IAEA TECDOC SERIES

IAEA-TECDOC-1755

IAEA-TECDOC-1755

Planning and Design Considerations for Geological Repository Programmes of Radioactive Waste

IAEA

International Atomic Energy Agency

PLANNING AND DESIGN CONSIDERATIONS FOR GEOLOGICAL REPOSITORY PROGRAMMES OF RADIOACTIVE WASTE

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHAMAS
BAHRAIN
BANGLADESH
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BRUNEI DARUSSALAM
BULGARIA
BURKINA FASO
BURUNDI
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
CONGO
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GEORGIA
GERMANY
GHANA
GREECE
GUATEMALA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA, ISLAMIC REPUBLIC OF
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAN MARINO
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWAZILAND
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
THE FORMER YUGOSLAV REPUBLIC OF MACEDONIA
TOGO
TRINIDAD AND TOBAGO
TUNISIA
TURKEY
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VENEZUELA, BOLIVARIAN REPUBLIC OF
VIET NAM
YEMEN
ZAMBIA
ZIMBABWE

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

IAEA-TECDOC-1755

PLANNING AND DESIGN CONSIDERATIONS FOR GEOLOGICAL REPOSITORY PROGRAMMES OF RADIOACTIVE WASTE

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2014

COPYRIGHT NOTICE

For further information on this publication, please contact:

Waste Technology Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Email: Official.Mail@iaea.org

Printed by the IAEA in Austria
November 2014

IAEA Library Cataloguing in Publication Data

Planning and design considerations for geological repository programmes of radioactive waste. — Vienna : International Atomic Energy Agency, 2014.
p. ; 30 cm. — (IAEA-TECDOC series, ISSN 1011–4289 ; no. 1755)
ISBN 978–92–0–109914–3
Includes bibliographical references.

1. Radioactive waste disposal in the ground. 2.Radioactive waste repositories. 3. Radioactive waste management. I. International Atomic Energy Agency. II. Series.

IAEAL 14–00940

FOREWORD

One of the IAEA's statutory objectives is to "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world." This includes addressing the management of radioactive waste generated through the use of atomic energy.

Disposal in a geological repository is the generally accepted solution for the long term management of high level and long lived radioactive waste. It also represents the most developed option, in line with the general principles defined in the Safety Fundamentals, a publication category of the IAEA Safety Standards Series, and with the principle of sustainability. Overall, adequate scientific and technical bases for ensuring the safe disposal of such waste are considered to be available. For practical reasons, it also applies in some cases to low and intermediate level waste.

The development of a geological repository is a long process, divided in different stages and based on a stepwise approach. Achieving progress in many disposal programmes is difficult, owing to institutional, administrative and economical aspects, reticence among decision makers to deal with controversial issues and the opposition of stakeholders. The experience of Member States has so far indicated that technical and safety aspects, together with institutional framework and stakeholder involvement issues, currently require several decades from the first conceptual and siting studies up to the effective operation of a repository. In addition to the assessment of the performance of the disposal system, which is an iterative process by nature, the application of reversibility to the decision making process can also add to the total duration of programme development.

The long periods involved in any repository development programme mean that a provision and commitment need to be made to long term data gathering, the wide transmission of knowledge and sustained expertise. This also requires the development of a quality management system and knowledge management that cover all aspects of repository development. The objective of planning is to account for factors affecting the future success of a project, and hence an informed planning basis is particularly relevant to the numerous, lengthy and uncertain issues regarding geological disposal programmes. Given the potentially long time frames involved, planning should ideally consider all elements which could affect programme implementation. This includes the effect of evolving or emerging requirements or drivers, which can be difficult to fully anticipate or assess.

This publication is aimed at providing the collective experience of some Member States with more advanced repository programmes on the manner a geological repository programme may be defined and planned, for the benefit of Member States contemplating or initiating their own programmes as well as Member States interested in improving their own programmes at different development stages. Special attention has been considered to aspects having an impact on timing, including the assessment of safety.

The IAEA wishes to thank all those involved in the preparation and review of this publication. The IAEA officers responsible for this publication were B. Neerdael and P. Degnan of the Division of Nuclear Fuel Cycle and Waste Technology.

CONTENTS

SUMMARY

The design and commissioning of a geological repository for solid radioactive waste is a complex undertaking that will require considerable resources, both in terms of manpower and time. Such programmes also lie at the interface between science and engineering technology and socio-political concerns. As such, repository development programmes require detailed planning, significant amounts of financing and the support and confidence of politicians, the general public and other stakeholders. This document provides guidance to interested Member States on how to plan, implement or improve their national approaches for developing programmes for geological repositories in the light of such complexities.

Although there is only one currently operational deep geological disposal facility in existence, the WIPP facility in New Mexico USA, over the past several decades many Member States have developed significant expertise and experience in managing the pre-operational stages of disposal programmes. Some of these advanced programmes have moved forward slowly but surely, whilst others have received setbacks. At the present time there is now a wide spectrum of programmes, in terms of their advancement towards operations, and based on this growing body of experience a well-structured and graded stepwise decision making approach is advocated to engender broad scale support for implementation. Consequently, several key phases are recognized in a repository development programme and these can be used as a basis to support planning and design. The recognized phases and their associated major activities are:

- Phase 1: Site evaluation and site selection;
- Phase 2: Site characterization;
- Phase 3: Facility construction;
- Phase 4: Facility operation and closure;
- Phase 5: Post-closure.

Milestone decision points are associated with the conclusion of each of the first four phases and these will generally be reflected in the provision of appropriate authorizations and approvals from Government. Although certain phases may be carried out partially in parallel, for example waste emplacement may commence while the construction of additional vaults is underway elsewhere, the implementing organizations will require authorizations in order to progress to the next phase.

In designing, planning and assessing the progress of a deep geological repository programme, responsible managers need to be aware of some key inputs. These inputs include knowledge of the waste inventory, knowledge about the natural environment, recognition of the various design options for the engineered systems, approaches towards stakeholder engagement and familiarity with the relevant regulatory and legal framework. The nature and content of these inputs may evolve to a greater or lesser degree over the long time scales that need to be considered in a geological repository development programme.

Inventory characteristics which need to be determined include key radionuclides, physical and chemical characteristics, heat generation and activity to allow designs of packaging (e.g. shielding), handling procedure and the overall disposal geometry.

The description of the natural system includes the features, events and processes (FEPs) that will or may impact on repository safety and design. An appropriate natural system description must include information about e.g. host rock properties, hydrogeological and geochemical properties, seismic and volcanic hazards, meteorological and other surface environment conditions. These factors relate to long term safety considerations and may influence the siting process as well as programme implementation.

The knowledge required for consideration of repository design options will result in preferences around engineered elements such as the use of access tunnels and shafts, emplacement mechanisms and emplacement geometry (vaults or boreholes), facility layout, the use of engineered barriers, etc.

Some of the processes for stakeholder involvement at the local, regional and national levels may be directly dictated by national policy and regulation, otherwise, learning from the experiences of advanced programmes indicates that gathering stakeholder support and acceptance requires stakeholder involvement at all stages of the programme.

Legal and governmental infrastructures, together with an institutional framework of policies, laws, and regulations for the safe disposal of radioactive waste, are prerequisites for successful planning and design.

The implementation of a repository development programme requires that certain activities are carried out during each of the identified phases. The process of site evaluation and selection can be applied in many different ways and although evaluation of the natural system is fundamental to the process, siting involves more than just geological surveys as it also requires detailed consideration of socio-political factors. Regardless of the path taken, the goal of this stage is to identify a site (or sites) that have the potential for providing favourable geological conditions for isolation of the waste inventory, the potential constructability of the disposal design concept, and the potential for sustained stakeholder acceptance.

The site characterization phase involves the detailed geo-scientific investigation of the natural system, at a level sufficient to confirm the continued suitability of a site. During this phase, the implementer will also be expected to progress from general repository designs to a more detailed level of engineering solutions that take account of the specifics of a site and a detailed waste inventory. Furthermore, the post-closure safety case and safety assessment approach should now also incorporate site specific details regarding FEPs. Naturally, the development, submission and acceptance of a safety case are required to conclude this phase, in advance of construction and operations.

The construction of a repository will likely be best accomplished through the use of proven technology and experience from the mining and tunnelling industry. Many options are available and will need to be assessed, dependant on the natural system and national circumstances. During construction there will be further opportunities for site characterization and, in particular, to monitor the rock/groundwater response to the progressive excavation. The initiation of disposal operations will commence after construction of the repository (or after construction of the first phase of the repository) and only after a license to operate is issued by the regulatory body.

The facility operations phase is characterized by on-going disposal operations with the transportation of waste to the facility and the movement from surface storage to the underground disposal facility. Construction work may continue in parallel with waste emplacement, and monitoring of the natural environment will be expected. At some future point, the decision can be made to close the facility and it is expected that approvals based on the submission of a final post-closure safety case and safety assessment, and a post-closure monitoring programme will be necessary to support that decision.

There are specific lessons that have been learnt concerning each of the first four phases of a repository development programme, as identified here and based on the experiences of advanced disposal programmes. These lessons provide the possibility to either reduce the duration of the overall programme or avoid early termination of the programme.

1. INTRODUCTION

1.1. BACKGROUND

Geological disposal refers to the disposal of solid radioactive waste in a facility located underground in a stable geological formation to provide passive long-term isolation of the radionuclides from the biosphere. Disposal means that there is no intention to retrieve the waste, although such a possibility is not ruled out. Geological disposal is a method for disposing of the more hazardous types of radioactive waste including heat generating and long lived waste, and spent nuclear fuels. The defining characteristic of the waste concerned is that it poses a significant radiological hazard for times well in excess of those for which site surveillance and maintenance can be guaranteed reasonably, if it were to remain in surface or near surface facilities.

Both positive and negative experiences associated with the development of repositories may help in elaborating the necessary guidance to interested countries on how to outline, implement or improve their national approaches when integrating all aspects for geological repositories. Given the potentially long time frames involved in developing geological repositories, planning should endeavour to consider all elements which could affect programme implementation.

A workshop on "*Planning and design of geological repositories*" was convened at the Agency Headquarters in Vienna from 25 to 27 September 2006. The workshop collected updated information and specific needs from Member States regarding the planning and design of geological repositories. Subsequent to the workshop, further consultancies and a technical meeting contributed to this report and it was considered necessary to place increased stress on the design of the programme and its milestones rather than on the concept of the repository.

Building and operating a geological repository for high level and/or long lived radioactive waste is a quite unique development for which there are almost no precedents and past experiences. At the time of writing, only one such geological repository[1] has been commissioned, the Waste Isolation Pilot Plant (WIPP) in USA. There is of course not yet any practical experience on how to close such disposal facilities.

The present report is thus based on lessons learned from advanced geological disposal programmes, currently at different stages in their development:

Operation:

- USA where the Waste Isolation Pilot Plant (WIPP) in Carlsbad, New Mexico has been in operation since 1998 for the disposal of defence-related, transuranic waste (TRU) with negligible heat generation;

Preparation of construction license applications and site confirmation:

---

[1] Another geological repository, Morsleben (Germany), was in operation from 1971 to 1998 in the abandoned salt mine for low and intermediate level waste and is currently being decommissioned with public participation.

- Finland where an underground characterization facility is being constructed at the Olkiluoto site since June 2004 and a construction licence for a spent fuel disposal facility in crystalline rocks is to be submitted by the end of 2012;
- Sweden where after several years of investigations Forsmark has been selected as a site for the final disposal for the country's spent nuclear fuel. In 2011, applications were submitted to the relevant authorities to build the repository;
- France where a construction licence application for a geological repository for high level and long lived waste in the Callovo-Oxfordian argillites should be submitted by 2015, notably based on the knowledge gained in the Bure MHM (Meuse haute Marne) Underground Research Laboratory;
- USA where a licence application for construction authorization of a geological repository for spent fuels at Yucca Mountain had been submitted in June 2008, but faced in 2009 the revision of the waste disposal strategy, in spite of the knowledge already gained in the site characterization facility.

Research, development & demonstration aimed at confirming the performance of a specific host rock:

- Germany for the salt option, based notably on knowledge gained at the Gorleben salt dome (where all characterization activities stopped in 2000 pending future decision on siting);
- Belgium for the Boom Clay with the HADES Underground Research Laboratory (URL) located in Mol;
- Canada for argillaceous and crystalline rock formations.

Identifying sites for geological disposal:

- In the UK where an approach based on voluntarism and partnership as a means of siting of a geological disposal facility has been initiated by the Government with the issue of a White Paper "Managing Radioactive Waste Safely – A Framework for Implementing Geological Disposal" in June 2008.

The quasi absence of references combined with the experience that each phase in repository development has taken a different duration in each of the considered national programmes results in difficulties in deriving typical time durations. Furthermore, uncertainties in overall societal context (e.g. policy, public acceptance, etc.) and the non-linearity of planning implications of site- and waste-specific changes render planning recommendations for those Member States contemplating or initiating their own geological disposal programmes delicate, even in case of efficient technology transfer from Member States with well advanced programmes.

Country-specific typical durations for some repository development phases are provided, based on actual experiences from Member States. It should be noted that these durations must not be considered as recommended or optimised durations. Indeed, as already mentioned, planning uncertainties are significant and durations must always be put in the context of institutional commitment as well as of human and financial resources availability.

The preparation of safety case and supporting safety assessment for the whole disposal system is an iterative process requested at certain points of programme development and data collection. IAEA Safety Standards Series [1-3] and the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management [4] have to be carefully considered, as meeting safety requirements remains a key issue in the decision making process.

1.2. OBJECTIVE

The objective of this document is to present practical and updated information on the way a geological repository programme for radioactive waste could be defined and planned, with special attention to all aspects having an impact on the timing.

1.3. SCOPE

The scope of this report deals with the planning and design considerations for geological disposal programmes of high level and/or long lived radioactive waste. This report recognizes that the treatment, processing, transportation and storage of waste are important factors in addressing planning and design issues for geological disposal programmes, but it focuses on disposal facility development and does not address these components further.

The present report considers only national geological disposal programmes. Multinational or regional repository programmes are therefore excluded from the remit of this report. Planning of such facilities indeed encompasses important and innovative developments (e.g. legal framework), for which no experience or example exists from which one could draw lessons for this report. Several international initiatives, under the auspices of the European Commission (EC) [5] or of the IAEA [6, 7] are referred to in this report.

The report covers spent fuel, high level waste, intermediate level waste and some low level waste identified for underground disposal. These encompass heat generating waste (vitrified fission products remaining from spent fuel reprocessing and non-reprocessed spent fuel assemblies) as well as low and intermediate, non-heat generating, alpha containing, long lived waste.

1.4. STRUCTURE

A brief overview of a conceptual roadmap for a geological repository development programme is introduced in Section 2 as basis for subsequent sections. Section 3 outlines the key inputs for repository programme planning. Section 4 discusses in more detail the implementation of the programme and its evolution with time, addressing key considerations at the various phases set out in the roadmap of Section 2. Section 5 identifies lessons learned relating these to country specific information, which is detailed in Annex. The same annex provides country-specific typical durations for some repository development phases. Finally, conclusions are presented in Section 6.

2. OVERALL PLANNING OF A REPOSITORY PROGRAMME

It is assumed in this report that countries have already established radioactive waste management strategies and policies [8], and created the waste management organization (WMO) and the regulatory body (RB) [9, 10]. The waste management organization is assumed to be responsible for the implementation of a geological repository programme and is the primary audience for this report.

The development of a geological disposal facility can take decades. Therefore, it is recommended that this development is divided into a series of phases. Each phase ends at a key decision point supported, as necessary, by iterative evaluations of a safety assessment for a given site and disposal design concept.

Such decisions involve the government, the regulatory body, the operator and other stakeholders [11], prior to commitment of additional development resources. Typical regulatory or governmental decision points are established for: policy definition; site selection (and consequently site characterization) [12]; licensing and the approval to build a geological disposal facility (construction); the approval to receive and emplace waste (operation); and the approval to permanently close the facility (closure) [13, 14].

Given the time scales involved, the large volume of information and its diversity, it is essential that the programme is subdivided into a series of steps so that the work can be performed, reviewed and assessed in manageable packages while meeting the overall objective of safety and of exercising proper control throughout the programme. There are various rationales for applying a stepwise approach:

- It enables objectives, success criteria, planning and resources to be defined at each step;
- It enables decisions to be made on whether to proceed further to the next step (and commit appropriate resources) or to revisit the previous one;
- It avoids "fait accompli" of embarking in one specific direction, option or solution without a legitimate basis and commitment;
- It provides multiple opportunities for the public and regulatory bodies to assess confidence in the quality of the technical programme and the safety cases supporting the decision-making process before proceeding to the next stage;
- Confidence in the safety and feasibility of geological disposal at a site is enhanced by the step-by-step process and the increased level of maturity of safety studies as the programme progresses.

It can therefore be seen that a geological repository programme will usually involve successive phases, with iterations as necessary, in order to manage the decisions as to whether to proceed, revise or abandon a particular programme direction, and consequently the necessary resources can be better allocated.

There is no universally applicable and perfect definition of what the specific phases should be in developing a repository. Nevertheless, despite limited experience in geological disposal implementation, several attempts have been made to define typical phases to be included within any national programme for the development of a geological repository. The reference section includes a number of guidelines and technical reports relevant to the planning and design of geological repository programmes that should be consulted in addition to the guidance provided in References [15-19].

To help structure the present report, an idealized sequence for repository development programme has been defined in this report. Despite the fact that this sequence and the content of each of its phases may be adapted for each national situation and regulatory and institutional framework, this sequence is believed to encompass all necessary aspects of repository development. It should be noted that these phases do not always need to be developed sequentially, but may sometimes be accomplished, at least partially, in parallel.

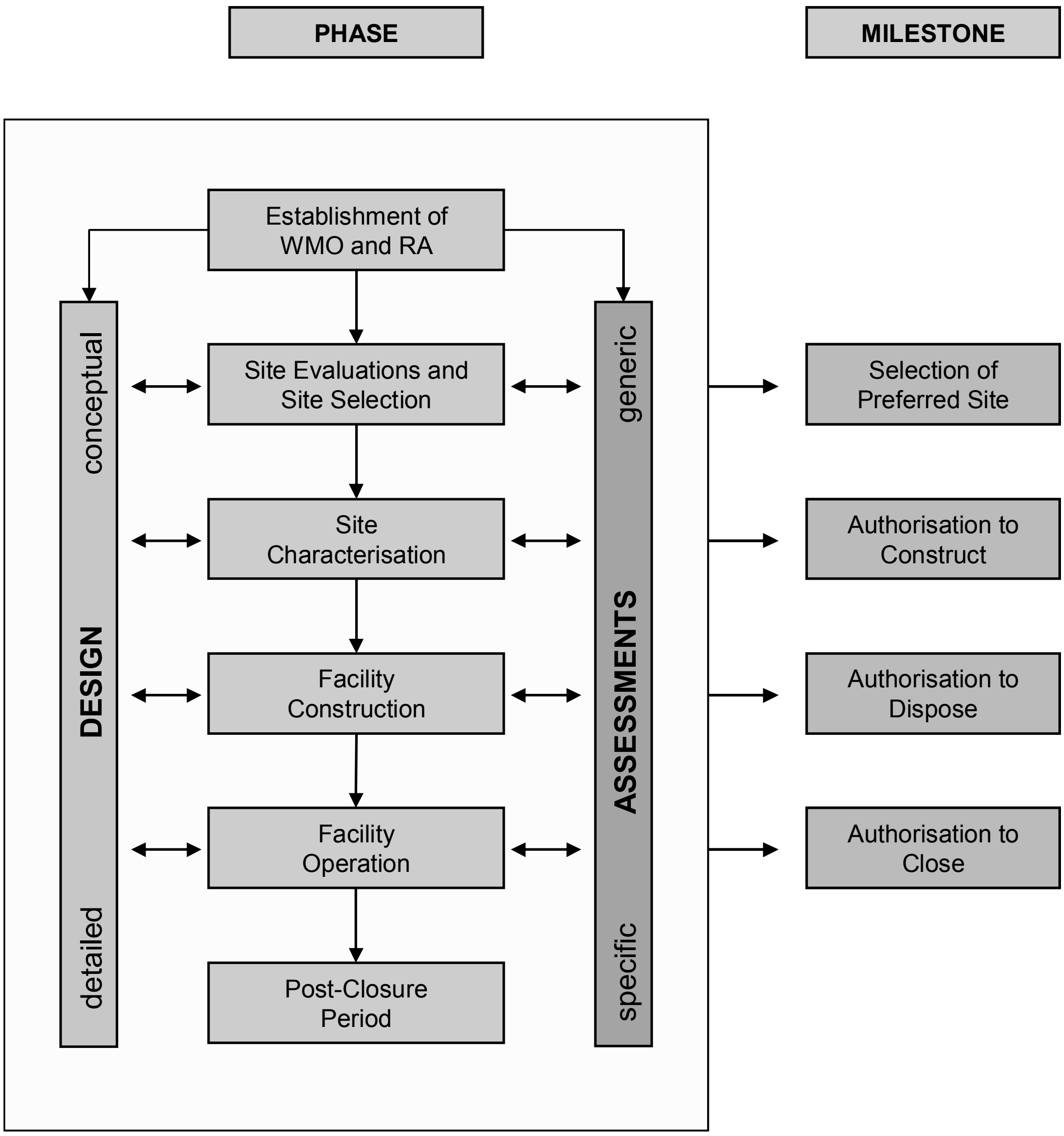

FIG. 1. Phases and milestones for planning a geological repository programme.

Time ranges for each phase are based on experiences within country-specific programmes but should not be considered as recommended or optimized durations. It may also be possible utilizing the experiences of other national programmes to improve on the times for each stage when compared with those achieved in some of the early programmes. Figure 1 shows the phases, the associated milestones and the processes supporting the attainment of each milestone.

While the IAEA Special Safety Requirements on Disposal of Radioactive Waste [2] groups all activities prior to waste emplacement into a pre-operational period, for the purpose of planning it is useful to break this period further down into several distinct phases. The suggested phases for planning are:

- Phase 1: Site evaluation and site selection;
- Phase 2: Site characterization;
- Phase 3: Facility construction;
- Phase 4: Facility operation and closure;
- Phase 5: Post-closure.

The number of phases may be larger when intermediate decision points are requested according to national regulations. Factors affecting the timing and duration of each phase are discussed in Ref. [20]**.** There are generally two referenced timing and duration issues. First, the issue of intergenerational equity encourages the initiation of a repository programme by the generation which benefited from the energy that gave rise to the waste. While long term (50-100 years) interim storage is possible, final disposal solutions should be pursued by the current generation. Secondly, all experience to date (and currently published programme schedules) suggests the phases leading up to facility construction can last decades. Facility construction can take up to a decade. Facility operation durations are highly dependent on waste volume, future arising, throughput limitations etc., and can last up to a century. The post-closure period is intended to be indefinite or permanent, subject to decisions regarding retrievability or reversibility by future generations.

2.1. PHASE 1: SITE EVALUATION AND SITE SELECTION

All geological disposal programmes are predicated on the eventual selection or designation of a particular site (or sites as may be necessary) for development of a geological repository facility. Thus an early responsibility of the waste management organization is to develop and implement the process for identifying (a) potential repository site(s). Typically this will involve a top down process starting from a national screening perspective, to consideration of regional aspects, and ultimately to specific localities and sites. Experience indicates that the site evaluation and site selection process can take many paths which are discussed in Section 4. Regardless, the eventual selection of a particular site (or sites) is a significant milestone that signals government endorsement to proceed to the next phase of repository programme development: detailed site characterization supporting a request for facility construction.

Site selection involves more than geological investigations, and will benefit from the integration of facility design concepts, preliminary safety evaluations, and stakeholder engagement, among other considerations (i.e. transportation, infrastructure resources, etc.). The level of technical detail and the means of stakeholder engagement will reflect the specific circumstances for each site and Member State but should be sufficient to provide adequate technical, regulatory and governmental confidence that the investment for the next phase of repository development is warranted.

It must be recognized that many sites may be potentially suitable, but given the numerous factors affecting site suitability evaluation, attempting to identify and justify a particular site as the best one is to be avoided. Rather, any selected or potential site must demonstrate adequate conformance with the safety criteria established at that point in time. More information on siting can be found in References [12, 15, 16].

2.2. PHASE 2: SITE CHARACTERIZATION

As mentioned above, the selection of a particular site (or sites) means endorsement by the government to proceed to the next phase of repository programme development including the detailed site characterization and any other activities necessary to support the next major milestone, an eventual request for facility construction. Construction of a disposal facility involves significant resources and it is assumed that the regulatory body will have established the safety criteria and the process for facility construction authorization prior to the request. The authorization for starting construction indicates a new government commitment to proceed with the geological disposal programme and, as such, represents the next significant milestone.

Site characterization involves the more detailed technical site investigations in order to increase the state of knowledge about a particular site. Site characterization may involve both surface and underground investigations to identify and understand particular features and processes. These processes are typically studied in different disciplines (hydrogeology, rock mechanics, geochemistry, etc.) but must be understood in an integrated manner. The site characterization effort may benefit from the construction of an underground research laboratory in the specific or analogue host rock. The research agenda for specific issues may be guided by preliminary safety case and safety or performance assessments that indicate phenomena with larger uncertainties and sensitivity to the demonstration of compliance with safety criteria [1-3, 13, 21].

Throughout the site characterization phase, the state of knowledge about the site technical characteristics will continue to increase and mature. Likewise the disposal design concept is also maturing, with greater specificity regarding the physical configuration, engineered barrier materials, and properties, etc. Together, this information will reach a point of detail and reliability that is considered sufficient to support a request for authorization to construct the facility.

2.3. PHASE 3: FACILITY CONSTRUCTION

After the site characterization process has confirmed the suitability of the site, excavation of the underground facility and construction of above ground infrastructure can commence subject to all necessary licences and approvals. Construction of the repository will be very costly and beginning excavation thus marks a significant level of commitment and investment.

The design for the underground excavations will need to be specified before excavations begin, taking into account many different factors and the increasing level of information from site characterization regarding e.g. the geotechnical and hydro-geologic characteristics of the host rock; the total volume of waste to be disposed; the size of individual waste packages and their handling systems; the multi-barrier concept design, or the anticipated heat output from the waste. The design will also need to account for waste retrieval if this is designated as a requirement for the facility. It should be expected, however, that the detailed design of the repository should be modified during excavation to take account of local variations and perturbations in the rock mass (e.g. presence of faults) as they are encountered.

Excavation of the repository could take place using a variety of methods, but will usually be done using appropriate mining and tunnelling equipment such as tunnel boring machines. The excavation of the repository is likely to be subject to specific mine safety regulations in addition to the other nuclear and environmental regulations that apply to the development of such a repository.

After construction of the repository (or the first phase of this structure in the case of modular design) it will usually be necessary to apply for an authorization to dispose of waste and this will require a safety case and reviewed safety assessment to be performed based on the ‘as built’ repository design. The key milestone that marks the end of this phase will be a license to handle and dispose of radioactive wastes in the facility and to begin disposal operations.

2.4. PHASE 4: FACILITY OPERATION AND CLOSURE

The facility operations phase is characterized by on-going disposal operations with the transportation of waste from surface storage to the underground disposal facility. In some cases the repository will be excavated in stages and in parallel with waste disposal operations. This will typically be the case when large amounts of waste are to be disposed and when waste will continue to arise over a long period of time. At some future point, the decision can be made to close the facility and it is expected that a final safety assessment will be necessary to support that decision. Closure includes the administrative and technical actions directed at configuring the facility for its physical isolation and the provision of other measures supporting the long term performance of the repository (e.g. seals, backfill, markers, monitoring systems, etc.).

As with facility construction that may occur in stages, the closure of the facility could also occur in stages rather than as a one-time event. Regardless, the decision to close the facility is supported by the final state of knowledge about the site characteristics (having gathered confirmatory data throughout the disposal phase), as well as the final as-built configuration for the facility design.

Given the potentially long periods for repository development and operation, the decision to close a facility may be made by future generations. This may be provisioned in the frame of knowledge management systems to facilitate the evaluation of safety by future organizations. Such systems will incorporate the final best-available information about the site geological characteristics, the facility configuration, and the waste inventory that will be necessary to perform a final safety assessment to evaluate compliance with the safety criteria established for closure and long term performance. In addition to the closure decision, regulations will determine what monitoring and surveillance requirements or other institutional controls are expected for the post-closure period.

2.5. PHASE 5: POST-CLOSURE

This phase refers to all activities needing to be performed during institutional control and also for an indefinite period of time afterwards. According to the time scales involved, it has to be supported by upgraded post-closure assessment based on a systematic scenario development, the considerations of features, events and processes that may occur during such geological time scales and consequently, the management of uncertainties [14, 22-24]. More information will be provided in Section 4.

3. KEY INPUTS FOR REPOSITORY PROGRAMME PLANNING

The process of planning and designing a geological repository requires the consideration of many aspects, both technical and non-technical, such as public/community engagement. The latter may often become a key issue to be taken into account in the early stages of programme development, as described to some extent below and in more detail in other publications [11, 25].

In order to support the milestone decision points introduced in Section 2, programme development needs to be based upon key inputs, such as waste inventory, knowledge about the natural environment, options and preferences for the design of engineered systems, as well as stakeholder engagement and the regulatory and legal framework. Taking into account all of these during the various stages of programme development is an essential consideration to contribute to programme success.

The purpose of this section is to introduce and discuss these key inputs that need to be referred to when designing, planning and assessing a deep geological repository programme. Primary factors guiding the scope of such a programme are the impact of the waste disposal inventory and the geological setting on the design of a safe disposal facility. As a programme develops, the inventory may change to reflect a range in power generation programmes or waste processing and packaging activities. Once a site is selected, the geology to be considered will remain unchanged but the understanding of the geology will advance as the programme of site characterization is progressing.

Key inputs also include the regulatory and legal framework which defines regulations and key requirements to be met in the performance and safety assessment approach throughout the repository programme development.

3.1. INVENTORY

The waste inventory (volume and characteristics) is a primary consideration in the planning for disposal as it will constrain the design, the scale of operations and may also influence the timing and duration of a repository programme. Inventory characteristics which need to be determined include key radionuclides, physical and chemical characteristics, heat generation and activity. These are required to allow designs of packaging (e.g. shielding), handling procedure and the overall disposal geometry.

Legacy waste (which may not have been conditioned in an optimal way to meet specific waste acceptance criteria) needs to be addressed when developing a repository programme.

The principal groups of waste that are considered here are [26]:

a) Spent nuclear fuel (whole or dismantled fuel bundles or elements, containing the original metallic uranium, uranium dioxide or mixed oxide (MOX) fuel matrices and the fission products and transuranics that were formed while the fuel was in the reactor);
b) High level waste (HLW) containing fission products and transuranic residues from reprocessing spent fuel;
c) Intermediate level long lived waste (e.g. from reprocessing, decommissioning and refurbishment)
d) Low level waste identified as being unacceptable for, or in the absence of, near surface disposal. National policy may determine whether LLW is disposed near surface or underground. This is largely dependent on activity, concentration and half-life;
e) Other types of radioactive waste including disused sealed radioactive sources as identified by Member States.

Changes in a reactor's operation may have impact on the spent fuel inventory and the period required for storage prior to transferring to a repository.

In addition to its relevance to the technical management of a facility, establishing and maintaining a comprehensive waste inventory has proven to be of significant interest to stakeholders. Overall, thorough waste analysis plans enhance the quality of the whole programme.

Knowledge of waste inventory is relevant for correct programme planning and implementation**.** In particular:

- An understanding and characterization of the waste inventory is of key importance early on in the programme for preparing the design of a repository;
- Characterize as early as possible and as detailed as possible the amount (volume and radionuclide content), category and characteristics (physical and chemical) of the waste forms to be disposed of;
- Acceptance criteria for waste forms should be discussed and prepared as early as possible (these will evolve and become more specific as waste characteristics and the safety case are understood as the level of detail increases);
- Maintain flexibility in the programme to incorporate possible evolutions in waste types and characteristics to be disposed of.

Planning for a disposal facility often has to address conflicting requirements, e.g. it is desirable to address historic wastes as soon as possible but the facility may not be able to take new wastes until they have cooled sufficiently. Many national programmes plan to dispose of more than one waste type and it is possible to provide a single geological disposal facility for a number of waste types. However, the cooling time, as an example, may lead to the need to develop separate facilities for existing and future wastes. Other factors such as the space available for disposal or limits identified by safety assessment, could lead to a requirement for more than one disposal facility.

Throughout programme implementation, the above considerations may be addressed in an increasingly formalized way, for example within a waste analysis planning frame. Such a planning framework includes a description of the overall waste inventory intended for disposal, projections for waste streams, and allows the development of waste acceptance criteria. During the operational phase of the programme, such acceptance criteria are essential to provide for safe operations and disposal, as well as a detailed description of the inventory actually disposed of.

3.2. NATURAL ENVIRONMENT CONSIDERATIONS

The natural environment of a disposal system is a key element in a repository development programme. The description includes the Features, Events and Processes (FEP's) that will or may impact on repository safety and design [23] and contain e.g. host rock properties for constructibility and favourable characteristics for waste isolation, hydrogeological and geochemical properties for long term safety considerations, seismic and volcanic hazards and tectonics, meteorological and other surface environment conditions that may influence the siting process as well as programme implementation (e.g. via the influence of extreme hot, moist, or cold conditions), etc. [16, 21, 24, 27].

Knowledge about the natural environment is essential at all stages of a repository development programme. Early on, the programme may need to consider generic information of various possible geological settings (e.g. by providing generic evaluations for varying types of host rock). After site selection, programme planning will need to integrate all site specific knowledge and its implications on further developments.

3.2.1. Various types of natural environment

Many types of rock formation are expected to be potentially suitable as a host formation for radioactive waste disposal. These include granite, salt, clay, or tuff. Others may be suitable as well. Experience to date suggests that a repository could be constructed in many rock types. However, specific consideration should be given to the overall context of a given site. The design of a disposal facility may permit a certain degree of flexibility concerning the characteristics of the geological formation.

3.2.2. Specific considerations relevant to programme planning and implementation

Planning a site characterization programme for different host formations and environments requires different technical approaches. These approaches must be tailored specifically to address each particular setting. They vary in scale, duration and function based on the relative complexity of the environment under investigation. Information from the characterization programme would be used in the preparation of a site specific repository design and to provide input to any additional or more focused information needs from site investigation in view of Environmental Impact Assessment (EIA) and safety assessment.

3.3. ENGINEERED SYSTEM CONSIDERATIONS

Because of the strong interdependence with the waste inventory and the geological setting, basic disposal design issues for the engineered system need to be resolved such as the use of vaults and shafts, emplacement mechanisms, facility layout, use of engineered barriers, etc. The combination of the natural and engineered barriers creates a disposal system with defence in depth.

With regard to planning a repository programme, there is benefit in using available and proven technology (vs. having to develop new technology) as a means to contain cost and improve confidence. It is recognized that specific site issues may call for the development of specific technology for construction or operational needs. However, in the execution of the repository programme, the option to introduce new technology that enhances performance or safety should remain.

3.4. REGULATORY AND LEGAL FRAMEWORK

For supporting the waste management and disposal programme, the Member State government will have established a national policy for the safe management and disposal of radioactive waste for the protection of human health and the environment [8]. The policy provides the basic safety philosophy for radioactive waste management and the steps necessary to ensure its implementation.

To efficiently implement a geological disposal programme, it is recommended that the Member States will have established an institutional framework of policies, laws, and regulations for the safe disposal of radioactive waste. Legal and governmental infrastructures are discussed in Ref. [9]. In addition, Ref. [10], also issued by IAEA, provides information on suitable institutional framework. Included in this framework should be the identification of responsibilities among the government, regulatory body, and operator for the geological disposal programme, as well as the process for stakeholder involvement.

Following, or concurrent with the development of the safety policy, safety regulations are made that define the post closure performance standards and the means for demonstrating compliance. It may be beneficial to a country initiating a geological repository programme to adopt already existing standards that may be used in other countries and/or recommended by the IAEA [1-3].

All this implies the promulgation of administrative rules, regulations, and decrees establishing:

- Guiding criteria on the characteristics of the host formation and site for a deep geological repository;
- Regulatory policy, standards and guidelines for assessing the performance of a deep underground repository;
- Interaction and responsibilities of authorities, and other stakeholders;

- Licensing framework, including criteria and standards for issuing authorizations.

Commensurate with the enactment of geological disposal safety regulation(s), the institutional roles and responsibilities for the government, implementing organization (operator) and the regulatory organization(s) are defined and a basic timetable for implementation is established. Experience (e.g. 1982 Nuclear Waste Policy Act of USA, 1991 [28] and 2006 French acts [29, 30]) strongly suggests the usefulness of establishing early in the programme a schedule of major milestones and goals for a geological repository programme, and to have this schedule endorsed by the government. The schedule should define the major objectives and the purpose of the decision points to be made by the government or regulatory body (i.e. to present an early generic safety strategy with conceptual design and site selection data, to provide a feasibility study for a given site, to proceed with licensing, etc.). These milestones in the decision making process should be designed to take full advantage of safety and environmental impact assessments and the safety case that would be available at that time, as these provide a way to communicate the basis of any decision the government might make at that point [31].

Some of the processes for stakeholder involvement at the local, regional and national levels may be directly dictated by national policy and regulation. For example, the French 2006 law calls for a public consultation prior to repository site designation and license application. Before one or several candidate sites are selected for the geological repository, the repository programme of the Member State should have a safety standard instituted in law or regulation.

3.5. STAKEHOLDER ENGAGEMENT

Confidence in the performance and safety of a geological repository [31] is based on numerous considerations (applicability and appropriateness of safety standards, institutional integrity, public confidence in trusted organizations, provisions for defence in depth, risk-benefit considerations, etc.). Unsuccessful stakeholder involvement might jeopardize acceptability and might cause serious setbacks to the programme. The use of natural analogues also contributed to enhance confidence building by reproducing similar processes for time scales and local conditions we are facing in geological disposal studies [27].

Planning for a geological repository requires adequate stakeholder involvement at all stages of the programme. Given the nature and relative complexity of these programmes, suitable time must be provided to ensure effective engagement. It is also important that key stakeholders are engaged early in the programme to ensure that they can influence the programme and more importantly that the programme and outcomes meet their expectations. Initial proposals could include a number of options being considered (e.g. reversibility, retrievability, monitoring for performance confirmation). Further options could be identified through stakeholder consultation and assessed. The provision of local benefits (jobs, regional development) could be included to provide local communities and local politicians with assurances that there will be no social detriment resulting from the development of a repository.

4. PROGRAMME IMPLEMENTATION AND EVOLUTION

4.1. SITE EVALUATION AND SITE SELECTION

The principal goal of this phase is to have a specific site (or sites) formally acknowledged and designated by the Member State regulatory process, indicating government endorsement to proceed to the next phase of repository programme development: the detailed site characterization supporting a request for facility construction.

Many terms are associated with the activities involving the site selection process, but are typically used to describe a particular level of detail or temporal stage in the process (e.g. a site survey may come before site evaluations which come before detailed site characterization, which may be then subject to site confirmation).

As described in [3], "In the siting process for a radioactive waste disposal facility, four stages may be recognized: (i) a conceptual and planning stage, (ii) an area survey stage, (iii) a site investigation stage of detailed site specific studies and consideration and (iv) a site confirmation stage."

For the discussion herein, the following terms are defined:

- *Siting*: the overall process of survey, screening and evaluation to identify potential sites and leading to a site selection;
- *Site evaluation, characterization, and confirmation*: the process of evaluating the merits of a particular site with a graded approach for the level of detail sufficient to support the decision to be made;
- *Site selection*: with respect to the milestones discussed in Section 2, site selection is a key decision point involving an administrative act to formally designate a site (or sites) for the intended development of a geologic repository. Sites selected for detailed characterization and evaluation earlier in the siting process are recognized to be a preliminary site selection rather than the milestone associated with formal governmental site designation.

The process of siting and of site selection can take many forms, and, though geological evaluation is fundamental to the process, siting assumes more than just geological surveys. Regardless of the path taken, the goal is to identify a site (or sites) that have the potential for *favourable geological conditions* for isolation of *the waste inventory*, the potential *constructability of the disposal design* concept, and the potential for sustained *stakeholder acceptance*.

A Member State may begin its siting process with certain a priori conditions that will affect the implementation of the siting process. For example, in requesting expressions of interest from volunteer sites, the waste management organization may first provide information on potentially suitable regions based on a national survey and preliminary screening to identify geological domains that are thought viable at that point. Alternatively, the Member State may wish to utilize existing facilities (e.g. mines) and would investigate existing site conditions and approach stakeholder concerns differently than from volunteer approaches. The Member State may begin with a disposal concept already defined (i.e. to address a particular waste inventory issue, or to benefit from existing disposal concepts previously developed by other Member States), and then search for a particular geological site condition compatible with the disposal design concept.

The primary lesson is that, while repository siting is fundamentally tied to geological considerations, many other factors (technical, societal and programmatic) can take equal importance. However, experience indicates the Member State will benefit in programme implementation if the process leading up to site selection is well defined and communicated in advance.

As noted earlier many factors influence the siting process and site selection, and some are considered key ones (see Section 3). Many of these factors are discussed below.

4.1.1. Waste inventory

The waste inventory has a strong interrelationship with the disposal system (the geological and engineered elements, the design of the surface and underground facilities, and the transportation network. The waste inventory is the actual disposal burden being addressed and its basic characteristics should be known prior to the siting process. Basic characteristics include: location (affecting potential transportation issues), waste type, volume, radionuclide inventory, heat production, material balance or chemistry, and potential or existing conditions which influence the performance or design of the disposal system. Detailed waste characterization allowing waste acceptance in the disposal facility may not be available at this stage.

4.1.2. Disposal design concept

The disposal design concept evolves and matures with time. At the beginning of the site selection process the disposal design concept may include multiple concepts without detailed engineering. This allows the disposal design concept to evolve as knowledge of the potential site conditions increases. As the point of site selection nears, basic decisions about the disposal design concept will need to be resolved and preliminary design and engineering information available to support the safety assessment associated with the request for site selection. Because of the strong interdependence with the waste inventory and the geological setting, basic disposal design issues need to be resolved such as the use of vaults, emplacement mechanisms, facility layout, use of engineered barriers, provision for single- or multi-level constructs, etc.

4.1.3. Geological setting

Because the geological setting is the primary disposal environment, much needs to be known and decided about the desired conditions. As the siting process is implemented, the amount of information (i.e. the geological characteristics) needed to support the preliminary or final site selection decision will change. Early on in the survey it is important to have basic site evaluation criteria for potential site suitability in order to narrow the potential sites or regions needing more detailed information. Typical basic criteria include distance to groundwater sources, seismic or volcanic potential, rock type, offset from faults, political border offsets, hydrologic flow and chemistry conditions, etc. Early on in the site screening process, it may be possible to rely primarily on existing information. As the site screening process matures, it may be necessary or desirable to generate site specific data from more extensive surface investigations, geophysical surveys, exploratory boreholes, or underground investigations including the establishment of underground research laboratories. It is important to note that the purpose of the siting process is to identify a specific site where a repository could be constructed, and the data needed should be of sufficient quantity and quality to support with confidence and credibility the decision to proceed to the next phase.

4.1.4. Stakeholder engagement

The potential for stakeholder acceptance of a geological repository is a fundamental consideration in the siting process. It is generally held that volunteer sites increase, but do not assure, the potential for sustained stakeholder acceptance. It is also recognized that whether stakeholder acceptance is existing or must be developed, the stakeholder acceptance factor is influenced by early, frequent and open communications with the potentially affected population and its representatives. To this point it is recommended that the waste management organization or other government institution develops a comprehensive stakeholder engagement plan prior to initiating the siting process. Such a plan would address issues of communication frequency and forum, the need for agreement documents and whether binding or in principle, the potential terms and conditions for possible community benefit, the criteria for the selection process and needed transparency, and how the safety assessment should be developed. More information regarding factors affecting public and political acceptance is provided in [25].

Experiences of the use of "Focus Groups" as done by Swedish Nuclear Fuel and Waste Management Company (Svensk Kärnbränslehantering AB, SKB), Finnish organization responsible for the final disposal of spent nuclear fuel, Posiva Oy (Posiva), Canadian Nuclear Waste Management Organization (NWMO) or UK Nuclear Decommissioning Authority (NDA) were positively assessed. Of course, effective stakeholder engagement using appropriate skills also requires an appropriate level of resources, supported by achievable schedules. Planning for siting of facilities may not rely solely on safety related (hydro-) geological considerations (e.g. the Gorleben facility in Germany). The involvement of adequate stakeholders in any siting process is a prerequisite that could be applied to all approaches whether or not they are based on volunteering.

4.2. SITE CHARACTERIZATION

A repository programme typically has reached a substantial level of maturity prior to entering this phase. Adequate planning and programme development for this phase will need to take into account the level of available knowledge, confront it with what is needed to reach the next major milestone – obtaining a license for repository construction – and assess further developments that are needed. This generally means progressing from an overall level of knowledge, from general design principles, and a safety assessment focused on post-closure safety, to a site-specific knowledge and a level of detail of engineering solutions which can then lead to a construction and operation phase. How this interrelates and may be taken into account for programme planning is outlined below.

Prior experience has shown that a time period of up to 10 or even to 20 years may be a reasonable estimate for programme implementation during this phase, to submit a license application. The duration of license review and possible receipt of construction authorization is strongly dependent on the national context and regulatory framework. It needs to be added to the duration of programme implementation.

4.2.1. Engineering – repository design and technology developments

This phase is characterized by the need to progress from what may have been general design principles prior to site selection to providing engineering solutions to a level of detail needed for license application. This level of detail may be close to the one needed prior to actual construction (i.e. blueprints and specifications at a level sufficient for construction contractors to begin work). Key related considerations for programme development include the need to address any construction and operational safety requirements in the context of a subsurface nuclear installation, as well as to revisit any prior design developments intended to perform as a barrier contributing to long term safety.

This will likely require substantial effort and may call for the need for technical staff with experience in various fields (e.g. subsurface construction and operation, transfer and handling of radioactive waste drums, etc.). Even if significant parts of development work may be given to external contractors, the waste management organization needs to develop an adequate level of understanding to specify and verify developments to be conducted. Such a process requires a number of years, and should be included through the entire duration of this development phase.

The need to find a balance between long term safety considerations and operational safety considerations is an issue that takes on significant importance during this phase of the programme. For this reason, substantial emphasis may need to be placed on the operational phase when developing repository design and engineering solutions to a further level of detail. Such considerations are driven by the more detailed knowledge of the host rock behaviour (rock mechanics, hydrogeology, geochemistry), of emplaced waste behaviour (heat generation, irradiation levels, radiolysis, release of gas including radionuclide trace elements), of the potential duration of repository operations (driven by overall waste inventory), and other considerations such as the decision making process to move to closure, the possible need for retrievability and its implications [19] or for in situ monitoring [32].

The programme needs to consider (and demonstrate) that the repository structures can be built with available technology. To some extent, technology and construction materials can be developed to be specifically adapted to repository requirements. Such development needs should be identified early on in this phase and included in programme planning. The programme also needs to consider and demonstrate that the repository structures "as built" will respect all operational safety requirements, and respond to any requirements specific to the operational phase. Finally, the programme must demonstrate that the method of construction is suited to respect any specifications related to long term safety considerations (e.g. by not degrading favourable host rock properties, by allowing for the emplacement of buffers and seals during closure, etc.).

The programme will need to consider the requirements for waste transfer and waste emplacement, as well as the specific operational requirements such as radiological shielding of disposal drifts, ventilation of the subsurface infrastructure and operational safety features as may be needed e.g. for fire safety. Depending on the overall repository design, disposal drift design, and choice of engineered barriers, these may call for specific technology developments.

The level of technological developments needed is closely linked to the site and host rock properties, as well as to the chosen strategy for drift closing (immediate or delayed). While in certain settings, proven construction and operation technology may be adapted, others may call for a more substantial technology development programme. In all cases, the construction and operation techniques should be appropriate for a radioactive waste facility.

The use of a URL, primarily developed for site characterization, may increasingly respond to such technological demonstration needs (e.g. by providing technology demonstration of actual design components) to enhance confidence in operational feasibility and safety [18]. Specific demonstrations that may need to be undertaken through the use of a URL are constructability of a disposal drift, emplacement of engineered barriers, handling, emplacement and potential for retrieval of waste canisters, and also approaches to sealing and backfilling.

4.2.2. Detailed site characterization for license application

Planning of further site characterization to a level of detail needed for license application is another key element driving overall programme development. As for the facility design, the technological developments needed in this phase of the programme might take advantage of prior site knowledge as input to evaluate remaining characterization needs.

It is assumed that a limited amount of site characterization has already been performed in the previous phase. This would include the evaluation of regional tectonic and seismic activity, risk for volcanic activity, local and regional fault system, and the analysis of local and/or regional borehole data. Based on this, the programme will likely need to conduct more detailed site characterization, e.g. performing additional surface characterization by drilling boreholes to obtain a more precise description of local and regional hydrogeology [16], evaluating variations in geochemical properties, or obtaining volumetric information via a more detailed seismic exploration focused on the future repository site [15]. The need and use of a site specific URL would generally be considered in this phase, to support in situ characterization of the rock mass.

The emphasis of site characterization is likely to shift from general scientific questions (as were necessary to provide initial modelling capability and safety assessments prior to site selection) to issues focused on specific site properties and on applied research related to the interaction between site and design components.

For this reason, substantial emphasis is likely to be placed on further URL developments. These will likely need to enhance the programme's predictive modelling capability (e.g. by providing experimental results over longer durations or by reducing parameter uncertainty) to provide greater confidence in safety assessments. Specific questions that may need to be addressed are refining the rock mechanical behaviour, in relation to excavation, ground support and operation as envisioned by the design. Refining knowledge of material interactions may be another key issue, e.g. between host rock, engineered barrier components, and waste containers. Its potential use for in situ testing and demonstration of engineering technologies was mentioned previously.

The required duration to prepare and implement such URL experiments and "demonstrators", is likely to condition the overall duration for this phase of site characterization.

4.2.3. Safety assessment

Programme planning may need to incorporate two key steps related to safety assessment. At the beginning of this phase, prior lessons learnt will contribute to conditioning the needs for design developments for this phase, as well as the needs for further site characterization. Then, prior to submitting a license application, safety assessment needs to incorporate improvements in site-specific modelling and parameter uncertainty, as well as updated repository design.

Adequate programme planning will need to explicitly provide for the interface between safety assessment, site characterization and design. An increased level of detail (waste streams and properties) will be used as input data for the repository.

4.2.4. Stakeholder engagement

In this phase, stakeholders may focus their attention on what is now a dedicated site. Two key issues may need to be planned for, with the aim of maintaining or obtaining stakeholder acceptance: (i) provide transparent information on programme progress and (ii) integrate stakeholder input on certain aspects of future programme management. As already mentioned, the discussions on issues such as retrievability, reversibility and monitoring remain of interest at this stage.

4.3. FACILITY CONSTRUCTION

Experience from advanced national repository programmes suggests that the earliest the construction could begin would be around 20 years from the start of the programme but it could take considerably longer, allowing time for the site selection and characterization stages, stakeholder engagement and for evaluation by the regulatory authorities of the application to construct the facility.

Given this long time horizon and the initial uncertainties regarding the nature of the site and the repository design it is not sensible to attempt to plan the full details of the construction stage at the start of a repository programme but a number of fundamental issues will need to be considered in advance, and these are discussed below.

4.3.1. Repository design and host rock constructability considerations

The primary input to the construction phase will be the detailed engineering design for the repository that will need to have been developed and submitted to the regulatory authorities together with the application to construct the facility. It is important that the repository design is not solely based on post-closure performance requirements but also takes account of 'constructability' in the site-specific host rock to ensure repository excavation and construction are both technically feasible and practical.

The physical characteristics of the host rock will impose a number of constraints on the repository design. This can become particularly relevant if a volunteer approach to siting is adopted because it is possible that the rock at any available volunteer site may not be suitable for certain design concepts. For example, the ability to excavate the wide-span caverns that are a feature of certain ILW repository designs is much reduced in soft plastic clays and salt compared to hard, crystalline rocks.

In broad detail the excavation of a radioactive waste disposal facility is similar to other mining and tunnelling operations and experience from these industries can be used when planning the construction of the repository (e.g. in specifying equipment needs, rates of progress etc.). It should be noted, however, that there may be a number of unique design specifications imposed by, for example, any requirement to build retrievability into the design that would cause the repository construction programme to deviate significantly from normal tunnelling operations.

All else being equal, it is sensible to design the repository so that it can be excavated and constructed using proven technology and experience from the mining and tunnelling industry. For example, if long circular-section tunnels are required (such as feature in many HLW and spent fuel repository designs) it may be beneficial to design them so that they can be excavated using standard size tunnel boring machines (TBMs). It is possible to commission non-standard size mining equipment but this usually incurs considerable extra cost in terms of both the TBM and tunnel support structures.

There is limited experience in some aspects of repository excavation and construction (e.g. constructing tunnels of certain diameters or using certain excavation methods) and there may be a requirement for some equipment and procedures to be tested and 'proved'. Ideally full-scale tests should be undertaken in a URL at the repository site or at an analogue site prior to full-scale construction. The requirements for proving will be greater if non-standard equipment and procedures are adopted rather than 'off-the-shelf' methods.

It is strongly recommended that mining and tunnelling engineers are engaged at an early stage in the repository programme, and ideally when the first conceptual designs for the repository are established, to ensure the design is feasible and, over time that the progressive evolution of the design is optimized taking into account site-specific conditions, practicality and cost-effectiveness of construction. Design modifications introduced at a later stage because construction issues had not been incorporated into the design will undoubtedly cause significant delays and cost increases for the programme. Experience from some early repository programmes is that insufficient consideration was given to practical construction issues at an early stage.

4.3.2. Construction health, safety and environmental protection issues

There is a natural tendency for the WMO to focus on the post-closure radiological safety and performance of the repository during its design because that relates to the primary function of a disposal facility. It should not be forgotten, however, that the excavation and construction of the repository will be a large civil engineering project that will be subject to conventional and mining industry health, safety and environmental regulations [33]. The applicable regulations and requirements should be identified at an early stage in the repository programme to ensure they can be met without conflict with the nuclear and radiological safety aspects. This is particularly important if it is planned that the repository will be excavated in stages and in parallel with waste disposal operations, such as happens at the WIPP repository in the USA. Implementation of international safeguards will also lead to technological implications for the repository [34].

4.3.3. Continued site characterization and monitoring

The WMO should have very strong confidence in their conceptual model of the subsurface rock and groundwater systems before construction begins. During construction, however, there will be further opportunities for site characterization and, in particular, to monitor the rock/groundwater response to the progressive excavation.

Long before construction begins, baseline monitoring of the natural undisturbed characteristics of the site should have started. It is recommended that during construction a "predict, observe and compare" approach to monitoring is adopted that is based around making conceptual or mathematical modelling predictions of, for example, changes to groundwater flow rates due to dewatering of the rock during pumping. Actual observations and monitoring data should then be compared to the predictions and any discrepancies evaluated to understand their significance for the site model [29].

4.3.4. Design change control

It is inevitable that during construction, actual observations of the rock mass will mean that the implementation of the repository design may need to be adjusted locally to account for heterogeneities in the rock (e.g. minor fractures or faster groundwater flows that were not predicted during the site characterization work). Procedures will need to be established and agreed with the regulatory authorities that define how design and implementation changes are controlled, and in particular whether they would require re-evaluation of all or parts of the safety case submitted with the application to construct the facility.

It will be important that the teams managing and performing the excavation and construction work understand the significance of design change control because the procedures that will be applied are likely to be significantly different to those routinely adopted in the mining and tunnelling industries. This will require appropriate training for those teams.

4.3.5. Skills and equipment resources

Construction of the repository will be an expensive activity and will require a considerable amount of resources, both personnel and equipment. Depending on whether the repository design allows for the use of 'off-the-shelf' mining and tunnelling equipment or bespoke systems, there could be considerable lead-in times to gather the necessary resources.

In any event, the WMO will need to establish an 'intelligent customer' capability to specify and procure the necessary services and to act as the technical programme integrator that will oversee and direct the excavation work, the on-going monitoring and iterations of the design and safety case.

The skills, resources and necessary lead-in times for construction should be explicitly planned for in the overall repository programme. It should be noted that the repository programme will be competing for excavation capability against the mining and tunnelling industries, and the cost and availability of these resources will be dependent on the general economic situation at the time.

4.3.6. Surface infrastructure

Construction of the repository will also need to account for the surface infrastructure, such as waste receipt and handling facilities, access shafts and galleries, transport links, utilities, etc. In addition, systems will need to be put in place to handle the large volumes of excavated rock that will be generated and transported to the surface – depending on the nature of this material it may or may not be considered a resource and could be reused on site or locally.

Construction of the surface infrastructure will be a combination of normal civil and nuclear plant requirements, and these may need their own construction authorizations that are separate to the subsurface repository excavations.

Experience from advanced repository programmes indicates that stakeholders are often more concerned with surface activities (especially transport of waste) than underground work, and so adequate resources needs to be made available for the planning and construction of these. There is a requirement for an overall project integration function that will coordinate the surface and subsurface construction activities so that there are no programme conflicts, for example that there is sufficient land area available to stockpile both excavated rock and construction materials.

4.3.7. License to operate

After construction of the repository (or construction of the first phase of the repository) a license to operate will be required from the regulatory bodies prior to commencing of waste emplacement activities. The process to obtain the license will vary according to the regulatory framework but, in most cases, will involve performing an updated iteration of the safety case on the basis of the 'as built' repository configuration and observed/monitored site conditions.

Any significant deviations that may have occurred from the design and site details assumed in the application for the license to construct will need to be specifically addressed and justified to the authorities. In practice, the authorities and control body would be kept informed of deviations from the plan as they arise during construction activities.

4.4. FACILITY OPERATION AND CLOSURE

The facility operation phase is characterized by on-going disposal operations with the transportation of waste to the facility and the movement from surface storage to the underground disposal facility. In some cases the repository will be excavated in stages and in parallel with waste disposal operations. This will typically be the case when large amounts of waste are to be disposed of and when waste will continue to arise over a long period of time. At some future point, the decision can be made to close the facility and it is expected that a final safety assessment will be necessary to support that decision. Closure includes the administrative, technical and safety actions directed at configuring the facility for its physical isolation and other measures supporting the long term performance of the repository (e.g. seals, backfill, markers, monitoring systems, etc.).

As with facility construction that may occur in stages, the closure of the facility could also occur in stages rather than in total as a one-time event. Regardless, the decision to close the facility is supported by the final state of knowledge about the site characteristics (having gathered confirmatory data throughout the disposal phase), as well as the final as built configuration for the facility design.

Given the potentially long periods for repository development and operations, the decision to close a facility may be made by future generations. This may be provisioned by knowledge management systems to facilitate the evaluation of safety by future organizations. Such systems will incorporate the final best-available information about the site geological characteristics, the facility configuration, and the waste inventory that will be necessary to perform a final safety assessment to evaluate compliance with the safety criteria established for closure and long term performance. In addition to the closure decision, regulations will determine what monitoring and surveillance requirements or other institutional controls are expected for the post-closure period.

Once the facility has been designed, constructed and readied for authorization to begin operations, the entire programme must be assessed for operability prior to requesting authorization to operate. A key point in the process to authorize operations would be to ensure that the facility can be started safely, and that all processes necessary for safe operations are verified, validated and documented. This activity can be accomplished in many different formats, however the more prevalent format would be to perform systems readiness or operational readiness assessments, the latter should be much more rigorous and robust to include all processes, procedures, systems, etc. Normally, the operational readiness assessment process is conducted for multiple systems that differ in function and safety classification.

Once the readiness or operational readiness assessments are completed and approved, authorization to begin operations can be achieved. In the performance of the readiness or operational readiness assessments, areas such as those listed below will be reviewed and consistently updated throughout the life of the facility.

4.4.1. Technical qualification programme

This section addresses the need to train and certify workers to be qualified for safe operations. For individuals responsible for oversight or operation of safety related systems, structures or components, a technical qualification programme should be designed specifically to ensure these individuals are qualified to perform work in associated areas. Such considerations probably only need to be integrated into later programme steps, as the facility is being prepared for operation.

4.4.2. General training of personnel

A training programme plan should be developed by the WMO. It should address mentoring activities and training that include intern programmes, career development programmes, and possible collaborative exchange activities with foreign WMOs. A very efficient way for training is the mentoring of staff in the team of a given waste management organization (or a subcontractor) for at least a few months. Opportunities for staff mentoring may be provided in national URLs or other institutions working on final disposal programmes and specific efforts may be carried out to orientate this scheme towards staff of new WMOs (or R&D organizations associated to such waste management programmes). Mentoring activities need not be limited to “in-house” training, but may be usefully opened up through international cooperation.

4.4.3. Waste analysis planning and waste acceptance criteria

Once the waste streams for disposal are identified the WMO can develop a waste analysis plan to ensure what waste characteristics are acceptable for disposal and which ones are not. The waste analysis plan also identifies where the waste is located, and what waste has been prepared for shipment, etc. The acceptance criteria are usually based on regulations or laws that provide a definition of waste types that can be disposed of. The waste analysis plan may also provide information that can be used to develop shipping schedules, packaging requirements, and target sites for shipment. The waste acceptance criteria set the requirement for characterization and certification of waste for shipment to the repository.

4.4.4. Waste characterization and certification

Waste characterization may occur at the generator site or an interim predisposal storage area and consists of analyses and/or documented knowledge that can confirm what waste exists in the container or stream, levels of radioactive activities, and identified hazardous materials such as pressurized vessels (fire extinguishers, etc.) corrosive material, ignitable material, explosive, liquids, and other materials that can affect the long term performance of the repository.

Once the waste has been characterized and documented to meet the waste acceptance criteria (WAC) developed for the repository, it can be certified and documented for disposal. Plans should be in place to manage those wastes that will not be accepted by WAC.

4.4.5. Configuration management system

The configuration management plan specifies processes ensuring general plant design description and systems design descriptions that are supported by programme implementation documents. This is a key element to the safe operation of the repository as it may affect areas such as maintenance, construction of additional facilities, operational safety, safety systems, procedures, processes, and quality assurance. The configuration management plan ensures a living document process for updates and plant modifications that can be referred to in the closure phase of the project. Drawings, engineering change orders, prints, and related documents must be checked for accuracy through a quality assurance programme, controlled and recorded by the engineering department, and monitored by operations. The configuration management process should retain all data concerning waste disposal activities from characterization to disposal.

Knowledge management covers all aspects of the site understanding, repository design and safety case development, and includes the integration, management system, communication and maintenance/archiving of such knowledge – including data, information, understanding and experience. A national and as well international support is needed, in order to feed the system continuously with professionals and to avoid losing experience when staff retire or leave the company. Knowledge is not only explicit, i.e. what can be found in files and documents. It has an important component that is the employee's tacit knowledge. Tacit knowledge can be managed and preserved through maintaining competence and appropriate human resources management and development.

It is recognized that data, software, documents, records and other information are generated over periods of decades and result in a substantial volume. The information set may be relied upon to support the safety case or safety assessment many years after its generation. Thus, a comprehensive configuration or knowledge management system is beneficial to manage the sheer volume of information that will be generated using a number of technologies (i.e. digital, paper). Issues of both knowledge storage and retrieval should be considered in association with technological changes.

4.4.6. Management systems

The integrated management system programme must include documented evidence of all aspects of the repository operation [35, 36]. The programme performs audits on waste characterization and certification processes to ensure proper procedural compliance, while simultaneously providing a corrective action plan and feedback process of continuous improvements. Areas such as procurement, construction/plant modification, regulatory compliance, and disposal operations are continually assessed by management systems during the life cycle of the repository.

The waste management organization must incorporate and be committed to management systems that provides the highest level of quality of all its products, services and business activities. The appropriate management systems, principles and practices are applied in fulfilling the organization's responsibilities to its customers, regulators, stakeholders and the general public under a well-established management system programme [37].

Clear lines of responsibility, planning, continuous improvement, open communication, teamwork, cooperation and mutually beneficial partnerships are required. As a learning organization, it is necessary to continually manage and improve the nuclear waste management processes on the basis of factual information, measurement and feedback. Management manuals and programme documents define organizational responsibility, authority and accountability for the quality of all work and resulting outputs.

Classification of repository structures and components important to the performance of the repository (as required in the safety case) are identified in a management system programme. Natural and engineered barrier systems are classified in accordance with criteria that recognize their importance in meeting the performance objectives identified in the safety case. As the design of the repository evolves, supporting classification analysis for the management system be reviewed and updated as necessary.

In the frame of management systems, establishing a monitoring programme is an important responsibility of the waste management organization. The effectiveness of the management system should be monitored and measured to confirm the ability of the processes to achieve the intended results and to identify opportunities for improvement. Management at all levels should carry out self-assessment to evaluate the performance of work and the improvement of safety culture. Independent assessments should be carried out to monitor quality and management should evaluate the results, take necessary action and record the actions taken and reasons for taking them. A management system review should be conducted at planned intervals to ensure its continuing suitability and effectiveness and its ability to enable the objects to be achieved.

The review should identify whether there is a need to make changes to improve the policies, goals, strategies, plans, objectives and processes. Non-conformances and corrective and preventative actions should be determined and remedial actions taken to prevent a recurrence. Opportunities for improvement should be identified and action to improve the processes should be selected, planned and recorded.

4.4.7. Integrated safety systems

The operations must address safety during both the operational and post-closure periods; and should consider any requirements for monitoring, nuclear safeguards, concurrent underground activities (excavation and waste emplacement), retrievability or reversibility, and closure. Scientific understanding, design of engineered barriers and the development of a safety case are subject to iterative improvement and adapting to a level of detail commensurate with the current step in the repository programme. This input includes the available level of understanding and detail of an overall safety concept (including understanding of hazards and/or risks, specifications of safety requirements, safety assessment and available lines of arguments for the safety case). It includes the available understanding of the natural environment as well as interactions and evolutions of engineered barriers within this environment and the characteristics of the waste disposed in the repository.

To ensure adequate consideration of prior knowledge as key input to the next step of programme implementation, an integrated safety management system (ISMS) could be set up, as has been done e.g. at the Waste Isolation Pilot Plant (WIPP) repository. The ISMS includes a quality management system (QMS), safety requirements, and other management systems, including the environmental management system. It envelopes all programmes and systems based on the following principles:

1) Plan all work activities;
2) Identify hazards;
3) Develop and incorporate hazard controls;
4) Perform work according to procedure;
5) Continuous feedback and improvements.

4.4.8. Nuclear safeguards and security

Operations must ensure that physical and cyber security measures are in place to protect information concerning special nuclear materials such as enriched uranium, plutonium, and possibly spent fuel. In addition, the programme must identify and develop adequate physical and cyber security measures to prevent access to the waste. While physical safeguards may be easier to provide for once waste has been emplaced into the repository, other situations such as interim surface storage or transfer/transport should also be taken into account for developing adequate safeguards within the programme [34]. These considerations also include development needs related to the monitoring of nuclear materials, accounting for fissile material, etc.

4.4.9. General safety requirements

The programme needs to include a process to establish safety requirements. At the early stages of a programme, this can be done based on IAEA Safety Standards Series (e.g. References [1-3]) and available knowledge gained from similar fields of activity, such as the operation of other nuclear facilities to specify requirements associated with hazardous waste (i.e. as pertaining to chemical hazards) and radioactive waste handling, waste storage, possibly waste reconditioning, overall radioprotection, etc. In addition, relevant prior experience with safety guidelines for subsurface construction and operation may be obtained from mining or civil engineers. It will also require on-going analysis of the available regulatory and legal framework, to identify all safety requirements.

As operations progress, safety requirements will be identified to a greater level of detail, in the direct relation to the level of knowledge on the natural environment and level of detail of facility design. Among other things, the geological disposal programme should ensure the prevention of criticality of fissile materials during the operational and post-closure periods. The overall programme links safety requirements and design by establishing a Configuration Management Plan that executes processes ensuring that General Plant Design Description and Systems Design Descriptions are supported by programme implementation documents.

4.4.10. Workplace health and safety

Workplace health and safety programmes for a repository must address both the risk of radiological exposure during waste emplacement operations and the risk associated with construction and industrial activities. The operator, as an employer, is ultimately responsible for worker health and safety and for ensuring that every reasonable precaution will be taken to protect workers.

Like nuclear power plants, there needs to be a programme in effect that identifies and maintains control of radiological hazards associated with the operation of the nuclear facility. This requires the need for sound operational procedures, work management practice, radiological surveys and programmes that monitor radiation exposure. Nuclear plant operators have found that occupational exposures are best managed through effective job planning, implementation and review to ensure that exposures are “As Low As Reasonably Achievable” (ALARA). Occupational exposure has to be determined on an individual worker basis and monitored over the working lifetime.

There also has to be well established occupational health and industrial safety programmes that address the normal risk associated with construction, industrial operations and subsurface mining excavation and operational work. This includes programmes to identify the regulatory controls and design standards needed to reduce the risk associated with excavation work such as that carried out in subsurface tunnelling and mining operations.

The implementing organization must place high priority on the health and safety of its employees. Protection of employees from injury or occupational disease is a major objective throughout the programme. The implementing organization will make every effort to provide a safe, healthy work environment. All supervisors and workers must be dedicated to the continuing objective of reducing risk of injury.

Supervisors will be held accountable for the health and safety of workers under their supervision. Supervisors are responsible to ensure that machinery and equipment are safe and that workers work in compliance with established safe work practices and procedures. Workers must receive adequate training in their specific work tasks to protect their health and safety. Every worker must protect his or her own health and safety by working in compliance with the law and with safe work practices and procedures established by the company. It is in the best interest of all parties to consider health and safety in every activity. Commitment to health and safety must form an integral part of the organization from the senior manager to the workers.

4.4.11. Conduct of maintenance and operations

Conduct of maintenance is an operational programme of the facility to ensure that equipment remains functional to serve the purpose of the repository mission and is critical to the success of the overall disposal programme. Conduct of maintenance programmes should be incorporated into the overall operational phase and be closely associated with the configuration management programme.

Conduct of operations is a programme established to ensure safe operations during the life cycle of the facility. It consists of several key attributes such as shift turnover processes, log record keeping, lock-out/tag-out safety processes for energized equipment, communications, operator aides, etc. This programme is part of the overall training initiative and assessed on a regular basis by management to assure operational capabilities of the facility, personnel, and equipment**.**

4.4.12. Emergency management

Each repository should have a programme to ensure that evacuation and response activities can be conducted to protect the worker, public and the environment in the event of an accident or radioactive/hazardous release [37]. The emergency management plan must be derived from hazards identified in the early stages of developing a safety envelope for operations. This consists of an Emergency Preparedness Hazards Assessment, with emergency plan (evacuation routes, staging areas, etc.), action levels (site evacuation, facility evacuation, general area evacuation) and activation of a centrally or remotely located emergency operations centre.

4.4.13. Regulatory compliance and change

For sustaining the waste management and disposal programme, the MS government will have established a national policy for safe management of radioactive waste for the protection of human health and the environment. The policy provides the basic safety philosophy for radioactive waste management and the steps necessary to ensure its implementation.

Subsequently, or concurrent with the development of the safety policy, safety regulations are made that define the post-closure performance standards and the means for demonstrating compliance. Programmes may be put into place to perform monitoring activities during facility construction, operations, closure and during post-closure to ensure the regulatory safety requirements are being met.

4.4.14. Monitoring

Monitoring information can assist the repository operator (and society) in taking decisions at various stages of a repository development programme [32]. Monitoring is expected to play an important role in both development and execution of geological disposal programmes. In particular, monitoring would provide essential information for the satisfactory completion of the various phases of the repository programme and, in doing so, will strengthen confidence in long term safety, which is the key objective of radioactive waste disposal. Delivering an effective monitoring programme through all stages of development will help to enhance public and key stakeholder confidence and will be an important support to the decision making process. Monitoring for geological disposal falls into two distinct areas: long term safety objectives and control activities.

To deliver an effective programme of monitoring across the phases will require a specification of monitoring requirements to be developed in advance of each phase of development and incorporated within the quality management system [38] to ensure effective management by identifying and/or developing appropriate techniques in time. Monitoring objectives may vary at different stages. The link with safeguards measurements should be organized when appropriate.

Due to the long timescales being considered, monitoring for long term safety may be limited to confirming insignificant or no change. After closure, the long term safety of geological disposal facilities, due to the duration of the hazard associated with the waste, cannot rely on institutional controls, including monitoring. However, continuing monitoring is likely to be a societal demand for some time after closure.

Routine monitoring of a range of operational activities will also be required. The activities to be monitored are similar to those in nuclear facilities, underground excavations and industrial plants. These activities are designed to ensure operational safety for both personnel and the public.

4.4.15. Stakeholder involvement and public affairs

The report in Ref. [25] sets out some technical, structure, process and behavioural factors influencing acceptance of geological disposal. The report does not advance prescriptions about what countries should do but aims to provide insights which may prove relevant. Some key factors were already discussed in this chapter. The report noted that as the programme moves through the stages of development and implementation, considerations associated with technical factors increasingly influence public and political acceptance. It also noted that failure to establish an effective framework (in the global context of energy production) tends to reduce public acceptance and that the rationale of using a “stepwise” process was that it allowed society in general to move forward or re-assess at a comfortable pace.

Recent experience in the stakeholder engagement programmes of some member countries has demonstrated that adequate stakeholder engagement may have been instrumental in improved political and societal acceptance of government policy and legal frameworks for geological disposal programmes (e.g. NWMO (Canada), Commmittee on Radioactive Waste Management - CoRWM (UK)).

Maintaining openness and transparency during the operational phase will be an important component of a successful programme of stakeholder engagement. Planning for stakeholder engagement should include provision of skills and expertise in communication and other relevant stakeholder interactions. Good stakeholder engagement provides a basis for confidence building, as it helps the operator to appreciate and effectively address issues which stakeholders consider important.

Unsuccessful stakeholder involvement might jeopardize acceptability and might cause serious setbacks to the programme, e.g. through strong local opposition making progress difficult to achieve, due to legal challenges preventing the programme from moving forward, and due to the impact the stakeholder opposition may have on political perception and on the overall policy framework in place for the programme.

4.4.16. Transportation programme

The transportation programme serving the repository can be complicated in that specific requirements for shipping packages, containers, transportation routes, negotiations with stakeholders and alliances need to be achieved and a strong public affairs programme in place. This would permit designed routes to be successfully identified and confirmed for shipments to traverse through dense population areas, infrastructures that require maintenance and long term inspections. Emergency Management programmes should be developed to ensure radiation protection, hazardous materials management, and scene controls are in place in the event of an accident resulting in a release. The overall transportation programme is very stakeholder intense and requires a robust public affairs programme to ensure transparency.

4.4.17. Routing and transportation corridors

Transportation corridors must be established early in the programme and consistently maintained with public involvement throughout the life cycle of the repository. It is required that these corridors be thoroughly negotiated with Member State officials, city officials and government departmental officials with public input to ensure transparency and identification of shipping routes to permit waste to pass through congested and densely populated areas. This activity involves a strong stakeholder input and public affairs programme that is robust and provides for continuous improvement and feedback. Vehicular inspections, both tractor and trailer can be expected including driver training and physical (health) requirements.

4.4.18. Packaging requirements

The various containers and shipping packages that are used to transport waste must undergo a rigorous testing phase under the scrutiny of a regulatory agency or department to ensure no breech of container during an accident event. These shipping packages will vary depending on type of waste under transport, i.e. spent nuclear fuel, high level, intermediate level and low level waste. Site operations must ensure that a process is in place that permits the safe opening of packages and waste handling to retrieve waste and prepare for emplacement in the repository.

4.4.19. Retrievability or reversibility operations

Although according to the IAEA definition, disposal is "(e)mplacement of waste in an appropriate facility without the intention of retrieval", the issue for retrievability is often raised by members of the public and may be viewed as a reflection of their current level of confidence in the safety of disposal; providing the option for retrieval may improve public confidence and trust. In some IAEA Member States' geological disposal programmes, requirements for reversibility of waste management decisions and actions, including provisions for the retrievability of waste packages after their disposal, have been introduced in the national legislation or regulations regarding long term radioactive waste management. In some other programmes, where such requirements have not been formally adopted, radioactive waste management organizations have chosen to introduce reversibility and/or retrievability provisions in their disposal concept. Some key considerations for planning and design are set out below.

It is generally accepted that geological disposal facilities should be designed to be passively safe with no intention to retrieve the waste. Nevertheless, various reasons have been discussed for including the concept of reversibility and the ability to retrieve the emplaced wastes in the disposal strategy. The intention is to increase the level of flexibility and to provide the ability to cope with or to benefit from, new technical advances in waste management and materials technologies and to respond to changing social, economic and political opinion.

The requirement to be able to retrieve waste from a geological repository has technological implications in terms of the design of the disposal system and the associated repository infrastructure [19]. During a potentially long period of repository implementation and operation, some critical decisions need to be made about how, when and if various implementation steps should be taken. This may include decisions as to whether the emplaced waste has to be retrieved. Since waste retrieval operations could be expected to take as long as emplacement operations, retrieval operations should be better accommodated in the design of the geological repository, if they are required.

4.4.20. Closure

The closure of the facility begins in the operational phase and continues through to the actively managed part of the life cycle of the repository. Configuration management systems document all changes that could impact the closure such as piping diagrams, wiring, contaminated equipment, structures, systems and components, etc. The closure phase is a multi-phased project that includes decommission and cleanup of the existing structures and repository including sealing the subsurface structures**.** This process cannot be specifically predicted in a generic sense, but can be planned for each facility predicated on the functional classification of the processes the facility is managing and the type of waste to be disposed of in the repository. Long term monitoring may be chosen to ensure environmental protection and prevention of human interference with the closed facility over time. The repository will need to be closed following predetermined closure plans and designs developed though safety case and safety assessments that have been conducted during operations. Any long term monitoring that may be required during post-closure will have been previously agreed to by all regulatory entities and the public.

4.5. POST-CLOSURE PHASE

Given the duration of geologic repository programmes, it must be recognized that the final requirements for post-closure monitoring or institutional controls, if any, will be defined by future generations. However, it is expected that throughout the repository development programme, even from its initial phases, the waste management organization will have some concept of a post-closure monitoring programme. This implies the regulatory authority will likewise have articulated potential institutional controls or other requirements for the post-closure phase, though at this point, the safety of the site relies entirely on passive systems and the repository is expected to perform as designed. As a matter of public confidence, post-closure monitoring and additional safety measures (e.g. site access restrictions) may be required during the institutional control period.

Lastly, there may be requirements for permanent markers of the facility (e.g. monuments, tracers, etc.) to be erected after the institutional control period (often considered to be 100 to 300 years). As with post-closure monitoring, final requirements, if any, for permanent markers will likely be decided by future generations, though a conceptual plan for permanent markers may be expected much earlier in the programme.

5. LESSONS LEARNED

Lessons are defined as having the possibility to either reduce the duration of the overall programme or avoid early termination of the programme. Experience has been gained over the years in geological repository programmes through almost all phases of development. Some geological repositories are already in operation and lessons have been learned during the process from initial programme development through to the stage of actual disposal. The following pages outline lessons learned in each main stage of the programme.

In Annex, experiences related to Finland, Belgium, France, USA, Germany, UK and Canada are developed and offer feedback about the planning and design of a geological repository programme. There is no intent to rank or prioritize the lessons presented below, as each situation is quite unique.

5.1. GEOLOGICAL REPOSITORY PROGRAMME

Experience shows that the time schedules originally envisaged prove to be ambitious in most countries (except Finland). As a result, in order to maintain nuclear power plants in operation and the spent fuel and/or vitrified waste stored in good safe conditions, it is important to plan additional interim storage capacity as soon as a need arises.

In order to minimize the potential for a programme to be blocked or interrupted, it is of great importance to maintain several options as long as possible and to be ready to develop alternatives when or if required. Experience in Germany with Gorleben siting suggests that a contingency plan would have been beneficial.

The design objective is to develop an “acceptable” solution rather than to try to offer in advance the “best” solution. Trying to develop a so-called ”best” solution can lead to public acceptance problems if the so-called “best solution” needs to be changed or adjusted for whatever consideration. In relation to this, the fact that the reference concept design (KBS-3) remained the same in Finland for more than 20 years contributed positively to public acceptance. It will likely be adjusted and optimized at the time of operations.

In Canada, the NWMO has recognized the benefits of using existing proven infrastructure and technology in developing a waste management strategy.

A geological disposal programme is a multidisciplinary programme and it is of great importance to advance and progress in each field at the same pace. It would not be consistent for example to develop a very detailed engineering programme ahead of the host rock characterization and site selection. The rate of advance of the overall technical programme is the rate of advance in relevant knowledge of the slowest discipline or field. However, experience shows that local political and public acceptances may slow down the technical and hence actual advance of the programme. The overall planning advance of the programme is driven by non-technical considerations in most countries.

5.2. PROGRAMME DEVELOPMENT AND IMPLEMENTATION

- *Early and frequent public involvement throughout the repository programme implementation is considered a prerequisite to a successful programme; it does not however provide any guarantee of success.* France for example has developed a regulatory framework specifically organizing public involvement in the disposal programme (1991 and 2006 Acts); in addition to conventional public inquiries, public debates with the population in that country have to be organized during the whole siting process. Finland established cooperation groups between the candidate municipality and the implementing organization in order to exchange information during initial field investigation (1987), which proved to be beneficial.
- *Establishing very early on a policy and clear decision milestones assists repository programme progress.* By establishing a multi-year development plan with specific milestones and objectives to be achieved before progression to subsequent phases, all parties (i.e. government, regulator, operator and public) are committed to facing the decision process even in the face of imperfect knowledge or other uncertainty. As suggested by the USA experience, it might be appropriate to establish these milestones and goals during the initial or subsequent legislative efforts establishing the overall repository programme policy and objectives. The lack of institutional framework in France in the 1980s led to a setback in the site selection process; it was solved by the introduction of specific legislation addressing high level waste (1991 Act).
- *Public and local political opposition has often been the reason why the programme for geological repository has been delayed or deferred.* A factor in the failure of the UK programme in the 1990s was the lack/***absence*** of structure and process for such a major national programme. In order to prevent such a situation, it is considered that commitment by the national parliament or the highest national authority outlining the importance of the programme through a special act or law might balance the opposition and set the real national priorities (Decision in Principle in Finland, 2008 White Paper in the UK.)
- *Overlapping of regulations should be avoided as much as possible*; for example the situation of radioactive and *chemically* hazardous waste (e.g. mercury), for which multiple disposal regulations apply, is considered very difficult to comply with (USA). It is preferable that the regulatory framework and safety requirement be cohesive and practical.
- *The "thermal" aspects in the strategy should be decided upon early.* The siting and design of repositories for heat generating waste forms need to consider the phenomenological effects arising from the thermal influence of the waste. There are many considerations in setting a thermal strategy that affect the overall repository system design and which represent complex trade-offs between, for example, operations, storage, surface and *underground* engineering, system and component performance, influence on phenomenology, etc. The time duration of the interim storage can be optimized to reduce complex interactions and simplify design aspects that may also affect complex interactions between the pre-closure, post-closure and waste management systems. By deciding early the

"thermal" strategy, later changes in the programme that would cause significant revision of the safety assessment and of the overall design of the facility can be avoided.

- *The reprocessing strategy* should be decided upon early in the geological repository programme. Whether direct disposal for spent fuel is decided or not is a very important milestone in the geological repository programme. In most countries, this type of decision is part of the government/parliament responsibility (decision in the 1970s in the USA for direct disposal). This decision impacts greatly on the design of the repository.
- *Availability of resources* has to be assessed and committed by the highest authority in the country in order to perform the geological disposal programme. For example, funding mechanisms and financial resources have to be established early on in order to assure completion of the programme. The same applies for availability of resources which are specifically needed to achieve the completion of the programme (copper in Sweden and Finland, bentonite as engineered barrier, etc.).
- *The specifics of a facility need to comply with the regulatory framework of a geological repository.* A geological repository is at the same time a nuclear facility (usually on surface regulated by common nuclear regulations) and also an underground facility (often ***regulated*** by specific mining regulations for countries with past or existing mines). This uncommon situation is quite specific and recent. The regulator has to define very early in the process the framework in which the geological repository will be regulated for example from occupational, health and safety matters (mining regulation or not).
- *Participation of the nuclear safety authority in the dialogue with the public and local stakeholders* might have been beneficial (STUK in Finland) in order for the public to gain confidence into the project. To achieve that, it is necessary that the nuclear safety authority be perceived as a real independent authority which has considerable competence in appropriate fields.

- *Organizations responsible for assessing long term safety should have high credibility with the regulator and/or public.* For both the operator and the government, perceptions of trust are a significant contributing factor with regard to public acceptance of a geologic repository. Public perception studies have suggested national technical organizations, universities, or independent expert groups have higher public credibility than some government agencies and/or commercial entities.

5.3. INTEGRATION OF DESIGN ON PLANNING DEVELOPMENT

5.3.1. Site selection

Selecting a site for geological disposal very early in the process before full characterization of the site would be risky. It is only after full characterization of the site through an exploratory programme performed from surface and/or from underground (characterization facility for example) that a site might be selected for a repository. The characterization programme and the overall siting programme will lose credibility from the stakeholder's point of view if the decision to site a repository is confirmed too early, for example before the completion of the characterization programme. In order to offset that risk, some countries (France, Sweden for example) have decided to run in parallel separate characterization programmes on different areas and/or host rocks. It might improve the credibility of the decision taken if a real choice exists between different sites. In addition, selecting a disposal site requires public and political acceptance; by deciding for a site prior to political acceptance might generate programme setback (e.g. Gorleben in Germany).

5.3.2. Site characterization

Each site (i.e. area and/or location) and its characterization requirements are unique and represent a major element in the geologic repository programme. Each site has unique natural characteristics (hydrology, geology, etc.) which must be studied in sufficient detail to support the site specific modelling expected for a proper safety assessment. Some phenomena (e.g. diffusion), which are noted by low rates of change or are spatially dependent, may require significant time to be characterized at relevant scales. While it may be possible (and is encouraged) to capitalize on more generic data from other sites and/or URLs, when this is appropriate, site specific data will be required to establish confidence in the site specific characteristics that influence long term isolation performance. Experience suggests site characterization can take many years to reach a state of knowledge sufficient to support a licensing safety case. The availability of adequate baseline (pre-disturbed) data for certain characteristics (e.g. surface, underground, climate, environmental, etc.) is a significant contributor to safety assessments and should be planned to be collected as soon as practical.

All technical issues have to be addressed early on in the design process. Topics such as criticality, gas generation, retrievability options, and safeguards are integral parts of the design studies at the time of site selection.

5.3.3. Licensing, construction and operation

Understanding of long term behaviour of disposal components is essential for the licensing, construction and operation of a geological repository. For the engineered barriers that are relied upon in long term performance, the phenomenology of material performance must be understood and defensible for use in the safety assessment of long term performance, in particular for post-closure. Quite minor changes in engineered barrier system (EBS) design might imply long lasting or innovative scientific work. Such work has to be planned very much in advance in order not to impact on the overall schedule (Belgian experience). The following points are noted:

- *Design changes to systems, components or structure important to long term performance have non-linear implications for planning.* Once a reference design is established, particularly beyond the conceptual stage, the effect of design change is pervasive and significantly impacts the safety case and safety assessment. When a system, component or structure important to long term safety is changed, it can affect the assessment of long term performance and may require new or revised analysis or material characterization;
- *Engineered barriers* are important components of the long term safety of the repository. Design of the barriers will be adjusted to the actual conditions encountered underground and to the final inventory to be disposed of in the

geological repository. It is only after a full characterization programme performed underground that detailed engineering of the barriers can be performed;

- *Unique technological developments are likely to be performed in advance of the actual operations of a geological repository.* This is due to the fact that some requirements are quite specific and somewhat new. In order to gain confidence from the public and all stakeholders, it may become necessary to develop actual demonstrations of the new technological tools which will be implemented in the geological repository.

5.3.4. Closure

The initiation of disposal operations does not mean the end of public involvement or an end to technical initiatives. Maintaining public confidence throughout the repository disposal operations phase is crucial to realizing the full potential of the repository capability. On-going public involvement and communications should be maintained and the increasing importance of operational issues on perceptions of local, near term safety should be recognized. In addition, while it may be possible to limit some technical initiatives, long term performance monitoring or performance confirmation efforts can be expected to continue.

5.3.5. Post-closure

No significant experience has been developed so far for the post-closure phase of a geological repository.

6. CONCLUSIONS

Deep geological repository programmes are unique in their planning and execution, which for on-going programmes have already lasted for several decades. They involve not only significant engineering, but also substantial measures of science and politics. As such, one should not plan the programme only as a traditional, well-constrained engineering project. The engineering aspects of a geologic repository tend to be well understood, with sufficient experience to accurately plan the effort and resources required (though added complexity arises because design changes may impact the safety case, and the analysis of such a potential impact needs to be planned for). In comparison, the scientific effort (site characterization, process modelling, etc.) has certain elements of basic research and is less predictable in the outcome, duration or resources that may eventually be required. Even greater uncertainty exists in planning for the political aspects of the programme.

Accordingly, the geological repository programme planner would do well to account for uncertainty with the thoughtful use of contingency in estimating both time and resources, and capitalize on the existing work of other programmes where available and relevant. A flexible and agile programme is needed to anticipate changes that may arise from new information or conditions (technical, regulatory or political). Many of the active geological repository programmes to date are characterized by schedule durations and costs beyond original expectations. The planning aspects considered most important to geologic repository programmes were provided in Section 3, and reflect a collective experience developed after substantial investment in time and resources by those nations with more advanced repository programmes. Regardless, in the perspective of a decades-long repository programme, these observations represent a limited experience over a wide variety of technical and political conditions that exist. Caution is advised in applying these experiences directly to developing programmes.

A geological repository programme benefits from the waste disposal policy and regulatory framework established prior to the initiation of substantial site work. These should be clear, comprehensive and in line with accepted principles promulgated internationally.

International collaboration holds many advantages for both the new and more developed programmes. This is especially true for the overall planning and design of a repository programme. Evidence suggests that relatively new geological repository programmes benefit from collaboration with the more developed programmes by capitalizing on the experience in developing a well-adapted institutional and regulatory framework, as well as in technical areas, such as research in URLs, data and modelling development, design considerations, safety assessment methodologies, management practices, and stakeholder involvement processes.

Mature programmes continue to benefit in a similar manner from international collaboration primarily through the sharing of knowledge and independent review, which consequently enhances the technical confidence established with the regulatory agencies and the public.

Public participation and stakeholder involvement has great importance to the planning of a geologic repository programme. Repository programmes that are envisioned to progress to closure or the post-closure phase are noted for programme durations measured in generations, and consequently take on a new significance regarding public perceptions and concern of the immediate generation. Thus, in planning the public involvement processes, one needs to take into account the concerns of the local community regarding personal safety and/or benefits, over the expected operational period that may last beyond the present generation.

Establishing very early on a policy and clear decision milestones assists repository programme progress. By establishing a multi-year development plan with specific milestones and goals needed for progression to subsequent phases, all parties (i.e. government, regulator, operator and public) are committed to facing the decision process even in the case of imperfect knowledge or other uncertainty.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Disposal of Radioactive Waste, Specific Safety Requirements, IAEA Safety Standards Series No. SSR-5, IAEA, Vienna (2011).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Geological Disposal Facilities for Radioactive Waste, Specific Safety Guide, IAEA Safety Standards Series No. SSG-14, IAEA, Vienna (2011).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management, INFCIRC/546, IAEA, Vienna (1997).

[5] VERHOEF, E., MCCOMBIE, C., CHAPMAN, N., *Shared Regional Repositories: Developing a Practical Implementation Strategy*, Euradwaste Conference, Luxembourg (2008).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Developing Multinational Radioactive Waste Repositories: Infrastructural Framework and Scenarios of Cooperation, IAEA-TECDOC-1413, IAEA, Vienna (2004).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Viability of Sharing Facilities for the Disposal of Spent Fuel and Nuclear Waste, IAEA-TECDOC-1658, IAEA, Vienna (2011).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Policies and Strategies for Radioactive Waste Management, IAEA Nuclear Energy Series No. NW-G-1.1, IAEA, Vienna (2009).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, General Safety Requirements, IAEA Safety Standards Series No. GSR Part 1, IAEA, Vienna (2010).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Institutional Framework for Long Term Management of High Level Waste and/or Spent Fuel, IAEA-TECDOC-1323, IAEA, Vienna (2002).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Stakeholder Involvement in Nuclear Issues, INSAG-20, IAEA, Vienna (2006).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Siting of Geological Disposal facilities, IAEA Safety Series No. 111-G-4.1, IAEA, Vienna (1994).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, Specific Safety Guide, IAEA Safety Standards Series No. SSG-23, IAEA, Vienna (2012).

[14] OECD NUCLEAR ENERGY AGENCY, Post-Closure Safety Case for Geological Repositories: Nature and Purpose, OECD, Paris (2004).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Experience in Selection and Characterization of Sites for Geological Disposal of Radioactive Waste, IAEA-TECDOC-991, IAEA, Vienna (1998).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Hydrogeological Investigations of Sites for the Geological Disposal of Radioactive Waste, IAEA Technical Series Report No 391, IAEA, Vienna (1999).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Scientific and Technical Basis for the Geological Disposal of Radioactive Waste, IAEA Technical Report Series No 413, IAEA, Vienna (2003).
[18] INTERNATIONAL ATOMIC ENERGY AGENCY, The Use of Scientific and Technical Results from Underground Research Laboratory Investigations for the Geological Disposal of Radioactive Waste, IAEA-TECDOC-1243, IAEA, Vienna (2001).
[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Geological Disposal of Radioactive Waste: Technological Implications for Retrievability, IAEA Nuclear Energy Series No NW-T-1.19, IAEA, Vienna (2009).
[20] OECD NUCLEAR ENERGY AGENCY, Timing of High-Level Waste Disposal, OECD, Paris (2007).
[21] INTERNATIONAL ATOMIC ENERGY AGENCY, "Reference Biospheres" for Solid Radioactive Waste Disposal, IAEA-BIOMASS-6, IAEA, Vienna (2003).
[22] OECD NUCLEAR ENERGY AGENCY, Systematic Approaches to Scenario Development, OECD, Paris (1992).
[23] OECD NUCLEAR ENERGY AGENCY, Features, Events and Processes (FEPs) for Geologic Disposal of Radioactive Waste, OECD, Paris (1999).
[24] OECD NUCLEAR ENERGY AGENCY, Management of Uncertainty in Safety Cases and the Role of Risk, OECD, Paris (2004).
[25] INTERNATIONAL ATOMIC ENERGY AGENCY, Factors affecting Public and Political Acceptance for the Implementation of Geological Disposal, IAEA-TECDOC-1566, IAEA, Vienna (2007).
[26] INTERNATIONAL ATOMIC ENERGY AGENCY, Classification of Radioactive Waste, General Safety Guide, IAEA Safety Standards Series No. GSG-1, IAEA, Vienna (2009).
[27] INTERNATIONAL ATOMIC ENERGY AGENCY, Use of Natural Analogues to Support Radionuclide Transport Models for Deep Geological Repositories for Long Lived Radioactive Wastes, IAEA TECDOC-1109, Vienna (1999).
[28] U.S. DEPARTMENT OF ENERGY, Nuclear Waste Policy Act of 1982, U.S. Department of Energy, Washington D.C. (1983).
[29] JOURNAL OFFICIEL DE LA RÉPUBLIQUE FRAÇAISE, LOI n° 91-1381 du 30 décembre 1991 relative aux recherches sur la gestion des déchets radioactifs, JORF, n°1 (1992).
[30] ANDRA, Radioactive Materials and Waste, Planning Act of 28 June 2006, ANDRA, Paris (2006)
[31] OECD NUCLEAR ENERGY AGENCY, Confidence in the Long-Term Safety of Deep Geological Repositories: Its Communication and Development, OECD, Paris (1999).
[32] INTERNATIONAL ATOMIC ENERGY AGENCY, Monitoring of Geological Repositories for High Level Radioactive Waste, IAEA-TECDOC-1208, IAEA, Vienna (2001).
[33] INTERNATIONAL ATOMIC ENERGY AGENCY, Occupational Radiation Protection Safety Guide, IAEA Safety Standards Series No. RS-G-1.1, IAEA, Vienna, (1999).
[34] INTERNATIONAL ATOMIC ENERGY AGENCY, Technological Implications of International Safeguards for Geological disposal of Spent Fuel

and Radioactive Waste, IAEA Nuclear Energy Series No NW-T-1.21, IAEA, Vienna, (2010).
[35] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for the Disposal of radioactive Waste, IAEA Safety Standards Series No. GS-G-3.4, IAEA, Vienna (2008).
[36] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for the Development of Disposal Facilities for Radioactive Waste, IAEA Nuclear Energy Series No NW-T-1.2 (2011)
[37] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of the Management System for Facilities and Activities, IAEA Safety Standards Series No. GS-G-3.1, IAEA, Vienna (2006).
[38] INTERNATIONAL ATOMIC ENERGY AGENCY, Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GS-R-2, IAEA, Vienna (2002).

Annex I

FINLAND

I–1. WASTE MANAGEMENT POLICY

In 1983, the Finnish Government set the objectives and the schedule for the national waste management programme in the Government decision. The practical implementation of the waste management, targets and schedules of the associated research and development programme were originally defined in this Government decision. The Nuclear Energy Act, promulgated in 1987, sets forth the general principles for the use of nuclear energy, the implementation of nuclear waste management, the licensing and control of the use of nuclear energy and the competent authorities [1]. This act authorizes the Ministry of Trade and Industry (KTM) to define the principles and schedules for nuclear waste management. KTM relies on the Radiation and Nuclear Safety Authority (STUK) to supervise and control the aforementioned activities involving radiation. Before the Finnish Government grants a construction and operation license for any nuclear facility, the Parliament must release a policy decision called the “Decision-in-Principle” (DiP).

According to the Nuclear Energy Act, nuclear waste generated in Finland must be processed, stored and disposed of in Finland. In 1995, the two Finnish nuclear power companies, Teollisuuden Voima Oy (TVO) and Fortum Power and Heat Oy (Fortum), established Posiva Oy (Posiva) to implement the final disposal programme for spent nuclear fuel and the related research, technical design and development (RTD or TKS, in Finnish) activities. Posiva is still jointly owned by TVO and Fortum. Other nuclear wastes are handled and disposed of by the power companies themselves.

With an amendment to the Nuclear Energy Act in 1994, the Government required that all types of Finnish nuclear waste-related activities should be carried out in Finland. KTM further refined the overall waste management policy in its decisions of 19 March 1991, 26 September 1995 and 23 October 2003. Nuclear waste is defined in the Nuclear Energy Act as radioactive waste in the form of spent fuel or any other waste generated in connection with the use of nuclear energy. Spent fuel is fuel discharged from the core of a nuclear reactor. Finland currently has four commercial nuclear power units: two in Loviisa, owned by Fortum, and two in Olkiluoto, owned by TVO. A fifth unit is under construction at Olkiluoto. Spent fuel from Olkiluoto OL1&2 is mainly Boiling Water Reactor (BWR) type, while that from Loviisa is Pressurized Water Reactor (VVER) type. Spent fuel from the new reactor at Olkiluoto OL3 will be European Pressurized Reactor (EPR) type.

I–2. SPENT FUEL DISPOSAL CONCEPT

The Finnish spent fuel management is based on a “once-through” fuel cycle. The spent fuel is disposed of directly without reprocessing through deep geological disposal. The direct disposal option was considered as suited to the conditions prevailing in the 1990s while anticipating the then current and foreseeable costs of the fuel cycle together with possible future alternatives and developments.

The plans for the disposal of spent nuclear fuel are based on the KBS-3 waste disposal concept in crystalline bedrock. Fig. I-1 shows the vertical option of the KBS-3 concept (KBS-3V).

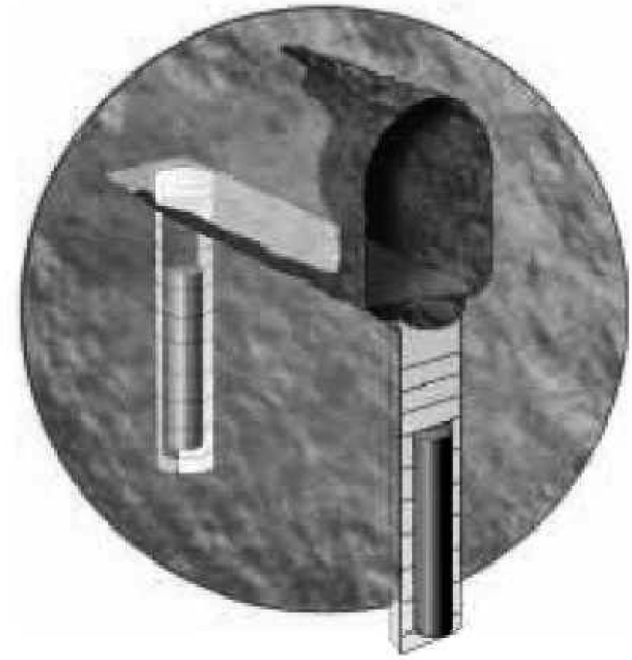

FIG. I–1. The KBS-3 concept for the disposal of spent nuclear fuel.

The KBS-3 concept was originally developed by the Swedish waste management organization (SKB). Posiva embraced this concept more than 20 years ago and since then it is developing the concept in parallel to the Swedish programme. This concept aims at long term isolation and containment of spent fuel assemblies in copper canisters with a nodular cast iron insert. The canister is emplaced several hundred metres deep into the bedrock. Each canister is isolated from the bedrock by a thick bentonite clay layer (the buffer). After emplacing individual canisters and bentonite buffer into deposition holes, repository tunnels and access routes to and from the surface are backfilled and sealed.

I–3. SITING PROCESS

According to the nuclear energy legislation, Finland's SNF shall be permanently disposed of within the country. The disposal programme was originally established by the Government in 1983. The programme was carried out until 1995 by nuclear utilities and since then, by Posiva Oy. The milestones of the siting process in the past were as follows:

- Site screening completed in 1985 on the basis of geological and scientific information, resulting in selection of about 100 potential areas for site investigations;
- Preliminary site investigations were conducted at five sites in 1987 to 1992;
- Detailed site investigations were conducted at four sites (three original sites and one additional site) between 1993 and 1999, and the environmental impact assessment was carried out from 1997 to 1999;
- Selection of the Olkiluoto site and its approval in the "Decision in Principle" process occurred between 1999 and 2001. (The Olkiluoto site was proposed in 1999 by Posiva Oy in the application for the "Decision in Principle". This application was approved by the host municipality in January 2000 and by the Government in December 2000. The decision of the Government was ratified by the Parliament in May 2001.)

Approval of the “Decision in Principle” of the government and its ratification by the Parliament is the first licensing step in the disposal project. Completion of this step confirms the political acceptance of the repository project by the government and Parliament. Subsequently, the construction license will be requested before construction of the facility begins.

I–4. DEVELOPMENT OF SITING CRITERIA

Different approaches were taken for the development of siting criteria for different stages of the siting process. The implementing organization developed the criteria for the screening process and preliminary investigations. STUK reviewed the results.

I–5. GENERAL PROCEDURES FOR DECISION MAKING IN EACH PHASE

In the siting process before the “Decision in Principle”, there were two main milestones (one in 1985 and another in 1992). The screening of potentially suitable sites and the results of the preliminary investigations were reported in 1985 and 1992, respectively. STUK reviewed these results and submitted statements to the Ministry of Trade and Industry that decided to continue the siting project. The decision on site selection was made by the “Decision in Principle”. In the “Decision in Principle” process, the Government approved the application of Posiva Oy, based on positive recommendations from STUK and the acceptance the host municipality. Finally, the Parliament ratified the Government’s decision.

I–6. ROLE OF HOST MUNICIPALITY

In accordance with the Nuclear Energy Act, acceptance by the host municipality is a prerequisite for the “Decision in Principle”. In 1987, when the first field investigation began, the implementing organization and the candidate municipalities established cooperation groups to exchange information. In the past few years, key issues such as the results of the environmental impact assessment have been raised and discussed extensively by the groups. The initial cooperation group continued its activities since 1987, and new groups were established in 1997.

I–7. REPOSITORY CONSTRUCTION AND OPERATION LICENSING

In June 2004, Posiva started building the Olkiluoto Underground Rock Characterization Facility, ONKALO, for site-specific underground investigations. ONKALO may also be used as part of the future repository. On basis of these confirming site investigations and other research, technical design and development work, Posiva will plan the repository in detail, prepare construction engineering solutions and assess safety.

According to the KTM decision of 23 October 2003 (Decision 9/815/2003), Posiva shall submit an application for the construction licence for a disposal facility by the end of 2012. In 2009, Posiva will submit the first outline version of the Preliminary Safety Analysis Report (PSAR) in support of construction license application. The PSAR will then be gradually updated to become the actual licensing application. A Final Safety Analysis Report (FSAR) will be submitted at the time of the operational license application, in 2018. The target is to begin disposal operations in 2020. Meanwhile, the spent fuel is stored at interim storage sites at Olkiluoto and Loviisa until the repository is available and ready to begin operations.

I–8. MAIN LESSONS

One important lesson learned from Finnish experiences was that early outline for waste management policy enables to carry on the programme during the coming years: In 1983, the Finnish Government set the objectives and the schedule for the national waste management programme in the Government decision. The practical implementation of the waste management, targets and schedules of the associated research and development programme were originally defined in this Government decision.

The legal and institutional framework for disposing of long lived radioactive waste in a repository was established early. The role of the different actors is quite clear in Finland. Also it helps the confidence building that the spent fuel disposal concept, KBS-3, has remained the same during the years. SKB and Posiva have investigated and developed the KBS-3 concept for more than twenty years.

During the execution of the waste management programme public involvement has been taken care of in various ways. Local municipalities and landowners played an important role in selection of the areas for preliminary site investigation, as well as in reviewing the results of geological investigations. The public in the concerned municipalities were openly informed of the results of the investigations. The cooperation groups, composed of the municipalities and the implementing organization, considered it important to let as many municipal residents as possible participate in and be involved in the discussions of issues concerning investigation activities.

As required by the legislation, the Ministry of Trade and Industry organized public hearings in the process of developing both the Environmental Impact Assessments (EIA) and the “Decision in Principle”. Any member of the public was solicited to express his or her opinions in both oral and written forms.

In the past, the Posiva Oy interacted with the public through opening local offices in site investigation areas, providing different types of information material to municipalities, and organizing public events, exhibitions. STUK has also conducted long term interactions with inhabitants and representatives of the municipalities by visiting them, organizing seminars and meetings, and disseminating materials. As a result, the Municipal Council of Eurajoki, where the Olkiluoto site is located, approved the siting proposal with clear majority. The good operation records of nuclear reactors in Finland have increased public confidence towards nuclear energy and evidently confidence towards waste management activities also.

REFERENCE TO ANNEX I

[1] KTM, Nuclear Energy Act (1987). The unofficial English translation is available at: http://www.finlex.fi/fi/laki/kaannokset/1987/en19870990.pdf , accessed 10.11.2006.

Annex II

FRANCE

II–1. INSTITUTIONAL FRAMEWORK

The importance of a politically and socially acceptable programme has been well established in France by prior experience. A first science and technology based programme developed in the 1980s had to be stopped as a consequence of lack of public acceptance of the framework in which programme progressed, and in the presence of public distrust in general following the way possible consequences of Chernobyl on public health and safety in France were handled.

This setback was overcome by instating a clear legal and institutional framework, defining responsibilities for implementer and safety authority, allowing for parallel research on various waste management options, and calling for an evaluation of these options after a set timeframe. Including reversible management option for deep geologic disposal was also seen as an attribute contributing to political and public acceptance of the process. The legal framework was instrumental to allow the implementer to progress with a technically sound programme that received broad political and public acceptance.

Efforts of transparency and communication with stakeholders, as well as opening up the deep geological disposal programme to intensive scrutiny by nationally mandated expert groups, and including broad implication of universities and national research institutions into the programme development, contributed to good acceptance of this waste management solution.

An interesting lesson learned, while the programme suffered an apparent setback in the late 1980’s, an adequate handling of the issue at the government level, with implication of stakeholders, led to the creation of a legal framework, a clear definition of responsibilities (government: set objectives; implementer: provide solutions; safety authority: provide evaluation and recommendation; and government: decide, finally, based on evaluation and recommendation), as well as setting objectives and a deadline for the next major milestone (provide a feasibility assessment by 2005) which significantly contributed to progress in the programme since then.

II–2. SITE SELECTION

Site selection including site characterization (scoping studies of key geological properties and of political and public acceptance at multiple sites, followed by more detailed studies on potentially acceptable site or sites, concluding with designation of candidate site for license application) may require two to three decades, if programme is well planned and progresses without major setbacks.

The integration of site characterization results into the safety case may highlight a number of further characterization needs. This should be planned for as part of an iterative progress in the safety case, from each major milestone to the next. Care should be taken that some resulting experimental needs may be lengthy and be on the critical path for updating the safety case for this next milestone.

In addition, “long term” experiments may be called for, whose duration would exceed time allowed until the next milestone, and possibly until expected license application and begin of construction. Clearly, these should not be required by default for the updated safety case, unless a strong argument is provided for that need. Such long term experiments (for example, long term tracer migration or long term mechanical rock response to construction and/or heating) may be conducted to yield some intermediate data in time for an updated safety case, and provide new insights to reduce uncertainty over a duration that might last throughout the operational and performance confirmation period.

II–3. REPOSITORY DESIGN

Generic repository designs and designs adapted to overall geological properties and waste inventory, as are typically provided during an early stage of a deep geological disposal programme, can probably be developed more rapidly than the time needed to carry out the parallel site related investigations. This is especially true as viable examples have been developed and presented to a great level of detail for a variety of host rocks.

Greater care must be used on planning design developments, first as the programme integrates increasing levels of detail from site characterization and waste inventory characterization, second as the programme is required to demonstrate feasibility in principle, followed by the detailed description accompanied by demonstration of key operational procedures (construction of key engineered barriers and waste canister handling and emplacement and retrieval, if an option is provided for the latter). Past experience has shown that, while repository design may overall be similar between different national programmes, details differ to take into account site and waste inventory specificities, as well as potential particular requirements derived from national stakeholder preferences.

The time frame needed to develop certain design details may equal or exceed that needed for the overall concept. As a programme progresses towards the license application stage, apparently detail technology issues take on increasing importance and benefit from adequate planning.

II–4. INTEGRATION AND THE SAFETY CASE

Planning on preparing and/or updating a safety case between major milestones requires integrating all activities:

- At the beginning of a phase, by evaluating lessons learned from the previous phase, deducing key requirements for further research and developments (e.g. requirements imposed on further design developments or to reduce uncertainty in a given phenomenological evolution), and setting objectives for the updated safety case, including possibly needed scoping on design variants;
- After a scoping study, plan for a decision point at which preliminary progress into the current programme phase is discussed in light of the envisioned safety case, with decisions leading to aimed at reference design, modelling capability, experimental results to reduce uncertainty;
- When nearing the next major milestone, to ensure all activities integrate well for an updated safety case.

II–5. PLANNING ON MAJOR REPORTS

Preparing reports to present the safety assessment, safety case and all related progress is a substantial endeavour for which time (one or several years) and resources (a substantial part of the staff involved in technical work) must be planned for.

Annex III

USA

The lessons learned from long standing programmes, involving both successes and failures, lead to an emphasis on broad public involvement in the government decision making process. Though now often deemed required for transparent government and the progress of unpopular initiatives, it remains uncertain if broad public involvement will actually increase public acceptance in a particular country or region, or in other waste management contexts (i.e. L/ILW vs. HLW).

Over the past many decades, the US has initiated several waste management programmes including environmental restoration projects (involving decommissioning and disposal of contaminated site or facilities), low level waste disposal, transuranic waste transportation and disposal in a geological disposal facility (Waste Isolation Pilot Plant), and the pursuit of a HLW/SNF disposal facility (Yucca Mountain). Most programme activities are governed by various regulations and also typically involve an environmental impact study to inform the public and decision makers as to a preferred option for addressing a particular waste management issue. This multi-decade experience, replete with successes and failures, provides a basis for broad observations relevant to future waste management initiatives.

Because the lessons are imprecise, complex, and multifaceted, it is not appropriate to prescribe them to a particular future application or instance. Thus the observations summarized here must be judged for relevance by the individual waste management planner and in the context of their waste management programme. The order of the observations presented does not imply relative importance or significance to a particular programme.

III–1. MULTIPLE REGULATORY FRAMEWORKS OF MIXED WASTE CREATE COMPLICATION IN COMPLIANCE

Chemically hazardous waste (e.g. mercury) and radioactively contaminated waste are presently governed by different treatment, storage and disposal regulations. On the occasion of a mixed waste inventory (i.e. chemically hazardous and radioactive), the demonstration of compliance with multiple disposal regulations is complex and may not be compatible with the most practical disposal safety strategy. It is preferable that the regulatory framework and safety requirements be cohesive and practical as to the cumulative or combined hazard and the protection of human health and the environment.

III–2. PUBLIC INVOLVEMENT HAS MAJOR IMPLICATIONS FOR THE OVERALL PROGRESS OF A REPOSITORY PROGRAMME

Beyond broad generalizations such as initial ‘not in my backyard’ objections, it is difficult to predict, and perhaps therefore difficult to influence, the position, effects, pervasiveness, of public perception, reaction or involvement in a disposal programme. Numerous factors clearly influence the local, regional and national opinion on the potential acceptance of a repository facility. These influences include but are not limited to: local culture and experience, economic status and basis of the local community or region, political status of the community or region, perceptions of trustworthiness and credibility in the implementer, the legislative process experienced by the host community or state, etc. Given the numerous influences on public acceptance, and their propensity to change with time or events, the geological repository programme planner should adopt a set of principles for public involvement and only expect to influence the probability of a favourable reception or progress, rather than any specific influence on the timing and duration of repository milestones.

III–3. ESTABLISHING PERFORMANCE AND DECISION MILESTONES ASSISTS REPOSITORY PROGRAMME PROGRESS

The complex uncertainties in the planning and execution of a geological repository programme over many years can thwart reasonable progress (and therefore increase time and cost) if those uncertainties are used to avoid the difficult but necessary decisions the government must take action on in deciding to proceed with the repository programme at each phase. By establishing a multi-year development plan with specific milestones and goals needed for progression to subsequent phases, all parties (i.e. government, regulator, operator and public) are committed to facing the decision process even in the face of imperfect knowledge or other uncertainty. A decreed or consensus repository programme plan, with objective goals and milestones, places appropriate pressure on the participants to make timely progress leading to the major decision points on whether to proceed, revise or abandon the objectives for a given phase of the repository programme. It may be appropriate to establish these milestones and goals during the initial or subsequent legislative efforts establishing the overall repository programme policy and objectives.

Annex IV

BELGIUM

IV–1. NEED FOR AN EARLY AND CLEAR INSTITUTIONAL FRAMEWORK

R&D activities regarding geological disposal started in Belgium mid-1970s with a rapid focus on Boom Clay, a poorly indurated argillaceous formations in NE Belgium, as potential host formation. As excavation of a facility in such “soft” clay had never been realised at depths considered as suitable (around 200 m), an underground research laboratory was constructed very early on in the programme (i.e. in the early 1980s).

Since its inception, the soundness of the scientific foundations of the Belgian programme as well as the potentiality to develop a safe repository facility in the Boom Clay have been assessed and confirmed at several occasions (SAFIR, 1989; SAFIR 2, 2001; NEA Peer Review of the SAFIR 2, 2003). These assessments and reviews have allowed the R&D programme to continue up to now, with increased in situ works.

However, as noted by the waste management agency in SAFIR 2 and stressed by the NEA Peer Review of this safety case, the Belgian programme is still missing societal foundations as well as institutional and regulatory framework.

The absence of such shared and formal basis and in particular the absence of a geological disposal policy as the chosen national solution for the long term management of high and intermediate level and/or long lived waste, may delay programme development by e.g.:

- Maintaining its generic nature;
- Making its boundary conditions difficult to define;
- Complicating R&D priorities setting;
- Complicating communication of its status;
- Complicating stakeholder involvement;
- Neglecting to address stakeholder issues.

This is the reason why ONDRAF/NIRAS, the Belgian Radioactive Waste Management Agency, is currently establishing a Waste Plan that is aimed at providing the elements for an in-principle decision to go for geological disposal focussing on stakeholder involvement. The Waste Plan will also give the opportunity to assess environmental impacts of alternatives to disposal (Strategic Environmental Impact Assessment as per the law of 13th February 2006) as well as to initiate a dialogue with all interested parties and the public at large.

The Waste Plan should also lead, in accordance with all interested parties, of a proposal for a decision making scheme which should clarify the various steps in the programme, the respective responsibilities and the associated planning.

IV–2. INTERACTION WITH THE REGULATOR SHOULD NOT BE LIMITED TO MAJOR MILESTONE DECISIONS

Interactions with the regulatory authorities used to be limited to review of major milestone documents (SAFIR type document). To ensure adequate and efficient steering of the programme, a more frequent interaction with the regulators is considered as needed. Such interaction in between the milestone reviews could help ensure:

- Shared views on what are the scientific and technological bases needed to move to the next step in the repository development programme;
- Shared interpretation of existing regulations at local, regional, national and international levels;
- Acceptance of the methodological approaches proposed by the implementers to assess radiological safety both operational and post-closure (scenarios selection, uncertainty treatment, calculations scheme) as well as to evaluate non-radiological impact to the environment.

This frequent interaction cannot undermine the independency of the regulator. Procedures could be developed where the various types of interactions (milestone decision review, intermediate) and their implication are defined.

IV–3. DEFINE A PRIORI SAFETY STRATEGY TO HELP PRIORITIZE AND ASSESS DEVELOPMENT

Overall, a safety strategy should define which safety function is to be ensured by which repository component(s) and during which duration. The safety strategy is a process that allows iteratively linking quantitatively safety, design, waste types and timeframe.

A reference safety strategy is needed as early as possible in the programme to help prioritize scientific and technical activities and hence allocate resources and define planning. Even at the inception of a repository development programme (i.e. in the absence of detailed site specific data and design) a safety strategy could be defined based on a priori knowledge and examples from other comparable programmes.

The safety strategy is to be reviewed at regular intervals to iteratively take (site, waste, design) specific information. Consequences for the planned scientific and technical activities should then be assessed in parallel.

IV–4. DEVELOP FROM EARLY ON A KNOWLEDGE MANAGEMENT SYSTEM

The timeframe involved in repository development implies that, even for the predisposal period, several generations of scientists and engineers will perform R&D activities. This increases the risk of duplication of activities and/or suboptimal use of available information.

Furthermore, huge amount of relevant information has already been acquired in other national repository programmes and in other industries.

For efficient use of resources and planning, a maximum of the available information should be made accessible and used by a national programme. In this respect, it is recommended to establish from early on in the repository development programme a knowledge management approach, policy and system.

IV–5. IT TAKES TIME TO ASSESS PHENOMENOLOGICAL IMPLICATIONS OF DESIGN CHANGES OR NEW WASTE TYPES

Quite minor changes in Engineered Barrier System (EBS) design may imply long lasting or innovative scientific work to be accepted from a phenomenological point of view, i.e.

confidence in the fact that the new material or component will not unduly affect the performances of other EBS components or of the geological host formation.

Such changes are performed frequently when assessing feasibility of a design choice, especially when comparing it to existing industrial practices and materials; as an example:

To increase workability of concrete to be used for the buffer of the super-container design for vitrified HLW and spent fuel, it was proposed to add super-plasticizers (SPL) to the theoretical composition derived from design requirements. Such SPL are of day-to-day usage in the classical industry and a wide range of product is available. Most of the SPLs are not fully characterized (presence of uncharacterized residues) and their long term behaviour (and that of their degradation products) is poorly known. Furthermore, complexation with radionuclide with potential enhancement of migration is possible. In order to help make choice, rapid assessment of the consequences of the addition of such SPL is difficult.

IV–6. NEVER UNDERESTIMATE THE PERFORMANCE OF YOUR HOST ROCK WHEN PLANNING AN EXPERIMENT

Argillaceous rocks are selected as potential host formations as they display high sorption capacities and diffusion dominated water movement. These characteristics reduce drastically transport of radionuclides towards the accessible environment. Spatial and temporal scales of any experiment aimed at confirming the performance of a potential argillaceous host formation and its relevancy in disposal conditions should therefore be thoroughly considered.

In the HADES underground research laboratory located into Boom Clay, an in-situ diffusion experiment with tritiated water and iodine (non-sorbed elements) has been running for more than 18 years. During this period, an activity has only been measured in the collecting filters located less than 1 m away from the injection filter. The collecting filters located at a distance of 2 m have not yet seen any activity (which is in accordance with model prediction based on a purely diffusive transport and laboratory derived parameters). In situ migration tests with sorbing tracers are in mm-scale and year-long experiments.

IV–7. ENSURE ADEQUATE PROCESS UNDERSTANDING IS PRESENT BEFORE EMBARKING INTO INTEGRATED IN SITU EXPERIMENT

Integrated in situ experiments combining numerous issues and processes (THMC, radiation, gas) are most representative of actual repository conditions and very useful for confidence building and communication purposes. These experiments are time intensive: difficulties in defining set ups, building the necessary underground location, running them for several years in order to be representative.

Inherently, these experiments are also difficult to interpret, mostly due to the lack of adequate understanding at single process level. Lessons learned have shown that it has been necessary, after the end of the integrated experiment, to set up single process experiments to be able to interpret the integrated experiment.

From a planning point of view, one should ensure that all the necessary phenomenological bases needed for the interpretation of the experiment at hand will be available at the time interpretation will take place. In that respect, transfer of knowledge from other underground research laboratories and parallel experimental set ups (single process and integrated ones) may help reduce the time needed to come to conclusive interpretation.

Annex V

GERMANY

In Germany, the Federal Government is responsible for the safe final disposal of radioactive waste. The responsibility for construction and operation is delegated to the Federal Office of Radiation Protection (BfS), a subordinated body of the Federal Ministry of Environment, Nature Conservation and Nuclear safety (BMU). However, because BfS does not provide for the necessary technical infrastructures it has nominated the private German Company for the Construction and Operation of Waste Repositories (DBE) to construct and operate the repository on behalf of BfS. Nevertheless, BfS will be the licensing applicant for the repository and the Federal State where the repository is located in will be the licensing authority. BMU on the other side establishes the safety requirements/criteria that are to be considered in the licensing process and oversees all licensing and implementing activities.

Since the early sixties, i.e. from the very beginning of nuclear energy, the German policy has decided that all types of radioactive waste are to be disposed of in deep geological formations.

The implementation of the repository is governed by the following laws and regulations:

- Atomic Act (1959), last amended March 2001;
- Radiation Protection Act (1986), last amended June 1994;
- Radiation Protection Ordinance (June 1989), last amended August 1997;
- Federal Mining Act;
- Safety Criteria for the Disposal of Radioactive Waste (1983), currently under review for further improvement under consideration of national and international developments;
- Act of the Assessment of Environmental Impacts (1990), last amended August 1997.

Because of the two-fold responsibility of the Federal Government for (1) the final disposal of radioactive waste and (2) the development of the respective regulatory framework a revision of the responsibilities considering the utilities being the applicant and the BMU being the regulation and licensing authority is under discussion since a long time. Respective revision activities, however, have not yet been taken up.

Regarding the type of host rock, already in the 1960s, a preliminary decision on the salt option was made in Germany due to the fact that a number of Permian salt deposits are available in the northern part of the country. Immediately after this decision, the Federal Government owned the former salt mine Asse located in the Federal State of Lower Saxony to serve as a pilot facility for the development of disposal techniques for low and intermediate level waste in geological salt formations. In addition, first simulation tests on high level waste disposal were started by running a series of heater experiments including both the disposal of reprocessed and vitrified HLW as well as the direct disposal of SNF.

In 1977, the Government of Lower Saxony preliminarily identified the Gorleben salt dome as the national candidate site and the Federal Government accepted this decision. However, neither a systematic decision making process nor a wide site investigation preceded this decision and it thus resulted in strong local and regional opposition to the project. In 1977 an application to start the licensing procedure was launched and accordingly, surface based investigations started in 1979. A decision on underground investigation followed in 1983. This decision was reached despite the fact that several experts found the site unsuitable due to some unexpected hydrogeological findings (particularly, the so called subrosion induced "Gorleben channel" at top of the salt formation). In 1985, underground investigations started and an exploratory shaft was built by 1996. In 1998, the German Government expressed certain doubts with respect to the suitability of salt as host rock in general and of the Gorleben site in particular. All exploration activities were halted by the end of 2000 and a moratorium was imposed for three to ten years. During this time all pending issues should be looked into, and new formation-independent site selection criteria should be developed in order to identify alternative sites with favourable geological settings. The entire procedure was meant to provide for the investigation of several sites and, at the end, the evaluation of these sites, including "Gorleben", and a final site selection.

To work out the site selection criteria BMU established the AkEnd Committee. The Committee was charged with developing a siting procedure based on a set of technical selection criteria that are independent of the rock characteristics. The Committee included experts with different backgrounds and different views. It followed a new approach (for Germany) of sharing information with the public: it organized public workshops and fora, established a website, gave lectures, and, published its decisions in 2002, including the minority opinions.

The key recommendations of the AkEnd Committee are: (1) safety first, (2) geological disposal as the only sustainable option, (3) national responsibility (i.e. no export from or import to Germany), (4) responsibility of today's generation: the repository design has to ensure the required long term safety and thus retrievability is not considered, (5) involvement of the public at large from the very beginning of the siting process and a site selection process that considers the following criteria:

- The thickness of the host rock must be at least 100 m;
- The disposal level shall not be closer than 300 m to and not deeper than 1500 m below the ground surface;
- The potential disposal area at the disposal level must be at least 3 $km^{2;}$
- The hydraulic conductivity of the host rock must be smaller than 1E-10 m/s;
- The aforementioned properties must be assured for 1 million years.

The decision how to continue the siting process is now with the federal government and is still pending. However, the actual policy is to begin operation of a geological repository around 2030. Considering a construction phase of about five years the repository license would be needed around 2025 leaving a time period of less than 15 years for site selection, investigation and confirmation.

V–1. LESSONS LEARNED FROM THE GERMAN CASE

In order to achieve a broad societal agreement the siting and implementation of a geological repository should be phased as follows:

- Phase I: Working out site independent geological criteria and a site selection procedure involving the local and the public at large from the very beginning (openness and transparency);
- Phase II: Political and societal confirmation of the identified repository implementation procedures (legal framework, society consensus);
- Phase III: Repository implementation (site selection and characterization, safety case and licensing application).

Annex VI

CANADA

VI–1. BACKGROUND

The Canadian federal government established its official policy for the management of radioactive wastes through its 1996 Policy Framework for Radioactive Waste. The Policy Framework consisted of a set of principles that hold waste producers and owners responsible, in accordance with the principle of "polluter pays", for the funding, organization, management and operation of disposal and other facilities for their wastes.

Under the 1997 Nuclear Safety and Control Act (NSCA), the federal government has legislative authority for the development and control of nuclear energy, which it regulates through the Canadian Nuclear Safety Commission (CNSC). The federal government is responsible for the development of policy for radioactive waste disposal. The CNSC ensures that the use of nuclear energy does not pose undue risk to health, safety, security and the environment. They license nuclear facilities, which will include nuclear waste disposal sites and facilities.

VI–2. NUCLEAR FUEL WASTE

There are 22 CANDU® power reactors in Canada owned by three provincial electrical utilities. Ontario Power Generation Inc. (OPG) owns 20 reactors while Hydro-Québec and New Brunswick Power each own one reactor. Bruce Power Inc. leases and operates the Bruce nuclear generating station from OPG where there are eight reactors. In 2005, the installed generating capacity of these 22 reactors was 16 000 megawatts of electricity [1].

As of June 2006, 18 of these reactors were operating, producing about 15% of Canada's electricity. In the province of Ontario, the 16 operating reactors owned by OPG provide 50% of the provinces total electricity production. Over the past 40 years, two million used fuel bundles (36 000 MgU or 8000 m^3) have been produced Canada, a number that is projected to double if the existing 22 reactors continue to operate for another 40 years. The used fuel bundles are initially stored in water filled bays located at each nuclear generating station. Once a fuel bundle has spent 10 years in a bay its rate of heat generation has decreased sufficiently that it can be stored in dry storage facilities also located at the reactor sites. In addition to these, AECL, the developer of CANDU® reactor technology, has responsibility for a small amount of spent fuel from its research and radioisotope production reactors at its nuclear sites and research reactors at universities.

VI–3. CANADIAN NUCLEAR FUEL WASTE MANAGEMENT PROGRAMME

In 1978, the governments of Canada and Ontario announced the Canadian Nuclear Fuel Waste Management Program of Research with the intention of verifying, that "permanent disposal in a deep geologic repository is a safe, secure and desirable method of disposing of radioactive waste" [2]. AECL was given the role of developing the technology for immobilization and disposal, and OPG's predecessor, Ontario Hydro, was given the responsibility for storage and transportation. In 1981, the two governments issued a second joint statement in which they announced the process by which acceptance of the disposal concept would be undertaken and that "no disposal site selection will be undertaken until after the concept has been approved" [3].

In 1988, a formal review of the disposal concept was initiated in accordance with the Federal Environmental Assessment and Review Process, and AECL was charged with preparing the Environmental Impact Statement (EIS) on the concept for disposal of Canada's nuclear fuel waste, which, together with nine reference documents, was issued to an Environmental Assessment (EA) Panel in 1994 [4]. The EA panel completed a process of review, including public hearings held in five provinces across Canada.

The research and development work conducted at the Canadian Underground Research Laboratory (URL), located near Lac du Bonnet, Manitoba, played an important role throughout this process. Construction of the URL and characterization of the site, followed by an initial phase of large scale in situ geotechnical testing provided an R&D framework for the EIS. Public tours of the URL were an integral element of the process of public acceptance.

The EA Panel conclusions in 1998 were: that there must be broad public support to ensure acceptability of any concept for managing nuclear fuel wastes; that safety is only one part of acceptability and must be viewed from both technical and social perspectives; that from a technical perspective safety of the concept was, on balance, adequately demonstrated but from a social perspective it was not; and that the concept as described in the EIS was not demonstrated to have broad public support, and therefore, in its current form did not have the required level of acceptability. The EA Panel report included recommendations for establishing a process to address these issues and recommended that Canada not move towards siting a repository until they were addressed and alternate options studied [5].

VI–4. NUCLEAR FUEL WASTE ACT

The Government of Canada accepted the recommendations of the EA Panel [6]. The Nuclear Fuel Waste Act (NFWA) was passed by the Federal Government and came into force in November 2002. The act required the nuclear energy corporations (OPG, Hydro-Québec and New Brunswick Power) to form a waste management organization, which they did – called the Nuclear Waste Management Organization (NWMO). Within three years, the NWMO was required to complete a study of options for the long term management of nuclear fuel waste and recommend a preferred approach to the Federal Government. The options to be studied included: deep geologic disposal; long term storage at reactor sites; and long term centralized storage above or below ground.

The act also required the establishment of a segregated fund for nuclear fuel waste management in Canada, with funding coming from all the nuclear fuel waste producers, including the nuclear utilities and AECL. The government of Canada will exercise oversight throughout the decision making process via the Nuclear Fuel Waste Bureau, established within the Ministry of Natural Resources Canada.

VI–5. NUCLEAR WASTE MANAGEMENT ORGANIZATION (NWMO)

In November 2005, the NWMO issued a report on their study of approaches for long term management of Canada's used nuclear fuel to the Federal Government [1]. The examination of the options presented led the NWMO to develop another approach referred to as Adaptive Phased Management (APM) that incorporates the most significant advantages of the options assessed. APM is a staged approach that has three phases of implementation:

— Phase 1: Preparing for central used fuel management (approximately 30 years);
— Phase 2: Central Storage and Technology Demonstration (approximately the next 30 years);
— Phase 3: Long term containment, isolation and monitoring (beyond approximately 60 years).

The main characteristics of Adaptive Phased Management include:

— Central containment and isolation of used nuclear fuel in a deep geological repository in a suitable rock formation, such as the crystalline rock of the Canadian Shield or Ordovician sedimentary rock;
— Flexibility in the pace and manner of implementation through a phased decision making process, supported by a programme of continuous learning, research and development;
— Provision for an optional step in the implementation process in the form of shallow underground storage of used nuclear fuel at a central site, prior to final placement in a deep repository;
— Continuous monitoring of the used fuel to support data collection (e.g., data for repository engineering design) and confirmation of the safety and performance of the repository;
— Potential for retrieval of the used fuel for an extended period, until such time as a future society makes a determination on the final closure and the appropriate form and duration of post-closure monitoring.

In June 2007, the federal government gave the NWMO responsibility for implementing Adaptive Phase Management [7]. In April 2008, the NWMO issued a draft Implementation Plan for public information, review and comment. The draft Implementation Plan sets out ideas about how to move forward over the next five years. The plan, which embraces seven strategic planning objectives, was developed with guidance received on public engagements initiatives carried out during the summer of 2007 [8].

NWMO strategic objectives:

1) Seek to build long term relationships with interested Canadians and Aboriginal people;
2) Advance technical and social research;
3) Develop and refine a funding formula and trust fund deposit schedules that address financial surety and long-term program funding;
4) Continually review, adjust and validate plans;
5) Continue to develop and maintain a governance structure;
6) Build NWMO as an implementing organization;
7) Proceed with the collaborative design of a process for site selection.

VI–6. PROPOSED DISPOSAL CONCEPT FOR USED NUCLEAR FUEL WASTE

OPG, being the principal owner of nuclear reactors in Canada and used nuclear fuel, has taken the lead in managing the programme for interim storage and long term management of used nuclear fuel.

The concept being considered is to excavate a deep geological repository (DGR) in a suitable rock formation, such as crystalline rock of the Canadian Precambrian Shield or Ordovician sedimentary rock. The waste would be placed in long lasting used fuel containers, the used fuel container (UFC) would be placed in the DGR, each container would be surrounded by a buffer material, and the repository would eventually be backfilled and sealed such that the repository would be passively safe, i.e. without requiring further societal attention. The optional step of implementing a shallow underground central storage facility (CSF) at the repository site could extend the time frame for emplacement substantially, e.g. by as much as 100 years.

Some of the key design features for the proposed DGR for used nuclear fuel are identified below:

— The waste form would be bundles of used CANDU® fuel. There are no plans to dispose of reprocessing waste, since used fuel is not currently reprocessed in Canada;
— The containers could be made of copper, or possibly carbon steel;
— The repository would include access shafts or ramps, access tunnels and disposal rooms. The disposal rooms would be nominally 500 to 1000 m deep;
— The containers could be placed directly in rooms or in boreholes drilled from the rooms.
— The buffer, backfill and other repository sealing materials could be clay based, cement based, or a mixture of these materials;
— The size and capacity of the repository would depend on several factors, including the amount and decay power of the waste.

VI–7. SUMMARY

Significant progress has been made towards establishing safe, secure and environmentally acceptable practice for the management of nuclear fuel wastes in Canada. A comprehensive programme of research concerning permanent disposal in a deep geological repository has been carried out. An Environmental Impact Statement describing a concept of a deep geological repository has been prepared and reviewed by an Environmental Assessment Panel established in accordance with a Federal Environmental Assessment and Review Process. The Government of Canada acted upon the recommendations of the EA Panel, passing legislation that requires the nuclear energy corporations to establish a Nuclear Waste Management Organization, complete a study of options and recommend a preferred approach for the long term management of nuclear fuel waste.

The NWMO completed its study and recommended Adaptive Phased Management, which incorporates the most significant advantage of deep geological disposal; long term storage at reactor sites; and long term centralized storage above or below ground. Most recently, the NWMO has been given responsibility for implementing APM and is currently in the process of developing a strategic plan.

REFERENCES TO ANNEX VI

[1] NWMO, Choosing a Way Forward, the Future Management of Canada's used Nuclear Fuel, Final Study, Nuclear Waste Management Organization Report submitted to the Minister, Natural Resources Canada (2005).
[2] CANADA/ONTARIO RADIOACTIVE WASTE MANAGEMENT PROGRAM, Joint Statement by the Minister of Energy Mines and Resources Canada and the Ontario Energy Minister (1978 June 5). Atomic Energy of Canada Limited Technical Record, TR-567 (1978).

[3] CANADA/ONTARIO JOINT STATEMENT ON THE NUCLEAR FUEL WASTE MANAGEMENT PROGRAM, Joint statement by the Minister of Energy Mines and Resources Canada and the Ontario Energy Minister (1981 August 4). Atomic Energy of Canada Limited Technical Record, TR-567 (1981).
[4] AECL, Environmental Impact Statement on the Concept for Disposal of Canada's Nuclear Fuel Waste, Atomic Energy of Canada Limited Report, AECL-10711 (1994).
[5] SEABORN, B., Nuclear Fuel Waste Management and Disposal Concept Environmental Assessment Panel. Nuclear Fuel Waste Management and Disposal Concept (B. Seaborn, Chairman). Canadian Environmental Assessment Agency Report (1998).
[6] CANADIAN ENVIRONMENTAL ASSESSMENT AGENCY, Nuclear Fuel Waste Management and Disposal Concept, Report of the Nuclear Fuel Waste Management Agency, Minister of Public Works and Government Services Canada, Catalogue No. EN-106-30/ 1-1998E, Hull, Quebec (1998).
[7] NWMO, Implementing Adaptive Phased Management 2008 to 2012, Draft Plan for Public Comment, Nuclear Fuel Waste Management Organization (2008).
[8] NWMO, Moving Forward Together, Annual Report 2007, Nuclear Waste Management Organization (2007).
[9] NWMO, NWMO News, Vol. 6, Issue 1, May 2008, Toronto (2008).

CONTRIBUTORS TO DRAFTING AND REVIEW

Baksay, A.	TS Enercon Kft., Hungary
Biurrun, E.	DBE Technology GmbH, Germany
Breen, B.	Nirex, United Kingdom
Carolissen, A.	Necsa, South Africa
Corsi, F.	ENEA, Italy
Hauser, A.	SERNAGEOMIN, Chile
Hossain, S.	Consultant, Germany
Hugi, M.	NAGRA, Switzerland
Hussain, M.	Pakistan Atomic Energy Commission, Pakistan
Hyodo, H.	Nuclear Waste Management Organization, Japan
Kitayama, K.	Nuclear Waste Management Organization, Japan
Kunc, K.	RAWRA, Czech Republic
Kuzyk, G.	AECL, Canada
Lalieux, P.	ONDRAF/NIRAS, Belgium
Markova, R.	Nuclear Regulatory Agency, Bulgaria
Mayer, S.	ANDRA, France
Motiejūnas, S.	Radioactive Waste Management Agency, Lithuania
Müller-Hoeppe, N.	DBE Technology GmbH, Germany
Neerdael, B.	International Atomic Energy Agency
Oliveira de Tello, C.C.	CNEN, Brazil
Orrell, S.A.	Sandia National Laboratories, USA
Paulamäki, S.	Geological Survey of Finland
Pfeiffer, F.	GRS, Germany
Rothfuchs, T.	GRS-Final Repository Safety, Germany
Salo, J.-P.	Posiva Oy, Finland

Svemar, C.	SKB AB, Sweden
Szücs, I.	Mecsekérc Environmental Co, Hungary
Taglioni, A.	ENEA, Italy
Tison, J.-L.	ANDRA, France
Twala, V.	Eskom, South Africa
Van Cottem, A.	Tractebel, Belgium
Wang, J.	Beijing Institute of Uranium Geology, China
Wattal, P.K.	Bhabha Atomic Research Centre, India
Wollrath, J.	BfS, Germany

Workshop

Vienna, Austria: 25–27 September 2006

Consultancy Meetings

Vienna, Austria: 25–29 June 2007, 7–10 July 2008

Technical Meeting

Vienna, Austria: 16–20 March 2009

IAEA
International Atomic Energy Agency

No. 23

ORDERING LOCALLY

In the following countries, IAEA priced publications may be purchased from the sources listed below or from major local booksellers.

Orders for unpriced publications should be made directly to the IAEA. The contact details are given at the end of this list.

AUSTRALIA
DA Information Services
648 Whitehorse Road, Mitcham, VIC 3132, AUSTRALIA
Telephone: +61 3 9210 7777 • Fax: +61 3 9210 7788
Email: books@dadirect.com.au • Web site: http://www.dadirect.com.au

BELGIUM
Jean de Lannoy
Avenue du Roi 202, 1190 Brussels, BELGIUM
Telephone: +32 2 5384 308 • Fax: +32 2 5380 841
Email: jean.de.lannoy@euronet.be • Web site: http://www.jean-de-lannoy.be

CANADA
Renouf Publishing Co. Ltd.
5369 Canotek Road, Ottawa, ON K1J 9J3, CANADA
Telephone: +1 613 745 2665 • Fax: +1 643 745 7660
Email: order@renoufbooks.com • Web site: http://www.renoufbooks.com

Bernan Associates
4501 Forbes Blvd., Suite 200, Lanham, MD 20706-4391, USA
Telephone: +1 800 865 3457 • Fax: +1 800 865 3450
Email: orders@bernan.com • Web site: http://www.bernan.com

CZECH REPUBLIC
Suweco CZ, spol. S.r.o.
Klecakova 347, 180 21 Prague 9, CZECH REPUBLIC
Telephone: +420 242 459 202 • Fax: +420 242 459 203
Email: nakup@suweco.cz • Web site: http://www.suweco.cz

FINLAND
Akateeminen Kirjakauppa
PO Box 128 (Keskuskatu 1), 00101 Helsinki, FINLAND
Telephone: +358 9 121 41 • Fax: +358 9 121 4450
Email: akatilaus@akateeminen.com • Web site: http://www.akateeminen.com

FRANCE
Form-Edit
5 rue Janssen, PO Box 25, 75921 Paris CEDEX, FRANCE
Telephone: +33 1 42 01 49 49 • Fax: +33 1 42 01 90 90
Email: fabien.boucard@formedit.fr • Web site: http://www.formedit.fr

Lavoisier SAS
14 rue de Provigny, 94236 Cachan CEDEX, FRANCE
Telephone: +33 1 47 40 67 00 • Fax: +33 1 47 40 67 02
Email: livres@lavoisier.fr • Web site: http://www.lavoisier.fr

L'Appel du livre
99 rue de Charonne, 75011 Paris, FRANCE
Telephone: +33 1 43 07 50 80 • Fax: +33 1 43 07 50 80
Email: livres@appeldulivre.fr • Web site: http://www.appeldulivre.fr

GERMANY
Goethe Buchhandlung Teubig GmbH
Schweitzer Fachinformationen
Willstätterstrasse 15, 40549 Düsseldorf, GERMANY
Telephone: +49 (0) 211 49 8740 • Fax: +49 (0) 211 49 87428
Email: s.dehaan@schweitzer-online.de • Web site: http://www.goethebuch.de

HUNGARY
Librotade Ltd., Book Import
PF 126, 1656 Budapest, HUNGARY
Telephone: +36 1 257 7777 • Fax: +36 1 257 7472
Email: books@librotade.hu • Web site: http://www.librotade.hu

INDIA
Allied Publishers
1st Floor, Dubash House, 15, J.N. Heredi Marg, Ballard Estate, Mumbai 400001, INDIA
Telephone: +91 22 2261 7926/27 • Fax: +91 22 2261 7928
Email: alliedpl@vsnl.com • Web site: http://www.alliedpublishers.com

Bookwell
3/79 Nirankari, Delhi 110009, INDIA
Telephone: +91 11 2760 1283/4536
Email: bkwell@nde.vsnl.net.in • Web site: http://www.bookwellindia.com

ITALY
Libreria Scientifica "AEIOU"
Via Vincenzo Maria Coronelli 6, 20146 Milan, ITALY
Telephone: +39 02 48 95 45 52 • Fax: +39 02 48 95 45 48
Email: info@libreriaaeiou.eu • Web site: http://www.libreriaaeiou.eu

JAPAN
Maruzen Co., Ltd.
1-9-18 Kaigan, Minato-ku, Tokyo 105-0022, JAPAN
Telephone: +81 3 6367 6047 • Fax: +81 3 6367 6160
Email: journal@maruzen.co.jp • Web site: http://maruzen.co.jp

NETHERLANDS
Martinus Nijhoff International
Koraalrood 50, Postbus 1853, 2700 CZ Zoetermeer, NETHERLANDS
Telephone: +31 793 684 400 • Fax: +31 793 615 698
Email: info@nijhoff.nl • Web site: http://www.nijhoff.nl

Swets Information Services Ltd.
PO Box 26, 2300 AA Leiden
Dellaertweg 9b, 2316 WZ Leiden, NETHERLANDS
Telephone: +31 88 4679 387 • Fax: +31 88 4679 388
Email: tbeysens@nl.swets.com • Web site: http://www.swets.com

SLOVENIA
Cankarjeva Zalozba dd
Kopitarjeva 2, 1515 Ljubljana, SLOVENIA
Telephone: +386 1 432 31 44 • Fax: +386 1 230 14 35
Email: import.books@cankarjeva-z.si • Web site: http://www.mladinska.com/cankarjeva_zalozba

SPAIN
Diaz de Santos, S.A.
Librerias Bookshop • Departamento de pedidos
Calle Albasanz 2, esquina Hermanos Garcia Noblejas 21, 28037 Madrid, SPAIN
Telephone: +34 917 43 48 90 • Fax: +34 917 43 4023
Email: compras@diazdesantos.es • Web site: http://www.diazdesantos.es

UNITED KINGDOM
The Stationery Office Ltd. (TSO)
PO Box 29, Norwich, Norfolk, NR3 1PD, UNITED KINGDOM
Telephone: +44 870 600 5552
Email (orders): books.orders@tso.co.uk • (enquiries): book.enquiries@tso.co.uk • Web site: http://www.tso.co.uk

UNITED STATES OF AMERICA
Bernan Associates
4501 Forbes Blvd., Suite 200, Lanham, MD 20706-4391, USA
Telephone: +1 800 865 3457 • Fax: +1 800 865 3450
Email: orders@bernan.com • Web site: http://www.bernan.com

Renouf Publishing Co. Ltd.
812 Proctor Avenue, Ogdensburg, NY 13669, USA
Telephone: +1 888 551 7470 • Fax: +1 888 551 7471
Email: orders@renoufbooks.com • Web site: http://www.renoufbooks.com

United Nations
300 East 42nd Street, IN-919J, New York, NY 1001, USA
Telephone: +1 212 963 8302 • Fax: 1 212 963 3489
Email: publications@un.org • Web site: http://www.unp.un.org

Orders for both priced and unpriced publications may be addressed directly to:

IAEA Publishing Section, Marketing and Sales Unit, International Atomic Energy Agency
Vienna International Centre, PO Box 100, 1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22488 • Fax: +43 1 2600 29302
Email: sales.publications@iaea.org • Web site: http://www.iaea.org/books

14-46781

International Atomic Energy Agency
Vienna
ISBN 978–92–0–109914–3
ISSN 1011–4289