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Experience in selection and characterization of sites for geological disposal of radioactive waste

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FOREWORD

The use of nuclear fuel to generate electricity and the use of radioactive materials in medicine, research and industry give rise to radioactive wastes, some of which have high levels of radioactivity and long radioactive half-lives. These wastes should be managed in accordance with the safety principles described in the IAEA publication The Principles of Radioactive Waste Management, Safety Fundamentals, Safety Series No. 111-F, IAEA, Vienna (1995). International consensus exists that such high level and long lived radioactive wastes, which must be isolated from the human environment for very long times, are best disposed of in geological repositories using a system of engineered and natural barriers. This consensus has been referred in the OECD/NEA publication The Environmental and Ethical Basis of Geological Disposal of Long-Lived Radioactive Wastes, A Collective Opinion of the Radioactive Waste Management Committee of the OECD Nuclear Energy Agency, OECD, Paris (1995). Basic principles and criteria for the disposal of high level radioactive waste are given in the IAEA's publication Safety Series No. 99, Safety Principles and Technical Criteria for the Underground Disposal of High Level Radioactive Wastes, which is being revised within the IAEA's Radioactive Waste Safety Standards (RADWASS) programme.

An important matter in the development of a geological repository for disposal of radioactive waste is the selection of a site that has characteristics that are favorable for isolation. A number of Member States have had national programmes under way for several decades to investigate sites to gather the geological information needed to design and construct a safe repository. The purpose of this report is to document this experience and to summarize what has been learned about the site selection and investigation process. It is hoped it will be of interest to scientists and engineers working in national disposal programmes by providing them information and key references regarding the disposal programmes in other countries. It may also be of interest to members of the public and to decision makers wanting an overview of the worldwide status of programmes to select and characterize geological disposal sites for radioactive waste. This experience also provided input to the development of a Safety Guide on the Siting of Geological Repositories, IAEA Safety Series No. 111-G-4.1, published in 1994 as part of the publications of the Radioactive Waste Safety Standards (RADWASS) programme.

This report was prepared during two consultants meetings and an Advisory Group meeting that took place during the period December 1991 to July 1993. Nineteen experts representing thirteen Member States shared their knowledge and experience to assist the Secretariat in preparing this report. The Secretariat would like to express its gratitude to all the experts who contributed to its preparation, particularly to A. Bonne of Belgium, who participated in the first consultants meeting in December 1991 and who chaired the Advisory Group meeting in June 1992, and to T. Brasser, who participated in the first consultants meeting and hosted the second consultants meeting in Braunschweig, Germany, in May 1993. M. Bell and J. Heinonen of the Division of Nuclear Power and the Fuel Cycle were the IAEA officers responsible for the preparation of this report.

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1. INTRODUCTION

1.1. BACKGROUND

A geological repository for radioactive wastes is a system of natural and engineered barriers whose function is to isolate the wastes from humans and the environment. The natural barriers include the host rock of the repository and the surrounding geological formations, each having their own geological, hydrogeological and geochemical properties. These barriers provide the conditions within which the wastes will be emplaced and also retard the transport of any radionuclides that may be released from the engineered systems to the accessible environment. Thus, selection of a site that has geological, hydrogeological and geochemical properties that are favorable to waste isolation is of prime importance. However, other factors involving technical, societal and economic matters must also be considered in site selection.

Over the last twenty years the IAEA has published a number of documents recommending siting criteria, factors to be considered in site selection, and methods to be used to investigate or characterize potential repository sites. During this same period, site selection and site characterization activities to establish repository sites have been performed in several countries. In other countries underground research laboratories have been developed to obtain typically generic information regarding candidate repository host rocks, to develop site investigation procedures and to improve and increase confidence in safety assessment models. The underground research laboratories, which are devoted for the purpose of research on the feasibility of disposal of high level, long lived waste are located at a site which is excluded from hosting of the disposal repository. However, there are already also underground research laboratories or corresponding exploratory shafts in the world which are sited at the potential or proposed repository sites. The primary purpose of these type of underground research facilities is the detailed investigation of the candidate repository site. Consequently, it is timely to review IAEA documents in the light of recent experience and to update guidance to Member States in this area.

1.2. OBJECTIVES

The objectives of this report are:

1. to discuss the general processes and factors to be considered in selection of geological repository sites; and

2. to review experience that has been gained in selecting and characterizing sites for deep geological disposal of radioactive wastes and in developing underground research laboratories, and to upgrade guidance on these subjects.

1.3. SCOPE

The development of a repository involves a number of activities, including siting, design, construction, operation, closure, and in some cases, institutional control and post closure monitoring. Safety assessments take place at several points during these stages, and some of these activities proceed in parallel. The focus of this report is, however, on the process for siting of a geological repository.

This report is primarily directed at deep geological disposal of high level radioactive wastes and spent nuclear fuel for which no further use is foreseen. However, relevant experience from siting of facilities for geological disposal of low and intermediate level wastes has also been considered, and information in the report is also relevant to siting and investigating facilities for disposal of these wastes.

1.4. STRUCTURE

This report begins with a summary of existing IAEA documents dealing with selection and characterization of sites for geological disposal of high level radioactive wastes (Section 2). It then discusses the objectives of site selection, and factors to be considered in site selection (Section 3), and the process of site selection (Section 4). Section 5 discusses considerations related to characterizing a candidate site to determine its suitability for development of a repository, and to confirming the suitability of a selected site during the period of repository construction and operation. Section 6 presents an overview of experience in siting and characterizing candidate sites in some countries, and makes recommendations based on this experience, while Section 7 summarizes the main points of the report. The report also contains a glossary defining relevant terms.

2. PREVIOUS IAEA GUIDANCE REGARDING SELECTION AND CHARACTERIZATION OF SITES FOR GEOLOGICAL DISPOSAL

The IAEA has, over a period of more than twenty years, published several documents addressing the topics of selection and characterization of sites for geological disposal of radioactive wastes. These include documents in the Safety Series (Safety Standards, Safety Guides and Recommendations) and documents in the Technical Reports Series, which contain technical information based on practice and experience, that is expected to be of interest to Member States.

The most recent of these was published in 1994 in the new series of the Radioactive Waste Safety Standards (RADWASS): A Safety Guide on Siting of Geological Disposal Facilities [1]. This Safety Guide defines the process to be used and guidelines to be considered in selecting sites for deep geological disposal of radioactive waste. In addition to technical factors important to site performance, this Safety Guide also addresses the social, economic and environmental factors to be considered in site selection.

Safety Series No. 99, Safety Principles and Technical Criteria for the Underground Disposal of High Level Radioactive Wastes [2], contains two criteria relevant to siting of a geological repository. Criterion No. 7 of Safety Series No. 99 deals with the characteristics of the host rock formation needed to safely isolate the radioactive waste, while Criterion No. 8 addresses the need to avoid sites with valuable natural resources that could lead to future disruption of the isolation system by human intrusion. These two criteria constitute important factors that need to be evaluated in any site selection process. It is planned to replace this publication by a new Safety Standards Series publication under preparation within the RADWASS programme.

Other IAEA publications, Safety Series No. 96, Guidance for Regulation of Underground Repositories for Disposal of Radioactive Wastes [3], Safety Series No. 60, Criteria for Underground Disposal of Solid Radioactive Wastes [4] and Safety Series No. 54, Underground Disposal of Radioactive Wastes: Basic Guidance [5] provide guidance on the factors that should be considered and the overall screening process to select sites for geological repositories.

The IAEA has also issued several publications in the Technical Reports Series describing methods for investigating sites and factors to be considered in site selection. These include Technical Reports Series No. 256, Techniques for Site Investigations for Underground Disposal of Radioactive Wastes [6], Technical Reports Series No. 215, Site Investigations for Repositories for Solid Radioactive Wastes in Deep Continental Geological Formations [7] and Technical Reports Series No. 349, Report on Radioactive Waste Disposal [8]. A related IAEA publication, Technical Reports Series No. 251, Deep Underground Disposal of Radioactive Wastes: Near-Field Effects [9], describes interactions between the geological environment and the engineered barrier system which need to be considered as part of site characterization. Finally, two reports in the IAEA's Technical Document (TECDOC) series of publications also contain information relevant to siting and characterization of sites for deep geological repositories. These are IAEA-TECDOC-563, Siting, Design and Construction of a Deep Geological Repository for the Disposal of High Level and Alpha Bearing Wastes [10], and IAEA-TECDOC-446, In Situ Experiments for Disposal of Radioactive Wastes in Deep Geological Formations [11].

3. FACTORS AFFECTING SITE SUITABILITY

3.1. THE OBJECTIVE OF SITE SELECTION

The basic objective of site selection is to select one or more suitable sites and to demonstrate that at least one of these sites, when combined with repository and waste package designs, provides adequate isolation of the radionuclides from humans and the environment for the desired period of time.

Disposal of radioactive waste involves substantial reliance on the conditions at a site to provide, or assist in achieving, long term confinement of waste. The process of selecting an appropriate site is therefore of great importance.

The requirements for a disposal site are normally set by regulatory bodies, which also set or approve site selection criteria. The Regulatory Body will judge the suitability of a site on the basis of a safety assessment, a review of the site selection process and the documentation of the data about the site. The ultimate practical goal of the site selection process is attained when the authorization needed for operation of the geological repository is obtained.

The site selection process includes the prioritizing of relevant siting factors. Factors influencing the long term safety of the repository must be given highest priority. For other factors, for instance those related to technical feasibility or cost questions, national practice, or local conditions a more flexible approach can be taken and their relative importance may vary according to the stage of the process.

3.2. OVERALL SYSTEM REQUIREMENTS AND SITING FACTORS

The siting factors must take into consideration more general requirements that apply to the disposal system. These general requirements refer to:

Long term safety

A site and system specific assessment of long term safety should be completed in the context of the national regulatory requirements. The outcome of such an assessment will not only depend upon site specific factors like geology, hydrogeology, geochemistry and seismicity, but also on the waste characteristics, the engineered barrier system and their interactions with the natural system. Changes in the properties of a site due to construction and operation of the repository and long term environmental changes must be considered in assessment of long term safety. It is important to note that the site and the engineered repository be considered as an integrated system and that long term safety be assessed through a systematic analysis of the performance of the overall system [12].

Technical feasibility and operational safety

The site should fulfill certain requirements in order to make it technically and practically feasible to construct a repository. It must, for instance, be possible to construct and operate the facility safely, without significantly disturbing the natural systems. This will introduce certain requirements and the formulation of design basis parameters for instance concerning mechanical stability of the host rock during construction and the general accessibility to the site.

Socioeconomic, political and environmental considerations

Siting of a repository should also consider social and environmental factors. The use of land within a country is dependent upon needs and demands from many different sectors of the society like industry, agriculture, nature conservation or recreation. It is recommended that plans for siting a radioactive waste repository be co-ordinated with the overall planning of land use in the areas considered. Potentially adverse as well as potentially positive influences of repository siting will should be evaluated. For instance, the adverse effects on the environment in terms of additional traffic, noise or excavated material could vary significantly between different potential sites. Similarly, positive effects like job creation and support to or development of local infrastructure could be viewed as important depending upon the specific situation in different communities being considered in the siting process.

Political and public attitudes will have a significant influence on the siting of radioactive waste repositories. The process of selecting, investigating and characterizing a site is a long lasting activity involving much formal as well as informal interaction between the proponent and local officials, the local population and regulatory authorities. The probability of success may be higher if this process can be done in an atmosphere of mutual respect and trust than if there is active opposition. Therefore, provided that requirements concerning long term safety, technical feasibility, social planning and environmental considerations can be fulfilled, it is legitimate to consider factors related to political and public attitudes in selecting potential repository sites. For instance, by choosing a site where there is already a good understanding and acceptance of nuclear activities, one might minimize the adverse social impact that could be caused by locating a repository where no such basis for public acceptance exists. On the other hand, the positive attitude at some sites or the need for employment must never be allowed to compromise the long term safety requirements to be met.

Table I summarizes the above points by presenting examples of factors that may be of importance for the siting of a radioactive waste repository. The list is not exhaustive and it is incorporated into this report only as an example of the types of factors that have been considered in siting processes. National siting projects should develop their own list of factors, which will be tailored to the circumstances of that particular project. The relevance of individual siting factors will vary depending on the stage of the siting process.

TABLE I. EXAMPLES OF FACTORS THAT MAY BE OF IMPORTANCE FOR SITING OF A GEOLOGICAL REPOSITORY

	General requirement	Related factors
I.	Long term safety	Biosphere characteristics Climatic changes Engineered barrier characteristics Geochemistry Geology Geomechanics Geomorphic activity Hydrogeology Potential for human intrusion Pre-existing boreholes and excavations Seismicity Tectonics Volcanic and hydrothermal activity Thermal stability Waste characteristics
II.	Technical feasibility and operational safety	Flood and landslide susceptibility Geology Hydrogeology Rock-mechanics Seismicity Site accessibility (transportation)
III.	Socioeconomic, political and environmental considerations	Agriculture Cultural/historical interests Economics Employment needs Environmental impact Potential for intrusion Existence of nuclear activities Industrial development Infrastructure Land ownership Nature conservation Planning for land use Planning for use of natural resources Political and public opinion Population parameters Transportation

3.3. EVALUATION OF SITING FACTORS

Each of the relevant siting factors needs to be assessed in order to clarify in more detail:

(a) how it influences the assessment of potential site suitability
(b) to what extent information about the factor is readily obtainable
(c) under what circumstances, if any, a factor be considered prohibitive for site selection
(d) at what scale, in time and space, the factor needs to be considered.

Theoretically, one might imagine an approach where detailed quantitative criteria are established in advance for each factor and all potential sites and the corresponding siting factors are evaluated against these criteria. In practice, this is, however, difficult to implement. Most importantly, safety depends on the performance of the disposal system as a whole, which is not directly related to an individual factor. Acceptability of a site is likely to be attained by balancing many of the factors so long as regulatory criteria for safety and environmental impact are met. Furthermore, some factors may be interdependent so that their relative importance varies from site to site.

The amount of information available or accessible about siting factors will vary considerably. Some information is readily available at an early stage while other information can only be obtained through field investigations at the site. One might even need underground exploration work to get a good estimation of certain parameters. The evaluation of some factors may only be achieved by the use of expert judgement. In addition, the assumptions used in evaluating a factor must be justified and documented. These facts should be clearly recognized in the documentation, organization and scheduling of the siting activities. For instance, information concerning factors related to society and social planning can be obtained at an early stage. The characteristics from the point of view of transportation for example can be quantified (in terms of distance from waste generating facilities, accessibility by train or boat, etc.) for every possible site in a country. The same is true for factors like population density, local or national plans for use of land, presence of nature reserves, etc. Data on many of the factors related to the properties of the geological formations, on the other hand, can only be obtained through field investigations at potential sites. For practical reasons, such investigations can only be performed at a few sites and the choice of these sites may be based upon more general regional information, for example from natural resource exploration, and generic assessment of the site suitability. Such information can be obtained through field studies in the geological medium of interest. For example, in Finland and Sweden, investigations have been performed at many sites including measurements in deep drill holes. The results of these investigations have provided a good general overview of the geological, hydrogeological and geochemical properties of the Fennoscandian Shield both in terms of typical values and their variation in different areas. Based on this type of information and other relevant available data, e.g. from other underground facilities, it is possible to make a preliminary assessment of the suitability of any proposed potential repository site. Such a preliminary assessment is to be confirmed or modified following more detailed investigations and characterization of the selected site(s).

Early in the site selection process, most criteria for site selection are formulated in a qualitative manner. In the course of the siting process and later, when sites have been selected and are being investigated, these qualitative criteria are translated into specific parameters which can be measured directly or indirectly. Table II lists some qualitative site selection factors and provides examples of related specific parameters which need to be determined during site specific investigations.

TABLE II. LIST OF SOME QUALITATIVE SELECTION FACTORS AND THE RELATED SPECIFIC PARAMETERS NEEDED TO BE DETERMINED IN THE SITE CHARACTERIZATION AND CONFIRMATION STAGES

Factors for site selection	Parameter in characterization and confirmation
geological	geometry/dimensions petrography fabric/structure discontinuities/faults occurrence of fluids
hydrological	hydraulic conductivity hydraulic gradient porosity
geochemical	diffusion coefficient or retardation factor and diffusion constant sorption capacity fluid chemistry mineral composition
geomechanical and thermal	porosity bulk density unconfined compressive strength cohesion elastic modulus angle of shear resistance in situ state of stress thermal conductivity thermal diffusivity specific heat permeability hydraulic gradient viscosity of fluids

4. THE PROCESS OF SELECTING A SITE

In the selection of a site that is suitable with regard to safety and the other requirements defined in Section 3, several approaches are possible. The question is, to find an optimum way to satisfy the requirements, taking into account the legal, economic and societal conditions.

A suitable site may be identified either by narrowing down the number of sites through a formal screening process or by evaluating one or more potential sites that have been designated or that have been volunteered. For either approach the potential site(s) must be able to provide, in combination with the repository design, a disposal system that meets the regulatory criteria for safety and environmental protection. There can be flexibility in the degree of reliance placed on the natural barriers or the engineered barriers in the disposal system design in order to meet the regulatory criteria but the safety requirements must be fulfilled regardless of the approach taken.

Despite differences in the approaches taken by different countries, the siting process can generally be described in terms of four stages [1]:

- conceptual and planning stage
- area survey stage
- site characterization stage
- site confirmation stage.

During the *conceptual and planning stage* the overall repository system or disposal concept is defined and an approach to the siting process is developed taking into account the national regulatory requirements and nuclear energy policy as well as the geological, geographical, and social conditions. It is during this stage that decisions are commonly made on whether to focus on one or more potential host geological media for disposal and made on the options for waste form, container and waste emplacement design.

During the *area survey stage* the number of potentially suitable areas or sites is narrowed down to one or a few that will be characterized. This may be done using a systematic survey and catalogue of regions that contain potentially suitable sites (or of the sites themselves). Such a catalogue may be prepared for all suitable geological media or only for a preferred geological medium and it may be done for the entire country or only for a selected portion of the country. Typically when a systematic survey approach is taken, the narrowing down to a few sites is done using criteria established for selected factors from such a list as Table I. Alternatively, the survey may be limited initially to sites that appear desirable either because of existing knowledge, the existence of underground facilities, or for socioeconomic reasons, e.g. sites near existing nuclear facilities or sites that have been volunteered by government, communities or landowners. Investigations of pre-designated sites may also be carried out in parallel with the area survey.

During the *site characterization stage* sufficient investigation of the site(s) is made in order to develop preliminary site-specific designs and to conduct a preliminary safety assessment. Only if investigations indicate that the site appears to be suitable *would* it be worthwhile proceeding with detailed investigations to confirm the suitability of the site. It is at this point that a single preferred site might be designated if investigations have been made on multiple sites. The extent to which multiple sites are characterized will vary between countries and will depend on requirements for different radioactive waste types (Section 6).

During the *site confirmation stage*, detailed site investigations are conducted to verify that existing site conditions are in general compliance with the anticipated site conditions, and to provide the information required to prepare and submit the license application for repository construction. Typically, the site specific data for the detailed design of underground openings and engineered barriers and for the safety assessments are obtained during the site confirmation stage. Site confirmation may continue through the construction and operation phases of the repository. Aspects of site characterization and site confirmation are discussed more fully in Section 5.

It is important that from the beginning of the siting process a quality assurance programme is established for all activities to ensure the quality of data and information in order to demonstrate compliance with relevant standards and criteria. The quality assurance programme be modified as needed as the siting project and quality assurance programme proceed through the subsequent stages.

Emphasis is given hereafter in this report on site characterization and site confirmation since these are the most visible and important stages in collecting the information for the final design and safety assessments and the development of underground research laboratories is in many cases seen in these stages.

5. SITE CHARACTERIZATION AND SITE CONFIRMATION

The terms 'site characterization' and 'site confirmation' do not have unique definitions that are uniformly used in the past by all countries. The reader is cautioned to be aware of specific usage, which may differ from those expressed in the IAEA Safety Guide on Siting of Geological Disposal Facilities [1]. Sections 5.1 and 5.2 provide a discussion of the most common usage of these terms.

5.1. SITE CHARACTERIZATION STAGE

The site characterization stage requires site specific information to establish the characteristics and the ranges of parameters of a site. This will require site reconnaissance and investigations, supplemented by laboratory work, to obtain geological, hydrogeological and environmental data. Other data relevant to site characterization, such as transport access, demography, societal considerations, also be gathered. The result of this stage is the identification of one or more preferred sites for further study.

Site investigations focus on relevant data as early as possible using exploration methods that require as few penetrations as possible of the host rock. This may be achieved using an iterative process of data collection, safety assessment and design, to focus the investigations on the relevant data and to minimize the potential for disturbing the repository system by excessive investigations.

Site characterization provides important baseline information on the repository area. Since many perturbations to the system will take place during subsequent site development, provisions be made during the site characterization stage to monitor and evaluate these perturbations.

The conclusions that are drawn from the results of the site characterization stage and its investigations must be consistent with national legislation. A report is usually prepared for the authorizing body, with documentation of all information including the preliminary safety assessment. It is expected that the final site selection will involve judgements based on socioeconomic, environmental and political considerations. In some countries the regulatory body will review the results of site characterization and decide whether the preferred site(s) is (are) suitable for construction of a repository and whether the planned site confirmation studies are adequate.

5.2. SITE CONFIRMATION STAGE

The purpose of the site confirmation stage is to conduct detailed site investigations at the preferred site(s) prior to the start of construction of the repository. The objectives of these investigations are to:

(a) verify understanding of site conditions; and
(b) provide site specific information required for detailed design, safety analysis, environmental impact analysis and for licensing.

Details of the site(s) and its (their) surroundings are obtained through the use of additional surface, laboratory and subsurface studies. Confirmatory investigations may continue during the construction and operational phases of repository development.

Upon confirmation of the suitability of the site, an application is submitted to the regulatory authority with sufficient information to permit decisions to be made as regards approval for construction of the facility. This proposal should include a safety assessment based on the results obtained from the site investigation, characterization and confirmation activities. An environmental assessment as specified by appropriate national authorities should also be prepared at this stage. The safety and environmental assessments may require updating during the construction and operation phases.

5.3. ROLE OF UNDERGROUND INVESTIGATIONS

After finishing the programme of surface investigations, drilling activities, hydrogeological monitoring and general data evaluation, additional information is needed that can best be obtained by underground investigations (e.g. shaft sinking, construction of access tunnels and construction of investigation drifts and galleries). Such information is of the following kinds:

(a) development of the methodology for site investigation and evaluation;
(b) development and demonstration of the engineering technology to construct and seal the repository; and
(c) gathering of site specific data needed for more detailed safety assessment.

Not all of this information needs to be evaluated at the selected site itself. After development of adequate investigation methods, some processes, such as the thermal interactions of high level wastes with the host rock, could be studied in underground laboratories or using natural analogues. But in every case, the transferability of data obtained in these ways must be evaluated.

The aim of underground investigations during site characterization is the site specific study of geological aspects such as dimension and facies of host rock, petrography and structure, localization of discontinuities, fault zones, hydrological aspects such as groundwater flow, scale effects, occurrence of liquids, geochemical aspects such as mineral constituents, chemical composition of brines and gases and radiation phenomena (combined in situ and laboratory tests with radioactive sources). In addition, the understanding of geomechanical aspects is of great importance for construction, operation and safety of the repository. Examples include understanding of stress conditions, hydraulic conditions, thermomechanical behavior, convergence and irradiation effects.

5.4. SAFETY ASSESSMENTS

The acquisition of site specific data and their iterative use in safety assessments allow a better understanding of the uncertainties and, in some cases, even quantifying of the uncertainties in the integrated assessments. In this way, a stronger basis is obtained for decisions about site suitability and design and for judgments based on results of the safety assessments.

With the acquisition of additional site specific data the sensitivity analyses identify more clearly the contribution of the various system components to the overall system performance. Even though the basic principle of a disposal system is based upon a multiple barrier concept the results of the sensitivity analyses performed for certain sites and host rocks show that the geological barrier dominates the overall performances [13, 14]. In cases where the engineered barriers play an as equally important role in the normal evolution of the system, they can perform only as such because of the protection provided by the geological barrier (low corrosion rate for instance).

6. OVERVIEW OF EXPERIENCE OF SOME COUNTRIES

Several Member States of the IAEA have completed siting activities for disposal of various types of radioactive waste. Although there is some commonality, variations in management, types of waste and the siting process have caused some differences in siting strategies used.

Considerable international consensus exists regarding the site selection factors that should be considered. International collaboration was set up by the CEC to identify in its member states areas with geological formations potentially favorable for the geological disposal of long lived or high level radioactive waste. In this selection process common site selection factors were applied [15]. International or bilateral collaboration has occurred in the area of site characterization techniques, e.g. in the underground research facilities, such as Stripa [16], Åspö [17], Asse [18], Mol [19], the Canadian URL [20] and Grimsel [21]. A brief overview of the status of the siting process in Member States is given in Table III.

6.1. SOCIETAL FACTORS

Experience has indicated that there is no single preferred approach to site selection. Generally the choice of approach depended largely on the institutional and societal attitudes in the country during the siting process.

As a consequence, a number of factors related to societal and political considerations have been formulated and applied (see Section 3.2). In the past the social and political factors were recognized but their importance was underestimated. In particular, the problem of public acceptance has received a higher priority. It is now acknowledged that these factors may determine the acceptability of technically suitable sites. The recognition of the importance of public interaction now emphasizes the need to initiate these activities at the earliest possible time.

In Spain the general strategy for waste management is under review by the Ministry of Industry and Energy. It will take into account the problems faced with in the site selection, public acceptance aspects and the developments in other countries. This review will delay the high level waste disposal programme about ten years; thus the geological disposal repository is expected to become operational in the year 2035 and the designation of candidate sites would take place in 2010 [22].

The Government of the UK has published in 1995 a 'White Paper', Review of Radioactive Waste Management Policy: Final Conclusions. A public inquiry was organized into the appeal by Nirex against the refusal of planning permission for the Rock Characterization Facility by the local planning authority, Cumbria County Council. It took place from September 1995 to February 1996. It was conducted in two parts: conventional planning matters; and policy and science matters. The scientific evidence was cross-examined principally by Cumbria County Council, Friends of the Earth and Greenpeace [23]. Following the inquiry the Environment Secretary announced in March 1997 his dismissal of the Nirex's appeal [24].

TABLE III OVERVIEW OF THE STATUS OF CURRENT SITING PROCESSES FOR GEOLOGICAL REPOSITORIES IN SOME MEMBER STATES

COUNTRY	WASTE TYPE	STATUS	HLW REPOSITORY HOST ROCK
BELGIUM	ILW/HLW	Underground research laboratory in operation at Mol (co-located) Site characterization in progress	CLAY
CANADA	SF	Site selection process will be initiated when environmental review is completed URL in operation	GRANITE
CZECH REPUBLIC	SF/HLW/ALPHA	Site selection in progress	GRANITE
FINLAND	LLW/ILW SF	Site in operation at Olkiluoto (co-located with NPP) Loviisa site constructed to be licensed for operation in steps Site screening completed, four potential sites under investigation	GRANITE
FRANCE	HLW	Site screening of four potential host media completed At least, two underground research facilities will be developed	GRANITE CLAY
GERMANY	LLW short lived ILW LLW/ILW HLW	Morsleben site in operation on experimental basis since 1978 Full scale operation 1981 Konrad site to be licensed Gorleben salt dome being characterized Two exploratory shafts being constructed	SALT
JAPAN	HLW	Site screening in progress	CRYSTALLINE SEDIMENTARY
KOREA, REP OF	LLW/ILW	Site screening completed Selection of site(s) for characterization/confirmation in progress	
SPAIN	HLW, SF	Site screening in progress	GRANITE, SALT, CLAY
SWEDEN	LLW SF	SFR for reactor waste in operation at Forsmark since 1986 (co-located) Screening for spent fuel repository in progress URL at Aspo in operation	GRANITE
SWITZERLAND	LLW ILW/HLW/SF	Site screening completed Wellenberg site proposed Site screening in progress URL in operation at Grimsel	CLAY, GRANITE
UK	LLW/ILW	Some characterization studies done at Sellafield	VOLCANIC
USA	TRU SF	WIPP facility initially constructed, awaiting authorization to accept TRU waste for disposal Yucca Mountain site selected and being characterized (co-location of test facilities) Exploratory shaft facility established and the tunnel has been completed	SALT TUFF

Legend	LLW	=	low level waste	HLW	=	high level waste
	ILW	=	intermediate level waste	URL	=	underground research laboratory
	SF	=	spent fuel	TRU	=	transuranic waste
	WIPP	=	Waste Isolation Pilot Plant	RCF	=	rock characterization facility

The Atomic Energy of Canada Limited (AECL) submitted in 1994 an Environmental Impact Statement on the Concept for the Disposal of Canada's Nuclear Fuel Waste for review under the Canadian Environmental Assessment and Review Process. The review process includes public hearings which are taking place in three phases: focusing on societal, scientific/technical issues and providing finally in the phase three, in 1997, an opportunity to present opinions and views on the safety and acceptability of AECL's disposal concept and its implementation. When the review is concluded a panel will make recommendations on whether AECL's concept is safe and acceptable [25].

Also in Sweden the issues of public acceptance, in particular, relations of local communities to siting a repository for spent fuel have turned out to be of crucial importance. The responsibility of the siting process is with the Swedish Nuclear Fuel and Waste Management Co. (SKB). To facilitate the process mainly in coordinating the activities of the different local communities and Country Boards, a national facilitator/coordinator has been appointed by the government [26].

France has appointed a negotiator to find communities willing to host radioactive waste facilities. Also the USA is making an extensive use of procedures which permit public review of programme site assessment processes and findings. The USA has initiated the use of public participation in siting high level radioactive waste facilities through the creation of the US Office of the negotiator similar to that in France [27].

6.2. EXTENT OF AREA SCREENING

Screening normally proceeds through several different scales: regional, area, and multiple sites, leading to the selection of a final site. No absolute qualitative criterion has been formulated for these scales. They have been treated in different ways by the various countries and within the same country for the different repository options.

It has been found advantageous to limit the areas to be investigated for further study early in the conceptual and planning stage. Areas to be investigated have been selected on the basis of:

- societal prerequisites (e.g. demographic criteria);
- geographical extension of the country;
- site concept limitations (e.g. coastal areas);
- state of knowledge of some areas.

This limitation does not mean that certain areas should be excluded from consideration in the site selection process.

As a consequence, the area survey stage may be substantially reduced or eliminated with early consideration of the confirmation issues which are investigated on the local scale. However, even for a designated or volunteer site some of the site investigations must be done at a regional scale. Due to different reasons regional investigations may be performed still in a relative late phase of site characterization studies. The role of these investigations may well be amendment, confirmation or validation.

For example the Gorleben site is close to the border of the former German Democratic Republic. Directly or indirectly due to the former restrictions in the border region all the regional investigations could not be executed in the extent desired. Thus extensive research has been carried out in the area recently. It includes a drilling programme, which has been executed in 1996 to assess the hydrogeological conditions in the 70 square km investigation area north of the Elbe River. About 10 000 m borehole was drilled and 43 groundwater gauges were installed in the different aquifers. The drill cores were examined and comprehensive geophysical measurement programme was carried out in the boreholes [28].

6.3. ADEQUACY OF DATA

6.3.1. Collection and use of data

For the conceptual and planning stage and early in the area survey stage, screening has been performed mostly on the basis of existing data. Examples of existing data include geographical and geological surveys, such as an inventory of land resources, exploration of land and mineral resources, water resources, and civil engineering studies for land infrastructures, e.g. highways, railways, tunnels, and caverns.

In some cases countries were able to satisfy the data needs for the identification of areas and regions on the basis of the available data. Other countries however, decided to perform limited field investigations (drilling, sampling and geophysics) in the area survey phase.

As data become available from site characterization, they can be used to make continuing assessments of the suitability of the site and the validity of the models as well as to redirect the site characterization programme should the evolving models so dictate. The bases for these iterative evaluations of site suitability and the information needed from site characterization are derived from the safety principles and the technical criteria.

In particular, in collating, handling and using data, experience indicates that the following points should be noted:

1. To ensure robustness of the site assessment, all sources of data and associated assumptions must be clearly traceable. Therefore, a QA programme should be established early in the process. This programme must be flexible to meet the changing level of detail required of site assessments.

2. Formal data evaluation processes may be required in order to take account of and resolve differences in expert judgement relating to some parameters.

3. Data collection must be guided by the requirements of the site assessment in order to ensure that the use of resources is optimized.

4. The adequacy of data, and plans for subsequent data collection, should be periodically reviewed to ensure that they meet the requirements for site assessment.

5. Several assessments may be required during the characterization of a particular site. The data used should be frozen at the start of each assessment to ensure adequate data control.

6. A system for records management is to be established at the earliest possible time and it would be maintained consistently across the entire disposal programme.

6.3.2. Underground research laboratories

Underground research laboratories (URLs) play an important role in the development of a geological disposal system for long lived and high level radioactive wastes. Several IAEA Member States are running extended experimental programmes in underground research facilities already since two decades.

The results produced have proved to be valuable in generic terms while assessing and developing the disposal concept. Those are, however, of particular specific importance in characterization of a potential repository site in detail and in validation of different models used in assessing the performance, safety and design of the repository system. Investigation programmes in these underground research laboratories commonly include [11]: determination of the natural conditions at the site, construction, construction response, backfilling, testing of buffer and sealing materials, heat and radiation impact, corrosion and migration processes. These programmes may also cover methodological approaches, parameter value determination or model validation. An underground research laboratory can be located at the potential disposal repository site. Or it can be developed at a site which is excluded from hosting the disposal repository. In the latter case the URL is devoted for generic studies which may typically include research on the feasibility of the disposal concept. Valuable experience has also been gained through the investigations related to siting of the generic URLs [26]. There has been a significant international participation in the research programs of the generic URLs, which has enhanced the international collaboration and technology transfer in the field. In the new Underground Research Facility planned by the Japan Power Reactor and Nuclear Fuel Development Corporation a substantial foreign participation in the research programs is anticipated. The URLs sited at the potential or proposed repository sites will in the first hand respond to the requirements that the proper assessment of a disposal site needs to include comprehensive underground experimentation, testing and validation.

Underground research laboratories have been established in representative geological formations in Germany, Sweden, Switzerland, Canada, and at a potential disposal site in Belgium. The extensive underground testing programme being executed in the potential disposal US repository site Yucca Mountain, Nevada involves an underground research facility. For that purpose the excavation of the Exploratory Shaft Facility (ESF) was started in 1993 and is being continued with the specially assembled tunnel boring machine since 1994 [27]. At the Gorleben site, Germany, two shafts have been sunk for exploratory reasons, down to the level of about 840 m below surface. When exploratory work will be done at the potential repository site the potential damage to the geological barrier is tried to be kept as low as possible [28]. Non-radioactive site-confirmation experiments have been ongoing in the WIPP facility, at and near the repository horizon, for approximately 10 years. In the French siting process, underground laboratories will be constructed at two candidate sites, at least.

6.4. Regulatory requirements

Regulatory requirements vary markedly between Member States. In some cases, such as in the USA, they can take the form of detailed criteria prescribing the performance of individual components of the repository system. In others, the emphasis is on demonstrating the overall safety of the repository system as a whole. In these cases targets are usually set for the performance of the system over certain periods of time. For example, in the UK the Department of Environment has provided guidance that a target on an annual individual risk of one in a million would be keeping with public acceptability of risk. In addition, the time for which safety must be demonstrated, or the performance criteria met, varies between countries. For example, some countries adopt 10 000 years as a suitable cut-off point for performance assessment, while in countries, such as the UK, there is no formal limit. In practice, detailed numerical predictions of the repository system performance are usually carried out up to a point of time, e.g. one million years, depending on the likely time scales for significant environmental change, and thereafter less detailed and more qualitative predictions of system performance are made.

In Belgium the site investigation programme is periodically submitted for evaluation to the authorities who formulate their recommendations and give directives for future investigations. Until now, the authorities have not imposed specific targets at certain milestones in the siting process. No details about the future site selection process have been worked out. The second SAFIR report with its safety studies will be presented by the National Organization for Radioactive Wastes and Fissile Materials, ONDRAF/NIRAS to the Belgian authorities in 1998 [29]. This evaluation report is expected to be an important milestone in the site selection process in Belgium. At present the schedule for site selection process high level and long lived waste repository is set by the ONDRAF/NIRAS on the basis of technical and scientific considerations. This implies that the site selection and characterization would be completed in 2015, and the repository construction would start in 2020 and the operation in 2025.

A new Atomic Law was approved by the Czech parliament in the beginning of 1997. The law clarifies the relations and responsibilities between radioactive waste generators and State. It establishes radioactive waste management and decommissioning funds and the new state controlled organization for waste management [30].

As regard to geological repositories for low and intermediate level radioactive wastes site characterization programmes in Sweden and Finland have obtained adequate site related data for licensing by the Regulatory Bodies in those countries. The safety assessment reports for these facilities were in compliance with national regulatory requirements [31, 32]. In Finland a second geological repository for low and intermediate level waste at the Loviisa power plant site is planned to be licensed for operation in steps. An application to use the repository as an interim storage facility has been submitted and permit is expected to be granted in the nearest future. The license for final disposal is also submitted together with the application for the renewal of the operation license of the power plant itself. The license is expected to be granted at the end of 1997 [33].

In some cases, regulatory requirements change during the repository development programme due to political or socioeconomic factors. Repository development programmes therefore need to be flexible and avoid focusing on particular regulatory issues.

6.5. Feasibility

The repository concepts under consideration by Member States include many engineered features whose performance is required to be demonstrated under simulated repository conditions. The progressive acquisition of site specific data and performance of specific tests related to the engineering features is needed by the repository developer:

- to select the most appropriate design and technique;
- to optimize the design;
- to demonstrate the behavior of repository components under repository conditions; and
- to determine the performances of the engineered barrier.

Examples of these can be found in the underground research laboratories that are being operated. Specific examples include the in situ demonstration at the Mol site of two different tunneling support methods for a specific clay formation [19], the research on the long term behavior of the near field and on migration aspects include e.g., performance of selected clay based backfill materials, demonstration of the feasibility of shaft sealing [29]; the buffer mass tests in hard rock at Stripa [34] and tests in salt at Asse [35] as well as the ongoing tests in Aspo on buffer, backfilling and sealing including studies on interaction between different barrier components and materials [26]. With the help of a URL on a potential repository site it is possible to demonstrate different important aspects of the feasibility of the disposal system. It is of particular importance to verify by large experiments with actual boundary conditions the models used in performance assessment.

The feasibility of operational underground repositories has been demonstrated by the construction of facilities in hard rock in Forsmark, Sweden [31] and Olkiluoto, Finland [32, 36].

7. SUMMARY

Several approaches exist for selecting a suitable site for a safe overall repository system, each of which may offer specific advantages under certain circumstances. The degree to which a country uses a systematic technical screening approach rather than an approach based more on socioeconomic considerations will commonly depend on the degree to which the alternatives address and satisfy the regulatory requirements for the siting process and the public concerns about it. Similarly, the degree to which investigations at multiple sites are carried out will commonly depend upon the degree of potential flexibility in the choice and the anticipated risk that a single site may not be confirmed as suitable. Increased commitment of limited resources and the potential for delays associated with maintaining comparable progress at multiple sites may be other factors determining the degree to which multiple sites are investigated.

There is no single preferred approach to site selection. The approach for each country depends upon the political, regulatory, social, geological and geographic conditions in the country. Regardless of the approach taken to select a site, site characterization and site confirmation must be performed.

The objective of site characterization is to improve the knowledge of a specific, selected site in order to create the data base needed for safety assessments and design. Site characterization should show that the natural conditions found and investigated at the site correspond with the assumptions made earlier in the project. Special attention must be paid to preserving the natural conditions of the sites; therefore an iterative process is required between site characterization, safety assessment and technical design. Site confirmation verifies the technical knowledge and safety assessments and continues until the repository is finally closed. The decision to build the repository is taken at the time the knowledge is sufficient.

There is considerable experience with the site selection and characterization process within Member States. Underground research laboratories (URLs) have become an integral part of the development of a geological disposal system for high level and long lived radioactive wastes and are usually considered as a phase of the detailed site investigation programme.

Non-technical factors may strongly influence, or even determine, the selection of a final site. In particular, public acceptance, co-location with existing nuclear installations and volunteer communities have received high weighing. Nevertheless, a potential site must be able to provide, in combination with the repository design, a disposal system that meets regulatory requirements for safety and environmental protection.

REFERENCES

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

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Principles and Technical Criteria for the Underground Disposal of High Level Radioactive Wastes, Safety Series No. 99, IAEA, Vienna (1989).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidance for Regulation of Underground Repositories for Disposal of Radioactive Wastes, Safety Series No. 96, IAEA, Vienna (1989).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Criteria for Underground Disposal of Solid Radioactive Wastes, Safety Series No. 60, IAEA, Vienna (1983).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Underground Disposal of Radioactive Wastes: Basic Guidance, Safety Series No. 54, IAEA, Vienna (1981).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Techniques for Site Investigations for Underground Disposal of Radioactive Wastes, Technical Reports Series No. 256, IAEA, Vienna (1985).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Site Investigations for Repositories for Solid Radioactive Wastes in Deep Continental Geological Formations, Technical Reports Series No. 215, IAEA, Vienna (1982).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Report on Radioactive Waste Disposal, Technical Reports Series No. 349, IAEA, Vienna (1993).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Deep Underground Disposal of Radioactive Wastes: Near-Field Effects, Technical Reports Series No. 251, IAEA, Vienna (1985).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Siting, Design and Construction of a Deep Geological Repository for the Disposal of High Level and Alpha Bearing Wastes, IAEA-TECDOC-563, IAEA, Vienna (1990).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, In Situ Experiments for Disposal of Radioactive Wastes in Deep Geological Formations, IAEA-TECDOC-446, Vienna (1987).

[12] OECD/NEA, Can Long Term Safety be Evaluated? An International Collective Opinion, Paris (1991).

[13] STORCK, R., et al., PAGIS: Disposal in Salt Formations, EUR-11778 EN, Brussels (1988).

[14] BONNE, A., et al., PAGIS: Disposal in Clay Formations, EUR-11776 EN, Brussels (1988).

[15] COMMISSION OF THE EUROPEAN COMMUNITIES, European Catalogue of Geological Formations having Favourable Characteristics for the Disposal of Solidified High Level and/or Long Lived Radioactive Wastes, EUR-6891 (E, F), Brussels (1979).

[16] SWEDISH NUCLEAR FUEL AND WASTE MANAGEMENT CO., Stripa Project Annual Report 1990, Tech Report 91-11, Stockholm (1991).

[17] Handling and Final Disposal of Nuclear Waste, Hard Rock Laboratory, Swedish Nuclear Fuel and Waste Management Co., Stockholm (1989).

[18] KUHN, K., and ROTHFUCHS, T., "High-level radioactive waste test disposal, Asse Salt Mine, Federal Republic of Germany", Proc. Int. Topical Mtg on High Level Nuclear Waste Disposal, Pasco, USA (1985).

[19] BONNE, A., "Geoscientific investigations in the Belgian R&D programme concerning the disposal of radioactive waste in clay", Geological Problems in Radioactive Waste Isolation, (P. Witherspoon, Ed.), LBL-29703, CONF-8907218, Berkeley (1991).

[20] SIMMONS, G.R., SOONAWALA, N.M., Underground Research Laboratory Experimental Program, Atomic Energy of Canada Ltd, Technical Report No. 153 (1982).

[21] NAGRA, Grimsel Test Site — Overview and Test Programs NAGRA Technical Report NTB.85-46, Baden, Switzerland (1985).
[22] SANTIAGO, J. L., "Recent Developments in Site Evaluation and Design of Experiments for Radioactive Waste Disposal in Spain", Report for the 7th Meeting of the NEA-SEDE-Group, Paris, 1996.
[23] HOOPER, A.J., Recent Developments in the United Kingdom Programme of Intermediate-Level and Certain Low-Level Radioactive Wastes, Report for the 7th Meeting of the NEA-SEDE-Group, Paris, 1996.
[24] UK DEPARTMENT OF THE ENVIRONMENT, "John Gummer Refuses Nirex Planning Appeal", News Release, London, 17 March 1997.
[25] DAVISON, C.C., "Canadian Developments in Site Evaluation and Design of Experiments for Nuclear Fuel", Report for the 7th Meeting of the NEA-SEDE-Group, Paris, 1996.
[26] AHLSTROM, P.-E., "Progress towards a Swedish repository for Spent Fuel", Geological Problems in Radioactive Waste Isolation, Sec. Worldwide Review (P.A. Witherspoon, Ed.), University of California, Berkeley, CA (1996) p. 213.
[27] DYER, J.R., VOEGELE, M.D., "High-level radioactive waste management in the United States background and status 1966", Geological Problems in Radioactive Waste Isolation, Sec. Worldwide Review (P.A. Witherspoon, Ed.), University of California, Berkeley, CA, (1996) p. 259.
[28] STIER-FRIEDLAND, G., "Present situation of repository projects for the disposal of radioactive waste", Report for the 7th Meeting of the NEA-SEDE-Group, Paris, 1996.
[29] MANFROY, P., ONDRAF/NIRAS, NEERDAEL, B., CEN/SCK, "Recent developments in the Belgian disposal programme", Report for the 7th Meeting of the NEA-SEDE-Group, Paris, 1996.
[30] KUCERKA, M., "The radioactive waste management policy and practice in the Czech Republic", Report for the 7th Meeting of the NEA-SEDE-Group, Paris, 1996.
[31] NORRBY, S., et al., "Licensing of the Swedish final repository for reactor waste", Management of Low and Intermediate Level Radioactive Wastes 1988 (Proc. Symp. jointly organized by the IAEA and the CEC, Stockholm, 1988), IAEA, Vienna (1989).
[32] Operation licence for the VLJ repository. The Government of Finland, 9th April 1992.
[33] AIKAS, T., VUORELA, P., "Recent developments in Finland", Report for the 7th Meeting of the NEA-SEDE-Group, Paris, 1996.
[34] PUSCH, R., Final Report of the Buffer Mass Test, Vol. III, Chemical and Physical Stability of the Buffer Materials, TR 85-14, Swedish Nuclear Fuel and Waste Management Co., Stockholm (1985).
[35] SCHNEEFUSS, J.U., HEUSERMANN, S., "Thermal simulation of drift emplacement: Experiment to demonstrate direct disposal in the Asse salt mine", Geological Disposal of Spent Fuel and High Level and Alpha Bearing Wastes (Proc. Symp. Antwerp, 1992), IAEA, Vienna (1993).
[36] VIENO, T., NORDMAN, H., Safety analysis of the VLJ Repository, Technical Research Centre of Finland (VTT), Nuclear Engineering Laboratory, YJT-91-12, Helsinki (1991).

GLOSSARY

barrier. A physical obstruction that prevents or delays the movement (e.g. migration) of radionuclides or other material between components of the system, e.g. a waste repository. In general, a barrier can be an engineered barrier which is constructed or a natural barrier which is inherent to the environment of the repository. Facilities may include multiple barriers.

barriers, multiple. Two or more barriers used to prevent radionuclide migration from an isolate waste in a disposal system.

clay. Minerals that are essentially hydrated aluminum silicates or occasionally hydratede magnesium silicates, with sodium, calcium, potassium and magnesium cations. Also denotes a natural material with plastic properties which is essentially a composition of fine to very fine clay particles. Clays differ greatly mineralogically and chemically and consequently in their physical properties. Because of their large surface areas, most of them have good sorption characteristics.

co-location. Location of a waste disposal facility in close proximity to a nuclear facility, particularly one that generates significant quantities of waste for disposal. Co-location has advantages in terms of reduced transportation distances, knowledge of site characteristics and public acceptance of nuclear activities.

designated site. A location that is identified by a government or other responsible authority as a candidate for development of a disposal facility.

geological repository. A nuclear facility for waste disposal located underground (usually more than several hundred meters below the surface) in a stable geological formation to provide long term isolation of radionuclides from the biosphere. Usually such repository would be used for long lived and/or high level wastes.

geological barrier. In the context of deep underground disposal according to the multi- barrier approach, this is the natural barrier provided by the stable formation in which the repository itself is constructed.

granite. Broadly applied, any holocrystalline quartz-bearing plutonic rock. The main component of granite are quartz, feldspar and, as minor essential mineral, mica. Granite formations are being considered as possible hosts for geological repositories.

groundwater. That part of subsurface water that is in the saturated zone, including underground streams. The term excludes water of hydration. Groundwater can be brought to the surface by pumping.

heat generating waste. Waste which is sufficiently radioactive that the energy of its decay significantly increases its temperature and the temperature of its surroundings. For example, spent fuel and vitrified high level waste are heat generating and thus require cooling for several years.

high level waste (HLW). (a) The radioactive liquid, containing most of the fission products and actinides originally present in spent fuel and forming the residue from the first solvent

extraction cycle in reprocessing and some of the associated waste streams.
(b) Solidified high level waste from (a) above and spent fuel (if it is declared a waste).
(c)Any other waste with a radioactivity level comparable to (a) or (b).
High level waste in practice is considered long lived. One of the characteristics which distinguishes HLW from less active waste is its level of thermal power.

host rock (or host medium). The stable geological formation in which a repository is located.

hydraulic conductivity. Ratio of flow velocity to driving force for viscous flow under saturated conditions of a specified liquid in a porous medium.

hydrogeology (or groundwater hydrology). A science that is concerned with the properties, distribution and movement of water below the surface of the land (i.e. in the soil and underlying rocks).

hydrology. The study of all waters in and upon the Earth. It includes underground water, surface water and rainfall, and embraces the concept of the hydrological cycle. (See also groundwater.)

in situ testing. Tests conducted within a geological environment that is essentially equivalent to the environment of a potential repository. A special underground laboratory may be built for in situ testing or tests may be done in an actual repository excavation. Only in such a facility can the full range of repository environment properties and waste repository system interactions be measured.

multibarrier. (See **barriers, multiple**.)

natural analogues. Situations in nature that parallel features of man-made systems, such as radioactive minerals or mineral deposits whose migration history over very long times can be determined and used to forecast the potential behavior of chemically similar radionuclides in a disposal facility over a long period of time.

performance assessment. An analysis to predict the performance of a system or subsystem, followed by comparison of the results of such analysis with appropriate standards or criteria. A performance assessment becomes a safety assessment when the system under consideration is the overall waste disposal system and the performance measure is radiological impact or some other global measure of impact on safety. Performance assessment can be used to describe the analysis and comparison of systems at a variety of levels and requirements.

performance confirmation test. Tests carried out at a repository, usually after waste emplacement but prior to license termination, to confirm that the repository is performing as anticipated when emplacement of wastes was authorized.

porosity. The ratio of the aggregate volume of interstices in a rock, soil or other porous media to its total volume.

quality assurance. All those planned and systematic actions necessary to provide adequate confidence that an item, process or service will satisfy given requirements for quality, for example those specified in the licence.

retardation. A reduction in the rate of radionuclide movement through the soil due to the interaction (e.g. by sorption) with an immobile matrix. Soils often retard movement of waterborne radionuclides being carried by fluid. The degree of retardation can be quantified.

safety analysis. The analysis and calculation of the hazards (risks) associated with the implementation of a proposed activity.

safety assessment. An analysis to predict the performance of an overall system and its impact, where the performance measure is radiological impact or some other global measure of impact on safety.

salt. A geological formation resulting from the evaporation of sea water containing mainly halite ($NaCl$) with smaller inclusions or layers of other minerals, usually the chloride or sulfate derivatives of the alkali or alkaline earth elements and clay. Salt formations occur as bedded or domal deposits. In a bedded formation the salt is still in a similar shape as deposited, e.g. roughly horizontal and laterally extensive. Domal salt, which resulted from an uplift of a bedded salt formation through fissures or cracks in the overlying strata with a higher specific gravity, may resemble the structure of a dome.

saturated zone. A subsurface zone in which all the interstices are filled with water under hydrostatic or lithostatic pressure. This zone is separated from the unsaturated zone, i.e. zone of aeration, by the water table.

shaft. In a geological repository, a near vertical access for humans, materials or ventilation from the Earth's surface to underground facilities.

site confirmation. The final stage of the site selection process for a nuclear facility (e.g. a repository). Site confirmation is based on detailed investigations on the preferred site which provide site specific information needed for safety assessment. This stage includes the finalization of the repository design and the preparation and submission of a licence application to the regulatory body.

siting. The process of selecting a suitable disposal site. The process comprises the following stages:
- concept and planning
- area survey
- site characterization
- site confirmation.

sorption. A broad term referring to the interaction of an atom, molecule or particle within pores or on the surfaces of a solid, the 'substrate'. *Absorption* is generally used to refer to reactions taking place largely within the pores of solids, in which case the capacity of the solid to absorb is proportional to its volume. *Adsorption* refers to reactions taking place on solid surfaces, so that the capacity of a solid is proportional to its effective specific surface area. *Chemisorption* refers to actual chemical bonding with the substrate. *Physisorption* refers to physical attraction, e.g. by weak electrostatic forces. An example of the latter process is ion exchange, whereby ions occupying charged sites on the surface of the solid are displaced by ions from solution.

speciation. A term that refers to the chemical form(s), valence and properties of a radionuclide under a particular set of environmental conditions (pH, Eh, ligands ionic strength, redox potential, etc.). Speciation study is valuable because the environmental of a nuclide is largely determined by its chemical form.

spent fuel (used). Irradiated fuel not intended for further use in reactors.

topography. (a) The configuration of (a portion of) the Earth's surface, including its relief and relative positions of its natural and man-made features.
(b) The practice of graphical representation of the same.

tuff. A rock composed of compacted volcanic ash. I is usually porous and often relatively soft. A tuff that has been consolidated and welded together by heat, pressure and possibly the introduction of cementing materials is referred to as welded tuff.

unsaturated zone. A subsurface zone in which at least some interstices contain air or water vapor, rather than liquid water. Also referred to as "zone of aeration". (See: saturated zone).

volunteer site. A location which the local community, government or other responsible body has requested to be considered for development as a disposal facility.

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