TECHNICAL REPORTS SERIES NO. 417

Considerations in the Development of Near Surface Repositories for Radioactive Waste

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CONSIDERATIONS IN THE DEVELOPMENT OF NEAR SURFACE REPOSITORIES FOR RADIOACTIVE WASTE

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Printed by the IAEA in Austria
August 2003
STI/DOC/010/417

TECHNICAL REPORTS SERIES No. 417

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INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2003

IAEA Library Cataloguing in Publication Data

Considerations in the development of near surface repositories for radioactive waste. — Vienna : International Atomic Energy Agency, 2003.
p. ; 24 cm. — (Technical reports series, ISSN 0074–1914 ; no. 417)
STI/DOC/010/417
ISBN 92–0–106103–X
Includes bibliographical references.

1. Radioactive waste disposal in the ground. 2. Low level radioactive waste disposal facilities. 3. Hazardous wastes — Management. I. International Atomic Energy Agency. II. Series: Technical reports series (International Atomic Energy Agency) ; 417.

IAEAL 03–00323

FOREWORD

Providing guidance on the disposal of radioactive waste constitutes an important and integral component of the IAEA programme on radioactive waste management. Low and intermediate level waste, even though it contains a small fraction of the total activity of all radioactive waste produced globally, represents more than 90% of the total volume of radioactive waste. Most of the radioactive waste produced in many developing Member States is primarily low and intermediate level waste. The IAEA has received many requests from Member States for technical assistance in the safe management of low and intermediate level radioactive waste. As a result, a number of activities have been initiated by the IAEA to assist Member States in the disposal of low and intermediate level waste, focusing on both technology and safety aspects.

This report presents an integrated, stepwise approach for the development (includes pre-operational, operational and post-closure phases) of near surface disposal facilities for low and intermediate level radioactive waste. The report has been developed in light of the considerable experience that has accumulated on the development of such disposal systems and is consistent with the current international requirements, principles, standards and guidance for the disposal of radioactive waste. It is considered that the systematic application of the various steps of the approach can contribute to the successful development of a repository programme. The approach is designed to be generic, integrating the various technical and non-technical factors, and flexible enough to be suitable for use in the various Member States, ranging from countries that have nuclear power plants to countries that have small inventories of radioactive waste from nuclear applications.

It is anticipated that this report will be particularly useful and of direct relevance to Member States that are currently developing, or have plans to develop, disposal facilities for low and intermediate level radioactive waste in the near future. The report is intended to respond to the disposal needs of the various Member States, ranging from countries with nuclear power plants to countries having small inventories of radioactive waste from nuclear applications.

The report was developed with the help of consultants and through an Advisory Group Meeting held in November 2001. The IAEA officer responsible for the completion of this report was R. Dayal of the Division of Nuclear Fuel Cycle and Waste Technology.

EDITORIAL NOTE

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1. INTRODUCTION

1.1. BACKGROUND

An important issue related to the generation of radioactive waste in nuclear power plants, nuclear fuel cycle facilities, and research laboratories, universities, hospitals and industry is its long term management. The safe disposal of radioactive waste, specifically the need to protect humans and the environment into the future, has been given particular attention both internationally and in Member States having well established nuclear energy programmes [1–22]. This issue is also of concern in many other Member States without power reactors and fuel cycle facilities that are using radioactive materials only for medical, industrial or research purposes.

The development of international recommendations and guidelines for the disposal of radioactive waste constitutes an important and integral part of the IAEA programme on radioactive waste management. In particular, near surface disposal is the preferred management option for low and intermediate level waste (LILW) in many Member States. Consequently, there has been a great deal of activity, including R&D projects, during the past few decades in different Member States, covering various aspects of LILW disposal. This has resulted in a large number of reports and conference proceedings on the topic, both within and outside the framework of the IAEA's radioactive waste management programme [18–37].

The IAEA radioactive waste classification system [38], based on waste characteristics and radionuclide content, provides a framework for defining a generic approach to radioactive waste management. The classification system identifies potential disposal options for various waste categories based on their specific characteristics, with specific activity and longevity of radioactive components being the key distinguishing features. For example, geological disposal, i.e. emplacement at depths of hundreds of metres, is recommended for disposing of high level waste (HLW) and long lived LILW. Near surface disposal is considered to be a suitable option for the disposal of short lived LILW containing radionuclides which decay to insignificant radiation levels within a few decades or centuries [7, 38, 39]. LILW containing limited concentrations of long lived radionuclides may also be disposed of in near surface facilities [7, 8, 40–42].

According to IAEA terminology, near surface disposal can include different types of disposal facilities. The most common near surface facilities consist of disposal units located at depths of only a few metres. Facilities where the waste is emplaced as deep as some tens of metres in rock cavities and boreholes are also considered to be near surface disposal facilities.

It is also worth mentioning that not all countries plan to dispose of short lived waste in near surface disposal facilities, for example Germany has decided to dispose of all radioactive waste, including the short lived variety, in geological repositories (hundreds of metres below the surface); even though the design of the repository for LILW is somewhat different from the one planned for HLW or spent fuel.

Short lived LILW is an important category of waste because, even though it contains only a small fraction of the total activity of all radioactive waste produced globally, it represents more than 90% of the total volume. Most of the radioactive waste produced in many developing Member States is primarily LILW. The amount of LILW is projected to increase significantly in the next few decades owing to the growing number of reactors due to be decommissioned. Not only countries with large nuclear programmes producing significant amounts of power reactor LILW need disposal facilities, but also those producing relatively small quantities of institutional waste. This need is likely to increase in the future.

Near surface disposal of LILW has been practised for decades in many Member States [43]. In the process, these countries have acquired valuable experience and have demonstrated that, if properly implemented, near surface disposal is a safe and cost-effective option [44]. Many Member States, on the other hand, are still in the conceptual or planning stage of developing disposal facilities for the waste being generated within their territory. Transferring the experience of Member States with developed nuclear programmes and established and operating disposal facilities is particularly important and useful to those Member States that are currently in the process of establishing disposal facilities. It is also useful to have this information presented in a coherent manner that provides guidance to countries that are planning to establish new disposal facilities.

Given this background, it was considered timely that a report be prepared, presenting this experience as part of the IAEA's mandate to provide guidance in the area of radioactive waste management. This will serve to document the various issues, both technical and non-technical, that must be considered during the sequential stages of the development (i.e. the operational, post-operational and post-closure phases) of near surface disposal facilities. An important part of the overall repository development process is the sequence of the various activities, their interactions and the iterative nature of the process. It is also important, therefore, to incorporate the presentation of the various activities into an integrated, step-wise approach to developing a disposal facility.

1.2. OBJECTIVES

The main objective of this report is to provide a reference publication to Member States on the various factors and approaches, including the sequence of activities and the processes involved therein, that are important in the development of near surface disposal facilities.

It is expected that this report will be particularly useful and of direct relevance to Member States that are currently developing, or have plans to develop, disposal facilities for LILW in the near future. The report is intended to respond to the disposal needs of the various Member States, ranging from countries with nuclear power plants to countries having small inventories of radioactive waste from nuclear applications.

A secondary objective is to contribute to the IAEA's on-going activities [45] related to providing guidance in the area of LILW management and to complement other IAEA reports and the international literature on this subject matter. This report is not intended, however, to provide a comprehensive review of disposal concepts, repository design, siting, safety assessment, construction, operation, monitoring, closure and post-closure activities. Detailed information on specific aspects, contributing to the repository development process, can be found in separate reports issued by the IAEA and other literature referred to in this report.

1.3. SCOPE

This report provides a review and discussion of the various factors, both technical and non-technical, and the step-wise process involved in developing near surface repositories. A discussion of approaches to address the various factors is presented on the basis of the aggregated experience of Member States and on international consensus. The discussion emphasizes that the various activities representing the different sequential stages of repository development need to be planned and undertaken as interdependent steps, as part of an integrated, iterative process in the context of the overall disposal system, eventually leading to the establishment of a disposal facility [1, 7, 13]. Although social, economic and environmental issues are important and are also discussed here, a more detailed discussion of non-technical factors and associated impacts of the near surface disposal of radioactive waste is presented in a separate report [44].

The primary focus of this report is near surface facilities consisting of disposal units located either below or above the original ground surface [46–48]. Facilities where the waste is emplaced at a greater depth (tens of metres) in rock cavities [25] or in boreholes [49] are also included in the IAEA's definition of near surface disposal and are discussed here as well. Two IAEA reports, dealing specifically with the safety and technology aspects of borehole disposal of disused radiation sources, are currently in preparation. This report does not cover geological repositories dedicated to HLW or long lived LILW, such as the Waste Isolation Pilot Plant (WIPP) facility in Carlsbad, New Mexico, or the disposal of waste from mining and milling of uranium and thorium ores. However, a number of publications in the area of geological disposal, which are relevant to near surface disposal, are also included in the list of references of this report.

Material for this report has been extracted and adapted from IAEA publications as well as applicable published materials from Member States and other international organizations. The source of particular information is provided and reports are referenced where supplementary information on specific topics can be found.

Waste management specific terminology used in this report is consistent with the latest IAEA publications in this area, specifically, the Radioactive Waste Management Glossary [39], the RADWASS publications [1, 7, 8] and the recent Technical Report on the Scientific and Technical Basis for the Near Surface Disposal of Low and Intermediate Level Waste [46].

1.4. STRUCTURE

This report is divided into eight sections. This first section presents introductory material.

Section 2 outlines the systematic approach that has been developed for the development of a near surface disposal facility, based upon past experience. The applicability of the approach to the different phases of the repository life cycle is outlined, as are the measures that can be taken to ensure safety and establish confidence in the development programme.

The subsequent five sections describe the key components of the approach in more detail. The need for the establishment of a waste management framework and the evaluation and characterization of the waste inventory as the initial steps in the approach are discussed in Section 3, together with the specific activities that are associated with these steps. Activities in the pre-operational phase are then described in Section 4, whilst those associated with the operational and post-closure phases are described in Section 5. At all stages of the repository life cycle, it is important to assess the impacts of the repository on safety, on socioeconomic issues and on the environment. The associated activities are described in Section 6. A further issue that needs to be considered at all stages is the establishment of confidence in the repository development programme. Section 7 presents technical, administrative and societal measures that can be adopted to establish confidence.

Finally, the summary and conclusions of the report are presented in Section 8.

2. APPROACH FOR DEVELOPMENT OF A NEAR SURFACE REPOSITORY

This section provides an overview of an integrated, stepwise approach and associated activities that can be used for the development, operation and closure of a near surface repository. It has been developed in the light of the considerable experience that has been accumulated relating to the development of near surface repositories and is consistent with the current international requirements, principles, standards and guidance for the disposal of radioactive waste [1, 2, 4, 7, 8, 13]. The approach and the activities associated with this are presented in Fig. 1.

The approach is shown as being a linear sequential process in Fig. 1, however, it should be recognized that there can be iterative loops between the various activities.

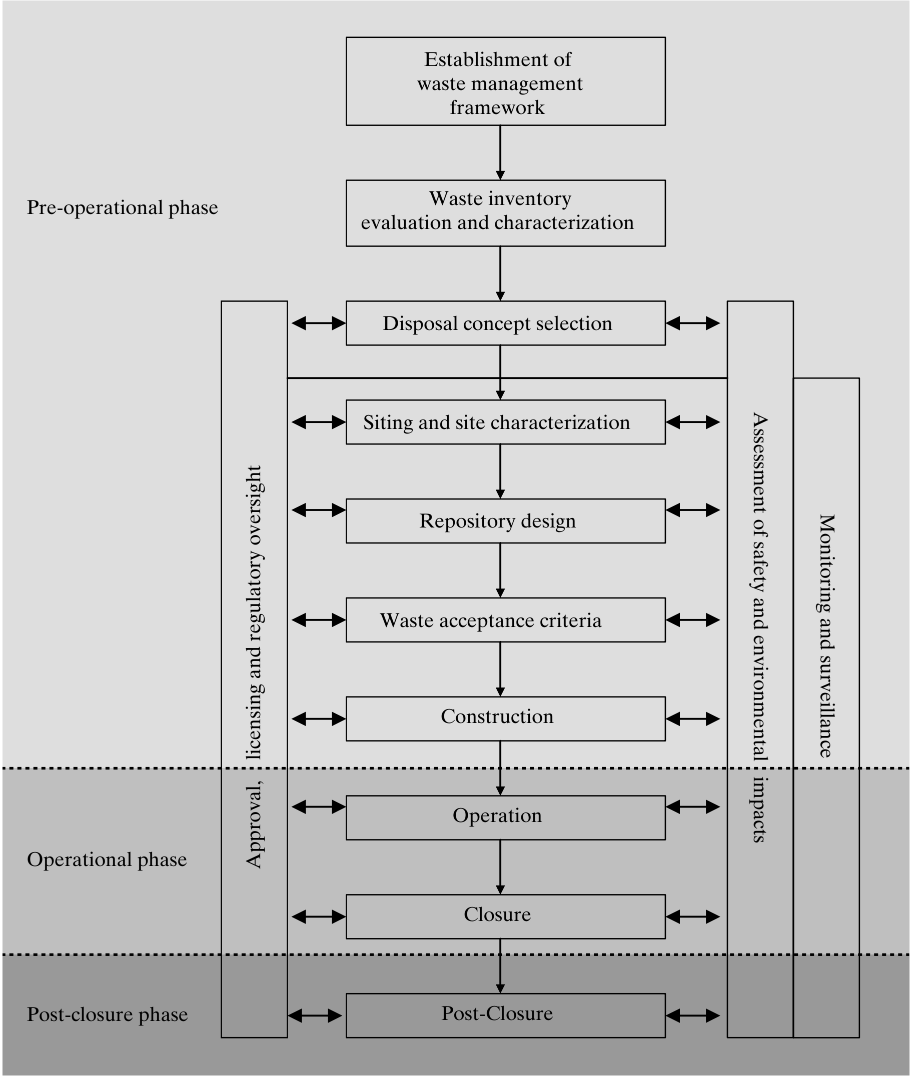

FIG. 1. Integrated, stepwise approach for the development of a near surface repository programme.

For example, once a site is operating, modifications can be made to its design and waste acceptance criteria in the light of results from assessments of its performance, outcomes of monitoring activities and changes in the inventory to be disposed. Furthermore, certain activities can run in parallel. For example, parts of the repository may be constructed at the same time as some parts are receiving waste and yet other parts are being closed. In addition, there are certain ‘cross-cutting’ activities, such as monitoring and surveillance, assessment of safety and environmental impacts, and approval, licensing and regulatory oversight, that need to be considered at all stages of the repository’s life cycle.

The approach is designed to be generic, flexible and suitable for use in the various Member States. It provides the basic sequence of steps that needs to be followed when developing a near surface repository. The development of each step is determined by a series of factors, such as the waste management framework and the availability of technical and financial resources, which are identified and discussed in detail in subsequent sections. While some of these factors such as national policy and legal framework, organizational and regulatory infrastructure, scientific and technical basis are likely to be similar in many Member States, other factors, for example the waste inventory, site characteristics or socioeconomic conditions, may be very different. Further factors, such as the availability of potential sites, regional and local geological conditions and climate, choice of disposal system concepts and designs, and involvement of stakeholders, are also country and repository specific and may affect the time taken to develop a repository. Therefore, it is necessary to use judgement and knowledge of local conditions when applying the generic approach shown in Fig. 1. Furthermore, the speed and specific details of each step in the development process will vary depending on these factors.

Before providing an overview of the approach (Sections 2.3 and 2.4), it is helpful to present the experience gained from the development of existing near surface disposal facilities (Section 2.1), which has been drawn upon to help develop the approach. It is also helpful to distinguish between the phases of the repository life cycle (Section 2.2), so that the steps of the approach associated with each phase can be distinguished.

2.1. PAST EXPERIENCE

As mentioned in Section 1.1, extensive experience has been accumulated in many countries with a large number of near surface disposal facilities [43]. Such experience shows that in many cases near surface disposal has been a successful operation, achieving safe isolation of radioactive waste at a cost significantly lower than alternative disposal options. There are also a number of cases, particularly with old facilities located in humid regions, where near surface disposal has failed to meet anticipated performance targets.

During the past 50 years, concepts for radioactive waste disposal have developed considerably. The most experience has been gained for near surface disposal facilities. Throughout this time, there have been many examples not only of successful repository development but also of failures in repository performance. The lessons learned from past negative experiences in repository performance have led to the development and adoption of improved disposal concepts and technologies employed at the currently operating near surface repositories such as Dukovany in the Czech Republic, the Centre de l'Aube in France, Rokkasho-mura in Japan, Vaalputs in South Africa, El Cabril in Spain, Drigg in the United Kingdom, and Barnwell and Richland in the United States of America. The main causes of poor performance of some near surface disposal facilities operated in the past can be grouped in two main categories, as discussed below.

In the past, some problems have resulted from the inadequate enforcement or the lack of appropriate waste acceptance criteria for facilities. As previously stated, near surface disposal is an option that requires the radioactivity of the waste to decay to adequately safe levels during institutional control periods. As a result of this requirement, the concentration and/or inventory of long lived radionuclides in the waste and repository need to be limited in accordance with the results of reliable assessments that show consistency with applicable safety standards. Since this has not always been the case, some old near surface repositories have been discovered to contain excessive amounts of long lived radionuclides; consequently the estimated radiological impacts of some evolution scenarios exceed current safety standards. Dose estimates above the safety standards may be due also to the subsequent adoption by the regulatory authorities of more stringent limits. Whatever the reason, there are several near surface repositories that are currently considered potential candidates for intervention because they contain excessive amounts of long lived radionuclides.

A further reason for inadequate performance of some old disposal facilities is the failure of the isolation barriers to provide the level of containment originally foreseen. Most repositories showing this kind of failure contain disposal units consisting of shallow trenches or pits that for one of various reasons have been filled by water. Entry of water into the disposal units has occurred from below, due to a rise of the water table and to its excessive proximity to the bottom of the trenches, or from above due to rainfall and inadequate cover, or from the side due to lateral migration of groundwater because of unusual meteorological conditions. Whatever the reason for the entry of water into the disposal units, leaching of the waste and subsequent mobilization of radionuclides indicate inadequate performance of the waste package. In order to have a significant mobilization of radionuclides, it is also necessary that the waste remain in contact with water for a fairly long time, which is more likely to occur in disposal units excavated in low permeability materials and without or with failed drainage systems (sometimes known as the bathtub effect). Where flooding of disposal units and mobilization of radionuclides have taken place, migration of radionuclides and subsequent contamination of groundwater have sometimes occurred, resulting in the eventual release of radioactive species to the surface [22, 50].

The systematic application of the various steps of the approach shown in Fig. 1 can help to avoid the problems that result in the inadequate performance of near surface disposal facilities.

2.2. PHASES OF THE REPOSITORY LIFE CYCLE

The life cycle of a near surface disposal facility comprises three major phases [7, 46], covering different types of activities of equal importance and requiring specific strategies, political decisions, and appropriate human and technical resources.

2.2.1. Pre-operational phase

This initial phase covers the period during which a disposal concept is selected and developed in relation to a specific site. The siting process involves close integration between the selection of a suitable site and the development of an adequate repository design. The objective of the activities in the pre-operational phase is licensing of the facility, eventually leading to the construction of the repository. Depending on the size of the project and national considerations, this phase can last from five to ten years or even longer.

2.2.2. Operational phase

During this phase, the repository is open and operational. LILW packages, complying with the waste acceptance criteria established during the pre-operational phase, are received and placed into disposal units; any auxiliary conditioning/packaging facilities and all supporting units are operating. The repository operational phase can typically last between 30 and 50 years or even longer.

At the end of the operational period, appropriate steps are taken to permanently close the repository. Facility buildings are decommissioned and, if contaminated, may be disposed of in the facility. A closure cap is usually constructed to control infiltration of water and erosion, and minimize the potential for human intrusion. Appropriate institutional controls are put in place prior to repository closure. Such controls can enhance both the long term safety of the repository and public confidence in its long term performance. Institutional controls may include active controls, such as monitoring, surveillance and remedial work; and passive controls, such as land use restrictions and record keeping.

2.2.3. Post-closure phase

During this phase, following closure of the disposal facility, the site is maintained under institutional control. Access to the site is controlled and a monitoring programme, approved by the regulatory body, is implemented. Controlled access to the site is important in that it serves to minimize the potential for human intrusion. During this period, any perturbation of the disposal system, revealed by the monitoring and surveillance programme, can be investigated and appropriate remedial action taken. At the end of the institutional control period, it is expected that the radioactivity in the waste will have decayed to acceptable levels and that the disposal facility will no longer present a radiological risk to humans and the environment. The duration of both the active and passive institutional controls needed to ensure safety depends on many factors, such as the waste characteristics, site characteristics and facility design, and economics. However, institutional controls for near surface disposal facilities are generally considered to be effective up to at most a few hundred years [8].

For repositories located in rock cavities, several tens of metres below the surface, adequate safety during the post-closure phase may be achieved without active institutional controls [7].

2.3. OVERVIEW OF THE APPROACH

2.3.1. Waste management framework and waste inventory

A pre-requisite for the development of a radioactive waste disposal facility is the establishment of a waste management framework and the subsequent evaluation of the waste inventory and waste characteristics.

2.3.1.1. Establishment of a framework

A radioactive waste repository can be established only within the framework of an existing waste management infrastructure and policy that includes [13]:

(a) A legal and regulatory framework for radioactive waste, including its safe disposal;
(b) A radioactive waste management policy and an associated plan for developing a repository;
(c) A clear identification of waste producers, repository operators and regulatory body, and a specification of their roles and responsibilities.

The establishment of this infrastructure and the planning of the repository need to be underpinned by appropriate cost estimation and financing.

2.3.1.2. Evaluation of waste inventory and characteristics

An early step, during the development of a national waste management policy and plan, is the assessment of the waste inventory [51] and the characteristics of the waste [52]. The characteristics of the waste that is generated and the estimates of waste inventories that have been and will be produced from various sources provide a basis for national policy decisions and for planning waste disposal activities. In particular, the characterization of the waste will assist the development of suitable waste conditioning and packaging prior to disposal.

2.3.2. Pre-operational phase

2.3.2.1. Selection of disposal concept

In the selection of the disposal concept, a number of factors need to be considered, of which the following are important:

(a) Characteristics of the waste destined to be disposed of in the near surface repository (the content of long lived radionuclides and the content of hazardous chemicals are of particular relevance);
(b) Total quantities of waste taken as reference for determining the dimensions of the repository;
(c) Geological, hydrogeological and other relevant characteristics of available candidate sites;
(d) Regulatory framework relevant to the disposal of radioactive waste;
(e) Cost estimates of the various disposal alternatives;
(f) Potential for approval by decision makers and other interested parties.

On the basis of the analysis of the relevant factors, a decision will need to be made at the national level about the type and number of disposal facilities that represent the optimum, or perhaps the only feasible, solution for the LILW generated in the country. Ignoring the possible strategy, adopted for example by Germany, of using only geological repositories for the disposal of radioactive waste, the issue becomes one of selecting a near surface disposal concept which is both feasible and adequate for taking care of a large part of the LILW that has to be disposed of.

Various near surface disposal concepts are briefly described in Section 4.1. It is reasonable to assume that at the end of the selection process one or more of those options will be selected for implementation. Whatever decision is eventually taken regarding the type of disposal concepts to be used, it is obviously essential that adequate confidence in their safety has been provided by means of the usual combination of safety assessments and environmental impact studies.

2.3.2.2. *Siting and site characterization*

The siting process proceeds in a manner that identifies a potential site that is likely to meet the technical and regulatory requirements, including socioeconomic needs, as well as having an appropriate level of public acceptance [7, 44, 53]. To achieve this goal, general site selection criteria need to be developed to guide the site selection programme and then be applied in the site selection process. Site selection may involve the investigation and evaluation of a number of sites, and finally the detailed characterization of a selected site.

2.3.2.3. *Repository design*

The design of a repository should take into account the site and waste characteristics and the regulatory requirements [48]. The design is developed on the basis of design criteria and specifications, in conjunction with performance and safety assessments. As the design process continues and evolves, more information will become available for assessment. As a rule, knowledge will continue to accumulate and evolve with further site investigations and other studies, leading to an improved understanding of the performance of waste packages and other barriers, and the refinement of assessments, which eventually will provide a basis for improving the design.

In view of the length of time that near surface facilities are likely to remain in operation, an additional element of the design process is the establishment of mechanisms for preserving design documentation and for updating the design.

2.3.2.4. *Waste acceptance criteria*

The acceptance of waste should take into account both radioactive and non-radioactive waste components and their associated hazards [7]. Waste acceptance criteria are predetermined specifications which the waste and/or waste package are expected to comply with for disposal [54]. They relate to the radionuclide content and other properties of the waste form and the associated container. The waste acceptance criteria are generally applied to waste packages and are established on the basis of site characteristics, repository design, safety assessment and other factors.

2.3.2.5. *Construction*

The construction activities can begin once a licence for construction has been issued. The objective is to build the disposal facility in a safe manner, ensuring that the facility will possess the properties specified in the design documentation used for licensing [7, 48]. Typically, repository construction work involves the following activities: site preparation; additional geological investigations and monitoring; construction of the repository structures (engineered barriers, etc.) and auxiliary structures; installation of instrumentation; any required testing.

2.3.3. Operational phase

2.3.3.1. Operation

Before disposing of any waste, the operator will test the installed equipment and instrumentation and submit to the regulatory body a comprehensive assessment of the proposed operations, taking into account all relevant information acquired on the repository during its design and construction [7, 48]. The regulator, if satisfied, will grant a licence for operation of the disposal facility, subject to any conditions that may be imposed to ensure that such operations are consistent with the applicable regulations. During operation, the following activities will typically be undertaken: receipt of waste; waste emplacement; extension of repository and backfilling of completed sections; surveillance and environmental monitoring; emergency preparedness checks and development and approval of the closure plan and monitoring strategy after closure. If required, modifications to the operation and design of the repository might be introduced during the operational phase as a result of changing regulatory requirements, new scientific and technical developments, and evidence of non-compliance.

2.3.3.2. Closure

After the facility lifetime is reached or the capacity is exhausted, the closure plan is invoked and the facility is finally closed [55]. The closure plan is developed and updated on the basis of the integration and analysis of all relevant factors. In most instances, a cover is constructed over the disposal units and the final monitoring plan is implemented. During the closure period, which may last from a few years to tens of years, monitoring and maintenance is conducted to ensure that the facility is performing as planned. Minor repairs might be required and, if no releases are observed, the level of monitoring may be reduced.

2.3.4. Post-closure phase

After closure, near surface disposal facilities are placed under institutional controls, which are considered an integral part of the overall system of protection [7]. Controls maintained over a repository after closure may enhance its safety, in particular by preventing intrusion. Monitoring may continue for several decades during the institutional control period to ensure that the repository is performing as expected. The level of monitoring is anticipated to decline over time, in accordance with the monitoring strategy developed before closure. If the repository is not performing as expected, then corrective actions might need to be taken.

2.4. ENSURING SAFETY AND ESTABLISHING CONFIDENCE

From Fig. 1, it can be seen that there are certain activities that are important during all phases of the repository life cycle. These are summarized below.

2.4.1. Assessment of impacts

A broad range of socioeconomic and environmental impacts needs to be assessed during the life cycle of a repository [44, 56]. Approaches have been developed to assess socioeconomic and other non-radiological impacts during the pre-operational, operational and post-closure phases (see, e.g., Ref. [44]), and radiological impacts both during the operational and post-closure phases (see, e.g., Refs [8, 50]). Of particular importance is the need to ensure that the assessment of impacts is undertaken in a transparent, structured and well documented manner, thereby increasing confidence in the assessment.

2.4.2. Approval, licensing and regulatory oversight

Approval and licensing is a step by step process that needs to be followed during the pre-operational, operational and post-closure phases. The details of the precise approval and licensing process can vary between Member States and the stage at which the development process finds itself. For example, during the early stages of the process, such as disposal concept selection, it is unnecessary to enter into a licensing process, although it might be helpful to obtain general approval of the selected concept(s) from a range of stakeholders, not just the regulatory body. In contrast, issuance of a licence by the regulatory body is a prerequisite for the construction, operation and closure of the repository, and might also be required for the siting and design of a repository. During the operational phase, the authorization for disposal may be issued for consecutive shorter periods than the expected lifetime of the project to allow the facility to be re-evaluated periodically for performance and regulatory compliance. The findings of impact assessments and of monitoring and surveillance programmes should be taken into account during the approval and licensing process.

2.4.3. Monitoring and surveillance

Monitoring of the various aspects of the disposal system is likely to be an important factor in decision making by the operator and the regulator, and serves a number of other purposes during the repository life cycle, for example compliance confirmation [57]. Account should be taken of the interdependence of the monitoring programme in the pre-operational, operational and post-closure phases aimed, in particular, at collecting baseline data and confirming the safety of the repository in terms of operational and post-closure considerations.

2.4.4. Establishing confidence

Measures to establish confidence in the repository development programme should be considered during all phases of the repository life cycle. Scientists, regulators, concerned groups and the general public all need to have confidence that the overall repository development process is robust and that it will produce a robust disposal facility for the isolation of the waste from the public and the environment in an acceptable manner whilst, at the same time, protecting those working at the facility. Some of the confidence generating measures involve scientific and technical activities, such as the validation, calibration and verification of models, and peer review [46], but other activities are administrative, such as the use of the quality assurance (QA) procedures, record keeping and publication of information, and even societal concerns [50].

3. WASTE MANAGEMENT FRAMEWORK AND WASTE INVENTORY

3.1. GENERAL

This section presents a summary of factors relevant to the establishment of an institutional infrastructure and national policy for the management of the inventory of short lived radioactive waste in a country that is destined for disposal. The establishment of such an infrastructure is a prerequisite for the development of a disposal facility. The approach to addressing the factors may vary according to the legal and cultural norms in different Member States.

General requirements for a national radioactive waste management infrastructure are given in Ref. [13]. Specific requirements for near surface disposal are provided in Ref. [7]. These requirements are relevant to all Member States having a potential need for near surface disposal facilities, though the extent to which the elements of the infrastructure are developed will depend on the amount and nature of radioactive waste requiring disposal.

3.2. LEGAL AND REGULATORY FRAMEWORK

An important step in the process of developing a disposal facility is the requirement that a legal and regulatory framework be in place for oversight and control of all waste management activities in the country. Within this framework, the basic requirements for ensuring the health and safety of the public and the workforce as well as the protection of the environment should be established by national laws. The legislation should specify the government agencies or ministries responsible for administering the law, usually by developing and controlling regulations and providing regulatory oversight. It is important that this be done prior to beginning the development process of the facility plan because the regulatory requirements play a critical role in defining acceptable options, sites and costs and other factors in disposal.

3.2.1. Legal framework

The IAEA Safety Standards publication [13] states that Member States are responsible for:

(a) Establishing and implementing a legislative and statutory framework;
(b) Establishing and maintaining a regulatory body;
(c) Making adequate infrastructure arrangements for the management of radioactive waste, with the prime responsibility for safety assigned to the facility operator.

The legal framework may or may not be prescriptive, for example legislation may establish detailed criteria for ensuring safety and environmental protection, or flexibility can be given to regulatory authorities in specifying objectives and technical requirements to ensure that the overall goals of the legislation are achieved. In most Member States, the regulatory authorities with responsibility for radiation protection, nuclear safety and environmental protection will also be responsible for control of radioactive materials.

3.2.2. Regulations

A set of national regulations, guiding the radioactive waste management programme and, specifically, the development of the disposal facility, needs to be established in accordance with the requirements and recommendations provided by the IAEA [1–14]. Regulations for the safe disposal of waste will cover collection, conditioning and storage of waste, selection of the disposal site, repository construction, disposal facility operation and closure, and monitoring and surveillance of the site both during operation and after closure. These regulations will be directed at protecting human health and the environment from potential releases of radioactive substances and from other potential non-radiological impacts such as accidents during construction work or disposal operations.

The regulations are intended to codify radiation safety requirements of general applicability and to address issues specific to the long term isolation of waste from the public and the environment. Specific requirements relating to the performance of engineered barriers may be included in regulations, for example in order to diminish the probability of inadvertent human intrusion, or may be dealt with by regulatory authorities on a case by case basis. The regulations should be clear, unambiguous and understandable by regulators, developers and the public so that they are easily enforceable.

The regulations include:

(a) Requirements and standards for protection and safety, and related administrative requirements;
(b) Authorization procedures (registration and licensing) for control of receipt, handling (including treatment and repackaging) and disposal of LILW;
(c) Provisions to monitor compliance, including inspection and audits to assess the status of safety and compliance with other regulatory requirements;
(d) Enforcement provisions to compel compliance with regulatory requirements;
(e) Requirements for investigation of accidents and management of emergencies;
(f) Requirements for dissemination of information on protection and safety;
(g) QA requirements.

Reference [6] provides a description of the basic elements of a regulatory programme that are generally applicable to LILW disposal. Sections 3.5–3.8 of Ref. [6] discuss goal based regulations versus prescriptive regulations.

In addition to regulations dealing with radiation, radioactive waste and transport safety [1–14], it should be noted that there will be many other relevant requirements, for example, relating to:

— Mineral prospecting;
— Land acquisition;
— Standards for construction;
— Worker safety and industrial hygiene;
— Protection of environment;
— Land use planning;
— Transportation of dangerous material;

— Required or suggested compensation to individuals, communities or companies affected by the project;
— Public information.

There is the potential for conflict between regulations established by different national authorities, and between the requirements of national and local regulations. Such conflicts can significantly increase the time and cost for disposal. It is necessary, therefore, to consider the full range of regulatory regimes that could have an impact on the work at the site and to resolve any conflicts between the regulations, prior to the start of repository development work.

3.3. POLICY AND STRATEGIES

Because management of LILW is an issue of national interest, each Member State should establish a clear national waste management policy and set forth a strategy for implementing that policy. Those responsible for the policy and implemention strategy must consider the expected waste generation in the country and provide direction for the management of the waste to achieve timely disposal. A waste management programme can then be developed, taking into consideration available resources. The policy and strategy define disposal routes for different types of waste and provide a road map to define the actions required to implement the disposal plan [58–61].

3.3.1. Evaluation of needs

The policy and strategies are developed, on the basis of a clear understanding of the waste generation patterns in the Member State. This requires a national inventory of all radioactive waste, including disused radiation sources, untreated legacy waste in storage facilities and mining and processing waste. The current inventory must then be projected to include future waste arisings, including those resulting from the decommissioning of nuclear facilities, in the Member State.

3.3.2. Development of a national strategy for waste management

Once the nature of the waste management problem is defined and projections of future waste generation are established, a strategy for waste disposal can be developed. Strategies for short lived LILW can be wide ranging, varying from storage for decay, obviating the need for development of a disposal facility, to co-operation with other countries in the region to share a common regional disposal facility, to developing a national LILW disposal facility in the Member State. Siting requirements and economic considerations may place important constraints on the potential options available.

The strategy needs to address certain basic elements that include:

— Places of waste generation;
— Access and transportation routes;
— Options for storage;
— Waste treatment and conditioning requirements;
— Potential disposal options for different waste types;
— Repository siting criteria;
— Need for single or multiple repositories;
— Waste collection and transportation;
— Developer and operator selection/designation;
— Responsibility for long term custody;
— Economic issues;
— Time frame for development of storage and/or disposal facilities.

The development plan for a strategy includes specific milestones against which the progress of the waste management project may be measured. It is important to assess the level of success in the development of the plan and, for example, to indicate resource deficiencies.

According to the risk they represent and the ease with which they can be processed, radioactive waste can be managed and disposed of in a facility located close to the source of the arisings or in a centralized facility. The approach adopted in a particular Member State will depend on national and local policy considerations, political and cultural norms, economic considerations and the state of development of the local infrastructure.

3.4. INSTITUTIONAL FACTORS

Successful implementation of a waste management programme requires that the respective responsibilities of waste producers, facility operators and the regulatory body are clearly identified. The regulatory body must be independent of the waste generators and the facility operator.

3.4.1. Waste generators

Waste generators manage the waste up to the point when it is transferred to another organization or agency in accordance with the institutional responsibilities established by the Member State. During this period, they must ensure that the waste is stored in accordance with the licence conditions established by the regulatory authority, such that the safety of the workforce and general public is ensured. The waste generators must also develop appropriate arrangements to ensure that the amounts of waste produced at their facilities are kept to a minimum and they must provide information about the quantities and characteristics of the waste to the organization responsible for maintaining the national waste inventory.

The waste generators may also have responsibility for treating and packaging it in a form suitable for disposal and in accordance with applicable requirements for transport. In this case, they must guarantee the quality of the waste form and waste package delivered for disposal. In some Member States, the organization responsible for waste storage and disposal (the waste management organization) also has responsibility for waste treatment and packaging.

3.4.2. Waste management organization

Many Member States have designated a single organization as being responsible for radioactive waste management. This organization may be a public body or a private organization, for example one owned and funded by the waste producers. In either case, the activities of the waste management organization will be regulated so that the health and safety of the public and the protection of the environment are ensured on an ongoing basis. Because these objectives need to be applied over an extended time period, perhaps over hundreds of years, the land on which a disposal facility is sited will generally ultimately be in public ownership.

The operator of the waste disposal facility is responsible for maintaining records as specified by the regulatory body [8] — see Section 7.6 of the present report. Such records should be maintained over an extended time period, for example, such that another operator could, if necessary, take over responsibility for the management of the facility and its eventual closure.

3.4.3. Regulatory body

A regulatory body needs to be established that is independent of generators and disposal site developers and operators. The Safety Standards publication [13] states that the regulatory body is responsible for:

- — Implemention of the authorization process;
- — Regulatory review and assessment;
- — Inspection and enforcement;
- — Establishment of safety principles, criteria, regulations and guides.

It is desirable that one regulatory body be designated to co-ordinate the efforts of the national agencies with an interest in the repository, for example, an agency concerned with non-radiological hazards, and to provide a single point of contact with the repository developer/operator. The regulator is responsible for ensuring public safety and protection of the environment through the issuance of licences and/or authorizations, and the oversight of all aspects of waste disposal according to the requirements of the licence and licence conditions.

3.5. COST CONSIDERATIONS

3.5.1. Costs incurred during the life cycle of a repository

The cost of development and operation of a repository should be estimated for all stages of the repository life cycle. Cost estimates become progressively more detailed and refined as the repository development programme is better defined, with early cost estimates being needed to enable funding mechanisms to be put in place and for decision making concerning the disposal concept.

The major activities contributing to disposal cost include:

- Siting;
- Land purchase, if needed;
- Design of the facility;
- Construction of the facility;
- Construction of access to the facility (road, railway, etc.);
- Elaboration of safety reports and licensing;
- Public information;
- Local incentives;
- Infrastructure development;
- Operation of the facility;
- Closure of the facility;
- Post-closure controls and maintenance or corrective actions, if needed.

As discussed in Ref. [19], construction cost per waste unit (volume or mass) depends strongly on the size of the facility due to the relatively high weight of costs which are independent of the amount of waste to be disposed of, such as those related to siting, design, construction, licensing and public involvement.

Besides the costs associated with the various activities described above, the cost of planning and implementing a QA programme and the cost of regulatory oversight to ensure safety of the disposal facility are to be considered as well. Cost estimates should take account of all steps in the waste management chain: waste collection, treatment, conditioning, packaging, storage, transportation and disposal.

Cost can vary considerably from one country to another, due to varying manpower or industrial costs and other factors. Studies of the factors affecting LILW disposal costs, conducted by the OECD Nuclear Energy Agency [19], lead to the following conclusions:

(a) In some countries, planning and licensing costs represent a significant portion of the total cost of the repository. This may be attributed to socio-political factors which, however, cannot be quantified. The upward trend of the costs implies further increases in the planning costs of future repositories.

(b) Unit construction cost, i.e. the ratio of total construction cost to the volume of disposed waste, is lower for repositories with large capacities (an economy of scale effect). This may be explained, in particular, by the fact that some of the repository infrastructure is unavoidable, representing fixed costs that have little dependence on the repository size.

(c) The construction cost of repositories with shallow disposal units is generally lower than that of rock cavity repositories or other greater confinement facilities. However, they have a different total cost structure: for example, post-closure monitoring and surveillance are typically required to a much lower extent or not at all for rock cavity repositories or for boreholes of equivalent depth.

(d) Operating costs are not affected by the repository size as much as the construction costs, the main reason being that a certain part of the operating costs is fixed, i.e. it is not proportional to the amount of annual delivery of waste.

3.5.2. Financing repository development and operation

An important aspect of national policy development is the identification of repository financing sources and of how funds will be provided during each life cycle phase. Different Member States have adopted varying approaches to repository financing, ranging from full government funding to full cost recovery from the waste producers utilizing the repository [62]. Such decisions will influence the ultimate cost to users of the repository. Financial constraints may influence the timing of repository development and the possible need to rely on short or long term storage as an ongoing management option.

Funding requirements may be increased significantly if the pre-construction phase is extended for some reason. Impact mitigation costs may also be significant, depending on the type and level of potential impacts addressed. In addition, the cost of mitigation measures may be affected by the outcome of public debate and by the availability of funds.

Closure and post-closure institutional control activities are another important cost consideration. In some Member States, the repository programme is required to set aside funds during operations to pay for repository post-operational expenses. These financial reserves may be collected as repository user fees and set aside in an interest bearing account for future use.

In radioactive waste management, it is a generally accepted principle that the costs of the management of waste should be borne by the operators of the processes from which the wastes are generated ('polluter pays' principle). In effect, the costs are borne by the users of electricity generated from nuclear energy and from users of outputs from other processes that lead to the generation of radioactive waste. In most Member States, funding for repository development and construction is obtained either through levies on users of outputs from waste generating activities, for example electricity users, or through general taxation.

For current and future production of waste, the total management costs must be funded by the producers. This is the approach adopted by national waste management organizations in many countries. Such an approach encourages users of radioactive substances to minimize the volume and hazard of their radioactive waste.

In some Member States, the government is, and has been, itself a significant producer of radioactive waste, through publicly owned organizations. In such cases, as a legacy of past activities, large inventories of historical waste may exist; the government, then, will often be a significant contributor to waste management funds.

3.6. WASTE INVENTORY

A comprehensive inventory of present and anticipated radioactive waste arisings is an important input to developing strategies for implementing radioactive waste management policy, in particular for the design of waste repositories. Technical guidance to Member States for the establishment of a waste inventory record keeping system (WIRKS) for the management and disposal of radioactive waste is provided in a recent IAEA publication [51]. The inventory should include predicted future arisings over several decades in order that optimal waste management solutions are developed [51, 63–65]. On the basis of the national waste inventory:

- LILW will be clearly identified.
- Pretreatment and/or treatment and/or conditioning for disposal will be defined.
- Technical options for disposal and the size of the facility will be determined.

3.6.1. Sources and inventory of waste

LILW can be derived from the following activities:

(a) The use of radioisotopes in medicine and in medical and biological research: animal carcasses, contaminated blood, small plastic bottles, needles and syringes, glass, etc.;
(b) The operation of nuclear power plants: ion exchange resins, concentrates from liquid waste treatment by chemical process or evaporation, contaminated equipment, tools and rags, activated components, used working clothes, etc.;
(c) Activities at nuclear research facilities: solid concentrates from liquid waste treatment, pieces of metal, small laboratory items, glass, plastics, cotton, rags, etc.;
(d) Decontamination and dismantling of redundant facilities: decontamination solutions and materials, contaminated building materials, pieces of metal, pieces of wood, electric wires, etc.;
(e) Disused radiation sources.

The LILW inventory has to include all existing waste, therefore data on legacy waste scattered in various locations, such as disused radiation sources in medical institutions and other old waste stored in inactive facilities, will need to be searched.

The usefulness of a waste inventory depends on the reliability and completeness of the information regarding the listed waste items. The list of waste characteristics and information elements that should be included in the inventory is:

- Identification of the producer or owner (company and name of the manager);
- Location of the production (identification of the laboratory, process item, etc.);
- Type of waste (solid, liquid, compactable, non-compactable, burnable, disused source, etc.);
- Volume;
- Radionuclides present;
- Activity per nuclide;
- Chemical and physical properties;
- Current conditions of waste form (raw, pretreated or conditioned, including properties of the conditioning material);
- Type and characteristics of container, and of overpack if any (constitutive material, dimensions, weight and handling items);
- Current storage conditions.

3.6.2. Waste form

Knowledge of the characteristics of the waste is important for waste conditioning, packaging, selection of disposal option and repository design. The parameters to be controlled, as well as the required equipment and procedures for waste characterization, are given in detail in Refs [52, 54, 66–69] and references therein.

The waste to be disposed of must be solid waste or in a solidified form. Such waste consisting of materials and objects can be very heterogeneous, being in solid form originally or solidified using conditioning technologies, for example sludge from chemical co-precipitation. Waste can be categorized as homogeneous waste or heterogeneous waste.

Heterogeneous waste is more difficult to characterize than homogeneous waste, and requires a more conservative approach in safety assessment and repository design.

Different types of conditioning materials are used to immobilize waste, with cement being the most commonly used material. Bitumen and polymers have also been used for conditioning different types of waste. Cement, bitumen and polymers can all contribute to the confinement of the radionuclides within the waste package.

The main objective of waste conditioning is to limit the potential for dispersion of the waste and to reduce the voids within the container, thus providing integrity and stability to the package. The current waste conditioning and packaging technologies are relatively well advanced. They are described in a number of IAEA publications, including the references provided above [52, 54, 66–69].

3.6.3. Waste packages

Waste packages are in themselves containment barriers, contributing to the isolation of radionuclides from the environment. Therefore, they are designed and fabricated to have sufficient mechanical strength to bear loads after repository closure and to be capable of withstanding accidents during the operational phase, as well as to comply with requirements for waste handling, transport and storage. Accordingly, consideration must be given to waste package design and fabrication, addressing in particular the following:

(a) Performance of waste packages during handling, transportation, storage and receipt at a disposal facility, with particular attention paid to the implications for radiation protection;
(b) Compatibility of mechanical behaviour compatible with the stability of the disposal structures;
(c) Ability to prevent or reduce the potential release of radionuclides to the environment during the post-closure period.

The long term behaviour of waste packages in repository conditions is subject to greater levels of uncertainty than their behaviour during storage. This uncertainty needs to be considered in the safety case for the repository.

There may be large volumes of heterogeneous or bulky waste such as contaminated soil or demolition rubble that could be occasionally disposed of without packaging. National waste acceptance and general safety requirements must be adhered to in adopting this practice. The approaches and methods commonly used to manage this type of waste are described in Refs [9–11].

4. PRE-OPERATIONAL PHASE

4.1. GENERAL

For the purposes of this report, the pre-operational phase of repository development encompasses the activities involved in selecting the disposal concept itself (e.g. engineered trenches on or near the ground surface versus deeper rock cavity type facilities), the siting process, repository design, development of waste acceptance criteria, licensing and construction. This section provides a discussion of the main factors that are important in each of these activities.

4.2. SELECTION OF DISPOSAL CONCEPT

Currently existing disposal options for LILW range from near surface facilities to engineered geological repositories. More than one hundred LILW disposal facilities are, or have been, operating and more than 40 repositories are under varying stages of development in Member States [43]. Examples of near surface repositories where the waste is emplaced in disposal units with a cover of only a few metres include Centre de l'Aube in France, Rokkasho-mura in Japan, Vaalputs in South Africa, El Cabril in Spain, Drigg in the UK, and Barnwell and Richland in the USA; many smaller repositories of the same type have been constructed also in various other countries [18, 21, 23, 24, 28–33, 35, 48]. Another type of near surface repository constructed in several Member States consists of one or more rock cavities at depths of some tens of metres [25]. Rock cavities can be natural or excavated in various geological formations. Examples of rock cavity repositories are the Swedish Final Repository (SFR) at Forsmark and Olkiluoto in Finland. These two facilities consist of different types of chambers mined in crystalline rock about 50 m below the surface and they are designed to accommodate LILW [30].

Other near surface disposal options have also been considered for particular types of waste or to improve the intrusion resistance of disposal units. The Intrusion Resistant Underground Structure (IRUS) facility [18] in Canada and other examples of these disposal options are aimed at providing greater waste confinement, relative to most conventional near surface disposal facilities where the waste is covered by only a few metres of non-load-bearing cover material. The common justification for greater confinement disposal options is to accommodate types of waste that for some reason do not meet the waste acceptance criteria of a repository based on shallow trenches, pits or mounds.

In safety assessments of near surface disposal facilities, it is generally assumed that, at the end of the institutional controls period, human intrusion may occur and, therefore, the estimated consequences need to meet the given safety targets. Particular types of LILW may fail to meet the established acceptance criteria either because their specific activity is too high or because the content of long lived radionuclides is moderately higher than the acceptable limit. Disused radiation sources are characterized by high specific activity and small volume. With the exception of those containing very short lived radionuclides, disused radiation sources usually do not meet the waste acceptance criteria for near surface disposal facilities. Since geological repositories are not currently available, many countries are considering the option of borehole disposal for disused radiation sources [49]. The depth of boreholes to be used for this purpose might vary between several metres and some hundreds of metres, depending on the characteristics of the sources and on the geological conditions of the site. Thus, this particular disposal option might be categorized, depending on the depth of the borehole, either as near surface or as geological disposal.

Large diameter boreholes, such as those at the Nevada Test Site [70], have been used for the disposal of LILW, including disused radiation sources exceeding the waste acceptance criteria for a near surface disposal facility. Different types of greater confinement facilities have been proposed for the near surface disposal of radioactive waste. An example of an alternative approach given above is the IRUS concept, developed in Canada, where greater confinement is achieved by means of strong intrusion-resistant barriers instead of increased depth [18].

The choice of the disposal concept depends on a number of considerations, including economic and technical factors, but always with a requirement that is crucial in the repository development process, i.e. there is reasonable assurance that the safety targets will be met.

Typical examples of near surface disposal concepts currently in use in various Member States are shown in Figs 2–7.

Also Figs B.6, B.7 (SFR) and D.1 (IRUS) from IAEA-TECDOC-1256 [48] can be used as illustrations of disposal concepts.

4.3. REPOSITORY SITING

4.3.1. Siting criteria

Guidelines for the selection of a potential disposal site usually include both technical and non-technical criteria. Typical examples include:

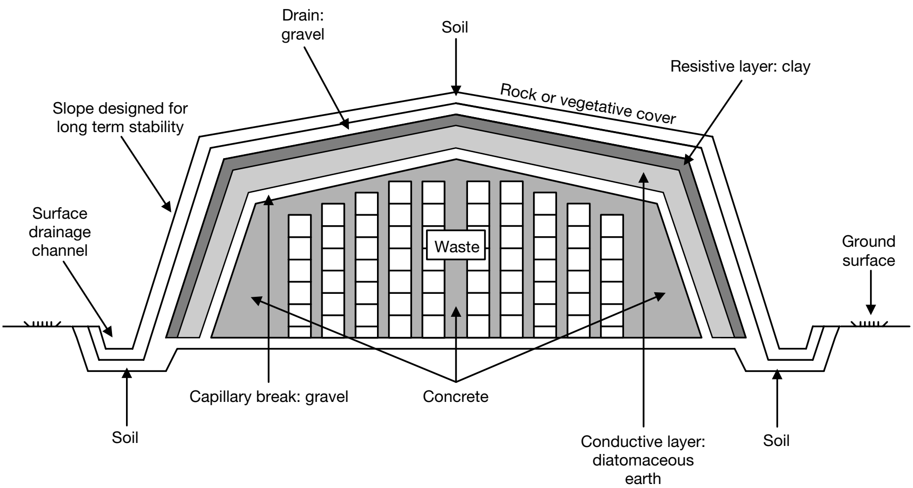

FIG. 2. An engineered disposal mound based on the multi-barrier concept [26].

— Availability of favourable geology, hydrogeology and topography;
— Absence of natural resources;
— Avoidance of areas of special cultural or ecological interest;
— Availability of local infrastructure, including utilities, human resources, transportation routes and basic physical services.

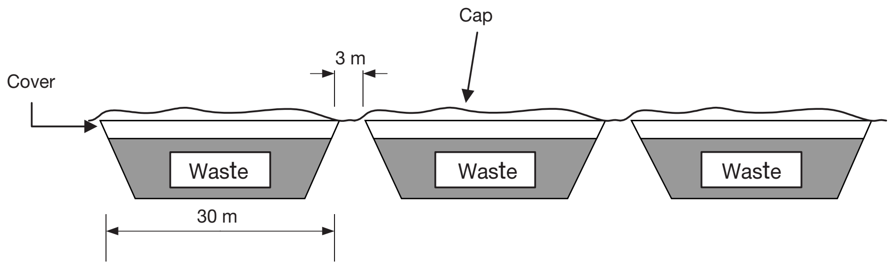

FIG. 3. A simple disposal trench [26].

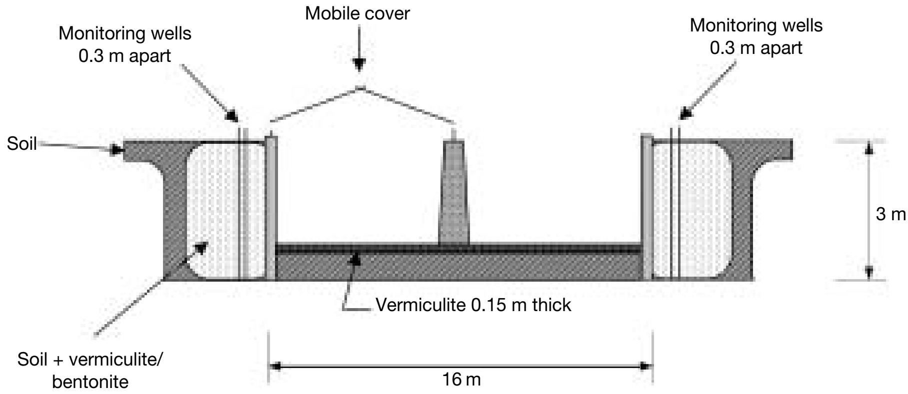

FIG. 4. Typical engineered earth trench design at Trombay, India [71].

Further examples of technical siting criteria are given in Refs [46, 53], and the references in Sections 2.3, 6.2 and 7.7 also cover non-technical criteria relevant to repository siting.

4.3.2. Site selection and characterization

Candidate sites are assessed on the basis of their ability to contribute to the isolation of the waste and limit radionuclide releases to minimize potential adverse impacts on humans and the environment. Important site characteristics include:

(a) Geology: The site is expected to possess a stable geology that contributes to the isolation of waste. In addition, the overall predictability of site evolution with regard to its performance in the future needs to be adequate.
(b) Hydrogeology: The hydrogeological characteristics of the site are expected to limit the contact between waste and groundwater, and thus minimize the mobilization and transport of radionuclides.
(c) Geochemistry: The geochemical characteristics of the site should be such that the potential for radionuclide migration is minimized. In addition, the chemical conditions should not adversely affect the durability and performance of the waste packages and engineered barriers.
(d) Seismicity: Seismic events expected to affect the site need to be assessed to ensure that the structures of the facility are designed and built in such a way that their performance will not be compromised.

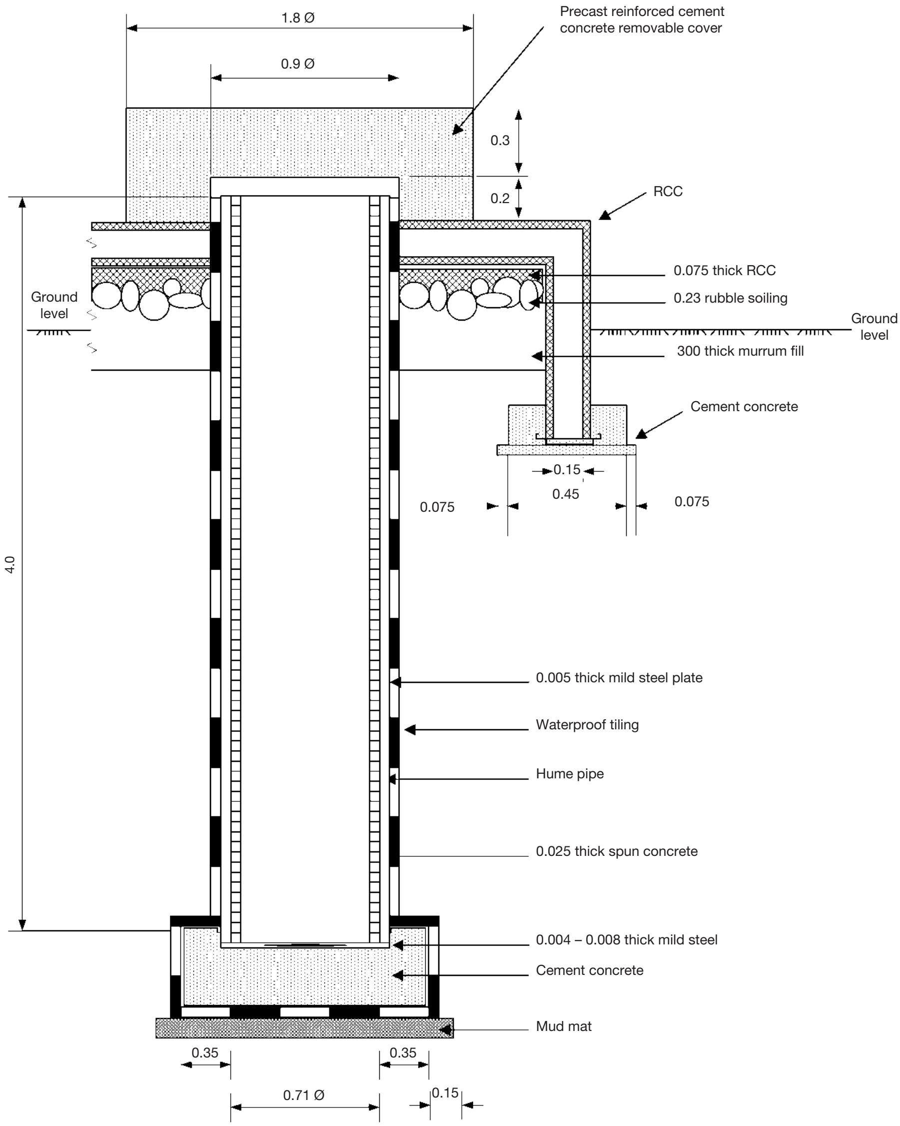

FIG. 5. A tile hole disposal structure at Tarapur, India (all dimensions in metres, not to scale) [71].

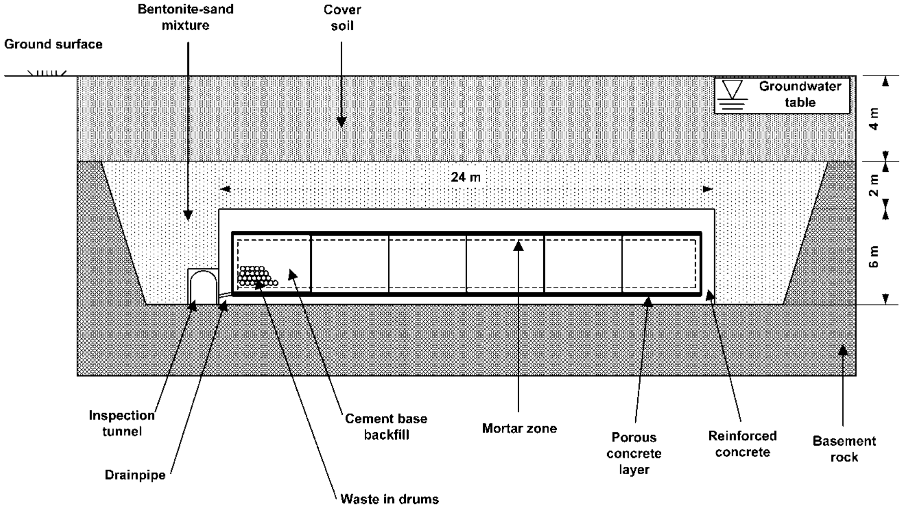

FIG. 6. A disposal vault at the Rokkasho near surface disposal facility [72] (not to scale).

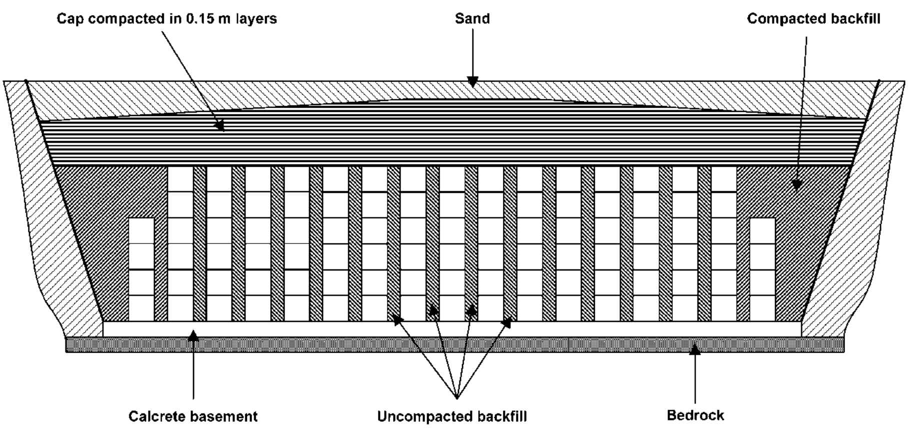

FIG. 7. A disposal trench at Vaalputs, South Africa [73].

(e) Topography: The geomorphological conditions of the site need to be such that surface processes, for example erosion and flooding, are expected to be minimal in rate and intensity, or absent, precluding therefore the possibility that the ability of the site to isolate the waste might be compromised.

(f) Climate: The climatic conditions of the site need to be such that the isolation barriers can be expected to perform as designed for the required period of time. In addition, possible climatic variations need to be analysed to ensure that the performance of the isolation system will not be adversely affected.

(g) Human environment: The implications of human activities in the area need to be considered — see the discussion in Section 6.2.

Data collected during site investigation are used as input to the design process and to the associated safety and environmental assessments undertaken to determine site suitability (Section 6). These data also provide baseline information on the undisturbed characteristics of the site, with which the characteristics of the site in the future can be compared, for example in the context of confirming the adequacy of the models used to represent the behaviour of the repository.

Data collection is the most extensive activity to the site investigation process. Guidance on this activity is given in Refs [74–76] and in other publications (Section 6.1) in much greater detail than in this report. When considering the type of information required, it is important to recognize that the actual data needs depend on the existing databases and also on waste type and inventory, repository design and site characteristics. The site selection process may reduce the need for some data, for example a site selected in an arid area may need only very limited groundwater information. The design of a disposal facility may reduce the need for a certain type of data.

Experience in site characterization in Member States, results of major international projects, international guidelines related to site characterization, and identification of the types of data that are needed to demonstrate compliance with the guidelines are discussed in Refs [24, 25, 53, 74–85].

4.3.3. Environmental impact assessment

The process of selecting a site for the development of a near surface disposal facility will normally require a comparison of different siting options, but it may include also the assessment of alternative disposal concepts (e.g. shallow disposal units versus rock cavities or other higher confinement concepts). This comparison process may be facilitated by a structured process of environmental impact assessment, in which the attributes of different sites are assessed in terms of their potential impact on the natural and human environments. This process is discussed further in Section 6.2 of this report. The environmental statement, documenting the results of the assessment process, will be an important supporting document to the application to proceed with investigations and development at a single candidate site.

4.4. REPOSITORY DESIGN

The repository should be designed to provide adequate isolation of disposed waste for a given period of time, which, for most near surface disposal concepts, is equivalent to the anticipated duration of institutional controls. The duration of that period of time and the required performance of the isolation barriers are key design features. The duration of institutional controls is generally pre-defined by the regulatory authorities, taking into account the characteristics of the site, the relevant regulatory requirements and various societal and ethical factors. The quantities and characteristics of the LILW that needs disposal are also critical factors for the design of the repository. On the basis of the characteristics both of the disposal site and waste and of the anticipated duration of institutional controls, it is feasible to proceed to the detailed design of the repository, including the limitation of its hazardous content through the definition of appropriate waste acceptance criteria. Guidance on the repository design process is available in Refs [25, 26, 33, 35, 36, 48].

For most near surface disposal facilities, the performance of the engineered barriers is important in determining the ability of the disposal system to provide adequate containment of radionuclides. Depending on the needs, the engineered barriers can vary from very simple ones to complex multiple barrier systems. The repository developer often has flexibility in selecting the optimal solution to address the specific performance requirements of the disposal facility that is being designed [26–36, 46–48, 86–91]. For example, it can be cost effective to dispose of very low level waste (VLLW) in near surface facilities with minimal engineering, especially in arid regions.

The major steps and activities in the design process are:

- Defining safety and design criteria;
- Establishing the design basis, for example the events and processes that require assessment;
- Acquiring and evaluating the input data;
- Developing the design;
- Estimating cost;
- Assessing the performance of different repository components and overall safety;
- Comparing elements of the detailed design with the design basis and criteria;
- Optimizing, reviewing and finalizing the design.

The design process for near surface disposal facilities has the following main objectives:

- Providing the integrity and structural stability of engineered barriers, backfill and covers;
- Preventing, minimizing and/or delaying contact of water with waste;
- Ensuring that drainage is adequate on the scale of both disposal units and the whole facility;
- Making adequate provisions for waste receipt and its storage, if required;
- Providing adequate defence against intrusion by humans and/or other organisms;
- Maintaining occupational exposures as low as reasonably achievable (ALARA);
- Minimizing non-radiological risks;
- Minimizing long term maintenance and other associated activities;
- Making provisions for monitoring of the facility and surrounding area;
- Providing an adequate buffer zone for monitoring and potential mitigation activities.

The main requirements for the development of a repository design are reliable design input data, competent designers and appropriate design tools. The design process is a stepwise iterative process, strongly linked to performance and environmental assessments (Section 6).

The iteration of the repository design process may generate, for example, the following results:

(a) Preliminary concept design plans (non-site-specific);
(b) Preliminary design plans (site specific);
(c) Preliminary safety analysis report (PSAR) to support the application for a construction permit;
(d) Final safety analysis report (FSAR) to support the application for an operating licence;
(e) Revision of the FSAR during operation of the repository in order to introduce the operational experience and findings from the R&D work in the field;
(f) Closure plan and safety assessment for the post-closure phase to support the application for the closure permit.

As the design process proceeds in an iterative manner alongside the safety and environmental assessment process, the design plans become more detailed, focused and optimized. In complex cases, there may be several design iterations so that the entire process may extend over a period of years, requiring ongoing collaboration with the generators of the input data, the safety assessors and the other participants in the repository development process. There may be a constant flow of information to the design groups, which is used for improvement of the design, as well as for the refinement of the performance/safety assessment.

During the design process, all regulatory requirements and features relevant to safety (both operational and long term), construction, operation, monitoring, maintenance, emergencies, QA, closure and post-closure issues need to be taken into account. This is also relevant to the various technical and performance features considered in the design. These features include, for example, compatibility of the engineered barriers with the other elements of the disposal system, both human made and natural, probabilities and consequences of potentially disruptive events such as human intrusion, flooding and strong earthquakes, prediction of degradation with time of barrier materials and possible modifications of leaching resistance of wastes and migration properties of radionuclides caused by physicochemical changes of the waste, the barrier materials and the transport fluid. The design has to provide the means to cope with the consequences of such changes as necessary.

In some countries (e.g. Belgium and Spain), the option to retrieve waste packages from the disposal facility is considered in the design process. Whether or not retrievability should be taken into account, it depends on the policy established in each Member State and on decisions made or regulations issued by the competent authorities.

Disposal of waste is defined as the emplacement of waste in an approved facility designed for disposal without the intention of retrieval. However, design features aimed at facilitating waste retrieval during a certain period of time could be advantageous, since the option of waste retrieval would provide a certain degree of flexibility that could facilitate both decision making and licensing. However, any design provisions taking waste retrieval into consideration should neither compromise the overall safety of the disposal system or cause undue burdens to the present generation or to future generations, nor be seen as a way of compensating for anticipated shortcomings. In any case, the issue of retrievability is not expected to have a significant impact on the design of most near surface disposal facilities as retrieval of the waste should be relatively straightforward as long as waste packages maintain their integrity.

4.5. WASTE ACCEPTANCE CRITERIA

The acceptance of waste at the disposal facility should take into account both radioactive and non-radioactive components and their associated hazards. Waste acceptance criteria are pre-determined specifications that establish requirements for the waste form and waste packages for disposal in a specific facility [7, 38, 40–42, 52, 54, 68]. They are established on the basis of the site and repository characteristics and, particularly in respect of the content of the radionuclides, the anticipated duration of institutional controls. In practice, the waste acceptance criteria need to be defined in such a way that the results of the safety assessment are consistent with the applicable safety targets (e.g. dose constraints). In a small number of cases, the waste acceptance criteria may be specific to a disposal unit or waste package rather than to the entire repository.

4.5.1. Radiological criteria

Radiological criteria for the protection of the workforce and the general public are established in national regulations, as discussed in Section 3. More detailed criteria for packaging and for repository design may be established directly by the regulatory authority or by the implementing organization, but subject to regulatory approval. These criteria should take account of normal operations and of accidental situations, including inadvertent human intrusion into the closed facility, and will encompass all phases of the repository life cycle.

For operational safety, package-specific activity concentrations are established for specific radionuclides or for groups of radionuclides, taking account of expected operating conditions and of potential accidents.

For post-closure safety, short lived LILW is waste that does not contain significant amounts of long lived radionuclides (i.e. with half-lives greater than 30 years [39]). Some Member States have specified upper bounds on the concentrations of long lived radionuclides that are acceptable for near surface disposal. In the IAEA classification of radioactive waste [38], concentration limits for long lived alpha emitters, based on practice in some countries [41], are quoted. The classification document also states that, in regard to the content of long lived radionuclides, a limit between short lived and long lived waste cannot be specified in a universal manner. In practice, admissible concentrations of long lived alpha and beta emitters, i.e. radionuclides that will not decay significantly during the period of institutional controls, need to be decided on a case by case basis, based on safety assessment. Limits for long lived radionuclides may be required for both the concentrations in the waste and in the total inventory in the repository [42].

The list of radionuclides commonly considered in post-closure safety assessments of near surface disposal facilities includes the following short and long lived radionuclides: ^{3}H, ^{14}C, ^{41}Ca, ^{59}Ni, ^{63}Ni, ^{90}Sr, ^{93}Zr, ^{94}Nb, ^{99}Tc, ^{129}I, ^{137}Cs, ^{151}Sm, ^{226}Ra, ^{228}Ra, ^{232}Th, ^{234}U, ^{235}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{241}Am [42]. In some cases ^{36}Cl and other long lived radionuclides are also considered.

4.5.2. Non-radiological criteria

Chemical, biological or radiolytic processes may take place within the waste or waste package, giving rise to the generation of gas [92–97] and/or heat, corrosion (with the accumulation of hazardous degradation products) and swelling of materials, depending on the characteristics of the waste.

Gas generation could be a potential problem if large volumes of metals and organic materials are disposed of. Potential gas generation issues should be addressed at an early stage in the development of a disposal concept and the design of the disposal units [97].

The disposal of materials that could present chemical or biological hazards has to comply with applicable regulations, and their properties need to be taken into account in safety assessments [7]. Besides the regulations addressing radiological safety, other existing regulations in relevant areas need to be taken into account. Reference [98] provides more detailed information on the management options for LILW with regard to its chemical toxicity. Concerning other hazardous components, it is necessary to develop specific waste acceptance criteria for the presence of such substances. These substances can include:

— Free aqueous liquids;
— Products which can react with the immobilizing material;
— Liquids which can be aggressive towards the waste package, its components and/or the disposal structures;
— Organic liquids, even if they are retained on absorbents (e.g. solvents, oils and paints);
— Products capable of reaction in a wet medium (sodium or sodium alloys);
— Explosives or products capable of strong exothermic reactions;
— Putrescible matter.

Physical criteria relating to waste packages may include:

— Weight, volume or dimension limits;
— Canister design features;
— Stress and corrosion resistance.

4.6. LICENSING AND AUTHORIZATION

The construction, operation and closure of a near surface repository must be subject to regulatory control, i.e. a site licence is issued before the start of construction, enabling the operator to perform the necessary construction activities [7]. Additional authorizations are generally required to proceed to the subsequent phases of the repository life cycle, particularly disposal operations and closure [7, 13]. In many Member States, the regulatory authority responsible for licensing nuclear operations is the same as that responsible for authorizing waste disposal, so that regulatory oversight is provided by a single national agency.

The detailed licensing procedure of a specific facility depends on the requirements and procedures adopted by the particular national programme. In most cases, the developer is required to apply for a licence before facility construction can begin. The application will be supported by a detailed safety case that assesses the level of potential radiation exposure to workers and the general public throughout the facility life cycle. The safety case should be regularly updated and, in particular, will normally be resubmitted to the regulator before operation and closure of the facility. It may also be necessary to resubmit the safety case at pre-determined intervals, for example, every five years. Reference [99] provides a structured format and content for the safety analysis report that makes up a substantial portion of the facility licence application. Reference [100] gives a specific example of a safety analysis report for licence applications prepared to meet specific licence requirements and illustrates the types of information and level of detail required in the application.

The licensing process can be described, in general terms, as follows:

(a) The developer (applicant) writes an application that addresses in a systematic manner the safety and environmental requirements of the regulations. The licence application must address all requirements of the regulations and must explicitly demonstrate that the proposed facility and proposed actions meet the regulatory requirements. The regulatory body may provide guidance on the format and content of the licence application.
(b) The licence application is submitted to the regulatory body for review and approval.
(c) The regulatory body may determine whether or not the licence application is complete before starting a detailed review. The detailed review will generate questions that require clarification by the applicant. The questions, with accompanying explanations of why they are being asked, are then submitted to the applicant for clarification.
(d) In an iterative process, the applicant will address all original and any subsequent questions until the regulatory body is satisfied that all licensing requirements are met or will be met by the proposed facility and actions.
(e) The regulatory body issues a licence that states the conditions under which the licensee may accept and dispose of waste.

4.7. REPOSITORY CONSTRUCTION

Following the issue of a site licence and approvals to proceed with construction, the facility will be built in accordance with the design plans included in the licensing documentation.

Typically, repository construction work involves the following activities:

— Site preparation;
— Additional geological/hydrogeological investigations and site monitoring;
— Construction of auxiliary buildings and structures, such as offices, and waste reception, inspection and repair or packaging facilities;
— Excavation and/or preparation of disposal units, including construction or emplacement of any associated engineered barriers;
— Installation of instrumentation for monitoring performance of the disposal system.

The extent and duration of construction work will depend on the type of facility, for example construction of rock cavity type repositories in hard rock may take several years. Construction of repositories on or near the surface will normally take a shorter time.

The construction of engineered barriers may influence the hydraulic conditions around the repository. Geochemical conditions may also be altered; for example, the use of cementitious materials may cause the pH to increase in the vicinity of disposal units in contact with groundwater.

Any design changes envisaged during construction require detailed assessment in regard to their impact on the safety or performance of the repository, and they are not to be implemented if they were to result in a decrease in the overall safety or performance of the facility.

During the construction, a QA programme that includes surveillance, testing and inspections needs to be adopted in order to ensure that the repository is built in accordance with the approved design.

Before the start of regular waste disposal activities, the repository is made operational in accordance with a startup (commissioning) plan. This includes a testing programme aimed at ensuring that the repository and the installed equipment, such as lifting gear, waste handling machines and any ventilation or drainage systems, function as required by the approved design specifications. One objective of the commissioning programme is to verify that the actual as-built parameter values are within the design range used in the safety assessment.

All information related to the construction process and quality controls are recorded and stored during the repository lifetime.

4.8. MONITORING AND SURVEILLANCE

The task of selecting a site for a near surface disposal facility necessarily requires the collection of large quantities of data on the potential sites being considered. Desk studies may be used for the initial identification of sites for detailed characterization. Site based activities normally involve the collection of data on the meteorological, hydrological and geological characteristics of the site. Monitoring and surveillance of existing disposal sites have provided valuable data on the performance of disposal facilities. References [22, 57, 101] provide examples and other necessary information on the development of overall monitoring strategies, taking account of all the stages of the repository life cycle.

The approval processes during repository development are highly dependent on data representing the undisturbed conditions at the potential repository site. During subsequent phases of development, monitoring activities will continue in order to establish the impact of repository development and, where necessary, compare this with initial predictions. A comprehensive monitoring plan is normally developed early during the pre-operational phase and revised, in particular, before the start of construction [57, 101], on the basis of the site characteristics and anticipated waste inventory. The monitoring plan may be modified, on the basis of any changes in facility operations or the results of performance assessment, for example, so that greater attention can be paid to those parameters which are important in repository safety.

5. OPERATIONAL AND POST-CLOSURE PHASES

5.1. INTRODUCTION

Following completion of construction and commissioning activities, the safety assessment is updated to take account of the 'as built' design and to reflect the results of any commissioning tests. The revised safety assessment report, sometimes termed the FSAR, forms the basis for the application to the regulatory authority for approval to operate the repository. Depending on the legal requirements of the country, it may be necessary also to submit a revised environmental statement to the appropriate authorities before proceeding with repository operation.

Waste handling and emplacement operations will be subject to ongoing inspection by the regulatory authorities, and it is normal practice that the regulators assess an updated safety case at regular intervals, for example, every five years. When emplacement operations have ceased, the operator will be required to seek approval to close the facility. This activity marks the end of the operational phase of the repository life cycle.

After repository closure, there will be a period of continued institutional controls during which regulatory oversight will continue. The duration of institutional controls, already referred to in the pre-operational phase as one of the key factors in establishing waste acceptance criteria, is reviewed at the time of closure on the basis of information on the waste in the repository and the results of the safety assessment submitted with the application for repository closure. In most Member States, an institutional controls period of the order of a few hundred years is considered reasonable.

5.2. WASTE RECEIPT AND EMPLACEMENT

The successful operation of a disposal facility depends on a number of specific factors related to the following:

- Submission of adequate information by the waste producer;
- Receipt of waste;
- Waste emplacement;
- Extension of repository and backfilling of completed sections;
- Surveillance and environmental monitoring;
- Emergency preparedness in the event of accident situations;
- Trained and competent staff;
- Implementation of a QA programme.

5.2.1. Receipt of waste

Prior to the receipt of waste for disposal, the repository operator should verify that the waste complies with the established waste acceptance requirements. This may involve audits of consignor arrangements, but could also be extended to include non-destructive measurements supported by sampling of the contents of selected waste packages. The operator will develop non-compliance procedures for dealing with the waste packages that do not meet waste acceptance requirements, for example due to their dose rate or levels of surface contamination being outside the established limits.

Records related to receipt of the waste must contain the following information:

- Origin of waste (waste generator);
- Waste package identification;
- Date of receipt and transport;
- Volume and weight of package;
- External radiation dose;
- Radionuclide activity and inventory;
- Waste canister properties;

— Description of waste package and conditioning matrix;
— Physical and chemical properties of waste form.

5.2.2. Waste emplacement

Emplacement comprises both the physical placement of waste in the repository and the subsequent management until that part of the repository is covered or sealed. Adequate controls are developed to ensure that workers follow safe operating procedures, including handling the waste in a manner that reduces exposures and the potential for accidents to a minimum, and that the waste is emplaced in a manner consistent with the licence. The controls will cover:

— Contamination and dose rate checks on external surfaces of the packages;
— Safe handling of the waste, taking into account the weight, size and radiation dose rate of the packages;
— Adequate storage arrangements if significant time elapses between waste acceptance and emplacement in the disposal units;
— Emplacement of the waste in the designated part of the repository.

5.2.3. Monitoring and surveillance during the operational phase

During operation of the repository, surveillance and environmental monitoring programmes are carried out to demonstrate that the repository is performing as designed with respect to impact on workers, members of the public and the environment, and is in compliance with the conditions of the licence. This requires the operator, for example, to carry out inspections of waste emplacement activities, monitor effluents, to assess workforce exposures and to operate a monitoring system on the site to detect any abnormal releases from the repository.

Environmental monitoring covers a broad range of media, including air, surface waters and groundwater, soils, flora and fauna. The broad nature of environmental monitoring provides early warning of release of contaminants. Data needs include:

(a) Information on systems to be inspected, for example:
  — repository cover and surroundings;
  — leachate collection system;
  — water runoff system;
  — site boundary;
  — markers;
  — monitoring devices.
(b) Information on systems to be monitored:

— repository leachate and drainage water;
— surface water;
— groundwater;
— air;
— soil;
— flora and fauna.

5.3. BACKFILLING OF COMPLETED REPOSITORY SECTIONS

All disposal units (trenches, pits, cavities, etc.) may be constructed in a single operation during the construction phase or, more commonly, additional disposal capacity may be added during repository operation. In the latter case, precautions must be taken to ensure that construction workers are protected from radiation hazards and that workers responsible for waste handling are protected from hazards arising from the construction activities.

Once a particular part of the repository is filled with waste to its capacity, it is normal practice that the voids around the waste packages and in the excavated area be filled with backfill material. In most near surface disposal facilities, the disposal units are exposed to meteoritic agents during disposal operations and backfill emplacement. In such cases, it may be necessary to protect the disposal unit with a temporary cover or seal to limit entry of rainwater as well as to provide radiation shielding.

5.4. EMERGENCY PREPAREDNESS

The extent of the inherent hazards in a disposal facility for short lived LILW will be small in comparison with those from most types of nuclear facilities. Nonetheless, as with all facilities dealing with significant amounts of radioactive material, provision must be made for dealing with unforeseen accident situations. This requires the analysis of accident scenarios and the development of emergency response plans, both on-site and off-site, aimed at mitigating potential consequences. The plans need to be approved by the regulatory body and periodically updated and exercised, if required by the operating licence.

5.5. CLOSURE

Closure of a repository comprises those operations necessary to convert the facility to a final form, such that, apart from monitoring and surveillance activities and controls to prevent intrusion into the facility, all active operations can cease.

Engineered barriers, in particular the final cover, are to be placed in a manner that will ensure integrity of the repository and provide the necessary hydrological containment and retardation of radionuclides, minimization of maintenance needs and protection against human intrusion, thus contributing to adequate performance of the overall isolation system. The human intrusion factor is particularly important for near surface facilities with shallow disposal units. For rock cavity facilities, the closure process includes sealing of engineered access routes such as shafts, drifts or other openings connecting the repository to the surface.

Closure is carried out in accordance with an approved closure plan, which includes an updated safety assessment and describes controls planned for the post-closure phase, the monitoring and surveillance programme and the record keeping system. The decision to use a particular closure option is based on the integration and analysis of all relevant information. The following factors are considered in developing a closure plan [55]:

— Regulatory requirements;
— Quality assurance;
— Waste inventory and characteristics;
— Site characteristics;
— Design;
— Operational experience;
— Societal requirements;
— Availability of materials;
— Availability of human and financial resources;
— Closure experience from other disposal facilities.

5.6. POST-CLOSURE PHASE

5.6.1. Institutional controls period

After closure, near surface disposal facilities are placed under institutional controls, ensuring the continuing safety of the public and protection of the environment until the level of inherent hazard in the waste diminishes to an insignificant level. At this point, institutional controls over the site can be discontinued.

The owner of the disposal facility during the institutional controls period has ultimate responsibility for ensuring safety and environmental protection. As discussed in Section 3.4, many Member States require that the facility be owned by a public organization, i.e. be government owned, during this period to provide the necessary continuity of responsibility. This ongoing responsibility of the owner will include:

— Implementation of the monitoring programme;
— Control of access to the facility;
— Implementation of corrective actions, if needed.

Although institutional controls will normally enhance repository safety, for example, by preventing inadvertent human intrusion, the repository operator may not rely on such controls to justify a reduction in the levels of isolation normally provided by the system of multiple barriers — waste form, waste container, backfill and capping materials. That is, care should be taken to minimize burdens placed on future generations [1]. It is a well established principle that the safety of a closed repository may not rely on institutional controls that necessitate extensive and continuing active measures [7]. For repositories located in rock cavities or larger confinement facilities (e.g. boreholes), several tens of metres below the earth's surface, the necessary extent of active institutional controls may be minimal or non-existent.

After closure of a disposal facility, the level of effort for maintenance and monitoring is expected to decline over time. However, if performance outside the predicted norm is encountered, the level of monitoring will need to be increased and, if necessary, mitigation measures planned and implemented.

5.6.2. Monitoring and surveillance during the post-closure phase

In accordance with the closure plan, environmental monitoring and surveillance programmes for the post-closure phase, dealing with inspection and monitoring of the site and its surroundings, are prepared by the repository operator and, if necessary, updated by the institution responsible for the implementation of controls after closure [55, 57, 101]. The content and duration of the programmes are specific to the local conditions and societal considerations. The programmes also take into consideration the results of monitoring programmes performed during the pre-operational and operational phases, involving air, water and soil or rock measurements. The necessary parameters and points to be monitored after repository closure are carefully selected on the basis of the evaluation of the information acquired earlier, to ensure that the site is monitored effectively without placing undue burdens on future generations.

In general, post-closure monitoring of a disposal facility serves several functions. It can provide an early warning of system malfunctions that might lead to unacceptable impacts on individuals and the environment. It can help to confirm the predicted performance of the disposal system. It can also play a role in providing confidence for stakeholders that the system is functioning appropriately. For example, infiltration through engineered covers may be monitored and compared with predicted values to assist in the validation of the models used.

The monitoring programme can be modified, where necessary, because of unexpected observations or changes in regulatory requirements. Satisfactory monitoring results over an extended period of time are probably an essential precursor to the discontinuation of institutional controls, depending on acceptable results having been achieved from the monitoring programme. Although the monitoring plan will be based on an assumed duration of the period of institutional controls, final decisions about discontinuing controls will be made by future generations, reflecting the state of knowledge and social considerations at that time. It is the responsibility of repository operators to ensure that the mechanism is in place to take this decision, in particular an adequate record of monitoring results should be maintained throughout the lifetime of the facility, including the post-closure phase.

5.6.3. Corrective actions

Over the lifetime of the repository, certain circumstances may require the operator to consider making improvements or taking corrective actions that may change the design or operation of the facility. These circumstances include:

- Changes to regulations;
- Unanticipated radionuclide releases;
- Procedural and design non-conformances;
- New scientific and technical developments.

The corrective actions can include:

(a) Natural remediation: mainly of relevance to those situations where leakage is minimal and contamination, even if untreated, does not pose a threat to humans and the environment.

(b) In situ corrective action:
   (i) Surface capping;
   (ii) Cut-off walls;
   (iii) Grout injection for engineered barriers.

(c) Waste stabilization:
   (i) In situ encapsulation: immobilization of contaminants by full encapsulation of the waste in a monolithic block, using cement grout;
   (ii) Compaction: provision of a more dense waste form that is less susceptible to leaching.

(d) Ex situ corrective actions: prevention of undesirable movement of a contaminant by changing hydraulic gradients. Ditches and drains can be used to intercept a contamination plume down gradient from a source. A pumping system may be needed where aquifers have become contaminated.

(e) Treatment of contaminated soils and vegetation: the experience gained with radioactive contamination has not been extensive and a programme of research and development may be required to ensure the efficiency of any proposed treatment for any specific waste disposal facility.

A more detailed discussion of corrective actions and relevant technologies is given in Ref. [102].

6. ASSESSMENT OF SAFETY AND ENVIRONMENTAL IMPACTS

Figure 1 shows that safety and environmental impacts need to be continuously and iteratively assessed during the pre-operational and operational phases of a repository in order to help support its development and implementation. Additional assessments may also be required in the post-closure phase to support particular decisions. The assessment methodologies used in each phase will be broadly similar. However, the degree of uncertainty inherent in the assessment will decrease as the programme matures and more input data become available, for example, from site monitoring and surveillance programmes, and more rigorous and comprehensive assessments will be expected by the regulatory body and other stakeholders.

A number of approaches and methodologies have been used to allow the assessment of impacts to be undertaken in a transparent, structured and well documented manner [8, 18, 20, 33, 35, 37, 46, 56, 103–118]. Examples and other issues relating to the assessment of impacts are discussed in Section 6.1 (safety impacts) and in Section 6.2 (socioeconomic and environmental impacts).

6.1. SAFETY IMPACTS

6.1.1. Types of assessment

A summary of the hierarchy of terms commonly used relating to the assessment of the safety impacts arising from the disposal of radioactive waste is given in Table I.

At the top of the hierarchy is the safety case. This uses the results from the safety and performance assessments of the repository and also presents other factors that are important for the assurance of safety such as the use of sound science and engineering, QA procedures, safety culture, multiple lines of reasoning, robustness and defence in depth, and institutional controls [119, 120].

At the next level, there are the performance and safety assessments. Performance assessment involves an analysis of the performance of a system or subsystem, followed by comparison of the results with appropriate performance criteria. In contrast, safety assessment is the analysis of the overall system and its impact, followed by comparison with appropriate safety criteria. The performance and safety assessments are, in turn, underpinned by performance and safety analyses (Table I). The results of a safety assessment can be presented in a way that provides reasonable assurance of the performance of individual system components. Thus, performance assessment can be viewed as an integral part of safety assessment.

Consideration can be given to radiological and non-radiological impacts arising in both the operational and post-closure periods of the disposal facility [42, 121].

TABLE I. HIERARCHY OF COMMONLY USED TERMS RELATING TO THE ASSESSMENT OF RADIOACTIVE WASTE DISPOSAL [118]

Safety case	
Includes performance and safety assessments. In addition, a full line of arguments and evidence that a sufficient set of processes have been analysed and appropriate models and data used; relevant overall measures of performance and safety are within acceptable ranges, allowing for uncertainties. More qualitative, parallel lines of evidence and reasoning may be also used to support results of the quantitative modelling and to indicate the overall safety of the system; e.g. that the disposal system does not rely solely on one component and the analysis does not rely overly on particular data or methods.	
Performance assessment	**Safety assessment**
Includes performance analysis. In addition, comparison of intermediate parameters with appropriate criteria set by regulation or design targets, for example maximum allowable temperatures, minimum groundwater travel time and contaminant release from a subsystem.	Includes safety analysis. In addition, testing of arguments that a sufficient subset of processes have been analysed, appropriate models and data used, plus comparison of calculated measures of overall performance to regulatory safety limits and targets.
Performance analysis	**Safety analysis**
Quantitative analysis of at least some subset of processes relevant to the behaviour of the disposal system and calculation of (at least) intermediate parameters of interest, for example thermal evolution, container lifetime and contaminant release from some subpart of the disposal system.	Quantitative analysis of the set of processes that have been identified as most relevant to the overall performance of the disposal system and calculation of a measure of overall performance relevant within the given national regulatory regime, for example individual dose to members of critical group and integrated total release of contaminants.

Indeed, it should be recognized that, following emplacement of the waste in the repository, releases of contaminants might occur even during the operational period. Such releases might result in impacts during both the operational and the post-closure periods.

6.1.2. Assessment purpose

The fundamental driving force for undertaking assessments of the safety of repository systems is the recognition that radioactive waste needs to be safely managed in a regulated manner, compatible with internationally agreed principles and standards [1, 2, 4, 7, 8, 13]. The objective of radioactive waste management is "to deal with radioactive waste in a manner that protects human health and the environment now and in the future without imposing undue burdens on future generations" [1]. This overall objective has led to the formulation of principles of radioactive waste management, which include requirements for the protection of human health, protection of the environment, protection beyond national borders, protection of future generations, the avoidance of undue burdens on future generations, development of an appropriate national legal framework, control of radioactive waste generation, management of interdependences and the safety of the facility. Thus, there is a fundamental need to assess whether any given disposal option will provide adequate protection of human health and the environment both now and in the future.

Depending on the stage of the implementation programme, assessments of safety can be undertaken at a generic/hypothetical level and a site specific level. The repository developer is responsible for undertaking the assessment, which will be subject to review by the regulatory authority. Peer review requirements for safety assessments are discussed in Section 7.2.

Generic/hypothetical assessments can be undertaken to help identify feasible disposal concepts (e.g. the disposal of disused radiation sources in boreholes [122]), or the choice of waste encapsulation technology so as not to prejudice the choice of the disposal option selected. For these generic studies, few data are likely to be available, since only an outline of the disposal concepts will be employed.

Site specific assessments can be undertaken throughout the life cycle of a disposal facility (Fig. 8), although they might not be required at every stage and the focus of the assessment might change (e.g. from site selection, to facility design to waste acceptance). Assessments can be updated and refined in the light of experience from earlier assessments, new field data obtained and increased understanding of the key processes. Thus, site specific assessments are seldom undertaken without some knowledge gained from previous assessments (see, e.g., Ref. [120]), and the safety assessment process must be seen as iterative.

As part of the licence application and approval process, a safety case usually has to be submitted by the waste disposal organization to the regulatory body for review. It

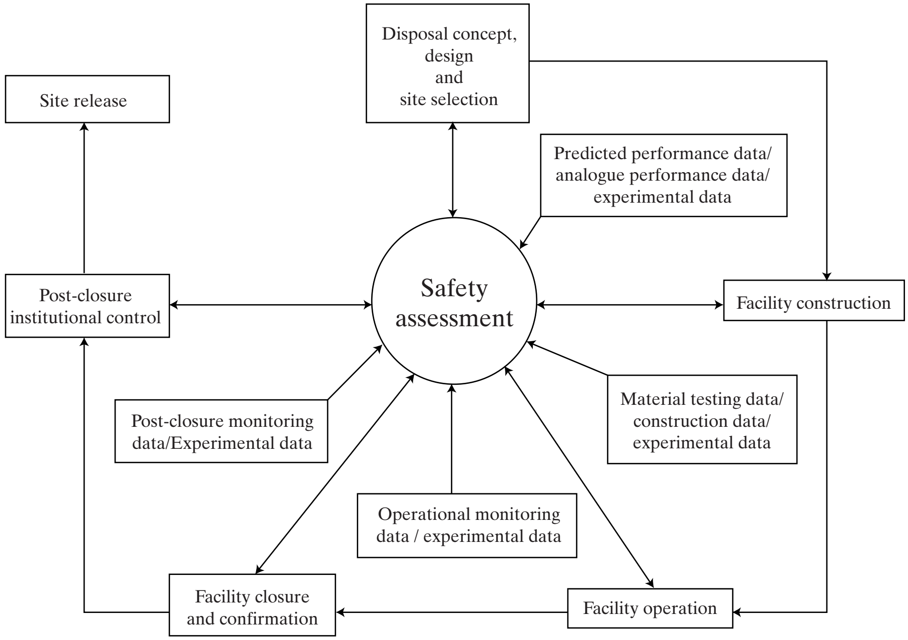

FIG. 8. Safety assessment and the life cycle of a radioactive waste disposal facility.

might also be presented to other stakeholders. Safety cases may be required at various stages in the licensing process, including approval to construct, operate and close the disposal facility, and whenever there are significant changes in the state of the facility or relevant legislation. The details depend on the legislation and other requirements and interests in the Member State where the disposal facility is or will be sited.

When the search starts for a disposal site, guidelines have to be set to limit the geographical areas considered, and these are generally based on a range of considerations such as geological, hydrogeological, geochemical, geomorphological and socioeconomic factors [7]. Potential sites have then to be identified and compared. In both these stages, safety assessments can play an important role, though post-closure safety of a disposal facility, once the safety targets can be shown to be achievable, has to be weighed against other considerations, such as ease of facility construction and transport of waste to the site, radiological and other risks during operation, and various socioeconomic factors. At this stage, although the safety assessments will be site specific, detailed geological and hydrogeological data may not yet be available for those sites. Examples include the assessments undertaken in the 1980s of four proposed low level radioactive waste disposal sites in the UK [123, 124].

When a particular site has been chosen for further investigation, safety assessments are an important input to site characterization and design of the disposal facility. Results from the assessments can help identify where additional data are required from the site characterization programme in order to be able to make the safety case more robust (see, e.g., Ref. [120]). In addition, the most cost effective improvements in disposal facility design can be determined through carrying out comparative assessments for various combinations of alternative waste packages, disposal modules and site management and closure measures. Assessments at this stage can also help identify and guide research needs. Various iterations of the assessments and continuous dialogue between the site characterization team, the disposal facility designers, research scientists and those carrying out the safety assessments are required.

The safety assessment can help to determine some of the principal controls and requirements on the disposal facility. For example, in establishing waste acceptance criteria for the disposal facility, the safety assessment can be used to determine requirements for waste packages and inventory levels, both for individual packages and for the site in total (see, e.g., Refs [125, 126]). The safety assessment can also be used in evaluating potential exposure pathways and in helping to establish and review the environmental monitoring programme for the site and the surrounding area. The safety assessment should be based on design(s) actually used or proposed for the disposal facility and the management of the site through the operational phase and the period of active institutional control, if established, after its closure [7].

6.1.3. Assessment methodologies

Various national and international activities [127–144] have been and are being currently undertaken to help develop approaches for safety assessment for radioactive waste disposal that are consistent, logical and comprehensive. In the particular context of deep disposal of HLW, examples include the PAGIS study of the European Commission [128] and the SITE-94 study of the Swedish Nuclear Power Inspectorate [136]. Whilst certain individual countries have developed similar formal approaches for the near surface disposal of LILW (see, e.g., Ref. [120] and certain papers in Ref. [33]), comparatively little effort had been focused on the development and application of safety assessment approaches for LILW disposal within international forums. However, in 1997 the IAEA launched a Co-ordinated Research Programme (CRP) on the Improvement of Safety Assessment Methodologies for Near Surface Waste Disposal Facilities (ISAM) [50]. The IAEA has also published a Safety Standards Series guide on safety assessment for near surface disposal of radioactive waste [8], reflecting the broad consensus on assessment methodologies that has developed internationally during the past two decades [103–118].

Whilst there are some differences in the details of the methodologies used for the evaluation of the safety of near surface disposal facilities, many of the more recent methodologies, such as those developed within ISAM, have identified the need to address the following key components (Fig. 9).

(1) *Specification of the assessment context.* The assessment context is intended to clarify what is going to be assessed and why it is going to be assessed. In addressing the assessment context, information is provided concerning the purpose, the audience, the regulatory framework, the assessment end-points, the assessment philosophy, the assessment time frames and the disposal system characteristics.

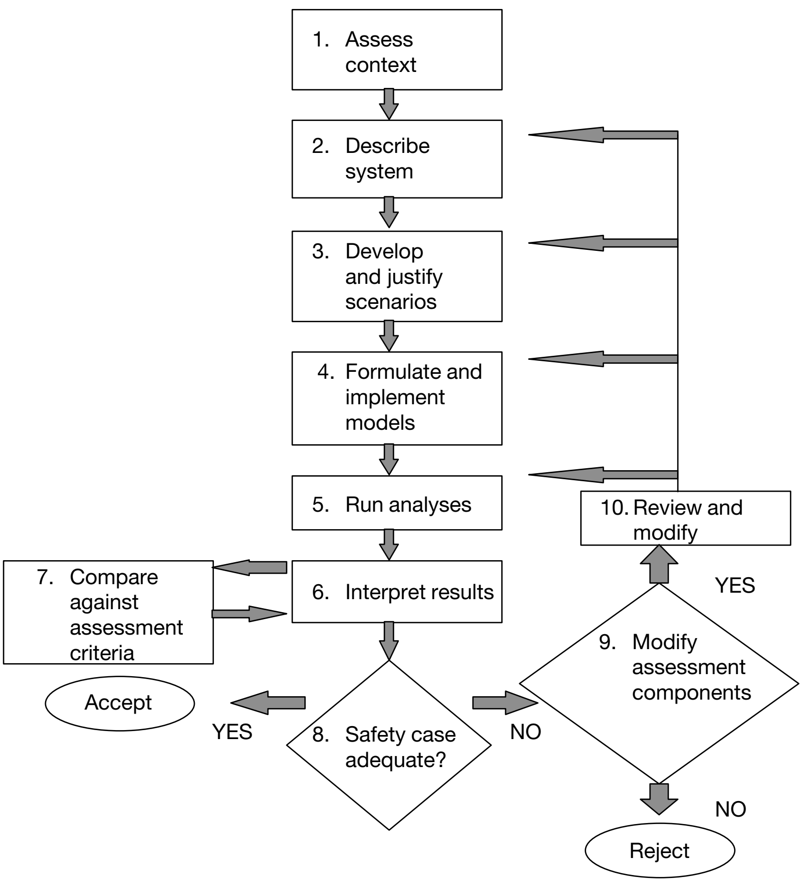

FIG. 9. The ISAM safety assessment methodology.

(2) *Description of the waste disposal system.* Information needs to be collated on: the near field (e.g. waste types, waste forms, waste inventory, disposal practices, engineered barriers and facility dimensions); the geosphere (e.g. lithology, hydrogeology and transport characteristics); the biosphere (e.g. exposure pathways, and human habits and behaviour). The limited availability or adequacy of data is an important factor in many safety assessments and hence when developing the system description, it is important to be aware of and to document the assumptions made and the associated uncertainties.
(3) *Development and justification of scenarios.* The performance of the disposal system under both present and future conditions should be evaluated. This means that many different factors must be taken into account and considered in a consistent way, often in the absence of quantitative data. This is often achieved through the formulation and analysis of a set of scenarios describing alternative future evolutions and conditions. The selected scenarios need to provide a comprehensive picture of the system and its possible evolution based on the assessment context and system description.
(4) *Formulation and development of models.* Once the scenarios have been developed, their consequences should be determined. First, a conceptual level model representing each scenario is established, which is then expressed in mathematical form. Solution of the mathematical models is usually achieved by developing one or more computer and appropriate input data.
(5) *Analysis of results and building of confidence.* Following the development of the scenarios and models, and their implementation in software tools, calculations can be undertaken to assess the impacts of the disposal facility. The results then need to be collated, analysed and presented. The results will have to be compared with criteria defined in terms of the specific assessment context. When analysing the results from an assessment, consideration should be given to various sources of uncertainty (e.g. scenario, model and data uncertainty). It is also important that the various stakeholders in the assessment have a reasonable degree of confidence in the results and the supporting assessment.

A more detailed description of these components is given in Refs [145–147], whilst their application to a series of test cases is described in Ref. [148].

6.2. SOCIOECONOMIC AND ENVIRONMENTAL IMPACTS

6.2.1. Introduction

A broad range of socioeconomic and environmental impacts may arise during the repository life cycle. The significance of these impacts will depend on considerations such as the existing land use, the location of the repository, the types and amounts of waste to be accepted, the specific repository technology selected, the number of workers employed and the proximity to populated areas. Potential impacts at the local, regional and national levels, including the topic of impact management, are described in a recent IAEA publication [44]. Socioeconomic and environmental issues, in the context of both near surface and geological disposal of radioactive waste, are discussed further in Refs [1, 21, 35, 56, 58, 63, 149–151].

Although the process of impact assessment is applicable to all facilities regardless of size, it will generally be the case that smaller repositories result in less significant environmental impacts, and the complexity of the assessment process will therefore be correspondingly less.

In many Member States, it is a requirement of national legislation that environmental impacts are assessed prior to the authorization to proceed with projects that have the potential to cause significant impacts on the environment. These cases would normally include near surface disposal facilities, and therefore a structured process of environmental assessment is generally a prerequisite for approval to proceed with repository development. As discussed in Section 4.3, environmental impact assessment also offers a means of comparing alternative candidate sites from the perspective of their level of environmental impact.

The main aim of environmental impact assessment is to identify potential impacts, assess their magnitude and, if potentially significant, to develop an impact management programme. This may be taken to mean a plan for the co-ordinated application of measures designed to mitigate, enhance, compensate, plan for contingencies, monitor and ensure continuing liaison with those interested in the programme [44]. An overview of the impact evaluation and management process is given in Fig. 10.

Following the granting of development consent, the relevant authorities will need to ensure that the provisions of the impact management programme are put properly into effect. Where the monitoring and surveillance programme indicates the potential for significant adverse impacts that are not included within the original assessment, additional impact management measures should be established to the satisfaction of the relevant authorities.

6.2.2. Management of socioeconomic and environmental impacts

The environmental impact assessment will consider impacts on the natural environment (e.g. ecologically sensitive areas); the built environment (e.g. the transportation network); social conditions (e.g. the community character); economic conditions (e.g. employment and labour supply); and land use (e.g. park and recreational lands). The level of potential impact experienced for an individual factor may be significantly greater in one life cycle phase than in another, with the greatest

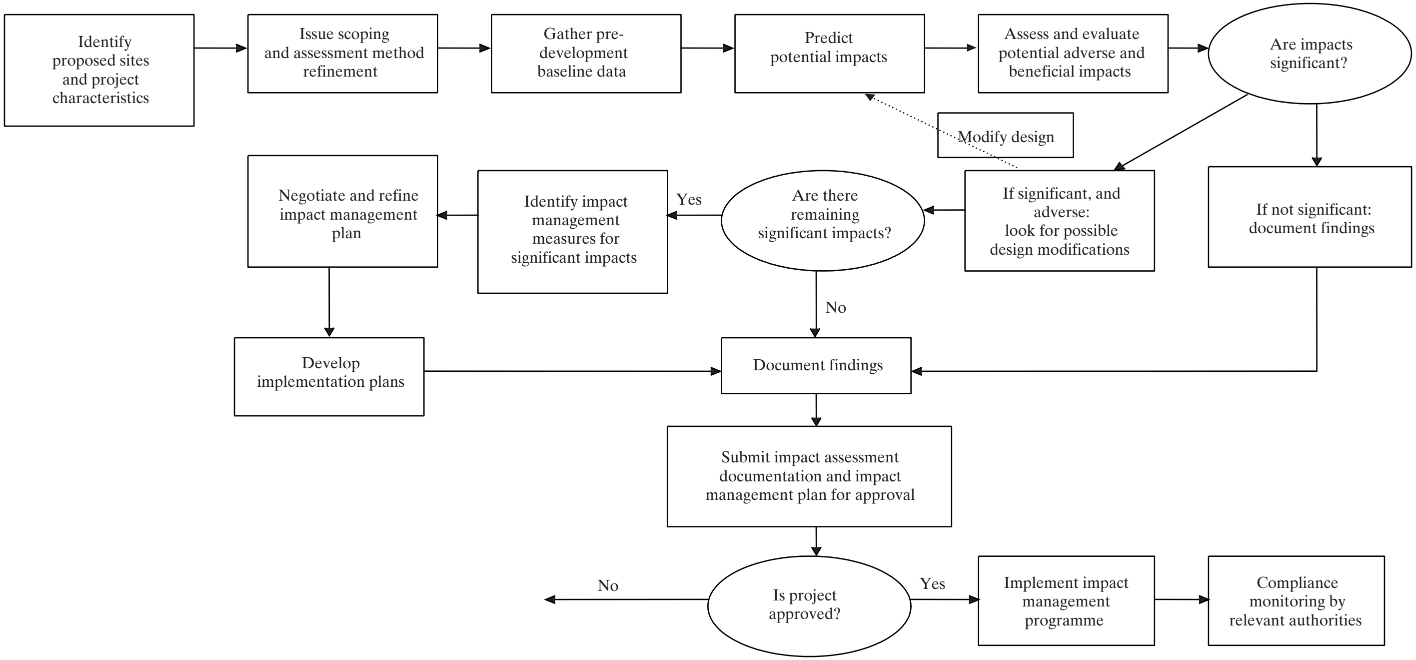

FIG. 10. Impact assessment and management process [44].

overall impacts being likely to occur during the construction, operation and closure phases.

A comprehensive listing of socioeconomic and environmental impacts is given in Ref. [44], together with examples of potential impact management measures. As mentioned above, the main relevant impacts will vary according to the specific project, though in most cases the impact assessment will include the negative impacts typical of a construction project and the impacts resulting from increased vehicle movements during construction and operation. Potential positive impacts include increased economic activity in the region.

Development of a waste disposal facility may place increased burdens on local services, for example emergency services. Also, in the event of a significant influx of workers from outside the locality of the repository there may be a need for additional housing and for educational and associated services. These aspects will require particular attention in the development of the impact management programme and it is likely that continuing close liaison between local authorities and the developer will be needed if such factors are to be addressed satisfactorily.

Impact management measures may be applied at different stages of the repository planning, siting and project approval phases. For example, candidate siting areas that have an impact on historical, cultural, ecological or archaeological sites, endangered biological species, or popular recreation areas may be excluded from further consideration by early application of the site screening criteria. Other impacts may be addressed following selection of a proposed site. For example, roads or utilities serving the site may require upgrading, or transportation routes through local communities may be avoided.

6.2.3. Environmental statement

The environmental impact assessment process, including development of measures to avoid, reduce or mitigate the predicted impacts is recorded in the environmental statement. In many Member States, it is a requirement of national legislation that this document be made widely available for comment before a decision is taken to proceed with development work at a proposed site. The decision making authority is then required to take account of public comments before deciding whether to give consent to allow development work to proceed. This issue is discussed further in Section 7.

7. ESTABLISHING CONFIDENCE

Establishing confidence in the repository development programme is an important consideration at all stages of the repository life cycle. It is particularly important that all stakeholders (e.g. government, regulatory bodies, public and technical/scientific personnel) should have confidence in the repository programme. Thus, it is important to develop confidence not only in the technical elements programme, with stakeholders such as the regulatory body, but also in the programme taking account of societal considerations.

A variety of measures can be used to help establish confidence [58, 146, 152–161]. These include:

(a) Application of a systematic approach to the repository development programme and its associated steps;
(b) Peer review of the programme as well as of its individual steps;
(c) Demonstration of the robustness of particular aspects of the programme, for example the site, design and safety case;
(d) Identification and management of uncertainties;
(e) Application of QA procedures throughout the programme;
(f) Documentation of the repository development programme, and the preservation and availability of the associated documents;
(g) Involvement of the public in decisions relating to the programme;

Each of these is discussed below.

7.1. APPLICATION OF A SYSTEMATIC APPROACH

A key component for establishing confidence in a repository development programme is the use of a systematic approach. The approach should have a number of confidence enhancing measures. In particular, it should:

(a) Ensure that each stage of the process, and the associated decisions made at each stage, are appropriately and clearly documented;
(b) Be rigorous, transparent and be based on methods that are scientifically and technically justifiable;
(c) Allow multiple lines of reasoning (i.e. a diversity of arguments) to be used;
(d) Allow iteration so that repository plans can be implemented in a stepwise manner with due consideration being taken of all key factors.

Figure 1, which has been developed for the purposes of this report, shows the systematic approach for establishing a repository. It is considered that following this approach (or one similar) will help to establish confidence in the repository development programme. In addition to applying a systematic approach to the overall programme, such an approach can be used for particular stages or aspects of repository development, for example the safety assessment (Fig. 9) and the site selection process.

7.2. PEER REVIEW

Peer review is an important activity that can be used to achieve scientific and technical confidence in the approaches, methods, data and decisions made in the development of a disposal facility [153]. Therefore, many radioactive waste management programmes include provisions for periodic and systematic reviews and for detailed scrutiny by other national and international experts active in the same field for important plans and documents related to the repository siting, design, construction, operation, closure and post-closure safety (see, e.g., Ref. [154]). Special peer review and advisory groups and/or task forces may be established to examine special features of the programme. The regulatory body may use independent experts such as peer reviewers or independent review bodies, which make use of their combined expertise, in order to strengthen the safety case (see, e.g. Ref. [155]).

7.3. DEMONSTRATION OF ROBUSTNESS

It is important that the siting and design of a repository provide sufficient isolation of the waste from human beings and other biota and thereby provide the required assurance of the safe disposal of the waste. Thus, when developing a repository, it is important to demonstrate the robustness of the site and design and the supporting safety case.

Safety assessment (Section 6.1) can have a key role in the demonstration of the site and of the design robustness through the provision of a basis for rational and technically sound decisions relating to their safety. Further confidence can be developed in the design through the use of multiple barriers (engineered and natural) for which it is possible to show that the system performance can remain satisfactory even if one of the barriers fails to function as expected. Additionally, field tests and monitoring can be undertaken to demonstrate the appropriate performance of the barriers. Operational monitoring data can be used to confirm that the facility and its different components perform according to the design objectives. Post-closure monitoring makes it possible to detect any unacceptable radiological impact and provides confirmation of the systems performance.

Some uncertainties, for example those associated with the long term degradation of the engineered barriers, are unavoidable. To accommodate such uncertainties the repository design may incorporate some degree of conservatism, for example the use of thicker barriers. Such designs are generally more costly, and so a balance will need to be struck between the increased costs and the increased safety.

Confidence in the isolation of the waste may be further enhanced by demonstrating the robustness of the safety case. A manifestly conservative assessment demonstrating conformity with regulatory requirements could be regarded as being robust. In addition, multiple lines of reasoning could be used within the safety case. Multiple lines of reasoning are a set of complementary arguments that use different approaches or sources of evidence to build confidence in assessments [113, 152]. Both qualitative and quantitative lines of reasoning can be used, including scoping and bounding calculations, natural analogues, a variety of safety indicators (not just dose and/or risk), and comparisons with other assessments [7, 8, 110, 142–144, 161].

7.4. IDENTIFICATION AND MANAGEMENT OF UNCERTAINTIES

Although repository development is an iterative process that is supposed to evolve continually, it is unavoidable that a number of uncertainties with respect to the behaviour of some components or of the system as a whole will still remain at each step in the repository life cycle. Uncertainties do not only apply to technical aspects but also to non-technical issues, such as societal or economic changes. Dealing with uncertainties is an important issue that should be brought to the attention of not only scientists but also other stakeholders such as regulatory bodies and the public [113].

Uncertainties in safety assessments can be considered to arise from three interlinked sources [8, 113]:

(a) Uncertainty in the evolution of the disposal system over the timescales of interest;
(b) Uncertainty in the conceptual, mathematical and computer models used to simulate the behaviour and evolution of the disposal system (e.g. owing to the inability of models to represent the system completely, approximations used in solving the model equations and coding errors);
(c) Uncertainty in the data and parameters used as inputs in the modelling.

In addition, a recent IAEA publication [147] suggests that a further type of uncertainty, subjective uncertainty (uncertainty due to reliance on expert judgement), is also linked with the above sources of uncertainty.

In order to build confidence to assist the decision making process, it is important that these uncertainties are identified and managed appropriately. It is impossible to guarantee with any absolute certainty that the 'correct' decision has been taken. However, the probability of making an appropriate decision can be improved by identifying and managing the uncertainties.

The management of uncertainties has four main components [156]:

(1) *Awareness.* The approach used should seek to identify all major potential sources of uncertainty.
(2) *Importance.* The safety case may be sensitive to some uncertainties, whilst many others are unimportant. Before attempting to reduce uncertainties, it is first necessary to determine whether the uncertainty has a significant effect on the overall outcome of the safety case. This can involve the use of scoping calculations and sensitivity analysis.
(3) *Reduction.* Having ascertained the importance of particular uncertainties, measures such as the collection of further site data can then be undertaken to reduce them.
(4) *Quantification.* The effect of uncertainties on the final safety assessment needs to be quantified using uncertainty analysis. Some uncertainties are more difficult to quantify than others, but an attempt should be made to quantify the most important uncertainties.

7.5. APPLICATION OF QUALITY ASSURANCE PROCEDURES

An important contribution to building confidence in a repository safety case arises from the application of a QA programme. A well designed and maintained QA programme is important for developing a disposal facility. The programme should consist of a planned and systematic set of procedures to document the various steps in a process and to provide confidence that the results of the process are of good quality [7]. It should provide a framework in which activities are performed and recorded, attesting to compliance with the procedures. The content of a QA programme that covers all activities related to the disposal of radioactive waste, from planning through siting, design, construction, operation and closure, including also the various steps in the safety assessment process and institutional control activities associated with the repository, is described in detail in Refs [157–159]. The nature and extent of QA required will differ from phase to phase and at different steps within each phase.

A major factor, distinguishing the repository projects from other nuclear projects, is the long timescales in question. The need to generate confidence in the long term safety requires that QA procedures be applied to the various elements of the assessments, in particular to data acquisition, design activities, development of models and methods of calculation, from the earliest stage. It also provides for the documentation necessary to demonstrate that the required quality standards have been achieved for all relevant assumptions made in the safety case (Section 7.6). In this way, it can be shown that reliable and traceable techniques and sources of information have been used, enhancing confidence in the results of the safety assessment.

As part of the overall QA programme, there can be specific procedures relating to particular aspects of the repository development programme. For example, procedures should be developed to ensure that the repository is constructed in conformance with the approved design. This is a major prerequisite of the construction process. The approved QA programme includes, for example, provisions for construction procedures, a comprehensive training programme, testing, inspections and records control, to ensure conformance of the as-built repository to the specified and approved requirements. The resulting information will form the basis for the commissioning of the repository and authorization to proceed with operations.

7.6. DOCUMENTATION AND MAINTENANCE OF RECORDS

The need to generate confidence in the safety of LILW disposal requires that all the activities in development, operation and closure of near surface disposal facilities be adequately documented. Records will include documents with safety implications such as design and construction documentation, operating records, radionuclide inventories, closure data and the QA programme. This information may be supported by a variety of other records and regulations including site investigation and monitoring data, laws and criteria governing waste disposal, licensing documentation, safety assessment results and land use controls.

The implementation process requires the development of a logical chain of arguments and its presentation in a manner that can be understood by everyone who will have an influence on the process. This requires the work to be presented using a variety of techniques appropriate to the various stakeholders. Thus, it is important to ensure that the work is presented in an understandable manner to meet the needs of the relevant stakeholders.

Project records must be maintained in a manner consistent with regulatory and other applicable requirements. For example, the records need to be stored in a suitable form in a safe place and protected, in particular, from fire, flood and theft. With regard to the technical and administrative challenge of long term record keeping, it may be beneficial to participate in international co-operation activities for maintaining records. In this way, improving the technical means and duplicating information at more than one location would provide the best chance for long term conservation. Record management is discussed in Ref. [160] and should be specified in the QA programme for the project (Section 7.5).

7.7. PUBLIC INVOLVEMENT

7.7.1. Public involvement in repository decision making

The development of a near surface disposal facility involves a number of sequential steps as discussed in Section 2 of this report, occurring over a time frame of several decades. For many of these steps, explicit approvals are required from national authorities, including regulators, before proceeding to the succeeding step. For example, selection of a preferred site for development will normally be subject to consent by the authorities responsible for land use planning. In some cases, the government or legislature of the Member State will approve the selected site, usually subject to appropriate subsequent approvals being obtained from the authorities responsible for nuclear safety and environmental protection. In a small number of cases (e.g. Switzerland, Sweden and Finland), there is direct participation of the public in decision making about site selection through the use of referenda.

Regulatory approvals are usually required before the start of construction of the facility, for receipt of waste packages and for closure of the facility. Ultimately, when safety risks have diminished to insignificant levels, the site will no longer be subject to regulatory or any other institutional controls.

The extent to which the public becomes involved in decisions relating to the development of a disposal facility varies among Member States, depending on the legal framework and cultural context. Nonetheless, recent experience suggests that early involvement of the public in the decision making processes will enhance the likelihood of project approval [44, 56, 58, 161].

Those interested in repository development may include representatives from local communities, administrative units (e.g. national, regional and local), government officials, regulatory agencies, community and public interest groups, environmental organizations, industry and trade groups, the scientific community and the news media. In some Member States, committees representing a range of local community interests (e.g. local government, schools, business and environmental groups and interested citizens) have been involved in different stages of the repository life cycle.

An important element in developing public acceptance is the level of public trust in the institutions involved in the repository development process, particularly in the development organization and the regulatory agencies. Establishing trust will be enhanced when opportunities for involvement are provided from the beginning of the planning process. In this way, individuals or organizations that are interested in the project can express their views and have access to information on the basis for decisions, including how public comments have been considered and addressed. Public involvement will be enhanced when project information is made available at different levels of detail so that key issues are not obscured by large quantities of detailed information. Detailed scientific information should be made available to those who wish to see it. By use of the Internet, it is now possible to present information in formats that meet both the above objectives.

7.7.2. Facilitating public involvement

Formal public involvement mechanisms, such as public hearings or written submissions, may be part of the regulatory approval and environmental impact review processes. To facilitate this information exchange and the public comment and response process, some Member States make independent information available to participating individuals and groups. In some cases, this has involved the participation of independent experts to review documents and data provided by the repository developer.

The process of environmental impact assessment can provide a framework for early public involvement [56]. In this case, the public may be encouraged to comment on the impacts intended for consideration in the assessment. Subsequently, public comment should be invited on the environmental statement submitted to the relevant national authorities and these comments should be considered before a decision is made. In any event, it will usually be helpful if specialists involved in the project, including regulators, are involved directly in public discussions. The aim of such discussions should not simply be to provide information about the project, but rather to obtain input in order that public views can be considered in the ongoing planning and design process.

During the siting phase, interest will be focused on the communities located nearest to the proposed site as well as communities which border that location and those along likely transport routes. In some Member States, local committees have been established to help in providing inputs to the repository planning process and, subsequently, to monitor implementation of mitigation measures and related repository operations and to serve as an information source to interested parties. For example, in Belgium, public participation is ensured by the various relevant topics being discussed in working groups composed of volunteers who represent the local population.

The approach adopted for site selection will itself have an impact on the nature and extent of public involvement. For example, some Member States have, at the outset, invited statements of interest from local communities regarding potential repository siting and development in their area (volunteerism). Others have sought input from local communities on the suitability of potential sites already identified through the application of site screening criteria. The optimal approach will be specific to the individual Member State.

A variety of ways may be used to make information available to interested organizations, including publications, leaflets, CD-ROMs, video cassettes, press conferences, media releases, panels, presentations and discussions. Some Member States have established visitor centres to facilitate greater public access to details about a project. The Internet is becoming increasingly important as a medium for making information available in easily accessible form. It may also be used as a tool for obtaining feedback from stakeholders, though care needs to be exercised in order that non-Internet users are not excluded from participation.

8. SUMMARY AND CONCLUSIONS

This report presents an integrated, step-wise approach for the development, operation and closure of near surface disposal facilities for low and intermediate level radioactive waste. It has been developed in the light of the considerable experience that has been accumulated in the development of such disposal systems and is consistent with the current international requirements, principles, standards and guidance for the disposal of radioactive waste. It is considered that the systematic application of the various steps of the approach can contribute to the successful development of a repository programme.

The approach is systematic and integrates the technical, economic, social, legal, organizational and administrative factors that need to be considered when developing a near surface disposal facility. These technical and non-technical factors have been summarized in this report and their importance at each stage of a repository development programme discussed. Relevant IAEA publications covering specific issues, such as regulatory requirements, siting, design, construction, operation and closure of a disposal facility, performance and safety assessments, surveillance and monitoring, and QA procedures and requirements, are referenced to provide further details on the specific activities and components that constitute the repository development process.

The approach is designed to be generic, flexible and suitable for use in the various Member States, ranging from countries that have NPPs to countries that have small inventories of radioactive waste from nuclear applications. Because it considers the complete life cycle of a repository, the approach is relevant to all near surface repository programmes in Member States, be they in the early planning stages or in a relatively mature operational or even post-closure phase. The development of each step in the approach is determined by a series of factors which are identified and discussed in this report. While some of these factors are likely to be broadly similar in many Member States, for example the national policy and legal framework, and the scientific and technical basis, other factors may be very different, for example the waste inventory, site characteristics, socioeconomic conditions or the involvement of stakeholders. Therefore, when applying the approach, it is recommended that Member States should do so with full consideration of the influence of these case-specific factors.

The speed and specific details of each step in the development process will vary depending on the relative importance of these factors. For example, progress in the development of a repository within a country with a well established radioactive waste management framework and a well characterized waste inventory can be expected to be more rapid than one in which the framework and inventory are less well developed. Similarly, progress in a country with a small volume of radioactive waste derived from use in industry and hospitals can be expected to be more rapid than in one with large volumes arising from a diverse range of sources since the level of complexity required in all aspects of the repository development and implementation programme is likely to be less. However, irrespective of the nature and importance of such case-specific factors, it is still considered important that the basic sequence of steps in the approach described in this report will be applicable to each case.

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Consultants Meetings

Vienna, Austria: 10–14 April 2000, 24–28 June 2002

Technical Committee Meeting

Vienna, Austria: 29 October – 2 November 2001