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RADIOACTIVE WASTE MANAGEMENT COMMITTEE

Publication of an ISAG Report on In-Situ Research Activities in Member Countries

1. Following its establishment by the RWMC in 1986, one of the first initiatives of the Advisory Group on In-Situ Research and Investigations for Geological Disposal (ISAG) was the preparation of a status report on the in-situ research and investigation activities in Member countries. A pre-publication copy of this status report, entitled "Geological Disposal of Radioactive Waste: In-Situ Research and Investigations in OECD Countries", is attached.

2. The report presents an overview of the status of in-situ research and investigations relevant to the deep geological disposal of radioactive waste, and detailed information on in-situ research, demonstration and investigation programmes in OECD Member countries. The latter is based on information on national programmes provided by Members of ISAG.

3. The report notes that, in recent years, in-situ research and investigations have become integral to the development and demonstration of the concept of deep geological disposal of long-lived radioactive waste. There exists a widespread acceptance of the role played by in-situ facilities in demonstrating the feasibility and safety of proposed disposal methods, as well as confirming the suitability of potential disposal sites. In-situ experiments and investigations are noted to be valuable in increasing the confidence in a proposed method of disposal in four primary ways: (a) development of site characterisation and investigation methods and instrumentation; (b) model validation; (c) provision of data in support of modelling and performance assessment; and (d) demonstration of engineering feasibility.

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4. In conjunction with the publication of the ISAG status report, a proposal has been made to issue a statement from the RWMC which provides a RWMC appraisal of the geological disposal concept. One of the various communication methods being considered for this appraisal statement is to publish it in the form of a Preface to the ISAG status report. This matter will be discussed under Agenda Item 10(b) of the RWMC meeting [see also RWM/DOC(88)7].

5. The Committee is invited to take note of the impending publication of the ISAG status report on in-situ research and investigations in OECD Member countries.

Geological Disposal of Radioactive Waste

IN-SITU RESEARCH AND INVESTIGATIONS IN OECD COUNTRIES

A status report
prepared by

THE NEA ADVISORY GROUP ON IN-SITU RESEARCH
AND INVESTIGATIONS FOR GEOLOGICAL DISPOSAL (ISAG)

1987

NUCLEAR ENERGY AGENCY

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

FOREWORD

The Radioactive Waste Management Committee (RWMC) of the OECD Nuclear Energy Agency (NEA) is an international committee of senior government and industry experts which reviews and directs NEA activities in the field of radioactive waste management. These activities include the promotion of information exchange and dissemination within OECD Member countries, and involve developments in the treatment, storage, transport and disposal of radioactive waste.

In 1986, the RWMC established an Advisory Group on In-Situ Research and Investigations for Geological Disposal (ISAG) to assist in the co-ordination of in-situ research, investigations and demonstration activities in OECD Member countries. The group includes representatives of underground research laboratories and provides a forum for exchanging information and planning joint initiatives at an international level.

One of the first initiatives of ISAG was the preparation of this overview report on in-situ research and investigations in Member countries, based on information on national programmes provided by members of the group. This report explains why deep geological disposal is the most favoured option for the disposal of high-level waste and spent fuel, as well as some alpha-bearing waste. It also provides an overview of the main aims and elements of in-situ research and investigation activities in OECD countries, and of initiatives taken at an international level.

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PREFACE

[RWMC Appraisal of the geological disposal concept;

see SEN/RWM(88)1, Agenda Item 10(b)]

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see SEN/RWM(88)1, Agenda Item 10(b)]

EXECUTIVE SUMMARY

In recent years, in-situ research and investigations have become integral to the development and demonstration of the concept of deep geological disposal of long-lived radioactive waste. This report provides an overview of the main aims and elements of in-situ research and investigation activities in OECD countries, and of initiatives taken at an international level.

The objective of geological disposal is to isolate long-lived radioactive waste from the human environment for a period of time such that any subsequent release of radionuclides from the repository will not result in significant radiation risks. The emplacement of packaged waste at depths on land in sufficiently stable and impermeable geological formation can ensure that the waste will remain immobilized and isolated until radioactive decay has reduced their radioactivity to negligible levels. Different types of geological media are being investigated in OECD countries, both for their general suitability as host formations and as actual repository sites. These potential host formations include clay, crystalline rock, salt/anhydrite, basalt, tuff and schist.

Decisions on the implementation of the geological disposal concept will rely primarily on demonstration of concept feasibility and on the level of confidence in demonstrating the long-term safety. Such a demonstration of feasibility is closely associated with factors that can only be considered in-situ on a host-formation or site-specific basis. This has led several OECD countries to develop specially designed test facilities, or underground research laboratories, in order to accumulate a body of knowledge and data about geological formations being considered as host for disposal repositories.

In-situ experiments and investigations can help increase confidence in a proposed method of disposal in four primary ways: a) development of site characterisation and investigation methods and instrumentation; b) model validation; c) provision of data in support of modelling and performance assessment; and d) demonstration of engineering feasibility.

One use of in-situ research involves the development of methods and instrumentation for specific site investigation and characterisation techniques. Detailed characterisation of any proposed site is necessary to develop site-specific designs and performance assessment models incorporating the appropriate data.

An important activity at the current time involves efforts to validate performance assessment models, ie., comparing site-specific observations with numerical model predictions to test the ability to predict specific phenomena as part of a safety assessment. Since possible variations in conceptual assumptions and parameter values can yield major differences in results, ways of reducing these uncertainties are desirable. Specifically designed model validation experiments are viewed as the best way to achieve this, and can be conducted in three main ways: a) performing laboratory-scale experiments; b) performing large-scale in-situ experiments; and c) studying natural

analogues. In-situ experiments are particularly valuable in addressing complex effects, such as coupled phenomena, waste form and packaging properties, behaviour of backfilling and sealing materials, and mining, thermal and radiation effects on geological media.

In-situ research and investigations are essential for providing data for use in support of modelling and performance assessment. Extensive field studies are being conducted to provide data on a variety of environmental parameters (eg., groundwater flow patterns, nuclide migration rates). Information on interactions between repository environments and waste packages is also being obtained from in-situ studies, as a complement to the traditional laboratory studies. Finally, demonstration of the engineering feasibility of repository design, construction, operation and closure have been conducted, or are planned, at several in-situ research facilities. Such activities are designed to demonstrate that specific technologies exist to implement a given disposal concept at a specific disposal site or in a particular host formation, and also to optimise the components of a disposal system.

Considerable information is provided in Chapter 6 and in Annex II on in-situ research, demonstration and investigation programmes in OECD Member countries. It is clear from these overviews that there exists a widespread acceptance of the integral role played by in-situ facilities in demonstrating the feasibility and safety of proposed disposal methods, as well as confirming the suitability of potential disposal sites.

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1. An aerial photograph and schematic of AECL's Underground Research Laboratory (URL) near Lac du Bonnet, Manitoba, Canada, where scientists are examining groundwater and rock at depth and observing the effects of heat and other stresses.

2. An aerial view of the surface facilities and shaft at the Asse mine in the Federal Republic of Germany, where basic research is being performed on the characteristics and behaviour of rock salt under waste disposal conditions.

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1. INTRODUCTION

Current philosophy in OECD Member countries on the methods and procedures for the disposal of radioactive waste arising from nuclear power generation is based on a substantial body of scientific research and development work conducted since the late 1940s. This is particularly the case for research into the disposal of high-activity, heat-generating waste. It has incorporated the exploratory examination of a wide variety of options, through the evaluation of conceptual designs, to the adoption of preferred concepts and, in recent years, the devotion of considerable effort towards concept implementation. The latter includes the development of procedures for conducting site characterisation and selection investigations, detailed design and feasibility studies and, perhaps of most importance, performing safety assessments. An integral part of each of these is the need to conduct in-situ research, at either generic or actual sites, so that:

a) the appropriate site investigation techniques are available;

b) detailed designs can be demonstrated to meet design standards; and

c) sufficient information is available for performance assessment models to predict post-operational safety with confidence.

This report presents an overview of the status of in-situ research and investigations relevant to the deep geological disposal of radioactive waste, and provides a general outline of recent developments and progress in OECD Member countries.

2. DEEP GEOLOGICAL DISPOSAL

Although most types of radioactive waste could be disposed of using deep geological disposal, more economic alternatives are available for those possessing relatively low levels of short-lived activity. Burial on land at shallow depth in an engineered repository is one such alternative which is currently practiced in several countries. Deep geological disposal, several hundred metres below the surface, is considered to be an appropriate solution for waste arising from nuclear power generation, and which contains long-lived or heat-generating radionuclides [see Figure 1]. In order to fully explain the main aims of disposal of radioactive waste in deep geological formations, it is necessary first to outline the main features of those radioactive wastes requiring deep disposal. These can be broadly classified as high-level waste from reprocessing operations, spent fuel elements (heat-generating) and alpha-bearing waste. As an illustration, Figure 2 presents the dominant radionuclides in spent fuel and in high-level waste [1].

2.1 Objective of Radioactive Waste Disposal

The main issue with respect to the disposal of radioactive waste is how to cope with the presence of long-lived radionuclides in spent fuel, high-level reprocessing waste and other alpha-bearing waste, and with the high radiotoxicity of some of these radionuclides. Therefore, the objective of disposal is to isolate and to immobilize such wastes for a period of time such that any subsequent release of radioactivity to the human environment, as a result of either natural processes or human activities, presents no significant or unacceptable radiological risks.

2.2 The Concept of Deep Geological Disposal

One possible solution for achieving the above-stated objective is deep geological disposal. With this method, the objective of disposal can be achieved by designing multi-component systems, where the waste package, the repository and the specific characteristics of the geological system (geology, geohydrology) provide multiple barriers to radionuclide release and transport. The deep geological disposal concept has the following features:

a) The emplacement of waste deep underground within geological formations of sufficient stability and possessing a sufficiently low permeability to ensure that the waste will remain immobilized and isolated for extremely long time-scales;

b) The safety of deep underground geological disposal relies upon a multi-barrier system and the repository is characterised by a high degree of reliability and predictability. The long-term safety performance of geologic repositories can be assessed using existing scientific techniques and methodologies;

c) Geologic disposal involves an entirely passive system of containment, with no requirement for continuing human involvement for its safety and, particularly, no long-term need for surveillance and monitoring of the site. The geologic barrier is one of the principal elements of the system;

d) The burden on future generations in terms of radiological doses and risks will be minimal, both from the viewpoint of potential migration of radionuclides through the geosphere to the biosphere with time due to natural processes, and from the viewpoint of potential intrusion by man, the likelihood of which depends to some extent on the depth of the repository, and the geological formation chosen to host the repository.

In addition to the above positive features of the geological disposal concept, there is a relative abundance of potentially suitable geological formations and there also exists, through the International Commission on Radiological Protection (ICRP), a suitable basis for judging the acceptability of disposal [2, 3].

The radiotoxic potential of the waste is an additional important feature which must be taken into account when developing a disposal system. Radiotoxicity can be derived from a summation of the comparative level of radioactivity of each radionuclide, relative to the limit on its annual level of intake by ingestion recommended by the ICRP. Figure 3 provides a graphical representation of the radiotoxicity calculated in this way for high-level radioactive waste, compared with the risk potential of an equivalent amount of uranium ore [4]. In the case of spent fuel and high-level reprocessing waste, the heat output may also be important, especially where interim storage is of short duration. Table 1 provides data on the thermal power of spent fuel and high-level waste. From this, it can be seen that, for high-level waste, the period of concern can extend to about 1 million years, a period of time far longer than that considered feasible for maintenance of institutional controls.

It is these two features, radiotoxicity and thermal power, that has led to the concept of the disposal of heat-generating and alpha-bearing wastes into deep geological formations as being widely recognised as the primary method of disposal [eg., 4 - 9]. Several assessments have shown that such a disposal system would, if properly located and designed, provide more than adequate shielding against radiation, as well as absorbing and dispersing heat and providing long-term waste isolation and immobilisation irrespective of human involvement. A deep underground location also decreases the likelihood of inadvertent intrusion by man.

The deep geological disposal concept consists of a system of barriers to the release of radioactivity, as illustrated in Figure 4. This multi-barrier approach relies upon three main elements: the near-field, the geosphere and the biosphere. The near-field constitutes an engineered emplacement and containment system for the waste, the geosphere comprises one or a sequence of geological formations selected so as to provide adequate isolation or containment of any radionuclides released from the waste, while the biosphere represents the accessible environment for man. The latter, while not being a barrier as such, utilises the decrease in concentration due to dilution and dispersion as its contribution to the effectiveness of the disposal system.

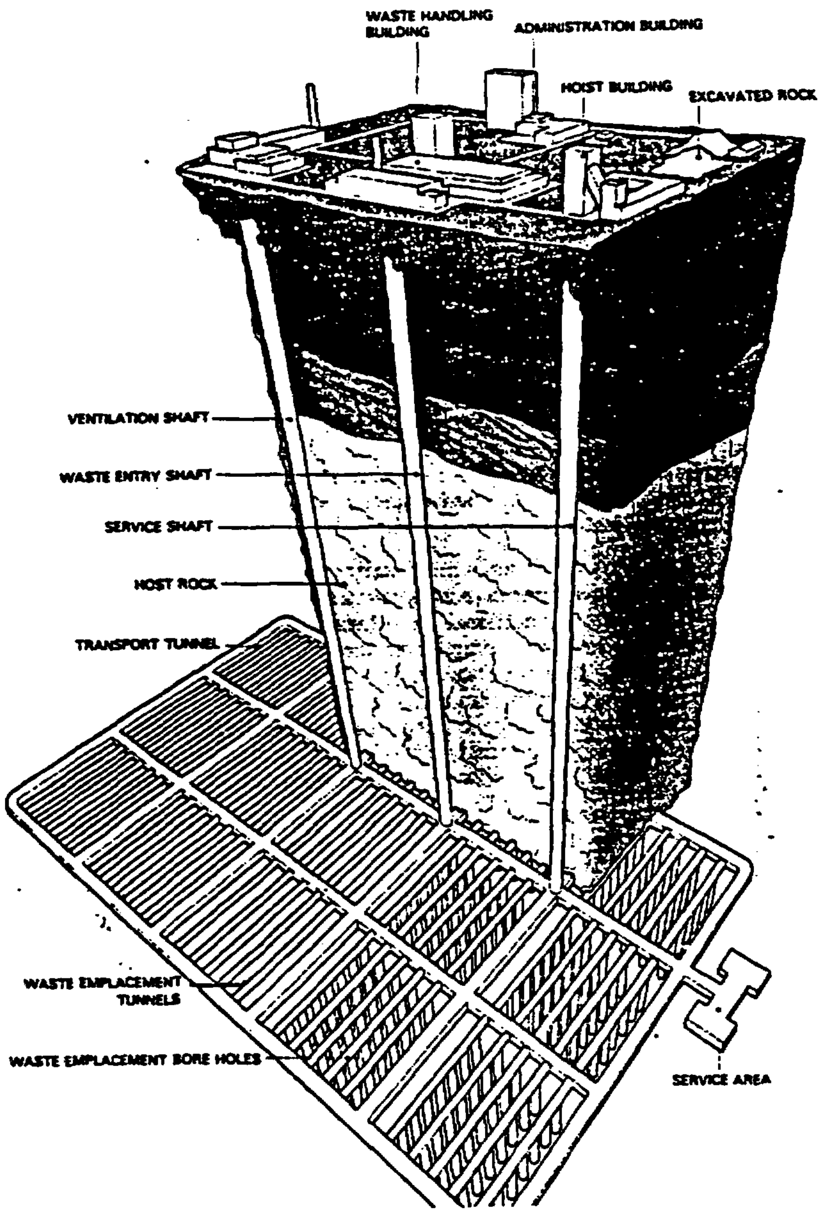


Figure 1. Schematic of One Deep Geological Disposal Concept for Radioactive Waste

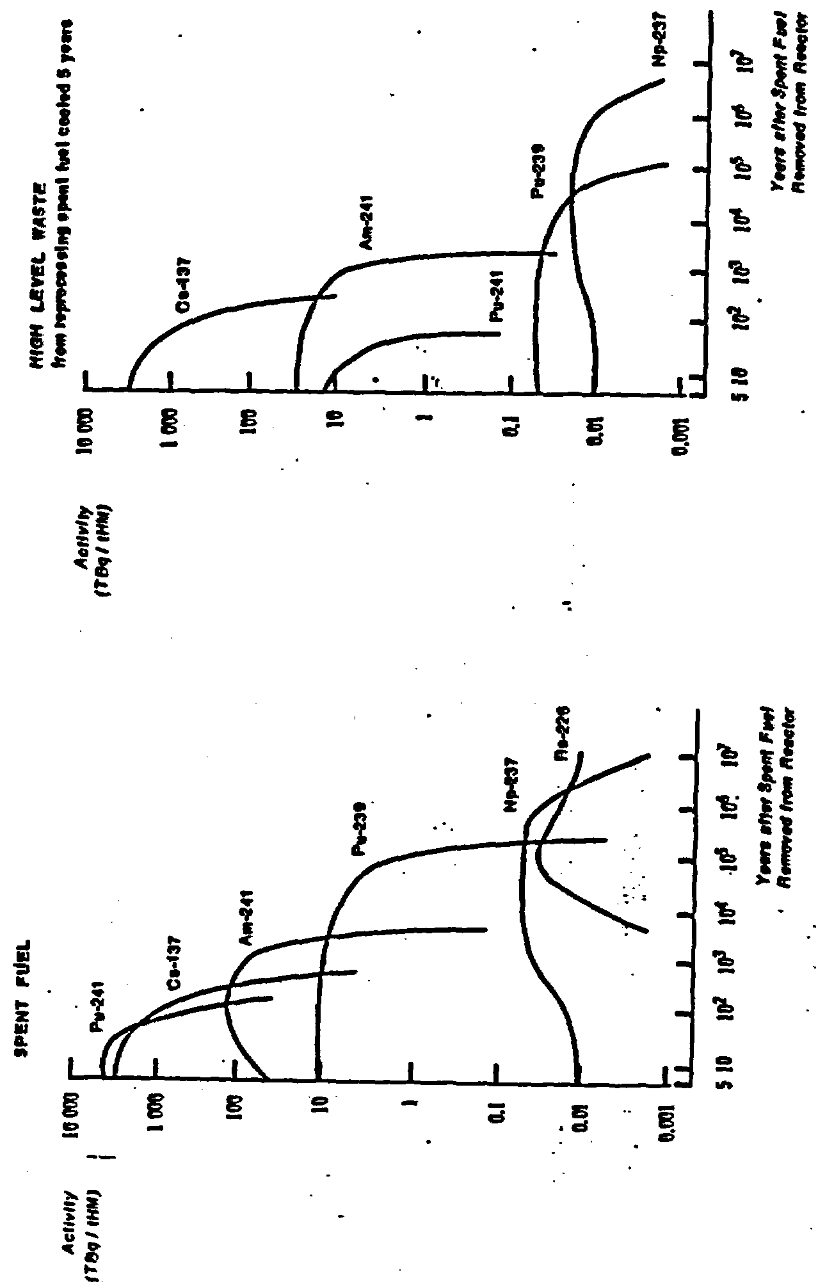


Figure 2. Dominating Radionuclide Inventory in Spent Fuel and in High-Level Reprocessing Waste (Assumes PWR fuel with a burn-up of 33 GW.day/tonne, reprocessed after 5 years of cooling) [1]

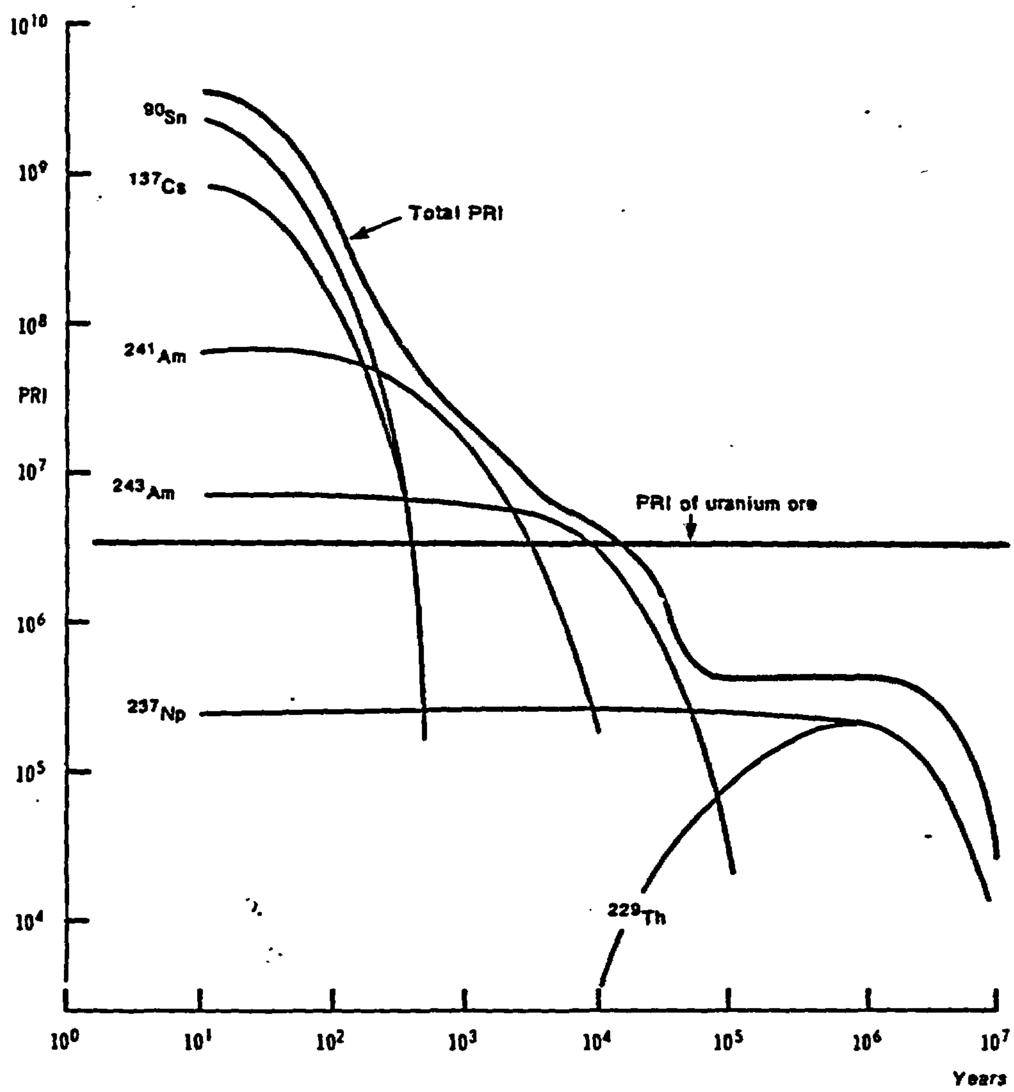


Figure 3. Typical Toxic Potential of Vitrified High-Level Waste from Reprocessing One Tonne of LWR Fuel as a Function of Time, Compared with the Toxic Potential of an Equivalent Amount of a 0.17% Uranium Ore [4]

Table 1

THERMAL POWER OF SPENT FUEL AND HIGH-LEVEL WASTE
AS A FUNCTION OF TIME *
(Watts/tHM of original fuel elements)

Time from Reactor Discharge (Years)	Spent Fuel	High-Level Waste
10	1 290	1 120
100	284	134
1 000	49.4	6.8
10 000	13.5	0.6
100 000	1.0	0.10
1 000 000	0.3	0.102.3

* Data illustrated are for a PWR with a fuel burn-up of 33 GW. day/tonne and subsequent reprocessing after 5 years of cooling [4].

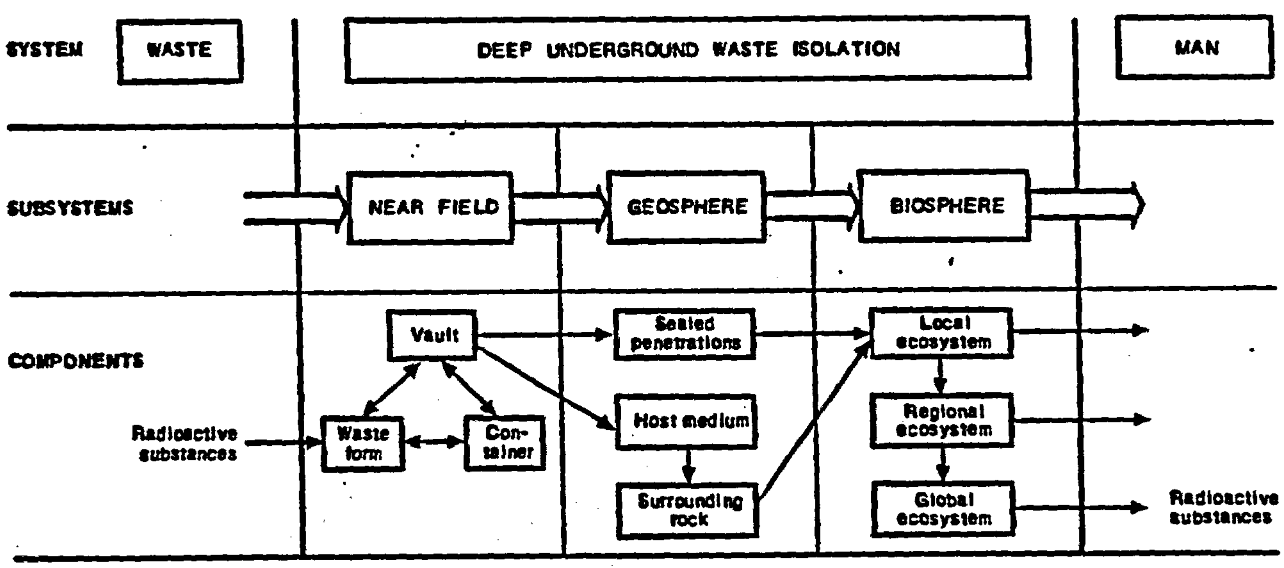


Figure 4. The Deep Geological Disposal System

3. PREFERRED GEOLOGICAL ENVIRONMENTS

Different types of geological formations are being investigated in OECD Member countries, both for their general suitability as host media and as actual repository sites. The choice of geological formation depends strongly on availability within each country. Table 2 provides examples of the main formations being investigated.

Table 2

MAIN CANDIDATE HOST FORMATIONS FOR DEEP GEOLOGICAL REPOSITORIES

FORMATION	COUNTRY
Clay	Belgium, France, Italy, Switzerland (marl), United Kingdom
Crystalline	Canada, Finland, France, Japan, Sweden, Switzerland, United Kingdom
Salt/Anhydrite	Federal Republic of Germany, France, Netherlands, Switzerland, United Kingdom, United States
Tuff	Japan, United States
Schist	France

3.1 Potential Host Formations

3.1.1 Clay

These range from highly consolidated shales to plastic clays. They are attractive as host media mainly because of their low hydraulic conductivity, their chemical reactivity and their plasticity. These attributes restrict the movement of groundwater, attenuate the migration of leachates and enable the host material to seal openings more readily. Another aspect of clays which makes them attractive as potential repository sites is their extensive, predictable occurrence within layered sedimentary sequences.

3.1.2 Crystalline Rocks

Geological media being considered within this category include all extrusive and intrusive igneous rocks (eg., granite, basalt), and high-grade metamorphic rocks (eg., schist, gneiss). They are attractive as host formations because of their high strength and mechanical stability. Where fracturing is infrequent, they also have low hydraulic conductivities. These attributes tend to result in them being considered suitable for the deepest disposal options. As a result, the risk of subsequent human intrusion in crystalline repositories is very low.

3.1.3 Salt

Salt occurs either in the form of bedded salt or salt domes (due to diapirism). In either form, it has a very low permeability coupled with low strength and high thermal conductivity. These properties imply that salt seals openings effectively and should not retain fissuring or faulting to any major extent. It is also capable of dispersing thermal energy from heat-emitting waste more effectively than other candidate host formations.

3.1.4 Other Formations

These include such rock as welded tuff and anhydrite. In general they possess the same characteristics which make the previously mentioned formations attractive, but in a different combination. For instance, welded tuff has the attribute of strength coupled with some of the mineralogical aspects of clays.

3.2 Other Considerations

While the different rock types and formations are attractive for the reasons stated above, each attribute may have limitations. For instance, while lack of strength implies good sealing properties, it may also result in unstable openings. In such a case, any repository would be relatively more costly to construct and operate.

A feature which should be borne in mind in all these descriptions is the inherent heterogeneity of each of these types of formations. This manifests itself differently depending on rock type, and varies from variable fracture frequency in crystalline formations to lenses of different mineralogy in clays.

4. CONCEPT FEASIBILITY AND SAFETY

Decisions on the implementation of the geological disposal concept in OECD Member countries will rely primarily on two factors. First, the demonstration of concept feasibility and, to a lesser extent, cost effectiveness, and second, on the level of confidence in demonstrating the long-term safety. It is these two areas which are currently the subject of a major research effort in OECD Member countries. Two recent NEA reports [4, 7] have outlined what must be demonstrated to establish confidence in the ability to manage high-level waste safely. This Chapter summarises what is meant by "demonstration", and what it is that must be demonstrated, particularly from the viewpoint of in-situ research and investigations.

4.1 The Meaning of Demonstration

It is possible to "demonstrate" in a direct way the satisfactory operation, from the safety standpoint, of a high-level waste solidification facility and a storage installation on a representative scale and over a limited period of time. On the other hand, for waste isolation over the very long term, "demonstration" necessarily has to be approached in a different way, in view of the very long time-scales involved. A direct demonstration of such a disposal system would require practical experience over a period equivalent to that for which the system is designed to contain the radioactivity. Since the objective is to ensure geological isolation and immobilisation over a considerable length of time, it is impossible to envisage a direct demonstration based on any "a posteriori" proof of safety. "Demonstration" of high-level waste disposal must, therefore, be indirect and based on a different approach. The collection of supporting evidence and preparation of a predictive safety assessment can constitute an indirect demonstration of this type, and can provide the degree of confidence required.

In practice, there is only one possible approach to demonstration of the safety of a deep underground disposal facility in a suitable geologic formation. This approach includes two aspects:

a) To prove that the facility can be constructed, operated and closed safely and at acceptable costs, using available mining and engineering experience. This may involve the use of in-situ experimental facilities; and

b) To provide indirect proof by preparing a convincing evaluation of the system's performance and long-term safety on the basis of predictive analyses confirmed by a body of technical and scientific data, much of it derived from laboratory or in-situ experimental work conducted at generic or potential disposal sites.

It is for these reasons that predictive analyses are used as scientific tools to assess the long-term behaviour of individual components of the system, as well as the long-term behaviour of the disposal system as a whole. Supported by results obtained from field experiments, and from other sciences such as geology, hydrology, chemistry and archeology, such "system performance assessments" have the potential to provide indirect proof of the suitability and long-term integrity of the repository systems proposed for the ultimate containment of high-level waste.

4.2 What Must be Demonstrated

To establish confidence in the ability to dispose of high-level waste safely, it is necessary to show that:

a) Repository designs are feasible in engineering terms;

b) Repository operations, backfilling and closure can be achieved in the manner envisaged in the design without compromising the long-term integrity of the repository;

c) Stress fields are sufficiently understood and predictions of below-ground distortions can be made to allow stable structures to be constructed for waste emplacement; and that prediction of the impacts of any changes in stress fields at the repository- host formation interface that will occur after closure can be estimated and assessed;

d) All significant mechanisms by which radionuclides might return to the human environment can be identified and assessed, and are amenable to predictive modelling;

e) Mathematical modelling of repository behaviour and radionuclide transport is feasible, and the results are sufficiently reliable for confidence in their validity;

f) The data needed by the models can be acquired, and are sufficiently reliable for their purpose; and

g) The results of safety assessments for the operating and post-closure periods are consistent with long-term safety objectives.

It can be seen from this list that demonstration of feasibility is closely associated with factors that need to be considered in-situ on a host-formation or site-specific basis. These factors include:

a) Developing methods for detailed site investigations to obtain an adequate understanding of the local geology and hydrology for design and construction, and to provide data for detailed safety assessments;

b) Developing safe handling, transport and emplacement techniques adapted to each type of host formation and disposal concept;

c) Developing techniques for plugging boreholes and shafts, and for sealing excavations; and

d) Conducting specific model validation experiments in order to provide a more realistic and reliable basis for performance assessments, and to increase confidence in the predictive models.

It is this need for site- or formation-specific activities that has led several OECD Member countries to develop specially designed test facilities, or underground research laboratories.

5. UNDERGROUND RESEARCH AND INVESTIGATION FACILITIES

5.1 Aims of In-Situ Research

In-situ experiments and investigations conducted under appropriate conditions can help increase confidence in a proposed method of disposal in four main ways:

a) By providing testing facilities to develop specific site characterisation and investigation techniques as well as experience in using a combination of techniques (methods and instrumentation);

b) By comparing site-specific observations with numerical model predictions to test the ability to predict specific phenomena as part of a safety assessment (validation);

c) By providing data for use in support of modelling and performance assessments; and

d) By evaluating the engineering feasibility of components of repository design, construction, operation and closure (demonstration).

In-situ research can help reduce uncertainties in parameter values used for performance assessments by providing more realistic data. This is important when both generic and site-specific assessments are conducted. If exact data cannot be obtained, in-situ research may also help reduce the range of parameter values used in making probabilistic assessments.

Generic studies of the safety of radioactive waste disposal systems indicate that safe disposal methods are available. However, further work is necessary to make some of the component models more realistic. Primary reliance is placed on predictive mathematical models to represent the various parts of the disposal system, i.e., the vault, geosphere and biosphere, in assessing the radiological consequences of disposal. Such models, in turn, have to be based on laboratory or in-situ experiments in order that confidence can be placed on the results of the assessments. In this respect, natural analogues play an increasingly important role. The interaction between modelling and observations is iterative in the sense that detailed process models will be developed on the basis of observations conducted in the laboratory or field. Such models should then be validated by, first, predicting the performance of specific phenomena, and then comparing this with laboratory or field observations. The detailed models, where necessary, are used to develop simpler models which can be used in modelling complete disposal systems.

In addition, further effort has been devoted, where possible, to demonstrating concept feasibility by conducting full- or reduced-scale testing of particular components of the disposal system. This is particularly the case for the vault or near-field environment, which is heavily dependent on engineering design involving civil engineering and geotechnical evaluations.

A further aspect of concept feasibility and assessment is the development of techniques to conduct field investigations on both a regional interest, little effort has been devoted to developing methods for measuring their properties and extent. Where previous studies have been conducted, the data produced is often inappropriate or unreliable. Hence, new techniques have had to be developed for site characterisation and evaluation.

A listing of several underground research laboratories is provided in Table 3. The number of such facilities indicates the widespread acceptance by OECD Member countries of the benefits of developing in-situ facilities, by either establishing a test facility at a generic site primarily to develop methodologies and test engineering designs, or on sites that are potentially suitable as disposal facilities.

Table 3: PAST AND PRESENT IN-SITU RESEARCH FACILITIES

GEOLOGICAL FORMATION	COUNTRY	TEST FACILITIES AT DEPTH	IN-SITU STUDIES AT POTENTIAL SITES
		LOCATION	LOCATION
<u>Crystalline Rocks</u>:			
Granite	Finland		
	Canada	Lac du Bonnet	
	France	Fanay-Augères Mine	Neuvy-Bouin (1)
	Japan	Kasama	
	Spain		
	Sweden	Stripa	
	Switzerland	Grimsel	
	UK		
	USA	Climax Mine	
Schist	France		Montrevel (1)
Gabbro	Sweden		
	Canada		
Diabase	Japan		
Basalt	USA	NSTF Hanford	Hanford
Tuff	USA	NTS	Yucca Mountain (1)
	Japan		
<u>Evaporites</u>:			
Salt Diapirs	France		Segré (1)
	F.R. Germany	Gorleben	Gorleben
	F.R. Germany	Asse	
	Netherlands		
	USA	Avery Islands	
Bedded Salt	Spain		
	USA	Lyons	Deaf Smith County
	USA	WIPP	WIPP
Anhydrite	Switzerland	Felsenau	
	USA		
<u>Other Sedimentary Rocks</u>:			
Clay	Belgium	Mol	Mol
	France		Montcornet-Sissone (1)
	Italy		
	Switzerland		
	UK		
Shale	USA		
	Japan		
	Spain		
Mixed Marine Sediment Sequence	F.R. Germany	Konrad (2)	Konrad

<u>Notes</u>: (1) Proposed location. (2) Low and intermediate waste only.

5.2 IN-SITU RESEARCH AND INVESTIGATIONS

5.2.1 Development of Site Characterisation and Investigation Methods and Instrumentation

It is necessary to conduct a detailed characterisation of any proposed site for a deep disposal facility in order to develop site-specific designs and performance assessment models incorporating the appropriate data, and to confirm that no significant geological features remain undetected. The geological, hydrological, geochemical and.geomechanical features exhibited by candidate sites that are relevant to design and safety analyses often require the development of specific site investigation techniques. For example, to retain as far as possible the integrity of potential sites, investigation techniques should, where possible, be non-destructive remote techniques. It is for this reason that, for example, seismic and radar methods are being specifically adapted for investigating potential disposal sites.

5.2.2 Model Validation

An important activity at the current time involves the validation of models to be used in performance assessments of waste disposal systems. Recent studies involving global performance assessments of potential disposal concepts, such as the Swedish KBS-3 [10] and the Swiss Project Gewähr [11], have shown that possible variations in conceptual assumptions and parameter values can yield major differences in the results. For this reason, it is necessary to seek ways of reducing the uncertainties arising from poor conceptual understanding of relevant processes, and to search for ways to provide more accurate data. Recent studies [12] have determined that the best way to achieve this may be to conduct specifically designed model validation experiments. These can be conducted in three main ways: a) performing laboratory-scale experiments; b) performing large-scale, in-situ experiments; and c) studying natural analogues.

A conceptual model, and the corresponding numerical model, is said to be validated when it is confirmed that the conceptual model and the computer code provide a sufficiently good representation of the actual processes occurring. Validation is conducted, therefore, by comparison of mathematical predictions with field observations and experimental results [13]. If this is not possible, for example, due to the long time-scales over which predictions must be made, then peer review procedures based on current experience and historical evidence need to be used.

Several initiatives have been taken at the national and the international level to help co-ordinate efforts devoted to validating performance assessment models. Notable among these is the INTRAVAL project initiated by the Swedish Nuclear Power Inspectorate (SKI). The objective of the INTRAVAL project is to evaluate the validity of different models aimed at describing the transport of radionuclides in the geosphere.

An illustration of the approach adopted in validating performance assessment models is provided in Figure 5. This iterative approach involves the following general steps: a) develop a conceptual model of a specific part of the disposal system, e.g. the behaviour of the backfill material; b) develop a numerical code; c) extract from existing literature the necessary input parameters; d) make predictions; e) compare these predictions

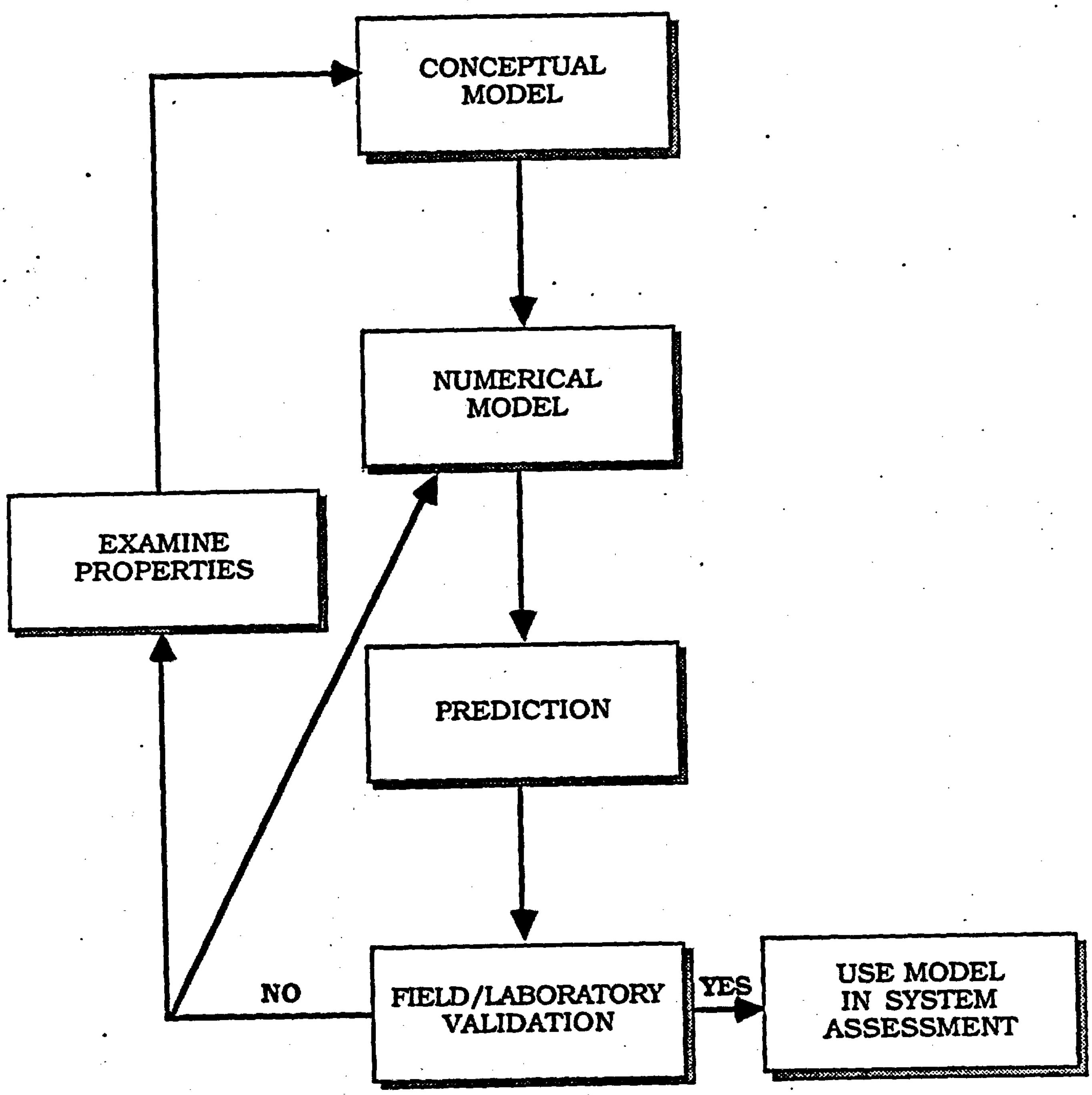


Figure 5. Iterative Approach to Model Validation

with laboratory or field observations; f) if these agree sufficiently, consider the model to be valid and use it as part of the overall system performance assessment; g) given that agreement between model predictions and observations is a necessary but not complete condition of validation, other considerations, such as the uniqueness of agreement (i.e., could other models also simulate the observation?) and completeness with respect to relevant processes and long time-scales, must also be taken into account; h) if the predictive models are not considered to be sufficiently validated, they should be further improved and compared with laboratory or field observations until considered to be satisfactorily validated.

It is recognised that complete validation of performance assessment models can never be achieved due to the long time-scales involved. Rather, the concept of model validation should be interpreted as an iterative process, with the objective being to achieve reasonable assurance that the models give a sufficient representation of important processes and hydrogeological features.

The types of phenomena that can be treated in this way are numerous, although a major difficulty exists in conducting validation experiments on processes involving long time-scales. In-situ experiments are particularly valuable in addressing coupled effects, such as thermal-mechanical-chemical-hydraulic phenomena, or the following specific areas of study:

a) Waste form degradation;
b) Corrosion of canister and overpacks;
c) Behaviour of backfilling and sealing materials;
d) Radiation effects on host medium;
e) Thermal effects on host medium;
f) Chemical and mineralogical changes/reactions;
g) Mechanical effects; and
h) Hydrological changes.

Validation of specific parts of waste repository systems with natural or man-made analogues may be possible if differences in release, transport and biological uptake mechanisms can be properly taken into account and all necessary information is available on sufficient levels. All the field data that are available from ancient artifacts, observations of buried glass blocks in Canada, the Oklo natural fission reactor in Gabon, the thorium deposit at Morro do Ferro, Brazil, and uranium ore deposits at Alligator Rivers in Australia and Cigar Lake in Canada, demonstrate that leaching rates of such materials under natural conditions tend to be much lower (sometimes several orders of magnitude) than is indicated by laboratory measurements [14]. A concerted effort is currently being made to use natural analogues for the validation of specific process models. The Natural Analogue Working Group established by the Commission of European Communities (CEC) has helped to co-ordinate research in this area [15, 16].

5.2.3 Data in Support of Modelling and Performance Assessment

Substantial scientific information supporting repository models is available, and the amount of this information continues to grow. Most of the information is obtained from laboratory studies, but an increasing amount is being obtained from larger scale, in-situ tests, and from observations of natural analogues. Laboratory studies have provided much information that is essential to an understanding of the interactions between repository environments and components of the waste package. Extensive field studies have been conducted to provide data on a variety of environmental parameters, such as groundwater flow patterns and radionuclide migration rates.

In-situ investigations at potential sites will play an essential role in providing reliable data for use in performance assessment. This will include surface observations on a regional scale, and detailed observations at a proposed site using boreholes and specifically designed in-situ testing.

5.2.4 Demonstration of Engineering Feasibility

Demonstrations of the engineering feasibility of construction, operation and closure of deep geological repositories have been conducted, or are planned, at a number of in-situ research facilities. The aim of each of these activities is to demonstrate clearly that specific technologies exist to implement a chosen disposal concept at a specific disposal site or in a particular host rock, and also to optimise the components of a disposal system. Examples of such demonstration activities include conducting actual emplacement of waste in a test site to demonstrate operational capabilities, observing the behaviour of backfill and sealing materials, and testing various excavation methods for shafts, tunnels and underground openings to examine the response of the rock mass to excavations so as to minimise rock damage and not hinder the containment provided by the host formation.

6. NATIONAL AND INTERNATIONAL IN-SITU RESEARCH AND INVESTIGATION PROGRAMMES

6.1 INTRODUCTION

The following Sections provide general overviews of in-situ research, demonstration and investigation programmes in OECD Member countries. It is clear from these overviews that there exists a widespread acceptance of the integral role played by in-situ facilities in demonstrating the feasibility and safety of proposed disposal methods, as well as confirming the suitability of potential disposal sites.

6.2 BELGIUM

INSTITUTIONAL FRAMEWORK

The Belgian researh and development programme on geological disposal of radioactive waste was initiated in 1974. The national agency NIRAS/ONDRAF was established in 1982 to take responsibility for implementing the current and long-term policy for radioactive waste management. Since 1983, the multi-year national programme for research on geological disposal has been implemented jointly by NIRAS/ONDRAF and SCK/CEN.

DISPOSAL CONCEPTS AND APPROACH

The main objectives of the Belgian R&D programme are:

a) To demonstrate the technical feasibility of geological disposal in a deep argillaceous formation; and

b) To assess the safety of the concept to dispose of conditioned radioactive waste in such formations.

These objectives are being pursued through an extensive in-situ research programme at an underground laboratory (Figure 6) constructed in clay (the Boom clay formation) at the site of the Belgian nuclear research establishment (SCK/CEN) at Mol, Belgium [1, 2, 3, 4, 5].

Specific in-situ investigations on corrosion behaviour of various structural materials and waste forms are being conducted under representative conditions (Figure 7). Important contributions have been made on the assessments of the hydrology of the clay body and the adjacent layers, the geotechnical aspects of constructing galleries in clay and radionuclide migration in clay (Figure 8).

Preliminary results of these investigations were very encouraging, and the decision was made to extend the underground laboratory to a pilot-size demonstration facility. The HADES (High Activity Disposal Experimental Site) Project is being developed within the framework of the CEC research programme on radioactive waste management and disposal.

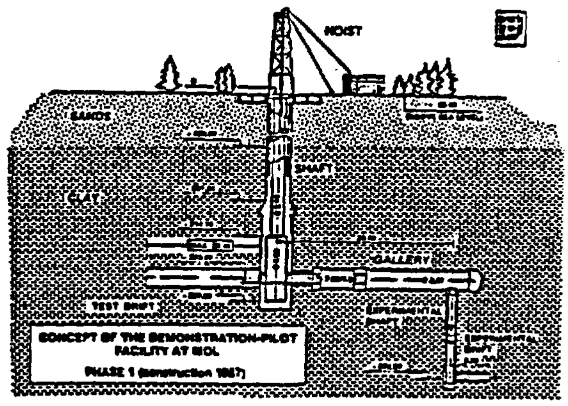


Figure 6. Demonstration/Pilot Facility, Mol

IN-SITU RESEARCH AND INVESTIGATIONS

In-situ investigations and testing in the underground facility of the HADES Project are organised according to the following structure:

a) In-situ research, aimed at improving technology related to in-situ investigation and observation, and at determining various in-situ characteristics related to:

   i) corrosion in an argillaceous environment of various waste package components (immobilisation matrices, container and canister materials) and structural components (concrete, cast iron, etc.);

   ii) geochemistry and migration of radionuclides, corrosion products, radiolysis products and alteration products in clay;

   iii) geomechanics in relation to underground structures; and

   iv) backfilling and sealing of open spaces and voids.

   Most of this research has been conducted since 1980 in the cast-iron-lined underground gallery, called the "laboratory".

b) In-situ tests aimed at the direct demonstration of:

   i) mining capabilities and behaviour of mined structures in simulated near-field conditions of a repository;

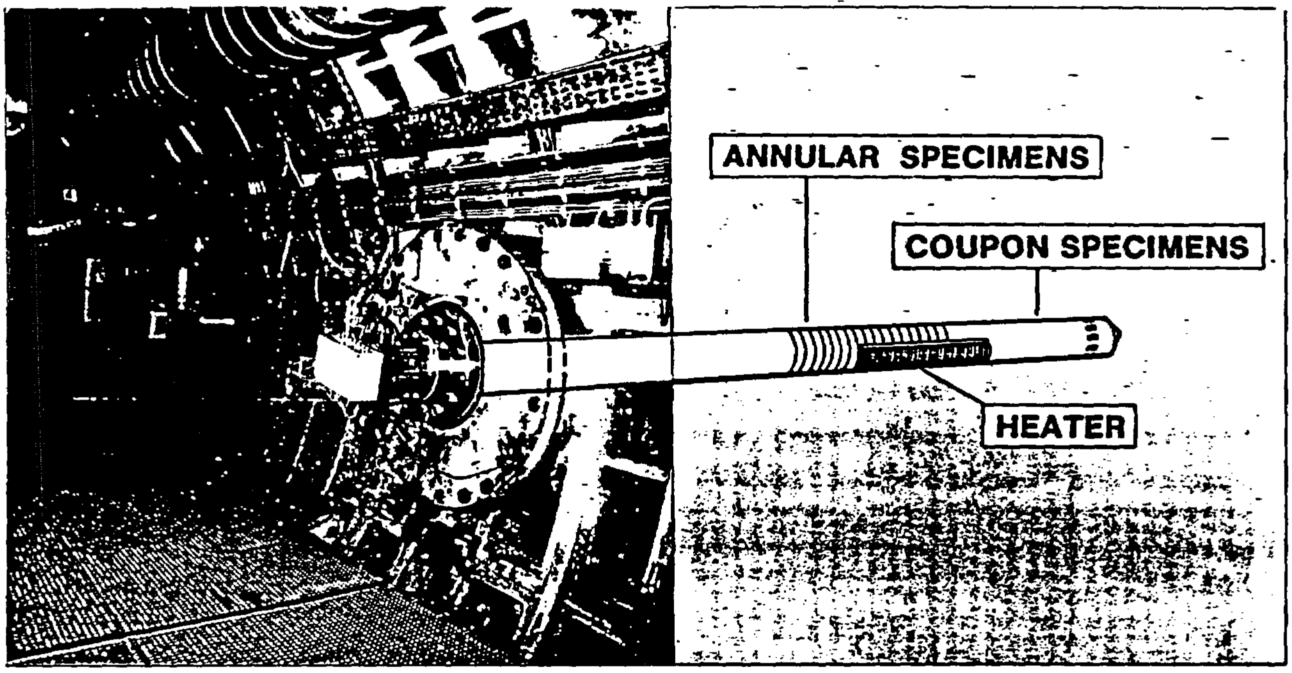


Figure 7. In-Situ Corrosion Experiment, Mol

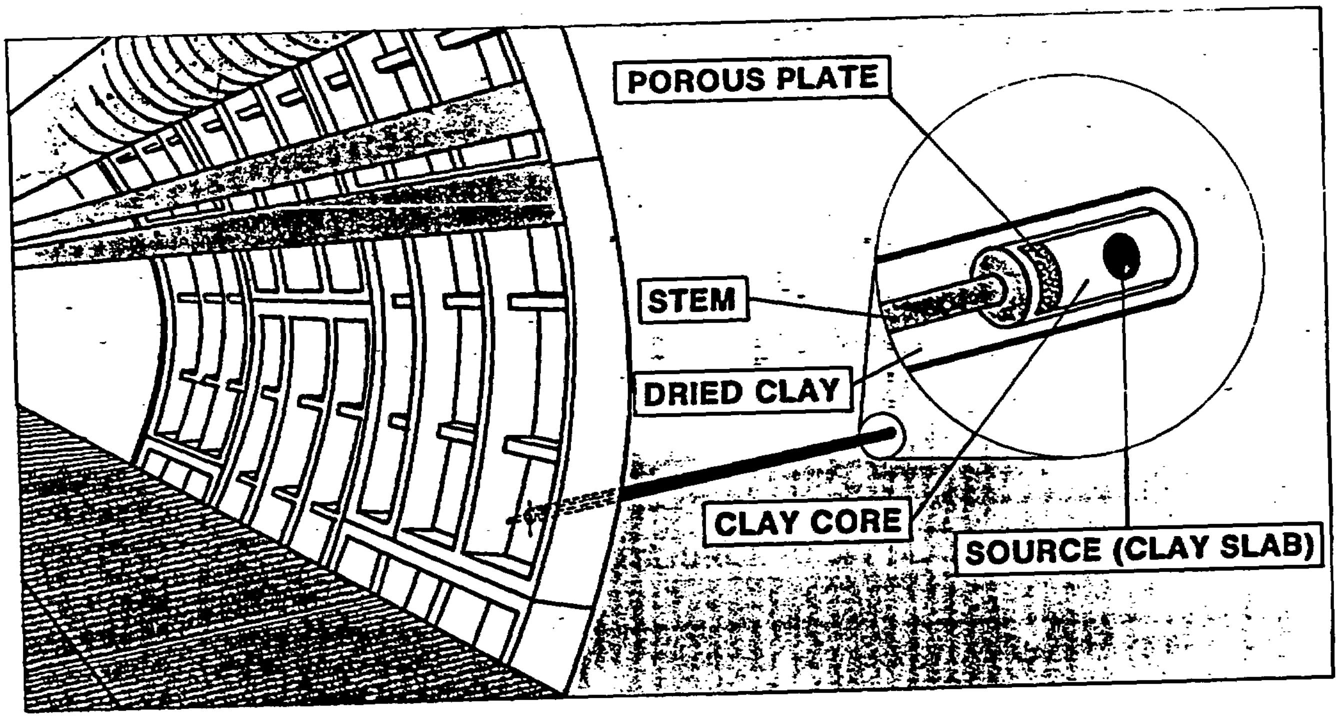


Figure 8. In-Situ Migration Test, Mol

ii) near-field effects of combined heating and radiation;

iii) interactions between the different waste package components; and

iv) backfilling and emplacement capabilities, and backfill behaviour.

These tests will be performed in the underground gallery, called the "test drift" (1987-1994).

c) Eventually, post-development tests requiring the construction of a larger underground facility for direct, full-scale demonstration with real waste types. This phase will be started after approval by the appropriate authorities (scheduled to be performed until 1995).

Bilateral agreements between SCK/CEN and ANDRA of France incorporate in-situ geotechnical investigations and a full-scale test on gallery construction according to the convergence/confinement principle. Presently, a bilateral agreement between SCK/CEN and PNC of Japan foresees common in-situ research on migration processes in the argillaceous environment.

6.3 CANADA

INSTITUTIONAL FRAMEWORK

In April 1981, the Canadian government approved a 10-year generic research and development programme, the Canadian Nuclear Fuel Waste Management Program (CNFWMP), with the following objectives [1]:

a) To assess the environmental and safety aspects of the concept of isolating immobilised fuel waste by deep underground disposal in plutonic rock;

b) To develop the technology for storage, transportation, immobilisation and disposal to the extent necessary; to provide data for the concept assessment; to design facilities; to specify operating processes and procedures; and to demonstrate that practical technology is available for implementation of the concept;

c) To establish the requirements, equipment and procedures for the site-characterisation and site-selection processes for the next phase of nuclear fuel waste management; and

d) To develop the basis for public acceptance and support through scientific and regulatory review, and public information, interaction and participation.

DISPOSAL CONCEPTS AND APPROACH

Atomic Energy of Canada Limited (AECL) was assigned responsibility for programme objectives (a) and (c) and for the immobilization and disposal aspects of objectives (b) and (d). The disposal concept being studied by AECL is a multiple-barrier system comprising a low-solubility waste form, a corrosion-resistant container, low-permeability clay-based buffer and backfill, and a stable geosphere that separates the emplaced waste from the biosphere. Research and development activities are in progress in all areas of the conceived disposal system to develop methods for establishing the radionuclide isolation capabilities of each barrier and to assess the performance of the entire multiple-barrier system.

IN-SITU RESEARCH AND INVESTIGATIONS

One focus of geoscience research is the Underground Research Laboratory (URL) located east of Lac du Bonnet, Manitoba, on a portion of a large granitic pluton, the Lac du Bonnet batholith (see Figures 9 and 10). The URL is a unique geotechnical research facility because it is being constructed in a previously undisturbed portion of the pluton that was well characterised before construction began, and most of the shaft and all potential testing areas are below the water table. The URL provides a representative geological environment in which to conduct a wide variety of geoscience research and development programmes [2].

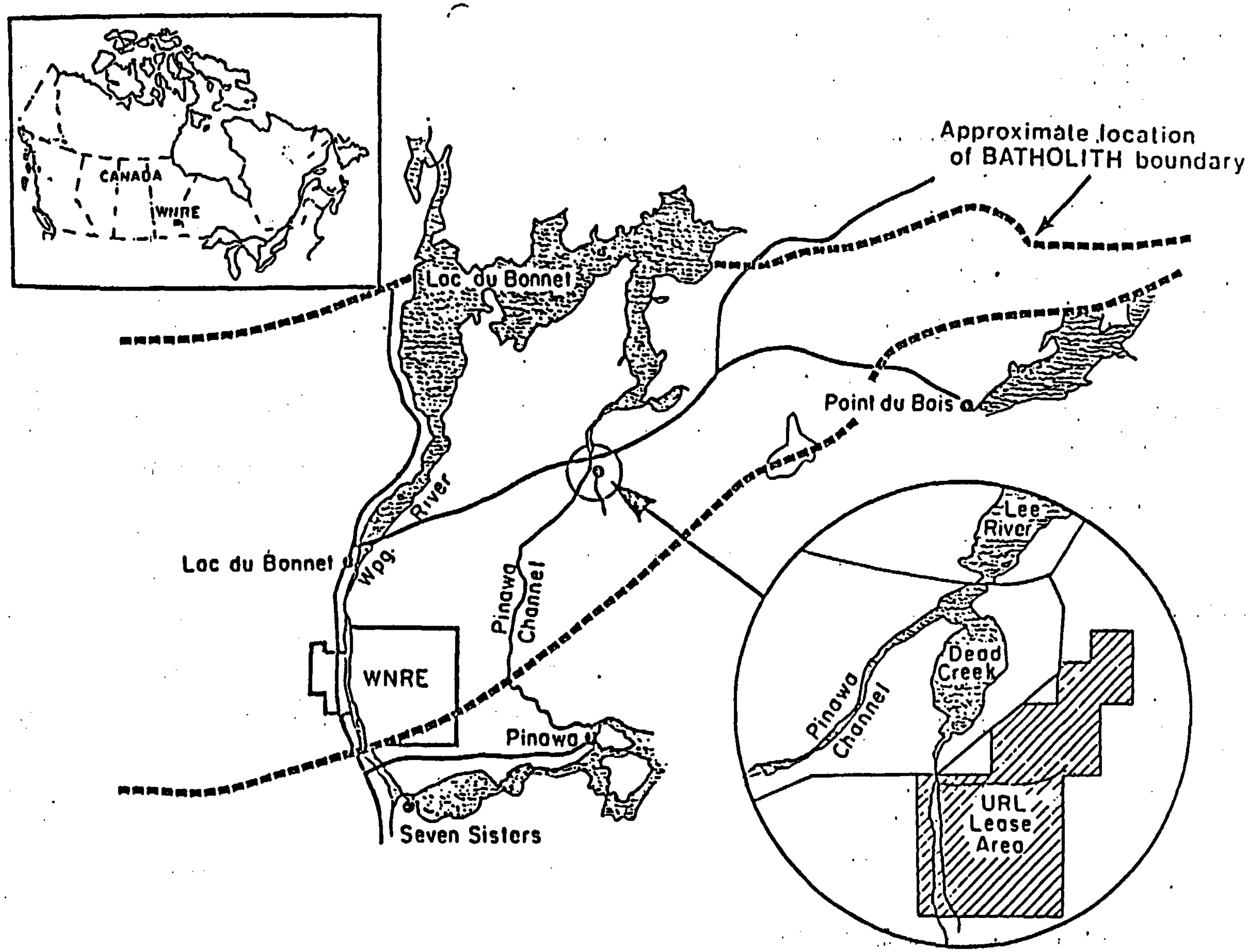


Figure 9. Location of the Underground Research Laboratory (URL)

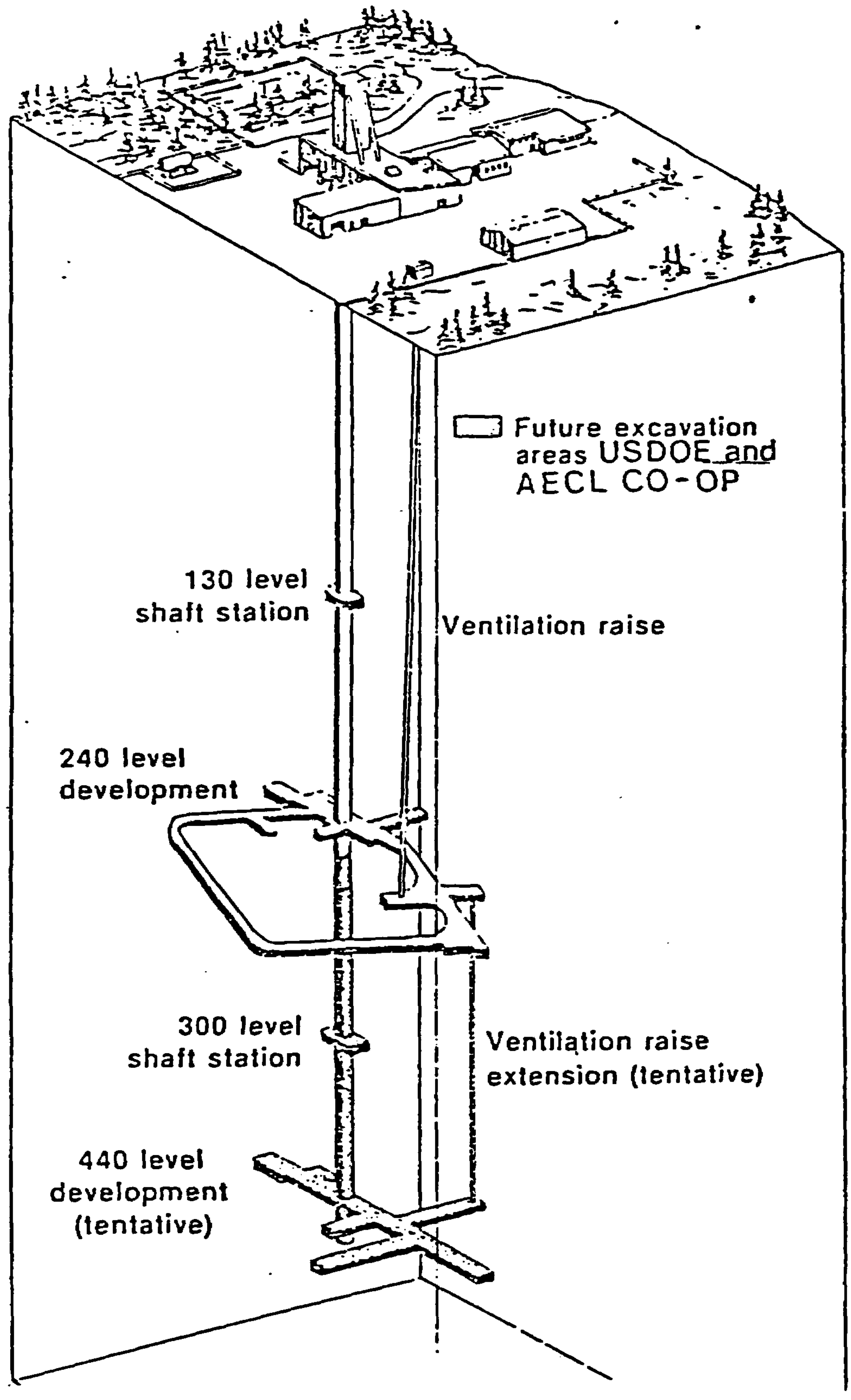


Figure 10. URL Facility

Current Plans

The general objectives of the URL programme can be summarised as:

a) To assess airborne, surface and borehole survey techniques for characterisation of the subsurface geological and hydrogeological environment in plutonic rock;

b) To assess the changes in physical and chemical conditions in the rock mass and groundwater caused by excavation of the URL; and

c) To perform experiments relevant to assessing the performance of the system being considered in Canada for nuclear fuel waste disposal.

The project comprises experimental and development activities and generally progresses from site evaluation, through facility development and characterisation, to the post-development or operating-phase experiments. These phases have been implemented or are planned on the following schedule:

a)	Site Evaluation and Monitoring	1980 to 2000
	- Site Evaluation	1980 to 1984
	- Site Monitoring	1984 to 2000
b)	Facilities Development and Characterisation	1982 to 1989
	- Surface Facilities Development	1982 to 1986
	- Shaft Excavation to 255 m	1984 to 1985
	- 240-Level Development and Characterisation	1985 to 1989
	- Characterisation and Grouting of Fracture Zone No. 2 ..	1986 to 1989
	- Shaft Excavation to 465 m	1987 to 1988
	- 440 Level Development and Characterisation	1988 to 1990
c)	Operating Phase Experiments	1989 to 2000

Recent In-Situ Studies

The in-situ studies at the URL began with an application of site evaluation methods prior to underground construction in order to assess models for predicting groundwater system response due to shaft excavation. [See (1) URL Drawdown Experiment, in Annex II].

During development of the URL underground access and testing areas, a thorough programme of characterisation is being undertaken to characterise the environment available for experiments, to determine the large-scale material properties and to study the hydrogeological/geomechanical effects of excavation on the rock mass. The characterisation activities study the geological [7], geomechanical [8] and hydrogeological conditions surrounding the excavations. Instruments are being developed, modified and assessed in all programmes [3, 9]. [See (2) Excavation Effects Studies, in Annex II].

Major fracture zones are prevalent throughout the Canadian Shield and are the dominant groundwater flow paths. In the URL, the hydrogeological, chemical and geological characteristics of a major fracture zone are being studied. Methods of sealing these zones in a controlled manner with grouts are also being developed and tested. [See (3) Characterise and Grout a Major Sub-horizontal Fracture Zone, in Annex II].

When the underground access to the URL testing levels has been completed and the characterisation activities have provided a sufficient data base with which to select sites and design, large-scale multidisciplinary experiments will be conducted. These experiments are now being planned. There are other concepts for experiments being considered that are not being formally planned and which therefore are not included in Annex II. These include studies of the mechanical, hydraulic and chemical migration parameters associated with major zones of moderately and highly fractured rock, and study of full-scale simulations of part of a repository emplacement room including backfill.

6.4 FEDERAL REPUBLIC OF GERMANY

INSTITUTIONAL FRAMEWORK

In the Federal Republic of Germany, research on radioactive waste management has been divided into basic and site-specific research and development. The division depends on whether a site has been pre-selected for a radioactive waste repository (all investigations as well as in-situ experiments are useful for site confirmation), or whether a site is being used as a research and development facility for basic research on formation properties and for development of investigation and disposal techniques only.

The basic research and development programme on radioactive waste disposal is supported and financed by the Federal Minister for Research and Technology. For the performance of in-situ tests, the Gesellschaft für Strahlen und Umweltforschung mbH (GSF), the major research centre for environmental sciences, owned by the Federal Republic and the Federal State of Bavaria, operates the Asse Salt Mine as the only underground laboratory and testing site in Germany. The Asse Mine is, in principle, available for joint research activities to all German institutions working in the field of geological disposal.

Site-specific research and development work, as well as the operation of radioactive waste repositories, is, according to the German Atomic Energy Act, the responsibility of the Federal Government represented by the Federal Minister for Environment, Nature Conservation and Reactor Safety. On behalf of the Federal Government, the Physikalish-Technische Bundesanstalt (PTB) acts as the applicant for radioactive waste repositories and is responsible for the necessary site investigations. Ultimately, the PTB will be responsible for the operation of the repositories. The Deutsche Gesellschaft zum Bau and Betrieb von Endlagern mbH (DBE), located in Peine (Lower Saxony), has been established for the construction and operation of the radioactive waste repositories.

DISPOSAL CONCEPTS AND APPROACH

The radioactive waste disposal concept in the Federal Republic of Germany is based on the use of three sites for different purposes [1]. These sites are Gorleben, the Asse Mine and the Konrad Mine.

Currently, the overall development of the Gorleben site and the Konrad Mine are being managed by PTB. At both sites, only site-specific investigations aimed at data collection and proof of repository safety are being performed. In-situ tests related to basic research and development, e.g., development of investigation methodologies and disposal techniques, are excluded.

Such research and development activities regarding the disposal of radioactive waste in salt formations are being performed in the Asse Mine. Since only proven technologies can be licensed for any commercial repository, the Asse Mine is being used particularly for conducting the necessary in-situ tests and full-scale demonstrations. Licensing of waste disposal operations in the Federal Republic of Germany is based on the preconditions that site investigations have shown favourable geological conditions and that in-situ tests in the Asse Mine have demonstrated suitable disposal techniques. This includes the determination of parameters and the modelling of processes, which are required for the safety performance assessment of the Gorleben site.

IN-SITU RESEARCH AND INVESTIGATIONS

Gorleben Site

The salt dome of Gorleben is being proved for its suitability for the disposal of all kinds of solid waste by in-situ investigations. Following an extensive drilling campaign and a hydrogeological survey, two exploratory shafts are being sunk. Upon completion of these shafts, a comprehensive underground site investigation programme will be initiated.

The following schedule has been adopted for development of the respository [2]:

a)	Sinking of shafts and underground development and exploration	Mid - 1990s
b)	Completion of safety report and delivery to licensing authority	1 year
c)	Licensing	1 year
d)	Construction of repository	4 years
e)	Start of disposal operations	2000 - 2010

Konrad Mine

After completion of a feasibility study involving geological, hydrogeological, rock mechanical and seismic research work as well as in-situ tests, a site confirmation programme was initiated in 1982. This work has been completed in July 1986, and all licensing application documents for the proposed repository for non-heat-generating waste have been submitted to the licensing authority. A decision on licensing is expected in 1989.

The following schedule has been adopted for development of the repository [3]:

a)	Expected issuance of license	1989
b)	Alteration of Konrad Mine and construction of disposal facilities	3 years
c)	Start of disposal operations	Early 1990s

Asse Mine - Underground Test Site

The Asse Mine is the only pilot radioactive waste repository and underground research facility in the Federal Republic of Germany. In this former salt mine, basic research work is being performed on the characteristics and the behaviour of rock salt under conditions of disposal of different types of radioactive waste, particularly high-level waste. The data measured thusfar have been used for modelling of a high-level waste repository to be built in an exploited salt dome. The techniques developed along with the underground disposal of low- and intermediate-level waste have been integrated into the Gorleben disposal concept. Currently, the Asse Mine is being used for advanced in-situ tests on critical aspects of geological disposal, particularly the inter-relation of waste and rock salt and its consequences for the long-term safety of the repository. In addition, advanced technologies for waste disposal as well as for construction, operation, backfilling and sealing of a repository are being developed and demonstrated. Most of the in-situ tests are part of the R&D programme of the GSF. Some tests are being performed by BGR (Bundesanstalt für Geowissenschaften und Rohstoffe), DBE (Deutsche Gesellschaft zum Bau und Betrieb von Endlagern), KfK (Kernforschungszentrum Karlsruhe) and KfA (Kernforschungsanlage Jülich). The GSF participates in a variety of ways in all of these tests.

The in-situ tests in the Asse Mine are being financed by the Federal Minister for Research and Technology (BMFT). Some tests are being performed under contract with, and with contributions by, the CEC. In the HLW test disposal, ECN (Netherlands Energy Research Foundation) performs a substantial part of the research programme. Participation of ANDRA of France is also envisaged. A bilateral agreement between the BMFT and the US Department of Energy provides for several joint R&D projects.

6.5 FINLAND

INSTITUTIONAL FRAMEWORK

According to the basic principle concerning nuclear waste management, each producer of nuclear waste is responsible for the safe handling and management of the waste as well as for the financing of these operations. This responsibility includes final disposal, and hence no governmental disposal organisations are foreseen. Utilities are obliged to levy funds for waste management during the operation of the power plants.

DISPOSAL CONCEPTS AND APPROACH

In-situ research and investigations in Finland have been conducted at two sites for low- and intermediate-level waste disposal, and at two sites for high-level waste disposal [1].

Repositories for low- and intermediate-level waste (reactor waste) disposal will be constructed between 1988 and 1992, and will commence operations in 1992. The nuclear power plant sites of Olkiluoto and Loviisa will be the sites for low- and intermediate-level waste disposal. At Olkiluoto, the waste will be bitumenized and disposed in steel drums in 35-m high silos at a depth of 100 m. In Loviisa, the waste will be cast in concrete cubes and placed in caverns at a depth of 120 m. The construction of the repository in Olkiluoto will be started in 1992.

The site for high-level waste disposal will be selected by the year 2000. The chosen site will be investigated and the facility designed between 2000 and 2010, with the repository being constructed between 2010 and 2020, and operational by 2020. Post-operational closure of the repository is anticipated between 2050 and 2060.

In April 1987, five sites were selected for preliminary investigations. Field surveys were started on two sites. Preliminary investigations will be conducted by the end of 1992. A few sites will be investigated in more detail during 1993-2000 [2].

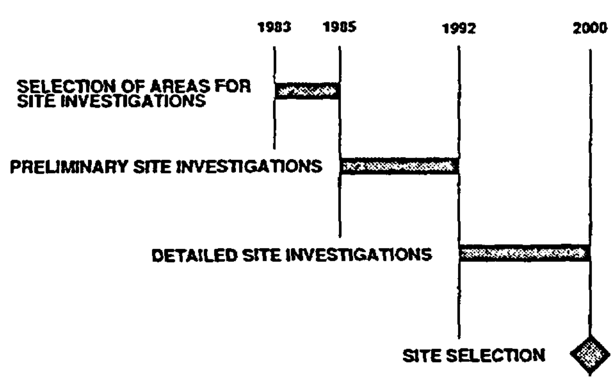


Figure 11. Time Table for the Investigations into Disposal of Spent Nuclear Fuel

IN-SITU RESEARCH AND INVESTIGATIONS

Low- and Intermediate-Level Waste

A comprehensive drilling programme has been conducted at both the Olkiluoto and the Loviisa sites. In addition to core logging, a number of measurements have been conducted: water sample analyses; temperature logs; caliper logs; and inclination measurements. As well, geophysical borehole surveys have been conducted, including resistivity surveys, sonic logs and radiometric surveys. Cross-hole seismic surveys have been conducted between boreholes up to 200 m apart.

Spent Nuclear Fuel

As the first stage (Figure 11) of the site investigations in 1983, 327 bedrock blocks, each about 100 square km in area, were selected. A site selection process resulted in the selection of 102 investigation areas at the end of 1985, each between 5 and 10 square km in area.

In the spring of 1987, five sites were chosen for preliminary investigations. The location of the chosen sites is presented in Figure 12. On two of the sites selected, Romuvaara (Kuhmo) and Veitsivaara (Hyrynsalmi), field surveys started in the spring of 1987. The Romuvaara area represents the oldest granite gneiss complex of the Archean basement, while the other area, Veitsivaara, represents an Archean granite formation. Both areas are characterised by the occurence of old Archean crystalline rocks.

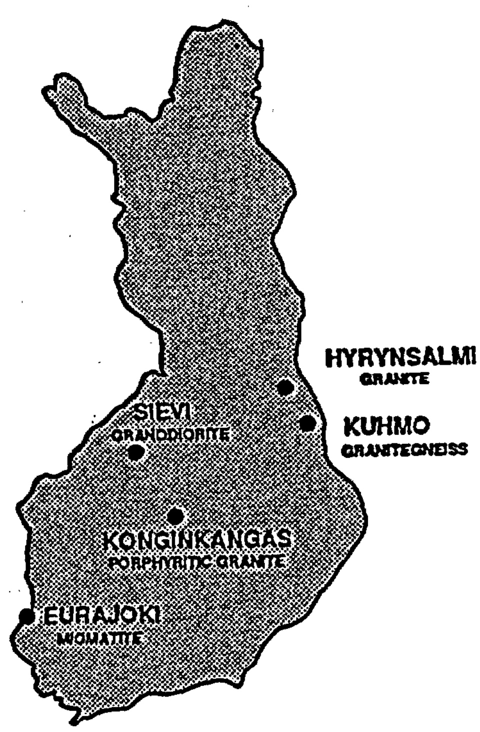


Figure 12. Investigation Areas and Rock Types

The investigations on the two sites have started with a generic review of bedrock maps and data. Structural analyses have been made with the help of stereo air-photos and geophysical maps. Field surveys started with geophysical profile measurements over a wide area and the surrounding fracture zones, with the VLF, VLFR, magnetic total and vertical component methods being used along with an electromagnetic radar ground survey. The measurements were continued systematically along a denser and more regular network.

In conjunction with geophysical studies, a detailed geological mapping of the outcrops was made with extra samples taken from soil overlying the bedrock. After these investigations, the first deep borehole was drilled and additional percussion-drilled boreholes were made for groundwater head monitoring. Investigations on each area will take approximately 3 years (Figure 13).

After the drilling phase, the geophysical and hydrogeological borehole measurements will be correlated to the information on the bedrock surface, and preliminary models will be constructed of both the hydrogeological data and the bedrock structures.

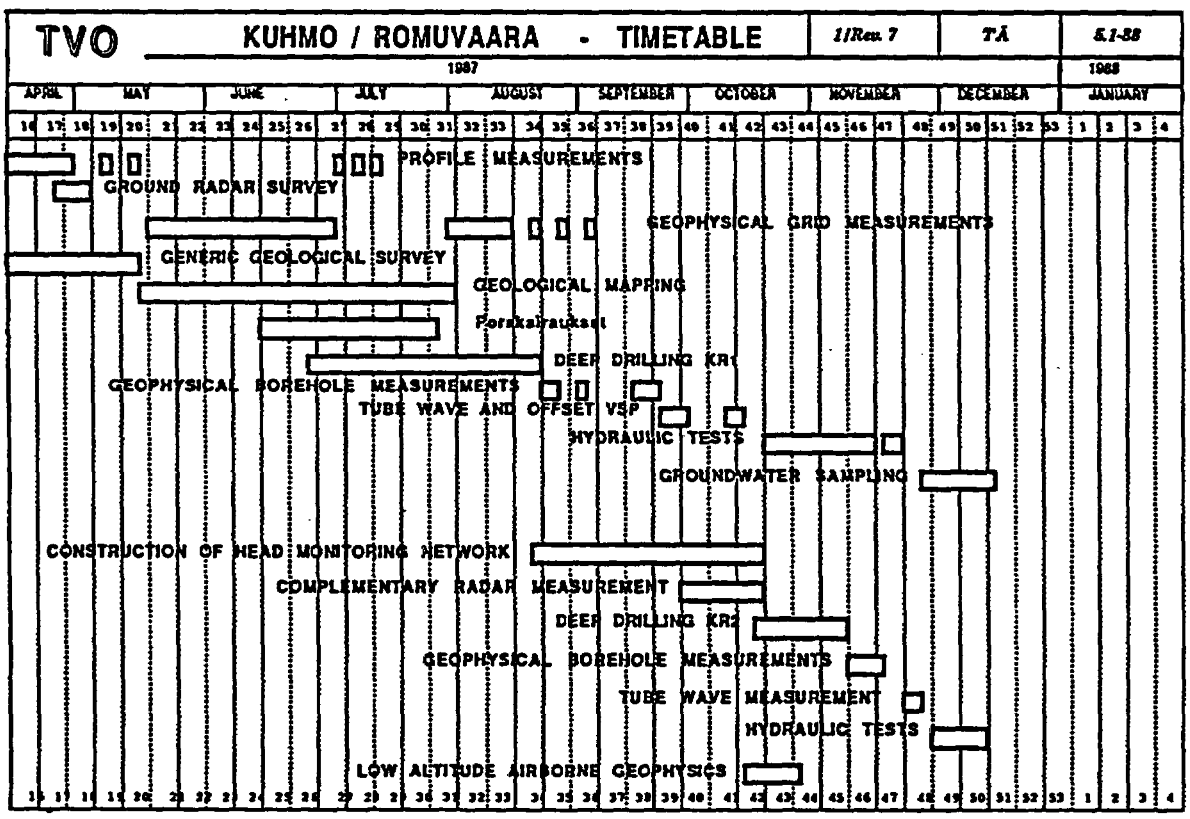


Figure 13: Time Table of the Investigations for the First Investigation Area

INSTITUTIONAL FRAMEWORK

The National Agency for Radioactive Waste Management (ANDRA) within the Commissariat à l'Energie Atomique (CEA) is responsible for the disposal of low-level waste at shallow depth, and for the geologic disposal of high-level waste and transuranic waste [1].

The in-situ geological programme entails:

a) Exploration of potential sites, and identification and qualification of a candidate site. This is the major ANDRA programme now in progress.

b) Supporting R&D, including:

   i) Testing and investigations of rock formations in order to identify their major safety-related characteristics and behaviour;

   ii) Development of reliable assessment methods and instrumentation. This work is conducted under the leadership of ANDRA and/or IPSN-DPT (Technical Protection Department of the Health Protection and Nuclear Safety Institute - CEA).

DISPOSAL CONCEPTS AND APPROACH

The ANDRA Site Qualification Programme

1. Approach and Schedule

Considering the broad variety of possible host rocks in France, it was decided to investigate the possibility of creating an underground repository in different rock types: (a) sedimentary rock, such as clay or salt; and (b) hard rock, such as granite or schist. All of these rock types display particular advantages, and it has been shown in different countries that a safe repository can be constructed in each type.

The possibility of having suitable sites in several host rocks provides considerable flexibility for the final choice of a French waste disposal repository. The first step of the site selection process was to compile a national inventory of the possible sites, based on criteria including long-term stability characteristics and favorable hydrogeology (i.e., very low permeability and good physico-chemical properties such as nuclide retention). This inventory was completed at the end of 1983. About 30 areas involving the four main host rocks (clay, granite, schist and salt) were identified as possible locations for a future repository. In some areas, a combination of layers of the different materials may improve the isolation ability of any repository.

Among the 30 areas, a preselection has been made of those which may warrant further investigation. Field investigations are being conducted to confirm the choice of the preselected sites and to meet the requirement that a candidate location be nominated for an Underground Site Validation Laboratory (USVL) by the end of 1989. The investigations depend on the type of geologic formation, but in all cases involve geophysical measurements from the surface and several deep drillings with core recovery. This field investigation phase started in early 1987 in four areas covering each of the different typical kinds of host rock (Figure 14).

After a candidate site has been selected, construction of the USVL will start. The laboratory will be the main tool to complete the site selection process by validating the site. With the data collected during this phase, it will be possible to demonstrate the technical feasibility and the economics of the repository, and to prepare a preliminary safety impact report to show that the consequences of the future repository for the environment are acceptable.

To achieve this, it will be necessary to conduct detailed investigations of the rock mass. In-situ experiments to confirm thermal and mechanical behaviour of the host rock and to evaluate and model the isolation capability of the system of barriers, including backfilling material and the different layers of the geosphere, will be required. Construction of the USVL will probably occur over two years, and it will be operated for two to three years. If the programme proceeds normally, site evaluation will be completed before the end of 1996 (Figure 15).

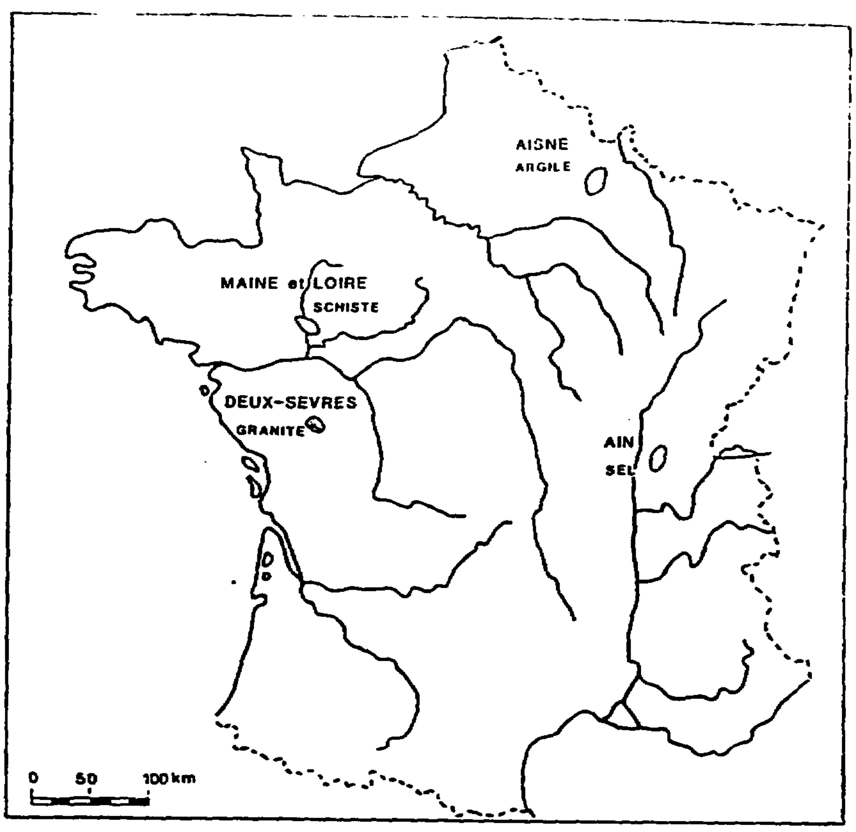


Figure 14. Investigation Sites for the USVL, France

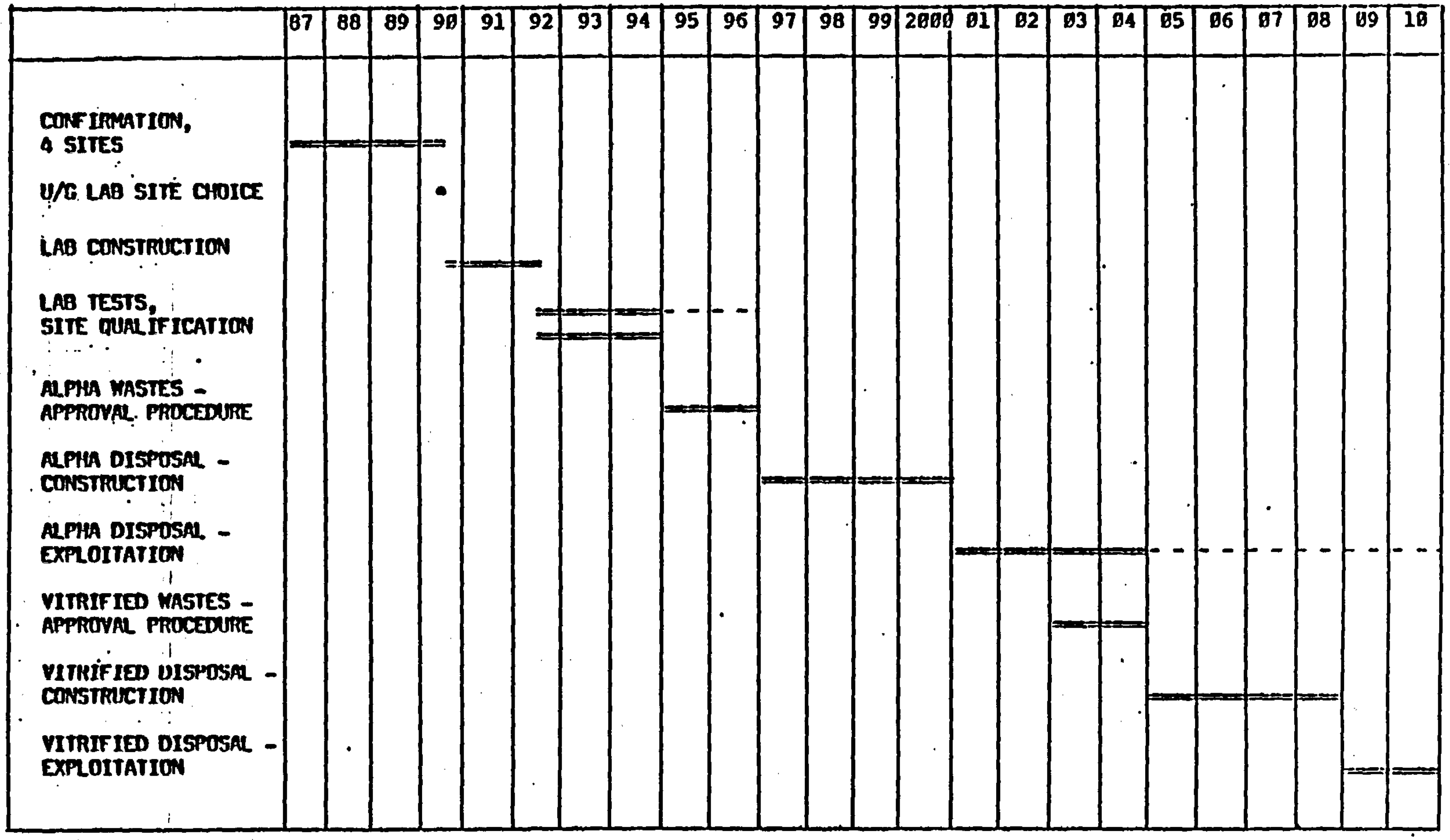


Figure 15. Deep Underground Repository Sites - General Planning

2. Current Status of the Exploration Programme

The first half of 1987 was devoted to important work related to public information on each site.

Geophysical investigations began in the second half of 1987 in the four departments (Figure 16). A variety of geophysical investigation techniques were used:

a) Aisne (clay) - 150 km of high-resolution seismic investigations were conducted, and 250 boreholes drilled.

b) Deux-Sèvres (granite) - 1500 km of airborne radiometric surveys were conducted.

c) Maine-et-Loire (schist) - in addition to 13 km of ground measurements, continuous magnetic, electrical resistivity and VLF (very low frequency) measurements were made along a 1500 km profile by helicopter.

d) Ain (salt) - the western limit of the salt basin was studied by 30 km of gravimetric surveys. Also, a detailed study of aquifers was conducted from the surface.

IN-SITU RESEARCH AND INVESTIGATIONS

Granite

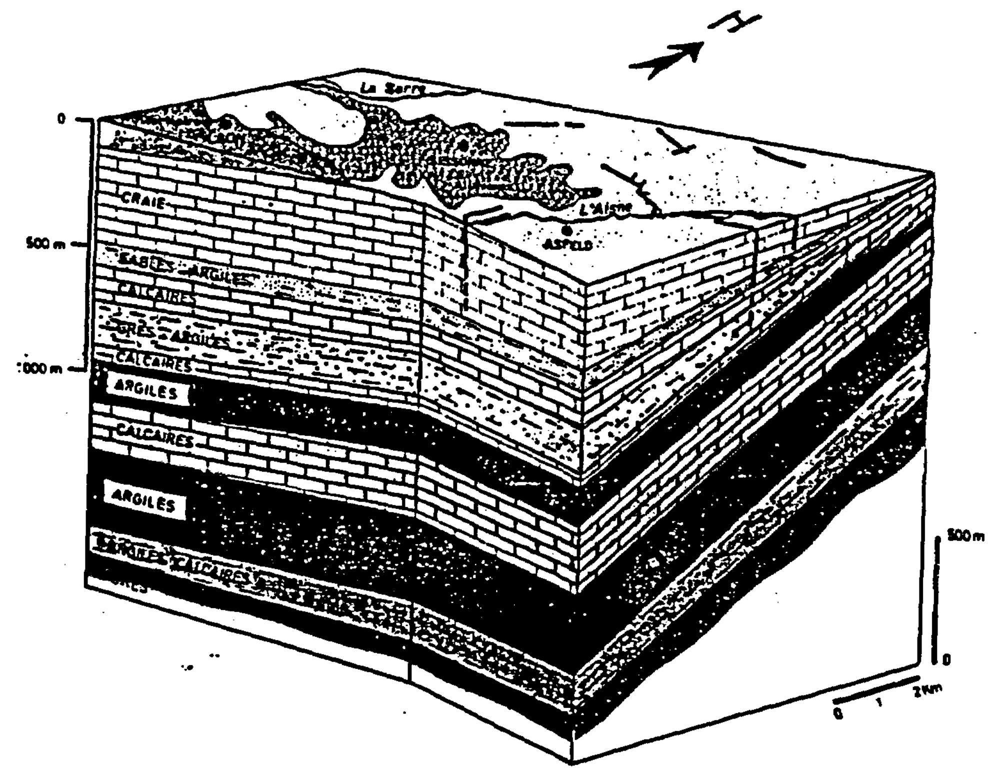
Within the R&D programme of the CEA, IPSN is responsible for safety studies relating to the disposal of radioactive waste [2]. IPSN studies of radioactive waste disposal in crystalline rocks began with the first five-year plan of the CEC (1976-1980). At that time, IPSN had initiated an intensive programme of research on geologic crystalline formations. That programme included the inventory of the granitic massifs potentially favourable for the disposal of HLW, and detailed studies on geology, geophysics and hydrogeology and related aspects (particularly modelling). Three granitic massifs were studied in detail. Two, located in Brittany, were subjected to thorough investigations of relevant aspects of geophysics, petrography, tectonics and hydrogeology. A deep borehole programme (2 holes) was conducted in the Auriat Massif, located in Limousin.

The 1000-m borehole at Auriat was the subject of numerous investigations regarding petrography of granite, mode of fracturing, permeability at different depths, geotechnical and thermal properties, thermal flux, chemical composition of groundwater and detailed analysis of the fractures. Some tests with tracers were also conducted.

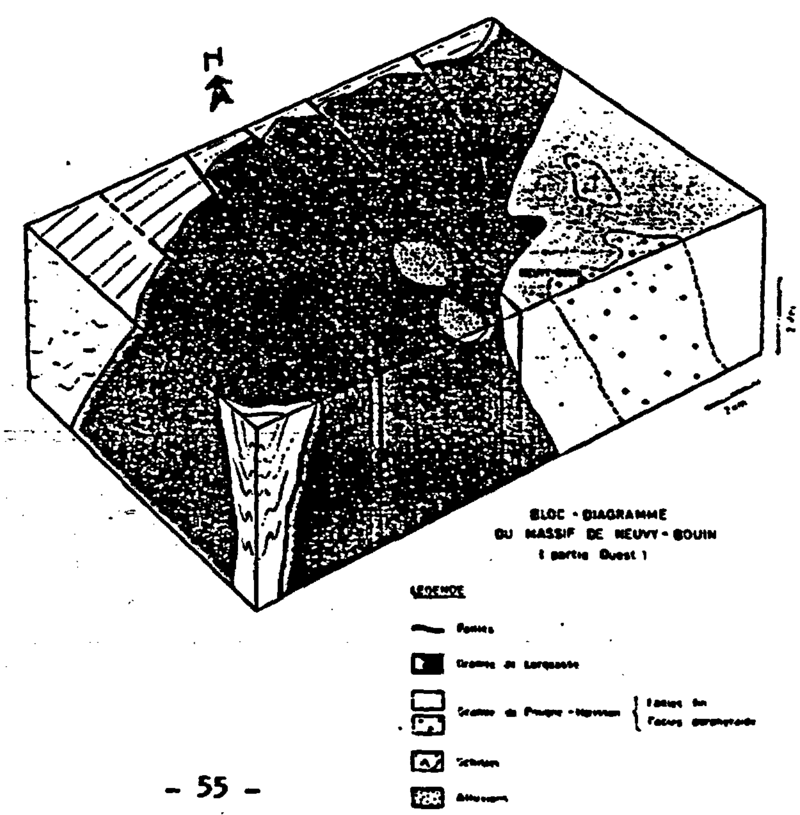
The Département de Protection Technique (DPT) of IPSN has also developed an underground research laboratory in the Fanay-Augères uranium mine, Limoges, in order to improve the knowledge of the properties and behaviour of fractured granite. Two main programmes have been conducted or are underway in this facility in the framework of shared contracts with the CEC: (a) the study of the influence of scale effects on measured values of permeability and dispersion coefficients; and (b) a thermo-hydro-mechanical experiment.

Figure 16. Investigation Sites for the USVL

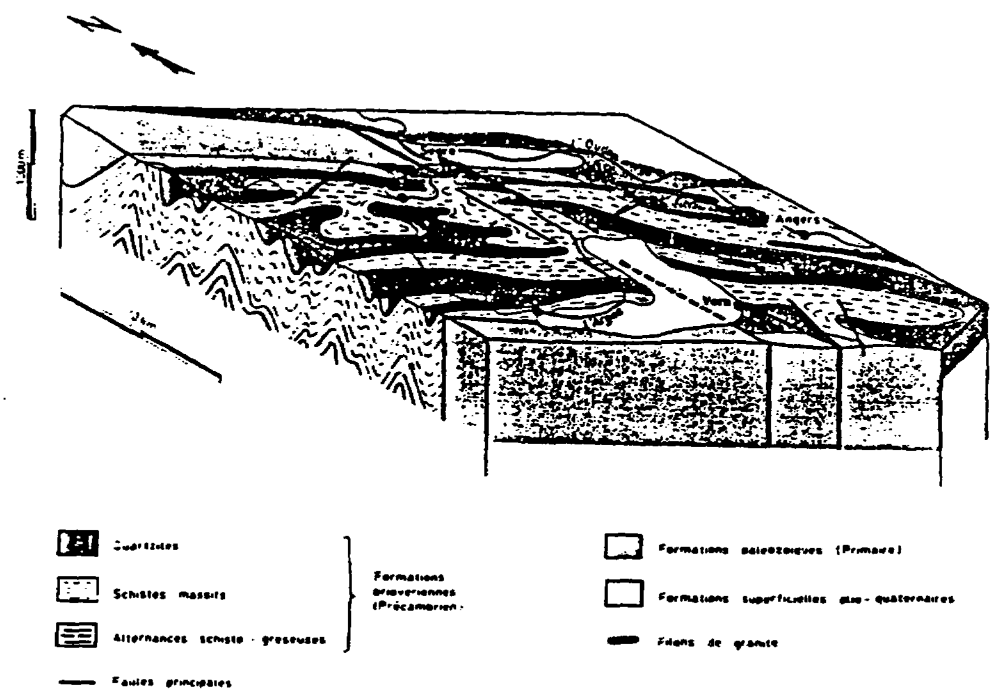
(a) Aisne (clay)



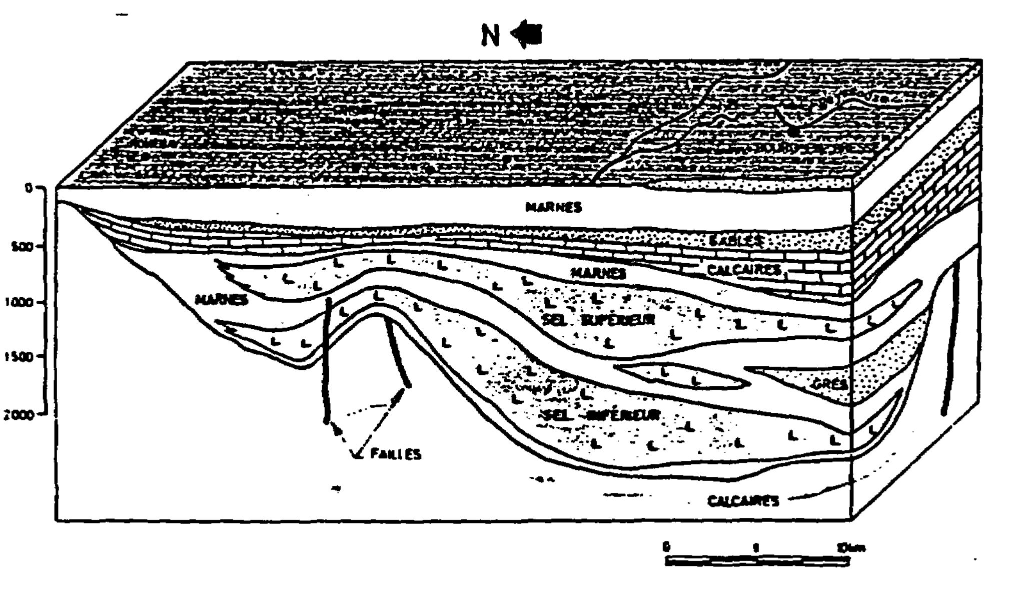
(b) Deux-Sèvres (granite)



(c) Maine-et-Loire (schist)



(d) Ain (salt)



The scale-effect experiment, now completed, was conducted in a 100-m drift, 170 m below the ground surface, in order to determine how large-scale hydraulic properties can be inferred from relatively small-scale measurements. The suitability of the site was determined by several hydraulic tests in boreholes and in the drift itself. A precise description of the fracture network has also been obtained.

The scale-effect experiment was conducted in ten boreholes, each 50 m in length, by injection tests between packers in chambers of different lengths. Permeability measurements at various scales, ranging from an individual fracture to a cubic hectometer, and punctual head measurements were conducted as well as the recording of the discharge rate in the drift. With the data collected, it has been possible to develop models of the fractured area, and to calibrate the area's hydraulic characteristics with the results of the permeability measurements. An equivalent continuous medium permeability tensor has been determined which reproduces satisfactorily the flow (heads, discharge rate) around the drift.

In order to determine hydrodynamic dispersion coefficients, tracer tests have been conducted by injecting, at different distances, various chemical tracers in several chambers isolated by packers in two boreholes, each 50 m in length. Experimental data have been interpreted with the use of a transport model.

The objective of the thermo-hydro-mechanical experiment has been to study the influence of heat on the permeability and mechanical behaviour of granite. This experiment is presently underway in the Fanay-Augères Mine, at a depth of 100 m. A large number of preliminary calculations were made using a finite-element code in order to define the characteristics and design of the experiment.

A heat source of 1 kW has been emplaced in 5 horizontal boreholes at 3 m below the floor of the 10 m X 10 m excavated rooms. The heating phase will last 50 days and the observation phase will last 6 months. The coupled phenomena which will be studied are:

a) Opening and closing of individual existing fractures;
b) Global hydraulic conductivity variation;
c) Deformation of the rock mass; and
d) Generated stress field and residual stress field after cooling.

The following measurements will be made:

a) Temperature distribution in the rock;

b) Strain distribution, using 3 extensiometers in boreholes and 18 extensiometers at the surface of the floor;

c) Hydraulic pressure (measurement in boreholes); and

d) Hydraulic conductivity (measurement in boreholes).

Various coupled thermo-hydro-mechanical models will be used, and an intercomparison of these models will be performed.

Elsewhere, ANDRA has experimented with a method of detecting fracture zones by electrical resistivity measurements between boreholes (MIMAFO method). This activity was conducted in the GRIMSEL underground laboratory (Switzerland).

Clay

Tests and studies undertaken by ANDRA have been made on the clay at Mol (Belgium) since 1984. They have been conducted essentially on the in-situ mechanical behaviour of the clay material (at a depth of 260 m) in the underground laboratory of SCK/CEN at Mol [1].

These studies have included:

a) Characterisation of the clay - In addition to systematic measurements on in-situ stresses, long-term dilatometer tests in boreholes began in 1987 with the installation of two instruments, one vertical and the other horizontal. These tests enable the study of the behaviour of a section of borehole under constant pressure. Similar tests on temperature will begin in 1988.

b) Full-scale behaviour of lined gallery - In the last part of 1987, a 12-m long gallery (4 m in diameter) was excavated at a depth of 260 m. The gallery is lined with a grooved (ribbed) and instrumented steel support wall, with sliding joints. This activity will provide full-scale information, during a two-year period, on convergence effects and for optimising the size (thickness) of the support walls (lining) for deep openings in clay.

This work is supported by the CEC.

Salt

a) Study of the effect of heat on crushed salt [1] - This study was designed to study the effects of heat on emplaced salt, in five boreholes excavated from a gallery located at a depth of 550 m in the Amélie mine of MDPA (Mines des Potasses d'Alsace). This activity began in October 1987 and will continue until 1989. Parameter measurements (pressure, deformation, temperature) will be conducted for six months following completion of the heating test.

b) Study of irradiated salt - This study is conducted within the framework of ANDRA's participation in the HAW project, being undertaken by GSF of the Federal Republic of Germany. It consists of two complementary studies:

   i) In-situ measurements in rock at the Asse mine are being taken of gamma doses and dose rates in different situations of irradiation fields in order to establish the laws of distribution and geometry of the radiation flux;

ii) In the laboratory, experimental irradiation allows the simulation of the effects of radiolysis on Asse salt and, in particular, the study of generated radiolytic gases, which can then be compared to the joint effects of irradiation and temperature, in an in-situ environment.

These experiments will begin in 1988, and will be undertaken with the co-operation of the CEA and with the participation of the CEC.

6.7 JAPAN

INSTITUTIONAL FRAMEWORK

The guideline for Japan's R&D activities on the geological disposal of high-level waste was established in 1985 by the Japanese Atomic Energy Commission (AEC). Under the direction of a five-year R&D programme announced by the Science and Technology Agency (STA), the Power Reactor and Nuclear Fuel Development Corporation (PNC) has been given the responsibility of performing in-situ experiments, while the Japan Atomic Energy Research Institute (JAERI) is responsible for developing regulatory criteria for safety assessment.

DISPOSAL CONCEPTS AND APPROACH

The overall programme of R&D for the geological disposal of high-level waste consists of four stages. The first stage involved is the selection of a favourable geological formation, and was terminated in 1985. However, this stage was not a designation of candidate rock types, and lithological suitability was also not assessed. Instead, as a result of a technical evaluation based on a literature assessment and general reconnaissance, it was concluded that most of the geological formations, with the exception of volcanic areas and unconsolidated Quaternary sediments, have favourable characteristics. The second stage involves the selection of candidate sites for a repository, and will be completed by 1995. The task of this stage is to conduct site investigations, including geological, geophysical, hydrogeological and hydrogeochemical studies, for a repository. The third stage is scheduled for the following five years and involves the demonstration of disposal technology at the candidate sites. The final stage of the programme, scheduled, at the earliest, for the year 2000, will include the verification of disposal techniques for the construction and operation of a repository.

IN-SITU RESEARCH AND INVESTIGATIONS

Preliminary in-situ experiments have been designed to improve the understanding of independent, small-scale and short-term phenomena in the near-field associated with geological disposal of HLW. Several test fields with different rock types (granite, gabbro, diabase, tuff) have been developed in galleries of metal mines and quarry chambers since 1978 [1]. The results of these tests have contributed substantially to development of in-situ investigation techniques and instrumentation, as well as site investigation techniques. These test fields are not considered as potential sites for a future repository. Therefore, in-situ experiments have been initiated at the second stage of the national R&D programme. The purpose of in-situ experiments at this stage includes:

a) Development and validation of techniques and methodologies for selection of candidate sites for a repository;

b) Development of techniques and methodologies for site characterisation in the deep geological environment;

c) Performance of various experiments for modelling and validation; and

d) Development and validation of appropriate technologies for construction and operation of a repository.

In order to conduct in-situ experiments for these purposes, the construction of an underground research laboratory is necessary to complete site investigations and to verify the technical feasibility and economics of a repository. Consequently, underground facilities will be constructed in sedimentary and crystalline rocks. However, in the interim until the construction of the facilities, in-situ experiments utilising the galleries of metal mines and quarry chambers are particularly important. Another contribution of in-situ experiments is to obtain a conceptual design and safety assessment of a repository, as well as to verify that the geological disposal system for HLW is feasible under the geological environment of sedimentary and crystalline rocks. Furthermore, in-situ experiments are very important for the development of appropriate methodology with regard to research and investigation on the process of site characterisation. Especially in Japan, the capacity and stability of natural barriers are very important since earthquakes and excavation effects may have considerable influence on rock dynamics, heat transfer, groundwater flow, hydrogeochemistry and basic radionuclide sorption in the deep geological environment.

In 1978, JAERI initiated preliminary investigations in gabbro at the Akenobe Mine in central Japan (Figure 17). Following this project, a 3-year programme of investigations in granite was started in 1983 in the quarry at Kasama, Ibaraki-ken (Figure 17). Heater, migration and corrosion-resistance tests on engineered barrier materials were performed during the first stage of the national programme. At the present, a further programme for in-situ experiments at the second stage of the national programme is being prepared.

In 1980, PNC initiated preliminary investigations in diabase at the Shimokawa Mine (Figure 17) in northern Hokkaido. Preliminary investigations in tuff also took place as part of a 6-year programme at the Hosokura Mine, in northeastern Japan (Figure 17). At the Hosokura Mine, permeability, migration and non-radioactive tracer tests , and corrosion tests on engineered barrier materials, have been conducted in rooms excavated in the gallery at a depth of 340 m below ground surface, and 186 m below sea level. Seismic transmission measurements at several levels in the galleries at the Hosokura Mine have been made as part of a comparative study of the influence of earthquakes on the deep geological environment and on the ground surface. Such a technique is viewed as a non-destructive tool to investigate inaccessible areas of rock, as well as to obtain estimates of possible effects. In-situ experimental programmes of the second stage of the national R&D programme have been conducted in boreholes, in the galleries and new test rooms of the Tono uranium deposit at a depth of 130 m, and in adjacent areas located near the Chubu Works (Figures 17 and 18) of PNC. The geology of this deposit is well studied, with structural and basic hydrogeological investigations having been conducted. Research and investigations on natural U-Th-series radionuclide migration processes in a natural analogue study, corrosion tests on engineered barrier materials, hydrological investigations of groundwater using argon and helium gases as tracer materials, and deep borehole investigations are the main activities that have been conducted recently at the Tono site. A further programme of in-situ experiments in the 5-year R&D programme at the second stage of the national programme has been conducted by PNC at the Tono site, and possibly will include several other sites in the near future.

Prior to the construction of the underground research laboratory at Horonobe in northern Hokkaido (Figure 17), preliminary site evaluation activities, which included borehole investigations for site characterisation, were conducted. More detailed evaluation of the site is currently underway by PNC.

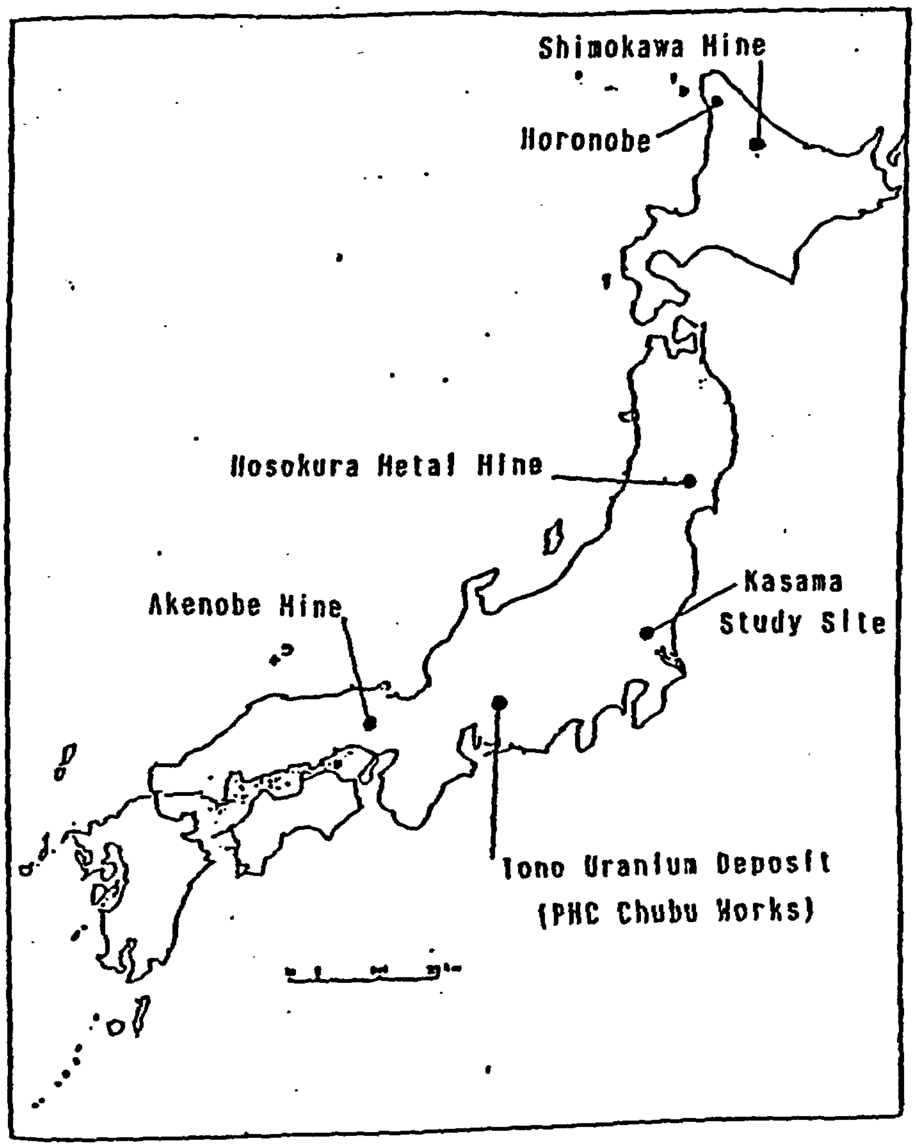


Figure 17. Location Map of In-Situ Experimental Areas

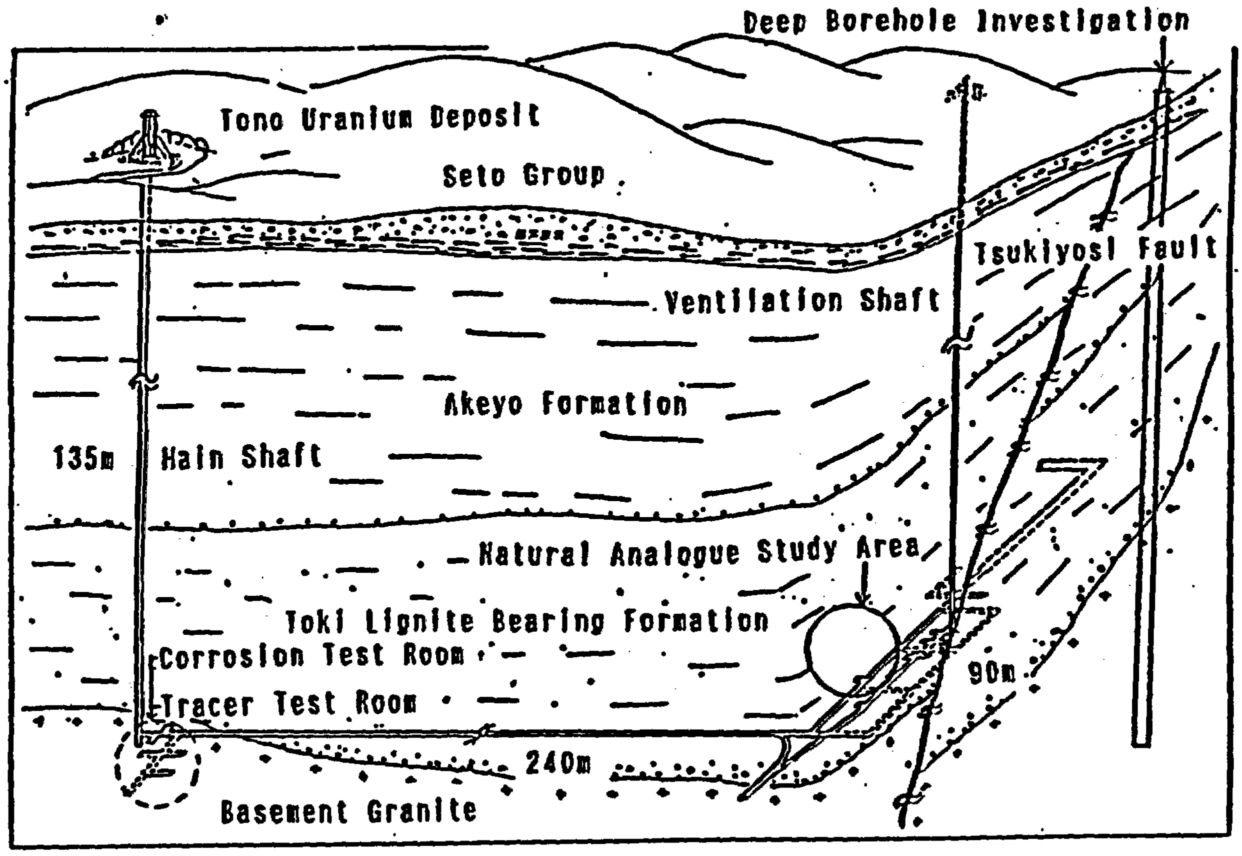


Figure 18. Arrangement of In-Situ Experiments at Tono Uranium Deposit and Adjacent Areas

6.8 SWEDEN

INSTITUTIONAL FRAMEWORK

In Sweden, the producer of nuclear waste has the responsibility for its management and disposal. The Swedish Nuclear Fuel and Waste Management Company (SKB), which is owned jointly by the reactor operators, handles practically all matters concerning nuclear waste and spent fuel outside the nuclear power plants. SKB conducts the research and development programme for handling and disposal of the waste. In accordance with the Nuclear Activities Act, this programme must be reviewed by the government every third year.

The National Board for Spent Nuclear Fuel (SKN), has the task to review and comment to the government on the SKB programme. SKN also proposes the fee structure on nuclear power production that the utilities must transfer to a special fund stipulated to cover the costs for present and future handling and disposal of high-level waste, spent fuel and decommissioning waste.

The Swedish Nuclear Power Inspectorate (SKI), is the safety authority for nuclear facilities according to the Nuclear Activities Act, and thus has licensing responsibilities for the safety aspects of repositories. The National Institute of Radiation Protection (SSI) supervises, in a similar manner, the implementation of the Radiation Protection Act. A permit to construct a repository must be provided by the government on recommendation from SKI. In practice, the three authorities co-ordinate activities to ensure that all aspects of final disposal are managed and assessed in a consistent manner.

DISPOSAL CONCEPTS AND APPROACH

For low- and intermediate-level waste, a final repository (SFR) has been constructed near the Forsmark reactor station. The SFR facility, which is planned to start operating in 1988, is located at a depth of 50 m in granitic rock under the Baltic sea, about one km from the coast line, and with entrance tunnels from shore. SKB plans to construct a repository in the SFR area for disposal of decommissioning waste about the year 2010.

With respect to spent nuclear fuel and high-level waste, the SKB programme includes a phase in the beginning of the 1990s for selection of a few candidate disposal sites for detailed investigations. Site selection will take place later during the 1990s, with a license application planned for the year 2000 and repository operations scheduled to start in the year 2020. The repository is intended to be situated deep in crystalline bedrock. A central facility for intermediate storage of spent fuel (CLAB) is in operation. This facility will make it possible to store the spent fuel for 40 years before disposal. During this time, the thermal content of the spent fuel will decrease considerably.

IN-SITU RESEARCH AND INVESTIGATIONS

There are two major in-situ research, demonstration and investigation programmes being conducted or planned in Sweden in support of research and investigations for the disposal of spent fuel [1]. These are the International Stripa Project, and the recently initiated underground research laboratory project, the Swedish Hard Rock Laboratory.

Stripa Project

The Stripa Project is an in-situ research project jointly undertaken by several OECD Member countries. The Project is conducted under the auspices of the OECD Nuclear Energy Agency (NEA), with SKB as the co-ordinating organisation. The project was established in 1980 to develop techniques to fully investigate sites located deep underground in granite rock formations that are potentially suitable for the disposal of heat-generating radioactive waste, and also to examine particular engineering design phenomena associated with enhancing the long-term safety of a high-level radioactive waste repository.

The research work conducted within the project is concentrated in the Stripa Mine, an abandoned iron ore mine located in central Sweden. Adjacent to the ore excavations is a granitic intrusion which is accessible at about 350 m below ground surface. Several drifts have been excavated at this level in order for specific experiments to be conducted.

The Stripa Project has been divided into three phases. Phase 1 was conducted from 1980 to 1985. The experiments in Phase 1 were grouped under the following headings:

a) Hydrogeological and hydrogeochemical investigations;
b) Migration in a single fracture; and
c) Buffer mass test.

Phase 2 began in 1983 and is due to be completed in 1987. Research was conducted in four main areas:

a) Hydrogeological investigations of the Stripa granite and migration of nuclides within single- and multiple-fracture systems;

b) Hydrogeochemistry of groundwater at the Stripa Mine;

c) Detection and characterisation of fracture zones in granite; and

d) Behaviour of bentonite clay as a backfilling and sealing material under field conditions.

The experience obtained from Phase 1 was used in the development of Phase 2 of the Project and in the planning of Phase 3. Both Phase 2 and 3 extend the findings of Phase 1 by continuing the broad areas of work and initiating new activities aimed at developing techniques and procedures for evaluating the performance and engineering development of a radioactive waste repository located in granitic rock.

Phase 3 of the Stripa Project started in September 1986 and is expected to continue until 1991. Research activities in this third phase will be conducted under two headings:

a) Fracture flow and nuclide transport; and

b) Groundwater flow-path sealing.

The main objectives of the fracture flow and nuclide transport research activities are:

a) To predict groundwater flow and nuclide transport in a specific unexplored volume of the Stripa granite and to make a comparison with data from field measurements by means of an integrated approach with existing site characterisation tools and methods, particularly those developed under Phases 1 and 2; and

b) To continue the development of site assessment methods and strategies and, where appropriate, apply them in later stages of the integrated site characterisation exercise outlined above.

The principal objectives of the groundwater flow-path sealing studies are:

a) To identify, select and evaluate sealing materials possessing potential long-term chemical and mechanical stability; and

b) To demonstrate, in a pilot test as well as in a full-scale field test, using suitable methods and techniques, the effectiveness of such materials for the long-term sealing of groundwater flow- paths in the Stripa granite.

Phase 3 of the Project continues and builds on the work conducted under Phases 1 and 2, and also develops new areas of research. An unexplored volume of granite (about 125 m x 125 m x 50 m) will be studied, and a combined deterministic/statistical flow model will be developed and compared with data from field measurements. This modelling approach will be used because previous investigations have shown that an equivalent porous media model is considered inappropriate for similar volumes of fissured crystalline granitic rock. If successful, this will significantly enhance the confidence in the application of predictive mathematical models to site-specific conditions.

The ultimate product of the Phase 3 programme will be the availability of the tools and knowledge to assess a potential radioactive waste disposal site. Techniques to conduct non-destructive site investigations will be developed and fully evaluated under rigorously controlled in-situ conditions, as will sealing methods designed to optimise the isolation potential of a repository established within crystalline granitic rock.

<u>Underground Research Laboratory</u>

Given that research activities at Stripa will be terminated in the early 1990s, it has been deemed to be of very high priority to construct an underground research laboratory where research can be pursued at a high scientific level to broaden the available body of knowledge. The research laboratory should be sited in an environment that is geologically and hydrologically unaffected by previous activities. This will provide an opportunity for many scientific experiments of vital interest for a safety analysis with good precision.

The underground research laboratory, the Swedish Hard Rock Laboratory, is also planned for other purposes than purely geoscientific studies. In preparation for the submittal of a repository siting application, integrated tests, pilot plants and in-situ tests may be necessary during the latter half of the 1990s. Such experiments can be conducted in the underground research laboratory. The goals of the underground research laboratory are to:

a) Demonstrate that the factors that control the safety of a final repository are understood and can be quantified or delineated; and

b) Validate models and assumptions included in the safety analysis.

The principal activities planned for the period 1987-2010 are:

a) Detailed investigation of the natural barrier (i.e., the rock) in bedrock of a final repository character. This includes development of methodology, collection of data and validation of models for groundwater movement and radionuclide transport.

b) Pilot in-situ tests for analysis of performance interaction between the repository's engineered and natural barriers.

c) Development of appropriate methods for implementation and quality assurance of repository construction.

d) Demonstration of system, technology and quality assurance.

6.9 SWITZERLAND

INSTITUTIONAL FRAMEWORK

In 1972, all producers of radioactive waste in Switzerland joined together to form NAGRA, the participants being the Swiss Confederation (which is responsible for radioactive waste arising from medicine, industry and research) and six utilities which presently operate, or are planning to operate, nuclear power plants.

In Switzerland, concepts for radioactive waste management are embodied in the Federal Government Ruling on the Atomic Act. The R-21 Guideline (1980) of the Federal Commission for Safety in Nuclear Installations (KSA) and the Nuclear Safety Department of the Federal Office of Energy (HSK) defines disposal as follows:

- A repository must be designed in such a way that it can at any time be sealed within a few years. After a repository has been sealed, it must be possible to dispense with safety and surveillance measures.

To protect man and the environment from the harmful effects of radioactive substances, a quantitative protection objective is defined:

- Radionuclides which escape into the biosphere from a sealed repository as a result of realistically assumed processes and events must not at any time lead to individual doses which exceed 10 mrem per year.

NAGRA is responsible for developing a deep geological repository for high-level waste by 2020, and an underground repository for low- and intermediate-level waste by around 2000. As a step in achieving these objectives, the results of a safety assessment project (Project Gewähr) were presented to federal authorities in 1985 [1, 2].

DISPOSAL CONCEPTS AND APPROACH

The Swiss concept for nuclear waste disposal proposed by NAGRA envisages the repository for low- and intermediate-level waste as a mined cavern system with horizontal access (Figure 19), and the high-level waste repository as a series of horizontal tunnels at a depth of about 1200 m below the surface (Figure 20). The LLW/ILW repository must be operational by the end of the century, and will probably be situated in the pre-alpine area of Switzerland. The facility for HLW is required by the year 2020 and is planned to be located in crystalline bedrock, or possibly a sedimentary formation in northern Switzerland, assuming that participation in an international project does not become a feasible and preferable option. The feasibility of both types of repositories in Switzerland has been demonstrated by Project Gewähr 1985 [1]. At the time of preparing this feasibility assessment, specific field investigations were available only for the HLW concept. They consisted of extensive geophysical explorations and six boreholes up to 2500 m deep. For the LLW/ILW repository investigations, geological and hydrogeological information was limited to data obtained from surface mapping and records from the construction of a hydro-electric power development project and a road tunnel.

In-situ investigations by NAGRA are determined by the above disposal concepts. They have been, or will be, conducted in the steps listed below:

a) HLW Repository:

Regional investigation and site selection	1980 - 1990/91
Detailed site investigations at 1 - 3 locations ..	1990/91 - 1997
Detailed site investigation at 1 location, with test shaft and underground laboratory	1997 - 2010
Repository construction and start of operations ..	2010 - 2025

b) LLW/ILW Repository:

Preparation of detailed investigation programmes and field inspections	1985
Investigation of three sites by boreholes and geophysical surveys	1986 - 1988
At least at one site, excavation of a gallery into the repository area, geologic and hydrogeologic investigations and in-situ tests ...	1988 - 1990
Application for a license for the repository site	1991/92
Start of repository operation	1998 - 2000

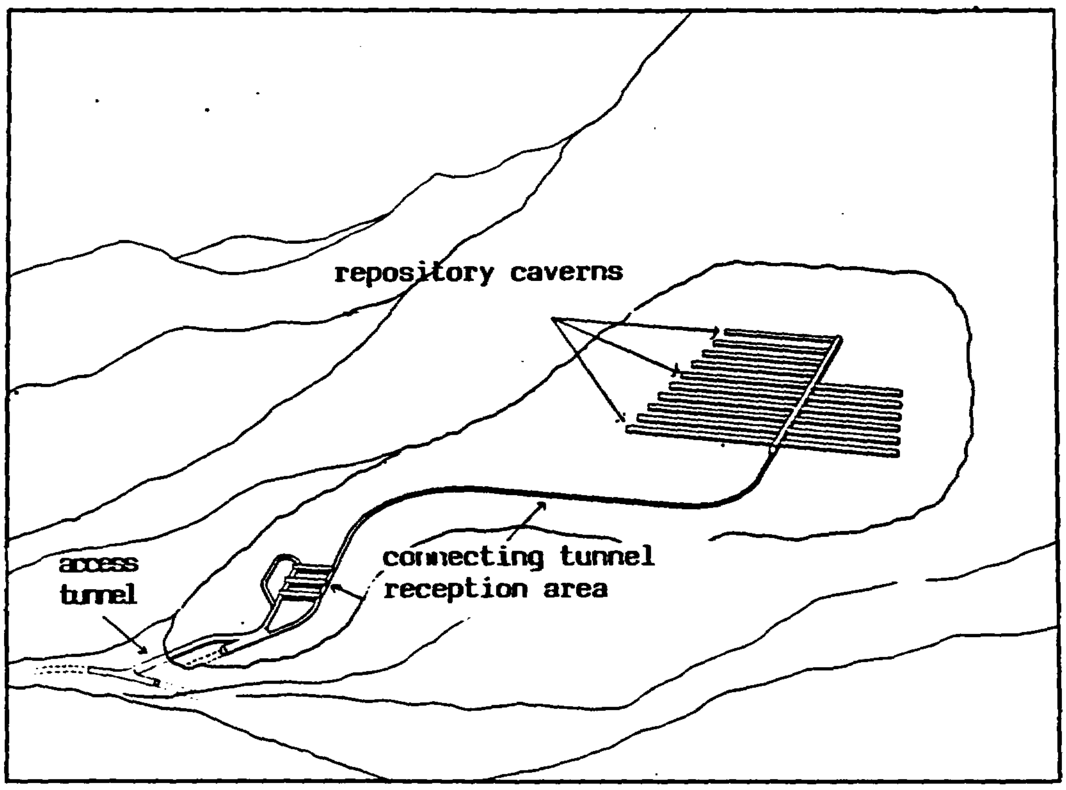


Figure 19. Perspective Overview of LLW/ILW Repository

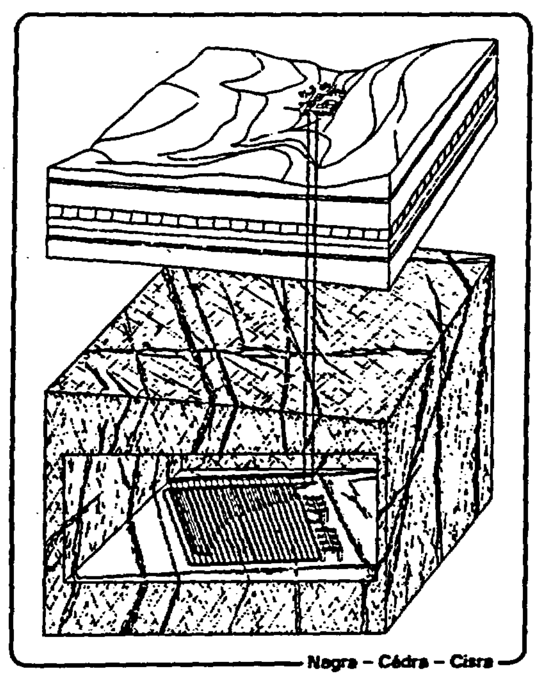


Figure 20. Perspective Overview of HLW Repository

Field Program for HLW Deep Disposal Project

The investigation area (Figure 21) was selected in northern Switzerland in a region where the top of the crystalline basement was expected at a maximum depth of 1500 m. The investigation area lies in a region of relatively low seismic activity between the two more seismically active areas around Basel and Schaffhausen.

Figure 22 depicts a geological section through the investigation area, from the Kaisten borehole to the Schafisheim borehole. The section is based on an interpretation of a seismic reflection survey. A large Permo-Carboniferous trough which has a west-east trend through the investigation area was discovered below the Mesozoic sediments.

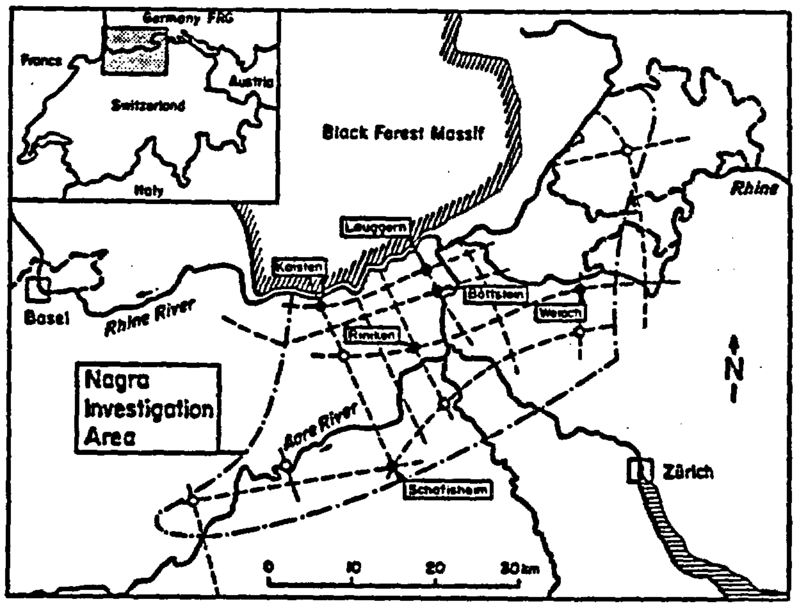


Figure 21. NAGRA Investigation Area with Deep Boreholes (black circles) and Seismic Reflection Lines (dashed lines)

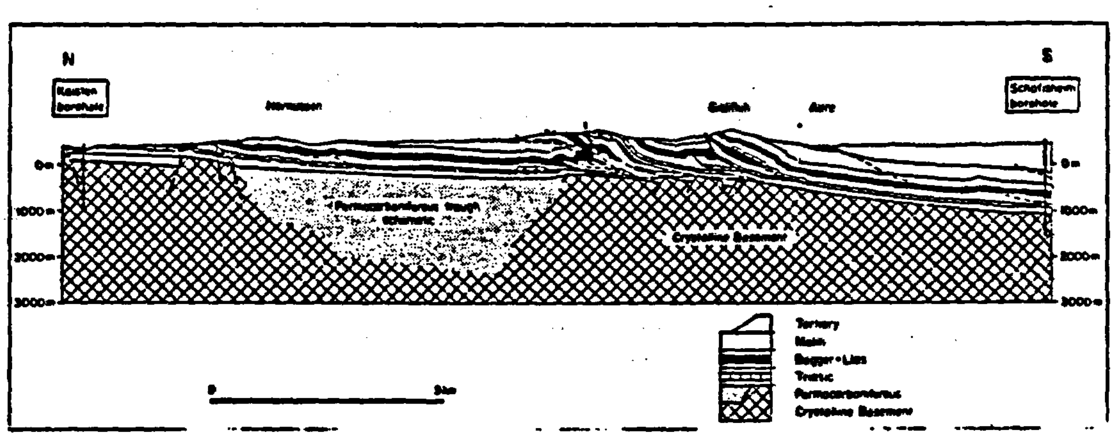


Figure 22. Geological Section Through the NAGRA HLW Investigation Area

To date, six boreholes have been drilled to depths between 1300 and 2500 m in order to explore the geological structure, with particular emphasis on detailed investigation of the crystalline basement below the sedimentary cover. Investigation of water flow systems in the basement, as well as their hydraulic and hydrochemical characterisation, provide the input data required for a hydrogeological model of the area, as well as for modelling transport through these formations.

The main aspects of the scientific investigation programme were:

a) Coring over 90% of the boreholes and detailed laboratory analysis of the cores.

b) Core orientation (very successful with a sonic televiewer) and detailed fracture orientation statistics.

c) Geophysical logging with practically all tools available today. For the granite of the Böttstein borehole, a synthetic faciolog was developed which corresponds remarkably well with the observed petrography.

d) Fluid logging to detect water inflow zones. Very small inflow zones were detected by logging the electrical conductivity of the borehole fluid during pumping. Subsequent detailed geological description of these zones for developing the transport models.

e) Hydraulic testing. Systematic double packer tests with intervals of 12-25 m were conducted to obtain a continuous profile of the hydraulic conductivity of the crystalline basement. Heat measurements during drilling.

f) Sampling of groundwater of the sedimentary aquifers and flow zones in the crystalline basement was conducted, mostly during the drilling operations which were interrupted when a promising flow zone was observed. The crystalline sections of the boreholes were drilled either with de-ionized water or inflowing deep groundwater.

Field Program for LLW/ILW Disposal Project

In-situ investigations with a view to selection of the LLW/ILW repository site commenced in Spring 1987. At Oberbauenstock (OBS) in central Switzerland, geophysical measurements have been conducted and test drilling as well as hydraulic testing have been performed galleries associated with a nearby road tunnel. The host rock at OBS is a hard (somewhat fractured) marl formation. The same stratum extends to another potential site, Wellenberg (WLB), in a neighbouring valley, for which permission for site investigations (boreholes and test tunnel) was sought in the Spring of 1987. It is hoped that field work at WLB can start in 1988. In-situ work of a similar scope as at OBS was conducted in September 1987 at Piz Pian Grand (PPG, gneiss). The commencement of field work at the fourth location, Bois de la Glaive (BdG, anhydrite), is still being delayed by local legal action.

Grimsel Test Site (GTS)

Methods used by the oil industry were adapted for the initial regional investigations by way of, for example, seismic exploration and deep drilling. The methodology and instrumentation for future field investigations in both disposal projects will, however, be increasingly adapted to the specific requirements of site characterisation and safety analysis for the repository. For this, as for other experiments, NAGRA commissioned a test site in crystalline rock at the Grimsel pass in central Switzerland in June 1984. The initial 5-year investigation programme at the Grimsel Test Site (GTS) is being conducted by NAGRA in partnership with two German research institutes: the Federal Institute for Geoscience and Natural Resources, Hannover (BGR), and the Research Centre for Environmental Sciences, Munich/Braunschweig (GSF). A second phase of investigations has recently been agreed upon.

The main objectives of the investigations at the GTS are:

a) To check the applicability of existing research results to the geological conditions in Switzerland;

b) To conduct specific experiments based on the NAGRA repository concepts;

c) To increase knowledge in the planning, implementation and interpretation of underground tests in various experimental fields; and

d) To acquire practical experience in the development, testing and use of test apparatus and measurement methodology.

The GTS consists of a tunnel system excavated with a full-face boring machine and left unlined except for some concrete flooring. The quality of the crystalline rock varies within the GTS, from very compact and practically dry rock,to fairly fractured rock with water inflows. Several near-vertical disturbed zones extend to the rock surface at 400 m to 500 m above the GTS. To date, over 3500 m of carefully cored and geologically mapped boreholes have been drilled in the various test areas.

Figure 23 shows the layout of the GTS. The basic goals of the individual scientific investigations at the GTS are outlined below:

a) Excavation effects: Testing the rock mass surrounding man-made openings in crystalline rock in order to assess the influence of these cavities on its properties (especially hydrogeology).

b) Geophysics: Testing and further development of non-destructive methods for locating hydrogeologically significant rock discontinuities and weaknesses from exploratory boreholes and underground openings, at short ranges of up to approximately 50 m, as well as in the far-field.

c) Heat-induced reactions: Investigations which provide an understanding of heat-induced reactions in fractured crystalline rocks.

d) Hydrogeology: The acquisition of additional hydrogeological data which can assist in developing a general hydrogeological model, readily adaptable to specific field situations, in fractured low-permeability crystalline rock. Development of the necessary investigation techniques.

e) Laboratory experiments: Complementing the in-situ tests by laboratory experiments which are also needed for the development of mathematical models.

f) Migration: a tracer test, which is in a first phase, is foreseen, and would be accompanied by acquisition of additional chemical and physical data necessary for understanding the transport of nuclides in the fractures of crystalline rock.

g) Neotectonics: Testing and further development of methods for locating neotectonically active disturbed zones.

h) Rock-stress measurements: Testing and further development of existing methods used in shallow boreholes in order to determine the rock stresses in deep boreholes.

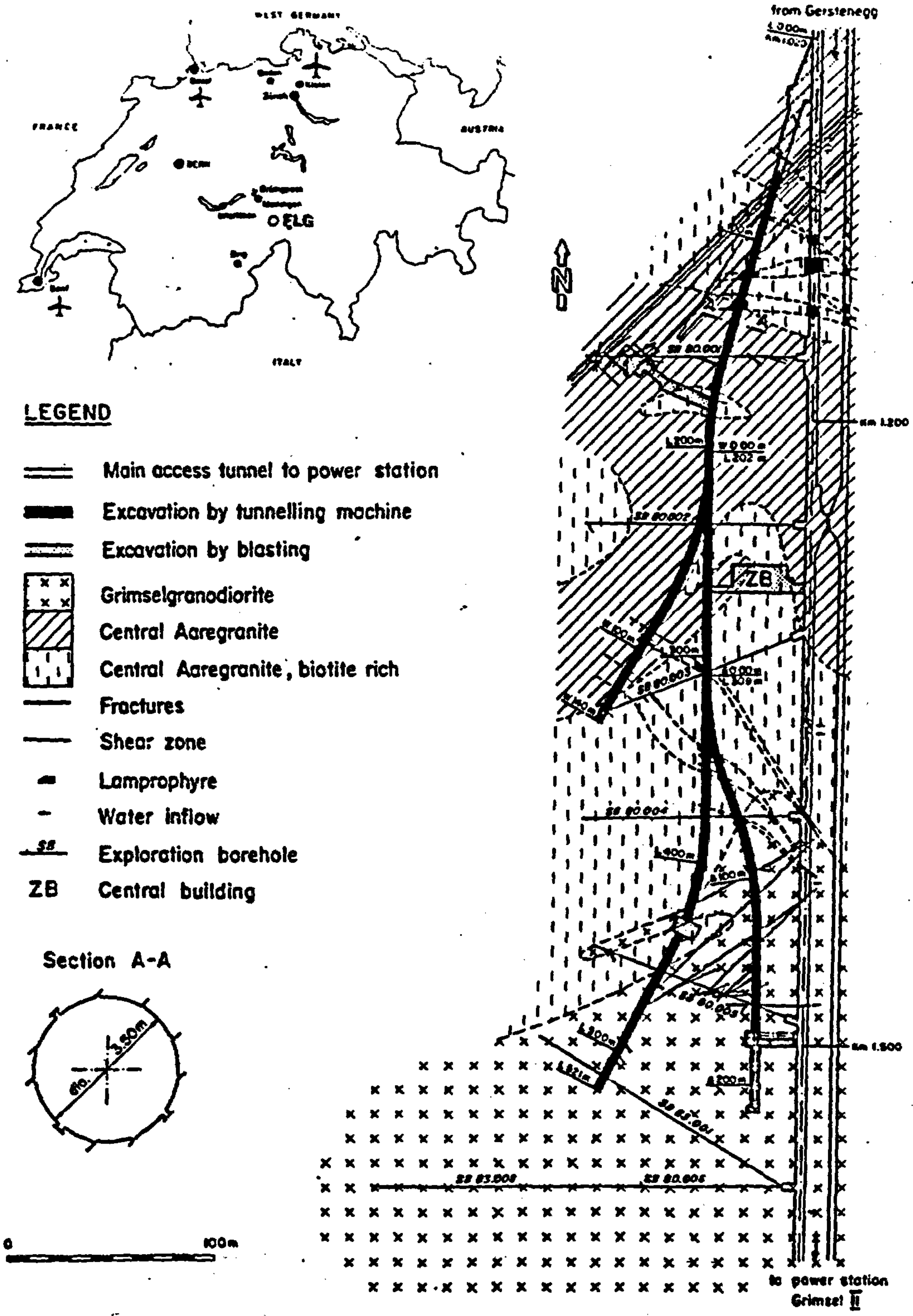


Figure 23. Grimsel Underground Test Facility (GTS)

6.10 UNITED KINGDOM

INSTITUTIONAL FRAMEWORK

The Department of the Environment (UK DOE) is the principal regulatory authority in the UK. It conducts research in support of its regulatory responsibilities on methods of disposal of radioactive waste through contracts with a variety of bodies such as the United Kingdom Atomic Energy Authority (UKAEA), the Institute of Oceanographic Sciences (IOS), the British Geological Survey (BGS) and the Natural Environment Research Council (NERC). The principal producers of radioactive waste in the UK include:

a) British Nuclear Fuels Limited (BNFL), which is responsible for the design, construction and operation of facilities for the supply of nuclear fuel cycle services, including reprocessing of irradiated fuel and the management of the resulting waste.

b) The Central Electricity Generating Board (CEGB) and the South of Scotland Electricity Board (SSEB), which operate Magnox and AGR power stations.

c) The UKAEA, which operates a number of prototype power reactors and undertakes a wide range of R&D activities in all aspects of the nuclear fuel cycle.

In 1982, BNFL, CEGB, SSEB and the UKAEA established an organisation, the Nuclear Industry Radioactive Waste Executive (NIREX), with the responsibility for securing the disposal of low- and intermediate-level waste.

DISPOSAL CONCEPTS AND APPROACH

Containment of vitrified high-level waste in engineered storage currently is envisaged for at least 50 years before disposal. An R&D programme will be conducted to provide information on options for safe disposal of these wastes.

NIREX had been investigating concepts for the separate disposal of low-level waste and intermediate-level waste, but in 1987 a policy decision was made by the Government to develop one repository for disposal of both waste types together.

IN-SITU RESEARCH AND INVESTIGATIONS

Since it maintains the national archive and has a long-term interest in improved understanding of the geological environment of the UK, the British Geological Survey has been involved in all the geological disposal research programmes [1]. These programmes have ranged from high-level to low-level waste, from granites to clays, and from landfill-style facilities to deep geological repositories.

Each programme has involved some form of in-situ research. This has generally consisted of drilling several boreholes, coupled with geological and geophysical surveying. The boreholes have been tested to determine the properties commonly of interest in studies associated with radioactive waste (i.e., hydrogeological and geochemical parameters). In earlier investigations, borehole tests tended to involve single boreholes, whereas, more recently, a cross-hole configuration has become more favoured. Another trend in the field investigations has been the desire to integrate testing with surveying, and to try to interpret more precisely the results from remote sensing methods.

British in-situ research has certain characteristics. Firstly, there is a wide range of experience in different rock types. Secondly, studies have been more concerned with the broad issues of a safety case rather than the more specific problems of site investigation. Thirdly, the lack of an underground facility in Britain has discouraged in-situ work on rock mechanics aspects and has tended to inhibit integrated studies. Lastly, geochemical and natural analogue studies have influenced investigations on time-scales and the ability to validate models.

Recently, British in-situ research has been changing and improving to meet the needs of actual site investigations and site-specific safety assessments. Hence, the BGS is currently involved in six field-based studies:

a) Study of methods of measuring parameters for safety assessments, at the Harwell research site (Cornwall);

b) Combining hydrogeological and geophysical measurements in the Cross-hole Programme of Phase II of the Stripa Project;

c) Natural analogue studies, both in the UK and elsewhere;

d) Migration of radionuclides in a shallow glacial sequence;

e) Geochemistry research programme associated with the recently terminated NIREX investigations of four sites for shallow-land burial of low-level waste; and

f) Integrated site characterisation and model validation programme within Phase III of the Stripa Project.

In-situ research also has been conducted by the UKAEA (Harwell), with funding from the Department of Environment, CEC and NIREX, on three research areas. Firstly, heat transfer measurements have been made over a four-year period with a 15 kW heat source in Cornish granite. The results, analysed in HYDROCOIN, demonstrated some small perturbations of conduction transfer by convection [2]. Secondly, flow studies in granite have provided statistics for fracture occurrence, orientation and aperture [3] and some measurements of channelling of flow in fractures by contacts between their faces [4]. These data are being used in statistical modelling to predict flow through networks of interconnected fractures. Thirdly, flow studies have recently been started on a shale site. Initial experiments are intended to measure flow both locally along major faults in the shale and through small fractures in rock adjacent to these faults.

Planned measurements of radionuclide diffusion through in-situ clay at SCK/CEN (Mol), and of water and gas flows through sandy and silty layers in clay at a site in England, are expected to start in 1987.

6.11 UNITED STATES

INSTITUTIONAL FRAMEWORK

The Nuclear Waste Policy Act of 1982 (NWPA) assigns the U.S. Department of Energy (DOE) the responsibility of locating, constructing, operating, closing and decommissioning a high-level nuclear waste repository. The U.S. Nuclear Regulatory Commission (NRC) has the statutory responsibility for reviewing DOE's license application and site investigation programmes. NRC regulations regarding the disposal of high-level nuclear waste are contained in Part 60 of the Code of Federal Regulations (10 CFR).

NUCLEAR REGULATORY COMMISSION

DISPOSAL CONCEPTS AND APPROACH - REGULATION OF CIVILIAN PROGRAMME WASTES

Before submitting a license application for a civilian programme radioactive waste repository, the DOE is required by the Nuclear Waste Policy Act of 1982 and by 10 CFR Part 60 to conduct a programme of site characterisation [1]. In-situ testing is viewed as an important element of site characterisation, and such tests are to be performed from the exploratory shaft(s) and underground openings on surrounding rock and on other materials and components such as the waste package, engineered backfill, linings and seals. The conditions under which these in-situ tests are to be conducted should represent, as closely as possible, the realistic repository environment (for example, temperature and stresses). The tests performed under such conditions would provide data to assess the suitability of a particular site and a particular geologic medium to host high-level nuclear waste, and also realistic input parameters for the design of a geologic repository.

In-situ tests can only be conducted for a limited duration compared with the long time-span during which the repository must function to isolate the waste. Analytical, experimental and numerical models must be used to make predictions far into the future. However, models have their own limitations on applicability and are sensitive to the quality of data used as input. Some of the uncertainties in the prediction process can be reduced by conducting appropriate in-situ tests on a representative volume of rock, and by using appropriate models to account for possible inherent spatial variations of physical, hydraulic and chemical properties within the rock formation. By comparing in-situ test data with modeling results, models can be validated, thereby reducing some uncertainties in the prediction process.

<u>NRC Technical Positions on In-Situ Testing</u>

The NRC staff technical positions on in-situ testing during site characterisation are:

a) Before submitting a license application, DOE should perform a necessary and sufficient variety and amount of in-situ testing to support, if the facts so warrant, a staff position that the requirements for issuance of a construction authorisation (10 CFR Part 60.31) have been met.

b) The in-situ testing programme should be developed with two major objectives: (i) characterisation of host rock and in-situ measurement of its properties prior to construction and waste emplacement; and (ii) determination of response characteristics of the host rock and engineered components to construction and waste emplacement.

c) DOE should present its site-specific and design-specific in-situ test plans in the Site Characterisation Plan (SCP).

d) Before developing the in-situ test plan, DOE should develop a rationale for in-situ testing and present this rationale with the test plan in the SCP. The overall goal of the rationale should be to ensure that all important parameters are identified and ranked according to their relative importance in supporting 10 CFR Part 60 licensing findings.

e) For successful site characterisation, DOE should integrate the data from surface borehole testing and laboratory testing on small-scale samples with the in-situ test results.

This technical position is general and covers in-situ testing for all potential repository sites and designs. It was developed and presented to the Department of Energy in an effort to provide on-going pre-licensing guidance.

DEPARTMENT OF ENERGY

DISPOSAL CONCEPTS AND APPROACH - DISPOSAL OF CIVILIAN PROGRAMME WASTES

In accordance with the US Nuclear Waste Policy Act of 1982, the US DOE has been preparing site characterisation plans for three potential repository sites: the Yucca Mountain site in Nevada, the Deaf Smith County site in Texas and the Hanford site in Washington. However, in December 1987, the Nuclear Waste Policy Act was substantially changed as a result of Congressional legislation amendments. Some of the major changes to the US DOE waste management programme include:

a) Phase-out of all research to evaluate the suitability of crystalline rock as a potential repository host medium; this may require some adjustment of some international agreements, which is yet to be negotiated with the appropriate parties.

b) Only the Yucca Mountain, Nevada, site will be characterised.

c) The Basalt Waste Isolation Project (Hanford, Washington) and the Salt Repository Project Office (Deaf Smith County, Texas) are to be closed down.

d) Provision is made for other states to volunteer a repository site.

e) The Monitored Retrievable Storage (MRS) facility is authorised, but construction is postponed until the repository construction is authorised.

f) An Office of Subseabed Disposal Research is created within the Office of Energy Research of the Department of Energy to conduct research, development and demonstration activities on all aspects of subseabed disposal of high-level radioactive waste and spent fuel.

Based on the requirements specified in the Nuclear Waste Policy Act and the legislative amendments outlined above, the Department of Energy has developed a draft site characterisation plan for the Yucca Mountain site in Nevada [2]. As part of the site characterisation plan, the DOE will describe the methodology used to identify the information needed from the characterisation study and the tests necessary to obtain that information.

The methodology used in developing the site characterisation plan was, to first identify a common set of issues that must be resolved to demonstrate compliance with applicable Federal regulations and to support site selection and licensing. The next phase was to develop "issue resolution strategies" for each of the issues. Since the issues are derived from applicable Federal regulations, the information needed to resolve them will be the basis for planning of the work that needs to be done to demonstrate compliance with the regulatory requirements. The issue resolution strategy provides a step-wise procedure for identifying and planning the work needed to support resolution of the issues.

As part of the issue resolution strategy, DOE utilises a process called "performance allocation". Performance allocation entails deciding which items within a geologic repository will be relied upon in resolving a particular issue. The function an item must perform and the processes that affect the performance are identified for each item. Using performance allocation, a testing programme can be developed which obtains the information necessary to demonstrate that an item will perform its particular function as expected. Once the appropriate information needs are identified, DOE can identify what underground tests should be conducted.

IN-SITU RESEARCH AND INVESTIGATIONS

The in-situ tests currently being considered for site characterisation at the Nevada candidate site can be grouped under three broad categories: (a) basic geologic characterisation tests; (b) hydrologic characterisation tests; and (c) near-field and thermally perturbed tests. The objective or rationale for performing a test is based on the performance allocation process. The performance allocation process identifies where or how information obtained from a site characterisation test will be used to:

a) Develop a better understanding of physico-chemical processes important for waste isolation;

b) Provide input data for design and performance assessment analyses; and

c) Validate performance assessment models.

As part of the site characterisation plan, detailed test plans and procedures are being written for the tests at the Nevada site. In addition, quality assurance procedures are required to ensure that the test data is accurate, reliable and traceable. Consultative drafts of test plans will be reviewed by the NRC and representatives of the State and Indian tribes in the first quarter of 1988. The test plan may change based on review recommendations or to reflect modifications in the information needs and strategies chosen to resolve the various issues.

Several of the test plans and procedures are being developed based on experience obtained from preliminary tests performed in boreholes in the Yucca Mountain site, or in the underground test facility in G-tunnel. These tests include geophysical investigations, the estimation of in-situ stresses, an excavation effects test and an electric heater test. The tests are useful for developing and evaluating instrumentation and methods for analysing the data obtained, and also for obtaining estimates of the parameter ranges and identifying possible sources of data uncertainty.

DEFENCE WASTE DISPOSAL PROGRAMME

DISPOSAL CONCEPTS AND APPROACH - DEFENCE WASTES

The experimental programme for the Waste Isolation Pilot Plant (WIPP) has been developed by the Department of Energy (DOE) to address those technical issues that concern the safe disposal of Defence Transuranic (TRU) Wastes and Defence High-Level Wastes (DHLW) in underground storage rooms [3]. This programme involves technology development through laboratory and theoretical studies and in-situ testing conducted in representative waste storage room configurations for both the ambient (for TRU) and heated (for DHLW) conditions.

IN-SITU RESEARCH AND INVESTIGATIONS

Technology development studies since 1975 have been investigating phenomena associated with radioactive waste emplacement in a rock salt environment, and have produced response models and predictive techniques using available laboratory and theoretical data. The in-situ testing programme at WIPP has been developed to evaluate these models and predictive techniques through full-size experiments in the actual host rock. The first portion of the in-situ tests (underway since 1984) are without radioactive materials and use electric heaters to simulate heat-generating waste where applicable. The second portion of the in-situ testing programme, scheduled for the early 1990s, will include the use of actual radioactive wastes and other radioactive sources.

The in-situ testing programme includes analyses and evaluations of data obtained from in-situ measurements that provide an understanding of the actual behaviour of salt surrounding full-size storage rooms while undergoing creep closure due to overburden stresses and thermal loadings from waste containers. Data analyses and evaluations also pertain to tests that are designed to measure TRU and DHLW container performance, materials interface interactions, and engineered barriers and seals performance in an actual salt environment. These tests are expected to provide a better understanding of the phenomena, provide in-situ data to validate models and theoretical studies, and demonstrate the behaviour of the salt, waste packages, and engineered barriers and seals in an actual underground salt environment. An underground layout of the in-situ tests at WIPP is illustrated in Figure 24.

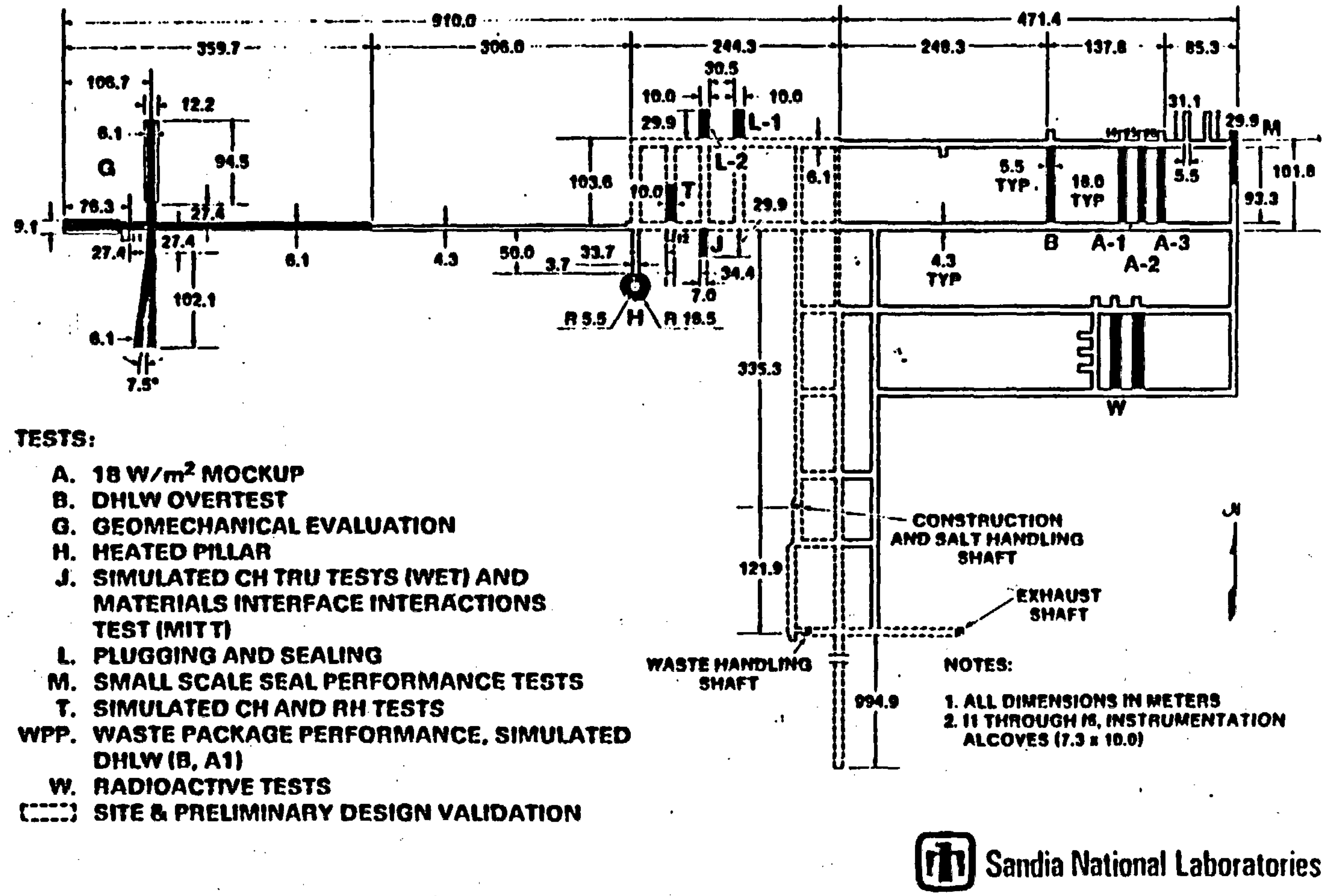


Figure 24. In-Situ Tests, WIPP

6.12 COMMISSION OF THE EUROPEAN COMMUNITIES (CEC)

On-site investigations, either for site characterisation or for generic purposes, has formed a major part of the research activities in the CEC programmes for a considerable time [1]. The activities at Auriat and Fanay-Augères (France), Altnabreac and Troon (UK), Mol (Belgium), Asse and Konrad (FRG), as well as the numerous Italian sites including Pasquasia (Sicily) are now well known. The investigations described below are a logical follow-up of this effort and are conducted within the third Community R&D programme on radioactive waste management and storage (1985-1989) as well as within the radioactive waste programme of the Joint Research Centre of the European Communities.

Underground Pilot Facilities

The salient feature of this programme is the participation of the CEC in the construction and operation of underground demonstration facilities, in which simulated or real waste forms will eventually, in a retrievable manner, be emplaced and monitored. At present, these include the HAW project in the Asse salt mine (GSF, FRG), the HADES project in the Boom clay at Mol (CEN/SCK, Belgium) and the ATLAS project in a medium to be specified in France (ANDRA, France).

The co-operation includes, among other things, participation of scientists of other Member states in the above-mentioned projects, especially by means of temporary secondment of personnel, and the completion of the programmes with their own specific activities, according to modalities specified on a case-by-case basis. The significant participation of ECN (Netherlands) in the HAW project and ANDRA in the HADES project are examples of this.

Site Characterisation and Improvement of Techniques

The main effort at the Community level is directed towards the detection and characterisation of fractures in geological media. A joint project is being undertaken by the BGS (UK), University of Exeter (UK) and ISMES (Italy) for the detection of faults in clays using hydrological techniques, gas emanation measurements and geophysical methods. The BRGM (France) pursues the development of an electromagnetic borehole probe for fracture location in granite. This is complemented by the improvement of geochemical downhole probes (CEA-IPSN). Finally, GSF and ECN are investigating a new deep, dry-drilled, large-diameter exploratory borehole in the Asse salt mine.

Rock Mechanics

This item is now recognised as being of basic importance for geological disposal. The behaviour of the rock mass and its response when subjected to excavation, heat output and gamma radiation from wastes, will be a major item of research for all the demonstration facilities listed above.

Additional specific research is conducted mainly at the Fanay-Augères underground laboratory, where a scaled thermo-hydro-mechanical test is being prepared by CEA-IPSN. The long-term stability of clay, either at ambient or elevated temperature, is being studied at the Mol site by a co-operative programme involving SCK/CEN, ANDRA and its sub-contractors.

As regards salt, a specific effort was made concerning the validation of rock mechanics computer codes via the Community project, COSA. In this project, the behaviour of a salt cube sampled from the Asse Mine and submitted to mechanical and thermal loading was predicted by ten European computer teams working independently under the co-ordination of the firm ATKINS (UK). The exercise was viewed as a useful step towards the quality assurance of the codes. A subsequent phase will consider the retrospective calculation of an in-situ heating experiment in salt.

Backfilling and Sealing

Major contributions are expected from the demonstration facilities, both for buffer and backfill materials. Supporting research will be conducted as regards sealing of in-situ boreholes and fractures in the Fanay-Augères mine (CEA-IPSN), the in-situ thermal testing of a clay-based buffer material at reduced scale (CEA-DRDD) and the behaviour of large, old, backfilled rooms in the Asse salt mine (GSF). The influence of heat on compaction of crushed salt is also being investigated by a heating test in a French potash mine, and is being co-ordinated by ANDRA. Backfilling tests will also be conducted concerning the deep borehole disposal concept in clay, as supported by ENEA and ISMES, to be conducted on an Italian site.

Migration of Radionuclides in the Geosphere

The MIRAGE II Project is continuing previous efforts on radionuclide migration in the geosphere and is now concentrating on five areas: (a) near-field studies with a view to source term; (b) modelling behaviour of actinides and fission products in natural aquifer systems; (c) in-situ migration studies and techniques; (d) natural analogues; and (e) development of geosphere migration calculation tools.

Amongst the actions undertaken in the framework of this project, the intercomparison exercises realised under the auspices of the COCO Club could be mentioned as an example. This exercise examines the role of complexes (humic acids) from specific sites (Fanay-Augèes, Mol, Gorleben) on radionuclide migration and on the characterisation and sampling of colloids from natural groundwater of reference sites. In-situ migration tests are being prepared at Drigg (BGS) and at Mol in the existing laboratory in clay (CEN/SCK). The boreholes at the ISPRA site are the subject of the FARM project by JRC-ISPRA.

Sites such as Loch Lomond (UK) and Langenberg (France) are natural analogues for radionuclide migration in, respectively, sediments and hard rock. These activities occur within the broader scope of the CEC Natural Analogue Working Group, initiated in 1985 by the Commission.

6.13 OECD NUCLEAR ENERGY AGENCY

Disposal into deep geological formations has always been a priority of the RWMC and in 1975 it established the Co-ordinating Group on Geological Disposal (CGGD) to provide advice and develop joint initiatives in this area. The work of the CGGD culminated in 1984 with the publication, jointly with the CEC, of a status report on geological disposal of radioactive waste [1]. One of the main conclusions of the report was that, on the basis of available information, disposal of either high-level waste or spent fuel was technically feasible, and that future research should concentrate on improving the understanding of specific aspects rather than establishing the viability of any particular concept. It further recommended that engineering demonstrations of disposal be conducted to further generate public confidence and understanding. Such findings were to play a major role in formulating the future programme of the RWMC.

The most recent review of the programme of work of the RWMC was conducted near the end of 1984. As a result, it was agreed to focus on two areas of major importance, namely performance assessment, and in-situ research and investigations. It was considered extremely beneficial to have an exchange of views at an international level on both topics, and thus two new advisory groups were established to replace the CGGD. Each group provides advice for the RWMC, helps co-ordinate the various activities in each area and recommends new initiatives where appropriate.

<u>Advisory Group on In Situ Research and Investigations for Geological Disposal (ISAG)</u>

The In-Situ Advisory Group (ISAG) has been established to:

a) Improve information exchange between different field projects and between field projects and performance assessments;

b) Keep close contact with the Performance Assessment Advisory Group (PAAG) on matters of mutual interest (e.g., validation, uncertainties and data acquisition);

c) Identify problems of mutual concern and seek ways that these may be overcome, e.g., by recommending and holding topical workshops;

d) Identify initiatives for co-operation; and

e) Advise the RWMC on matters of interest and/or concern.

In fulfilling the terms of reference, ISAG places emphasis on improving information exchange among field projects located in all candidate host rock formations (i.e., clay, salt, granite, tuff, basalt), and also between those groups or organisations conducting in-situ investigations and those conducting performance assessments. In particular, ISAG incorporates activities associated with:

a) In-situ experimentation at various underground laboratories, eg. Stripa (Sweden), Grimsel (Switzerland), URL (Canada), Mol (Belgium);

b) Investigation of potential disposal sites, e.g., Forsmark (Sweden), Yucca Mountain (US), Konrad (FRG);

c) Engineering and laboratory studies in support of (a) and (b); and

d) Improving information exchange between scientists working in (a), (b) and (c) and those conducting performance assessments.

The NEA International Stripa Project

The International Stripa Project started in 1980 on the strength of the results achieved under the Swedish-American Co-operative Programme which began in 1977. Three phases of research have been agreed: (a) Phase 1 (1980-85); (b) Phase 2 (1983-87); and (c) Phase 3 (1986-91). Research is conducted in a former iron ore mine located in central Sweden in granite bedrock, some 360-400 m below ground.

The International Stripa Project is one of the prime examples of co-operation in the area of radioactive waste management. By combining the resources of several nations, it has been possible to conduct cost-effective field research such that tools and methodologies now exist for the characterisation of granite host rocks to gather data for safety assessments and for designing repository systems. Also, large-scale demonstration experiments have been conducted to enhance confidence in repository design concepts.

NEA Performance Assessment Advisory Group (PAAG)

The objective of PAAG is to provide an international forum to consider post-closure performance assessments for the safe disposal of all radioactive waste types, with the emphasis on the long term, in order to help build confidence within the technical community in this area.

In meeting this objective, PAAG:

a) Exchanges information and experience to further the development of performance assessment methodologies, and avoid duplication of effort;

b) Identifies initiatives for co-operation on the development and use of performance assessment methodologies, in particular in the areas of model development, data acquisition and regulatory requirements;

c) Advises the RWMC on scientific and technical aspects of performance assessments by periodic reports to the Committee; and

d) Assists the RWMC in the co-ordination of existing and new activities of NEA in the area of performance assessments, including peer reviews on request.

The following technical areas are addressed by PAAG: a) Model development - including verification, validation and code development and exchange; b) Data acquisition - including data base development, assessment of uncertainty in data and co-ordination with in-situ research and laboratory studies; and c) Regulatory needs - including the development of performance objectives and criteria. PAAG plays a major role in advising the RWMC on these and related matters.

NEA International Sorption Information Retrieval System (ISIRS)

The International Sorption Information Retrieval System (ISIRS), a data base for the storage and manipulation of information related to the sorption of radio-elements from solution onto geologic materials, was established in 1981 with the support of 11 Member countries. During this period, data base management software was developed by Pacific Northwest Laboratories (PNL) in the United States, acting on behalf of the Operating Agent - the US Department of Energy. In 1983, the Participating countries agreed to transfer the data base and computer software from PNL to the NEA Data Bank at Saclay, France, and recommended that the Technical Committee of ISIRS undertake an evaluation of the performance of the system. Subsequently, the RWMC accepted a recommendation of the Technical Committee that ISIRS be continued as a service to interested countries, within the framework of the NEA.

The objective of ISIRS is to advance the understanding and prediction of the migration of radionuclides through geologic media in support of safety assessments for radioactive waste disposal. Its scope covers:

a) Development and preparation of an expanded data base for the continued operation of ISIRS;

b) Testing and updating of this data base, as well as the maintenance and upgrading of a number of operational features; and

c) Retrieval of data from ISIRS in response to requests from Participants.

NEA Thermochemical Data Base (TDB)

The development of an international chemical thermodynamic data base is a recent activity of the NEA conducted jointly between the NEA Data Bank and the Division of Radiation Protection and Waste Management of NEA. The main difference between the TDB and ISIRS is that, while K_d values are essentially empirical and are intended to represent a number of physical and chemical phenomena acting together in specific circumstances, thermodynamic data are fundamental values which can be used in any specific or generic situation. The development of this data base involves not only a compilation of all relevant published thermodynamic data, but also a detailed critical review and, finally, the selection of a recommended "best data set". The first 10 elements to be reviewed are: uranium, neptunium, plutonium, americium, technetium, cesium, strontium, radium, iodine and lead. The thermodynamic data being compiled and reviewed for each species include:

$\Delta_f G°$	the standard Gibbs free energy of formation	($kJ.mol^{-1}$)
$\Delta_f H°$	the standard enthalpy of formation	($kJ.mol^{-1}$)
$S°$	the standard entropy of formation	($J.mol^{-1}K.^{-1}$)
C_p	the standard heat capacity (at constant pressure)	($J.mol^{-1}K.^{-1}$).

Uncertainties and, if available, the temperature functions are also examined. Emphasis is placed on data for 298.15° K, 10^5 Pa and zero ionic strength.

In addition, an interface programme is being developed which makes it possible to extract specific data from the thermodynamic data base and to convert them into a form in which they are readable by geochemical modelling codes, such as PHREEQE, MINEQL and EQ3/6.

In 1987, an NEA Expert Group on Geochemical Modelling and Data (GGMD) was established primarily to advise on activities related to ISIRS and TDB.

NEA Probabilistic Systems Assessment Code User Group (PSAC)

The PSAC User Group was established by the RWMC in early 1985 following a request from the United Kingdom to help co-ordinate the development of probabilistic assessment codes for radioactive waste management applications. PSAC provides an international forum for:

a) Exchanging information and experience;
b) Comparing and verifying codes;
c) Peer reviews;
d) Conducting joint code development activities; and
e) Discussing topical technical issues.

Only those Member countries actively developing probabilistic systems assessment codes are invited to participate in the User Group. Currently, the 15 Group members are drawn from organisations in Belgium, Canada, Federal Republic of Germany, Finland, Japan, Sweden, Switzerland, United Kingdom and United States, as well as the Joint Research Centre of the CEC.

The main emphasis is placed on code exchange and intercomparison as well as discussion of specific technical issues. No budget is involved although substantial resources are required within Participating countries in order to perform computer calculations and intercomparisons. This activity is conducted in co-operation with the NEA Data Bank.

HYDROCOIN

The NEA is participating in the Secretariat of the Swedish-initiated HYDROCOIN exercise. The purpose of the study is to obtain improved knowledge of the influence of various strategies for groundwater flow modelling for the safety assessment of final repositories for nuclear waste. Calculations are made with different mathematical models used by a number of organisations. The study is intended to address:

a) Impact on groundwater flow calculations of different solution algorithms;

b) Capabilities of different models to describe field measurements; and

c) Impact on the groundwater flow calculations of incorporating various physical phenomena.

The project has fourteen Participating organisations, including the Swedish Nuclear Power Inspectorate (SKI) as managing participant and OECD/NEA as a member of the project Secretariat. It began in 1984 and is currently nearing completion.

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ANNEX I

MEMBERSHIP, NEA ADVISORY GROUP ON IN-SITU RESEARCH AND INVESTIGATIONS FOR GEOLOGICAL DISPOSAL (ISAG)

BELGIUM

BONNE, A., Centre d'Etudes Nucléaires, Laboratories of the SCK/CEN, Boeretang 200, B-2400 Mol.

NEERDAEL, B., Centre d'Etudes Nucléaires, Laboratories of the SCK/CEN, Boeretang 200, B-2400 Mol.

CANADA

SIMMONS, G., Atomic Energy of Canada Limited, Whiteshell Nuclear Research Establishment, Pinawa, Manitoba ROE 1LO.

FINLAND

VUORELA, P., Geological Survey of Finland, Kivimiehentie 1, SF-02150 Espoo.

AIKÄS, T., Teollisuuden Voima Oy, Frederikinkatu 51-53 B, SF-00100 Helsinki.

FRANCE

BARBREAU, A., Commissariat à l'Energie Atomique (CEA), DPT/IPSN, B.P. N° 6, F-92265 Fontenay-aux-Roses Cedex.

ANDRE-JEHAN, R., Agence Nationale pour la Gestion des Déchets Radioactifs (ANDRA), B.P. N° 510, 29-33, rue de la Fédération, F-75752 Paris Cedex 15.

FEDERAL REPUBLIC OF GERMANY

BREWITZ, W., Dr., Gesellschaft für Strahlen und Umweltforschung (GSF), Institut für Tieflagerung, D-3300 Braunschweig.

JAPAN

NAKAMURA, H., Head, High Level Waste Management Laboratory, Department of Environmental Safety Research, JAERI, Tokai Research Establishment, Tokai-Mura, Naka-Gun, Ibaraki-Ken.

YAMAKAWA, M., Dr., Waste Isolation Office, Waste Management and Raw Material Division, Power Reactor and Nuclear Fuel Development Corporation (PNC), 1.9.13 Akasaka, Minato-ku, Tokyo.

KOMATSU, T., Nuclear Fuels Division, Atomic Energy Bureau, Science and Technology Agency, 2-2-1 Kasumigaseki, Chiyoda-ku, Tokyo.

SWEDEN

KAUTSKY, F., Swedish Nuclear Power Inspectorate (SKI), Box 27106, S-102 52 Stockholm.

STILLBORG, B., Dr., Swedish Nuclear Fuel and Waste Management Co. (SKB), Box 5864, S-102 48 Stockholm.

SWITZERLAND

FRANK, E., Dr., Federal Nuclear Safety Inspectorate, CH-5303 Würenlingen.

LIEB, R., Société Coopérative Nationale pour l'Entreposage de Déchets Radioactifs (NAGRA), Parkstrasse 23, CH-5401 Baden.

ZUIDEMA, P., Dr., Société Coopérative Nationale pour l'Entreposage de Déchets Radioactifs (NAGRA), Parkstrasse 23, CH-5401 Baden.

UNITED KINGDOM

BOURKE, P.J., Atomic Energy Authority, Chemistry Division, Building 10.30, AERE, Harwell, Didcot, Oxon OX11 ORA.

BLACK, J., British Geological Survey (BGS), Keyworth, Nottinghamshire NG12 5GG.

UNITED STATES

TYLER, L.D., Sandia National Laboratories, Division 6332, Albuquerque, New Mexico 87185.

NATARAJA, M.S., Chief, Rock Mechanics Section, WMEG, Nuclear Regulatory Commission (NRC), Mail Stop 623-SS, Washington, D.C. 20555.

BUCKLEY, J., Nuclear Regulatory Commission (NRC), Mail Stop 623-SS, Washington, D.C. 20555.

VOSS, C., Battelle Memorial Institute, 2030 M Street Northwest, Suite 800, Washington, D.C. 20036.

MATALUCCI, R.V., Dr., Sandia National Laboratories, Division 6332, Experimental Programs, Albuquerque, New Mexico 87185.

CEC

P., Dr., Commission des Communautés Européennes, Direction Générale XII, 200, rue de la Loi, B-1049 Bruxelles, Belgique.

CÔME, B., Commission des Communautés Européennes, Direction Générale XII, 200, rue de la Loi, B-1049 Bruxelles, Belgique.

NEA SECRETARIAT

OLIVIER, J.-P., Head, Division of Radiation Protection and Waste Management, 38 boulevard Suchet, F-75016 Paris, France.

CARLYLE, S., Division of Radiation Protection and Waste Management, 38 boulevard Suchet, F-75016 Paris, France.

CHAMNEY, L., Division of Radiation Protection and Waste Management, 38 boulevard Suchet, F-75016 Paris, France.

A N N E X I I

SUMMARY OF IN-SITU TESTS

ANNEX II

SUMMARY OF IN-SITU TESTS

BELGIUM

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
Corrosion Experiments	Clay	Mol, HADES	Selection of waste package and structural materials.	Samples in direct contact with clay or with a clay atmosphere.	
Migration Experiments	Clay	Mol, HADES	Determination of various parameters relevant for migration calculations.	Tracered clay slabs are emplaced in the clay and experiments are monitored by overcoring or direct sampling of interstitial fluids.	
Hydrologic Experiments	Clay	Mol, HADES	Determination of hydraulic and hydrologic configuration around underground facility.	Individual pressure meters and piezometers, or arrays of such.	
Bacchus Experiments	Clay	Mol, HADES	Combined backfill-heater test.	Reduced-scale, precompacted clay backfill emplacement and heating experiment. Monitoring of the backfill and surrounding clay mass for heat penetration.	
Geomechanical Experiments	Clay	Mol, HADES	Development of techniques for determination of in-situ geomechanical characteristics and acquisition of data for model support.	Various types: dilatometer tests, convergence-confinement tests, pressure measurements, reduced-scale mine-by test.	[5]

BELGIUM (continued)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
HADES Mine-by Test	Clay	Mol, HADES	Demonstration of mining capabilities and model validation.	Full-scale tunnel construction in clay mass. Equipped with an array of pressure and displacement sensors.	
Cerberus	Clay	Mol, HADES	Combined heat/ irradiation test for demonstration purposes.	Emplacement of a 15 kCi Co source and 500 W heat source in the clay medium and monitoring by temperature sensors. Also, monitoring of gas releases.	

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(1) URL Drawdown Experiment	Granite	URL Lease Area, Manitoba	Process Studies: (1) Validation -Site characterisation methodology -Detailed groundwater system modelling.	Test designed, conducted, modelled and analyzed by AECL. Test also modelled by others. Final analysis of entire test is in progress. Validation of site characterisation methods and models.	[3, 4, 5, 6]
(2.1) Excavation Effects Study (Shaft Between 0 and 255 m)	Granite	Underground Research Laboratory, Manitoba	Process Studies: (1) Coupled hydraulic and mechanical effects of vertical excavation (2) Large-scale mechanical properties. Instrumentation: (1) Geotechnical instrument assessment and development. (2) Hydrogeological/ geomechanical instrument development.	Tests designed, conducted, modelled and analysed by AECL. Tests also modelled and some analyses by others. Modelling and analyses of selected tests. Additional modelling and analysis during 1988. Improvements in stress change and hydraulic head monitoring.	[8, 10]
(2.2) Excavation Effects Study (Room 209 Instrument Array)	Granite	Underground Research Laboratory, Manitoba [Room 209 on the 240-level]	Process studies: (1) Coupled hydraulic and mechanical effects of horizontal excavation. (2) Large-scale mechanical properties (3) Model development and validation. Instrumentation: (1) Mechanical instrument assessment. (2) Hydrogeological/ geomechanical instrument testing.	Test designed and monitored by AECL; field test completed in 1986. Test modelled by 3 groups prior to release of field data. Comparison of models and field data and critical analysis of models is in progress. Assessment of displacement instru-	[9] (preliminary information only)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(2.2) continued				ments and coupled stress change/hydraulic head monitoring is completed.	
(2.3) Excavation Effects Study (Shaft Extension Between 255 and 465 m)	Granite	Underground Research Laboratory, Manitoba [Shaft at depths of 283m, 360m, 417m]	Process Studies: (1) Coupled hydraulic/ mechanical effects of vertical excavation. (2) Large-scale mechanical properties. (3) Model development and testing. Instrumentation: (1) Develop coupled hydrogeological/ displacement instruments.	Tests designed, conducted, modelled and analysed by AECL and US DOE. Tests began in August 1987 and will continue into 1989. Coupled mechanical/ hydraulic measurements are being made. Analyses will be completed in 1990.	
(2.4) Excavation Effects Study (440-level)	Granite	Underground Research Laboratory, Manitoba	Process Studies: (1) Coupled hydraulic/ mechanical effects of horizontal excavation. (2) Large-scale rock mass properties. (3) Model development and testing.	Tests will be designed, conducted modelled and analysed by AECL and US DOE. Tests will begin in 1989.	
(3) Characterise and Grout a Major Sub-horizontal Fracture Zone	Granite	Underground Research Laboratory, Manitoba	Process Studies: (1) Geological, hydrogeological and geochemical characteristics of a sub-horizontal fracture zone. (2) Develop and apply controlled grouting methods. (3) Monitor the coupled mechanical/ hydraulic response of the zone.	Tests are being planned, conducted and analysed by AECL and US DOE. General geological, hydrogeological and geochemical characterisation drilling and instrumentation was completed in 1987; monitoring continues. Geochemical instrumentation installed in 1987 and monitored during	(Documentation is being prepared)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(3) continued				shaft excavation in 1987. Grouting technology demonstration tests have been conducted where the access shaft penetrated the fracture zone. A full grouting test is being planned by AECL and US DOE where the ventilation raise will penetrate the fracture zone; the test will take place in 1989.	
(4) Excavation Response Experiment	Granite	Underground Research Laboratory, Manitoba	Process Studies: (1) Evaluate the ability to predict mechanical and hydraulic response of a rock mass to excavation. (2) Determine the mechanical and hydraulic properties of the rock mass and their coupling. (3) Study the basic mechanisms governing fluid flow and rock mass deformation. Instrumentation: (1) Develop and verify instrument and monitoring techniques for mechanical and hydraulic response.	The experiment is being planned by an AECL and US DOE planning committee; the experiment plan will be completed in 1989 and the experiment is expected to begin in 1990. Data is relevant to repository and geosphere modelling and repository sealing.	
(5) Heated Block Experiment	Granite	Underground Research Laboratory, Manitoba	Process Studies: (1) Determine the in-situ thermal/ mechanical/hydrological	The experiment is being planned by an AECL and US DOE planning committee;	

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION PRESENT STATUS/ OPERATOR	REFERENCES
(5) <u>continued</u>			properties of a specific fracture in a block of rock containing one or more fractures under independently controlled stress and temperature. (2) Develop and verify analytical techniques for assessing the behaviour of fractured rock. (3) Obtain data for studying the effects of specimen scale on fracture properties. <u>Instrumentation</u>: (1) Further develop techniques and instruments to monitor the response of a fractured block of rock.	the experiment plan will be completed in 1989 and the experiment is expected to begin in 1990. The experiment will provide an intermediate point for correlating certain aspects of the behaviour of laboratory specimens with larger in-situ experiments (scale effect studies) and parameters for the design and interpretation of other in-situ experiments.	
(6) Pressure Chamber Experiment	Granite	Underground Research Laboratory, Manitoba	<u>Process Studies</u>: (1) Determine the mechanical, thermal and thermal/mechanical response of a large volume of fractured rock under controlled boundary conditions. (2) Assess the ability of models to simulate the coupled response of a large volume of rock under varying temperature and pressure conditions. (3) Determine the permeability characteristics of a large volume of rock under controlled injection conditions.	The experiment is being planned by an AECL and US DOE planning committee; the experiment is expected to begin in the mid-1990's. This is the only experiment being planned for the URL that will influence such a large volume of the rock mass under controlled experimental conditions. This is the only experiment that will provide in-situ data for the thermal, mechanical and thermal/mechanical	

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(6) continued				response in the geosphere.	
(7) Single-Fracture Migration/Sorption Experiment	Granite	Underground Research Laboratory, Manitoba	Process studies: (1) Determine rates of migration, retardation and sorption, and matrix diffusion along a natural fracture, in-situ. (2) Compare field-derived parameter values with laboratory-derived characteristics to assess the effects of scale, sample preparation and other factors. Instrument and Method Development: (1) Further develop test procedures for in-situ migration studies. (2) Assess and develop analytical and numerical modelling capabilities for non-radioactive and radioactive transport in fractures.	The experiment is being planned by an AECL and US DOE planning committee; the experiment plan will be completed in 1989 and the experiment is expected to begin in 1990. The experiment will provide in-situ data on non-radioactive and radioactive transport in natural fractures and will allow assessment and improvement of models.	
(8) Buffer/ Container Experiments	Granite	Underground Research Laboratory, Manitoba	Process studies: (1) Study under realistic boundary and operating conditions the behaviour of the buffer/container/ borehole cell under: - wet and dry rock/ buffer interface conditions - container/buffer temperatures of less than 100°C and up to 150°C	The experiment is being planned by an AECL and US DOE planning committee; the experiment plan will be completed in 1989 and the experiment is expected to begin in 1990. The performance of the container/buffer/ borehole cell must be understood and	Early concepts discussed in [11]

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(8) continued			- buffer emplaced as pre-compacted blocks and compacted in-situ. (2) Provide a data base on the container/buffer rock system performance to improve, develop and assess models. Instrument and Methods Development: (1) Improve geotechnical instrumentation and sampling methods. Demonstration: (1) Borehole drilling. (2) Buffer compaction.	the modelling and monitoring methods must be developed and demonstrated for use in repository design and performance assessments.	
(9) Borehole Sealing Experiment	Granite	Underground Research Laboratory, Manitoba	Process Studies: (1) Define the engineering properties and permit selection of cement-based materials for sealing boreholes up to 100m in diameter. (2) Compare the hydraulic performance of different seal materials and seal configurations. (3) Develop the testing techniques required to demonstrate the effectiveness of emplaced seals. Demonstration: (1) Develop, test and demonstrate appropriate technology for placing cementatious seals in horizontal and vertical boreholes.	The experiments are being planned by an AECL and US DOE planning committee; the experiment plan will be completed in 1989, and the experiment is expected to begin after 1990. These experiments will assess the effectiveness of cement-based seals as an alternative or a complementary material to the clay-based borehole seals.	Early concepts discussed in [11]

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(10) Shaft Sealing Experiments	Granite	Underground Research Laboratory, Manitoba	Process Studies: (1) Validate models predicting the performance of sealing materials and the physical interactions of backfills and bulkheads with host rock. (2) Compare performance of bulkheads designed using different concepts. (3) Evaluate the relative water flows in the seal, at the seal/ rock interface and in the excavation disturbed zone in the surrounding rock. Instrument and Methods Development: (1) Select appropriate materials and develop and demonstrate emplacement technologies for backfill and cement-based concrete bulkheads in shafts. (2) Evaluate instrumentation, develop associated test methods and demonstrate the ability to test shaft seals.	The experiments are being planned by an AECL and US DOE planning committee; the experiment plan will be completed in 1990. These experiments will assess and demonstrate sealing and backfilling methods for shafts; these studies will support the repository safety assessment.	Early concepts discussed in [11]

FEDERAL REPUBLIC OF GERMANY

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
HLW Test Disposal	Rock Salt	Asse	Demonstration of disposal technique with HLW sources. In-situ tests on thermal and radiation effects on rock salt.	Development and instrumentation of test field. GSF, in collaboration with ECN/ Petten.	[4]
ILW Test Disposal	Rock Salt	Asse	Development and demonstration of borehole disposal techniques, investigation of rock mechanical effects and the behaviour of borehole sealing.	Development and instrumentation of test field. KFA	[5]
Direct Disposal of Spent LWR Fuel	Rock Salt	Asse	Development and testing of a disposal technique for spent fuel elements in 60 Mg waste casks. Investigation of thermo-mechanical effects around disposal drifts.	Development of test field, and testing backfilling. Joint project managed by KfK, and performed in collaboration with BRG,DBE,GSF.	[6]
Disposal of LLW and ILW by In-Situ Solidification In Underground Vaults	Rock Salt	Asse	Demonstration of the in-situ solidification disposal technique for palletised waste.	Development and testing of disposal technique. KfK, in collaboration with GSF, NUKEM.	[7]
Construction of Mine Dams in Salt Formations	Rock Salt	Asse	Development and optimisation of mine dams for the sealing of disposal drifts and mine sections. Testing of short- and long-term permeability (gas and brine).	Development and instrumentation of test field. Selection and testing of building materials. Modelling of test configuration for construction improvement.	[8]

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
continued				Managed by DBE, in collaboration with GSF and BRG.	
Backfilling and Sealing of Boreholes, Disposal Rooms and Drifts	Rock Salt	Asse	Development and testing of backfilling and sealing techniques.	In-situ tests at sealed-off LLW disposal rooms.	[9, 10]
Disposal Borehole (600 m)	Rock Salt	Asse	Development of a dry drilling technique for deep disposal boreholes, including a surveillance method for gas analysis and geotechnical measurements.	Testing of drilling equipment and planning of the in-situ test. ECN, in co-operation with GSF.	[11]
Thermo-mechanical Test Field (TMV 5)	Rock Salt	Asse	Large-scale heater test for investigation of creeping behaviour and the detection of fracturing induced by heat load.	Test field development and instrumentation in progress. BGR.	[15, 16]
Geochemical Tests	Rock Salt (sylvite, halite)	HOPE (abandoned potash mine)	Geotechnical tests in a flooded salt mine for the determination of solution processes as a result of a brine intrusion.	Flooding nearly completed. Investigation programme in progress . GSF in collaboration with Kavernen Bau und Betriebsgesellschaft (KBB).	[12]
Ventilation Test (GSF)	Granitic Rock	Grimsel	Development of methodologies for: Measurement of low rock mass permeability in granitic and fractured rock.	All experiments and tests in operation.	[13]

FEDERAL REPUBLIC OF GERMANY (continued)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
Heater Test (GSF)	Granitic Rock	Grimsel	Measurement of rock stresses with and without heat load.	BGR, GSF.	[14]
Tiltmeter Measurements (GSF)	Granitic Rock	Grimsel	Field data collection on granitic rock.		
Rock Stress	Granitic Rock	Grimsel	Modelling of groundwater flow in fractured rock.		

Note:

BGR = Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover
DBE = Deutsche Gesellschaft zum Bau und Betrieb von Endlagern, Peine
ECN = Netherlands Energy Research Foundation, Petten
GSF = Gesellschaft für Strahlen- und Umweltforschung mbH München
KFA = Kernforschungsanlage Jülich
KfK = Kernforschungszentrum Karlsruhe GmbH
NUKEM = Nuklear Chemie und Metallurgie GmbH Hanau

FRANCE

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
Hydro-thermo-mechanical Test	Granite	Fanay-Augères Mine, Tenelles	(1) To develop a methodology. (2) To develop measurement techniques. (3) To perform, at a reduced scale, the study of the effect of the thermal load simultaneously on the mechanical and hydrological properties of granite in time and space. (4) To develop and compare coupled-model studies of the interaction of thermal effects, mechanical effects and hydrological processes. (5) Validation of models.	Heating source: 1 kW. Measurement of strain, stress and hydraulic conductivity variations of rock. Coupled modelling and intercomparison of models. CEA-IPSN-DPT.	[3]
Scale Effects	Granite	Fanay-Augères Mine, Tenelles	(1) To develop a methodology. (2) To develop measurement techniques. (3) To understand how the hydraulic properties at large scale can be inferred from relatively small-scale measurements. (4) To study hydrological processes. (5) To validate models.	Hydraulic injection test in boreholes. Tracer tests in boreholes. Modelling. CEA-IPSN-DPT.	[3]

FRANCE (continued)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
MIMAFO TEST	Granite	Grimsel Test Site, Switzerland	(1) To develop a methodology. (2) To compare results with other methodologies (radar, seismic tomography). (3) To develop data processing in resistivity mapping.	Resistivity mapping between drift and borehole or between two boreholes at the same place where radar and seismic mapping have already been tested	
Crushed Salt Backfilling	Salt	Alsace Potash mine, Mine Amélie	(1) Thermo-mechanical behaviour of crushed salt and rock salt. (2) Mechanical interaction between crushed salt and rock salt. (3) Evolution of fluids and trapped air in crushed salt pores.	6 vertical boreholes instrumented with electrical heaters (110° C), and with measurement systems for temperature, interstitial pressure and borehole closure.	[1]
Irradiation Effects	Salt	HAW Project, Asse Mine	(1) To develop in-situ dosimetry instrumentation. (2) To determine laws of distribution and geometry of irradiation field. (3) To experiment with irradiation in the laboratory for radiolytic gas measurements.	Measurements of gamma flux in different situations of the irradiation field. Radiolysis of salt samples for gas production and analysis. Co-operative programme between ANDRA and GSF.	
Steel Lining in Deep Clay	Clay	HADES Project, Mol	(1) To design and to develop appropriate support for ribs galleries in deep clay using convergence property of material. (2) "Thin lining" may decrease excavation costs and reduce risk during excavation.	4-m diameter gallery supported by mine steel with sliding joints. Lining is instrumented for: - convergence measurements - stress measurements in lining - joint displacement - 12.5-m gallery completed in December 1987.	[1]

FRANCE (continued)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
Long-term Behaviour of Deep Clay	Clay	Experimental laboratory, Mol	(1) To develop in-situ techniques for geo-mechanical characterisation of non-frozen clay. (2) Long-term behaviour of deep clay in normal conditions and following heating.	Using various types of dilatometers, convergence/confinement test, pressure measurements, reduced-scale mine-by test.	

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
Tracer Test in a Single Fracture (Non-radioactive)	Tuff	Hosokura Mine, Gallery	Hydrological processes. Migration processes. Hydraulic measurements.	First stage of hydrological study.	[3, 9]
Corrosion Test	Tuff	Hosokura Mine, Gallery	Corrosion of simulated borosilicate glass, canister and overpacks.	Two-year study. Mitsubishi Metal Corporation, contracted by PNC.	[3, 9]
Heating Test	Tuff	Hosokura Mine, Gallery	Thermal effects.	These experiments were cancelled by closure of the mine in November 1986.	[10]
Evaluation System on Seismic Characterisation	Tuff	Hosokura Mine, Gallery	Comparative study of influence of earthquakes at deep underground and surface locations. Mechanical effects.	Two-year study. Co-operative research project between PNC and Central Research Institute of Electric Power Industry. Continues until 1989.	[3, 4]
Hydrogeological and Hydrogeochemical Investigations	Granite	Tono Uranium Deposits	Hydrological processes. Methodology and development of hydraulic measurements in boreholes.	Second stage of hydrological study. Shimizu Construction Co.Ltd, Taisei-Kiso Co.Ltd, Geophysical Surveying & Consulting Co.Ltd and Daiwa Consulting Co.Ltd. Contracted by PNC.	[7, 8]
Evaluation of Fracture System in the Deep Geological Environment	Granite	Tono Uranium Deposits	Rock mechanical effects. Characterisation of fracture systems in deep borehole.	First stage of evaluation of fracture systems in a deep borehole. PNC.	[7, 8]

JAPAN (continued)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
Corrosion Test	Granite	Tono Uranium Deposits	Corrosion of simulated borosilicate glass, canister and overpacks.	Two-year study. PNC.	[7]
Heating Tests on Fractures in Granite	Granite	Kasama Granite Quarry	Thermal effects. Permeability. Mechanical effects.	Full-scale test. Thermal conductivity in buffer mass.	[1, 5, 6]
Migration Test in a Vertical Fracture Zone in Granite	Granite	Kasama Granite Quarry	Hydrological processes. Coupled processes.	Non-sorbing tracer test.	
Corrosion Test	Granite	Kasama Granite Quarry	Evaluation of stress. Corrosion cracking.	Room Temperature at 75°C. Hazama-gumi Construction Co.Ltd., et al. Contracted by JAERI.	

SWEDEN

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
Buffer Mass Test	Granite	Stripa	Sealing of rock.	Phase I, II and III.	Reports in the STRIPA series of reports
Crosshole Investigations	Granite	Stripa	Rock mass characterisation.	As above	As above
Hydrogeochemical Investigations	Granite	Stripa	Groundwater characterisation.	As above	As above
Hydrogeological Investigations	Granite	Stripa	Groundwater migration in rock.	As above	As above
Migration Tests in Fractures	Granite	Stripa	Groundwater migration in rock.	As above	As above
Fracture Network Modelling	Granite	Stripa	Rock mass characterisation.	Phase II and III.	As above

SWITZERLAND

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
KRISTAL Deep Drilling Program	Crystal-line basement	Northern Switzer-land	Instrumentation development. Regional site characterisation of potential HLW sites.	Drilling and coring, geophysics, hydraulics, hydrochemistry. 6 boreholes drilled; interpretation in progress. Next drilling in 1988.	[1, 2, 3, 4, 5, 6]
OBS	Marl	Oberbau-enstock	Site characterisation of potential LLW/ILW sites.	Geophysics, drilling and coring, hydraulics, hydro-chemistry. OBS,PPG,BdG: First phase, 1987. WLB: expected start in 1988.	[7, 8, 9, 10]
PPG	Gneiss	Piz Pian Grand			
	Anhydrite	Bois de la Glaive			
WLB	Marl	Wellenberg			
GTS . Excavation effects . Geophysics . Thermal effects . Hydrogeology . Migration . Neotectonics . Rock stress	Granite	Grimsel Test Site	Process studies (hydrogeological, nuclide transport, thermal effects). Instrumentation (hydrological, geophysics, rock stress). Demonstration (tunneling).	Started in 1983. Some tests accomplished; some are still operational. Programme to 1990.	[11, 12, 13]

UNITED KINGDOM

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
Drigg In-Situ Migration Experiments	Glacial Sand	Drigg, Cumbria	Combination of far-field modelling validation and instrument/methodology development.	On-going. Tracer studies with radioactive tracers. BGS, Coughborough Univ., Univ. of Wales, Inst. of Science and Technology, Delft Soil Mechanics Laboratory.	[5, 6, 7, 8, 9, 10]
Faults in Clay	Clay/ Mudrock	Wiltshire	Assessment of site investigation methods. Application to far-field modelling of migration.	On-going (1986-1989). Geophysical detection and hydrogeology of faults. Far-field modelling. BGS, ISMES (Italy) and Univ. of Exeter.	Only internal progress reports to date.
Site Characterisation and Validation	Granite	Stripa	To simulate site characterisation and to validate far-field models.	On-going (1986-1991). Development of site investigation and characterisation methodologies. Stripa Project [BGS, SGAB].	[5, 6, 7, 8, 9, 10]
Heat Transfer	Granite	Harwell Granite Research Site, Cornwall	Study heat transfer to predict temperature of HLW and thermally induced water flow.	Completed; has yielded data for modelling purposes. Harwell.	[2]
Fracture Flow	Granite	Harwell Granite Research Site, Cornwall	Obtain statistics on occurrence, orientation, aperatures and connections of water-bearing fractures.	Completed; has provided data for modelling of water flow and radionuclide movement. Harwell.	[3, 4]

UNITED KINGDOM (continued)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
Fracture Flow	Shale	Harwell Shale Research Site, Cornwall	Study of flow and channelling in fractures and fault zones.	Started 1987. Development of models. Harwell.	
Radionuclide Diffusion	Clay	Mol, Belgium	Measurement of radio-nuclide diffusion.	To start 1987-1988. Comparison with laboratory data. Harwell.	
Water and Gas Flows	Clay	Site to be announced	Study of flows through permeable layers and fractures.	To start 1987-1988. Assessment of importance of fast-leakage pathways. Harwell.	

UNITED STATES

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
A. <u>BASIC GEOLOGIC CHARACTERISATION TESTS</u>:					
(1) Drift-Wall Mapping	Tuff	Yucca Mountain, Nevada (NNWSI)	Document lateral variability/lithologic continuity. Obtain information on fractures for assessing host rock isolation and containment ability.	Drift mapping along approx. 100-m exposures in several directions from exploratory shaft facility (ESF). Data to be combined with fracture-mapping to determine 3-D fracture network.	[2]
(2) Lateral Coring from Drifts	Tuff	NNWSI	Study structural/lithologic continuity within waste emplacement block beyond the drifts.	Data will add to ability to extrapolate results of in-situ tests within the ESF to rest of repository.	[2]
(3) Borehole Condition/ Convergence Monitoring	Tuff	NNWSI	Monitoring of borehole stability convergence and related rock mechanics/engineering properties.	Monitored in selected instrumentation boreholes, and demonstration tests of large-diameter horizontal boring machine.	[2]
(4) Overcore Stress Tests	Tuff	NNWSI	Determine in-situ stresses, in order to optimise repository design, evaluate excavation stability, and obtain input and boundary condition data for geomechanical models.		[2]

UNITED STATES (continued)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(5) Demonstration Breakout Room Test	Tuff	NNWSI	Evaluate rock-mass responses to mining effects.		[2]
(6) Sequential Drift-Mining Test	Tuff	NNWSI	Validate geomechanical models. Define limits for the relaxed zone. Improve mining evaluations. Correlate air and water permeability measurements for reference in hydrological calculations.		[2]
(7) Crosshole Seismic Test	Tuff	NNWSI	Obtain calibration data for gross rock characteristics and fracture variabiltiy in order to assist extrapolation of structural and stratigraphic conditions.		
(8) Seismic Surveys	Tuff	NNWSI	Obtain geologic data.	Seismic refraction/ reflection studies.	[2]
(9) Caliper Log	Tuff	NNWSI	Evaluate formation damage and monitor changes in borehole diameter.		[2]
(10) Gamma-density Log	Tuff	NNWSI	Identify differences in lithology, stratigraphy and mineralogy.	Measurements of apparent bulk density.	[2]
(11) Sonic Log	Tuff	NNWSI	Detect changes in lithology and stratigraphy, porosity and dynamic modulus.		[2]

UNITED STATES (continued)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(12) Neutron-Epithermal Neutron Log	Tuff	NNWSI	Determine moisture content and bulk porosity.		[2]
(13) Fluid Temperature Log	Tuff	NNWSI	Detect occurrence of perched water zones.		[2]
(14) Electric Survey	Tuff	NNWSI	Identify anomalies/ discontinuities.		[2]
(15) Shaft Convergence Test	Tuff	NNWSI	Determine horizontal stresses. Evaluate relaxation phenomena as they apply to material characterisation/shaft design.		[2]
(16) Plate-loading Test	Tuff	NNWSI	Assemble data base of deformation modulus measurements. Determine large-scale deformation modulus.	Used for performance assessment sensitivity analyses, and for extrapolation to adjacent rock masses.	[2]
(17) Slot-strength/Flat Jack Test	Tuff	NNWSI	Determine field-scale compressive bearing strengths, for comparison to laboratory measurements.		[2]
(18) Boring Machine Test	Tuff	NNWSI	Demonstrate boring machine technology to bore long horizontal waste canister emplacement holes.		[2]

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
B. <u>HYDROLOGIC CHARACTERISATION TESTS</u>:					
(1) Matrix Property Test	Tuff	NNWSI	Determine magnitudes/ variations of rock matrix hydrologic properties. Determine functional relations between moisture content, permeability and matrix potential.		[2]
(2) Intact-fracture Test	Tuff	NNWSI	Evaluate fluid flow/ chemical transport properties of single, undisturbed fractures. Calibrate, test and validate fracture flow models.		[2]
(3) Infiltration Test	Tuff	NNWSI	Determine the hydrologic conditions under which fracture and matrix flow occurs.		[2]
(4) Bulk Permeability Test	Tuff	NNWSI	Determine validity of continuum hypothesis for fluid flow. Evaluate excavation effects.		[2]
(5) Radial Borehole Test	Tuff	NNWSI	Detect vertical movement of water in the unsaturated zone. Evaluate potential for lateral movement of water. Evaluate excavation effects on hydrologic properties.	Test will provide data on tortuosity, effective porosity and the unsaturated zone.	[2]

UNITED STATES (continued)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(6) Excavation Effect Test	Tuff	NNWSI	Estimate effects of shaft excavation and lining on modification of hydrologic properties.	Topopah Spring welded unit.	[2]
(7) Hydrochemistry Test	Tuff	NNWSI	Estimate resistance time of water. Evaluate chemical reactions operative in unsaturated zone. Evaluate recharge characteristics.	Data on chemical composition/physical properties of water in pores, fractures and perched zones within the unsaturated zone.	[2]
(8) Tracer Test	Tuff	NNWSI	Determine vertical flow rates through unsaturated zone to water table. Determine extent to which nonsorbing tracers diffuse into water-filled pores of tuff.		[2]
(9) Perched-Water Test	Tuff	NNWSI	Evaluate hydrogeology of Calico Hills nonwelded unit. Determine realistic hypotheses for mechanisms of flow, flow paths and travel times.		[2]
C. NEAR-FIELD AND THERMALLY PERTURBED-ZONE TESTS:					
(1) Waste Package Environment Test	Tuff	NNWSI	Assess expected performance of waste package subsystem.	Obtain information on near-field hydrological, thermal and mechanical conditions.	[2]

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(2) Canister-scale Heater Test	Tuff	NNWSI	As above for NNWSI.	Will include monitoring radon/radon daughter concentration accumulation as a function of heat load.	[2]
(3) Small-scale Heater Test	Tuff	NNWSI	Evaluate thermal behaviour of welded tuff. Monitor possible migration patterns around heater. Verify laboratory/field scaling assumptions by evaluating thermo-mechanical expansion parallel to the heater.		[2]
(4) Heated Block Test	Tuff	NNWSI	Validate 3-D deformational and temperature models. Determine dependency of fracture permeability on stress and temperature. Monitor changes in moisture content distribution as a function of temperature and position for performance assessments. Evaluate potential of cross-borehole measurements for monitoring mechanical and hydrological changes.		[2]

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
D. <u>THERMAL/ STRUCTURAL INTERACTIONS</u>:			Address technical issues of underground stability and rock deformation.		
(1) Room Thermal Loading Test	Salt (Bedded)	S.E. New Mexico; Waste Isolation Pilot Plant (WIPP)	Understanding/demonstration of behaviour of a full-sized Defence High-Level Waste (DHLW) storage room (structural stability; extent of heat transfer to host rock and effects on room deformations). Validate predictive models and techniques.	Rooms (5.5 m x 5.5 m) represent a reference storage room with waste canisters vertically emplaced in the floor. US DOE; Sandia National Laboratories (SNL).	[3]
(2) DHLW Overtest of Thermal Effects	Salt (Bedded)	WIPP	Evaluate effects of high heat on storage rooms, and on the structural stability and waste encapsulation potential of storage rooms. Validate predictive techniques for accelerated thermal conditions. Evaluate long-term effects of heat and room closure on crushed-salt backfill.	US DOE; SNL.	[3]
(3) Heated Pillar Test	Salt (Bedded)	WIPP	Evaluate response of a large rock mass, and validate predictive models for response under stress and thermal loadings: - Behaviour of room and pillar as a result of salt creep - Mechanical properties/ failure modes. Compare data to laboratory-model pillar test data, and to data from other salt mines.	11-m diameter salt pillar surrounded by heater blanket. Geometry permits evaluation of structural finite-element codes by using an axisymmetric 2-D model. US DOE; SNL.	[3]

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(4) Geomechanical Evaluation	Salt (Bedded)	WIPP	Evaluate behaviour of different drift cross-sections and geometries, and validate models/ codes to predict responses: - Effects of room geometry on creep deformation of 2-D drifts - Response of 3-D drift intersection and the validity of using 2-D models. Verify techniques for developing drift designs.	Phased mining of a long 2-D drift, a 3-D drift intersection and a wedge-shaped salt pillar. Wedge pillar designed to fail in order to study/define failure mode from observations of acoustic emissions and deformation measurements. US DOE; SNL.	[3]
(5) In-Situ Stress Test	Salt (Bedded)	WIPP	Verify hydrostatic stress states assumed to exist at the site, and compare in-situ stress data with laboratory data.	Series of long boreholes drilled horizontally along the axes of drifts to be excavated later. Hydrofrac tests conducted. Fluorescent dye added to hydraulic fluid to facilitate measurement. US DOE; SNL.	[3]
(6) Clay-Seam Shear Test	Salt (Bedded)	WIPP	Evaluate relevant response and stability characteristics of the test rooms: - Determine the effective friction coefficient of clay seams - Compare laboratory and in-situ data - Evaluate calculated displacements along clay seams.	US DOE; SNL.	[3]

UNITED STATES (continued)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(7) Acoustic Emissions Monitoring	Salt (Bedded)	WIPP	Evaluate salt fracturing and development of progressive failure of a salt pillar: - Timing of yielding and fracturing - Failure mode - Ultrasonic velocity of salt.	US DOE; SNL.	[3]
E. PLUGGING AND SEALING:			Measurements of (1) characteristics of formation fluid flow, and (2) material performance for restricting fluid flow through man-made openings.		
(1) Permeability Measurements	Salt (Bedded)	WIPP	Evaluate fluid flow characteristics, potential accumulation and dissipation of waste-generated gas, and influence of the disturbed zone.	Will examine permeability/porosity, permeability variations with distance from the mined face, and influence of interspersed clay and anhydrite seams. US DOE; SNL.	[3]
(2) Plug Test Matrix	Salt (Bedded)	WIPP	Evaluate long-term durability of plug material in host-rock environment: - Interactions and geochemical stability of candidate plug materials - Emplacement techniques - Post-test laboratory investigations of samples.	Plug materials (grouts, concretes, salt mixtures) placed in boreholes and subjected to ambient, wet and thermally elevated conditions. US DOE; SNL.	[3]

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(3) Borehole Plug Test	Salt (Bedded)	WIPP	Assessment of material type and emplacement technique appropriate for plugging and monitoring plug performance in deep boreholes: - Sealing performance - Interaction of plugs with host-rock - Emplacement techniques/ procedures - Stability/durability of recovered plug materials.	US DOE; SNL.	[3]
(4) Gas Testing	Salt (Bedded)	WIPP	Characterisation of naturally occurring gas (nitrogen) entrapped in the host-rock. Evaluate impact of discovered gas on operational safety. Determine gas pressure, void volume and geometry and gas composition.	US DOE; SNL.	[3]
(5) Small-scale Seal Performance Tests	Salt (Bedded)	WIPP	Evaluate emplacement techniques and in-situ performance of candidate seal materials. Evaluate structural behaviour and geochemical interactions of the seal materials/host rock. Evaluate time-dependent and sealing effects of the seal/host rock interactions. Develop and validate predictive techniques and models.	US DOE; SNL.	[3]
(6) Large-Scale Seal Performance Test (Bulkhead Test)	Salt (Bedded)	WIPP	Evaluate and demonstrate performance of a full-sized seal emplaced in a drift-like configuration.	Current seal design concept consists of: (1) a bentonite centre core, (2) a salt-brick and mor-	[3]

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(6) continued			Address emplacement techniques, structural integrity and fluid flow restriction capability. Validate flow and structural models.	tar support structure and (3) cementitious material on both ends. US DOE; SNL.	
(7) Backfill Emplacement	Salt (Bedded)	WIPP	Evaluate and demonstrate full-scale backfill emplacement techniques/ equipment. Determine achievable emplacement consolidation of candidate backfill materials for use in modelling and structural analyses. Determine structural interactions/fluid flow performance of a backfilled storage room.	Crushed-salt-based backfill in storage rooms. US DOE; SNL.	[3]
(8) Moisture Transport and Release Tests	Salt (Bedded)	WIPP	Develop predictive models for moisture transport, release and accumulation: - Characterise/model movement of naturally occurring moisture in the host rock. - Evaluate quantity, rates and characteristics of moisture release to openings as a function of temperature and time.	Measuring moisture release to both heated and unheated boreholes drilled in test rooms. US DOE; SNL.	[3]
F. WASTE PACKAGE PERFORMANCE:			Measurements of near-field effects adjacent to waste container to evaluate durability and containment integrity of the waste package.		

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(1) Simulated DHLW Technology Experiments	Salt (Bedded)	WIPP	Evaluate performance and containment integrity of DHLW packages in a non-radioactive environment. Evaluate interactions of waste containers, back-fill materials and host rock.	Emplacement of 18 full-size simulated DHLW package in boreholes. Some containers intentionally defected. US DOE; SNL.	[3]
(2) Materials Interface Interactions Tests	Salt (Bedded)	WIPP	Evaluate various waste forms and package materials as they interact in a relevant brine and thermal environment: - Performance of non-radioactive DHLW glass (DWPF) - Compare DWPF performance to other waste glasses. Develop technical data base.	US DOE; SNL.	[3]
(3) Simulated CH and RH TRU Technology Experiments	Salt (Bedded)	WIPP	Evaluate durability, corrosion behaviour and crushing resistance of waste containers. Evaluate interactions of the waste containers with several backfill materials, and the migration and sorption of non-radioactive chemical tracer migration by these backfill materials.	CH: Contact-handled. RH: Remote-handled. US DOE; SNL.	[3]
(4) WIPP Radioactive Tests	Salt (Bedded)	WIPP	Evaluate near-field radionuclide migration (waste-form leaching release). Conduct/evaluate the safe handling and retrieval of radioactive materials. Evaluate moisture-release phenomena and	To be conducted in early 1990s. US DOE; SNL.	[3]

UNITED STATES (continued)

TEST NAME	ROCK TYPE	SITE/ PROJECT	PURPOSE OF TEST	DESCRIPTION/ PRESENT STATUS/ OPERATOR	REFERENCES
(4) continued			effects of radiolysis on waste package materials and backfills. Verify phenomenological and predictive models. Evaluate cost effectiveness of waste package and backfill designs.		