Proof of Evidence

of

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BSc, PhD, DIC, MIMM, MHKIE, FGS, CEng, CGeol

Fracture Flow Modelling

Rock Characterisation Facility:
Longlands Farm,
Gosforth,
Cumbria

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STEPHEN RAYMOND HENCHER will say

1. PERSONAL DETAILS

1.1. I am Senior Lecturer in Engineering Geology in the Department of Earth Sciences at the University of Leeds and consultant to Friends of the Earth concerning planning permission for the RCF facility at Sellafield. I hold a BSc in Geology and a PhD in Engineering Geology from the University of London. I am a chartered engineer and chartered geologist. After my PhD I worked for WS Atkins as an engineering geologist on a variety of works in the UK and overseas. Following two years on site during the construction of Drax Power station I worked for the Hong Kong Government for five years, mainly on landslide prevention. I also led investigations on slopes which had collapsed despite careful investigation. During this period I learned to appreciate the importance of extreme factors in geotechnical analysis and the dangers of oversimplification.

1.2. My current research mainly concerns mechanical properties of rocks and rock masses. My most relevant research concerns the application of discrete fracture models to the study of fluid flow through rock masses. This work is being carried out with the support of elf aquitaine and relates to modelling of oil reservoirs. Many of the principles are however directly related to work on water flow through fractured rock masses such as is found at Sellafield. The software we are using (Fracman and Mafic) is also being used as part of the research effort at Sellafield.

1.3. In 1991 I was awarded the Engineering Group prize of the Geological Society and am currently the UK representative to Council of the International Society for Rock Mechanics.

2. SUMMARY

2.1. It will be demonstrated in this proof that:

2.2. Hydrogeological conditions at Sellafield are predominantly controlled by flow through the network of interconnecting fractures such as joints and faults; however current understanding of the factors which control fracture flow is at a very early stage of development.

2.3. The methods and techniques of investigation and analysis required for a post closure performance assessment (PCPA) for a nuclear waste repository in a saturated, fractured rock mass are not well developed or proven. These issues are currently under investigation within international underground research laboratories.

2.4. The characterisation facility proposed by Nirex is distinct in purpose from an underground research laboratory in that it is intended to be confirmatory rather than experimental.

2.5. Premature construction of a characterisation facility prior to resolution of the scientific issues currently being addressed within the international research laboratories might jeopardise the possibility that Nirex would ever be able to produce a reliable PCPA for the Sellafield site.

3. SCOPE OF EVIDENCE

3.1. This proof will address the crucial aspect of fluid flow through fractures.

3.2. The nature of fluid flow through fractures will be reviewed briefly and difficulties in investigating and modelling the processes involved will be discussed.

3.3. The proof will introduce some of the relevant work being carried out as part of the international research into safe disposal of nuclear waste.

3.4.Evidence will be presented from investigations at Stripa, Asp” and elsewhere which gives little confidence that solutions to the various unknowns and uncertainties will be achievable in the short term.

3.5.It will be argued that until Nirex are able to demonstrate that they understand data from existing sites and ongoing planned activities in generic laboratories, they should not disturb the site at Sellafield, possibly irrevocably.

3.6. It is concluded that to proceed to the RCF stage of repository development prior to satisfactory completion of underlying generic research work and validation of numerical models would be premature and ill-conceived.

4. IMPORTANCE OF FRACTURE FLOW

4.1. The potential host rocks at Sellafield in the BVG are a complex series of volcaniclastic sediments and extrusive volcanic rocks which have undergone a long and eventful geological history involving burial, periods of mountain building and extension. During that long history the rock has become heavily fractured. The rock mass is broken up by several major faults extending for tens or even hundreds of metres. Similarly there have been numerous phases of joint development, each superimposed on the pre-existing fracture system. As a result of these physical processes the potential repository host rocks are extremely fractured.

4.2. Investigations at Sellafield to date have confirmed that fluid flow through the potential repository zone is predominantly controlled by the network of fractures rather than by flow through the rock itself (the matrix). This situation is typical for old, tightly packed but fractured rocks in contrast to more highly porous and permeable rocks such as many sandstones within which matrix throughflow may be more important.

4.3. The proof for an eventual repository safety case will require it to be demonstrated that the nature of the fracture network is fully understood and that the potential for this network to act as a conduit for water from the repository has been established.

4.4. Study of the rock mass at Sellafield reveals a long and complex history of fluid flow with at least nine separate episodes of mineralisation (NIREX, 1995a, p8). During each period, water rich in minerals has flowed through the rock fractures. Evidence of each episode is given by thin mineral coatings which were deposited on the surfaces of the fractures in response to local changes in pressure, temperature or chemistry. The complexity of the history and origins of the rock mass at Sellafield is reflected by the difficulties that Nirex have encountered in their attempts to correlate fracture data with flow data at the site.

4.5 Open fractures which permit water to flow through the rock mass at the present day have been encountered at different levels in each of the various rock strata and in all boreholes during the Sellafield investigations to date. However it has proved difficult to identify or to characterise the individual fractures controlling flow.

4.6. It appears however that the main flowing fractures are often, but not exclusively, associated with the most recent episode of mineralisation (ME9) (NIREX, 1995a). It may be concluded therefore that many of those fractures which have been shown to be permeable under the artificially severe conditions of the well tests have also carried fluids in the recent geological past under natural heads and conditions and presumably will do so in the future.

4.7.Dr Holmes (PE/NRX/13) specifically outlines the stance of Nirex concerning the need for the RCF. He notes (par. 2.8) that observations from surface-based investigations are limited. He also notes that currently the results from several feasible models predict conditions that would not meet regulatory requirements. From paragraphs 2.9 and 2.10 it is clear that, according to Nirex, the key points that must be addressed concern the persistency (extent) and connectivity of the fractures. Nirex argue that these issues could be resolved by the examination of the in-situ rock at a larger scale than has been possible using boreholes.

4.8. Generally, the Nirex proofs of evidence are in agreement that the main purposes of the RCF are:

- to extend knowledge of the fracture network to a larger scale
- to investigate the interconnection of fractures, particularly in the flowing zones, and
- to investigate the disruption of the fracture system due to excavation disturbance.

4.9. In the following sections the nature of fracture flow and the methodologies available for quantification of fracture flow will be discussed.

5. THE NATURE OF FRACTURE FLOW

5.1. Most fractures through rock are originally formed by tension (by pulling apart) rather than by shear (in which the two sides of the fracture are moved in opposing directions parallel to the fracture plane). Fractures through rock are often rough both at the scale of the mineral grains making up the rock but also at larger scales reflecting their complex propagation. When first created, surfaces of tensile fractures often match quite precisely therefore leaving little gap for the passage of fluids. Where there is a shear component during formation however the irregular surfaces of the fracture may override each other causing the gap to grow locally between the fracture walls. Shearing may also occur at a later stage either in response to natural changes in stress or due to artificial disturbance.

5.2. The amount of flow possible along fractures in a rock mass depends upon the aperture (gap) between the two walls of the fracture. The rate of flow increases approximately with the aperture cubed (taken to the third power). Slight variations in the gap between the fracture walls therefore can result in significant changes in fracture flow.

5.3. The gap along a fracture will vary laterally. Locally the gap is dependant upon many things, especially the small and large scale geometry of the fracture walls. Over time the gap may change as fracture walls move and become mismatched. The geometry of fracture walls may also be changed significantly by weathering or alteration. Loose material may be washed out whilst other parts of the gap may become infilled with material such as clay transported by flowing fluids. Fractures are often extremely variable in their characteristics over short distances and therefore properties cannot be extrapolated with confidence.

5.4. Examination of any large cutting in rock cannot help but impress upon the observer the localised nature of flow through fractures. Wet, flowing points are often seen to occur quite distinctly from the rest of the apparently dry rock mass. Such localised flow is known as channelling and often has a dominating influence on the hydrogeology of fractured rock masses.

5.5. Channel flow generally follows a complex and tortuous path between the two rock walls of a single fracture and along the intersections of different fractures. The interaction of fractures may allow the development of a continuous flow path through the rock mass. As discussed later, the statistical potential for fractures to intersect on the basis of their perceived typical geometries within the rock mass is the starting point and main controlling factor within mathematical models of discrete fracture networks.

5.6. As an example of the sometimes overriding importance of conduit or channel flow, Dershowitz (1994)[FOE/6/2] reports how the development of a new oil well caused large drops in production to existing wells at distances of several km within two days. This impact must have been due to the presence of a highly transmissive and discrete flow path between the new well and the existing well. Very significantly, they report that other wells, sited between the two which were clearly linked showed no effect. In other words, if those intervening wells had been investigation boreholes, they would not have allowed identification of the critical flow paths. Similar observations were reported verbally by Meehan in his keynote lecture to the 1st North American Rock Mechanics Symposium at Austin Texas (1994)[FOE/6/13].

5.7. It may be seen that due to the complex and variable nature of fluid flow within fractured rocks, the measurement of parameters pertinent to quantification of the potential for fluid flow is not straightforward.

6. IN-SITU ASSESSMENT OF FRACTURE FLOW

6.1. This section addresses the likely success in obtaining critical data from the RCF.

6.2.. Nirex identify the principal area of remaining uncertainty as the characterisation of the flow zones and, in particular, the way in which these are connected such that the movement of groundwater through the BVG and into overlying strata is permitted(PE/NRX/14, par. 9.9).

6.3. It is noted by Nirex that boreholes are only able to sample the rock over a limited volume and that therefore many features, such as fractures, are inadequately sampled (PE/NRX/14, par. 9.8).

6.4. It is concluded by Nirex (PE/NRX/14, par. 9.11) that these remaining uncertainties can only be addressed through in-situ investigations in an RCF.

6.5. Despite the expressed confidence of Nirex that the construction of an RCF will resolve the current uncertainties, it should be appreciated that there are many practical difficulties in investigating fracture systems through rock masses, no matter what the scale of observation. Although it would be possible to measure certain parameters for exposed fractures in much more detail within an RCF, it would remain very difficult to extrapolate away from the point of observation with confidence (see also Kokelaar PE/FOE/2).

6.6. Factors that are of major importance in determining the potential for fractures to convey water through rocks include:

- aperture (gap between walls of fractures)
- persistence (lateral extent)
- connectivity (nature of intersections between fractures).

6.7. Each of these is difficult to measure in practice, not only in boreholes but also in excavations. For example, aperture depends upon the stress state. If the rock has relaxed due to excavation then a false aperture may be measured. Even then extrapolation away from the point of observation is rarely justified because the aperture often varies laterally.

6.8. Similarly true persistence of rock joints is one of the most difficult parameters to measure or estimate as it is rare that the terminations of fractures are seen in exposures and even then only a two dimensional picture is obtained. This is true not only for boreholes but also in tunnels and even in very large exposures such as in quarries. The most that can generally be achieved is that joint sets (series of near parallel fractures) can be characterised typically as greater than some minimum length in lateral extent, or it may be observed that they tend to terminate against some other set of discontinuities.

6.9. Regarding continuity, it is never possible to gain more than a crude idea of whether or not fractures are likely to intersect, a precondition for a fracture controlled flow path to exist. Even if fractures are seen to intersect it does not follow that a flow path is formed.

6.10. It seems highly unlikely that the larger scale fracture trace observations, cited by Nirex as being one of the prime purposes of constructing the RCF, will yield more than a generally improved understanding of the fracture network in the BVG.

6.11. A more fundamental difficulty than the problems associated with extrapolation of observed fracture characteristics away from the excavation walls concerns the question of how those observations can be translated into fluid flow predictions.

6.12. Identifying potential paths for fluid flow can be extremely difficult. However, it is vitally important for understanding the fluid flow through a rock mass as emphasised by Pyrak-Nolte (1994)[FOE/6/17]. Younger (1995)[FOE/6/20] shows how fluid flow through the rock mass can be almost totally dominated by "conduit flow". Similarly Dverstorp (1991)[FOE/6/3] confirm the importance of being able to identify variable channel transmissivity in an assessment of fracture flow through the rock mass.

6.13. As an example of the difficulties faced, Kikuchi (1993)[FOE/6/6] reports on a careful experiment on flow through a single fracture (6m x 7.5m), the top half of which was removed following the experiment. They showed the importance of localised and tortuous channel flow through the fracture (flow being controlled by local slight variations in width of the gap between the joint walls). Such factors would be very difficult if not impossible to investigate or appreciate in the difficult conditions of a field experiment in an excavation at great depth.

6.14. Thomas (1995)[FOE/6/19] describes recent work from the Kamaishi underground research laboratory in Japan. Following careful examination of exposed fracture traces and measurement of their seepage characteristics, the authors attempted to differentiate between fractures that were observed to be either flowing or non-flowing using recently developed neural network methods (a state of the art iterative self learning program). Several important lessons stem from this careful study that are relevant to the likely success of similar exercises in an RCF at Sellafield which would be located in much more complex geological conditions than at Kamaishi:

- Predictions of whether or not fractures would be wet on the basis of geological parameters such as roughness, aperture, orientation and infill were not good (53% correct and even then the degree to which prediction was made rather than back-assessment is not clear).

- The influences of in-situ stresses prior to excavation, redistribution of stresses around the cavern, movement of blocks adjacent to the cavern, fluid pressures around the cavern and other factors such as storage of individual fractures and time (what changes might be expected in the future) were not incorporated into the neural analysis. This was presumably because of lack of data; a similar constraint on important data would be likely in the proposed RCF.

- No account was taken apparently of the influence of the zone of disturbance around the excavation, a factor which is known to play a significant role in such investigations, and which would be expected similarly to limit the relevance of any observations in the proposed RCF.

6.15. The disturbance caused by the construction of the RCF may mean that flow measurements might have limited application to a future safety case or may even confuse the issues. Brotzen (1991)[FOE/6/1] argues that, in underground excavations, the large distortions in the field of hydraulic potentials will mean that measured inflow to tunnels and shafts (e.g. in the proposed ventilation experiment, PE/NRX/16, Fig. 5.3) is irrelevant to backfilled repositories. Brotzen argues that transport experiments on long term performance must be located far away from the influence of such structures.

6.16. Similarly Pusch (1992)[FOE/6/16], with reference to work carried out at the Stripa mine and at Asp” in Sweden, reports on the severe disturbance caused by tunnel construction in granite. The authors note that adjacent to excavation, bulk hydraulic conductivity differed in axial and radial directions by up to 10,000 times. Clearly one cannot expect measurements of flow from the walls of the proposed RCF to be directly relevant to an understanding of hydraulic flow within the undisturbed rock mass. Nevertheless this is apparently a crucial part of the scientific programme of Nirex for "measuring the hydraulic conductivity of the BVG on a large scale" (PE/NRX/16, p.27)

6.17.. These problems are exacerbated by the phenomena of two phase flow in which two fluids, for example water and gas, are transported together through the fracture system. Two phase flow may cause considerable difficulties in understanding the results of observations from an excavation (which of course is full of gas). For example at the Stripa research site, one of the strong contenders for the inexplicable results of the inflow to the drift experiments concerned two phase flow of water and gas (Long, 1992)[FOE/6/10]. Further fundamental research and development in this area is necessary.

6.18. It is very questionable that examination of fractures in an underground excavation will provide the best way of establishing or confirming hydrogeological conditions and for determining the nature of those fractures and particular sections of fractures which control the fluid pathways.

6.19. It is concluded that the possibility of being able to characterise actual flow paths other than very locally within the proposed RCF is remote and even then extrapolation would not be possible with any confidence.

These findings cause doubts that data collection activities, even at the relatively large scale of the proposed RCF, will be sufficiently revealing or conclusive to allow a safety case to be made.

6.20. Furthermore, given that the implications of excavation impact are not understood, premature RCF excavation may prove to be counterproductive with respect to the information gathering requirements for the production of a reliable PCPA.

7. RELIANCE ON SIMPLIFIED MODELS

7.1. It is clearly impossible to obtain a true and complete understanding of as complex a rock mass as that found at Sellafield such that fluid flow could be understood and predicted perfectly. Even were the location of each fracture and its individual characteristics known, they could not be accounted for in analysis. As discussed above it is currently extremely difficult to predict or understand flow even through a single fracture. For a rock mass several kilometres in diameter the difficulties are compounded considerably.

7.2. To address this dilemma mathematical models are employed within which the processes of fluid flow are represented by equations.

7.3.. The mathematical equations employed are inevitably simplifications of natural processes. They are based on a limited theoretical understanding of the processes involved.

7.4. Characteristics of the host rock are represented using averaged statistical representations of properties to generate numerical predictions. Those properties will be varied to account for the scatter in recorded data and the degree of confidence in values.

7.5 Clearly models can only be expected to provide reasonable predictions of flow where:

- the processes of flow are represented realistically by the equations,
- the engineering parameters selected for the rock mass are appropriate and correct.

7.6. Currently two main types of models are being used to make flow predictions for Sellafield. These are continuum and discontinuum models.

7.7.In continuum models the various strata are represented as relatively large 3D blocks or 2D areas within which properties are averaged or change gradually across the model.

7.8. Nirex (1995b) attests that their continuum (porous-medium) models give a good representation of the overall behaviour of flow and transport through volumes of rock containing many fractures. Dverstorp (1991)[FOE/6/3] concludes however that transport predictions made with an averaging continuum model will be hazardous for low permeability fractured rock.

7.9. One of the aims of the Finnsj”n study in Sweden was to determine whether the fractured rock "behaved as a stochastic continuum on any practical scale" (Geier 1992)[FOE/6/4]. It was concluded however that;

> "even a set of 5 packer tests, all near the center of a block, gives very little information about the block conductivity on a 40m scale. This means "conditional" SC [Stochastic Continuum] models based on such data may not be "well conditioned" ". (page 188)

This reaffirms the difficulties in using a continuum model to represent a heterogeneous, fractured rock mass.

7.10. In discontinuum models there is no assumption of homogeneity. A representation of fracture distribution and parameters is generated which statistically matches the range of perceived field conditions. Such models however, whilst looking more realistic, are themselves still grossly simplistic representations.

7.11. Discontinuum models are in a rapid state of development and refinement but as yet have an unproved track record. Geier (1992)[FOE/6/4] reports that discrete fracture models rely on the geotechnical model being "statistically homogeneous" which may limit their application. For example Kulatilake (1990)[FOE/6/7], in his work at Stripa, found the largest "statistically homogeneous" region to be 10m long.

8. IMPORTANCE OF VALIDATION OF FRACTURE FLOW MODELS

8.1. For models to be acceptable they must be verified (the mathematical equations must be correct and proven to be coded properly within the computer programme) and validated (tested against real examples of the processes that are being modelled).

8.2. Nirex (1995)[S/94/004] discuss some of the models that they are currently using for predicting fluid flow in a way that suggests that they are already adequate for generating reliable numerical predictions of fluid flow through the rock mass. It is stated that the continuum porous-medium model program NAMMU...and the fracture-network program NAPSAC "... are well verified ... and have been used for many years in radioactive waste disposal studies..." [S/94/004](page 6).

8.3. The distinction between 'verification' and validation' needs to be appreciated. A model may be verified in the sense that the computer programme works properly, that there are no errors in the way that the mathematical formulae have been coded and that the equations interact in the way that they are supposed to. The fact that software has been verified does not mean necessarily that the mathematical equations used adequately replicate the physical processes modelled.

8.4. Assessment of the match between the process being described and the capacity of the model adequately to replicate it, is known as validation. Predictions of the model are checked against the performance of the natural system. A model may be perfectly well verified but prove useless for predicting behaviour in the real world.

8.5.Long (1993)[FOE/6/11] reviews various methods for validating fracture flow models. She concludes that much more needs to be done and that;

> "to know that the models developed for fractured rock are valid, it is simply necessary to use these models to make predictions and see how well they do."

This simple requirement is indeed what is necessary provided all constraints are well understood.

8.6. The codes require validation, not only for short inter-borehole or borehole to drift experiments, although small well controlled experiments are obviously a first stage. They also need validation for volumes of rock on the scales appropriate to the PCPA and over long periods of time.

8.7. The process of resolving these outstanding validation issues is currently the subject of an international research programme.

9. THE INTERNATIONAL VALIDATION RESEARCH EFFORT

9.1. Hydrogeological conditions dominated by fracture flow are typical of many of those rock masses currently being investigated world-wide as part of the nuclear waste disposal research effort.

9.2.The investigations in Sweden at Stripa, Finnsj”n and Asp”, in Canada at Manitoba and at Kamaishi in Japan are especially relevant to consideration of the Sellafield case although none of these geological situations are as complex as the conditions at Sellafield.

9.3.In these research laboratories various experiments are being carried out in order to establish the veracity of the mathematical models used in their representation of fluid flow through fractures. Two main categories of experiment are undertaken:

- Tracer tests in which materials such as dyes are used to follow the passage of flow.

- In-flow tests in which flow into the excavation is measured.

Using such tests, measured flow paths and in-flow rates may be compared against predictions of flow path and flow rate that have been prepared in advance. Such comparisons allow a means of model validation.

9.4. Reported success rates of such validation tests are not high.

9.5. Even where extensive investigation has been undertaken and the actual fractures controlling flow identified and characterised fully, as at the Underground Research Laboratory, Manitoba, prediction is often inaccurate (Martin 1990) [FOE/6/12]. With this URL, one particular fracture through the rock mass was encountered which had characteristics considered ideal for testing methods of instrumentation and analysis. Lang (1988) [FOE/6/9] describes the situation as a "unique opportunity". In the event, despite such favourable circumstances, whilst the mechanical response of the fracture was predictable, "predictions of the permeability and hydraulic pressure changes in the fracture, and the water flows into the tunnel, were poor". (page 295)

9.6. Similarly Rouleau (1992)[FOE/6/18] reports on the results of tracer tests within a carefully investigated area of gneiss at Chalk River, Ontario and notes wide discrepancies between predictions and measured times for transport. The authors consider the numerous variables that might contribute to the errors. Given the difficulties in attempting to account for each of these, the authors recommend that effort should be made to recognise those factors that dominate performance and that effort should be concentrated on these.

9.7. Geier (1992)[FOE/6/4] discusses the recent discrete fracture modelling of the Finnsj”n rock mass. It is reported that modelling was only partially successful - partly due to limitations of data (discontinuities in boreholes were not orientated). It is recommended that further field investigations are needed to focus on detailed properties on the scale of a few connected fractures. They also argue that more in-situ testing is needed for investigating channelling effects both within and between fractures. These recommendations are clearly of a fundamental nature and are not merely matters of confirmation.

9.8. Of the various examples quoted of the use of the software employed by Nirex, the most recent example and best documented is that of Stripa. Herbert (1992)[FOE/6/5] claims a degree of success in prediction of tracer movement. Herbert (1994)[FOE/5/8], discussing the use of NAPSAC at Stripa, reports that "this model was able to predict subsequent tracer transport breakthrough and account for dispersion in terms of the dispersive effects of the fracture network geometry." However the prediction was made over a distance of only 28m and more importantly the 'prediction' was generated using drift inflow data and heads. Furthermore Olsson (1992)[FOE/6/14] in his overview reports only partial success for the models used at the Stripa project (including NAPSAC) in predicting the results of various inflow and tracer tests.

9.9.Only one reasonable prediction (by Golder Associates) was made for flow to the validation drift at the Stripa site, and that was based on empirical expectations (broad experience) without rational explanation. Olsson (1995)[FOE/6/15] comment that "none of the models was able to demonstrate what mechanism or process produced the observed reduction in inflow" (to the validation drift)(p. S28). It is apparent that the results for this very small and intensely investigated rock mass remain unexplained with numerous possible explanations (Long (1992),[FOE/6/10]; Olsson, (1992),[FOE/6/14]). The experiments were successful in improving knowledge and techniques but much remains unknown and there is clearly a need for more, fundamental research. The failure in this inflow validation test of the NAPSAC model which is used by Nirex, clearly has significant implications for the RCF proposal.

9.10. LaPointe (1995)[FOE/6/8], predicts that recently developed state of the art techniques shortly to be tested at Asp”, Sweden should be able to distinguish between broadly different types of transmissivity fields. However, it is argued that it may prove very difficult to use the techniques for validation tests within complex rocks where the fractures intersect. One of the characteristics of the Sellafield site is the complexity of the intersecting fracture network within the BVG.

9.11. It is clear that processes of model validation for flow through fracture networks is at an early stage. Most of the available software has only recently been developed, is under constant refinement and awaits validation.

9.12. Nirex is unique in planning to pursue disposal of long lived radioactive wastes within saturated fractured rock prior to resolution of this issue.

10. THE DISTINCTION BETWEEN A ROCK CHARACTERISATION FACILITY AND A RESEARCH FACILITY

10.1.It is acknowledged that before the final design or licensing of a repository, characterisation of the rock mass and in-situ experiments will need to be conducted from underground workings at or close to the level of the proposed repository.

10.2. It is critical at this stage, however, that the distinction between a Rock Characterisation Facility (RCF) and an Underground Research Laboratory (URL) is made clear.

10.3. There are 3 major differences between an RCF and a URL, concerning:

- purpose
- timing of programme
- constraints

Each is discussed in turn below.

10.4.Purpose: A URL is used to carry out experiments and validation exercises in order to develop the scientific understanding and practical skills necessary for the future design and construction of a repository. Underground Laboratories have been established in many countries to address underlying scientific issues that remain to be resolved concerning the geological disposal of nuclear wastes, particularly the difficulties associated with predicting fluid flow through fractured rock. A generic laboratory can be developed in an experimental and tentative manner without concern for the safety case for that particular rock mass.

10.5.In contrast, the RCF proposed by Nirex is part of a specific repository development programme and is merely the confirmatory underground stage of geological investigation. The emphasis in all the proofs prepared by Nirex for this inquiry is on confirmation. In other words, Nirex consider that the basic science is already adequate and that all that is now required is physical observations of the rock mass.

10.6.Timing of Programme: The programme of works and timetable for a URL need to be flexible to allow the findings from each stage of the research to be taken into account in the planning of later experiments. In contrast the RCF planned by Nirex is designed to be constructed according to a rapid engineering programme.

10.7. Constraints: Within a URL the technical constraints on investigation and experimentation only concern veracity of the experimental approach. Investigations within the RCF, however, would need to be limited to ensure that unacceptable damage would not be done to the integrity of the site as a geological barrier. Any exploratory boreholes and adits driven from the main shafts, for example, could form potential rapid paths for radionuclide transport in the future. The investigators will not have the relatively free hand that they would have in a URL.

10.8. In all other countries where fracture flow is envisaged to be a dominant feature of the safety case, the development of a characterisation facility at a proposed repository site has been postponed until the generic scientific work has allowed outstanding issues to be resolved.

11. IS THE TIME RIGHT FOR THE CONSTRUCTION OF AN RCF AT SELLAFIELD?

11.1. Mr Folger (PE/NRX/12, paragraph 7.5) notes that Nirex recognised in 1992 that, without confirmatory information from exploratory excavation [i.e. an RCF], the hydrogeological picture would be too uncertain to allow a planning application to be made for a repository.

11.2.Furthermore in paragraph 9.19 he states that;

> "if, but only if, results gathered during the RCF sinking prove to be essentially confirmatory of geological and hydrogeological assessments derived from surface-based investigations', then a planning application for a repository could be submitted within six months or so of excavating down to the most promising horizon for repository development."

As discussed above the emphasis given by Nirex is on confirmation rather than experimentation or validation.

11.3 . The crucial question is whether or not Nirex are yet ready to move to the confirmatory underground site investigation stage of repository development.

The answer to this question rests on the following key issues:

- Have critical data requirements been identified unambiguously and sensibly?
- Is generic scientific understanding of flow through fractured rocks adequate?
- Are the implications of premature site invasion understood?

11.4.Nirex state that the RCF is required to allow the collection of critical data on fracture extent and connectivity. The difficulties of data collection with respect to in-situ measurement of parameters pertinent to fracture flow characterisation were discussed above. Nowhere in the Nirex proofs is it explained how observations at a larger scale will directly improve the safety case in other than general qualitative ways.

11.5.. Furthermore, as discussed above, resolution of the data-gathering problem will not, in itself, enable reliable predictions to be made. The understanding of fluid flow through fractured rocks is currently insufficient to enable measurable data on fracture characteristics to be utilised to generate reliable predictions.

11.6.Regarding validation, the simple answer is that discrete fracture flow models have not yet been validated in the field (nor verified theoretically for complex conditions).

11.7. No one is in a position to predict how long it will take to overcome these difficulties, but it is probably going to be decades despite the fact that none of the current international underground research laboratories have hydrogeological conditions as complex as those found at Sellafield. Nirex do not address the problem of validation in their proofs. The prognosis of Nirex achieving validation during the sinking of shafts is not good.

11.8. As noted earlier LaPointe (1995) [FOE/6/8] predicts that the tracer tests scheduled at Asp” will be unable to provide data from which validation will be possible. Such difficulties need to be addressed by Nirex rather than proceeding with an apparently ill-defined experiment, with little chance of success. Until such time as valid modelling approaches are available to enable characterisation data to be utilised for the generation of a reliable PCPA it would be inappropriate to begin the rock characterisation stage of repository development.

11.9. Furthermore proceeding with the RCF stage of the development of a repository before the fundamental science is clearly understood may destroy the very hydrogeological data on which a safety case would be based eventually.

12. CONCLUSIONS

12.1. The main concern regarding the construction of an RCF is that of timing. It is not apparent that the RCF proposal as outlined by Nirex allows sufficient time to address the remaining scientific uncertainties regarding fluid flow through fractured rocks. Resolving these uncertainties is fundemental to the safety case for a nuclear waste repository.

12.2. Whilst the factors involved in fracture flow are not clearly defined and understood, and numerical models are still very limited in representing fracture rock masses realistically, it would be inappropriate to proceed towards investigations aimed specifically at proving a safety case.

12.3. Prior to the implementation of the characterisation stage of repository development, outstanding fundamental uncertainties, particularly concerning the validation of models, should be pursued through research within a generic laboratory.

12.4. Following completion of this work, it is imperative that proposals to move to the underground rock characterisation stage of site investigation are subjected to a proper process of scientific peer review. The review should be rigourous, especially on the hydrogeological and transport issues which are the crux of repository safety.

13. REFERENCES

FOE/6/1 Brotzen (1991)

Brotzen O. (1991) The study of relevant and essential flowpaths. Proceedings of a NEA/SKI Symposium on Validation of Geosphere Flow and Transport Models (Geoval), Stockholm, pp 73-80.

FOE/6/2 Dershowitz (1994)

Dershowitz W. & LaPointe P. (1994) Discrete fracture approaches for oil and gas applications. Proceedings 1st North American Rock Mechanics Symposium, Rock Mechanics, Nelson & Laubach (eds) Balkema: Rotterdam, pp 19-30.

FOE/6/3 Dverstorp (1991)

Dverstorp B. & Andersson J. (1991) Analyzing transport in low permeable fractured rock using the discrete fracture network concept. Proceedings of a NEA/SKI Symposium on Validation of Geosphere Flow and Transport Models (Geoval), Stockholm, pp 139-147.

FOE/6/4 Geier (1992)

Geier J.E., Axelsson, C-L, H„ssler L. & Benabderrahmane A. (1992) Discrete fracture modelling of the Finnsjön rock mass: Phase 2. SKB Technical Report 92-07, 207p + 16 appendices.

FOE/6/5 Herbert (1992)

Herbert A.W. & Lanyon G.W. (1992) Discrete fracture network modelling of flow and transport within a fracture zone at Stripa. Proceedings of Conference on Fractured and Jointed Rock Masses, Lake Tahoe, Preprint Volume 3, 699-708.

FOE/6/6 Kikuchi (1993)

Kikuchi K. & Mito Y. (1993) Characteristics of seepage flow through the actual rock joints. Proceedings 2nd International Workshop on Scale Effects in Rock Masses, Lisbon, pp. 305-312.

FOE/6/7 Kulatilake (1990)

Kulatilake P.H.S., Wathugala D.N. & Stephansson O. (1990) Analysis of structural homogeneity of rock mass around ventilation drift Stripa mine. Proceedings of the International Symposium on Rock Joints, Loen, Barton & Stephansson (eds) Balkema: Rotterdam, pp 75-82.

FOE/6/8 LaPointe (1995)

LaPointe P.R., Thomas A.L. & Lee G. (1995) Projection Onto Convex Sets (POCS): A new method for constrained stochastic simulation of rock properties for geotechnical design and fluid flow modelling. Proceedings 35th US Symposium on Rock Mechanics, Lake Tahoe, pp 695-702.

FOE/6/9 Lang (1988)

Lang P.A. (1988) Room 209 excavation response test in the underground research laboratory. proceedings of an NEA Workshop on Excavation response in Geological Repositories for Radioactive Waste, Winnipeg, pp. 295-329.

FOE/6/10 Long (1992)

Long J.C.S., Olsson O., Martel S. & Black J. (1992) Effects of excavation on water inflow to a drift. Proceedings of Conference on Fractured and Jointed Rock Masses, Lake Tahoe, Preprint Volume 3, 559-570.

FOE/6/11 Long (1993)

Long J.C.S. (1993) Construction of equivalent discontinuum models for fracture hydrology. Chapter 11 in Comprehensive Rock Engineering, Volume 4, (J.Hudson, editor-in-chief), Pergamon Press, pp. 241-295.

FOE/6/12 Martin (1990)

Martin C.D., Davison C.C. & Kozak E.T. (1990) Characterising normal stiffness and hydraulic conductivity of a major shear zone in granite. Proceedings of the International Symposium on Rock Joints, Loen, Barton & Stephansson (eds) Balkema: Rotterdam, pp 549-556.

FOE/6/13 Meehan (1994)

Meehan D.N. (1994) Rock mechanics issues in petroleum engineering. Proceedings 1st North American Rock Mechanics Symposium, Rock Mechanics, Nelson & Laubach (eds) Balkema: Rotterdam, pp 3-17.

FOE/6/14 Olsson (1992)

Olsson O.(ed.) (1992) Site Characterization and Validation - Final Report. Stripa Project 92-22 364p.

FOE/6/15 Olsson (1995)

Olsson O. & Gale J.E. (1995) Site assessment and characterization for high -level nuclear waste disposal: results from the Stripa Project, Sweden. Quarterly Journal of Engineering Geology, 28, S-17-S30.

FOE/6/16 Pusch (1992)

Pusch R. & Stanfors R. (1992) The zone of disturbance around blasted tunnels at depth. International Journal of Rock Mechanics Mineral Science & Geomechanics Abstracts., 29, No. 4, pp 447-456.

FOE/6/17 Pyrak-Nolte (1994)

Pyrak-Nolte & Montemagno (1994) The effect of the critical path on fluid flow through a fracture. Proceedings 1st North American Rock Mechanics Symposium, Rock Mechanics, Nelson & Laubach (eds) Balkema: Rotterdam, pp 81-88.

FOE/6/18 Rouleau (1992)

Rouleau A. & Raven K.G. (1992) Site specific simulation of groundwater flow and transport using a fracture network model. Proceedings of Conference on Fractured and Jointed Rock Masses, Lake Tahoe, Preprint Volume 3, pp. 587-593.

FOE/6/19 Thomas (1995)

Thomas A.L. & La Pointe P.R. (1995) Conductive fracture identification using neural networks. Proceedings 35th US Symposium on Rock Mechanics, Lake Tahoe, pp 627-632.

FOE/6/20 Younger (1995)

Younger P.L. & Elliot T. (1995) Chalk fracture system characteristics: implications for flow and solute transport. Quarterly Journal of Engineering Geology, 28, S39-S50.

FOE/5/8 Herbert (1994)

Herbert A.W (1994) NAPSAC (Release 3.0) Summary Document. AEA-D&R-0271

S/95/006

NIREX (1995a) Sellafield Geological and Hydrogeological Investigations. The Flow Zone Characterisation of the RCF Area. Summary Report..

S/94/004

NIREX (1995b) Post-closure performance assessment. Modelling of groundwater flow and radionuclide transport. Science Report.