Unclassified **NEA/RWM(2001)6/REV**

Organisation de Coopération et de Développement Economiques
Organisation for Economic Co-operation and Development

28-May-2001

English - Or. English

NUCLEAR ENERGY AGENCY
RADIOACTIVE WASTE MANAGEMENT COMMITTEE

NEA/RWM(2001)6/REV
Unclassified

GOING UNDERGROUND FOR TESTING, CHARACTERISATION AND DEMONSTRATION

(A Technical Position Paper)

English - Or. English

JT00108467

TABLE OF CONTENTS

FOREWORD

The NEA Co-ordinating Group on Site Evaluation and Design of Experiments for Radioactive Waste Disposal – SEDE[1] decided in late 1998 to prepare a Technical Position Paper on Going Underground for Testing, Characterisation and Demonstration, in order to summarise information, in an international perspective, concerning the development of underground research laboratories (URLs) to support the deep disposal of high-level and/or long-lived radioactive waste. A questionnaire was sent out to the national organisations (implementing agencies, regulatory authorities, Research & Development institutions) represented within the SEDE and this report represents their views on the subject, together with input from other recent commentaries and reviews of the use of underground facilities in programmes for the deep disposal of high-level and/or long-lived radioactive waste.

The present Position Paper was prepared by the NEA Secretariat from a draft prepared by Tim McEwen (QuantiSci, United Kingdom), under the supervision of the SEDE *ad hoc* group in charge of this initiative, i.e. Timo Äikäs (Posiva, Finland), Patrick Lebon and Gérald Ouzounian (ANDRA, France), Jean-Yves Boisson (IPSN, France), Javier Rodriguez (CSN, Spain), Al Lappin (SNL, United States), Dennis Williams (USDOE/YMP, United States), and Philippe Lalieux (NEA [now ONDRAF, Belgium]). Tim McEwen was supported by Posiva and the NEA. This Position Paper was discussed and approved for general distribution by the Radioactive Waste Management Committee of the NEA and is intended for an audience of technical decision-makers and specialists.

---

1. The NEA Co-ordinating Group on Site Evaluation and Design of Experiments for Radioactive Waste Disposal (SEDE) and the NEA Performance Assessment Advisory Group (PAAG) were disbanded in October 1999. The recently launched Integration Group for the Safety Case (IGSC) subsumes previously separate activities in the programmes of work of the SEDE and the PAAG.

EXECUTIVE SUMMARY

This Technical Position Paper has been prepared in order to provide a compilation, in an international perspective, of information on underground testing facilities for the deep disposal of high-level and/or long-lived radioactive waste. It is based on the results of a questionnaire that was sent out to the national organisations (implementing agencies, regulatory authorities, Research & Development institutions) represented within the SEDE (the NEA Co-ordinating Group on Site Evaluation and Design of Experiments for Radioactive Waste Disposal) and represents their views on the subject, together with input from other recent commentaries and reviews of the use of underground facilities for the deep disposal of high-level and/or long-lived radioactive waste.

The Position Paper is aimed at being beneficial to technical decision-makers in helping them in planning underground programmes, so that the best use can be made of existing and planned underground facilities. It concentrates on potential future uses of existing and planned underground facilities by analysing strategic and programmatic aspects, the regulatory framework in which to view the future uses of underground testing facilities, and the link with the overall decision-making process in the stepwise approach to repository development.

In particular, it reviews the possible requirements for further work after nearly 30 years of *in situ* activities and assesses the relationships and contrasts between underground facilities where generic R&D takes place and those located at proposed disposal sites.

The Position Paper includes discussion on the further needs for underground testing, the main aspects to consider when planning a programme of underground testing, and international co-operation in underground testing. Use is made of the acronym URL (Underground Research Laboratory), which is qualified either by the use of the prefix “site-specific” (when referring to a potential disposal site) or “generic” (when referring to a facility developed elsewhere). The use of the URL acronym for an underground testing facility does not, therefore, prejudge the uses to which it could be put.

Section 2 of the Position Paper discusses the requirements for possible work in URLs, from the standpoint of the operation of both generic and site-specific URLs. It covers the wide range of objectives that has been assigned to existing and proposed URLs and draws on the extensive work that has taken place in such facilities over the last 30 years. It discusses the justification for a URL programme by answering questions, such as “do we need URLs and, if so, why?”

The role of a URL in a repository development programme is discussed in terms of the stepwise, or incremental, approach that is known to be required if the programme is to be successful. The contrasts in the objectives between generic and site-specific URLs are covered in detail. These contrasts are discussed with reference to the different types of work that are likely to be required and to the variations in emphasis that need to be placed on aspects of work within a URL depending on the type of rock in which it is located.

Work within site-specific URLs is discussed in terms of how it is effectively a continuation of the site-characterisation programme and how the decision is made as to the most appropriate time to "go underground". Work in a site-specific URL is also reviewed in terms of reducing uncertainty in three areas, those of groundwater flow and radionuclide transport, natural and induced changes in the geological barrier, and the design and construction of the repository.

The general trends in *in situ* experiments are presented by considering the progress in underground testing that has taken place over the last 30 years and how the emphasis of such testing has shifted towards ever more sophisticated tests that are designed to investigate more specific aspects of the rock mass and the engineered barrier system and, in particular, their interactions. The inherent limitations of testing in URLs are discussed in terms of the differences that are likely to exist in this area between those that are generic and those that are site-specific.

The main aspects to consider when planing an underground facility are covered in Section 3 of the report and are discussed in relation to those that are of most relevance in planning either a generic or a site-specific URL. Defining the strategy for a URL programme and how it might be planned are covered under five main headings: the establishment of baseline conditions; minimising damage to the geosphere; the establishment of a formal method for comparing predicted and measured parameters; the development of underground facilities; and the temporal aspects of such a programme.

The review of international co-operation in underground testing draws on recent work in this area carried out on behalf of the EC and the NEA. Such co-operation has been shown to be beneficial, in terms of producing a positive influence on progress in deep disposal and is also frequently cited as being likely to provide an increased level of public acceptance for radioactive waste disposal.

The extensive conclusions of this review are presented and are listed under five main headings of: the purpose of URLs, future work in URLs, the strategic role for URLs, the need for URLs, and planning a URL programme. URLs are generally considered needed for the comprehensive characterisation and evaluation of a potential disposal site, as well as for developing the disposal concept and examining any alternatives. URLs also have a strategic role in helping to build confidence in the concept of deep geological disposal.

1. INTRODUCTION

1.1 Objectives of the Technical Position Paper

This Position Paper is aimed at being beneficial to technical decision-makers in helping them in planning underground programmes, so that the best use can be made of existing and planned underground facilities. It concentrates on potential future uses of existing and planned underground facilities by analysing:

- strategic and programmatic aspects,
- the regulatory framework in which to view the future uses of underground testing facilities, and
- the link with the overall decision-making process in the stepwise approach to repository development.

In particular, it reviews the possible requirements for further work after nearly 30 years of *in situ* activities and assesses the relationships and contrasts between underground facilities where generic R&D takes place and those located at proposed disposal sites.

Examples of the subject areas which are discussed in the Paper, and which are considered helpful in defining the uses that can be made of a URL include:

- the role of the URL in a repository development programme,
- the justification for a URL programme,
- the contrasts and similarities in objectives between generic and site-specific URLs,
- important issues to consider when judging the appropriate time for “going underground”,
- defining the strategy for a URL programme, and
- the inherent limitations of testing in URLs.

This Paper is, therefore, distinct from the recent IAEA review of the use of results obtained from underground research laboratory investigations (IAEA, in preparation), which presents a review of underground work to date and comments on potential future uses of existing and planned underground facilities. This paper is not intended to provide a catalogue of past and current *in situ* experiments and demonstration activities or a series of generic recommendations or requirements on how best to carry out underground investigations. It is also not intended to provide a review of the efficacy of past and current underground testing programmes.

1.2 Structure of the Technical Position Paper

The Position Paper is divided into four main sections:

- the needs for underground testing,
- the main aspects to consider when planning a programme of underground testing,
- international co-operation in underground testing, and
- conclusions and recommendations.

These main sections are completed with a set of references and by two annexes that provide information on the terminology used to describe underground testing programmes and the status of such programmes within the NEA Member countries.

1.3 Relationship with other international initiatives

Several other recent international initiatives have been concerned with the use and operation of underground testing facilities; amongst these are the following:

- the European Commission CLUSTER (Club of Underground Storage, Testing and Research Facilities) which is aimed at stimulating co-ordination and co-operation in underground research facilities and increasing the exchange of information on multinational research projects carried out in the framework of the EU R&D programme on Radioactive Waste Management (Haijtink and Davies, 1998; Anderson, 1999);
- the document "*The Use of Results Obtained from Underground Research Laboratory Investigations*" drafted under the auspices of the International Atomic Energy Agency and which reviews existing *in situ* tests and experiments to date and assesses the uses of the results gained underground (IAEA, in prep.); and
- the OECD Nuclear Energy Agency report on the "*Geological Disposal of Radioactive Waste: Review of Developments in the Last Decade*" which summarises the key technical achievements in the development of deep repositories within the NEA Member countries (NEA, 2000).

The Position Paper is not intended to duplicate these other initiatives but rather to look at the same area of interest from a different perspective. It has, however, benefited from the results of these other reviews. In addition, this Position Paper has provided support for an NEA report in preparation on "*Underground Laboratories in Nuclear Waste Disposal Programmes*", which is intended for a wider audience of policy makers and interested public.

1.4 Terminology

Different terms are used in different countries to describe underground facilities, ranging from those applied to facilities at proposed disposal sites to those applied to facilities where generic R&D activities take place. The term Underground Research Laboratory (or its acronym URL) is in common parlance to refer to all of these facilities. However, the terms "laboratory" and "research facility" have connotations with R&D and are both possibly somewhat inappropriate when referring to actual repositories or those facilities that are located at proposed disposal sites[2]. A list of some of the most frequent acronyms that have been or are used to refer to these underground facilities is provided in Annex 1. The choice of the acronym commonly emphasises the message the implementing organisation would like to give regarding the URL rather than the actual status of the facility.

Despite the above remark concerning the difficulties of applying the terms laboratory and research to an underground facility that could be used for a variety of purposes, in this Position Paper we will be consistent with the terminology used in the recent IAEA review (IAEA, in prep.). That

---

[2] Several waste disposal organisations, such as Nirex and USDOE, have developed acronyms to refer to their underground facilities where the terms research and laboratory were specifically excluded, reference being made to the Rock Characterisation Facility (RCF) at Sellafield and the Exploratory Studies Facility (ESF) at Yucca Mountain.

review uses the term URL and distinguishes between generic URLs, those not located at designated disposal site, and site-specific URLs, those at designated disposal sites. We include existing or prospective repositories under the heading of site-specific URLs. Examples of generic URLs include the Underground Research Laboratory (Canada), Tono (Japan), Grimsel (Switzerland), and Äspö (Sweden). Examples of site-specific URLs include Mol (Belgium), Konrad (Germany), Sellafield (United Kingdom), and WIPP (United States). A complete listing of URLs in NEA Member countries is given in Annex 2.

Three terms are used in the title of this Technical Position Paper and it is considered helpful if they are defined at the outset:

characterisation: *in situ* investigation of the geological, hydrogeological, geochemical, structural and mechanical properties and behaviour of the geological environment,

testing: evaluation of the performances of characterisation methodologies, engineered materials, excavation methods, etc. which may be used in the development of a repository, and of the conceptual and numerical models that are used to assess the performances of the repository system and/or some of its constituents; and

demonstration: illustration, at full scale and under real and/or simulated repository conditions, of the feasibility of the repository design and of the behaviour and performance of various (or all) of the components of the repository.

2. REQUIREMENTS FOR UNDERGROUND TESTING

2.1 Introduction

The radioactive waste community generally agrees as to the usefulness of an underground testing programme for increasing confidence in the ability to dispose of high-level and/or long-lived waste safely (Savage, 1995; Kickmaier and McKinley, 1997; Olsson, 1998; McCombie and Kickmaier, 1999). The most important objective of a URL often is to allow an in-depth investigation of the selected geological environment and to provide the opportunity to allow testing[3] of models at more appropriate scales and conditions than can be achieved from the surface. In some areas, such as in demonstrating operational safety, in acquiring geological information at a repository scale and in constructional and operational feasibility, a URL provides the only reliable source of *in situ* data. In other areas, it can provide less tangible, but no less important, advantages in enhancing confidence in the disposal technology within the general scientific community and amongst the public at large. The presence of a URL can also promote an informed dialogue between an implementing waste management agency (frequently referred to as the implementer) and the nuclear regulatory authorities (the regulators). An outline of the role of a URL in the development and assessment of repository concepts is illustrated in Figure 1.

A wide range of objectives has been assigned to existing and proposed underground testing facilities. There is a requirement, therefore, to provide a rationale for any additional work, especially within generic URL programmes, either at existing or at new facilities. The question needs to be asked, “do we need URLs and, if so, why?”, and some answers to this question are outlined in Table 1. Work at site-specific URLs will, necessarily, be focused on providing site-specific data for repository safety assessments and it is, therefore, less of a problem to justify any further work in these facilities.

A considerable amount of work has been performed over the last few decades in underground facilities. The level of international collaboration between countries’ disposal programmes that is evident today has not always been present, but, from the outset of several URL programmes such as the Stripa Project, co-operation between national disposal programmes has been extensive.

---

[3] “Testing” of, and “confidence building” in, models are terms which are currently used instead of “validation”, as the rigorous validation of models and codes may not be possible (see for example Jing *et al*., 1999, and Section 2.4). A helpful discussion of the meaning of the term validation is provided in NEA (1999), where it is discussed with reference to the development of confidence in the long-term safety of geological disposal.

Figure 1. **The role of a URL in the development of a geological disposal concept**

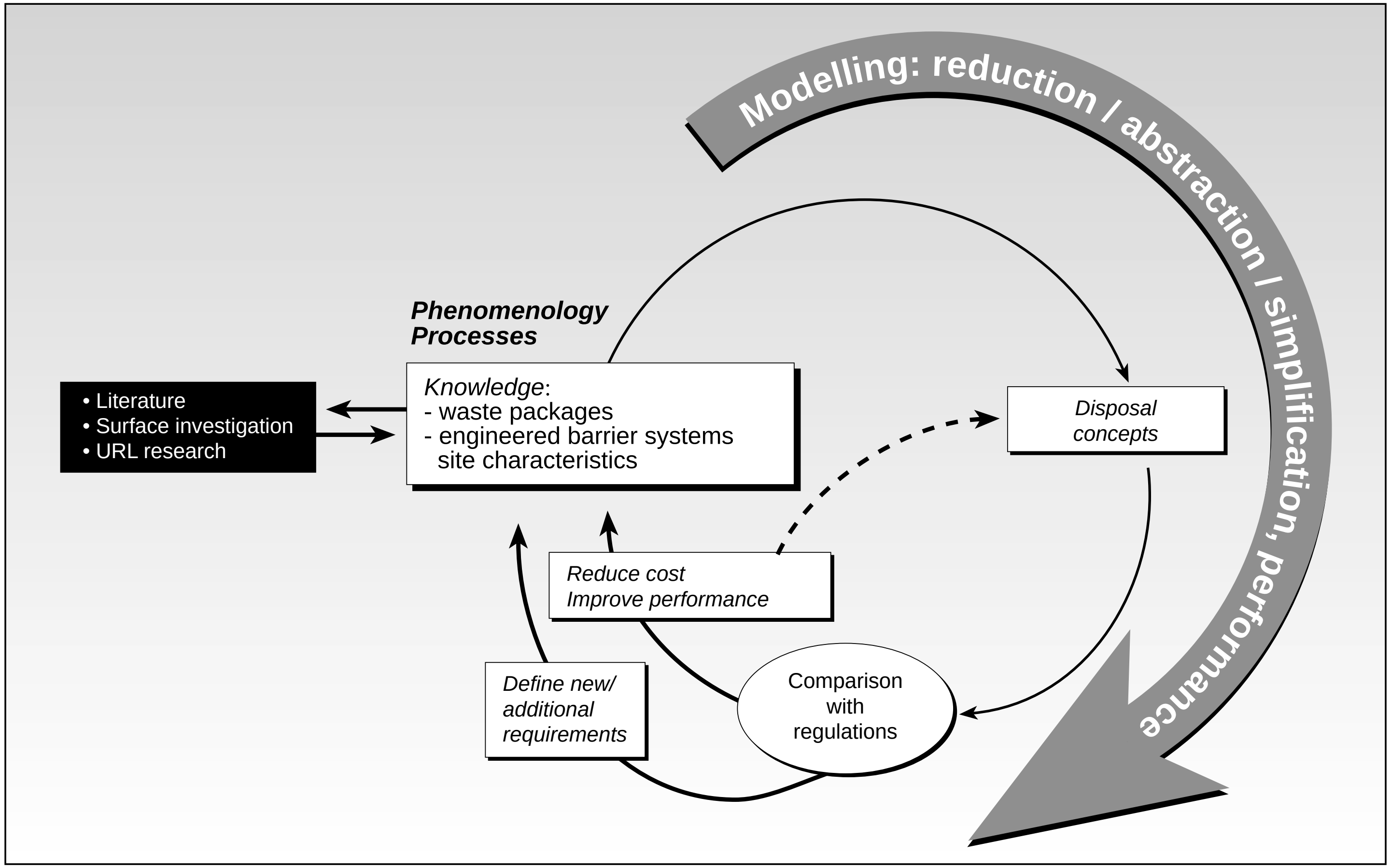


Table 1. **The justifications for a URL programme.**

The concept of deep disposal and its long-term safety assessment require (principally):

- careful, mechanistically oriented descriptions of: i) the repository host rock; ii) all significant release paths from the repository to the human environment; and iii) waste and engineered barriers within the system
- the definition of key safety-relevant parameters in both the near- and far-fields (e.g. of the rock mass and the EBS), obtained using minimally invasive techniques
- an adequate understanding of the complex and probably coupled processes in the near-field and the geosphere that may lead to radionuclide transport to the human environment
- the ability to scale structural, flow, and transport parameters and processes from the URL/laboratory scales to the geometric and chronological scales required for safety assessment
- predictive, short-term and long-term modelling of the repository behaviour

URLs offer the chance of developing and demonstrating the ability to provide some types of data for safety assessments in realistic *in situ* conditions. Except for measurements made on the operational scale and over operational timeframes, however, some form of extrapolation and/or upscaling of the results will always be required before they can be used in any safety assessment.

URLs help address issues such as:

- measurement of the properties of the geosphere;
- understanding the behaviour of the EBS and the geosphere;
- demonstrating the feasibility of deep disposal;
- demonstrating the ability to design, construct and operate a disposal facility in the type of rock and at the depth envisaged;
- determining optimum design and operational procedures for implementing the components of the repository system; and
- development of a reliable monitoring strategy for a repository.

URLs:

- provide access to representative geologic conditions;
- provide facilities for full-scale, *in situ* research, development, and demonstration;
- are either generic or site-specific (site confirmation);
- contribute to building confidence within a waste-management program, within the technical community, and with the public and other stakeholders;
- “showcase” a program's knowledge and competence;
- allow an informed, substantive dialogue to take place between the implementer and the regulator(s); and
- allow the demonstration of concepts and methodologies for disposal to scientists, regulators, politicians, and, possibly most importantly, to the public.

As is emphasised in Anderson (1999) and NEA (2000), considerable co-operation now occurs between URL programmes within NEA Member countries in general and EU countries in particular covering a large range of potential disposal environments. Future work in URLs needs to consider the following:

- the 30 years of *in situ* R&D work to support the development and the assessment of geological disposal systems that has been carried out in URLs;
- the decreasing emphasis on basic feasibility studies and on the accumulation of fundamental geological data – increased effort is now being focused on the optimisation of methodologies and on the testing of key performance-assessment models and safety-relevant issues;
- the increasing importance being placed on full-scale “demonstration-type” experiments on Engineered Barrier Systems (EBSs).

The questions that need to be posed when considering the requirements for underground testing are:

- What role does a URL play in a repository development programme and how do the roles of a generic URL differ from those of a site-specific URL?
- How does the operation of a URL help in the decision-making process for repository development?
- How might a URL programme help in developing confidence in the concept of deep disposal?
- How do the needs of the safety assessment influence a URL programme?
- At what point in a site-characterisation programme do you move from surface-based investigations to those within a URL?

2.2 The role of a URL in a repository development programme

The role of a URL within a repository development programme is contingent on several factors. A URL can be developed relatively early in a repository programme, such as has been the case in several countries, including Belgium, Sweden, Germany, Switzerland, the USA, and Canada, and used both for direct R&D activities related to the disposal concept of the particular country and as a communication tool.

The majority of NEA and EU Member countries consider that the development of URLs has benefits beyond those connected principally with R&D (Anderson, 1999, NEA, 2000). In particular, URLs have provided a focus for scientific collaboration and information exchange at a variety of levels, from those within the national and international waste management community and the scientific community at large to the involvement of the local population. Great value is generally seen in this collaboration and in allowing scientific and non-scientific visitors to such a facility. This active communication of ideas and concepts in an environment which may be similar to that proposed for final disposal appears to be only beneficial and is likely to increase the confidence of all the stakeholders in the repository project. Included in this category are not only those directly involved in such a venture, together with the regulatory authorities, but also the scientific community, the public at large, and politicians.

Many of the problems associated with the public's antipathy and hostility towards the disposal of radioactive waste can be traced to misunderstandings in what is being proposed and a lack of trust in the proponent's disposal plans. An open URL programme can go a long way in helping overcome such difficulties. The main objectives of such a programme are listed in Table 2.

Table 2. **A general outline of the main objectives of a URL.**

- Technology and methodology development
- Providing data for safety assessment[4]
- Testing of models to be used in safety assessment[5]
- Help locate suitable disposal volumes and design repository layout
- Maintaining existing know-how and the integration of new results into existing disposal concepts
- Demonstration of repository concepts
- Confidence building in the scientific community
- Communication of ideas and help in increasing public confidence of disposal

Where then does a URL sit within a repository development programme? Within one country's disposal programme, must a URL be developed for each geological environment that is being considered and do these URLs need to be all located within the one country, or is it sufficient to collaborate with URLs in other counties? The route to repository development is always programme-specific, and the role of a URL, whether it be generic or site-specific, within a programme can vary depending on the specific requirements of each country. The essential elements of many repository development programmes are, however, often similar (see the box below on *The Stepwise Approach Towards Geological Repository Development*). Examples of the different approaches that have been taken are discussed below.

Finland, for example, concluded that the presence of suitable generic URLs in Sweden at Stripa and Äspö, which were located in similar rocks to those being considered in Finland for deep disposal, precluded the need to develop their own generic URL. They are proposing, however, to develop a site-specific URL at Olkiluoto, as part of their more detailed characterisation programme. Posiva already operates a small underground test facility (known as the Research Tunnel) at the VLJ repository for low- and intermediate-level waste at Olkiluoto. The advisory bodies in France involved with deep disposal have, since 1982, consistently promoted the need for a URL at each potential repository site. The 1991 Waste Act specifically requires the development of at least two URLs. As a result of this policy, the French government not only authorised in December 1998 the construction and use of a URL in an argillaceous formation at the potential disposal site at Meuse/Haute-Marne, but also recommended the development of another URL in a granitic area.

---

[4] Data obtained from a URL cannot necessarily be used directly in a performance assessment without some explicit assumptions being made as to their generic utility. For example, data from a URL regarding the performance of a seal can only be used with specific assumptions regarding the applicability of its observed performance over timeframes well in excess of the time available for a realistic experiment.

[5] It can be argued that, if at all possible, model "validation" should be completed prior to the development of any site-specific URL. In this context, however, a distinction needs to be made between the development of conceptual models (for the types of processes that are relevant to the environment in question) and the development of the constitutive laws (where it is only the values of specific parameters that are site-specific).

The Stepwise Approach Towards Geological Repository Development

Whatever the precise form of the disposal programme, the development of a deep geological repository is characterised by several stages and is likely to require several decades for completion. Such a stepwise (or incremental) approach to repository development will invariably require underground testing, characterisation, and demonstration. The incremental development of a repository and its associated safety case is discussed in detail in a recent NEA report (NEA, 1999) in terms of confidence building and its communication. Additional information can be found in NEA (2000). A brief description of the rationale for, and aims of, the stepwise approach towards repository development is given below.

The novelty and complexity of the task of repository development mean that the detailed planning, licensing, and implementation of a disposal facility cannot be accomplished in a single step. Rather, an incremental and flexible procedure is needed that will allow a gradual increase in confidence to be developed in the disposal option as technical information and experience are acquired. The increased confidence that comes with a stepwise approach can also, to some extent, be derived from observations of predictable system behaviour over longer periods of time (from so-called "demonstration activities"). This procedure will, in addition, allow a repository programme to respond flexibly to changes in regulatory guidance and its interpretation or even, possibly, to changes in basic safety standards.

A stepwise approach is, however, valuable not only for these technical and procedural reasons, but also because of the resulting requirement for smaller, incremental steps to be taken in the decision-making process. Discrete, relatively straightforward steps facilitate the traceability of this process and allow feedback from the regulators or from the public. These smaller steps also promote the strengthening of public and political confidence in the safety of a facility and allow trust to be developed in the competence of the regulators and the implementers of a disposal project.

Such a flexible approach means that alternative options, wherever possible, remain open with regard to the future development of the repository, and provides an opportunity for earlier decisions to be re-evaluated. Despite this flexibility, discrete stages need to be defined at the beginning of any programme to allow for its planning and, in order to preserve confidence in the stepwise approach itself, there needs to be a general understanding of what is to be broadly achieved at each step and what would be required in terms of information and confidence to make such a step.

In most programmes, a lengthy, stepwise development process is foreseen through generic and site-specific investigations (including the development of URLs) leading to repository implementation, although the meaning of the term "stepwise approach" differs between countries, according to technical, financial, regulatory, societal, and political factors. A clear, common definition of what this term means in practice is, therefore, unavailable. Typically, this approach involves a number of developmental stages, punctuated by interdependent decisions that are taken throughout the development of a facility including, for example, interim surface storage, siting and design, safety assessment, site characterisation, the licensing of construction, repository operation and closure, and repository sealing

Table 3 illustrates the position of a URL in the stepwise development of a repository programme. In parallel with the differences in approach to repository development evidenced from the discussion above, the manner in which the stepwise approach can be tailored to the needs of a country's regulatory, legal, and planning system needs also to be considered. Differences in approach here are likely to have an effect on the role played by a URL. Examples of how this might influence a URL programme are:

- whether a generic URL is concluded to be necessary and whether any such URL should be located within one's own country,
- whether a generic URL is required for each geological environment being considered for disposal purposes,
- whether the programme in a generic URL should continue in parallel with work within a site-specific URL,
- to what extent a site-specific URL is necessary, or whether the majority of the R&D activities could take place within a generic URL, with the role of the site-specific URL being limited to that of a detailed phase of the site-characterisation programme.

Table 3. **The position of a URL within the development of a repository programme.**

A stepwise approach of underground testing, characterisation and demonstration is favoured for repository development notably in order to:

- Define the potential host disposal environment(s) basic disposal concept(s)
- Plan and implement a generic URL programme to answer key questions and to optimise exploration methods and repository design (a possible strategy is for several countries to participate in international programmes rather than develop their own facilities)
- Operate a site-specific URL to obtain data for the preparation of a safety case and licensing + demonstration

Different routes to repository development can have considerable implications in terms of both cost and time. The steps, or discrete stages, will also vary depending on the role that a URL plays within in a repository programme. Whatever type of URL is developed, it will likely play a prominent role in the development and presentation of the safety case and in the enhancement of confidence in the strategy for disposal[6].

The recent development of a proposed R&D strategy for the United Kingdom for the disposal of High-Level Waste and/or Spent Fuel (HLW/SF) (QuantiSci, 1999) discusses the needs for a generic URL, both for the situation where all such work could be carried out in collaboration with existing URLs in other countries and also for the situation where a generic URL could be developed in the United Kingdom. The conclusions of this report provide a useful summary of the arguments in favour of international collaboration in the use of generic URLs, and many of these arguments are

---

[6] Some programmes may consider it necessary to have their own national generic and site-specific URLs.

believed to be applicable not only to the situation in the United Kingdom, but also elsewhere[7]. The subject of international collaboration is also discussed in more detail in Section 4 of this report.

The QuantiSci (1999) report concluded that the United Kingdom has considerable scope to become involved in international collaborative studies, as a large majority of the R&D topics for HLW/SF disposal listed in the report were identified as being suitable for such co-operative work. Participation in international programmes, particularly those involving practical studies, was seen as a useful way of developing and maintaining a national skill-base, and early involvement in such programmes was perceived to be a useful boost in the conceptual and generic phases of the disposal programme, when national opportunities would otherwise be limited.

The discussion on international collaboration presented by the QuantiSci (1999) report raised the key question of whether it would be appropriate for the United Kingdom to have a generic URL stage in the disposal programme. The most significant factors to consider in making this decision were considered to be:

- the type(s) of geological environment which either emerged from the siting process or which it was decided to carry forward in the generic phase of the programme. If these contain environments that were significantly different from those being evaluated in other countries, then the use of domestic generic URLs would need to be considered;
- any requirement to be able to demonstrate United Kingdom-specific engineering aspects of the programme prior to gaining access to the repository site;
- the fact that much work on rock properties has already been carried out internationally in URLs, and the UK would initially want to look back at what has been achieved and catch up with relevant national deep disposal programmes.

It was concluded for a future United Kingdom disposal programme for high-level waste and/or spent fuel that there seemed to be a logical case for conserving resources by basing the programme on existing international experience of URLs, engineering designs and geological environments, built up over the last 20 years, during which the UK has had no programme to look at HLW/SF disposal. It was also concluded that, internationally, there is not a great deal of first principles R&D that remains to be done in generic URLs. Rather, the focus is turning to demonstration of repository technology. An important point here was, however, the ability to demonstrate that results were truly transferable from a “foreign” geological environment to those emerging from the UK siting programme[8].

In summary, it was concluded that there is a clear case for recommending that, from the outset of the disposal programme, the UK should adopt an active approach to becoming involved in relevant future overseas URL programmes and that, so far as possible, it should focus its siting and design programme on those with substantial existing information and experience. This could then avoid the requirement to have a generic URL in the UK.

---

7. This report does not represent United Kingdom government policy but will be used to help formulate future policy on HLW/SF disposal.

8. The dependence of relevant rock mass properties, e.g. hydraulic properties, structural response, etc., upon variables such as fracture frequencies, orientations, and characteristics should, in theory, be generic. The combination of local, empirical information, such as local fracture densities and intersections, etc., together with generic correlations should lead to site-specific ranges of behaviour. It is, therefore, not the results that should be expected to be transferable but the relationships between the generic variability and the site-specific input variables.

These conclusions are possibly of most direct relevance to countries with small nuclear programmes, such as many of those who have recently joined the NEA and/or who are applicants for EU membership, who would find it difficult, if not impossible, to justify the expense of developing their own generic URLs. Other countries, such as Spain for example, are already actively involved in other countries' URL programmes, due mainly to the difficulties of developing such facilities at home. Some countries may also decide that this co-operative working is the most sensible approach to follow, both from a cost perspective and also in terms of simplifying their own disposal programme. The use of existing URLs in other countries is likely to speed up the repository development programmes in several states and be beneficial for all programmes concerned.

A general conclusion of the discussion above is that, at least within Europe, the existing generic URL facilities cover the likely range of disposal environments and that, from a purely scientific standpoint, there is now less requirement to develop additional generic URLs[9]. A country may, however, wish to develop its own generic URL for other reasons, perhaps associated with public acceptability.

2.3 Relationship of the URL with the overall regulatory context and the decision-making process for repository development

A URL programme, in particular one in a generic URL at the earlier stages of repository development, has an important role in the regulatory context, in that it supplies information that is of direct relevance to the regulatory authorities in their assessment of the general feasibility of the proposed disposal concept. Later in the disposal programme, much of the confirmatory data regarding the host rock and the detailed designs of the repository system will be obtained from a site-specific URL. In a well-managed disposal programme, the regulators and the implementers will be in regular dialogue and the implementers will be keen to demonstrate to the regulators that they have sufficient confidence in the proposed disposal concept. In terms of the system design and the strategy that will need to be followed for testing and implementing such a system, an R&D programme carried out in *in situ* conditions is likely, in many situations, to be more convincing than one carried out elsewhere. Similarly, the regulator will likely require the implementer to demonstrate that he adequately understands and is capable of modelling the processes that determine the migration of radionuclides, both in the near-field and also in the geosphere. *In situ* experiments, in many cases, will provide the most convincing support to this understanding.

Each of these stages in a disposal programme can represent increments in the licensing process, where the implementer is required to demonstrate, most probably by the production of a safety case, that he can satisfy the requirements of the regulatory authority. A repository system needs to be developed in a flexible and incremental manner, from both a technical and non-technical standpoint. Much of the work underground is associated with the process of confidence building, and flexibility in the approach to repository development allows the programme planning to be responsive to the accumulation of data from the R&D and site-characterisation programmes. This process is well

---

[9] Significantly less work has been done in Europe in bedded salt than in other geological environments. The programme at the French site at Amelie (in bedded salt) ceased in 1992, as ANDRA has no plans to investigate this type of disposal environment. In the USA, however, a large amount of work has been carried out in this rock type since 1982 at the Waste Isolation Pilot Plant (WIPP), near Carlsbad, New Mexico, both during its stage as a URL and now as part of the testing programme associated with the issues that require clarification in the WIPP recertification as a final repository for long-lived, defence-related waste.

described in NEA (1999) in terms of building an increased level of confidence in the disposal concept. This confidence then needs to be communicated, both to the regulator and to the public.

2.4 Contrasts in objectives between generic and site-specific URLs

Various areas of work that are carried out in generic and site-specific URLs may have distinctly different emphases, although the types of work carried out may, in many ways, be similar. The objectives for the work that can be performed in either of these two facilities are listed in Table 4, the characteristics of this work are presented in Table 5, and the factors to be considered in designing generic and site-specific URL programmes in Table 6.

Some of the areas of work outlined in Section 2.4.2 on site-specific URLs, such as groundwater flow and radionuclide transport and natural and induced changes in the geological barrier, are also applicable to the work that could be carried out in a generic URL. They are included in this latter section because they are likely to be investigated in more detail in a site-specific URL than in a generic URL.

Table 4. **Objectives of the work carried out in both generic and site-specific URLs. Several of the items listed under the generic URL could possibly be carried out within a site-specific URL, however the emphasis of the work is likely to be different in the two types of URL.**

Generic facility	Site-specific facility
• Develop disposal concepts • Test methods for characterisation and monitoring • Develop linkage between descriptive/conceptual and numerical models describing near-field behaviour • Develop linkages between characterisation parameters measured in boreholes (basically 1D) and those measured in the URL (2D and 3D) • Develop understanding of sensitivity of rock mass performance to variability in measured characterisation parameters • Develop and test methods for constructional components and construction techniques • Test components of the disposal system under realistic conditions • Test alternative disposal and operational options • Build technical confidence • Develop and possibly demonstrate industrial-scale project • Build national, multi-disciplinary team • Develop experience and know-how • Foster international co-operation	• Site evaluation and confirmation • Characterisation of geosphere immediately adjacent to repository • Identification of suitable volumes/blocks of rock and detailed design and repository layout • Reduction in inherent conservatism in conceptual and safety assessment models by collection of additional *in situ* data, testing of models, etc. • Monitoring of near-field responses of the repository for regulatory purposes • Demonstration of technology and techniques (and maintenance of up-to-date testing and interpretation techniques) • Detailed design and testing of operational aspects • Non-technical confidence building • Address some of the Environmental Impact Assessment issues • Continuation of surface-based investigations before repository construction • Test flexibility of repository design and design-as-you-go (if that is the policy)[10]

The essential difference between generic and site-specific URLs is related to whether emphasis is placed on developing an understanding of the processes that occur in rocks, which is generic in nature, and which would normally be studied in a generic URL, or whether the emphasis is on the collection of site-specific data. Processes are to some extent specific to particular types of rock,

---

10. The design-as-you-go approach has been favoured by SKB and, more recently, Posiva, as a method of repository development in crystalline rock that would allow you to position the waste canisters in optimal locations. This is achieved by developing an initial design basis for your repository, with reference to canister spacing etc., but also by taking the local properties of the rock into account when deciding on whether to utilise any particular deposition position. A similar process would also apply to the location and orientation of disposal tunnels, etc.

so an understanding needs to be developed of the rock type of interest in a generic URL (where, or if, one is available). Where a generic URL is unavailable, a site-specific URL will have to be used for all the types of work[11]. Data on material properties and the state of the system (e.g. temperature) are site-specific, although relevant parameter ranges can be obtained from a generic understanding. For example, the various URLs in granitic rock have provided SKB, Posiva, and others with a good understanding of the variability in properties in different types of granitic environments.

Table 5. **Characteristics of the types of work which can be carried out in generic and site-specific URLs and the constraints that apply to this work.**

Generic URL	Site-specific URL
• Essentially a research-based programme • Opportunity for training in characterisation techniques and R&D • Allows selection to be made between and demonstration of construction techniques • Development of testing methodologies • Development of generic database[12] • Invasive methods for characterisation and R&D permitted • Testing of safety assessment models • Testing of monitoring strategies	• Baseline conditions confirmed and geosphere monitoring system in place before construction • Construction of URL determined by repository concept and other site conditions • Characterisation of host rock and development of upscaling rules to a larger area[13] • Collection of host rock-specific data • Perturbations to host rock minimised • Programme linked specifically to safety assessment requirements for licensing • Essentially not research-based

---

11. This is essentially the situation at the WIPP.

12. This “database” needs to contain not only data but also generic concepts, such as the development of scaling laws which relate, for example, measurable characterisation parameters to the response of the rock mass.

13. This is almost certainly to be for a volume of the rock mass that is smaller than that of the whole repository.

Table 6. **Factors to consider in designing generic and site-specific URL programmes.**

Generic URL	**Site-specific URL**
• Primarily a research facility • Select site that is both relevant and scientifically interesting and able to be modelled • Emphasis on scientific development[14] • Needed to develop and test methodologies • Needed to obtain generic data unobtainable from surface-based R&D • Very useful for demonstration and communication of ideas and concepts • Guarantee of no repository construction?	• A *real* disposal site • Minimise perturbations to geosphere • Rigorous Quality Assurance programme • Construction techniques generally limited to those applicable to repository concept, but also testing of construction techniques • Scientific programme designed to minimise uncertainties from surface-based investigations • Collection of data relevant to detailed design and licensing safety assessment Demonstration of repository concept at full, or other pertinent scales and optimisation of disposal technology

At a potential repository site the requirement is to:

- collect site-specific data for performance assessment,
- collect site-specific data and use it to develop an optimised repository design or layout,
- provide a final design for the engineered barrier system and service systems needed for the repository, and
- optimise the repository operational system.

Research and demonstrations of operational feasibility, which can be carried out in a generic URL, can of course also be carried out at a potential repository site (or in a site-specific URL) if one so chooses.

A generic URL performs a somewhat different role, in that it allows technique and equipment development to take place, so that they are available at the selected site, whilst also allowing confidence in the disposal concept to be increased. The rationale for the Äspö HRL programme is a good example of this approach (Olsson, 1998). A generic URL programme could continue simultaneously with one in a site-specific URL, possibly accepting experiments that might compromise the integrity of the geological barrier at the site-specific URL or could delay the initial onset of repository construction. A generic URL could also be used to test the viability of retrievability procedures over extended periods of time.

2.4.1 Work in generic URLs

Generic URLs have been developed in the past for a variety of reasons. The earlier URLs often followed on from the initial ideas and concepts that had been developed for disposal and

---

[14] Rather than focusing on the collection of "representative data", examining what might be termed correlation functions that could be applied across the expected range of data for the rock type(s) of interest is preferable.

examined rather specific aspects of the near-field. Examples of such URLs are Stripa (Sweden), which was operational during the development of KBS-3 (SKB, 1983) and the Climax Granite within the Nevada Test Site (United States) where a full-scale demonstration project, which included a large-scale heater test, was carried out. Emphasis was often placed on the thermal aspects of HLW/SF disposal and primary R&D was carried out on radionuclide migration, groundwater flow into underground openings, etc. Later URLs have been developed also for other reasons. The HRL at Äspö (Sweden) was conceived to provide, for example, in addition to the more classical R&D activities that had taken place at Stripa, information to test and validate the use of technologies that could be used to provide cost reductions and simplify the repository concept without compromising safety. The Äspö programme was also designed to demonstrate the technology that was proposed for the deep repository.

The Äspö HRL programme has been organised so that all important steps in the development of a repository are considered. In other words, the Äspö HRL constitutes a dress rehearsal for the Swedish deep geological repository for spent fuel and other long-lived waste. The focus of current and future work is on the development and testing of site-characterisation methods and their ability to provide data for performance assessment, the verification of models describing the function of the natural and engineered barriers, and the development, testing, and demonstration of repository technology (Olsson, 1998).

The main original purpose for the development of the HADES facility at Mol was to provide evidence that it was indeed possible to construct suitable openings at likely repository depths in the Boom Clay. There was, at the time, doubt as to whether this would be feasible. In contrast, there are, today, few of these fundamental problems, the purpose of a generic URL being related more to demonstrating that disposal techniques are credible and that disposal can be carried out safely.

Some URLs, such as Mont Terri (Switzerland), have been developed recently to examine specific rock types. The Mont Terri Rock Laboratory is an international project developed from a road service tunnel in the folded Jura Mountains under the auspices of the Swiss National Hydrogeological and Geological Survey. The research at Mont Terri is primarily aimed at increasing the basic understanding of low-permeability, indurated argillaceous media, and is therefore not focused exclusively on deep disposal (Thury, 1997, Thury and Bossart, 1999a and 1999b). The Opalinus Clay present at Mont Terri is markedly more indurated than the Boom Clay at Mol and is considered as an adequate equivalent not only of the potential host rocks in northern Switzerland (Opalinus Clay) but also of those in eastern France (Jurassic mudstones) (Sugier and Lebon, 1997) and in Spain. The Mont Terri Partner Organisations also felt that *in situ* data were required in order to assess the hydraulic and transport properties of the Opalinus Clay and to study the complex, coupled processes that occur in such indurated clays using experiments that could not be carried out either in deep boreholes or in the laboratory. Information was also thought to be needed on rock mechanical stability at depth, so that the feasibility of repository construction could be assessed.

Considerable differences exist among the types of rocks that are being considered for the deep disposal of long-lived and High Level Waste (HLW) and this is reflected in the types of underground experimental programmes that are carried out.

In crystalline rocks, the geometry of the potential fast pathways, essentially controlled by the connectivity of the fracture network, is complex but the processes of groundwater flow and solute transport are relatively well understood. Extensive surface-based investigations can be carried out before going underground and one of the most significant difficulties can be how a repository can be fitted into the rock between the more transmissive and ubiquitous fracture zones.

In argillaceous rocks, the geometry is considerably simpler and the spatial variability of important properties, such as the hydraulic conductivity, can be low, thereby allowing a greater confidence in the potential suitability of a site for disposal purposes to be based on surface-based investigations than is probably the case for crystalline rocks[15]. The processes associated with radionuclide transport can, however, be complex and are frequently, if not invariably, coupled. The extent to which these types of rock can be self-healing is also of interest (as the extent of this process can vary considerably depending on the plasticity of the rock) and this is an important factor to consider when investigating and modelling the Excavation Damaged Zone (EDZ) (NEA, in prep.).

Extensive experience of waste disposal in rock salt has been gained from the work that has been carried out over many years at the WIPP (Waste Isolation Pilot Plant) in New Mexico and where disposal of defence-related TRU is now taking place in bedded salt. In Germany, low- and intermediate-level waste (LILW) has been disposed of in the Morsleben salt dome, and a long period of *in situ* experimental work has taken place at the Asse salt mine, where LILW has also been disposed. The fluid content of rock salt is commonly very low and the rate of solute transport also considerable less than in crystalline rocks.

The work within a generic URL can continue even while a site-specific URL is in operation in the same type of geological environment. There may be experiments that would be useful, but which may be undesirable to carry out in a site-specific URL. An example of this could be a large-scale, long-term test that would interfere with the repository construction programme, but that could continue in a generic URL.

Commonly, generic URLs are located at sites with geological properties that are similar, or at least relevant, to those being considered for the proposed disposal option. Some generic URL sites are selected because it is considered that they are potentially less favourable than actual disposal sites, and an example of this type of site is Äspö, which was selected partly on the prediction of the fracture density being greater than that likely at a selected disposal site in Sweden. Research at sites which are different from those of the proposed disposal options may be valuable in allowing comparisons to be made between the preferred disposal option and the generic site. This could be helpful in demonstrating that the preferred option is notably superior in some way. It is interesting in this regard that the German R&D programme has included experimental work at the GTS (Grimsel, Switzerland) and, more recently, at the Mont Terri (Switzerland) and Tournemire (France) URLs.

Of interest also is the approach that is being followed by IPSN, the technical advisor to the French regulatory authorities. IPSN have been keen to obtain direct experience of working underground in advance of the development of a URL by ANDRA (the French Waste Management Agency). To that effect, IPSN have carried out *in situ* investigations in their own generic underground facilities (e.g. Fanay-Augères and Tournemire) and have participated in various generic URLs (e.g. Stripa and Mont Terri). At the time of the development of the Tournemire URL in the early 1990s within a disused railway tunnel in the south of France, the *in situ* behaviour of indurated mudstones was indeed poorly understood (Barbreau and Boisson, 1994, Boisson *et al.*, 1998a, 1998b). Tournemire was the only URL in such rock before the development of the Mont Terri URL in Switzerland. The rock type at Tournemire, although being a mudstone, is different from that which will be investigated by ANDRA at the Meuse/Haute Marne URL (Lebon, 2001a, b). This difference is of interest in that it allows a comparison to be made between superficially similar, but actually different geological environments in terms of the methods used for their characterisation. It does, however, highlight the potential problems that exist in the transferability of data from a generic to a

---

15. Small-scale heterogeneities may be difficult to detect in such rock types using conventional methods of field testing. However, their influence on hydraulic and transport properties may be detectable using geochemical techniques.

site-specific URL and the possible limitations of a generic URL in a radioactive waste disposal programme (see also Table 8).

SKI used the data obtained by SKB at Äspö to develop a hypothetical repository at that location based on the KBS-3 concept. This was then used as the basis for the SITE-94 performance assessment (SKI, 1996) so that SKI could develop further their own competence, rather than simply follow the developments of the implementers. By gaining their own experience, SKI's capabilities to review judgements made by SKB in their assessments increased substantially.

In principle, retrieval of waste or waste packages is technically feasible in all geological formations considered for radioactive waste disposal. Demonstrating that retrieval of the waste could realistically be undertaken may help in building public confidence in a decision to emplace waste, as any such decision, if later proved to be erroneous, could be reversed and the waste retrieved from the repository.

ANDRA does not plan to test retrievability in its Meuse/Haute Marne URL in the current programme of testing up to 2006. However, such tests are planned for subsequent phases. Although it is possibly unwise, or unnecessary, to limit all such retrievability testing to generic URLs, a generic URL may be a more appropriate location in which to carry out such tests, as it is easier than in a site-specific URL to allow damage to the surrounding rock to take place, e.g. due to the emplacement of instrumentation or the exhumation of experiments.

2.4.2 Work in site-specific URLs

Table 4 lists the general objectives for the work carried out in site-specific URLs, which is commonly viewed, in part, as the normal continuation of a site-characterisation programme. At some point in a detailed characterisation programme, a decision has to be made to “go underground” and the types of questions that need to be asked regarding this matter are summarised in Table 7.

ANDRA has recently received consent to develop a URL in Jurassic argillites at the Meuse/Haute Marne site and is currently searching for an additional site in crystalline rocks[16]. Under current French law, these URL sites cannot accept radioactive waste during this research phase, which aims at proving these sites are adequate for disposal. After 2006, however, the French parliament could pass a complementary bill to authorise the principle of geological disposal for radioactive waste management and one of the URL sites could then become the final repository site. The present phase is the first in the incremental safety processes. The investigations planned now for these URLs are concerned with demonstrating that feasible solutions exist for the safe disposal of long-lived waste at depth at these two sites. The proposed underground programmes take into account the political settlement dates and the development plan for the repository concept.

SKB’s current repository development programme, as outlined in SKB (1995), includes a period of detailed characterisation at the proposed repository site, which will include excavation down to the repository depth. The purpose of this phase is the collection of additional data for PA and design issues to supplement the data obtained from surface investigations and boreholes. It includes drilling and investigations from boreholes drilled from the tunnels. The detailed characterisation phase will end with the submission of a licence application for the disposal of 10% of the expected amount of

---

[16] One of the key points regarding ANDRA’s URLs is that, despite the fact that they are to be constructed at potential disposal sites, they are designed as URLs and not as prototype repositories, e.g. they have shaft dimensions that are not designed to accommodate waste packages. This is to demonstrate that the existence of the URL does not imply any approval for repository development.

spent fuel. Much of the data collection and characterisation activities will probably correspond to what other organisations plan to perform in their site-specific URLs. SKB foresees that a monitoring programme will have already been initiated during the site-characterisation phase and that this monitoring program will be continued and probably expanded during the detailed characterisation phase.

Table 7. **Important issues to consider when judging the appropriate timing for “going underground” in a site-specific URL.**

If you go underground: • the natural system will be heavily disturbed[17] • you make the first step towards repository construction • there is better access to the relevant parts of the host rock • public confidence may increase (public access to underground facility: visual inspection, long-term presence of implementing organisation, familiarisation with the project, etc.)
Delay going underground until: • all measurements required on the undisturbed system are complete, i.e. baseline groundwater pressures and hydrochemical conditions have been established[18] • those experiments that can be performed only in the unperturbed system are complete, e.g. large-scale pumping tests • you believe you understand how to scale properties and behaviour with respect to flow and transport[19] • there is general agreement as to the underground lay-out of the repository (at least its basic design) - in certain cases the access shaft or ramp to the URL could become part of the final repository[20]
Go underground: • when surface investigations cannot sensibly provide the required information • when direct access to the relevant parts of the host rock is required to make progress (experiments that can only be carried out underground, e.g. validation of models by *in situ* tests, optimisation of excavation techniques, etc.)[21] • when definitive decisions have to be made regarding the location and layout for the repository
When going underground: • the extent of damage to the geosphere barrier should be minimised, preferably by locating access routes to the URL where repository access would later be required. • avoid a large number of boreholes drilled from the surface, except where they are subsequently assimilated by underground access.

---

[17] disturbances include: i) changes in hydraulic heads; ii) mixing of different types of groundwater (e.g. disturbance of hydrochemical stratification, upconing of groundwater); iii) degassing of groundwater due to depressurisation; iv) excavation-damage to the rock in the vicinity of underground openings.

[18] minimum duration of any long-term monitoring needs to be agreed with the regulator.

[19] this is only possible if the necessary work has been carried out in a generic URL; however, if no suitable generic URL were available, this work would have to be carried out in a site-specific URL, in which case this point would need to be ignored.

[20] If the access (shaft, ramp, etc.) to the URL is part of the final repository system, enough information must be available and the design must be sufficiently advanced (including any corresponding preliminary safety assessment) to plan and construct the proposed underground structures. If these shafts are to be used for possible eventual waste handling, this aspect of the repository design also needs to be considered at this stage.

[21] This is particularly important if the host rock has a very low permeability as, in this case, obtaining reliable data using surface boreholes will be extremely difficult. Specialised testing techniques will have to be used *in situ*.

SKB has proposed that the Äspö HRL continue in operation in parallel with this detailed characterisation and that work at Äspö concentrate on research into processes and the development of technology for disposal.

Nirex prepared extensive documentation to justify the development of the RCF at Sellafield (e.g. Nirex, 1997a). Their main justification was related to the requirement to obtain information to address uncertainties. The three main areas of uncertainty that were of interest to Nirex were (and other implementing organisations would likely have similar uncertainties):

- groundwater flow and radionuclide transport,
- natural and induced changes in the geological barrier, and
- design and construction of the repository.

Nirex concluded that the requisite information could not be obtained from surface-based investigations. In addition, the RCF would provide information that could be collected more effectively underground. These areas of uncertainty are likely to be common to the majority of future proposed site-specific URLs and, therefore, they are examined in more detail using appropriate examples.

2.4.2.1 Groundwater flow and radionuclide transport

Models of groundwater flow through a crystalline rock mass are generally based on the assumption of the presence of connected fractures and fracture zones that can have lengths of up to hundreds of metres. The limitations imposed by the surface-based investigations result in significant assumptions having to be made regarding the use of such data in assessment calculations, because the cross-sectional area of such fractures intersected by boreholes is very small in proportion to their total area. Due to such limitations, other descriptions of the fracture network, which could imply significantly higher groundwater flows through the repository volume, could be possible, although less likely. In order to increase confidence in the assessment of the site, investigating such fracture networks in more detail is considered necessary by all implementing organisations, and the greater scale of a URL compared with boreholes allows this to be achieved. In addition, observations of changes in groundwater pressure and chemistry associated with the construction of the URL access shafts provide valuable additional information over large volumes of the rock mass. The monitoring of the groundwater inflows into the access ramp at the Äspö HRL provides a good example of this (although, in this case in a generic URL) and other similar programmes have been carried out or planned at, for example, the Canadian URL.

In an argillaceous or evaporitic environment, the problem may be different, in that flow and transport in fractures may not be dominant, and may be related more to the difficulties associated with performing measurements in boreholes in rocks with very low permeabilities. The problems of understanding the spatial scaling ubiquitous in crystalline rocks, and the difficulties associated with obtaining the requisite data, may be less of a problem in low-permeability sediments or evaporites, i.e. the potential host rocks. A site-specific URL programme is more likely to concentrate on the properties of the host rock, with investigations of the more permeable and probably more spatially variable components of the sedimentary sequence being investigated using surface-based boreholes[22].

---

[22] This is because a repository in an argillaceous or evaporitic environment will presumably have been located away from the more significant potential fast pathways (most likely faults) and the most conductive horizons.

2.4.2.2 Natural and induced changes in the geological barrier

It is important to be able to demonstrate that future changes, which could be natural or induced by repository construction and operation, would not create new pathways that could result in unacceptable groundwater flows or cause damage to the engineered barriers of the repository that would significantly affect its performance. Measurements in boreholes are not thought to allow acceptable information to be obtained on the response of the rock mass to excavations of the dimensions similar to those of an actual repository, whereas a URL provides appropriate conditions in which to study the different types of disturbances that could take place (mechanical, hydraulic, thermal, or geochemical). Nirex came to such a decision when considering the need for a site-specific URL at Sellafield[23]. Posiva came to similar conclusions regarding the need for a URL at Olkiluoto (their chosen site for the disposal of spent fuel in Finland), as did Nagra in Switzerland (Nagra, 1995). At each site, some items of interest are likely to be site-specific and could be examined better within a URL than from the surface. In the case of Sellafield, one of these was that further information was considered necessary to confirm that the fracture network system had indeed existed for several million years. At another site, especially one in Scandinavia, glacially induced changes might be considered most significant in this regard.

The favourable chemical conditions that exist at depth are important to preserve, as this factor is crucial to the future behaviour of the EBS, and the chemical behaviour of the geological environment immediately around the repository (sometimes referred to as the near geosphere) needs to be assessed. Detailed chemical characterisation of the groundwater system in the host rock can best be achieved from sampling underground.

2.4.2.3 Design and construction of the repository

For sites in crystalline rock, a further consequence of the uncertainties discussed above, together with limitations on the availability of geotechnical data on the rock mass, is that a firm view can generally not be taken on the benefits that could be gained from particular depths, locations, and layouts for the proposed repository from surface-based investigations alone. In order to take such decisions, the way in which groundwater flow and dilution and the geotechnical properties of the rock mass would vary with such parameters needs to be established, and measurements underground are required to resolve such questions. Preliminary views as to the location and possible depth range for a repository can, however, be developed as has been the case recently in Finland (e.g. Anttila *et al.*, 1999), based mainly on the location of fracture zones and on geotechnical constraints regarding the depth. In this case, the extent to which a change in depth could have consequences for long-term safety, other than from a purely mechanical standpoint, is unclear.

In sedimentary and evaporitic environments, the potential disposal depth may be easier to select using surface-based boreholes. In the case of the WIPP, a range of possible depths for the disposal horizon was determined with relation to potentially transmissive formations noted in core samples, and the specific disposal horizon was selected from detailed examination of the rock exposed in the first shaft constructed (Jarolimek *et al*., 1983). At Mol, the HADES facility was located at the centre line of the Boom Clay. The work on repository design in these rock types may, therefore, be related more to the orientation and geometry of the disposal tunnels and other underground openings, rather than on the precise depth for disposal.

---

[23] The waste vaults proposed by Nirex for ILW disposal were considerably larger than those proposed by other disposal organisations for the disposal of spent fuel/HLW.

Unsaturated rocks are only being considered for the deep disposal of spent fuel at Yucca Mountain. An underground transport test facility has been sited, designed, and constructed at Busted Butte, 8 km southeast of the potential Yucca Mountain repository area, in unsaturated tuffs that are similar to the units beneath the potential repository horizon (Bussod, 2001). The principal objectives of the tests, which were initiated in April 1998, are to evaluate fundamental processes and uncertainties associated with flow and transport in the unsaturated zone site-scale models for Yucca Mountain. These include but are not restricted to:

- The effect of heterogeneities on flow and transport under unsaturated and partially saturated conditions. In particular, the test aims to address issues relevant to fracture/matrix interactions and permeability contrast boundaries.
- The migration behaviour of colloids in fractured and unfractured tuffs.
- The validation, through field testing, of laboratory sorption experiments in unsaturated tuffs.
- The evaluation of the 3-D site-scale flow and transport process model (i.e. equivalent continuum/dual-permeability/discrete-fracture-fault representations of flow and transport) used in performance assessment abstractions.
- The effect of scaling from lab scale to field scale and site scale.

2.4.3 Monitoring

Long-term monitoring of a repository is generally considered to have an important role in confidence building. One way to assist in developing such confidence, employed at WIPP, is to set up a monitoring programme with a set of minimum protection objectives so that, if they were to be exceeded, prescribed action could be taken.

Attempting demonstrations of monitoring in an active or developing repository may not be practical or sensible and may be better carried out in a generic URL. This would allow for the use of more invasive methods of monitoring and the testing of waste recovery strategies etc. Further demonstrations may have to be carried out later in the site-specific URL. Regulators and other major stakeholders should be involved in the planning, execution, and interpretation of monitoring programmes from the outset. Some disposal organisations have merely made reference to monitoring in their planning strategies, whilst others, Nagra in particular, have devised a so-called Repository Surveillance Strategy, although even this is actually only conceptual in design.

Points to note concerning possible strategies for monitoring, which could influence the programmes of work both in a generic and a site-specific URL are:

- Obtaining radiological data for short-term validation of the success of a disposal methodology is likely to be extremely difficult and could lead to a more open-ended operational stage for a repository (i.e. also a possibly extended period of work in a site-specific URL)
- Repository safety must be demonstrable at least before closure, but monitoring cannot be a prerequisite for that safety (this may also extend the potential life of a site-specific URL)
- Monitoring should be supported by established intervention thresholds
- More monitoring may be required than is actually necessary for demonstrating a safe operation

- Given that monitoring will be carried out to assist in model validation, the level of monitoring might be reducible as those models are further refined
- Monitoring for validation in URLs and test facilities can be useful, but transferring conclusions from one site to another, i.e. from a generic to a site-specific URL, might be problematic.

Monitoring within URL programmes to date has, however, been included for the purposes of site characterisation and model-validation studies. No consensus exists at present as to the extent of monitoring that is required or what should be expected of a monitoring programme. Regulatory bodies will likely take a keen interest in the design and operation of monitoring systems, and agreeing with them early in a URL programme on the objectives of any monitoring and the extent to which demonstrations of the capability of such systems will be necessary is advisable.

2.5 General trends in *in situ* experiments

The discussion above has included commentary on the fact that the types of experiments carried out in URLs have changed over the years. Some clear trends in these changes can be discerned although, before this can be discussed, a distinction needs to be made between work in generic URLs, where the emphasis is often on the development and testing of state-of-the-art techniques and in achieving a fundamental understanding of the processes involved in solute transport, and site-specific URLs, where the emphasis of the work is linked to the safety of the disposal concept, but also to current social concerns as is demonstrated by recent developments in thinking about reversibility (ANDRA, 1999).

In the early underground programmes, a major focus of the work was the development of methodologies and equipment for underground characterisation and the demonstration of the feasibility of various aspects of the disposal concepts involved. Such demonstrations included the drilling of large diameter holes at Stripa, consistent with the KBS-3 type disposal concept, and the emplacement of dummy waste canisters at Asse. The collection of data on the rock types of interest for disposal also was a priority, because few data were at that time available.

The emphasis of this underground work soon began to shift towards the optimisation of investigation equipment and more detailed analyses of the usefulness and applicability of such equipment *in situ* in providing the data necessary for groundwater flow and solute transport modelling. Particular emphasis was placed in this area in crystalline rocks with respect to the development and testing of geophysical and hydrogeological equipment. In parallel with this was the increased interest in testing models, such as those applied to heat transport and the associated impacts of thermally induced stresses, which were tested at sites such as Climax (United States), Grimsel (Switzerland), and Stripa (Sweden). Testing geomechanical models was of particular interest at Asse (Germany) and Mol (Belgium), because potential stability problems were of more direct interest in clays and salt than in crystalline rock. More recently, testing groundwater flow and solute transport models has been of increased interest, which has included a greatly increased interest in the use of geochemistry, both to understand and place constraints on the effects of flow and transport mechanisms, but also to provide some verification of models.

With an increase in the sophistication of safety assessments and the requirements from specific engineering designs, the development of testing programmes that are designed to investigate specific aspects of the rock mass has become necessary. This trend in the engineering requirements is most clearly seen in experiments at actual repository sites, such as the WIPP (United States). However, it is also evident from the types of testing that are planned or are taking place at the Äspö

HRL (Sweden). The planning stage of such experimental programmes now has a greater input from repository engineers and performance assessment personnel and they are better integrated into the experimental teams. In addition, the questions to be answered by these experiments are now more closely specified and are related more to specific uncertainties identified in the assessments.

The emphasis has now shifted even more towards understanding the interaction between the EBS and the geosphere and also towards testing models for certain key processes, which has inevitably involved the examination of processes that are coupled. The extent to which models for these complex natural systems can be used in a predictive manner in performance assessment is being investigated in collaborative programmes such as DECOVALEX (Development of COupled models and their VAlidation against EXperiments in nuclear waste isolation), a programme that is developing and investigating coupled thermo-hydromechanical codes (e.g. Jing *et al.*, 1999). The results from the first two phases of DECOVALEX indicate that one of the main ingredients in developing models that could be used for long-term predictions for use in performance assessment is a proper site-specific study to understand a site, its behaviour, and its features. This will require testing to be carried out in a URL in many cases.

The general trend in *in situ* experiments can be summarised as:

- A decreasing emphasis on basic feasibility studies and on the accumulation of fundamental geological data and an increased focus on:
  - i) the optimisation of methodologies,
  - ii) the collection of specific data to understand coupled processes and the validation of complex models,
  - iii) the testing of key performance assessment models (for generic more so than for site-specific URLs), and
  - iv) the investigation of issues of long-term stability, in particular in relation to chemical conditions at depth.
- The increasing importance placed on full-scale “demonstration-type” experiments on EBSs (e.g. FEBEX[24] (Fuentes-Cantillana *et al.*, 1998; Fuentes-Cantillana and García-Siñeriz, 1998) RESEAL[25] (Volckaert *et al.*, 1998b), PRACLAY[26] (Ondraf/NIRAS, 1998) and the Prototype Repository Project[27] and the Canister Retrieval Test[28] at Äspö (Olsson, 1998; SKB, 1999). Such experiments are likely to include the demonstration of

---

[24] FEBEX: Full-scale Engineered Barriers EXperiment: Consists of an *in situ* test in natural conditions and at full scale at Grimsel, Switzerland, a mock-up test at nearly full scale, and a series of laboratory tests to complement the large-scale information.

[25] RESEAL: Sealing of a repository for radioactive waste in argillaceous rock. The demonstration of the feasibility of making an effective seal in semi-industrial conditions. Consists of small- and large-scale *in situ* tests supported by laboratory and modelling work.

[26] PRACLAY: PReliminAry demonstration test for CLAY disposal of high-level radioactive waste. This is a demonstration of the feasibility of the Belgian reference concept for disposal of HLW at Mol. It consists of a 30-m-long “dummy” disposal gallery, a study of the THM behaviour of the clay and the EDZ around the gallery.

[27] The Prototype Repository project aims to test and demonstrate the integrated function of SKB's deep repository components at full scale, to develop and test appropriate engineering standards and QA methods, and to simulate appropriate parts of the repository design and construction process.

[28] The Canister Retrieval Test is designed to demonstrate that the retrieval of SKB's waste canisters is technically feasible during any phase of the operation.

retrievability, where this is a policy requirement (e.g. Grupa *et al.*, 2000), and a retrievability test will be carried out at Äspö (Olsson, 1998).

The questions that need to be asked regarding the requirements for *in situ* testing therefore relate to the extent to which sufficient fundamental geological data are currently available to assess the feasibility of deep disposal. This factor is of current interest in Japan in relation to the recently published H12 assessment (JNC, 2000), which concluded that such fundamental data are indeed necessary from two proposed URLs, one in crystalline rocks and one in sediments, because the overall long-term stability of the geosphere in Japan's dynamic geological environment and, therefore, the concept of deep disposal in Japan, has been called into question. It is also pertinent to the design of the experimental programmes at Mont Terri (Switzerland) and Meuse/Haute Marne (France) in indurated clays, as the complex coupled solute-transport processes in clays are still not well understood. For these URL programmes, however, a detailed knowledge of such processes may not be a necessity if radionuclide movement through such clays can be shown to always be extremely slow. The requirements for fundamental geological data will depend on the extent to which understanding such complex processes and the effect that uncertainties in this understanding might have on the results of PA calculations is considered necessary.

Summaries of some of the URL programmes discussed above are provided in IAEA (2000) and the general use of URLs is also covered in Kickmaier and McKinley (1997) and Haijtink and Davies (1998).

2.6 Inherent limitations of testing in URLs

The inherent limitations on testing in URLs are dependent on whether the URL is site-specific or generic. As was discussed in Section 2.5, work within a generic URL can use invasive methods for characterisation and R&D, whereas damage to the geosphere in a site-specific URL should be minimised. The extent to which this damage is considered to be a real problem will be a controlling factor in the design and construction of the site-specific URL and in the types of experiments that are carried out. The inherent or possible limitations within both generic and site-specific URLs are listed in Table 8.

Table 8. **Inherent or possible limitations of work within both generic and site-specific URLs.**

Generic URL	Site-specific URL
• Problems in transferability of results from generic to site-specific URLs • Relatively short time scale of experiments compared with time over which long-term safety assessment is required • Experiments with radionuclides sometimes not allowed[29] • Complex boundary conditions, if using existing underground access, e.g. Grimsel	• Damage to the geosphere needs to be limited • Limitations on scales of testing (due to comparative sizes of URL and repository) • Limitations on scales of testing, both temporally and spatially, compared with those required for long-term safety assessment (i.e. volume of rock tested possibly unrepresentative) • The practical impossibility of determining the properties of rock mass in detail over the full extent of the repository volume • The limitations of using only URL data to supply the information required[30]

The consequences of these limitations are that:

- practical factors limit the extent to which the properties of the rock mass and their spatial variability can be determined within the entire volume that will be used for the repository. However, this does not detract from the need to develop a URL as the majority of the information could never be obtained from surface-based investigations[31].
- reliable measurements of certain parameters may prove impossible to obtain, e.g. relevant solute transport parameters over scales of more than a few centimetres,
- the volume of the rock mass tested or investigated will be small in comparison with the volume required for the repository[32], and
- the limitations imposed by the practicalities of testing mean that significant temporal upscaling will also be required[33].

---

29. Experiments with radionuclides have been carried out in generic URLs at Grimsel, Mont Terri, Äspö, and Asse.

30. The problem of supplying the required data needs to be thought of in a tripartite manner, i.e. a generic URL, a site-specific URL, and surface-based investigations may all be needed to obtain the data required for assessment and other purposes. This is to emphasise the point that a site-specific URL may be insufficient on its own.

31. The implication here being that there are practical limitations to what can be determined regarding the properties and structure of the rock mass, even when a URL has been developed. This fact should not, however, be used to imply that a URL is, therefore, unnecessary. Without a URL, the majority of this information could not be obtained to the level of detail and accuracy required, and a surface-based borehole programme would be insufficient in this regard. Further surface-based work will, however, likely be necessary in conjunction with the URL programme, and in this way obtaining the data required for assessment purposes and for repository design should be possible.

32. The variability and heterogeneity of a host rock can be determined from investigating a relatively small volume and this can be extrapolated to judge the performance of a larger volume.

33. Temporal upscaling is a problem general to PA and is not specifically related to URLs.

The first three of these require that the properties of the rock mass will always need to be upscaled and that a balance needs to be struck regarding the costs and potential benefits of the limited number of underground tests and measurements that can be performed and the extension of the results from these to the measurements already made from the surface. Correlations need to be found between the relatively simple and continuous measurements possible using geophysical techniques (e.g. wireline logging) and the significant transport and flow properties of the rock mass. A good example of this type of work, but involving only surface-based measurements, is provided by Nirex's investigations of the spatial variability of the rocks at Sellafield (Nirex, 1997b). In a URL programme, this type of work will need to be correlated with the measurements made underground.

In terms of temporal upscaling, the problem is that if attempts are made to speed up experiments, (by, for example, increasing pressure gradients in tracer testing) so that results are obtained over convenient time scales, the frequent outcome is that the processes taking place in the rock or fluid change and are no longer relevant to the processes that would take place naturally. The problem of time is also related to scale, in that large-scale tests that would provide information over large length scales will often take too long to complete, so that experiments have to take place over smaller length scales. These experiments do not then sample the larger scale properties of the rock mass and the results are, therefore, biased. This problem increases inversely with a decrease in the permeability of the rock and is, therefore, likely to be of greatest significance in argillaceous and evaporitic rocks.

Detailed measurements of certain parameters may be found to be necessary (perhaps bounding values could be shown to be sufficient) or the significance of some effects produced by the repository, e.g. the EDZ, may be found to be small and experiments to study their properties and geometries are not required. Such decisions can only be taken by examining the influence of these factors on the long-term safety of the repository system.

3. MAIN ASPECTS TO CONSIDER WHEN PLANNING A URL

The criteria and conditions to consider when planning a site-specific URL are generally more stringent than those that must be considered for a generic URL. For instance, factors such as minimising damage to the geosphere during URL construction and making certain that sufficient baseline data have been obtained in advance of URL construction are important to the development of a site-specific URL, but are not critical in the development of a generic URL. Several successful generic URLs, e.g. Stripa, Grimsel, Mont Terri, Tono, and Kamaishi, have been developed from existing underground structures without taking into account several of the important factors to be considered when developing a site-specific URL. Table 9 lists the considerations that are of most relevance in the development of generic and site-specific URLs. Table 10 lists the attributes of an R&D programme that could be developed in a generic URL.

Table 9. **Aspects that are of most relevance in planning either a generic or a site-specific URL programme.**

Generic URL	**Site-specific URL**
• Demonstration of baseline (in particular hydrogeological and geochemical) conditions in advance of construction[34]. • The extent to which the geological environment needs to be similar to that proposed/possible for final disposal. • Where should the emphasis be placed on the work programme, on fundamental R&D or more on practical aspects of disposal?	• Demonstration of baseline (in particular hydrogeological and geochemical) conditions in advance of construction. • Minimisation of damage to geosphere due to construction of URL. • Establishment of a formal method of comparing predictions based on surface-based investigations with observations/ measurements underground.

Some of the most detailed published information regarding the planning of a URL programme is provided in a series of reports from Nirex. For example, Nirex (1997a) describes the planning of the proposed programme in the RCF.

The initial stages of planning a URL programme, in particular one in a generic URL, need to consider the strategy that should be followed to define the programme. Table 11 lists some of the possible stages in such a procedure for selecting a site for a generic URL.

---

[34] This would be a practical proposition and also preferable for a generic URL that was constructed independently, e.g. Äspö, but for not one developed using an existing underground structure, e.g. Grimsel.

Table 10. **Attributes of R&D programme in a generic URL.**

Classification of R&D:

- Parameters specific to host rock
- Engineering and construction-related programmes
- Testing of specific equipment
- Development of characterisation methodologies
- Developing an understanding of relevant processes
- Development and testing of conceptual and mathematical models
- Demonstration of repository operation

Strategy for programme choice. The right URL programme is dependent on:

- Type of URL required
- Boundary conditions set by repository concept
- Status of the national disposal programme
- Types of host rock and wastes considered
- Operating time for any existing facility

Planning process:

- Input from the end-users
- Define questions that need answering
- Identification of key uncertainties (in data and understanding)
- Potential to optimise site-characterisation programme
- Translate to working programme (define relationships with disposal programme)

3.1 Establishment of baseline conditions

The construction of a URL will perturb the natural system and, in particular, the groundwater regime. A certain understanding of the natural system will need to be achieved in advance of any construction, because the changes due to construction will be irreversible and because the construction of the facility provides an opportunity to develop and test models of the site over large volumes of the rock mass.

Baseline is the description that is generally applied to the conditions in a system, e.g. a groundwater system, prior to some form of induced perturbation. The undisturbed conditions incorporate the effects of natural features and processes that account for the spatial and/or temporal variability in the system prior to construction of an underground facility. Prior to URL construction, sufficient baseline information on groundwater pressures and hydrochemical conditions needs to have been acquired so that:

- the disturbance created by the facility can be measured and used to test and develop models of the site and
- a sufficient database exists on undisturbed conditions that the properties of the rock mass in the region of the proposed repository (or, in the case of a generic URL, the facility itself) can be interpreted within the context of the regional groundwater flow and hydrochemical models.

Table 11. **Defining the strategy for a generic URL programme.**

How is the decision made as to whether a generic URL is required[35]?

- Is carrying out work only in other countries' URLs acceptable or is one required in your own country and what are the reasons for this decision?

At which stage must a rock type be selected for a generic URL?

- Does a URL have to be developed in the same rock type that is being considered for disposal?
- If no specific rock has been defined, how do you select the most appropriate site for a generic URL, or do you wait until a rock type has been defined?
- Is operating two or more URLs simultaneously sensible or necessary, or is selecting one rock type before developing any URL programme preferable?
- If you select a single rock type for disposal, is continuing research in a URL in another type of rock necessary and, if so, for what purpose?

What sort of generic URL is required?

- Is developing a URL as a new facility necessary, i.e. on a greenfield site, or is one developed based on an existing underground opening equally suitable?
- Does a URL have to be at a similar depth as the repository?

What are your expectations from operating a generic URL?

- Where should the emphasis be placed in the work programme, on fundamental R&D or more on practical aspects of disposal?
- Do you intend to repeat experiments that have been carried out in other URLs and, if so, what is their purpose?
- What do you expect experiments in a URL to tell you? To what extent do you believe that the results of these tests are likely to provide convincing evidence that your disposal strategy will be acceptable?

For how long do you continue a generic URL programme?

- Will the programme cease when a single site has been selected for disposal? If not, what will its purpose be after that time?

Both Nirex and SKB were able to demonstrate that baseline conditions had indeed been established at Sellafield and at Äspö (Gustafsson *et al.*, 1991; Stanfors *et al.*, 1997; Rhen *et al.*, 1997). Further monitoring at Sellafield using the Long-term Monitoring System has subsequently demonstrated that little has changed over a period of a further two years (Nirex, 1998). Several studies were also carried out at Yucca Mountain to determine similar baseline conditions before any underground construction commenced (e.g. Brechtel *et al.*, 1995). Determination of such conditions using existing equipment and techniques is generally thought to be possible at hard rock sites and at sites where sediments overlie the basement. The techniques that would be used in less permeable argillaceous sequences and in rock salt are likely to be essentially similar, although the potential

---

[35] See, for example, the discussion of a possible future UK disposal programme in Section 2.2.

changes due to construction may well be of lower magnitude and be measurable over a smaller volume of the rock mass while the response time of the system may be longer. Definition of the baseline conditions may require as little as two years after monitoring boreholes are installed and instrumented at a crystalline site, but could require as much as a decade at a low-permeability argillaceous or evaporitic site, or where hydraulic conditions are not in a steady state to begin with and existing trends need to be defined.

3.2 Minimisation of damage to geosphere

In a site-specific URL, minimising the damage to the geosphere due to URL construction is important. Any type of access, if not adequately sealed, provides a potential fast pathway with a cross-sectional area that may be considerably greater than that of a natural structure or an exploration borehole. Therefore, any access to a URL should be incorporated into the repository if possible. Developing a URL at the same depth as that proposed for disposal is preferable and perhaps necessary, so that the data obtained are of greatest relevance to final repository design. Whether a URL should preferably be developed within that part of the rock mass proposed for disposal (and subsequently to try and incorporate the URL within the repository design) or at some distance from the disposal zone is unclear. In the first case, the potential impact on the rock mass is lessened, although the extent to which this is significant is likely to be site-specific and is likely to depend on the available volume of potentially suitable rock. Where suitable rock volumes are constrained, such as was the case at Sellafield and possibly at one or more of the sites being investigated by Posiva (e.g. Anttila *et al.*, 1999) this could be an issue. In the second case, which for example represents the current situation at WIPP, the test facility remains largely separate from the disposal zone and would allow testing to continue while disposal was taking place. This could be an issue in terms of the stepwise licensing process for the repository, in particular where retrievability was a requirement, but could also be of importance for public acceptance.

The location and underground geometry of access shafts or ramps to a site-specific URL are also of significance. Although their incorporation into the final repository access will minimise their impact, the ability to model the impact of alternative access locations and geometries in advance of their construction will be necessary. This is so that the extent to which they could allow preferential transport pathways to develop along their lengths, or allow preferential hydraulic connection between fast pathways in the geosphere, which would normally be unconnected, is minimised. Modelling will, therefore, be required of the long-term efficacy of shaft seals. In order to be able to carry out this modelling, the current groundwater flow system will need to be understood. Future climate change and neotectonic effects may, however, produce significant changes in the directions of flow, significant changes in hydraulic gradients or may cause damage to the shaft seals, and these factors may also need to be considered. A sufficient understanding of such future potential changes to the repository environment will, therefore, be required and a URL provides an opportunity to provide the required information.

This aspect of a site-specific URL has potentially important constraints on the planning of a site-characterisation programme. The need to demonstrate that any access to the URL is well located will require that modelling the effects of future changes to the groundwater flow system will need to have been carried out before the access locations and the forms of access are selected.

3.3 Establishing a formal method for comparing predicted and measured parameters

A formal approach to the comparison of predictions from models with data that are subsequently collected underground is important to develop. This process of model validation has been discussed extensively and should have an important influence on the design of any URL programme (NEA, 1999, Nirex, 1997a). It can be described mainly in terms of building confidence in the disposal concept.

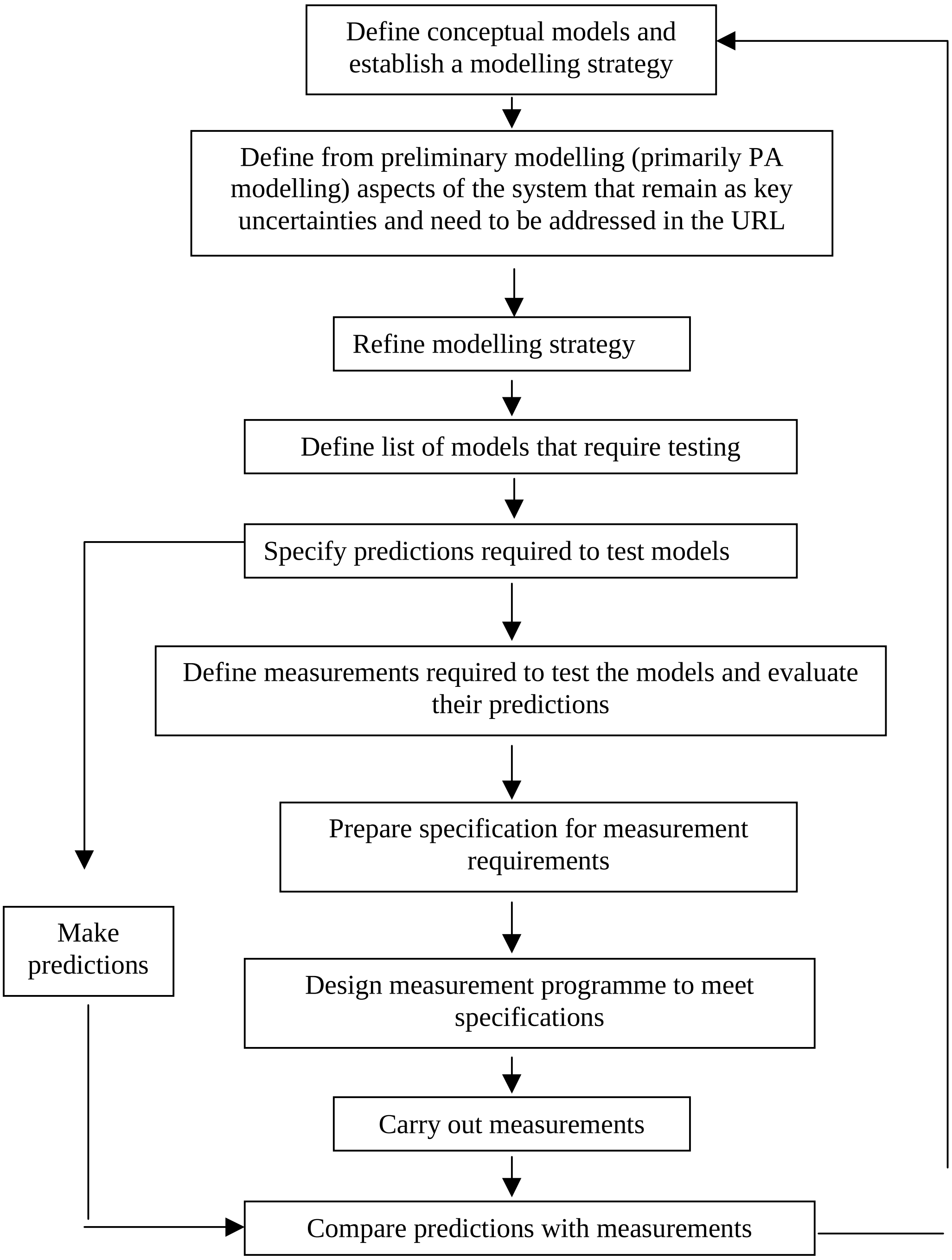
A system is required that allows for models to be tested and progressively refined until sufficient confidence exists in the ability of the model to represent adequately either the whole system or some particular part of it. Development of procedures will be necessary whereby model predictions are produced in advance of the measurements being made underground. The protocols for these procedures and the predictions from the models will need to be published before construction of the URL commences and should establish the extent to which it is expected that the measurements should match the predictions. Such predictions are frequently scale-dependent and, for example, a regional-scale model should not be expected to be capable of predicting accurately the small-scale variability within the system. A flow chart for developing such a strategy is shown in Figure 2.

The establishment of a formal method can be considered as a four-stage process:

- evaluation of the available information from an applicable generic URL, including a comparison of borehole and *in situ* information;
- collection of preliminary surface/borehole-based characterisation data at the specific site;
- the prediction, based on a combination of site-specific characterisation data and correlation functions developed as part of the generic URL activity, of the behaviour to be seen in a limited number of experiments in the site-specific URL;
- the carrying out of limited experiments in a site-specific URL and their comparison against predictions.

One of the most important factors to be considered when designing a programme for a URL is how to decide on the priorities for data collection and testing. The justification for constructing and operating a site-specific URL is that certain data cannot be sensibly collected using only surface-based boreholes. The precise data that will need collecting will depend on the geological environment and on the results of performance assessment calculations that will indicate where the greatest uncertainties lie. The URL programme should be designed so as to try and reduce these uncertainties in the most efficient manner possible. Such a programme needs to be tailored around the requirement for a stepwise approach to repository development and so that there is sufficient confidence at each step to proceed to the next.

Figure 2. **Flow chart for developing a programme of prediction, data collection, and model testing for a URL (based on Nirex, 1997a).**



3.4 The temporal aspects of a URL programme

The subject of the temporal co-ordination of a URL programme is discussed in Savage (1995), including all aspects of a programme from the initial analysis associated with selecting a site, through its construction, to the time at which experiments underground are likely to start. It is based on published work from SKB for the development of the Äspö HRL (e.g. SKB, 1989; Stanfors *et al.*, 1991) and is, therefore, biased towards testing in crystalline rock. It does, however, represent one of the only published accounts of the temporal aspects of a URL programme and Tables 12 and 13, taken from Savage (1995), indicate, in general terms, the length of time necessary for the various components of the siting and construction programme before underground experiments can commence. The times for Stages 1 and 2 given in Table 12 assume that the URL is being sited independently and do not, therefore, refer to a site-specific URL, nor to a URL that is being developed as part of an existing underground structure, e.g. a tunnel, such as was the situation at Mont Terri. Subsequent information on temporal aspects of the Äspö programme are presented in Olsson (1998).

Further information on temporal aspects is provided by three examples from the development of three URLs in the USA, those at Climax, the Yucca Mountain ESF and Busted Butte.

Climax was developed as a generic full-scale demonstration project located underground adjacent to existing underground workings at the Nevada Test Site, USA. Although the workings were excavated for this demonstration project, existing infrastructure to include equipment, labour, utilities, and access deep into the mountain were available. Construction of the facility started in June 1978 with post-test characterisation being completed in 1985 (LLNL, 1985).

The Yucca Mountain ESF was envisioned as part of the Site Characterisation Plan in 1988 as a site-specific URL but construction was not begun until 1994. No existing infrastructure or initial access into the mountain was available. Two major tunnel drives have been accomplished largely for access (total length 11 km) with numerous adjacent smaller excavations, niches, and alcoves for the many test installations. Excavation of niches and alcoves for additional testing is continuing and further excavations are anticipated over the next several years. If licensed, the initial tunnel drive will be the principal access to the repository area.

Busted Butte is a generic URL developed as part of the Yucca Mountain Project to evaluate radionuclide transport properties of the Calico Hills formation that lies deep below the proposed repository area. At Busted Butte, a distal extension of the formation lies near the surface and much more accessible than at the proposed repository site. Plans for the URL development began in 1997, construction was completed in 1998 and testing is now underway and is planned to continue until 2001. The facility is small, less than 1000 m of tunnel was excavated and its development was facilitated by the location of major infrastructure at the nearby ESF (LANL, 1998).

An example of the time required to develop a generic URL using access from a pre-existing facility, in this particular case a road tunnel, is provided by the Mont Terri URL. Its initial develop programme is outlined in Table 14.

Table 12. **Outline of possible programme in advance of URL construction to illustrate temporal constraints (Stages 1 and 2 are of relevance only to a generic URL that is not being developed as part of an existing underground structure, e.g. a tunnel).**

1. Regional analysis (12 – 18 months)
• Specific area within granite selected for analysis (30 x 30 km approx.) using data already available and new desk surveys • Region for hydrogeological reconnaissance survey defined • Region for hydrochemical reconnaissance survey defined • Regional geological mapping (if required) • Regional geophysical surveys • Simple initial modelling
First report produced, with geological and hydrogeological predictions
2. Siting stage (12 – 18 months)
• Narrowing down of area of interest • More detailed geophysics including localised seismics • More detailed geological mapping • Initial drilling programme • Simple hydraulic testing • More detailed modelling • Comparison with initial prediction
Second report prepared (recommendations for siting URL)
3. Detailed pre-construction investigations (18 – 24 months)
• Second drilling phase • More detailed hydraulic testing and monitoring • More detailed hydrochemical analysis • Numerical hydrogeological simulations of URL construction etc. • Monitoring boreholes drilled, tested and completed • Detailed plan for URL construction developed • Plans for testing and monitoring during construction developed
Total time required pre-construction = 3.5 to 5 years

Table 13. **A general outline of the construction of a URL in hard rock illustrating the temporal constraints.**

1. Location of URL (18 – 24 months) **[Equivalent to end of Siting Stage (Table 12)]**
1. Decision on location of URL 2. Decision on location and design of access shaft/tunnel 3. Modelling of influence of URL on groundwater system 4. Drilling of monitoring boreholes for URL construction 5. Testing and completion of boreholes 6. Monitoring of boreholes for > 12 months before construction 7. Prediction of excavation effects and inflow zones
2. Initial construction phase (24 months)
1. Construction of access shaft commences 2. Forward drilling and testing, installation of monitoring equipment 3. Validation: findings continuously compared with predictions 4. Updating of geological and hydrogeological models as required (Tunnel drivage rates purposely slow to maximise data input and allow opportunities for validation exercises.)
3. Construction of URL galleries (24 months)
1. Continued monitoring of effects of URL construction 2. Continued validation exercises 3. Final, detailed design of experiments 4. Temporal and spatial separation of experiments and/or construction
4. Comparison of pre-investigation predictions with conditions found

Table 14. **Project history of the development of the Mont Terri URL in Switzerland.**

Time	**Activity**
1989	Excavation of the reconnaissance gallery at Mont Terri (constructed to investigate geological and geotechnical aspects of the rock mass for subsequent construction of the motorway tunnel). Detailed geological mapping by SNHGS (Swiss National Hydrological and Geological Survey) and NAGRA.
February 1995	SNHGS obtained the authorisation for an initial project.
June 1995	Presentation of a proposal to the members of an OECD/NEA working group (the “Clay Club”). Great interest, negotiations, and agreements.
January 1996	Excavation of eight niches, start of drilling operations and experiments.
April 1997	Application for the excavation of a new gallery and an extended research programme.
June 1997	Authorisation of the Government of the République et Canton du Jura.
November 1997	Start of the excavation of the new gallery.
April 1998	End of excavation of the new gallery.
September 1998	Start of drilling operations in the new research gallery.

A different type of development is evidenced by the Mol facility in Belgium. This represents a programme that has grown linearly with time and proceeded, at least in the early stages, relatively slowly:

1974:	review by Belgian Geological Survey of potential sites and selection of the Boom Clay under the nuclear site to be an experimental site.
1975/1976:	geological reconnaissance borehole and geotechnical sampling
1976/1980:	preliminary characterisation of core samples in surface laboratories, preliminary hydrogeological investigations and PA studies. Testing (thermal aspects, corrosion) at the surface in a clay quarry.
1980:	decision to build the HADES URL
1980/1983:	construction of shaft and of 35-m gallery (cast-iron lining, and use of freezing technique)
1983/1984:	construction of small diameter experimental shaft and gallery in unfrozen clay
1985:	URL fully operational, first corrosion test loops installed
1985/1987:	studies on geomechanics (mine-by test), first *in situ* migration tests

1987: construction of the test drift (virgin clay, concrete lining) including a section lined with sliding steel ribs for ANDRA

1988/today: development, installation and follow-up of the main *in situ* experiments including large-scale integrated tests such as CERBERUS, BACCHUS, CACTUS, PHEBUS, ARCHIMEDE, MEGAS, RESEAL, CORALUS, 3-D MIGRATION, etc. In parallel development of a hydrogeological network on regional scale, updating of PA, studies of effects of Quaternary changes, development of modelling activities in different fields, etc.

1996: creation of the EIG PRACLAY (joint venture SCK/CEN - NIRAS/ONDRAF)

1997/1999: construction of the second shaft (PRACLAY site). Disposal mock-up in operation

From 2000: integrated URL to be managed by EIG PRACLAY

2002: construction of the connecting gallery between HADES and the second shaft, dismantling of some existing experiments, recommendations for *in situ* THM test

2003: construction of the PRACLAY gallery and installation of the PRACLAY THM test

2004/2008: heating/cooling phases of the test

2009/2010: dismantling of test and final interpretation

The times required for siting and construction of a URL are probably similar for all types of rock. The construction time for a shaft will tend to vary with its depth and, as URLs in sedimentary rocks may be shallower than those in crystalline rocks, less time may be needed to construct shafts in sediments[36]. Other constraints to shaft construction, however, such as the requirements for lining and support in weaker or more transmissive rocks, may result in construction times being similar in many types of rock, even for shafts with considerably different depths. In addition, the rate of shaft construction may be deliberately slowed to allow testing to take place during its construction.

Important factors to consider when designing an underground programme in terms of the times necessary for carrying out experiments and tests include:

- The time required for a rock mass to return to equilibrium, with respect to its hydraulic pressure distribution, is dependent on its transmissivity. In the poorly transmissive environments that are likely to be selected for URLs, this time may be considerable. This equilibration time will probably be greatest in rock salt and argillaceous rocks and smallest in crystalline rocks. Waiting for true pressure equilibrium to be attained may not be practical in all cases.
- Chemical equilibrium is likely to take longer to attain and may never be reached within the lifetime of the URL. Irreversible chemical changes could be significant, at least in

---

[36] Access may not be provided by a shaft but by a ramp (drift) (and possibly by both) or, in the situation where a URL is being constructed under a hill, by a tunnel. Äspö has access both by shaft and ramp; Mol has access only by vertical shafts, whereas the ESF at Yucca Mountain has access by tunnel.

the region of the rock mass close to the underground openings where oxidation is most likely.

- Carrying out tracer tests underground in poorly transmissive rocks at spatial scales that are similar to those of the repository or to the lengths of the transport paths to the biosphere is not possible due to temporal constraints. Temporal and spatial upscaling will be required in order to bridge this gap. However, spatial upscaling is likely to require a considerable amount of data on rock mass properties at different scales.

4. INTERNATIONAL CO-OPERATION IN UNDERGROUND TESTING

Sections 2.1 and 2.2 of this report refer to the recent reports and papers by Anderson (1999), NEA (2000), and McCombie and Kickmaier (1999) which provide reviews, respectively, of the co-operation in underground testing within the countries of the EU and Switzerland, i.e. countries that have been involved in EU-funded underground R&D programmes and also the developments in the geological disposal of radioactive waste over the last decade. The conclusions of these two reports with reference to URLs are very similar. The majority of countries questioned had a very positive attitude towards co-operative projects, a prime motive for this co-operation being the increased level of networking initiated, which was believed to promote a better utilisation of joint resources, resulting in a good transfer of knowledge among the various participants.

Within NEA member countries, there is at least one URL in each of the potential rock types for disposal (Tables 15 and 16). Further information of these URLs is provided in Appendix 2 and in IAEA (2000).

Table 15. **Geological media considered for deep disposal in NEA Member countries.**

Geological media	***Considered in***
Argillaceous	Belgium, France, Germany, Hungary, Italy, Japan, the Netherlands, Spain, Switzerland, UK
Crystalline	Canada, Czech Republic, Finland, France, Germany, Japan, Spain, Switzerland, Sweden, UK, USA
Saliferous	Denmark, Germany, the Netherlands, Spain, USA

The importance of international collaboration is evident from the review carried out by the NEA (NEA, 2000) and also by the impressive list of successful co-operative projects, many of which involved the use of URLs. The extent to which organisations can gain technically from sharing insights from experience and even resources in co-operative work in URLs is understood. There has been a gradual building of confidence in many nations in the scientific understanding of waste-disposal processes and the work that is required to produce credible evaluations of safety based on this enhanced scientific understanding. Co-operative efforts will also be helpful, with specific reference to the application of URLs, to both regulators and implementers:

- to demonstrate the wide consensus that exists at the technical level;
- to optimise the use of technical and financial resources; and
- to clarify understanding of the key concepts in repository development, e.g. the meaning of the stepwise approach to repository development and how URLs are involved in this process.

Within the EU and elsewhere in the world, the different URLs contribute significantly to the R&D needs of a large number of countries. The survey of URLs within the EU (Anderson, 1999) suggested that future co-operation should focus on:

- regular exchanges of information,
- the verification and validation of experimental results in different environments, and

- the continuation of multi-partner projects involving different teams and different countries.

EU countries with small nuclear programmes considered that the co-operative nature of the underground work was an essential element of their disposal strategy. Countries that are currently reviewing their strategies for the disposal of long-lived waste, such as the UK and Canada, represent a special case. Currently, the UK, via Nirex, is involved in co-operative research at Äspö and is not involved with work in URLs located in other geological environments. The current review of UK disposal policy (see Section 2.2) may result in the UK developing its own generic URL or/and becoming involved in underground programmes in clays and rock salt. In contrast, AECB (now CNSC), the Canadian regulatory authority, has suggested that the requirement for a generic URL may be deleted when the Canadian disposal programme is reconstituted.

Table 16. **Existing URLs and URLs that are planned in NEA countries, together with the countries currently involved in co-operative underground R&D programmes.**

Facility	Country	Participants in R&D
Crystalline and volcanic rock URLs:		
Grimsel	Switzerland	Switzerland, France Germany, Spain, Sweden, Japan, USA
Äspö HRL	Sweden	Sweden, Finland, France, Germany, Japan, Spain, Switzerland, UK, USA
Olkiluoto	Finland	Finland, Sweden
Pinawa URL	Canada	Canada, Japan, France
MIU	Japan	Japan, Switzerland
ESF, Yucca Mountain	USA	USA
Argillaceous rock URLs:		
Mol	Belgium	Belgium, Germany, Spain, France
Mont Terri	Switzerland	Switzerland, France, Germany, Spain, Japan, Belgium
Tournemire	France	France, Germany
Meuse/Haute Marne	France	France[37], Japan
Horonobe	Japan	Japan
Saliferous URLs:		
Asse	Germany	Germany, the Netherlands, Spain
WIPP	USA	USA[38]

Japan has ambitious plans to expand the current site at Tono, with the construction of a vertical main shaft at a new location (the MIU Project). In addition, Japan also plans to develop a URL in sediments at Horonobe. Several Japanese companies are already involved in international co-

---

[37] Other partnerships under discussion.

[38] The USDOE is keen to offer other participants the opportunity to carry out experimental work in the WIPP.

operative programmes of research in Europe, Canada, and Japan. For example, JGC has a collaborative agreement with ANDRA and plans to carry out tests in the new URL at Meuse/Haute Marne. Various Japanese companies are also involved in R&D programmes at Mont Terri, Grimsel, and Äspö. The formation of the new Japanese implementing organisation on HLW disposal (NUMO) in 2000 and the proposed new URL developments in Japan are likely to increase the level of international co-operation.

Other counties that have long-lived waste that will require disposal, such as those in Eastern Europe, Russia, countries of the Former Soviet Union, and China, are likely to become increasingly involved in international co-operative ventures.

The USA is in a rather different position, in that it has a licensed site for disposal of defence-related, alpha-contaminated long-lived waste (WIPP) and has another site at Yucca Mountain that is being characterised for potential use as a repository for spent nuclear fuel and high-level radioactive waste. Although the Yucca Mountain site can be considered different in concept from those presently being considered in other countries, there are many commonalities at the physical-process level that could provide opportunities for co-operative work with URLs. The USDOE is currently promoting the use of the WIPP as an international test bed that covers mostly licensing, handling, transportation, and transparency/non-proliferation issues as well as elementary particle observation, biophysics, and resource extraction. The USDOE is further considering the establishment of a similar international center for repository technology at the Yucca Mountain site.

France has always considered that a site-specific URL would be a necessary component of its disposal programme. The large co-operative French programme of research that has been carried out overseas in generic URLs since 1984 was designed to prepare personnel for eventual involvement in their own URL programme. This programme was reviewed in accordance with the 1991 law and ANDRA intends to invite international participation in its research programme at the Meuse/Haute Marne site.

Co-operation between programmes is believed to have produced benefits in several areas, not all of which could be described as being directly technical or scientific. The following have been cited as beneficial in this regard:

- The recent NEA review of geological disposal in the last decade (NEA, 2000) states that one of the most frequently cited factors in producing a positive influence on progress in deep disposal has been the international co-operation in R&D, notably that in URLs.
- The same report also states that URLs, in addition to providing invaluable test beds for practical methods and theoretical models, are also extremely effective confidence building instruments for all those who can observe their operation (implying that they are of use not only for researchers, but also for regulators, politicians, and members of the public).
- The development of URLs, both generic and site-specific, is recognised as being an important stage in the stepwise approach to eventual repository construction and licensing. Similarly, a stepwise approach is recognised to be valuable in the planning, licensing, and implementation of repositories.
- One of the most frequently cited developments that would help progress in waste disposal (NEA, 2000) is related to increased public acceptance. Under this category is included confidence building in the scientific basis and safety assessments of disposal, e.g. by the application of demonstration-scale experiments in URLs.

5. CONCLUSIONS

The conclusions that can be drawn from this review of the use of URLs can be placed into several subject areas:

5.1 The purpose of URLs

URLs are needed for different purposes and can be classed as generic or site-specific, depending on whether they are to be developed at a site that will not be used for radioactive waste disposal or at one where such disposal is proposed.

- In the first instance, they are essentially research-based in nature, although this research has to be well-focussed and applied. In the second, they can be considered as an essential component of the site-characterisation programme for the potential disposal site, which will have commenced as a surface-based programme but which, at some point, must be moved underground.
- A site-specific URL can be viewed, in part, as the normal continuation of a site-characterisation programme. At some point in a detailed programme, a decision has to be made to "go underground" and this decision raises a series of questions that need to be answered before URL construction should proceed.
- Several areas of uncertainty associated with the characterisation and assessment of a potential disposal site can only be addressed by the development and operation of a site-specific URL. The three main areas, for all geological environments, seem likely to be:

    – groundwater flow and radionuclide transport,
    – natural and induced changes in the geological barrier, and
    – design and construction of the repository

  although their relative importance may vary.
- Generic URLs can be developed relatively early in a disposal programme and can help formulate disposal concepts and aid in the dialogue with the regulators. These URLs are of relevance to the host geological environment of interest.
- The considerable differences among the types of rocks that are being considered for the deep disposal of long-lived and HLW are reflected in the types of underground experimental programmes that are carried out.

5.2 Future work in and the use that could be made of URLs

Future work in URLs needs to consider the following:

- the 30 years of *in situ* R&D work to support the development and the assessment of geological disposal systems that has been carried out in URLs;
- the decreasing emphasis on basic feasibility studies and on the accumulation of fundamental geological data – increased effort is now being focused on the optimisation of methodologies and on the testing of key performance-assessment models and safety-relevant issues;
- the increasing importance being placed on full-scale demonstration-type experiments on EBSs.

As regards this future work and the use that could be made of URLs:

- The radioactive waste community generally agrees as to the usefulness of an underground testing programme for increasing confidence in the ability to dispose of high-level and/or long-lived waste safely.
- The most important objective of a URL often is to allow an in-depth investigation of the selected geological environment and to provide the opportunity to allow validation of models at more appropriate scales and conditions than can be achieved from the surface. In some areas, such as in demonstrating operational safety, in acquiring geological information at a repository scale, and in constructional and operational feasibility, a URL provides the only reliable source of *in situ* data.
- The presence of a URL can also promote an informed technical dialogue between an implementing waste management agency (or implementer) and the nuclear regulatory authorities.

The general trend in *in situ* experiments can be summarised as:

- A decreasing emphasis on basic feasibility studies and on the accumulation of fundamental geological data and an increased focus on:
    i) the optimisation of methodologies,
    ii) the collection of specific data to understand coupled processes and the validation of complex models, and
    iii) the testing of key performance assessment models (for generic more so than for site-specific URLs).
- The increasing importance placed on full-scale demonstration-type experiments on EBSs (e.g. FEBEX (Grimsel), RESEAL and PRACLAY (Mol), Prototype Repository Project (Äspö)).
- The demonstration of retrievability, where this is a policy requirement.

5.3 The strategic role for URLs

URLs have a strategic role in helping to build confidence in the concept of deep geological disposal:

- The majority of NEA Member countries consider that the development of URLs have benefits beyond those connected principally with R&D. In particular, URLs have provided a focus for scientific collaboration and information exchange at a variety of levels, from those within the national and international waste management community and the scientific community at large to the involvement of the local population. There is generally considered to be great value in this collaboration and in allowing scientific and non-scientific visitors to such a facility.
- This active communication of ideas and concepts in the environment of a URL, which may be similar to that proposed for final disposal, appears to be only beneficial and is likely to increase the confidence of all the stakeholders in the repository project. Included in this category are not only those directly involved in such a venture, together with the regulatory authorities, but also the scientific community, the public at large, and politicians.

- Whatever the precise form of the disposal programme, a stepwise (or incremental) approach to repository development, a process that will invariably require a URL, is the most appropriate to follow.
- Any disposal programme needs to remain sufficiently flexible so that it can respond to the accumulation of additional data, to the findings of safety assessments, and to the legal, regulatory, and societal framework in which it must operate. However, discrete stages need to be defined at the beginning of any programme to allow for its planning and, in order to preserve confidence in the stepwise approach itself, there needs to be a general understanding of what is to be broadly achieved at each step and what would be required in terms of information and confidence to make such a step.
- Much of the work underground is associated with the process of confidence building, and flexibility in the approach to repository development allows the programme planning to be responsive to the accumulation of increased data from the R&D and site characterisation programmes.
- Long-term monitoring of a repository is generally thought to have an important role in confidence building. Regulatory bodies will likely take a keen interest in the design and operation of monitoring systems and agreement with them early in a URL programme on the objectives of any monitoring and the extent to which demonstrations of the capability of such systems will be necessary will be important.

5.4 The need for URLs

URLs are needed for the comprehensive characterisation and evaluation of a potential disposal site, as well as for developing the disposal concept and examining any alternatives. In order to carry out a PA, a large number of processes must be modelled that will, in turn, require the development of new models. Even with the aid of a URL, testing these models at the temporal and spatial scales that will be required for a PA will not be possible. Experiments in a URL should be designed, however, to allow the conceptual basis of these models to be tested, i.e. does a model consider the relevant processes, and also to be applicable to the *in situ* conditions, i.e. can the model be applied successfully to the relevant rock structures and at the scales of interest underground.

The work done in URLs has inevitable limitations, the consequences of which are that:

- no amount of testing within a URL can be expected to determine either the extent or the spatial variability within the volume of the rock mass that will be used for the repository[39]
- obtaining reliable measurements of certain parameters, e.g. relevant solute transport parameters over scales of more then a few centimetres, may prove impossible (however, sufficient data are required in order to provide some acceptable level of validation of models)
- the volume of the rock mass tested or investigated will be small in comparison with the volume required for the repository (but needs to be sufficient to be able to provide data over an acceptable volume of the rock mass considered for disposal)
- the limitations imposed by the practicalities of testing mean that significant temporal upscaling will also be required.

---

[39] Nor should it be a requirement from the regulators.

In order to allow decisions to be made between the design alternatives of the disposal concept, there needs to be integration between a URL and the actual repository in order to provide continuity in the R&D programme.

5.5 Planning a URL programme

The initial stages of planning a URL programme, in particular one in a generic URL, need to consider the strategy that should be followed to define the programme. Some of the possible stages in such a procedure for selecting a site for a generic URL require answering questions such as:

- How is the decision to be made as to whether a generic URL is required?
- At which stage must a rock type be selected for a URL?
- What sort of URL is required?
- What are your expectations from operating a URL?
- For how long do you continue a generic URL programme?

The main aspects to consider when planning a URL can be placed under five headings:

- the establishment of baseline conditions,
- minimising damage to geosphere,
- establishing a formal method for comparing predicted and measured parameters,
- the development of underground facilities, and
- the temporal aspects of a URL programme.

One of the most important factors to be considered when designing a programme for a URL is how to decide on the priorities for data collection and testing. The URL programme should be designed so as to try and reduce these uncertainties in the most efficient manner possible. Such a programme needs to be tailored around the requirement for a stepwise approach to repository development so that there is sufficient confidence at each step to proceed to the next.

5.6 International co-operation in underground testing

Most countries have a very positive attitude towards co-operative projects, a prime motive for this co-operation being the increased level of networking initiated, which is believed to promote a better utilisation of joint resources, resulting in a good transfer of knowledge between the various participants.

The importance of international collaboration is evident from the impressive list of successful co-operative projects, many of which involved the use of URLs. Co-operation between disposal programmes is believed to have produced benefits in several areas, not all of which could be described as being directly technical or scientific.

URLs, in addition to providing invaluable test beds for practical methods and theoretical models, are also extremely effective confidence-building instruments for all those who can observe their operation. Included in this category are not only researchers, but also regulators, politicians, and members of the public. One of the most frequently cited developments that would help progress in waste disposal is related to increased public acceptance, and the application of demonstration-scale experiments in URLs can play a major positive role in this area.

6. REFERENCES

Andersson, J. 1999. A study on the co-operation of research in underground facilities within the EU on aspects of disposal of radioactive waste. *Report of the European Commission*, Report DOC. XII-53-99.

ANDRA. 1997. Underground Research Laboratory – East of France – State of knowledge and experimental program. *ANDRA Report*.

ANDRA. 1999. Scientific and technical basis for the reversibility of geological disposal. *Proceedings of the International Workshop on Reversibility*, Paris, November 25-27, 1998. ANDRA (ed.).

Anttila, P., H. Ahokas, K. Front, H. Hinkkanen, E. Johansson, S. Paulamäki, R. Riekkola, J. Saari, P. Saksa, M. Snellman, L. Wikström, and A. Öhberg. 1999. Final disposal of spent nuclear fuel in Finnish bedrock – Romuvaara site report. *Posiva Report* Posiva 99-11.

Barbreau, A., and J.-Y. Boisson. 1994. Caractérisation d'une formation argileuse: synthèse des principaux résultats obtenus à partir du tunnel de Tournemire de janvier 1992 à juin 1993. *Report of the European Commission* EUR 15756 FR, 156 p.

Boisson, J.-Y., J. Cabrera, and L. De Windt. 1998a. Etude des écoulements dans un massif argileux : laboratoire souterrain de Tournemire. *Report of the European Commission* EUR 18338 FR, 300 p.

Boisson, J.-Y., J. Cabrera, and L. De Windt. 1998b. Transfers characterisation through an argillaceous formation : main results from the IPSN Tournemire tunnel. In: *In situ* testing in underground research laboratories for radioactive waste disposal. *Proceedings of a CLUSTER seminar*, Alden Biesen, Belgium, 10-11 December 1997, EUR 18323, pp 95-112.

Brechtel, C.E., M. Lin, E.R. Martin, and D.S. Kessel. 1995. Geotechnical characterization of the North Ramp of the Exploratory Studies Facility. *Sandia Report* SAND95-0488/1.

Bussod, G. 2001. An unsaturated zone transport field test in fractured tuff. In: *Confidence in Models of Radionuclide Transport for Site-specific Assessment*. Workshop Proceedings, Carlsbad, New Mexico, United States, 14-17 June 1999, OECD/NEA, pp. 215-217.

Fuentes-Cantillana, J.L. *et al.*, 1998. FEBEX: Pre-operational Stage Summary Report. *Enresa Report* No. 01/98.

Fuentes-Cantillana, J.L., and J.L. García-Siñeriz. 1998. FEBEX - Final design and instrumentation of the *in situ* test at Grimsel. *Enresa Report* No. 12/98.

Grupa, J.B., D.H. Dodd, J.-M. Hoorelbeke, B. Mouroux, J.M. Potier, J. Ziegenhagen, J.L. Santiago, J. Alonso, J.J. Fernández, P. Zuidema, I.G. Crossland, B. McKirdy, J. Vrijen, J. Vira, G. Volckaert, T. Papp, and C. Svemar. 2000. Concerted action on the retrievability of long-lived radioactive waste in deep underground repositories. Final Report. *Report of the European Commission* EUR 19145.

Gustafsson, G., M. Liedholm, I. Rhén, R. Stanfors, and P. Wikberg. 1991. Äspö Hard Rock Laboratory. Predictions prior to excavation and the process of their validation. *SKB Technical Report* TR 91-23.

Haijtink, B., and C. Davies (compilers). 1998. *In situ* testing in underground research laboratories for radioactive waste disposal. *Proceedings of a CLUSTER seminar*, Alden Biesen, Belgium, 10-11 December 1997. EUR 18323.

IAEA. (in prep.). The use of results obtained from underground research laboratory investigations. IAEA-TECDOC.

Jarolimek, L., M.J. Timmer, and R.F. McKinney. 1983. Geotechnical activities in the Exploratory Shaft--Selection of the facility interval, Waste Isolation Pilot Plant (WIPP) Project, Southeastern New Mexico. TME 3178. Report prepared for the U.S. Department of Energy.

Jing, L, O. Stephansson, C.-F. Tsang, J.L. Knight, and F. Kautsky. 1999. DECOVALEX II Project. Executive Summary. *SKI Report* 99:24.

JNC (Japan Nuclear Cycle Development Institute). 2000. H12: Project to Establish the Scientific and Technical Basis for HLW Disposal in Japan, Project Overview Report. JNC TN1410 2000-001.

Kickmaier, W., and I. McKinley. 1997. A review of research carried out in European rock laboratories. *Nuclear Engineering and Design*, 176, pp. 75-81.

LLNL (Lawrence Livermore National Laboratory). 1986. Spent-Fuel Climax: An evaluation of the technical feasibility of geologic storage of spent nuclear fuel in granite, Executive Summary of Final Results, Report prepared for the U.S. Department of Energy.

Lebon, P. 2001a. Current understanding of transport at Meuse/Haute-Marne site and relevant Research and Development programme in the planned Underground Research Laboratory. In: *Confidence in Models of Radionuclide Transport for Site-specific Assessment*. Workshop Proceedings, Carlsbad, New Mexico, United States, 14-17 June 1999, OECD/NEA, pp. 239-250.

Lebon, P. 2001b. Le programme de recherche du laboratoire de recherche souterrain de Meuse/Haute-Marne. *Actes des journées scientifiques ANDRA*, Nancy 7-9 décembre 1999. EDP Sciences Publications.

(LANL) Los Alamos National Laboratory. 1998. LA Testing Status Report: Busted Butte unsaturated zone transport test, FY 98, BAB0000000-0717-5700-00013.

McCombie, C., and W. Kickmaier. 1999. Underground Research Laboratories: their roles in demonstrating repository concepts and communicating with the public. In: *Proceedings of Euradwaste 1999, Radioactive waste management strategies and issue*s, Luxembourg, 15 to 18 November 1999. EUR 19143, pp. 274-281.

NEA. 1993. International Stripa Project 1980-1992 (3 Vol.). OECD/NEA and SKB Fairhurst, C, Gera, F, Gnirk, P, Gray, M and Stillborg B. Overview Volume I – Executive Summary; Gnirk, P (ed.) Overview Volume II – Natural Barriers; Gray, M (ed.) Overview Volume III – Engineered Barriers.

NEA. 1997a. Lessons learnt from ten performance assessment studies. Report of the *Working Group on Integrated Performance Assessments of Deep Repositories.*

NEA. 1997b. Field tracer experiments. Role in the prediction of radionuclide migration. *Proceedings of a GEOTRAP workshop,* Cologne, Germany, 28-30 August 1996, OECD/NEA.

NEA. 1999. Confidence in the long-term safety of deep geological repositories – Its development and communication. *OECD/NEA.*

NEA. 2000. Geological disposal of radioactive waste: Review of developments in the last decade. *OECD/NEA.*

NEA (in prep.) Characterisation and representation of the Excavation Disturbed or Damaged Zone (EDZ). Lessons learnt from a SEDE Topical Session., Paris , France, September 1998, *OECD/NEA.*

Nirex. 1997a. Planning the scientific programme for the Rock Characterisation Facility. *Nirex Science Report* No. S/97/006.

Nirex. 1997b. Spatial heterogeneity of the rock mass within the Potential Repository Zone. *Nirex Science Report* No. S/97/005.

Nirex. 1998. Review of Baseline groundwater pressures and hydrochemistry between November 1996 and October 1998. *Report by an Independent International Review Group*. Nirex Report.

Olsson, O. 1998. The role of the Äspö Hard Rock Laboratory in the Swedish nuclear waste programme. *Proceedings of Waste Management '98.*

Ondraf/NIRAS. 1998. The PRACLAY Project: Demonstration test on the Belgian disposal facility concept for high activity vitrified waste - Final Report. *Report of the European Commission* EUR 18047.

QuantiSci, Ltd. 1999. A Research & Development strategy for the disposal of high-level radioactive waste and spent nuclear fuel. *Report to the Department of the Environment, Transport and the Regions,* Report no. DETR/RAS/99.016.

Rhén, I. (ed.), Gustafson G, Stanfors R, Wikberg P, 1997. Äspö HRL – Geoscientific evaluation 1997/5: Models based on site characterisation 1986-1995. *SKB Report* TR 97-06.

Rhén, I. (ed.), Bäckblom G (ed.), Gustafson, G, Stanfors R, Wikberg P, 1997. Äspö HRL – Geoscientific evaluation 1997/2: Results from pre-investigations and detailed site characterisation. Summary report. *SKB Report* TR 97-03.

Rhén, I., G. Gustafson, and P. Wikberg. 1997. Äspö HRL – Geoscientific evaluation 1997/4: Results from pre-investigations and detailed site characterisation. Comparison of predictions and observations. Hydrogeology, groundwater chemistry and transport of solutes. *SKB Report* TR 97-05.

Savage (ed.). 1995. *The scientific and regulatory basis for the geological disposal of radioactive waste*. John Wiley and Sons, Chichester, 437 p.

SKB. 1983. Final storage of spent nuclear fuel – KBS-3. *Report of SKBF/KBS.*

SKB. 1989. Handling and final disposal of nuclear waste. Hard Rock Laboratory. Background report to the R&D Programme 89. *SKB Report.*

SKB. 1992. Treatment and final disposal of nuclear waste - Äspö Hard Rock Laboratory. Background Report to RD&D Programme 92.

SKB. 1995. RD&D Programme 95. Treatment and final disposal of nuclear waste. *SKB Report*.

SKB. 1996. Äspö Hard Rock Laboratory: 10 years of research, *SKB Report*.

SKB. 1999. Äspö Hard Rock Laboratory. Annual Report 1998. *SKB Technical Report* TR-99-10.

SKI. 1996. SKI SITE-94 - Deep repository performance assessment project. *SKI Report* 96:36.

Stanfors, R., M. Erlström, and I. Markström. 1997. Äspö HRL – Geoscientific evaluation1997/1: Overview of site characterisation 1986-1995. *SKB Report* TR 97-02.

Stanfors, R., P. Olsson, and H. Stille. 1997. Äspö HRL – Geoscientific evaluation 1997/3: Results from pre-investigations and detailed site characterisation. Comparison of predictions and observations, Geology and mechanical stability. *SKB Report* TR 97-04.

Sugier, N., and P. Lebon. 1999. Underground research laboratories in France – results of the reconnaissance phase and research programs. *Proceedings of the Seventh International Conference on Radioactive Waste Management and Environmental Remediation.* (ICEM 99), Sept. 26-30, 1999, Nagoya, Japan.

Thury, M. 1997. The Mont Terri Rock Laboratory. *Nagra Bulletin* No. 31, 33-44.

Thury, M., and P. Bossart. 1999a. The Mont Terri rock laboratory, a new international research project in a Mesozoic shale formation, in Switzerland. *Engineering Geology* 52, 347-359.

Thury, M., and P. Bossart. 1999b. Mont Terri Rock Laboratory: Results of Hydrogeological, Geochemical and Geotechnical Experiments Performed in 1996 and 1997. *Swiss Natl. Hydrol. Geol. Surv., Geological Report* Nr. 23, 224 p.

Volckaert, G., F.-X. Holvoet, A. Gens, J. Vaunat, Th. Lassabatere, Ch. Imbert, M. Villar, E. Mouche, A. Genty, C. Lepotier, F. Cany, and A. Millard. 1998. RESEAL: a large scale *in situ* demonstration for REpository SEALing in an argillaceous host rock; In: *In situ* testing in underground research laboratories for radioactive waste disposal, *Proceedings of a CLUSTER seminar*, Alden Biesen, Belgium, 10-11 December 1997. EUR 18323, pp. 39-57.

Annex 1

TERMINOLOGY APPLIED TO URLS AND OTHER ACRONYMS USED

1. Terminology applied to underground facilities

Underground Research Laboratory (URL) - Term first applied by Atomic Energy of Canada Limited (AECL) to their underground facility at Pinawa (Manitoba, Canada). Subsequently in common use in several different countries to apply to any type of underground facility, now commonly prefixed by other descriptive terms (see below).

First generation URL – a term used by Nagra to refer to a URL which is developed relatively early in a disposal programme, primarily for the purposes of research on the feasibility of radioactive waste disposal, for developing methodologies and for training in underground testing. In the majority of cases, such URLs are specifically excluded from being used in the future for disposal of radioactive waste.

Generic URL – synonymous **with** first generation URL**.**

Second generation URL – a URL developed at a potential disposal site as part of the detailed investigation of the site. It can be best considered as a phase of underground site characterisation and as a continuation of the **investigations** that started on the surface. It also has several additional purposes, such as the demonstration of disposal techniques, which are described in this report. (This term is now infrequently used.)

Site-specific URL - synony**m**ous with second generation URL, referred to in a recent IAEA report (IAEA, in prep.).

On-site URL - synonymous with second generation URL referred to in a recent IAEA report (IAEA, in prep.).

Rock Characterisation Facility (RCF) – a term coined by Nirex to refer to the proposed underground phase of their investigations at Sellafield (United Kingdom). The acronym has subsequently been used by, for example, Nagra to refer to a second generation or site-specific/on-site URL.

Exploratory Studies Facility (ESF) – the term used to refer to the underground phase of the investigations at Yucca Mountain (Nevada, United States), which includes many kilometres of Tunnel Boring Machine-driven tunnels and will later include a variety of experimental galleries**.**

Experimental Region - the term used to describe the area of the WIPP (Waste Isolation Pilot Plant) designated for experimental testing. In March 1999, the WIPP (New Mexico, United States) became the first operational deep geological repository for long-lived waste to be developed in an NEA Member country (in the WIPP case, the waste are defence-related, alpha-contaminated long-lived waste or TRU waste).

The Hard Rock Laboratory (HRL) – the term used by SKB to refer to the underground testing facility at Äspö (south-eastern Sweden), which was constructed to investigate the feasibility of disposal in crystalline rocks. It is specifically excluded from being used as a future repository.

The Grimsel Test Site (GTS) – the term used by Nagra to refer to the test facility at Grimsel in crystalline rock (**southern** Switzerland). Access is provided in association with the tunnels of a pumped storage scheme. It is specifically excluded from being used as a future repository.

High Activity Disposal Experimental Site (HADES), renamed the Underground Research Facility (URF) – the underground testing facility at Mol in the Boom Clay (north-eastern Belgium). Also included at this site, since 1997, is the PRACLAY demonstration facility.

The Tono URL Project, also known as the Mizunami Project or the Mizunami URL (MIU) – the development of a new URL at Tono (central Japan). It is specifically excluded from being used as a future **repository**.

Research Tunnel – the name given to the short tunnel for experimental work at the Olkiluoto I/LLW repository (Finland).

Several other underground test facilities exist in the world. The majority of these are not given any specific names, other than those associated with their location, e.g. Mont Terri (Jura Mountains, Switzerland), Horonobe (Hokkaido island, northern Japan). A table listing all the formerly or currently operating underground facilities in NEA Member countries is included in Annex 2.

2. *List of other acronyms used in the document*

AECL	Atomic Energy of Canada Limited, Canada
ANDRA	National Agency for Radioactive Waste Management, France
BfS	Federal Office for Radiation Protection, Germany
DBE	German Specialised Engineering Company for Final Disposal of Radioactive Waste
EC; CEC; EU	European Commission; Commission of the European Community, European Union
EBS	Engineered Barrier System
EDZ	Excavation Damaged/Disturbed Zone
GEOTRAP	NEA International Project on the Transport of Radionuclides in Geologic, Heterogeneous Media
GRS	Company for Nuclear and Industrial Plant Safety, Germany
HLW	High-Level Waste
IAEA	International Atomic Energy Agency, Vienna, Austria
ILW	Intermediate-Level Waste
IPSN	Nuclear Protection and Safety Institute, France
JNC	Japan Nuclear Cycle Development Institute (former PNC)
LANL	Los Alamos National Laboratories, United States
LLNL	Lawrence Livermore National Laboratories, United States
LLW	Low-Level Waste
NAGRA	National Co-operative for the Disposal of Radioactive Waste, Switzerland
NEA	Nuclear Energy Agency of the Organisation for Economic Co-operation and Development, Paris, France
Nirex	United Kingdom Nirex Ltd, the radioactive waste management company in the United Kingdom
NRI	Nuclear Research Institute, Czech Republic
PA	Performance Assessment

Posiva	Radioactive waste management company in Finland
RAWRA	Radioactive Waste Repository Authority, Czech Republic
RWMC	NEA Radioactive Waste Management Committee
SCK/CEN	Nuclear Energy Research Centre, Mol, Belgium
SEDE	NEA Co-ordinating Group on Site Evaluation and Design of Experiments for Radioactive Waste Disposal
SNHGS	Swiss National Hydrological and Geological Survey
SF	Spent Fuel
SKB	Nuclear Fuel and Waste Management Company, Sweden
SKI	Nuclear Power Inspectorate, Sweden
US DOE	United States Department of Energy
US DOE/CAO	United States Department of Energy, Carlsbad Area Office
US NRC	United States Nuclear Regulatory Commission
VLJ	Low- and Intermediate-Level Waste Repository at Olkiluoto, Finland
WIPP	Waste Isolation Pilot Plant, Carlsbad, New Mexico, United States
YMP	Yucca Mountain Project, United States

Annex 2 - UNDERGROUND TESTING FACILITIES (as of 1999) - (usual name in bold)

Country	Location	Principal Operator(s)	Facility	Type	Geology (potential host rock)	Depth [m]	Operation Period
Belgium	Mol/Dessel	SCK, EIG PRACLAY	**HADES Underground Research Facility** & **PRACLAY**	Site-specific	Plastic (non-indurated) clay (Boom Clay)	230	HADES since 1980 PRACLAY since 1997 (access shaft)
Canada	Lac du Bonnet, Manitoba	AECL	**Underground Research Laboratory (URL)**	Generic	Granite	240-420	Since 1984
Czech Republic	Príbram	RAWRA, NRI	Former U mine (**Shaft 16**)	Generic	Granite	450	Planning
Finland	Olkiluoto	Posiva	**Research Tunnel** (repository for LLW and ILW waste – VLJ)	Generic	Granite	60 - 100	Since 1993
France	**Meuse/ Haute Marne**	ANDRA	URL	Site-specific	Shale (indurated clays) (Calovo-Oxfordian Argillites)	450 - 500	Surface work started in 1999
France	Not yet selected	ANDRA	URL	Site-specific	Granite		Planning
France	**Tournemire**	IPSN	Former railway tunnel and adjacent galleries	Generic	Shale (indurated clays)	250	Since 1990
France	**Fanay-Augères**	IPSN	Galleries in U mine	Generic	Granite		1980 - 1990
France	**Amelie**	ANDRA	Galleries in potash mine	Generic	Bedded salt		1986 - 1992

Germany	**Gorleben**	BfS, DBE	Exploratory facility	Site-specific	Salt dome (Zechstein Rocksalt)	>900	Shafts 1985-1990. Exploratory work for potential repository site suspended
Germany	Morsleben	BfS, DBE	Former salt and potash mine, repository for LLW and ILW waste (**ERAM**)	Site-specific	Salt dome (Zechstein Rocksalt)	>525	1981-1998. Disposal operation permanently terminated in 1998
Germany	**Asse**	GSF	Forschungsberg-werk. Galleries in former salt mine	Generic	Salt dome	>800	1965-1997 (backfilling of unused excavations underway)
Germany	**Konrad**	BfS, DBE	Galleries in former Fe mine	Site-specific	Limestone covered with shale (Oxfordian Oolitic Limestone)	800	Since 1980 (in licensing stage for a LLW/ILW repository)
Hungary	**Pécs** (Mecsek Mountain)	PURAM	Former U mine	Site-specific	Indurated clay (Boda Claystone Formation)	1000	1995-1999
Japan	**Kamaishi**	JNC	Galleries in former Fe-Cu mine	Generic	Granite		1988 - 1998
Japan	**Tono**	JNC	Galleries in former U mine	Generic	Sedimentary rocks		Since 1986
Japan	Mizunami	JNC	URL (**MIU**)	Generic	Granite		Drilling phase
Japan	Horonobe	JNC	URL	Generic	Sedimentary rock		Planning
Sweden	Äspö	SKB	**Hard Rock Laboratory (HRL)**	Generic	Granite	<460	Since1990
Sweden	**Stripa**	SKB, DOE, NEA	Galleries in former Fe mine	Generic	Granite	360 - 410	1976 - 1992

Switzerland	Grimsel	Nagra	**Grimsel Test Site (GTS),** (from a dam tunnel)	Generic	Granite	450	Since 1983
Switzerland	**Mont Terri**	SNHGS	Underground Rock Laboratory from a road tunnel	Generic	Shale (indurated clay) (Opalinus Clay)	400	Since 1995
United Kingdom	Sellafield	Nirex	**Rock Characterisation Facility (RCF)**	Site-specific	Tuff (Borrowdale Volcanic Group)	750 - 1000	Project stopped in 1997 (refusal of the planning permission)
United States	Yucca Mountain, Nevada	USDOE	**Exploratory Studies Facility ESF**	Site-specific	Tuff (Topopah Springs Formation)	300	Since 1993
United States	**Busted Butte**, Yucca Mountain, Nevada	USDOE	Testing facility	Generic	Bedded tuffs (Calico Hill Formation)	100	Since 1998
United States	Nevada Test Site	USDOE	**G-Tunnel**	Generic	Tuff		1979 - 1990
United States	Nevada Test Site	USDOE	**Climax**	Generic	Granite	420	1978 - 1983
United States	Carlsbad, New Mexico	USDOE/CAO	**Waste Isolation Pilot Plant**	Site-specific	Bedded salt (Salado Formation)	655	Since 1982