval. In establishing dose constraints, the regulatory body should take into consideration that:

(a) Radiation protection for any persons who are exposed as a result of activities in the predisposal management of radioactive waste is required to be optimized, subject to dose constraints, and with the doses to individuals from all sources and activities kept within specified dose limits (Ref. [6], para. 2.2; Ref. [13], Section 2);
(b) Such dose constraints should be established so as to ensure that the cumulative doses due to radioactive releases from all such activities do not exceed the relevant effective dose limit for doses to any member of the critical group. People distant from the source and future generations should also be taken into account.

CONTROL OF DISCHARGES AND CLEARANCE

Control of discharges of radioactive effluents to the environment

2.6. While the safe management of radioactive waste requires releases from the various waste management processes to be optimized, effluents may be released to the environment within authorized limits as a legitimate practice [1].

2.7. The Safety Fundamentals publication on The Principles of Radioactive Waste Management (Ref. [1], para. 308) states that:

> "The preferred approach to radioactive waste management is concentration and containment of radionuclides rather than dilution and dispersion in the environment. However, as part of radioactive waste management, radioactive substances may be released within authorized limits as a legitimate practice into the air, water and soil, and also through the reuse of materials."

The discharge to the environment of effluents containing small amounts of radioactive material, carried out in a controlled fashion, may be the most reasonable option. The regulatory body should set limitations for the discharge to the environment of such effluents following the guidance provided in Ref. [11].

2.8. Reference [11] provides recommendations and guidance to the regulatory body on setting such limitations. The limitations on discharges should be such as to ensure that individual doses are within the dose constraints established by the regulatory body for the practice concerned. The limitations imposed should be such as to ensure that the annual dose to any member of the public is not greater than 300 µSv per year deriving from any single facility. If the possibility exists of there being several users of radioactive material or waste management facilities operating in the same area, the regulatory body may have to consider reducing the limitations on discharges to ensure that there is no possibility of an individual receiving doses deriving from several sources, giving rise to a combined dose that exceeds the relevant dose limit. By means of radiological assessment it should be demonstrated that the proposed discharges would not result in doses to the public that exceed these levels.

2.9. Specific regulatory limitations on discharges can be set for each individual case. Alternatively, regulatory limitations on discharges could be set on a generic basis by making conservative modelling assumptions. Generic assessments are likely to result in overestimates of radiological consequences in individual situations but may be more readily interpreted and followed by users and operators and more easily enforced. The regulatory body can provide assistance to users and operators in conducting their own assessments. However, this needs a much greater level of technical support by the regulatory body, which in many situations may not be warranted.

2.10. Users and operators should demonstrate compliance with the regulatory requirements for limitations on discharges by means of monitoring of releases and monitoring in the environment [11] or by means of calculations. The procedures and the measurement techniques for such monitoring or calculations should be subject to the approval of the regulatory body. Records should be kept of the results of such monitoring and calculation.

Clearance

2.11. The BSS require that:

> "Sources, including substances, materials and objects [including waste], within notified or authorized practices may be released from further

requirements of the [Basic Safety] Standards subject to complying with clearance levels approved by the [regulatory body]. Such clearance levels shall take account of the exemption criteria specified in Schedule I [para. I-3: effective doses of the order of 10 μSv or less in a year; and either no more than about 1 man Sv collective effective dose committed by one year of the practice or an assessment that shows that exemption is the optimum option] and shall not be higher than the exemption levels specified in Schedule I or defined by the [regulatory body] on the basis of the criteria specified in Schedule I, unless otherwise approved by the [regulatory body]" (Ref. [13], para. 2.19).

2.12. The user or operator should have a formal mechanism in place to demonstrate compliance with regulatory requirements in respect of clearance (removing material from regulated areas). Additionally, there should be compliance with other requirements in respect of release from regulatory control regarding any other hazardous aspects of the waste (e.g. infectious or toxic properties).

2.13. Any radiation markings should be removed from any material to which regulatory controls no longer apply. Similarly radiation markings should be removed from containers containing material to which regulatory controls no longer apply, and markings should be removed from or covered on containers from which material subject to regulatory control has been removed, or empty, clean containers normally used for carrying or storing radioactive material.

2.14. Information on material from which regulatory control has been removed should be recorded and retained for examination by the regulatory body as required.

REMOVAL OF REGULATORY CONTROL FROM BUILDINGS AND SITES

2.15. When buildings and sites are decommissioned and before the removal of regulatory control, if appropriate, any residual radioactive waste should be properly managed, removed and transferred to an authorized storage or disposal facility. The facilities and sites should be decontaminated to the levels required by the regulatory body. Recommendations and guidance are provided in Ref. [12].

3. ROLES AND RESPONSIBILITIES

GENERAL

3.1. The management of all radioactive waste is required to take place within an appropriate national legal infrastructure that provides a clear allocation of responsibilities [1] and effective regulatory control of the facilities and activities concerned (Ref. [14]; Ref. [2], paras 3.5–3.9). The national legal infrastructure should also facilitate compliance with other national and international laws. 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. Requirements in respect of the responsibilities for establishing such an infrastructure and the responsibilities of the regulatory body for ensuring the safety of waste management are established in Refs [2, 14].

3.2. A national strategy for the management of radioactive waste should be developed in accordance with the safety objectives and principles [1]. A strategy is necessary in order to define the infrastructure and the means to be adopted for the management of radioactive waste. A key element in the strategy is the extent to which national or regional waste management facilities are developed rather than managing the waste at a number of locations, where it arises. There may be significant safety benefits to be obtained from the use of specialized national or regional waste management facilities. However, the decision should be made with account taken of, among other things, the quantities and types of waste generated and the expertise available and its distribution in the region or State. In the siting of a nationally or regionally designated facility or facilities for radioactive waste management, it may be appropriate to take advantage of facilities where larger amounts of radioactive waste are managed, such as national laboratories at which the necessary expertise is available.

3.3. In many of the situations covered by this Safety Guide, a strategy involving a combination of on-site and collective waste management in regional or national facilities is adopted. Thus waste containing short lived radionuclides may be dealt with locally at the site where it is generated and waste containing long lived radionuclides may be dealt with at a national and/or regional facility.

3.4. Thus waste management may involve operations carried out solely at the site where the waste is generated or it may involve the transfer of radioactive waste to a specified waste management facility. A specified facility, in particular a facility for the management of disused or spent sealed sources, may be in another State.

3.5. One aim of radioactive waste management should be to minimize waste generation and to produce waste in a form that conforms with the requirements for subsequent handling, processing, transport and storage, or that meets the acceptance requirements for disposal. The management option selected may also result in waste or material that is suitable for return to a manufacturer or supplier of radioactive material, to be recycled or discharged as liquids or gases to the environment under regulatory authorization [11], or for regulatory control to be removed from them as discrete entities.

3.6. The predisposal management of waste may involve the transfer of radioactive waste from one operator to another or the processing of waste in another State. The established legal infrastructure [14] should include provisions to ensure that there is a clear allocation of responsibility for safety during the entire predisposal management process for waste, including any transfer between operators. Consideration should also be given to the decommissioning of any facility at which waste is managed. This continuity of responsibility for safety should be ensured by means of appropriate authorizations by the regulatory body (for example, by means of a licence or a sequence of licences, in accordance with the national legal infrastructure and agreements among the States involved in the transboundary movement of waste).

3.7. Both regulatory and operational responsibilities for radioactive waste management should be clearly delineated and functionally separated as far as possible in order to ensure effective and strict regulatory control over the different steps in waste management and the organizations involved.

RESPONSIBILITIES OF THE REGULATORY BODY

3.8. The overall role of the regulatory body in relation to the safety of radioactive waste management is to establish safety standards and ensure compliance with these standards. The requirements for waste safety established in Ref. [14] can be fulfilled in a number of ways. It is appropriate for the regulatory body to provide national guidance on how these can be met. The specific responsibilities placed on the regulatory body in relation to waste management are:

(a) To review and assess applications from users and operators for the authorization of waste management activities and to establish conditions for authorization;
(b) To issue, amend, suspend or revoke authorizations;
(c) To conduct compliance assurance activities including inspections of the facilities in which waste arises and is managed;
(d) To ensure that corrective actions are taken if unsafe or potentially unsafe conditions are detected;
(e) To take the necessary enforcement action in the event of a violation of the regulatory requirements.

3.9. Further specific responsibilities [2, 14] placed on the regulatory body include:

(a) To develop and update waste management regulations, safety principles and requirements;
(b) To provide advice on development, interpretation and application of legislation;
(c) To ensure that no activities generating radioactive waste commence without provision for proper management of the waste and that adequate and suitable storage capacity is available;
(d) To ensure that an appropriate waste classification scheme is established with due consideration of national and international safety standards;
(e) To ensure that standards and criteria relating to the safety of facilities, processes and operations for radioactive waste management are established, including handling, processing, transport, storage and disposal; these should address acceptance of waste packages for disposal in existing and planned facilities;
(f) To ensure that responsibilities are assigned to appropriate parties who generate or manage radioactive waste for ensuring the preparation and retention of relevant documents and records covering all the steps in waste management, that the record keeping is carried out properly and that records are maintained for an appropriate period of time;
(g) To establish safety standards for the decommissioning of facilities including conditions on the end points of decommissioning;
(h) To establish standards for the removal of material from facilities or activities under regulatory control and to provide guidance on and obtain

appropriate regulatory approval for the authorized discharge of liquids and gases containing radionuclides;

(i) To ensure that its own staff and those of users and operators have the necessary expertise and competence to perform their functions adequately and, where necessary, to ensure that adequate training is provided.

3.10. The regulatory body should require the user or 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 documentation should include a safety assessment report commensurate with the complexity of the facility and, in relation to waste management, details of the following:

(a) Chemical, physical and radiological properties of the waste to be generated;
(b) A description of proposed radioactive waste management activities relating to waste generation (anticipated waste quantities, waste minimization and control), waste processing (pretreatment, treatment, conditioning, storage and transport), and a description of facilities and their associated systems;
(c) A safety assessment of the facilities and thus a demonstration of the integrity of the facility and the associated measures for waste control;
(d) Storage arrangements;
(e) Arrangements for removal of regulatory control from material, activities and facilities, if permitted under the national regulations;
(f) Arrangements for waste to be removed from the site for storage, treatment or disposal at some other site;
(g) Discharge proposals (points and method of discharge and related controls);
(h) Discharge and environmental monitoring programmes and safety assessment proposals;
(i) Decommissioning plans and procedures;
(j) Staff competence and training provisions;
(k) A contingency plan in the event of an accident which involves radioactive waste.

RESPONSIBILITIES OF USERS GENERATING AND OPERATORS MANAGING RADIOACTIVE WASTE

3.11. The operators of facilities in which radioactive material is handled, used or processed have the primary responsibility for the safe management of any associated radioactive waste. This should include disposal but where no disposal facilities are available it should involve safe long term storage. Recommendations are given in the following paragraphs on how to meet the requirements established in Refs [2, 14], and further details may be given by the regulatory body.

3.12. Prior to commencing the construction or significant modification of any waste management facility, or any activity that may generate radioactive waste, the operator responsible is required to submit to the regulatory body an application including the information specified in para. 3.10 (Ref. [14], Section 5). The submission 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 would be met (see para. 3.11 of Ref. [6]).

3.13. Prior to the commencement of operations involving radioactive material, the operator should carry out commissioning tests, as required by the regulatory body, in order to demonstrate compliance with the design requirements and safety requirements.

3.14. The operator may handle, process, store and/or dispose of waste in an approved manner using its own facilities or may transfer waste to the operator of an authorized facility for the management of radioactive waste. In so doing, the operator should ensure that radioactive waste is transferred only in accordance with the waste acceptance criteria established by the operator of the waste management facility, and that waste consignments are accompanied by the necessary waste inventory information. The operator should ensure that the waste is transported in accordance with the IAEA Regulations for the Safe Transport of Radioactive Material [9, 10] (the Transport Regulations). The operators should be responsible for the safety of all management activities even if the work is contracted to a third party or until the waste becomes the responsibility of the operator of another authorized facility for waste management. The operator should also have full responsibility for ensuring that the waste packages comply with the acceptance requirements for any long term storage or disposal or with requirements approved or set by the regulatory body.

3.15. At the outset of planning for operations, the operator should prepare outline plans for decommissioning activities.

3.16. The operator should keep a record of all waste generated and stored, and of all waste that has been disposed of or transferred to the responsibility of another operator. The regulatory body should define the required time period for which the records are required to be retained.

3.17. To meet their overall responsibility for the management of radioactive waste, users and operators should ensure that they will have adequate resources, including human and financial resources, throughout the lifetime of the facility.

3.18. It should be the responsibility of the operator:

(a) To ensure that the generation of radioactive waste is kept to the minimum practicable;
(b) To establish and implement a suitable waste management programme with an appropriate management system to ensure compliance with conditions of authorization;
(c) To ensure that radioactive waste is managed by providing appropriate collection, segregation, characterization, classification, treatment, conditioning, storage and disposal arrangements, including timely transfer between waste management steps;
(d) To ensure that equipment and facilities are available to carry out the activities for radioactive waste management safely;
(e) To ensure that suitable staff are adequately trained and have operational procedures available to perform their duties safely;
(f) To maintain an awareness of practices in waste management and to ensure the feedback of relevant operating experience;
(g) To conduct safety assessment, commensurate with the complexity of the facility and its potential impact on human health and the environment;
(h) To establish and keep records of information on the generation, processing, storage and disposal of radioactive waste, including the maintenance of an up to date inventory of stored radioactive waste;
(i) To ensure the monitoring, recording and reporting to the regulatory body of discharges in sufficient detail and accuracy to demonstrate compliance with any discharge authorization;
(j) To report promptly to the regulatory body any discharges or releases exceeding the authorized amounts;

(k) To provide an inventory of radioactive waste held, discharges made and radioactive material removed from regulated facilities and activities to the regulatory body at such intervals, in such a form and containing such details as the regulatory body may require;
(l) To assess the integrity of the waste control measures and facilities to ensure that they are fault tolerant;
(m) To establish contingency plans and emergency procedures;
(n) To notify the regulatory body of events and accidents;
(o) To provide any other information on radioactive waste as required by the regulatory body.

3.19. The operator should appoint an appropriately qualified person with overall responsibility for day to day control over the management of radioactive waste. The person may also be the radiation protection officer, depending on the size and complexity of the operating organization. The appointed person should be given the specific responsibility of advising the management on all matters relating to the safe management of radioactive waste. Appropriate authority and resources should be provided to the appointed person to ensure that the operator's obligations as specified in para. 3.18 are fulfilled.

4. GENERAL SAFETY CONSIDERATIONS

STRATEGY FOR RADIOACTIVE WASTE MANAGEMENT

Choice of preferred options

4.1. Radioactive waste management may be carried out locally (on the site of origin), at a national and/or regional waste management facility, or a combination of both. The decision for on-site waste management or a national and/or regional waste management facility should be made as part of the national waste management strategy.

4.2. The extent to which on-site waste processing is undertaken by users or operators will depend 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, chemical adjustment), treatment, conditioning and storage. However, as a minimum, waste minimization, segregation, basic characterization and associated storage should be undertaken on the site. Both users and operators should ensure that the transfer of any waste to a disposal facility or other radioactive waste management facility is in accordance with the waste acceptance requirements.

4.3. While these and subsequent considerations for on-site waste management apply to the users, they apply equally in the case of a national or regional waste management facility.

Control of waste generation

4.4. As a first priority the operator should adopt any available provision to avoid the generation of radioactive waste, for example through appropriate design and operation of the facilities and by using whenever possible radionuclides of relatively short half-life that will decay to insignificant levels within a short time scale. As a second priority, the operator should consider the recycle and reuse of radioactive material and 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 potential risk. The implications of minimizing the generation of waste should be assessed as part of the safety assessment.

4.5. For reasons of safety, material which is not needed, such as equipment packaging, should not be taken into radiologically controlled areas. This reduces the potential generation of radioactive waste and the spread of radioactive contamination and minimizes waste volumes.

4.6. Another essential aspect of waste minimization is to use the minimum amount of radioactive material consistent with achieving the objective of the application. Due consideration should be given to options to limit the amount of radioactive material used in any particular activity.

4.7. Wherever possible, when purchasing sealed sources, contractual arrangements should allow the return of sources to the manufacturer or predetermined waste manager following use. This is particularly important for high activity sources from which regulatory control cannot be removed until after many years of decay storage or for sources containing long lived radionuclides.

4.8. Reuse and/or recycling of radioactive material 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 risks may arise outside the authorized undertaking, the required approvals from the regulatory body should be obtained. Recycling and reuse can involve the following activities:

(a) Reuse of sealed sources by the owner or a new owner with appropriate legal provisions;
(b) Recycling of sealed sources by the manufacturer;
(c) Decontamination and/or reuse of material such as equipment and protective clothing;
(d) Recycling and reuse of material that fulfils the conditions for the removal of control from material as defined by the regulatory body.

4.9. The non-radiological hazards of waste should also be minimized. If possible, 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 waste

4.10. A fundamental element at all steps of waste management, from waste arising to disposal, is the characterization and classification of waste. Characterization can be used for different purposes, such as identifying the potential hazards associated with the particular types of waste, designation of waste as suitable for storage to decay or specifying a particular processing, storage or disposal option, and planning and designing waste management facilities. Classification enables the selection of the most appropriate waste management option and is often considerably influenced by the radioactive half-life. Waste containing radionuclides with short radioactive half-lives, which can be managed by safe storage until their decay to insignificant levels, should be segregated with priority. In this context due consideration should be given to impurities with long radiological half-lives, which are not always detectable during the original characterization of short lived waste. Reference [15] provides guidance on waste classification. The data from the characterization processes should be recorded and a record should be maintained for an appropriate period of time.

Interdependences between steps in radioactive waste management

4.11. The interdependences between the different steps of radioactive waste management should be recognized, since the way in which waste is managed or treated at one step can have a significant influence on subsequent steps. Failure to do so may result in a waste form that does not comply with safety specifications for storage or disposal and may be technically difficult and costly to reprocess into a form that does comply, or may give rise to unnecessary radiation exposure. For example, processing of radioactive waste without taking into consideration the subsequent waste acceptance requirements for disposal may lead to the need for additional conditioning.

FACILITIES GENERATING RADIOACTIVE WASTE AND FACILITIES FOR RADIOACTIVE WASTE MANAGEMENT

Management system

4.12. Good management is a prerequisite to ensuring the safety of radioactive waste management and the protection of human health and the environment [2]. In the type of activities under consideration in this Safety Guide, where the use of radioactive material and the management of radioactive waste may not be one of the core activities, the application of good management practice to the management of radioactive waste should be given particular attention. Good management and the demonstration of quality in the waste management programme should be achieved by establishing and working within a formalized management system. The efforts expended on providing for and ensuring waste safety within the management system should be commensurate with the complexity of the activities undertaken, the waste generated and the waste management programme. The programme should address the management structure, responsibilities and training needs, control measures, performance standards and methods of assessment.

4.13. Management systems should be established and applied by the users, the operators and the regulatory body.

4.14. Important elements of management systems include, but are not necessarily limited to:

(a) Definition of management structure and responsibilities;
(b) Development of formal working procedures;

(c) Training and qualification of staff;
(d) Design control;
(e) Procurement of materials and services;
(f) Document control and records;
(g) Inspection, testing and maintenance;
(h) Non-conformance control and corrective actions;
(i) Assessment (of management system effectiveness — internal and external auditing).

Safety culture

4.15. Efforts are required to be directed to ensuring that an appropriate safety culture exists in all the organizations involved with the use of radioactive material and the generation and management of radioactive waste and its regulatory control. This should be aimed at creating a necessary awareness of the need for proper management of radioactive waste at all levels within the various organizations and should discourage complacency in any aspect of related operations (Ref. [1]; Ref. [13], para. 2.28; Ref. [16]).

4.16. All parties concerned should continue to question the adequacy and effectiveness of radioactive waste management programmes and seek at all times to make improvements in the arrangements concerning safety.

Financial and human resources

4.17. Sufficient financial and human resources should be made available by users and by operators to ensure that radioactive waste management programmes can be carried out safely and in accordance with the conditions of authorization.

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

Radiation protection

4.19. A radiation protection programme is required to be in place that adequately ensures radiation safety and control of the access to areas where radioactive waste is managed.

4.20. All the necessary provisions should be in place to keep the doses due to the exposures below established limits and to optimize protection and safety, economic and social factors being taken into account [13], and, to the extent warranted by the complexity of the operational activity, to follow the recommendations of appropriate Safety Guides in respect of operational radiation protection [17–19].

4.21. Appropriate radiation monitoring of the areas where waste is managed should be carried out and radiation dosimetry should be provided for the workers who could be exposed to radiation during activities for radioactive waste management. Material to be removed from controlled areas should be adequately monitored.

Environmental monitoring

4.22. Environmental monitoring should be a condition for authorization [13] for any large waste management facility or facilities where radioactive waste is generated, but smaller, less complex facilities may not need to perform environmental monitoring. The need for monitoring should be closely linked to the possibility of significant radiation doses being received by the general public. However, a limited amount of monitoring may sometimes be necessary for purposes of reassurance of the public.

4.23. Environmental monitoring programmes, if required, should be established in accordance with the potential 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 the measurement of radiation levels and contamination levels. When environmental monitoring is indicated, pre-operational monitoring should be carried out to establish the local background level of radiation and the concentrations of radionuclides in environmental materials, which can vary from location to location.

Emergency preparedness

4.24. The user or the operator is required to ensure that an emergency plan is in place to respond to a radiological emergency. The plan should be commensurate with the potential seriousness of an emergency that could occur at the facility where the waste is generated or managed. The emergency plan should include, as a minimum, the training of staff to be competent to recognize and react to an emergency, the assignment of the responsibilities of various parties involved, and appropriate arrangements and equipment to ensure the protection of emergency workers. Requirements in relation to emergency preparedness and response are established in Ref. [20].

Security

4.25. Security arrangements should be in place at facilities where radioactive waste is generated or managed to ensure that waste is not accidentally or deliberately removed from its proper location without authorization. Particular attention should be paid to material or equipment of intrinsic value or that could pose a serious threat to human health or the environment if control over it were lost [13].

SAFETY ASSESSMENT AND ENVIRONMENTAL IMPACT ASSESSMENT

4.26. Safety assessment is required to be carried out to demonstrate that the performance objectives of the waste management facility and the processes that are used can be satisfied and that the overall system is acceptable for licensing or authorization (Ref. [2], para. 5.3). The results of the safety assessment should include the predicted impacts on the workers, the public and the environment. The quantities and concentrations of radioactive material or other hazardous material that may be safely discharged from the facility should be determined and documented. The extent of the safety assessment depends on the propensity for risk (the severity of harm that may be caused by the hazard and the likelihood of harm) to the workforce, the public and the environment from the proposed operations.

4.27. A systematic and structured approach to the assessment should be demonstrated, with account taken of all steps in the waste management process, both as individual stages and as a part of an integrated waste management system. The assessment process should include interdependences between steps of waste management and between the organizations involved. Normal and abnormal operating conditions should be considered and actions should be proposed to reduce the identified risks to an acceptable level, in compliance with the requirements of the regulatory body.

4.28. A simplified assessment approach should be adequate for the majority of small users and operators. An example of a fault schedule for such an assessment is given in Appendix II. The purpose of the fault schedule is to identify hazards to operators and to propose engineered, administrative and contingency controls to result in acceptable risks. Risks should be categorized both from a radiological and a non-radiological perspective.

4.29. For simpler and smaller operations the integrated waste management system may be fairly straightforward and can be covered in brief. The focus of safety assessment for users and operators managing small quantities of waste should be on demonstrating compliance with regulatory requirements.

4.30. The results of the safety assessment should be assembled as a report. The report should cover both radiological and non-radiological risks, which may arise under normal and abnormal conditions, and the 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 for operational documentation, which should be implemented by users and operators.

4.31. Non-radiological environmental impact assessment is usually carried out under environmental laws and is outside the scope of this Safety Guide.

5. PREDISPOSAL MANAGEMENT OF RADIOACTIVE WASTE

GENERAL

5.1. Predisposal management of radioactive waste includes a number of processing activities, covering 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 (such as a hospital, laboratory or research centre) and/or at a centralized waste management facility.

PROCESSING OF WASTE

5.2. The processing of radioactive waste can involve the steps of pretreatment, treatment and conditioning, which can involve a number of operations that change the characteristics of the waste. Processing may be necessary for safety, technical or financial reasons. Processing is necessary to eliminate or reduce the hazards (e.g. radiological, physical, chemical and biological hazards) associated with the waste.

5.3. Waste should only be processed after its precise characterization. The processing method selected should be such as to ensure that the waste would meet the acceptance requirements for subsequent storage, disposal and transport, or release from regulatory control as approved by the regulatory body.

5.4. The methods for processing should be selected on the basis of the waste characteristics. Radioactive waste generated from use of radioactive material can generally be categorized into the following main groups: solid waste, liquid waste and gaseous waste. The waste in the groups may consist of waste containing radionuclides that are differentiated by activity (for alpha, beta–gamma and neutron emitters), by half-life, and by the physical, chemical and biological properties of the waste matrix.

5.5. The generation of secondary radioactive waste should always be taken into account in selecting a processing method. The implications of secondary waste arising should be taken into account in the safety assessment and environmental impact assessment. This is of particular concern with operations such as decontamination, sawing or cutting, shredding and crushing of solid waste for volume reduction purposes.

5.6. In selecting the method for processing radioactive waste, due consideration is required to be given to the exposure of workers in normal operation and in possible accidents identified for each processing method.

Pretreatment of waste

5.7. Pretreatment of radioactive waste is the initial step in its management carried out following generation. Pretreatment activities include collection, segregation, chemical adjustment and decontamination. For this initial step waste streams should be segregated at the source of generation and, as a prerequisite, adequate waste identification and classification should be performed according to the classification scheme in place. The operator of a waste management facility receiving radioactive waste should verify the waste characteristics by routine or random measurements or other means in order to confirm the information provided by the users 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.

5.8. Generally, the collection and segregation of different types of radioactive waste should be undertaken on the basis of a defined 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, cost, complexity and risks associated with subsequent waste management steps. Particular attention should be paid to the segregation of higher activity waste, particularly during decommissioning. 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.

5.9. The containers used during collection and segregation of radioactive waste should be physically and chemically compatible with the waste, should provide adequate containment of the material and should provide protection of the workers against chemical, biological, physical or other hazards (such as injury by contaminated sharp objects). Materials used should be robust and where appropriate, such as for biological radioactive waste, use should be made of double wrapping or a suitable outer container. The containers should be appropriately identified and labelled, and distributed in working places where it is expected that the radioactive waste will be generated. Consideration should be given to the safe handling of the waste containers (for example, by providing refuse cans with foot pedals) and their use in the next waste management steps. As soon as radioactive waste begins to accumulate, information on the nature of the waste collected should be recorded by the user. The following information should be recorded for each waste container:

(a) Identification number;
(b) Radionuclides present;
(c) Activity (measured or estimated) and date of measurement;
(d) Origin (e.g. room and laboratory);
(e) Actual and/or potential hazards (e.g. chemical hazards and infectious hazards);
(f) Surface dose rate and date of measurement;

(g) Quantity (mass or volume);
(h) Responsible person.

5.10. Segregation of radioactive waste should be performed with the following factors primarily taken into consideration:

(a) Activity and radionuclides present;
(b) Half-life of radionuclides present: short lived radionuclides (for example, half-lives not exceeding 100 d) suitable for decay storage or long lived radionuclides (for example, half-lives exceeding 30 a);
(c) Physical and chemical form of the waste, such as aqueous, organic, combustible or non-combustible, compressible or non-compressible, homogeneous or non-homogeneous (containing sludge or suspended solids);
(d) Non-radiological hazards (toxic, pathogenic, infectious, genotoxic, biological, pharmaceutical or mixed properties);
(e) Further processing, storage or disposal activities.

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

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

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

Treatment of waste

5.13. Treatment of radioactive waste includes those operations intended to provide for safety or economy by changing the characteristics of the waste. The basic treatments applicable are volume reduction, removal of radionuclides and change of composition.

Solid radioactive waste

5.14. There are various options for the treatment of solid waste (see Appendix III). In general, with the exception of conditioning, they are not applicable to spent and disused sealed sources. Potential options for the treatment of solid waste and major safety considerations are listed below:

(a) Compaction should be carried out only if it is ensured that:
   — There is no waste that could damage the waste package;
   — Hazardous (such as infectious) waste is excluded (or disinfected) to avoid a hazardous release (such as a release of micro-organisms);
   — Pressurized containers are excluded to avoid uncontrolled releases of gas or 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 sources are excluded to avoid high risks of contamination;
   — Pressurized containers are excluded to avoid uncontrolled releases of gas and/or contaminants;
   — Volatile toxic materials are excluded, if the incinerator is not designed for them;
   — Materials with a high moisture content are controlled to ensure complete combustion;
   — There will be subsequent management of radioactive ash;
   — Frozen materials are controlled to ensure complete combustion;
   — Active dust control is applied, particularly dust from handling ash;
   — Treatment and control of the generated exhaust gases are in place and gaseous effluents are discharged within the authorized discharge limits.

Liquid radioactive waste

5.15. There are various options 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 pH and the content of solid particles, salts and acids, and the possibility and ease of their removal. The treatment process should be carried out in accordance with criteria derived from the safety assessment and implemented through formally approved operating instructions. Adequate safety monitoring should also be provided.

5.16. Liquid radioactive waste streams should be segregated if they vary greatly in chemical or radionuclide content. For instance, solutions with different chemical properties should be stored separately if immediate discharge is not possible. Uncontrolled chemical reactions that may produce heat, aerosols or precipitates should be prevented. An example is the need to segregate acidic solutions from alkaline solutions since change of pH or redox conditions might lead, for instance, to the release of volatile radionuclides such as iodine.

5.17. Combining of liquid streams should only be carried out if the safety assessment has demonstrated the procedure to be acceptable and if it is documented according to the approved operating instructions. In general, mixing of dissimilar waste streams (such as aqueous and organic waste and waste containing short lived and long lived radionuclides) should be avoided unless there is a specific purpose (such as neutralization). In this way the complexity and potential hazards of the waste streams are minimized.

5.18. Different processes may be applied for the treatment of aqueous and organic waste streams. For small amounts of aqueous radioactive waste direct discharge to the normal sewerage system or directly to the receiving water body may be authorized by the regulatory body. Further guidance is given in Section 2. For other aqueous waste, chemical precipitation, evaporation, ion exchange and ultrafiltration processes are all utilized.

5.19. In 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 the evaporation process, the following factors should be considered: the generation of secondary waste; the integrity of the evaporator (in terms of corrosion resistance); the potential fire risk if volatile organic materials are present; and the containment of radioactive spray as well as the subsequent conditioning of active concentrates. When using an ion exchange process, the points to be considered are the generation of secondary waste needing specialized conditioning, the reactivity of the resins with strong oxidants (such as strong nitric acid), the radiolytic degradation of resins and the spent resin produced that needs specialized conditioning. The use of ultrafiltration necessitates consideration of the leakage from high pressure systems, possibly leading to inadvertent dispersal of liquid waste, and the subsequent need for conditioning of radioactive solids or sludges.

5.20. For organic waste, incineration (with the exception of materials of low flash point or volatile toxic materials), immobilization and absorption processes may be applied. When incineration is used, consideration should be given, as 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 inside the facility in which the waste is generated, particularly in handling ash, as well as to the subsequent management of contaminated ash. As to the immobilization and absorption processes, long term stability of the final waste form should be evaluated.

5.21. Concentrates arising from the treatment of liquid radioactive waste (secondary waste) should be immobilized to produce a stable, solid waste form. Waste forms produced should accord with criteria established on the basis of the safety assessment, for which account is taken of the requirements for transport, storage and eventual disposal.

Airborne discharges

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

5.23. Airborne discharge streams containing particulate radioactive material should, where necessary, be cleaned by means of filters or by other means prior to release to the atmosphere. Unless they are only contaminated 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, they may be allowed to decay without the need for further treatment and may then be removed from regulatory control.

Biological radioactive waste

5.24. Radioactive waste of a biological nature should be managed by taking into consideration the associated radiological and non-radiological hazards (biological and/or infectious; physical, chemical flammable and/or explosive hazards). For infectious biological radioactive 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.

5.25. Practices for radioactive waste management are not usually appropriate or sufficient to control biological hazards. At the same time, biological radioactive waste cannot always be treated using the same methods as non-radioactive biological waste. A number of options do exist for the processing of biological radioactive waste involving 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 organics and micro-organisms present in the waste. Chemical processes are used to decontaminate biological waste by disinfection.

Conditioning of radioactive waste

5.26. Conditioning of radioactive waste involves those operations that convert the processed waste into a form which is suitable for handling, transport, storage and disposal. The 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. The conditioning of radioactive waste should ensure maximum compatibility between the waste, the matrix and the container; maximum homogeneity of the waste form; minimum free space in the container; and low leachability, as well as control over the complexing agents and organic compounds. The operations may include immobilization of the waste in a matrix. The relevant acceptance requirements and acceptance criteria should be approved by the regulatory body.

5.27. Consideration should be given in the safety assessment to the materials to be conditioned and the relevant acceptance requirements and/or acceptance criteria for storage and disposal of the waste. The storage and disposal of the waste should be authorized by the regulatory body.

5.28. In making the 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 entire waste package and can influence the performance of the package with respect to the relevant acceptance criteria.

5.29. Each waste package should be provided with a durable label bearing the identification number, and a proper record of each waste package should be kept under the management system. All records should be securely stored, easily accessible and retrievable over an extended period. Information should include as a minimum for each individual package:

(a) Origin of the waste;
(b) Identification number of the package;
(c) Type and design details of the package and unloading documentation;
(d) Weight of the package;
(e) External size and/or volume of the package;
(f) Maximum dose rate at contact and 1 m (transport index) and date of measurement;
(g) Results of surface contamination measurement;
(h) Radionuclide content and activity content;
(i) Content of fissile material (such as ^{239}Pu–Be sources);
(j) Physical nature;
(k) Presence of potential pathogenic, chemical and other hazards.

ON-SITE HANDLING

5.30. Handling of radioactive waste on the site includes all transfer (movement) operations from the source of generation to the processing, storage and/or disposal location. 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) Under adequate operational radiation protection control;
(c) With appropriate labelling of the radioactive waste packages and vehicles;
(d) In accordance with the site radiation protection programme, security procedures, safe transport and emergency planning, as well as the standards established by the national legislation.

5.31. A survey for non-fixed surface radioactive 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, a maximum allowable radiation dose rate at the surface of each radioactive waste package, or at a specified distance from the surface, should also have been defined as part of the package acceptance requirements for storage.

5.32. The unexpected presence of radioactive contamination on a radioactive waste package may be an indication that the package itself or one nearby has been breached or physically damaged. Preplanned and documented procedures should be in place and should be followed in such an event. As a minimum, the area around the suspect packages should be confined, the person responsible for waste safety should be notified, and procedures should be implemented to identify the source of contamination and to ensure that it is contained. The simplest means of containing the source of contamination is to place it in a secondary overpack container if possible.

STORAGE OF RADIOACTIVE WASTE

5.33. Storage of radioactive waste may be necessary:

(a) For decay, prior to the removal of regulatory control;
(b) Prior to pretreatment, treatment and conditioning;
(c) Prior to disposal or transfer to another authorized facility.

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

5.35. The safety of storage arrangements should be ensured for any radioactive waste management activity. On-site storage may be used to allow decay to levels where control may be removed from the material. Storage may be necessary for operational reasons (for example, for unconditioned radioactive waste prior to subsequent conditioning or off-site transfer). 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 may not be 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 unconditioned radioactive waste in order to limit any leakage from packages.

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

(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 closure and/or sealing of the packages and their continued integrity under storage conditions;
(d) The envisaged storage period and possibility of further extension;
(e) The ability to comply with handling, storage and security requirements;
(f) The need and type of monitoring, e.g. airborne radioactive substances in the storage facility;
(g) The possibility of identification of potential damage to waste packages and facilitating of corrective measures.

Storage of radioactive waste prior to its discharge or removal from regulatory control

5.37. Many radionuclides, in particular those in use in research and medical applications, have half-lives ranging from a few hours to a few months. A decay storage period of ten half-lives reduces the initial activity to less than one thousandth of the original activity. Practical experience shows that storage for decay is usually suitable for all types of radioactive waste, solid, liquid and gaseous, containing radionuclides with half-lives no greater than about 100 d. Nevertheless, waste with longer half-lives may also be safely stored for decay to insignificant levels and consideration should be given to storing such waste on a case by case basis.

5.38. Storage for decay, where appropriate, is the preferred management option for reasons of safety and technical and economic reasons. Radioactive waste, contaminated with short lived radionuclides, with a suitable activity content or activity concentration, should be collected and stored safely for sufficient time until the waste meets the regulatory criteria for the removal of the material from regulated facilities and activities or for authorized discharge. There may be some exceptions, such as contaminated animal carcasses, which may have to be disposed of because of concern for pathological or infectious hazards.

5.39. Storage of radioactive waste for decay and subsequent removal from regulatory control needs rigorous administrative control measures. Activity should be carefully measured and waste should be segregated, both at the point of generation and at the end of the decay storage period. Representative measurements should be carried out or samples taken and analysed prior to removal of each batch from control. In taking samples, consideration should be given to the protection of workers against radiological and non-radiological hazards.

Storage of radioactive waste prior to processing

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

(a) Storage of packages in specially designated areas, premises, or specially constructed facilities (on-site or centralized facilities);
(b) Compliance with the acceptance criteria for waste storage;
(c) Checking of packages on receipt (such as checking for the integrity of the waste package, for surface contamination and for compliance with the supporting documentation);
(d) Separate storage of different waste types (including mixed waste) according to the presence of pathogenic, organic, toxic or other waste;
(e) Reliable labelling of packages;
(f) Tracking of the current status of waste and availability of supporting documentation.

Storage of radioactive waste prior to its disposal

5.41. Treated and conditioned radioactive waste should be stored separately from unconditioned waste, inactive raw materials and maintenance materials. The packages should be stored for example in bins, racks, pallets or skids. Storage locations should be planned so as to minimize handling and transport.

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

5.43. The storage proposals should be considered in the safety assessment and environmental impact assessment to demonstrate the acceptability of the proposed design and operational arrangements. The safety objectives during storage should be such as to ensure that stored waste will remain adequately contained, that there is adequate shielding against radiation from the stored waste and that the stored packages will not degrade and give rise to problems in handling and disposal.

5.44. In some cases, dedicated storage or final disposal facilities are not yet in place. Although the need for radiotherapy and other medical, industrial and research activities continues, ultimate disposition of the associated waste is not yet possible. In these cases, such operations may not be able to comply fully with all the recommendations in this section. This guidance is intended to assist those responsible for safety to design a radioactive waste management programme, which provides for the protection of health and the environment to the extent achievable.

FACILITIES FOR PREDISPOSAL MANAGEMENT OF WASTE

5.45. The safety of predisposal radioactive waste management facilities should be ensured through the use of good engineering and management practice. In particular the defence in depth principle, providing for multiple levels of protection against failures for technical reasons or due to human errors, should be adopted. This should include:

(a) Multibarrier systems of several physical barriers on the migration pathway of the 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 environment in case of failure of or damage to the barriers.

5.46. At all stages of the lifetime of radioactive waste management facilities (siting, design, commissioning, operation and closure or decommissioning) technical and organizational means to apply the defence in depth principle should be provided with regard to the following three aspects:

(a) Measures to prevent deviation from normal operation;
(b) Measures to prevent accidents and mitigate consequences;
(c) Measures for emergency planning.

Design of facilities for processing and storage of waste

5.47. In designing facilities for processing radioactive waste consideration should be given to:

(a) Separating the radioactive waste processing systems from the other systems, as well as from the premises and facilities, where other potentially hazardous materials are stored;
(b) Providing auxiliary systems, for example for sampling or decontamination;
(c) Providing radiological control at all stages including control over the receipt of waste and elements affecting personnel protection and protection of the working environment;
(d) Providing adequate containment (e.g. fume cupboards, drip trays, sealed and dipped work benches) and shielding (e.g. lead or concrete blocks);
(e) Providing for demarcation of the working premises according to their classification (e.g. labels, rope or other barriers) for area and personnel, as appropriate;
(f) Providing for radiation control (measurement of dose rates and surface contamination);
(g) Providing technological control, such as recording of the characteristics of raw waste and control over the characteristics of the final product (radioactive waste form);
(h) Arranging the location and layout of the equipment and systems in a way that provides ease of access for normal operation, maintenance and control;
(i) Providing for the safe handling of waste by having appropriate handling equipment and selecting short and uncomplicated routes;
(j) Providing easily decontaminable surfaces;
(k) Providing adequate drainage and ventilation systems (e.g. by means of air filtration, air pressure differentials and flow considerations);
(l) Providing normal and emergency electrical supplies;
(m) Providing premises for emergency equipment;
(n) Providing fire protection systems;
(o) Providing security.

5.48. Depending on the quantities of radioactive waste to be processed and/or stored, safety arrangements can range from storage in a shielded cabinet to dedicated separate rooms or facilities. The specific arrangements depend largely on the activity and other chemical and physical characteristics of the radioactive waste and the amounts involved, as well as on the technologies available. The requirement to optimize radiation protection and the preference for maintaining working areas free of radioactive waste with long half-lives means that the provision of a separate small room where the waste can be stored in an orderly way should be considered. However, where only very small amounts of radioactive waste are produced over many days of work, the use of a local store or cabinet close to the workplace may be preferable.

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

5.50. The design of storage facilities should allow for regular inspection, including radiation control (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 should ensure that the storage conditions are such as to maintain the characteristics of the waste packages for the designed storage period. The design of the storage facility should be such as to ensure that the radioactive waste can be removed from the facility for subsequent processing or disposal, and that the facility can be extended in the future if necessary.

Decommissioning of facilities for processing and storage of waste

5.51. The operator should give consideration to aspects of decommissioning of the facility at every stage of the facility's lifetime. This is particularly the case in respect of facility design and 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, the 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 the waste is removed before decontamination and dismantling.

5.52. In arrangements for decommissioning, four stages should be considered:

— Stage 1: justification and feasibility study to define the decommissioning goal and determine whether it involves the removal of all radioactive material;
— Stage 2: source removal, involving removal of contained radioactive waste and sources of radioactive material;
— Stage 3: decontamination, including removal or reduction of contamination of materials, items, buildings and areas of the facility;
— Stage 4: dismantling, essentially reduction in size of the objects and components of the facility to facilitate their management (decontamination, handling) and subsequent removal from the site;
— Stage 5: final radiation survey, a systematic radiation survey of the decommissioned facility to ensure that the objectives of radiation protection have been fulfilled;
— Stage 6: depending on the decommissioning goal, the facility can be left either to unrestricted use or else to use with restrictions and/or surveillance requirements.

5.53. It should be borne in mind that there may be a need for extended storage of waste arising from the decommissioning activities. The decommissioning activities could be combined depending on the type and scale of the processing or storage facility, on the type of radioactive waste, and on the national strategy and the availability of centralized storage and disposal facilities. Recommendations and guidance are provided in Ref. [12].

OFF-SITE TRANSPORT OF WASTE

5.54. The transport of radioactive waste is subject to national regulations and the IAEA Transport Regulations [9, 10].

5.55. Prior to the transport of radioactive waste packages from the sites where they are generated, 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 user the safety related information and formal documentation that is necessary for its acceptance.

5.56. Information to be provided upon transfer of waste should include as a minimum for each individual package:

(a) Comprehensive identification of the user;
(b) Identification number of the package;
(c) Type and design details of the package and unloading documentation;
(d) Mass of packages;
(e) External size and/or volume of the package;
(f) Maximum dose rate at contact and at 1 m (transport index) and the date of measurement;
(g) Results of surface contamination measurements;
(h) Radionuclide content and activity content;
(i) Content of fissile material (such as ^{239}Pu–Be sources), if applicable;
(j) Physical nature;
(k) Origin of waste;
(l) Potential pathogenic, chemical and other hazards;
(m) Total number of drums or containers in the consignment;
(n) Total mass of the consignment.

5.57. All documentation corresponding to a waste package should be verified by a designated person prior to transport to ensure compliance with the waste acceptance requirements and the IAEA Transport Regulations [9, 10] and any national transport regulations.

5.58. 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 the spent or disused sealed source. However, consideration should be given to whether the design of the original packaging is in compliance with the IAEA Transport Regulations and whether the package continues to meet its design standard. If the original package is not available, the spent or disused sealed source should be repackaged in accordance with the IAEA Transport Regulations [9, 10].

SPECIFIC ASPECTS

Spent and disused sealed sources

5.59. Sealed radioactive sources have a wide range of activity depending on their original intended use: from a few megabecquerels for calibration sources up to many terabecquerels for medical teletherapy sources. While spent or disused sealed sources may be a small fraction in terms 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 radiation output of teletherapy sources and other large disused sources of radiation may have fallen below useful levels for their initial purposes, the potential for radiation induced injury from such sources remains substantial. It should be noted that ^{137}Cs teletherapy sources may contain caesium compounds in a dispersible form and that these can represent a very significant hazard if their primary containment is breached.

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

(a) The further authorized use of the disused source by some other authorized organization;
(b) Return of the source to the supplier;
(c) Temporary storage in its original shielding (for example for radionuclides with half-lives of less than 100 days);
(d) Conditioning (for example overpacking);
(e) Long term storage (such as in a dedicated storage facility);
(f) Disposal.

5.61. The most sustainable option for managing disused sealed sources is to recycle them for further use. If this is not possible, the preferred management option for disused sealed sources and always for spent sources is the return of the source to its supplier. This option is not always available for many old sources, however, as the original supplier may not be known or may no longer exist. For spent and disused sealed sources with short half-lives, not exceeding around 100 d, 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.

5.62. All spent and disused sealed sources should be conditioned unless the half-life of the radionuclides they contain is short enough to permit their removal from regulatory control in a period of around two to three years). Long lived sources are generally conditioned by means of encapsulation into welded steel capsules to facilitate future management. Conditioning methods should be approved by the regulatory body.

5.63. In instances where the operator does not have either the facilities or the expertise for the conditioning of spent and disused sealed sources by encapsulation or adequate storage facilities, arrangements should be made to transfer the sources to another licensed organization with proper and adequate facilities. Centralized facilities should be established for the safe long term storage of spent and disused sealed sources containing ^{226}Ra, ^{241}Am and other long lived radionuclides.

5.64. The management of disused sealed sources can involve potentially serious hazards. Sealed sources should not be 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 container be physically modified. Peripheral components of large irradiation equipment (those not directly associated with the source) should be removed, monitored and disposed of appropriately. A safety assessment and environmental impact assessment should be carried out before any operations are undertaken. For sources (such as spent radium sources) with a potential for leakage, particular radiological precautions should also be taken during the handling and storage. Special attention should be paid to monitoring for surface and airborne contamination. These sources should be stored in a dedicated area with appropriate ventilation and equipment (see Appendix VI).

5.65. The most important consideration in the management of sealed sources, once they are no longer useful, is the maintenance of continuity of control. The operator and the regulatory body should make provision to maintain and periodically review the status of control of such devices and material.

Orphan sources

5.66. There have been many cases of sealed sources being acquired for specific purposes (such as industrial process control) and of subsequently being lost because the operating organization ceases operation and control over the sources is lost. Many portable radiography devices contain valuable heavy metals and become attractive for scrap purposes. These are some of the reasons for spent and/or disused sealed sources being lost from regulatory control.

States should establish and implement appropriate strategies for these ‘orphan’ sources. An example of a strategy for the identification and location of spent and/or disused sealed sources is presented in Appendix VII.

5.67. In all cases the strategy should ensure that whenever an orphan source has been identified, appropriate recovery measures are taken. These measures should include the identification of the responsible organizations and funding within the State to recover, handle, condition, store and, if necessary, dispose of the source.

Accidental generation of radioactive waste

5.68. Loss and misuse of radioactive material (such as sealed sources) can give rise to accidents resulting in the radiation exposure of workers and members of the public and the contamination of working premises and land. This can lead to the unplanned and accidental generation of radioactive waste. Both users and operators should take measures to ensure that technical and organizational means are in place, including the necessary contingency arrangements, for the processing and storage of any such accidentally generated radioactive waste.

6. ACCEPTANCE OF RADIOACTIVE WASTE INTO DISPOSAL FACILITIES

6.1. Radioactive waste should only be disposed of in facilities licensed to accept the type of waste in question. National disposal facilities for radioactive waste should be designated as part of the national strategy for radioactive waste management.

6.2. The operator of a waste disposal facility should establish specific acceptance requirements and procedures, subject to approval by the regulatory body, for different types of radioactive waste and packages and should make them available to users. The radioactive waste should comply with waste acceptance requirements that address:

(a) The extent of waste processing (stable form and container resistance);
(b) The maximum content of liquid (usually up to 1% of the total radioactive waste volume);

(c) The mechanical, chemical, structural, radiological and biological stability of the waste form;
(d) The limitations on activity (for example, activity per package);
(e) The absence of a potential for criticality;
(f) The extent to which the waste should be non-pyrophoric, non-explosive or non-reactive;
(g) The possibility of generation of toxic gases;
(h) The limitation of heat generation.

6.3. The operator of the disposal facility should also clearly identify the documentation to be provided by the waste supplier as well as the relevant waste package records. Waste packages should be inspected in an appropriate manner on receipt at the radioactive waste management facility. Caution should be applied to the receipt of all packages as they may not be in compliance with the agreed specification and associated documentation. Inspection should include verification of:

(a) The number of packages and their identification;
(b) Physical integrity of the package;
(c) Surface contamination levels;
(d) External dose rate for the package;
(e) Completeness of documentation.

6.4. 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 user and the data obtained as part of the receipt control should be recorded.

7. RECORD KEEPING AND REPORTING

7.1. A suitable and comprehensive recording system should be developed for radioactive waste management activities. Information on waste inventories should be properly recorded, updated (such as changes to waste characteristics during processing), transferred (between waste management steps or to another responsible organization) and retained in such a way as to ensure that relevant information is accessible in the future, as necessary. The user or operator responsible for the safety of radioactive waste management 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 long term storage and/or disposal.

7.2. Users and operators should ensure that record keeping of data relating to the main radioactive waste characteristics is adequately carried out for:

(a) Source of origin;
(b) Amount (volume and/or mass);
(c) Radiological properties;
(d) Physical and chemical properties;
(e) Classification according to the national waste classification system;
(f) Thermal properties, when applicable;
(g) Any chemical, pathogenic or other non-radiological hazard associated with the waste and the concentration of hazardous materials.

The operators should provide means and 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 management programme activities providing for and assuring safety systems as well as operating activities should also be well documented.

7.3. The user and the operator should also keep records of information relating to the safety of the facility for the predisposal management of radioactive waste during commissioning, operation, upgrading or decommissioning.

7.4. Regular reporting may be requested by the regulatory body. Reports may include:

(a) Details of material from which regulatory control has been removed or that has been discharged to the environment;
(b) Details of spent and/or disused radiation sources returned to suppliers;
(c) The present inventory of radioactive waste, including identification, origin, location, physical and chemical characteristics and, as appropriate, a record of the radioactive waste removed from the facility;
(d) Safety assessment methods used;
(e) Results of safety assessments;

(f) Results of effluent monitoring and environmental monitoring;
(g) Results of internal audits and other findings relating to the safety of radioactive waste management;
(h) Emergencies, if any, that occurred during the processing of the waste, the methods adopted for dealing with them and the lessons learned.

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

7.6. The regulatory body may also require the user or the operator to submit on a regular basis a summary of the status of waste generation and waste management. Relevant requirements are established in Refs [2, 14].

8. MANAGEMENT SYSTEMS

8.1. Users and operators should establish and implement a management system that ensures:

(a) The effective organization of all activities relating to radioactive waste management and the operation, maintenance and control of the systems, according to the design characteristics;
(b) The maintenance of records and control and record keeping of the documentation relating to radioactive waste management and the associated facilities;
(c) Control over activities in waste management in terms of compliance with the requirements for radiation protection and safety;
(d) The elaboration and implementation of internal procedures, instructions and programmes on radioactive waste management to ensure compliance with the requirements for radiation protection and safety.

8.2. The management and demonstration of quality is achieved by establishing and working to a formalized management system with appropriate related quality assurance requirements approved by the regulatory body. The quality assurance requirements should be commensurate with the complexity of the activities undertaken and with the waste management programme. They should specify the management structure and its responsibilities and the necessary training, control measures, performance standards and methods of assessment. The management system should be such as to ensure the compliance of the activities in radioactive waste management with the conditions for authorization and to facilitate the provision of information to the regulatory body.

8.3. Guidance is given on the detailed components of management systems in Ref. [21][2].

8.4. Users and operators should audit the implementation of the management system in their organizations on a regular basis. When deviations are identified, appropriate corrective actions should be proposed, taken and recorded.

8.5. The auditing should include revision of the procedures to remove any unwarranted complex procedures that do not contribute to safety within the licensed activity.

[2] The IAEA is currently revising the safety standards in the area of quality management issued in Safety Series No. 50-C/SG-Q (1996). A revised Safety Requirements publication will cover management systems for protection and safety in all facilities and activities. The term ‘management system’ has been adopted in the revised publications. This reflects the evolution of the approach to ensuring quality and embraces all aspects of the management of facilities. It brings the safety, health, environmental, security, quality and economic objectives together in one coherent system. The Safety Requirements publication will be complemented by a number of Safety Guides, including those on thematic guidance for management systems, management systems for the safety of the treatment, handling and storage of radioactive waste, and management systems for the safety of the disposal of radioactive waste.

Appendix I

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

GENERAL

I.1. Sources of ionizing radiation are produced for a broad range of applications in medicine, industry, agriculture, research, education and other areas. As a result of the initial production of the radioactive material and its diversified 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 are contaminated, such as paper, plastic gloves and covers, counting tubes, glassware, 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 or accidents 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 their amounts.

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

RADIONUCLIDE PRODUCTION

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

MEDICAL APPLICATIONS

I.4. Radioactive material is used in medicine for diagnosis, therapy and research including:

(a) In vitro radioassay for clinical diagnosis and research using unsealed sources containing radionuclides;
(b) In vivo use of radiopharmaceuticals for clinical diagnosis, therapy and medical research using unsealed sources containing radionuclides;
(c) Radiotherapy using sealed sources which are either implanted into 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. ^{125}I is the main radionuclide, with each assay usually involving a very small activity. Following each individual assay and after the expiry date of the kit, the radioactive material and contaminated items are normally considered to be waste.

I.6. For the main in vivo applications, the particular organ to be studied or treated will govern the type of radiopharmaceutical to be used and the quantity to be 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 h. 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 h, generators need to be replaced at approximately weekly intervals. The waste arising from the preparation of ^{99m}Tc labelled agents, such as discarded vials, syringes and swabs, are potentially contaminated with the radionuclide. However, the radioactivity decays away rapidly owing to the short half-life, so that regulatory control can be removed and the waste can be disposed of as non-radioactive.

I.7. Radionuclides such as ^{131}I, ^{32}P, ^{90}Y and ^{89}Sr are administered to patients for therapeutic purposes in activities ranging from 200 MBq to 11 GBq. 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 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 the irradiation of blood products.

TABLE 1. TYPICAL UNSEALED RADIONUCLIDES USED IN MEDICINE AND BIOLOGICAL RESEARCH

Radio-nuclide	Half-life	Principal application	Typical activity per application	Waste characteristics
^{3}H	12.3 a	Radiolabelling, biological research, organic synthesis	Up to 50 GBq	Solvents, 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	Less than 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	14.3 d	Therapeutic nuclear medicine	Up to 200 MBq	Solid, liquid
^{33}P	25.4 d	Biological research	Up to 50 MBq	
^{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
^{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

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

Radio-nuclide	Half-life	Principal application	Typical activity per application	Waste characteristics
^{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	Therapeutic nuclear medicine, medical and biological research	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	13.2 h 60.1 d	Medical and biological research, diagnostic nuclear medicine	Up to 500 MBq	Solid, liquid, occasionally vapour
^{131}I	8.0 d	Therapeutic nuclear medicine	Up to 11 GBq	
^{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 SOURCES USED IN MEDICINE, INDUSTRY AND RESEARCH

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

TABLE 2. SEALED 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		Mobile equipment
	^{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		
	^{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	Fixed in equipment
	^{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
	^{160}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	
	^{192}Ir	74.0 d	Up to 5 TBq	

APPLICATIONS IN RESEARCH AND EDUCATION

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

(a) The production and labelling of compounds resulting in waste containing megabecquerel activities of radionuclides, such as ^{3}H, ^{125}I, ^{14}C or ^{32}P. The range of radionuclides 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 nuclear fuel cycle facility. The research is usually conducted in laboratories, with the use of a small amount of fissile material (uranium and plutonium) and relatively long lived fission products, mainly ^{137}Cs and ^{90}Sr. The waste generated includes solid material and liquids containing fission products and fissile material.

(e) Basic research in the fields of physics, materials science and biology.

INDUSTRIAL AND OTHER APPLICATIONS

I.10. Sealed radiation sources are used extensively for various industrial applications including non-destructive testing (radiography and gauging) and the sterilization of food and other products. Sealed sources are also used for process control and for the calibration of laboratory equipment. The dominant radionuclide is present in a very concentrated form; the total activity will depend on the application and on the nature of the emission from the sources. Sealed sources are considered to be waste when they have decayed to the extent that they are no longer useful for their original purpose, because the appliance 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 sources as a tracer is the evaluation of the wear and corrosion of key components in plant and machinery, such as the wear of engine components, furnace linings and metallic surfaces. Unsealed sources also have applications in the 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 radioisotopic tracer techniques are generally of greater magnitude than applications in the laboratory.

I.12. Sealed and unsealed sources are also used in teaching and in instruction for emergency planning and civil defence. All these applications generate waste with activity that is normally very low.

WASTE TYPES

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

Aqueous radioactive waste

I.14. At radioisotope production facilities, aqueous waste results from chemical processing, mainly the etching and dissolving of target materials. The waste, 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 will 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, giving rise to radioactive excreta, blood, carcasses and bedding. Some of this material may become part of the aqueous waste stream, creating a potential biological hazard. In some cases longer lived radionuclides are used to label microspheres for such studies. These microspheres are solid but they may easily become suspended in the liquid waste. Small animal carcasses may also be macerated to a liquid form suitable for discharge as aqueous based waste.

I.17. Aqueous waste also arises from radiochemical neutron activation analysis. This waste can be extremely variable 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 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. Whatever the field of work, contaminated equipment and facilities may need to be cleaned, decontaminated and/or disinfected, giving rise to radioactive aqueous waste which may have associated biological hazards. This waste may contain large quantities of complexing agents used to solubilize the radioactive contaminants.

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 amounts of beta and gamma emitting radionuclides. The volume of liquid organic waste produced from nuclear applications of radionuclides is generally small compared with the amounts of radioactive waste of other classes.

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

I.21. A number of non-water-miscible organic solvents, including carbon tetrachloride, trichloroethane and perchloroethylene, may arise in various operations. Where small amounts of water miscible organic solvents (such as acetone or alcohol) are used, they are normally treated as if they were aqueous waste.

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

Solid radioactive waste

I.23. Most solid waste produced in medical and research laboratories falls into the category of combustible waste. This group includes tissues, 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 that used radionuclides.

I.25. It should be noted that these categories are not mutually exclusive. This classification, which should be used for solid waste segregation, 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 combustible and may also be categorized as compressible, provided that there is no biological hazard.

I.26. The trash component of solid waste includes protective clothing, plastic sheeting and bags, rubber gloves and mats, shoe covers, wipe rags and towels. Much of this material is only marginally contaminated. The material possibly exhibits no measurable contamination but is initially classified as radioactive waste purely because it arose in controlled areas. It may be possible to clear this material and it may be disposed of as industrial waste [11]. However, certain individual waste 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 sources may have a widely varying activity depending on their original use: this varies from a few kilobecquerels for check sources up to many terabecquerels for teletherapy sources. While disused sealed 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. It should be noted that, although the radiation output of teletherapy sources and other large sources may have fallen below useful levels, the potential for injury from such sources remains substantial. It should be noted in particular that ^{137}Cs teletherapy sources normally contain caesium compounds in dispersible form and represent a severe hazard should their primary containment be breached.

I.28. Contaminated material and equipment may be generated either from medical or research activities and may constitute components of dismantled experimental rigs, or surgical implants. They may be made of glass, metal or plastic, and their activity varies widely according to use (see Tables I and II).

I.29. Activated materials may include shielding materials and isotope cans from isotope production or material testing in research reactors. Their activities may be expected to be dominated by that of ^{60}Co and other activated impurities in steel. For cyclotron based production the dominating nuclide would be ^{65}Zn, produced from copper. Activity 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 varying with animal species and experimental procedures. Carcasses may present biological and chemical hazards if they are permitted to 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 disposal option.

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

Gaseous or airborne radioactive 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 or ^{81m}Kr or ^{99m}Tc and short lived positron emitters like ^{18}F and ^{11}C for the investigation of the ventilation of the lungs.

Appendix II

FAULT SCHEDULE FOR SAFETY AND ENVIRONMENTAL IMPACT ASSESSMENTS

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

Process steps	Itemize all steps and interfaces in the waste management process
Hazard	Identify hazards for each stage and interface for normal and abnormal conditions
Control measures	
Engineered	Provide information on engineered control measures. Examples include, but are not limited to: protection devices, containment, shielding, thermal and/or electrical insulation, security devices and/or systems
Administrative	Provide information on administrative control measures. Examples include, but are not limited to: operating instructions, procedures, limits, conditions, requirements
Mitigated risk	Quantify mitigated (controlled) risk for each stage under normal and abnormal conditions once control measures have been taken into account
Contingency arrangements	Provide information on contingency measures. Examples include, but are not limited to: radiological and personal protective equipment, power shut off devices, external but supporting safety arrangements

Appendix III

FLOW DIAGRAM FOR THE MANAGEMENT OF SOLID RADIOACTIVE WASTE

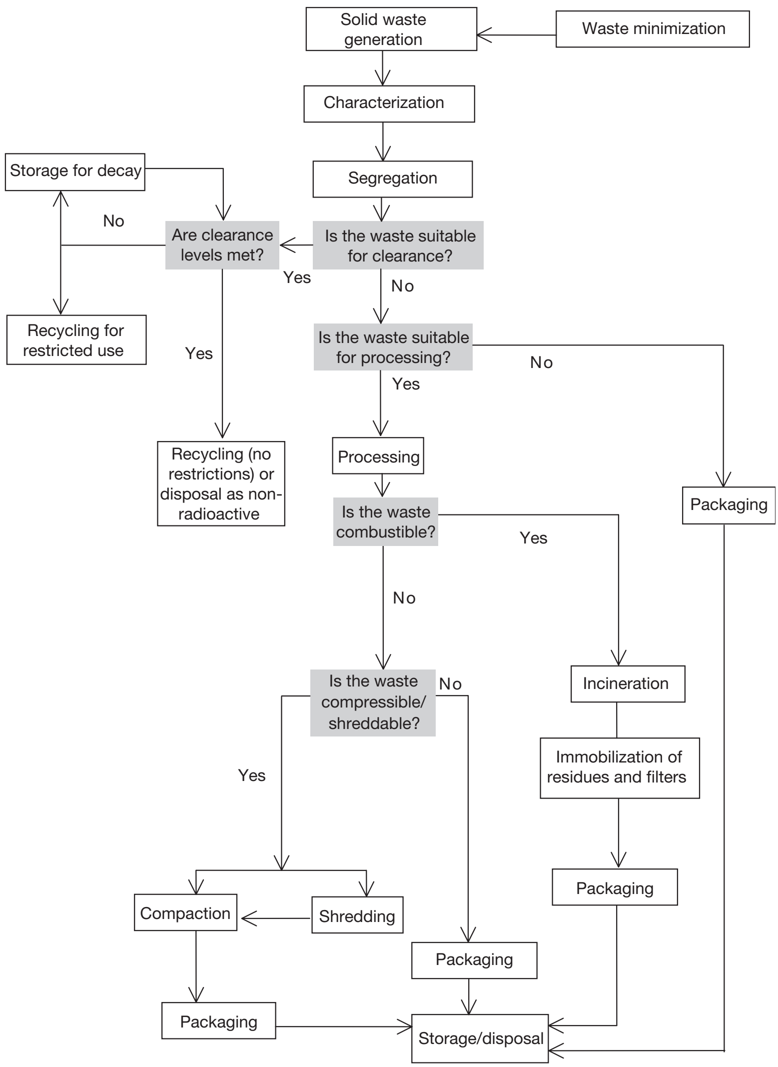

FIG. 1. Flow diagram illustrating the steps in solid radioactive waste management.

Appendix IV

FLOW DIAGRAM FOR THE MANAGEMENT OF BIOLOGICAL RADIOACTIVE WASTE

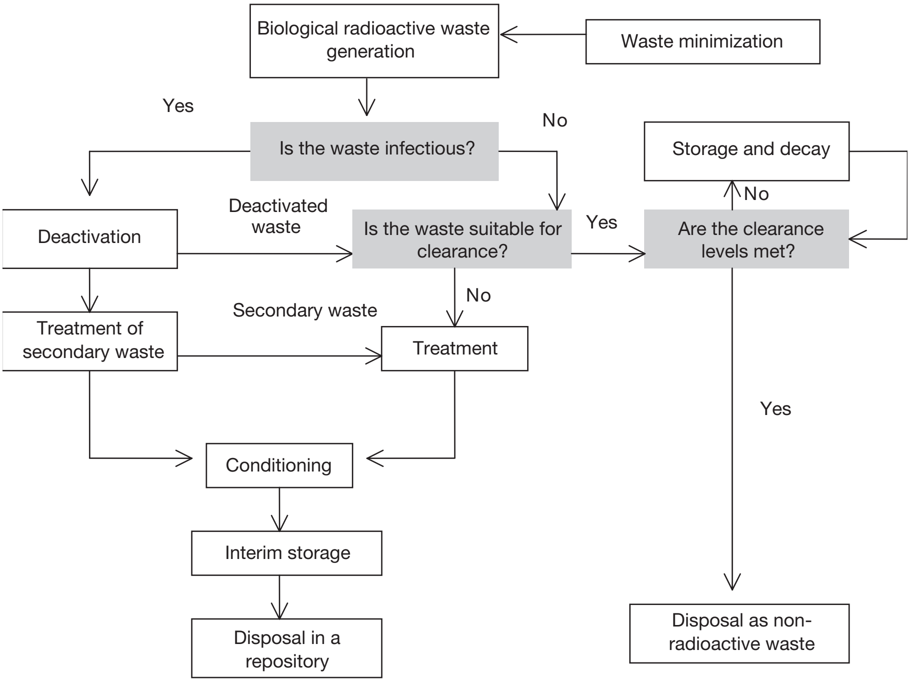

FIG. 2. Flow diagram illustrating the main steps in the management of biological radioactive waste.

Appendix V

FLOW DIAGRAM FOR THE MANAGEMENT OF DISUSED SEALED RADIATION SOURCES

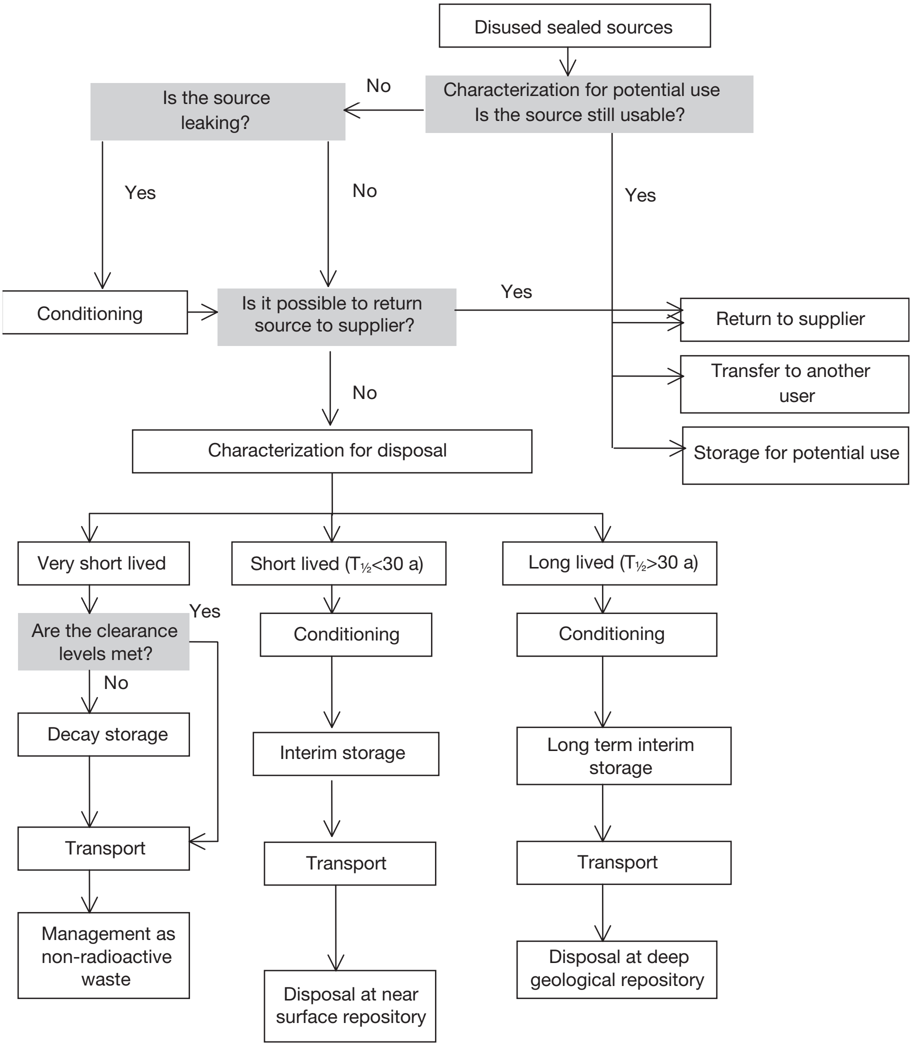

FIG. 3. Flow diagram illustrating the main steps in the management of disused sealed sources.

Appendix VI

DISUSED AND SPENT RADIATION SOURCES AND IDENTIFICATION OF TECHNIQUES FOR THEIR MANAGEMENT

TABLE 4. EXAMPLES OF COMMON DISUSED SEALED SOURCES AND THE TECHNIQUES AND EQUIPMENT USED FOR THEIR SAFE MANAGEMENT

Categories						Handling equipment		Monitoring	Packaging	Storage container
Sources	Isotope	Half-life	Applications							
α	Low activity									
	^{241}Am	432.2 a	Smoke detectors	Lightning rods	Static elimin-ators	Glove box	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 fluores-cence analysers			Glove box		α detection	Tight container	Drum with concrete
	^{239}Pu	24 181 a	Smoke detectors			Glove box			Tight container	
β, γ	Low activity		Long or short half-life							
	^{241}Am	432.2 a	Gauges	X ray fluores-cence analyser	Bone densito-metry		Tongs		Stainless steel internal drum	Drum with concrete
	$^{90}Sr/^{90}Y$	28.2 a	Gauges	Brachy-therapy			Rubber gloves			

TABLE 4. EXAMPLES OF COMMON DISUSED SEALED SOURCES AND THE TECHNIQUES AND EQUIPMENT USED FOR THEIR SAFE MANAGEMENT (cont.)

Categories					Handling equipment		Monitoring	Packaging	Storage container
Sources	Isotope	Half-life	Applications						
	^{147}Pm	2.6 a	Gauges			Rubber gloves			
	^{63}Ni	100 a	Electron capture detectors			Rubber gloves			
	^{109}Cd	462.6 d	X ray fluores-cence analysers			Rubber gloves			
	^{60}Co	5.3 a	Gauges	Calibration	Shielded screen	Tongs	β, γ detection	Lead shielded pot	Drum with concrete and lead
	^{137}Cs	30.2 a	Gauges	Calibration	Shielded screen	Tongs		Lead shielded pot	Drum with concrete and lead
β, γ	High activity		Short half-life						
	^{192}Ir	73.8 d	Gamma-graphy		Lead hot cell	Manipu-lators	β, γ detection	Lead shielded pot	Drum with concrete

TABLE 4. EXAMPLES OF COMMON DISUSED SEALED SOURCES AND THE TECHNIQUES AND EQUIPMENT USED FOR THEIR SAFE MANAGEMENT (cont.)

Categories				Handling equipment		Monitoring	Packaging	Storage container
Sources	Isotope	Half-life	Applications					
	^{170}Tm	134 d	Gamma-graphy	Shielded screen	Tongs		Stainless steel basket	
	^{169}Yb	32 d	Gamma-graphy	Shielded screen	Tongs			
	^{75}Se	120 d	Gamma-graphy	Shielded screen	Tongs			
β, γ	High activity		Long half-life					
	^{60}Co	5.3 a	Gamma-graphy	Lead hot cell	Manipu-lators	β, γ detection	Lead container	400 L drum with concrete
	^{60}Co	5.3 a	Tele-therapy	Concrete hot cell	Manipu-lators		Lead container	or concrete container
	^{60}Co	5.3 a	Irradiators	Concrete hot cell	Manipu-lators		Specific, to be defined	Specific to be defined
	^{137}Cs	30.2 a	Irradiators	Concrete hot cell	Manipu-lators		Specific, to be defined	Specific to be defined

TABLE 4. EXAMPLES OF COMMON DISUSED SEALED SOURCES AND THE TECHNIQUES AND EQUIPMENT USED FOR THEIR SAFE MANAGEMENT (cont.)

Categories						Handling equipment		Monitoring	Packaging	Storage container
Sources	Isotope	Half-life		Applications						
Special										
	^{226}Ra	1600 a	Lightning rods	Static eliminators		Glove box	Tongs	γ detection	Tight container	Lead shielded container
	^{85}Kr	10.7 a	Gauges	Lightning rods		Glove box	Tongs	Air control		
	^{3}H	12.3 a	Electron capture detectors	X ray fluorescence analysers		Glove box	Tongs	^{3}H control	Stainless steel internal drum	Drum with concrete
Neutron										
Neutron	$^{241}Am/Be$	432.2 a	Moisture detectors	Oil well logging		Neutron protection		Neutron detector		Neutron protection
Neutron	^{252}Cf	2.65 a	Moisture detectors	Oil well logging	Brachy-therapy	Neutron protection				
Neutron	$^{226}Ra/Be$	1600 a	Moisture detectors	Oil well logging		Neutron protection				
Neutron	$^{238}Pu/Be$	87.74 a	Moisture detectors	Calibration instrument		Neutron protection				

Appendix VII

STRATEGY FOR THE IDENTIFICATION AND LOCATION OF SPENT AND/OR DISUSED SEALED RADIATION SOURCES

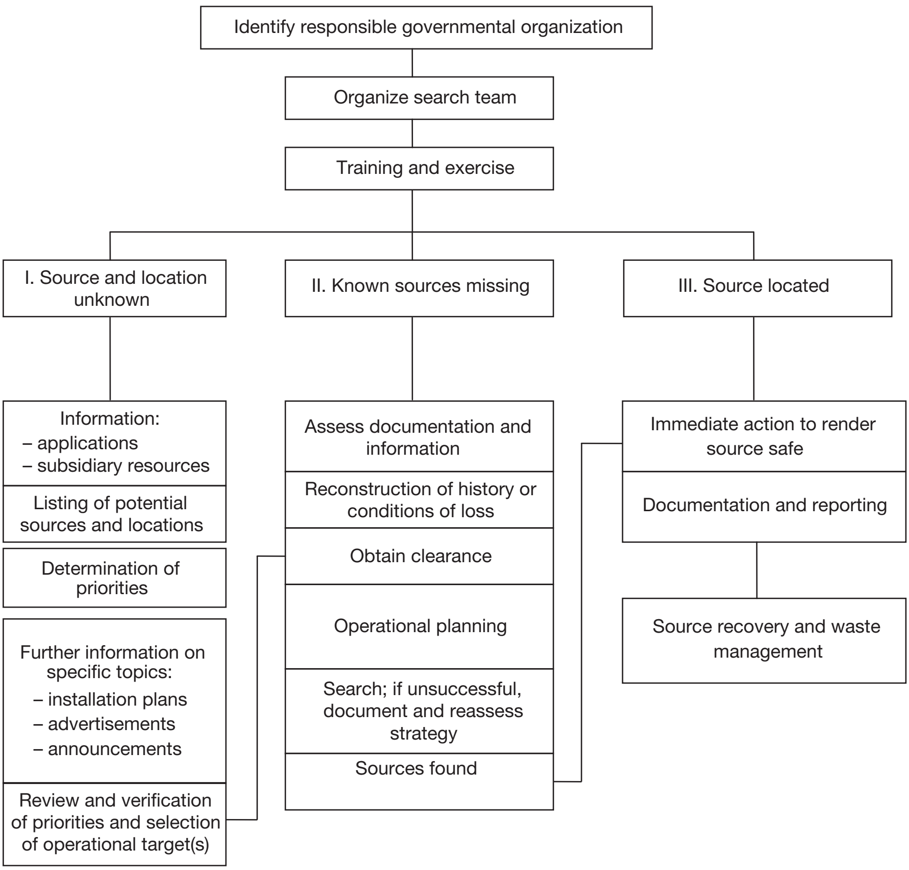

FIG. 4. An example of a strategy for identification and location of spent and/or disused sealed radioactive sources.

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