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UNITED KINGDOM NIREX LIMITED

Rock Characterisation Facility

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PROOF OF EVIDENCE

OF

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SCIENCE OVERVIEW

CONTENTS

TABLE & FIGURES

Back to NRX13 Menu . Back to POE Menu . Back to Homepage

DR JOHN HOLMES will say:

1. PERSONAL DETAILS

1.1 I am Director for Science for United Kingdom Nirex Limited ('Nirex'), an appointment I took up in October 1992. I have overall responsibility for the Science Programme that Nirex is undertaking to assess the post-closure safety performance of a repository at Sellafield and to provide information to assist in its design.

1.2 I hold a first-class honours degree in Natural Sciences from Cambridge University, a PhD in Mechanical Engineering from Imperial College, London, and a Master of Business Administration degree from Brunel University. I am a Chartered Engineer, a Fellow of the Institute of Energy and a Member of the Institute of Management. Since September 1994 I have been a UK representative on the Organisation for Economic Co-operation and Development ('OECD') Nuclear Energy Agency's Radioactive Waste Management Committee.

1.3 Prior to my appointment at Nirex, I was employed by British Coal (formerly National Coal Board). Between 1979 and 1990 I worked at British Coal's Coal Research Establishment where I successively held the posts of Project Engineer, Head of Technology Assessment Group, Head of Physics Group and Head of Power Generation Branch. These appointments gave me experience of managing research and development projects requiring the integration and coordination of a broad range of scientific and engineering disciplines. Between 1990 and 1992 I was a member of the Directing Staff of British Coal's Management Centre.

2. SUMMARY

Scope of Evidence

2.1 The scientific evidence presented by myself and Drs Chaplow, Hooper and Mellor addresses matter 6 identified by the Secretary of State in his Rule 6(10) Statement of 27 February 1995. My evidence sets the context for the detailed scientific evidence of Drs Chaplow, Hooper and Mellor.

Repository Concept and Regulatory Framework

2.2 The Nirex repository concept for the Sellafield site has been developed as a multi-barrier containment system comprising engineered (physical and chemical) and natural barriers. The engineered barriers are designed to retain most (around 99.99%) of the radioactivity in the vaults. The natural barrier is provided by the geological setting of the repository which should ensure low flow of groundwater through the repository to permit the effective operation of the engineered barriers. It should also ensure sufficient dilution of those residual radionuclides that escape from the vaults in order to limit concentrations in groundwater reaching the surface.

2.3 Government stated in the *1995 White Paper* (para 78, page 22) [GOV/208] that a risk target is appropriate as an objective in the design process for a repository and that this should be a risk to an individual of 10^{-6} per year of developing either a fatal cancer or a serious hereditary effect.

Nirex Science Programme

2.4 The objective of the Nirex Science Programme is to evaluate the post-closure safety performance of a repository at Sellafield. The Nirex management team for the Science Programme directs the activities of interdisciplinary and experienced teams of specialist contractors and consultants towards the effective achievement of this objective.

2.5 Quality assurance procedures and independent peer review contribute to the achievement of high standards of scientific work, as recognised by the RWMAC and by the Royal Society Study Group which reviewed the Nirex Science Programme. Wide ranging peer review is assured by the dissemination of results from the programme : 500 reports, journal articles and conference papers have been published to date.

2.6 The Nirex programme, in common with deep disposal programmes overseas, makes extensive use of models in its evaluation of post-closure safety performance. Building confidence in this evaluation is largely about building confidence that the models are adequate representations of reality. Testing (validation) of the models involves the systematic comparison of model predictions with independent field operations and experimental measurements. The RCF programme is essential in this process.

The Need for the RCF

2.7 Current models of groundwater flow at Sellafield predict flow through a repository and dilution of radionuclides emerging in groundwater from a repository which, when taken with our current view of other factors influencing repository performance, indicate that a repository could be developed at Sellafield which would meet regulatory requirements.

2.8 However, limitations on observations that can be made using surface-based investigations currently allow other models to be developed which would predict groundwater flow and dilution inconsistent with meeting regulatory requirements for post-closure safety of a repository.

2.9 The RCF is needed to acquire information that will allow us to test our judgements on, and firm-up our descriptions of, the networks of connected fractures in the BVG and overlying sedimentary rocks, thought to have lengths of up to hundreds of metres, which control flow and dilution. This will allow us to narrow the range of predictions of flow and dilution, and to apply models with confidence across the PRZ and surrounding rocks.

2.10 The RCF will enable us to overcome limitations of surface-based investigations by allowing us to investigate on lengthscales of tens and hundreds of metres the networks of connected fractures. We will also be able to make direct observations in three dimensions rather than in essentially one dimension in a borehole.

2.11 The RCF is also needed:

- to establish that construction of the repository, or future naturally induced changes, would not result in new pathways for water flow which would significantly impair repository performance; and
- to permit decisions on repository depth, location, layout and orientation.

2.12 The RCF is to be developed in three phases and a decision on whether to propose development of a repository could be made at the end of the first, shaft sinking phase. If the site is found suitable and so a decision is made to propose repository development at this stage, work would need to continue into Phases 2 and 3 to address remaining uncertainties, and so ensure that the repository would be constructed as soon as reasonably practicable, in line with Government policy. Results from that work would probably be reported within the framework of a plan, agreed with the regulatory authorities, for the progressive supply of information leading to a decision by the regulatory authorities on approval to start disposal of wastes in the repository following its construction and commissioning.

2.13 As with any scientific investigations, progress cannot be planned with precision. Results from Phase 1 of the RCF could be inconclusive and provide insufficient confidence to extrapolate models across the PRZ. In this case, it would be necessary to carry out further investigations over more of the PRZ using the galleries planned for Phase 2 and possibly Phase 3, before a decision on whether to propose repository development is made. A flexible approach is needed in planning the design of Phase 2 and Phase 3 galleries so that they could permit access to specific features of the rock, as necessary, to address specific uncertainties which may remain in the future.

Responses to Nirex's Plans for the RCF

2.14 The need for the RCF in Nirex's programme to evaluate the suitability of the site at Sellafield has been recognised by the RWMAC, the Royal Society Study Group and the Nirex Review Panel. ERM, advisers to Cumbria County Council, have expressed the view that the proper assessment of a site for the long-term disposal of radioactive waste needs to include a stage of underground experimentation and validation.

Programmes in Other Countries

2.15 Review of planned repository programmes in other countries leads to the conclusion that the proposal to carry out a stage of underground investigations in an RCF at Sellafield prior to a decision on whether to propose development of a repository is consistent with general practice internationally.

3. SCOPE OF EVIDENCE

3.1 The scientific evidence presented by myself and Drs Chaplow, Hooper and Mellor addresses matter 6 identified by the Secretary of State in his statement of 27 February 1995:

> "*The results available so far from studies and surveys of the geology and hydrogeology of the area; the additional information that might become available only from the RCF, if developed; and the benefits to be gained from obtaining that additional information, if any, weighed against the possible impact the RCF might have on the site and surrounding area.*"

3.2 I have overall responsibility for the Science Programme and head the team of senior managers of the Science Programme comprising Drs Chaplow, Hooper and Mellor. My evidence sets the context for their detailed scientific evidence. They are responsible for managing a substantial multi-disciplinary programme, carried out primarily by specialist contractors in the various fields, and each is supported by an inhouse team of Nirex scientific staff. They will summarise and interpret the substantial body of information arising within their respective areas of responsibility in a manageable form. The size of this body of information is illustrated by the number of reports which record it: 500 published reports, journal articles and conference papers and 1,600 volumes of underpinning factual data on geology and hydrogeology.

3.3 The evidence of Dr Chaplow and Dr Hooper establishes that the results available so far support the continuation of investigations at Sellafield, which continues to hold good promise as a potentially suitable location for a repository.

3.4 Their evidence also identifies areas of uncertainty where information is required from the RCF to enable Nirex to decide whether to propose development of a deep repository for disposal of radioactive waste at Sellafield and to obtain regulatory approval to start disposal operations if a repository is constructed. They will explain why the required information cannot be obtained by other means.

3.5 Dr Mellor describes the programme of activities planned for the RCF to deliver the necessary information and explains how the RCF has been designed to enable those activities to be carried out.

3.6 As a context for their evidence remaining sections of this Proof of Evidence present the following information:

Section

> 4 : describes the Nirex repository concept for Sellafield and summarises the regulatory framework.
>
> 5 : summarises the approach being followed to develop an assessment of the post-closure safety performance of a repository at Sellafield.
>
> 6 : summarises the results so far and key remaining uncertainties, and describes the role of the RCF in addressing those uncertainties.
>
> 7 : summarises responses to Nirex's plans for the RCF.
>
> 8 : compares the Nirex programme to characterise the Sellafield site with programmes for the evaluation of sites for deep repositories for radioactive waste in other countries.

4. REPOSITORY CONCEPT AND REGULATORY FRAMEWORK

Repository Concept

4.1 In order to provide safe disposal of radioactive wastes a repository and its geological setting must ensure that any radionuclides that are released before they have decayed do not return to the surface at concentrations which would pose radiological risks exceeding regulatory requirements.

4.2 The Nirex repository concept for the Sellafield site has been developed to achieve this objective. The concept takes account of the geological setting and of the nature and quantities of wastes in the disposal inventory. Nirex is currently planning on the basis of a design capacity of 300,000 m^3 of Intermediate-Level Waste and 100,000 m^3 of Low-Level Waste disposed over a period of 50 years.

4.3 In common with other disposal agencies internationally, Nirex has a disposal concept which uses a multi-barrier containment system. Vaults would be excavated at depth in a stable geological setting. Wastes, packaged in steel or concrete containers, would be placed in the vaults which would then be backfilled with a cement-based material. The concept is illustrated in Figure 4.1.

4.4 It makes use of both engineered (physical and chemical) and natural barriers. The physical barrier would be provided by the containers and grouts in which the wastes are packaged. Results of research to date indicate that a very high level of physical containment should be maintained for at least one thousand years, during which period around 99% of the radioactivity in the repository would decay.

4.5 The chemical barrier would be provided by surrounding waste packages with a cement-based backfill. It would operate over a longer period than the physical barrier (around 1 million years or more) and would act to contain most (around 99%) of the long-lived radionuclides (i.e. the 1% of the total radioactivity which is not contained by the physical barrier). The main way in which radionuclides can potentially be transported away from the vaults is by flow of groundwater. The backfill works by making the groundwater entering the repository vaults alkaline (high pH). These alkaline conditions ensure that many radionuclides, for example plutonium and uranium, are not very soluble and hence the groundwater cannot transport them in solution away from the vaults. Also, the backfill is porous and the pore surfaces are able to retain radionuclides that have dissolved in the groundwater by the process of sorption.

4.6 The natural barrier would be provided by the geological setting of the repository. By placing the wastes deep below the ground in stable rocks with little natural resource potential they would be isolated from the effects of naturally occurring processes, for example future ice ages, and human activities. Understanding developed through the Nirex programme to date indicates that, as well as providing a mechanically stable environment for the waste packages and the surrounding backfill, the geological barrier has, in practice, two key functions in respect of transport of radionuclides in groundwater:

- to ensure that there are low flows of groundwater through the repository so that the physical and chemical barriers can operate to retain short-lived and most long-lived radioactivity; and
- to ensure sufficient dilution of those residual radionuclides that are released from the vaults in order to limit concentrations in groundwater reaching the surface.

4.7 Establishing whether the geological setting at Sellafield can perform these two functions is a key objective of the Site Characterisation Programme and of the RCF.

4.8 Corrosion of the containers and degradation of organic matter in the repository would generate gas, a very small proportion of which is radioactive. The gas must not build up pressures that would damage the repository and surrounding rocks, and hence the backfill and surrounding rocks need to be sufficiently permeable to gas to permit it to escape from the vaults. The geological setting needs to have characteristics which ensure that gas does not reach the surface in concentrations that would pose a flammability hazard or lead to concentrations of radionuclides in gas at the surface which would pose radiological risks exceeding regulatory requirements.

4.9 Paragraphs 4.5 and 4.8 above have identified two potential pathways for radioactivity to return to the human environment: transport of radionuclides in groundwater and migration of radionuclides in gases. A third may also be identified being return of radionuclides to the environment as a result of natural disruptive events or inadvertent human intrusion. These pathways need to be considered in order to evaluate whether a repository located at Sellafield would be safe after closure. For each pathway, it is necessary to consider how much radioactivity may return to the surface, at what time, and the likely impact on future human inhabitants of the area affected. Potential for interactions between the pathways must also be considered. Particular attention has been given to the groundwater pathway which has the potential to return more radioactivity to the surface than other pathways. Dr Hooper's evidence describes Nirex's approach to the evaluation of risk arising from the groundwater pathway and our current estimates of that risk. He also summarises the current position on our understanding of the other pathways.

4.10 In order to evaluate safety, the overall system performance of the repository, i.e. the combined effect of its engineered and natural components, needs to be considered. The characteristics of the site are an input to this evaluation of overall system performance. As understanding of the issues which are most important to system performance increases, the design of the repository is refined in order to ensure that best practicable means are used to limit risks as required by the regulatory framework described in the following paragraphs.

Regulatory Framework

4.11 Current Government policy on the standards of safety for a deep repository, and the nature of the safety case that must be made, is set out in the *Review of Radioactive Waste Management Policy*, *Final Conclusions* White Paper issued in July 1995 (*"The 1995 White Paper"*) (paras 74 to 82, pages 21 to 23) [GOV/208]. This White Paper (para 74, page 21) [GOV/208] states that in terms of policy the 1984 Green Book (*Disposal Facilities on Land for Low and Intermediate Level Radioactive Wastes - Principles for the Protection of the Human Environment)* [GOV/302] is superseded by that White Paper and its regulatory requirements are also now out of date. The White Paper makes reference at paragraph 74 to the Regulators' Consultation draft of *Guidance on Requirements for Authorisation* under RSA93 issued in August 1994 ("*HMIP Consultation Document*") [GOV/307].

4.12 Relevant Government Policy on the environmental safety criteria for radioactive waste repositories is set out in paragraphs 75 and 78 of the *1995 White Paper* [GOV/208]:

> "*75. Forming a judgement about the level of safety afforded by a disposal facility involves assessment of the means by which radionuclides in the wastes might move from the wastes through the immediate physical and chemical environment of the facility (and, in the case of deep disposal, through the surrounding host rocks) back to the human environment. For deep disposal facilities, this involves considering the potential behaviour of radionuclides over extended periods - in excess of thousands of years. The safety case provided by a repository developer or operator will need to address all these issues. The regulators will need to be satisfied that good engineering practice has been used in developing proposals for design, construction and operation of the facility and that good science has been adopted in investigating the suitability of the site, in supporting research and development work, in the interpretation of the resulting data and in the development of safety assessment methodologies.*
>
> *78. In the Government's view, the nature of the disposal system makes it less amenable to such quantified risk assessments than is the case, for example, for new nuclear reactors. Reliance cannot be placed exclusively on estimates of risk to determine whether a disposal facility (or a nuclear plant) is safe. While such calculations can inform a judgement about the safety of a facility, other technical factors, including ones of a more qualitative nature, will also need to be considered in arriving at the decision. The Government therefore confirms the preliminary conclusion of the review that it is inappropriate to rely on a specified risk limit or risk constraint as the criterion for determining the acceptability of a disposal facility. A risk target, however, should be used as an objective in the design process and this should be a risk of 10^6/y of developing either a fatal cancer or a serious hereditary defect. Where the regulators are satisfied that best practicable means have been adopted by the operator to limit risks and the estimated risks to the public are below this target, then no further reductions in risk should be sought. However, if the estimated risk is above this target, then the regulators will need to be satisfied not only that an appropriate level of safety is assured, but also that any further improvements in safety could be achieved only at disproportionate cost."*

4.13 Risk arises to an individual if that individual receives a radiological dose from radioactivity originating in a repository. For each year that a dose is received there is a risk that a fatal cancer or serious hereditary defect will subsequently occur. The Government has set a target for this annual risk of 'one in a million'. The *HMIP Consultation Document* (paras 6.7 to 6.9, page 17) [GOV/307] indicates that the target applies to a representative member of the critical group and that, for doses less than 0.5 sieverts per year, the dose received by an individual (measured in sieverts) should be multiplied by 0.06 to calculate the consequent risk. It also notes (para 6.11) that the target risk is well below that implied by the natural background radiation in the UK which varies from about 1 in 10,000 per year to more than 1 in 1,000 per year. Hence the risk target for the repository is one hundredth to one thousandth of the risk implied by natural background radiation.

4.14 In respect of the "other technical factors" *(the 1995 White Paper*) (para 78, page 22) [GOV/208], the *HMIP Consultation Document* (Chapters 5 to 7, pages 14 to 22) [GOV/307] sets out the draft principles and requirements against which the Inspectorates will assess any application for authorisation under RSA 93. It also sets out (Chapter 8, pages 23 to 27) draft guidance on information that the developer will need to provide to the Inspectorates in order to demonstrate that a proposal is consistent with the principles and requirements.

5. THE NIREX SCIENCE PROGRAMME

Approach

5.1 The current main objective of the Nirex Science Programme is to evaluate the post-closure safety performance of a repository at Sellafield. It has three main components as follows:

- Site Characterisation Programme: activities to acquire and interpret site specific data in order to understand and describe the geological and hydrogeological processes that will influence the post-closure performance of the repository;

- The Nirex Safety Assessment Research Programme: laboratory, field and mathematical modelling studies of processes influencing the retention of radionuclides in the repository, the migration through the geosphere of radionuclides which may escape from the repository and their behaviour in the biosphere; and
- The Safety Assessment Programme: to develop the models and methodologies required to evaluate the overall performance of the repository.

The programme is managed to ensure that these components are integrated to secure a focused approach to achievement of the overall objective of the Science Programme.

5.2 The Science Programme is founded on four important operating principles:

- having in place a Nirex management team with the knowledge and experience to direct activities towards the effective achievement of the objective;
- the use of interdisciplinary teams of specialist contractors and consultants to carry out the activities who have appropriate expertise and experience. (These teams, which are augmented from time to time as necessary, have built up a substantial body of experience, since 1989 for Site Characterisation, 1982 for the Research Programme and 1986 for Safety Assessment);
- the use of quality assurance procedures applied to all activities including data acquisition, calculations and interpretation; and
- independent peer review and challenge.

5.3 Peer review is applied both to plans for activities in the Science Programme and to the results of those activities. It is carried out by Nirex staff, by contractors working on the programme, by consultants not otherwise engaged on the programme and, as appropriate, by the Nirex Review Panel (see Section 7 below). A Royal Society Study Group was also set up at the invitation of Nirex to review the basis and methodology of the Science Programme (see Section 7 below). In a less formal way, review and challenge is provided by the publication of reports, journal articles and conference papers on the results of the Science Programme.

5.4 As indicated at Paragraph 3.2, 500 reports, journal articles and conference papers on the Nirex Science Programme have been published to date. In addition, the factual reports, comprising around 1,600 volumes which record the detailed results of the Site Characterisation Programme, are available to interested parties for reference.

5.5 The quality of the work being undertaken by Nirex has been recognised by independent reviewers. For example, the November 1994 report of the Royal Society Study Group at Section 1.9, page 10 (*Disposal of Radioactive Wastes in Deep Repositories)* ("*The Royal Society November 1994*") [COR/605] comments:

> "*We have been impressed by the quality of individual items of scientific work undertaken and commissioned by Nirex, which command high respect from others engaged in parallel work world-wide.*"

And at Section 6.8, page 110:

> "*Nirex site characterisation work at Sellafield has been of very high quality*."

5.6 Similarly, the RWMAC state in their *Fourteenth Annual Report* of June 1994 (para 3.10, page 11) [GOV/406]:

> "*However, there is no reason to modify the view expressed in the Thirteenth Annual Report to the effect that the work carried out for Nirex by contractors (who are the contributors to Report No. 524) would, on detailed review, be shown to have been well-conducted, and of the highest quality. Indeed, some of the techniques being used at Sellafield are at the leading edge of international experience. As indicated in the Thirteenth Annual Report, the basic data set and much of the geological interpretation is unlikely to be subject to significant challenge in terms of fundamental accuracy*."

In their *Fifteenth Annual Report* of May 1995 (para 4.6, page 13) [GOV/407] the RWMAC state:

> "*The Committee would record, again, its view that the field work, and the interpretation of site data, being carried out by Nirex staff and by Nirex's contractors is of the highest quality*."

Use of Models

5.7 The Nirex programme, in common with deep disposal programmes overseas, makes extensive use of models in its evaluation of post-closure safety performance. Building confidence in this evaluation is to a large degree about building confidence that the models are adequate representations of reality. Different types of models may be identified as follows:

- conceptual models: which represent our description of system components and our understanding of the processes which will determine the way they will behave;
- mathematical models: in which the conceptual models are represented in mathematical equations to permit calculations to be carried out and hence predictions of performance to be made; and
- computer models: many mathematical models are sufficiently complex that a computer is required to carry out the necessary calculations, hence the mathematical models are encoded for computer application.

In the modelling of real world situations, simplifications are introduced in the transition from conceptual models to mathematical models and finally to implementation using computer codes. Checks must be carried out to ensure that these simplifications do not make the models inappropriate for their intended use.

5.8 The use of models to describe the behaviour of a system is commonplace in modern development of technological systems and assessment of their safety. Use of a model is particularly appropriate where a similar system is not already in operation, or where an experiment cannot be carried out which directly reproduces the system and behaviours of interest; in this case a repository and its behaviour over many thousands of years. It is important that the models are tested to check that they adequately describe the way components of the system behave. This is the process of model validation which involves the systematic comparison of model predictions with independent field observations and experimental measurements.

5.9 Model development and validation is an iterative process in which models are developed on the basis of observations and understanding of the relevant physical and chemical processes. Predictions of independent observations and experimental measurements are then made, and the comparison of predictions and observations used to refine the models or to discriminate between different models of a particular system. As explained at Section 6 below, the RCF has an essential role in validating models used in the assessment of the post-closure safety performance of a repository at Sellafield as it can provide information on the geology and hydrogeology which cannot be obtained from the surface.

5.10 Consideration has been given internationally to whether sufficient confidence can be developed in the evaluation of the post-closure safety performance of underground repositories. In 1991, the inter-governmental Organisation for Economic Cooperation and Development ('OECD') published a collective opinion of the Radioactive Waste Management Committee of the OECD Nuclear Energy Agency and the International Radioactive Waste Management Advisory Committee of the International Atomic Energy Agency (IAEA). This covered the methodology and means for assessing the safety of radioactive waste disposal practices and concepts (*Can Long Term Safety Be Evaluated? An International Collective Opinion*) (pages 6 and 7) [NRX/13/1]. (The opinion was also endorsed by the experts for the Community Plan of Action in the Field of Radioactive Waste Management of the Commission of the European Communities.) In their collective opinion, the two international bodies confirmed that:

> "*safety assessment methods are available today to evaluate adequately the potential radiological impact of carefully designed radioactive waste disposal systems on humans and the environment.*"

They also considered:

> "*that appropriate use of safety assessment methods, coupled with sufficient information from candidate disposal sites, can provide the technical basis to decide whether specific disposal systems would offer to society a satisfactory level of safety for both current and future generations*."

6. THE NEED FOR THE RCF

Results So Far

6.1 Results of the investigations to date show that the characteristics of the site are broadly as envisaged in 1989 when the site was selected for detailed geological studies, but that we now have a much more detailed picture of the site than then existed.

6.2 In particular, evaluation of the post-closure safety performance of a repository at Sellafield has provided a much improved understanding of the factors influencing performance. On the basis of that understanding, the following are identified as key factors in ensuring the safe disposal of radioactive waste:

- groundwater flow through the repository which is sufficiently low to enable the physical and chemical barriers to retain short-lived and most long-lived radionuclides; and
- sufficient subsequent dilution of those residual radionuclides that are released from the vaults in order to limit concentrations in groundwater reaching the surface.

6.3 Results so far from the Site Characterisation Programme indicate that the flow of groundwater through the potential repository host rock, the Borrowdale Volcanic Group ('BVG'), is low and flow is predominantly through networks of connected fractures, rather than the intact rock. As indicated in Dr Hooper's evidence (**PE/NRX/15**, para 5.21) models of flow currently predict a most probable value for flow of 140 m³ per year through a repository located in the BVG.

6.4 In contrast to the low rates of flow in the BVG, the results of the Site Characterisation Programme indicate high flow towards the sea in the upper parts of the overlying sedimentary rocks. Any radionuclides dissolved in groundwater emerging from the BVG would therefore be diluted by much higher flow of water in the overlying rocks. As indicated in Dr Hooper's evidence (**PE/NRX/15**, para 5.32) current models predict a most probable value of dilution of around 2000 : 1 for those radionuclides which determine peak risks up to 1 million years after closure of the repository.

6.5 Dr Hooper's evidence presents a preliminary evaluation of the post-closure safety performance of a repository at Sellafield based on our understanding of site characteristics. He shows that, if the assumptions underlying the predicted flows and dilutions identified at 6.3 and 6.4 above were confirmed or shown to be unduly conservative by the RCF, and taking into account our current view of other factors influencing repository performance, a repository could be developed at Sellafield which would meet regulatory requirements.

Remaining Uncertainties

6.6 Three key areas of uncertainty nevertheless remain which must be addressed before a decision can be made whether to propose development of a repository at Sellafield and to obtain regulatory approval to start disposal operations if a repository is constructed. The information needed to address these areas can only be gathered from the RCF. They are as follows:

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

6.7 The main purpose of the RCF is to provide information to address these uncertainties that cannot be obtained from surface-based investigations. In addition, it would provide information that can be collected more effectively from underground investigations than from the surface. For example, it is now considered that information on the spatial variability of the rock in the Potential Repository Zone ('PRZ'), previously planned to be acquired by drilling boreholes PRZ 6 to 10 (*Nirex Report 325)* (pages 12 and Figure 7) [NRX/13/2], can be gained more effectively by underground drilling from RCF galleries. This would avoid the need to create five new drilling pads.

Groundwater Flow and Radionuclide Transport

6.8 Models of groundwater flow through the PRZ and surrounding rocks used in the evaluation of post-closure safety performance are based on information generated by the Site Characterisation Programme. These models need descriptions to be developed of the networks of connected fractures thought to have lengths up to hundreds of metres, which control the flow. Such descriptions currently must be based on observations of fracturing and in-flows in boreholes, with borehole cores typically 100 mm in diameter, augmented by remote sensing techniques such as seismic surveys, which give less precise information than direct observation, and hydraulic testing in the boreholes. Because of the limitations of these observations, important judgements have to be made to provide these descriptions.

6.9 In the preliminary evaluation of post-closure safety performance described in Dr Hooper's evidence (**PE/NRX/15**, Section 5), such judgements were applied in arriving at a description of the networks of connected fractures considered to best represent the information available. However, given the limitations of available information, it was recognised that other descriptions implying significantly higher flows and lower dilutions, albeit improbable, could plausibly be developed. Dr Chaplow describes the information provided by the Site Characterisation Programme, subsequent to carrying out of this preliminary evaluation (**PE/NRX/14**, Sections 5 and 6) which has added to confidence that the site at Sellafield offers a stable setting able to perform the two key functions identified at paragraph 4.6 of this evidence. But neither this information, nor any which could be gathered from further surface-based investigations, overcomes these limitations.

6.10 We need to acquire information that will allow us to test our judgements on, and firm-up on our descriptions of, the networks of connected fractures in the BVG and overlying sedimentary rocks, in particular their lengths, widths, frequency and ability to allow water to flow. This will allow us to narrow the range of predictions of flow and dilution, and to apply models of groundwater flow and radionuclide transport with confidence across the PRZ and surrounding rocks.

6.11 The RCF will enable us to overcome limitations of surface-based investigations by providing direct access to a large volume of rock and by allowing us to investigate on lengthscales of tens and hundreds of metres the networks of connected fractures. We will also be able to make direct observations in three dimensions rather than in essentially one dimension in a borehole. The ways in which the RCF enables us to overcome the limitations are as follows:

- We can examine and test the network of connected fractures in detail where they are exposed on the walls of the shafts and galleries (for example 5 metre diameter shafts provide direct observations at 50 times the lengthscale of the 100 mm cores obtained from boreholes). We can observe continuity between shafts and drill out from the shafts and galleries to intersect and test networks of connected fractures at distances of tens and hundreds of metres from the shafts. As a result we can get much better information on lengths and orientations of fractures and their associations with particular geological features. We can observe directly how the individual fractures are connected to each other; and
- By observing the response of groundwater pressure and chemistry in the monitoring network to the sinking of the shafts, we get information on the ability of the networks of connected fractures to allow water to flow which can be related directly to the physical observations indicated above. Also we can drill out into the networks of connected fractures and carry out controlled experiments to test their transport properties.

Hence the extent to which judgements have to be made in describing the networks of connected fractures in the models is much reduced.

6.12 This new and different information will enable our models of groundwater flow to be tested by making predictions in advance of what we will observe and then comparing observation to predictions. In particular, the RCF will enable us to test the extent to which:

- the descriptions of the networks of connected fractures (for example, their lengths, frequency, widths and ability to allow water to flow) which form the basis for the models match the observations; and
- the models are able to predict the observed responses in the monitoring network.

6.13 This testing will lead to improved understanding of the groundwater system and to the refinement of models which can be used to make predictions with increased confidence across the PRZ and surrounding rocks. Also, the range of predicted flows and dilutions will be reduced by narrowing the ranges of parameters describing the networks of connected fractures in the models, and by eliminating models shown to be inconsistent with the data.

Natural and Induced Changes to the Geological Barrier

6.14 The discussion above has concentrated on our view of the way the site currently behaves. It is important to be able to demonstrate that future changes, which may be natural or induced by repository construction, will not create new pathways that would result in unacceptable flows or cause damage to the engineered barriers of the repository that would significantly impair its ability to retain radioactivity.

6.15 Dr Chaplow's evidence (**PE/NRX/14**, Chapter 7) summarises the results so far on natural and induced changes. He indicates that work done to date to examine the past history of the site as a guide to geological conditions in the future has shown that Sellafield offers a stable geological setting. There is good evidence to indicate that the networks of connected fractures controlling flow in the BVG have persisted for millions of years. Further information is needed to confirm this is so. Also, on the basis of measurements in boreholes and on experience from other sites, we predict that excavation of the RCF or the repository should not create new pathways that would result in unacceptable flows. Information from the RCF programme, relating more closely to the lengthscales of repository construction, is needed to confirm this.

6.16 Our current estimates of the disturbance caused by excavation are based on measurements in boreholes, numerical modelling and on experience from other sites. However, it is not possible actually to measure from boreholes the response of the BVG rock at depth to an excavation of dimensions approaching those of a repository. We can measure this response directly as we construct the RCF shafts and galleries. We will be creating openings in the rock far closer to the dimensions of the repository vaults and drifts than in boreholes, the only 'excavations' into the BVG in the PRZ so far carried out. Our confidence in our estimates of changes induced by construction will therefore be substantially enhanced by construction of the RCF. Also the RCF will enable us to make direct observations of the fracturing, associated mineralisation and of the geochemistry of the rocks and groundwater which will enable us to firmup on our view of the history of changes in the rocks as a guide to potential future natural changes.

Design and Construction of the Repository

6.17 A further consequence of the uncertainties identified above, together with limitations of available information on the geotechnical characteristics of the rock, is that we are not yet able to take a firm view on the benefits to be gained from particular depths, locations, layouts and orientations of a repository within the PRZ, because we need further information on the extent to which varying these factors matters in terms of repository performance.

6.18 In order to take decisions on the depth, location, layout and orientation of the repository in the PRZ, we need to establish how groundwater flow and dilution, and the geotechnical properties of the rock, would vary with these parameters. By enabling us to develop a much firmer view of the nature of networks of connected fractures, and their relationships to the geology, and by enabling us to measure how the geotechnical properties of the rock vary with depth and location, the RCF will provide us with a firm basis for design optimisation.

Forward Programme

6.19 It is noted that the Government expects (*the 1995 White Paper*, para 62) [GOV/208] that for major projects:

- developers will make early application for disposal authorisations, at about the same time that they seek full planning permission for the project, although it would be determined separately; and
- if the regulators are content, the authorisations could be granted containing conditions which if met at specified stages should lead to approval to start operations in due course when the plant is built and commissioned.

On these and other matters the White Paper says (para 62) that further guidance will be given in the revised and updated version of *Radioactive Substances Act 1960: a guide to the administration of the Act.*

6.20 In the *HMIP Consultation Document* [GOV/307] the Inspectorates referred to a "*staged application procedure, agreed with the developer*, [which] *could facilitate the timely resolution of an application*" for an authorisation to dispose of waste (para 4.1), but (para 4.2):

> "*...envisaged that the Inspectorates will not be in a position to make final recommendations in relation to such authorisations until the relevant workings have been excavated and geological investigation has confirmed their suitability. Thus, the formal issue of authorisation will be the culmination of a progressive and extensive process beginning with informal discussions between the developer and the Inspectorates.*"

Whether or not an application for an authorisation, staged or otherwise, is made at about the same time as a planning application for a repository, the *Draft Guidance* refers to the possibility that the Inspectorates would be consulted by the planning authority on the planning application, and gives notice of the Inspectorates' intention (para 4.3) to

> "*...comment on whether or not there appears to be any impediment, in the light of the information available to them at the time of being consulted, to the eventual authorisation of disposal of waste of the categories and quantities intended.*"

6.21 Nirex's working assumption is therefore that for present purposes two key decision points can be identified in the development of a repository as follows:

- a decision by Nirex to propose development of a repository, which will lead to an application for planning permission to develop the repository and possibly, at about the same time, to an application for authorisation under RSA 93; and
- a decision by the regulatory authorities, after completion of repository construction and commissioning, to approve the start of disposal operations.

6.22 A decision by the Company to propose development of the repository must be made on the basis of confidence that approval of disposal of wastes would be given by the regulatory authorities. In the light of the above statements of Government policy, and draft Guidance by the Regulators, Nirex's working assumption is that it will prepare assessments of the post-closure safety performance of the repository for each of these decision points. That prepared for the first decision point will necessarily be preliminary and will be filled out and finalised to enable the regulatory authorities to take a decision on approval of the start of disposal operations.

6.23 Hence, in respect of the three key areas of uncertainty to be addressed by the RCF, the Company considers that the following position needs to have been achieved before a decision could be taken to propose development of a repository:

- We need to be confident about our ability to predict groundwater flow and dilution: this confidence will be derived from the underpinning of our predictions by information from the RCF. Our predictions will also need to demonstrate values of groundwater flow and dilution consistent with meeting regulatory requirements for individual risk and an acceptable safety case;
- We need to have established that neither construction of the repository, nor future naturally induced changes, would result in new pathways for water flow which would significantly impair repository performance; and
- A firm basis for the optimisation of repository depth, location, layout and orientation should be established. Decisions would have been taken on these parameters, albeit allowing for finalisation of details in the light of continuing investigations underground, and information obtained during repository construction.

6.24 The safety assessment prepared for the first decision point will need to address all the factors influencing the post-closure safety performance of the repository, and will also identify specific remaining uncertainties and the steps to be taken to resolve them. In parallel with the RCF, work will continue in other areas of the Nirex Science Programme to develop this safety assessment.

6.25 The RCF project is to be carried out in three phases; the first being the construction of the shafts and connecting galleries and the second and third being the construction and extension of galleries at depth in the BVG. Two shafts are to be constructed, providing two separate exits to the surface, to meet the safety requirements of the Mines (Safety of Exits) Regulations 1988 for personnel working underground in Phase 2 and Phase 3. Scientific investigations will be concentrated in the South Shaft with more limited investigations in the North Shaft.

6.26 The first phase, being the first opportunity to carry out tests in situ and at lengthscales close to those of the repository, should provide an important step forward in our understanding and confidence in respect of key remaining issues. The shaft sinking phase is identified in *Review of Data Requirements for Groundwater Flow and Solute Transport Modelling and the Ability of Site Investigation Methods to Meet These Requirements* (Section 3.6.1, Page 116) [GOV/610] as playing a major part in the process of model validation, allowing a large quantity of data to be collected on the rock mass and the first opportunity to test the groundwater flow models on a large scale. It is expected, therefore, that the four year scientific programme associated with Phase 1 could put the Company in a position to take a decision on whether to propose repository development.

6.27 However, as with any scientific investigations, progress cannot be planned with precision. Results from Phase 1 of the RCF could be inconclusive and provide insufficient confidence to extrapolate models across the PRZ. In this case, it would be necessary to carry out further investigations over more of the PRZ using the galleries planned for Phase 2, and possibly Phase 3, before a decision on repository development is made. A flexible approach is needed in planning the design of Phase 2 and Phase 3 galleries so that they could permit access to specific features of the rock, as necessary, to address specific uncertainties which may remain in the future.

6.28 The Company is planning on the basis that if it has judged the site suitable and it decides to make a planning application at Sellafield, three years will elapse between the making of the application and the granting of planning permission. If a decision is made to propose development of a repository at the end of Phase 1 of the RCF, then work would need to continue in the RCF during this period. This further work in Phase 2 and Phase 3 would address remaining uncertainties, probably within the framework of a plan, agreed with the regulatory authorities, for the progressive supply of information leading to a decision by the regulatory authorities on approval to start disposal of wastes in the repository following its construction and commissioning: see *HMIP Consultation Document* (paras 4.1 and 4.2, page 11) [GOV/307].

6.29 Much of this test work planned for Phase 2 and Phase 3 would need to be carried out before commencement of repository construction activity in the BVG which would disturb the rock in the PRZ and consequently prevent good quality data being acquired, particularly in respect of groundwater flow and radionuclide transport. It is also planned that activities would be carried out in Phase 2 and Phase 3 of the RCF, prior to repository construction activities in the BVG, to confirm the characteristics of the rock at the proposed location of the repository and so enable finalisation of detailed design, in particular the layout of repository vaults.

6.30 If there were to be a hiatus in RCF activities while the repository planning application were being determined, commencement of repository construction activities in the BVG would be delayed by several years following grant of planning permission for the repository. The delay would be increased by around three years if just one shaft had been constructed in Phase 1, as the second shaft would have to be completed before the test work and pre-construction investigations could be commenced in Phase 2 galleries. Such delays would conflict with Government policy (*The 1995 White Paper*)(para 177, page 45) [GOV/208] on the repository which is that:

> "*...once a suitable site had been found, it should be constructed as soon as reasonably practicable.*"

6.31 Smooth continuation from Phase 1 into Phases 2 and 3 would also enable the Company to maintain the expertise developed by the teams of scientists working on the project.

7. RESPONSES TO NIREX'S PLANS FOR THE RCF

7.1. The need for the RCF in Nirex's programme to evaluate the suitability of the site at Sellafield has been recognised by the RWMAC, the Royal Society Study Group set up to review the Nirex Science Programme, and the Nirex Review Panel.

7.2 The RWMAC is the independent body that advises the Secretaries of State for the Environment, Scotland and Wales, on civil radioactive waste management issues. The terms of reference of the Committee are (*RWMAC Fourteenth Annual Report)* (page 44) [GOV/406]:

> "*To advise the Secretaries of State for the Environment, Scotland and Wales on the technical and environmental implications of major issues concerning the development and implementation of an overall*

policy for all aspects of the management of civil radioactive waste, including research and development; and on any such matters referred to it by the Secretaries of State."

7.3 In its response to Nirex's decision to bring forward plans for the RCF (*Response by the RWMAC : UK Nirex Ltd's Consultative Document on a Rock Characterisation Facility*) (para 16, page 6) [GOV/408], RWMAC indicated:

> "*At the meeting on 2 October* [1992] *the RWMAC welcomed these proposals, which have followed on from Nirex's decision of June 1992, particularly in the light of the realistic approach now being adopted to the ordering of the progressive collection and analysis of geological and hydrogeological information essential to the robust assessment of the safety case.*"

The same report in describing the conclusions of a RWMAC Study Group visit to investigations in the United States and Canada in 1992, states (para 18, pages 6 and 7):

> "*Those present on the visit returned convinced as to the necessity for underground access to the site of a deep waste repository ahead of the approval being sought for the construction of the repository.*"

7.4 In its *Thirteenth Annual Report* published in May 1993 (paras 4.27 and 4.28, page 17) [GOV/405] the RWMAC commented on Nirex's decision to propose development of the RCF as a free-standing phase as follows:

> "*4.27 The RWMAC welcomes these proposals to develop an underground RCF in order to establish the suitability, or otherwise, of the Sellafield site with sufficient confidence, before committing to a planning application for the repository, and also to adopt some of the principles of a 'two-staged inquiry'. In the Committee's Eleventh Report, published in 1990, we expressed the view that one option for the way forward in the planning process could involve a first stage inquiry for a deep shaft and underground exploration prior to the submission of a full planning application for the deep repository. Nirex's plans are now very much in line with the views expressed previously by the RWMAC.*
>
> *4.28 The RWMAC has visited a number of underground research laboratories for radioactive waste management studies in different countries and support the need for underground access to the site of a deep waste repository ahead of approval being sought for the construction of that repository.*"

7.5 In its *Fifteenth Annual Report* published in May 1995, the RWMAC stated (para 4.11, page 14) [GOV/407]:

> "*The RWMAC is of the view that Nirex correctly justifies the RCF as an integral, necessary part of the overall science programme required to establish the post-closure safety case for the repository ahead of construction. The scope and timescale of the investigations planned are appropriate to the status of the Sellafield project.*"

7.6 The Royal Society Study Group was formed following an approach by Nirex in 1993 to the Royal Society with an invitation to assemble an independent expert group to consider and comment upon the basis and methodology for the scientific evaluation of the long-term performance of an underground repository for radioactive waste. Study costs were reimbursed by Nirex, but the study was undertaken so as to ensure independence and full control by the Royal Society. The Study Group report published in November 1994 concluded (*The Royal Society November 1994*) (Section 1.6, pages 6 and 7) [COR/605]:

> "*The RCF is an essential component of the Nirex programme. Its construction should begin as soon as is practicable, bearing in mind the need to complete some site characterisation studies in advance of the disturbance to the hydrogeological regime that building the RCF will cause. International experience shows that the RCF will need to operate for several years in order to make a substantial contribution to PCPA's and this is a further reason why we think the target date of 1998/9 is too early.*"

7.7 The Royal Society Study Group also identified the major problems of characterisation and validation to which the RCF will be able to contribute as follows (*The Royal Society November 1994*) (Section 6.6, page 108) [COR/605]

"- *establishing the geometry of rock fractures;*

- relating the pattern of conductive features to the overall fracture geometry;

- establishing the seismic properties of the rocks in relation to other physical properties and to conductivity, in order to provide a basis for interpretation of seismic results outwith the area of the RCF;

- permitting direct measurements of rock stress to be made and relating it to fracture apertures and flow;

- permitting precise and uncontaminated water sampling to be undertaken for palaeohydrogeological investigations;

- permitting tracer tests at various scales to assist in determining parameters for groundwater flow and radionuclide transport modelling."

The same section of the report added:

"*In addition the RCF can contribute to the assessment of the possible side effects of repository construction on the host rock.*"

7.8 The Nirex Review Panel comprises Professors Coward, Lloyd, O'Nions and Sparks and was set up in 1993 to provide independent advice on the appropriate strategy and approach for geological characterisation of Sellafield, to review geological and hydrogeological reports prior to publication and to provide ad hoc specialist advice. In their annual report for 1994 published in February 1995 (*The Nirex Review Panel Annual Report 1994*) (Section 3.2, page 6) [COR/516] they conclude:

"*The major issues identified above and other detailed aspects of fluid flow through fractured media cannot be adequately addressed through observations made only at the surface or from boreholes. For these reasons the Panel has held the view from its inception that at some stage a RCF will be required. Without such a facility it will be impossible to make a sound safety case.*

The Panel is encouraged to note that the Royal Society Study Group has endorsed the view that Nirex should proceed with the construction of the RCF. The Panel considers that the present understanding of the Sellafield site is sufficiently encouraging to justify a major continuation of the site characterisation programme to include the construction of a rock characterisation facility. We concur therefore with the Royal Society Study Group in endorsing the Nirex strategy in this regard."

7.9 Environmental Resources Management ('ERM'), who are advisers to Cumbria County Council, have expressed some reservations about Nirex's proposals for the RCF, particularly in respect of its timing (*Boreholes and Rock Laboratories to Demonstrate a Safety Case : Response to the October 1992 Rock Characterisation Facility Consultative Document (Nirex Report 327) - Interim Technical Report ITA/7*) (Executive Summary pages (i) to (v)) [COR/608]. However, in the same document they express views which are broadly in line with those of Nirex on the need for, and role of, a RCF. Thus in the Executive Summary at pages (ii) and (iii):

"*The regional borehole programme also has certain limitations. These are due mainly to the fact that investigations are confined to one dimension. Even with 20 deep regional boreholes, there are questions about scale and three-dimensional behaviour of the rock volume that cannot be answered satisfactorily. Nirex have submitted applications for various RCF and monitoring boreholes (known as RCM and Potential Repository Zone or PRZ boreholes) as a precursor stage to the RCF proper.*

The term URL covers many different kinds of in-situ research and site characterisation facilities. The UK Nirex Ltd Rock Characterisation Facility (RCF) is, in essence, a site-specific URL, designed to investigate the Sellafield geology and hydrogeology. URLs can provide access to the deep geological environment, complementing the surface drilling and investigation programme. They enable in-situ research and characterisation to take place by allowing three-dimensional, larger volume rock analysis. The physico-chemical conditions in URLs are generally intended to be similar to those expected in an actual repository.

There are two overall reasons for building URLs:

> *- URLs provide data to support models and performance assessment of repositories and enable validation of those models and performance assessments. Research in a URL is particularly valuable in developing and demonstrating the methods, techniques and instrumentation involved in site characterisation;*
>
> *- URLs can be used to assess the feasibility of the construction methods, operational details and final closure of a future repository.*

It is now generally accepted that the proper assessment of a site for the long-term disposal of radioactive waste needs to include a stage of underground experimentation and validation, in the form of some facility resembling a URL."

And at Section 4.4.5, page 43:

"*The biggest advantage of a RCF over the surface investigations is the access it will give to large volumes of rock in three dimensions. Scale is very important in rock studies. Experiments on the BVG rock to date have either been on small cored samples or on weathered outcrops in the Lake District further to the east. The RCF will enable Nirex to examine and experiment on large volumes of rock under conditions that are as close as possible to those in the repository. The opportunity of being able to work in three dimensions is also very valuable. Although cross-borehole tests from the surface can give much useful hydrogeological information, the amount of data is limited. (Note that Nirex have not yet exploited the full potential for cross-borehole experiments in their current borehole programme.)*

From Nirex's point of view, an important aspect of the RCF is that a large number of investigations can take place simultaneously under the same roof. Deep regional boreholes only allow step-by-step testing, requiring long time-scales to complete a whole programme. There is also a whole range of tests that cannot be carried out from the surface - rock stress monitoring is just one example.

While the proposed Nirex RCF will provide access to a large underground volume from a relatively small surface area, additional environmental impacts in the form of monitoring boreholes will accompany the RCF proposal. There would also be extended use for monitoring in some or all of the existing regional boreholes."

8. PROGRAMMES IN OTHER COUNTRIES

8.1 While the nature of wastes, repository concepts and host rocks being investigated vary between countries planning to develop a deep repository for radioactive wastes, they all have in common a planned stage of underground investigations in order to establish firmly the suitability of a site. Additionally, some of these countries, for example Canada, Sweden and Switzerland, have developed underground laboratories whose purpose is not to investigate the suitability of a candidate repository site, but to develop the techniques and methodologies for underground site investigations. Nirex participates in, or has links with, research programmes of these 'generic' underground laboratories. Planned programmes in other countries are outlined in Table 8.1.

8.2 Inevitably, there are significant differences between the plans of different countries and between their regulatory and legal frameworks. However, a number of general conclusions may be drawn as follows:

- as in the UK, the programmes planned to establish the suitability of sites in other countries comprise surface-based investigations followed by a stage of underground investigations conducted from excavations made for the purpose;
- a stage of underground investigations is, in each country, a precursor to a decision on whether to propose development of a repository, and is generally a distinct and separate stage from repository construction; and
- the durations of surface-based and underground investigations planned for Sellafield lie within the range of plans in other countries.

8.3 It is therefore concluded that the proposal to carry out a stage of underground investigations in an RCF at Sellafield prior to a decision on whether to propose development of a repository is consistent with general practice internationally. Mr Folger's evidence (**PE/NRX/12**, Sections 6 and 7) has already explained how the Nirex approach to site selection and site investigations, including the RCF, is consistent with IAEA recommendations for a site selection process which culminates in a siting decision following a site confirmation stage.

9. REFERENCES

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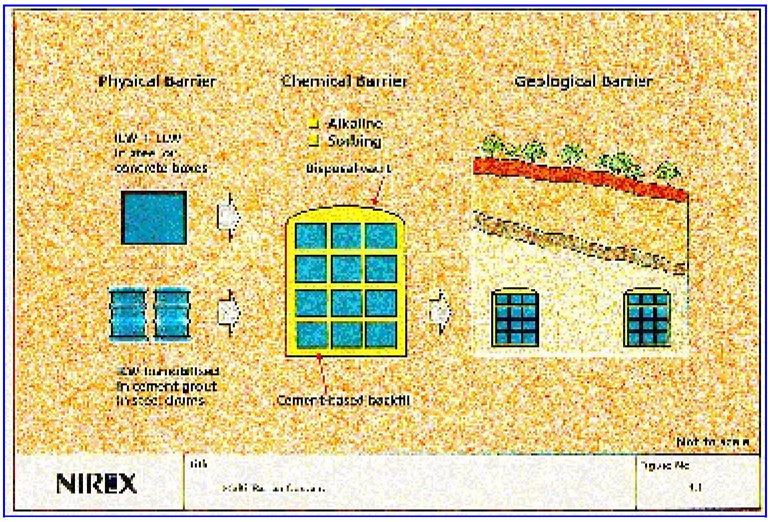
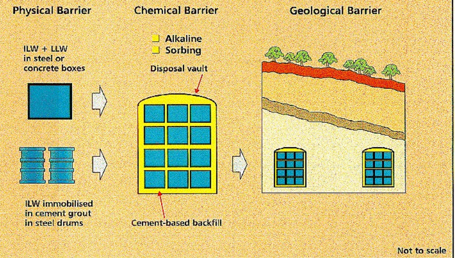
TABLE 8.1: DEEP REPOSITORY PROGRAMMES IN OTHER COUNTRIES

Belgium	It is planned that a repository for high-level waste will be located in the Boom clay and an underground laboratory in that formation at MolDessel has been in operation since 1983. Detailed studies for a deep repository are planned to commence in 2015 with repository construction around five years later.
Canada	Detailed site characterisation at the lead candidate site (yet to be chosen) is planned to take 12 years, followed by a stage of underground investigations complemented by further surface investigations taking a further seven years. A decision to apply for regulatory approval for repository construction would follow that stage of underground investigation.
Finland	Detailed characterisation of three candidate sites commenced in 1993 following preliminary investigations at five sites. A decision to select one site for a stage of underground investigations is planned for the year 2000, eight years after the commencement of detailed site characterisation. An underground laboratory is planned to operate over a seven year period between 2003 and 2010 leading to a decision on whether to apply for a construction licence for the repository in 2010, 18 years after commencement of detailed site characterisation.
France	Three potential sites are being investigated for a deep repository. Detailed surface-based characterisation began in 1994 and, by way of example, at one site it has comprised 15 boreholes at least 300m deep complemented by geophysical studies. It is planned to commence construction of rock characterisation facilities on at least two of the sites in 1996, i.e. two years after commencement of detailed surface-based characterisation. A decision on whether to propose a repository at one of the sites is planned for 2006. This decision would therefore be made some 12 years after commencement of detailed site characterisation.
Germany	Detailed surface-based characterisation of a salt dome at Gorleben was carried out over a six year period between 1979 and 1985. These surface-based investigations comprised four deep boreholes, 44 shallower boreholes and geophysical surveys. Excavations to enable underground investigations to be undertaken commenced in 1986, some seven years after commencement of detailed site investigation. If suitability of the site is confirmed, it is planned to construct a repository which could be operational by 2008.
Spain	Choice of a site for detailed characterisation is planned for the year 2000. It is then planned that a 15 year programme, comprising surface-based investigations followed by a rock characterisation facility, will be carried out prior to decisions on repository construction.
Sweden	It is planned to carry out detailed site characterisation, initially comprising boreholes and surface-based geoscientific surveys at two sites over a four year period commencing in 1995. An underground laboratory would then be constructed at one site. Following construction of the laboratory, comprising a tunnel and/or shaft and associated investigations, taking in all around four years, a decision will be made on site suitability and therefore whether to propose development of a repository. Repository construction would commence approximately 10 years after commencement of site characterisation. Underground data collection would continue during the repository construction phase leading to a final safety report.
Switzerland	Detailed characterisation of two potential sites is planned to be carried out in the period from 1994 to 2000. Subsequently, an underground laboratory is planned for one site to provide sufficient geological data to allow an application for a repository construction licence.
USA	Comprehensive detailed surface-based characterisation began at Yucca Mountain in Nevada in 1991 following its designation in 1987 by Federal statute as the candidate repository site. Construction of an underground laboratory commenced in 1993. It is planned that this will lead to a decision on an application for a licence in 2001 and, if this is approved, repository construction would start in 2004, 13 years after the commencement of detailed site characterisation.

FIGURE 4.1 MULTI-BARRIER CONCEPT
(Click on image to see in full size)





NIREX	Title: Multi-Barrier Concept	Figure No. 4.1