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UNITED KINGDOM NIREX LIMITED

Rock Characterisation Facility

Longlands Farm, Gosforth, Cumbria

**SUPPLEMENTARY
PROOF OF EVIDENCE**

OF

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GEOLOGY AND HYDROGEOLOGY

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1. SUMMARY

- 1.1 This supplementary proof provides responses to various points made in the Objectors' proofs of evidence related to aspects of the geology and hydrogeology of the Sellafield site.
- 1.2 Responses are made to points raised by
 - i. Professor Mather (PE/CCC/4 for Cumbria County Council)
 - ii. Dr Green and Dr Western (PE/FOE/1 for Friends of the Earth)
 - iii. Dr Kokelaar (PE/FOE/2 for Friends of the Earth)
 - iv. Professor Smythe (PE/FOE/3 for Friends of the Earth)
 - v. Mr Reeves (PE/FOE/4 for Friends of the Earth)
 - vi. Dr Salmon (PE/FOE/5 for Friends of the Earth)
 - vii. Dr Hencher (PE/FOE/6 for Friends of the Earth)
 - viii. Dr Allison (PE/FOE/7 for Friends of the Earth) (paragraphs 4.14 and 4.17)
 - ix. Dr Wogelius (PE/FOE/8 for Friends of the Earth) (paragraph 9.9)
 - x. Dr Haszeldine (PE/GNP/3 for Greenpeace Ltd) (except Sections 13 and 14)

Principal Points of Agreement

- 1.3 There are three main areas in which there appears to be substantial agreement between all parties, namely:
 - i. the accuracy and reliability of the basic factual data on the geology and hydrogeology as revealed by the investigations carried out so far does not appear to be in question;
 - ii. that an RCF will ultimately be required at a potential repository site prior to a decision to propose that site for development does not appear to be in dispute; and
 - iii. it is necessary to establish the baseline hydrogeological conditions at the site before construction of the RCF.

Principal Points of Disagreement

- 1.4 The assertions made in the Objectors' proofs, and which form the principal points of disagreement, fall essentially into three categories:
 - i. Sellafield is a 'poor' site for a repository and hence there is no need for the RCF;
 - ii. the RCF will not take us significantly forward; and
 - iii. an application to construct an RCF at Sellafield is premature.
- 1.5 These three categories of issues are briefly reviewed in turn in the following paragraphs, the reasons why I disagree with the Objectors are stated and indications are given as to where the individual points of disagreement are addressed in the body of this supplementary proof.

'Sellafield is a poor site'

- 1.6 The assertions by the Objectors that Sellafield is a 'poor' site take a number of forms, which are summarised as follows:
 - i. **The site does not conform to generic characteristics of a potential repository site.** This is the assertion made primarily by Professor Mather (PE/CCC/4, paragraph 3.1). He asserts that there are a number of 'requirements' for a potential repository site and that the Sellafield site, by not matching up to these 'requirements', should be regarded as a 'poor' site and abandoned. Dr Salmon (PE/FOE/5) makes similar assertions (paragraph 2.21, page 17).
 - ii. **There are 'better' sites elsewhere in UK at which further investigations should be concentrated.** This is a major assertion by Professor Mather (PE/CCC/4, paragraphs 4.6 and 4.7) which follows from his earlier assertion that Sellafield is a 'poor' site and should be abandoned. Friends of the Earth and Greenpeace, because they adopt the position that further investigations are required at Sellafield before construction of an RCF, only refer in passing to the possibility that there may be 'better' sites elsewhere. Dr Haszeldine (PE/GNP/3, paragraph 16.10) suggests that alternative

sites be considered and investigated. Mr Reeves (PE/FOE/4, paragraphs 2.2, 3.2, 4.4 and 8.7) asserts that other sites in the UK should be investigated to provide a basis for selection of the optimal disposal site. Dr Allison (PE/FOE/7, paragraph 4.17) also asserts that alternative sites should be investigated.

- iii. **The site is complex.** Professor Mather (PE/CCC/4, paragraph 5.7), Dr Kokelaar (PE/FOE/2, paragraph 5.1) and Dr Allison (PE/FOE/7, paragraph 4.14), assert that the site is so complex and unpredictable that it will never be possible to adequately characterise it.

1.7 I disagree that Sellafield is a 'poor' site for a repository and firmly believe that the results so far of the investigations and studies indicate that the site shows good potential as a repository site. I believe this because:

- i. the results of the investigations carried out so far have provided a good understanding of the geology and hydrogeology of the site; and
- ii. assessments of the likely performance of the total repository, such as those described in Nirex 95 [COR/522] and in Dr Hooper's evidence ([PE/NRX/15](#)), based on site-specific data, provide confidence that a repository could be developed at Sellafield which would meet regulatory requirements.

1.8 The Objectors' assertions that Sellafield is a 'poor' site are based on three flawed approaches, as follows:

- i. **the inappropriate use of geological and hydrogeological 'criteria'** for the assessment of site suitability. As set out in [paragraph 6.26](#) of [PE/NRX/12/S1](#), Nirex's view is that the suitability of any particular site must be based on a safety assessment of the predicted performance of the complete repository system at that site. Such an approach is not followed by the Objectors in asserting that Sellafield is a 'poor' site based upon both qualitative 'criteria' which were intended to assist in the early stages of area selection (for example PE/CCC/4, paragraph 3.1; PE/FOE/5, paragraph 2.4) and qualitative hydrogeological 'criteria' (for example PE/CCC/4, paragraph 6.2.9; PE/GNP/3, paragraph 12.5);
- ii. **the selective identification and exaggeration of issues related to the geology and hydrogeology of the site** as a basis for asserting that Sellafield is a 'poor' site (for example PE/GNP/3, paragraphs 7.1 and 8.2); and
- iii. **the inappropriate treatment of technical issues that are important to the behaviour of the hydrogeological system at Sellafield** and which therefore have significance regarding the performance of a repository at the site (for example, hydraulic conductivity of the BVG (PE/CCC/4, paragraph 6.2.9 and PE/GNP/3, paragraph 12.5), interpretation of salinity profiles (PE/CCC/4, paragraph 6.7.1) and patterns of groundwater flow (PE/CCC/4, paragraph 6.6.5; PE/GNP/3, paragraphs 8.1 to 8.4))

'The RCF will not take us forward'

1.9 There are two main themes within the Objectors' evidence that can be grouped under this general heading, namely:

- i. **the RCF will not provide sufficient information** to establish whether the site will prove suitable for a repository because it is impossible ever to characterise a complex site to the extent required (for example PE/CCC/4, paragraph 5.7; PE/FOE/2, paragraph 5.1; PE/FOE/7, paragraph 4.14); and
- ii. **the RCF will not provide important information** (for example, on the regional hydrogeology PE/CCC/4, paragraph 7.2) needed to assess the suitability of the site.

Sufficiency of Information

- 1.10 I disagree with the first theme on the grounds of a fundamental difference in the apparent approach of the Objectors and Nirex as to how to treat spatial variability (heterogeneity, or 'complexity') in constructing groundwater flow and radionuclide transport models. Whilst the Objectors appear, on the whole, to expect precise deterministic characterisation of the whole flow system to be necessary to build an adequate model, Nirex is adopting state-of-the-art geostatistical techniques which use a stochastic description of the flow system built on a limited programme of observations and experiments. The Nirex approach is held in common with most organisations concerned with evaluating flow and transport in heterogeneous systems.

Importance of Information

- 1.11 A particular issue raised by the Objectors is that the RCF will not provide information on issues of importance to the establishment of the potential of the site to host a repository. For example, the extent to which the RCF will provide information on the regional hydrogeology has been questioned (PE/CCC/4, paragraph 7.2). I do not agree with this assertion.

'The RCF is Premature'

- 1.12 A consistent theme within the Objectors' evidence is that the RCF is premature. Two main assertions are made, namely:
- i. **Further work is required before an RCF is constructed.** Dr Haszeldine (PE/GNP/3, paragraphs 5.6, 9.8, 14.1, 14.22 and 16.6), Drs Green and Western (PE/FOE/1, paragraphs 9.7 and 10.5), Professor Smythe (PE/FOE/3, paragraphs 7.9, 8.7, 9.10, 10.3 and 10.8), Mr Reeves (PE/FOE/4, paragraph 8.5), Dr Salmon (PE/FOE/5, paragraphs 5.5 and 6.1-6.6), Dr Hencher (PE/FOE/6, paragraphs 6.20, 10.8, 11.8 and 12.3) and Dr Allison (PE/FOE/7, paragraphs 4.43 and 6.20) all assert to varying extents, that additional work needs to be undertaken before construction of an RCF at Sellafield should commence. In asserting that additional work is required to characterise the site prior to construction of an RCF, the Objectors are presumably conceding that the site may hold sufficient promise ultimately to justify construction of an RCF and hence, hold potential as a repository site.
 - ii. **The hydrogeological baseline conditions have not been established.** This argument (PE/FOE/4, paragraph 8.5; PE/FOE/5, paragraph 5.5) is used to assert that additional periods of monitoring are required of 4 or 5 years to establish baseline and therefore, that the RCF is premature. The subject of baseline is addressed in [Appendix 2](#) of **PE/NRX/14** and in section 10 of this supplementary proof.
- 1.13 The RCF is an important part, but nonetheless only a part, of an integrated programme of site characterisation activities. Thus further surface-based investigations, laboratory tests, interpretation and modelling are being undertaken in parallel with the RCF (see [Table 6.3](#), **PE/NRX/14**). Those investigations which are required before the RCF construction starts have either been carried out, are in progress or are planned for completion prior to commencement of the RCF. There are other investigations which are located outside the area of influence of the RCF which can proceed in parallel with the RCF and do not therefore need to be undertaken before RCF construction commences.
- 1.14 I believe that baseline conditions have been established. This has been confirmed by a review undertaken for Nirex by Professor Lloyd (Professor of Hydrogeology at University of Birmingham) [NRX/14/3]. A further two years of monitoring will be undertaken before RCF construction commences.

Technical Issues

Generic characteristics of a potential repository site

- 1.15 Professor Mather, in paragraph 3.1 (PE/CCC/4, page 5) states that there are "*requirements of a geological barrier*" and lists a series of characteristics which he states are those listed in paragraphs 3.2.6 and 3.2.7 of Nirex Report 71 (*PERA*) [COR/501].
- 1.16 Dr Salmon (PE/FOE/5) seeks to make a similar point in section 2 of his evidence. At paragraph 2.4 (page 6) he identifies what he states to be "*key hydrogeological criteria for the assessment of environmental suitability for radioactive waste disposal*". He then concludes in paragraph 2.21 (page 17) that "*I consider*

that the Sellafield site does not satisfy at least two of the hydrogeological criteria previously considered as necessary pre-requisites for the construction of a deep radioactive waste repository".

- 1.17 The issue of geological criteria is addressed at [paragraphs 6.24](#) to 6.28 of Mr Folger's supplementary proof (PE/NRX/12/S1). As indicated there, the suitability of any particular site must be based on a safety assessment of the predicted performance of the complete repository system of the site, not on criteria for site performance in relation to particular attributes.
- 1.18 A similar point arises from sections 3 and 4 of Professor Mather's evidence (PE/CCC/4) in which he asserts that:
- i. the 'BUSC' concept (low permeability basement under sedimentary cover) was identified as providing the best overall performance of land-based options with respect to post-closure radiological safety (PE/CCC/4, paragraph 3.3, page 9); and
 - ii. the Sellafield site *"has none of the hydrogeological characteristics associated with the BUSC concept"* (PE/CCC/4, paragraph 4.4, page 11).
- 1.19 The statements made by Professor Mather are contested on three issues:
- i. he is wrong to rely on comparisons with qualitative, generic environment descriptions when quantitative, site-specific data are available;
 - ii. he is wrong in claiming that the Sellafield site has none of the hydrogeological characteristics of a BUSC environment; and
 - iii. he is wrong in his interpretation of the information contained in the paper by Bredehoeft and Maini (CCC/4/1) which he quotes.
- 1.20 As described in [chapter 6](#) of PE/NRX/14 site characterisation investigations have confirmed that at Sellafield:
- i. basement rocks (BVG) lie under a younger sedimentary cover.
 - ii. groundwater movement is dominantly in the sedimentary cover, particularly the near surface permeable sandstones of the Sherwood Sandstone Group.
 - iii. the intrinsic permeability of the basement is low.
 - iv. over the PRZ, the groundwater in the sedimentary cover is predominantly fresh and in the basement is saline, indicating little connection.
- 1.21 These are the characteristics of the environments described by Bredehoeft and Maini (CCC/4/1).
- 1.22 I disagree with the approach taken by Professor Mather and Dr Salmon in seeking to compare conditions at Sellafield with secondary qualitative criteria set up to assist in identifying suitable generic sites for investigation. The appropriate basis for assessing the suitability of a site that has been investigated is by carrying out safety assessment studies and comparing the results with regulatory requirements. Nirex has presented a preliminary assessment for the groundwater pathway at Sellafield in Nirex 95 [COR/522]. Nevertheless, Sellafield does demonstrate the characteristics of a BUSC site described at paragraph 6.3.3 in Nirex Report 71 [COR/501] and of the examples given in the Bredehoeft and Maini paper (CCC/4/1).

Alternative Sites

- 1.23 Professor Mather makes a number of statements about Sellafield and possible alternative sites in paragraphs 4.6 and 4.7 of his evidence (PE/CCC/4). In particular he asserts that the Tremadoc rocks in the area of East Central England are likely to be far less complex than the BVG. I am not aware of any evidence to support this view, and he refers to none.
- 1.24 In respect of Professor Mather's "*inherently less robust*" (paragraph 4.6, PE/CCC/4) point it is acknowledged that there could be other sites that would offer lower levels of post-closure radiological risk to an individual, but the pursuit of risks below the 10^{-6} design target is not a requirement of government policy or the regulators (see Mr Folger's supplementary proof (PE/NRX/12/S1) [paragraphs 6.3](#) to 6.5). However, whereas we now have a very substantial base of knowledge on the characteristics of the site at Sellafield, knowledge of the alternatives described by Professor Mather is comparatively sparse. It cannot be assumed therefore that any specific alternatives would necessarily be more robust in radiological terms.
- 1.25 Dr Haszeldine (paragraph 16.10, PE/GNP/3), Mr Reeves (paragraphs 2.2, 3.2, 4.4 and 8.7, PE/FOE/4), and Dr Allison (paragraph 4.17, PE/FOE/7) all state their view that alternative, unspecified sites should be investigated. No evidence, other than their assertions that Sellafield is a 'poor' or 'marginal' site, is presented by them to support the investigation of these unspecified alternative sites.

Complexity

- 1.26 Professor Mather (PE/CCC/4, for example paragraph 8.6), Dr Kokelaar (paragraphs 3.3, 4.1 and 5.1; PE/FOE/2), Dr Allison (paragraph 4.14; PE/FOE/7) and Dr Salmon (paragraph 2.8, PE/FOE/5) make repeated claims that the Sellafield site is complex. Complexity is something that must be addressed in a safety assessment and which influences the design of the investigation programme and modelling approach, it is not a disqualifier of a site. Natural complexity has been addressed in an appropriate way by Nirex.

Geology

- 1.27 Dr Kokelaar states his view (paragraph 5.1; PE/FOE/2) that the BVG has exceptional geological complexity that renders prediction of the 3-D distribution of the rocks and fractures extremely difficult. His evidence exaggerates the complexities. The taking of a variety of features of the BVG in the Lake District and implying that they all apply to the local area of the RCF and PRZ is misleading.
- 1.28 Professor Smythe, by selectively presenting information, has sought to undermine the geological interpretations presented by Nirex in order to justify the need for a 3-D seismic survey (paragraphs 10.2 and 10.8; PE/FOE/3). Not only is it considered that the claims made by Professor Smythe concerning the interpretations of the structural geology are unjustified, but he has also failed to appreciate that the evidence presented by Nirex already includes proposals to carry out such a survey prior to the commencement of RCF construction.

Groundwater flow through fractured rock

- 1.29 Professor Mather and Dr Haszeldine have asserted that only a single fracture in the rock could render the site unsuitable and, by applying inappropriate secondary hydrogeological 'criteria' have sought to demonstrate that the Sellafield site is unsuitable (paragraph 6.29, PE/CCC/4; paragraph 12.5, PE/GNP/3).
- 1.30 They have used an inappropriate basis for relating small scale measurements in boreholes to the large scale characteristics of the rock mass as a whole in order to represent the site in a way that is incompatible with large scale measurements made at the site.
- 1.31 Dr Haszeldine has reported some alternative groundwater flow modelling and sought to demonstrate that it indicates results which are significantly different from those reported by Nirex (PE/GNP/3, paragraph 7.27).
On the basis of a review of the modelling work undertaken by Dr Haszeldine it is concluded that the differences he reports between his modelling and that undertaken by Nirex arise for the following reasons:
- i. the selection of a geological structure and hydraulic parameters by Dr Haszeldine to produce an extreme and pessimistic conceptual model of the Sellafield site; and
 - ii. the failure by Dr Haszeldine to acknowledge the difference between regional effective values of hydraulic conductivity and point measurements made in boreholes.
- 1.33 It is my assessment that if realistic parameters were used, Dr Haszeldine's models would produce results broadly comparable to those presented in much more detail by Nirex in Nirex 95 [COR/522]. These results indicate that the site is likely to meet the regulatory safety requirements.

Hydrogeological Studies

- 1.34 Issues raised by the Objectors relating to the following aspects of hydrogeology have been addressed:
- i. hydrogeological conceptual models;
 - ii. patterns of groundwater flow;
 - iii. numerical groundwater flow modelling;
 - iv. the role of the RCF in understanding regional hydrogeology; and
 - v. recommendations for further investigations.
- 1.35 The groundwater flow models presented by Nirex in Nirex 95 [COR/522] incorporate all the relevant features of the Sellafield site and indicate that the site is likely to meet regulatory safety requirements. Hence there is no reason why the RCF should not proceed to provide the necessary information to allow Nirex to decide whether to proceed with a planning application for a repository.
- 1.36 My review of the Objectors' assertions that further surface-based investigations are required before the RCF is constructed has revealed that their recommendations are already largely included in the integrated programme of site characterisation works being undertaken by Nirex and that, where necessary, these can be completed before the programmed date for commencement of the RCF or can proceed in parallel with the RCF.
- 1.37 The RCF programme addresses many issues including aspects of local and regional hydrogeology.

Geochemical Studies

- 1.38 The principal assertions made by the Objectors related to geochemistry are:

- i. the lack of boreholes drilled specifically to obtain hydrogeochemical data is one of the major deficiencies of the current borehole programme (paragraph 6.5.1, page 29, PE/CCC/4);
- ii. geochemical information has been used to identify three groundwater regimes which rely heavily on the distribution of salinity for their definition (paragraph 6.5.2, page 29, PE/CCC/4);
- iii. the nature of the saline transition zone in the PRZ (paragraph 6.5.5, page 31, PE/CCC/4) suggests an upward flow of groundwater from the BVG into the SSG in this area (paragraph 6.7.1 on page 40 and 41 of PE/CCC/4);
- iv. geochemical indicators of residence time have been overinterpreted. (paragraph 6.7.1 on page 40 and 41 of PE/CCC/4; paragraph 11.7, page 29, PE/GNP/3);
- v. the Nirex conceptual model is simplistic and hides the complex inter-relationships between the various groundwater regimes. It also appears unrealistic with respect to the likely point of discharge of groundwater to the surface. (paragraph 6.7.1 on page 40 and 41 of PE/CCC/4);
- vi. the chemical analyses are suspect because of mixing between water from fractures and from matrix (paragraph 11.4, page 29, PE/GNP/3); and
- vii. rates of regional flows of subsurface waters in the future could be much more rapid than any inferred today (paragraph 10.3, page 26, PE/GNP/3).

1.39 I disagree with these assertions because:

- i. rigorous procedures designed to achieve high quality data, have been applied to the collection of groundwater samples from the boreholes drilled by Nirex to date. The quality of information derived from these boreholes has been reviewed by the Royal Society Study Group, and is deemed to be of a high standard;
- ii. the basis on which the three groundwater regimes are defined is clearly documented and is supported by a range of independent datasets. They are not purely defined on the basis of salinity, although salinity is a key indicator of the different regimes;
- iii. the inference of upward flow of groundwater from the hydrogeochemical data is made on the basis of considering a localised dataset (around the saline transition zone in the PRZ) without imposing the context provided by the larger dataset or the knowledge of the prevailing hydraulic conditions;
- iv. geochemical indicators of groundwater residence times have been interpreted in context with each other to build confidence in overall conclusions despite uncertainties prevailing with any individual method;
- v. a clear picture of the hydrochemical conditions is represented by the Nirex conceptual model and it has not been necessary to modify this substantially as more data are added to the database;
- vi. the chemical analyses derived from well tests performed in the boreholes primarily sample from the fraction of the rock mass that flow under test conditions. These are primarily the more mobile waters contained within the fractures; and
- vii. the suggestion that rates of regional flows of subsurface waters in the future could be more rapid than any inferred today is based on speculation for which there is no existing evidence.

Baseline Hydrogeological Conditions

- 1.40 The need to establish the baseline hydrogeological conditions at the site is not in dispute. Mr Reeves and Dr Salmon claim that a further 4 or 5 years of monitoring are required before the RCF should commence (PE/FOE/4, paragraph 8.5, PE/FOE/5, paragraph 5.5).
- 1.41 I disagree with the statements and assertions made by Dr Salmon and Mr Reeves for the following reasons:
- i. Mr Reeves underestimates the data available to Nirex, which includes a number of data series of greater than 20 years duration;
 - ii. inappropriate comparisons are made with regional groundwater schemes whose expected hydrological impact is orders of magnitude greater than is compatible with the RCF, or even with a repository; and
 - iii. a scientific review of the technical objectives of monitoring indicates that there is no justification for the arbitrary periods of additional monitoring suggested as being required by Mr Reeves and Dr Salmon.
- 1.42 The baseline geochemical data is 'fit for purpose' because:
- i. it has allowed a clear picture of hydrochemical conditions to emerge which it has not been necessary to modify substantially as more data are added progressively to the database; in other words, the hydrochemical understanding is robust.
 - ii. thus, it has permitted the construction of a regional hydrogeological model which has met with broad acceptance as a useful representation of the system (e.g. PE/CCC/4 at 6.6.7; Royal Society Study Group [COR/605] at p 107 "*A relatively robust description of the present-day generalised flow in an east-west plane is emerging.*").
 - iii. it has identified areas within the region where further investigations could be focussed to refine the regional model.

Tectonics and Earthquakes

- 1.43 Dr Haszeldine seeks in his evidence to establish that a potential hazard exists related to tectonic activity and earthquakes which, to his knowledge, has not been addressed by Nirex in work published to date (PE/GNP/3, paragraph 7.1).
- 1.44 However, his statements and assertions are flawed in several ways, namely:
- i. the evidence quoted by Dr Haszeldine (paragraph 7.5, PE/GNP/3) for major expulsion of water during earthquakes is from large earthquakes of a size far greater than those observed to occur in Britain;
 - ii. the extrapolation of the 'radius of influence' of such a large earthquake to west Cumbria in the way done by Dr Haszeldine is questionable;
 - iii. recent research is indicating that hydrogeological changes produced by earthquakes are associated with small enhancements in shallow permeability of the ground, not with expulsion of water from depth;
 - iv. the tectonic regime in the UK is not extensional;
 - v. the last stage of movement on the Lake District Boundary Fault Zone was not extensional, even though the fault originally developed as a 'normal fault' in an extensional regime; and
 - vi. the Rampside earthquake was associated with shallow liquefaction of beach sands. There is no evidence to suggest that it was associated with ejection of deep groundwater.

Comparison with investigation practices elsewhere

- 1.45 Dr Haszeldine and Professor Smythe seek to draw comparisons between the Nirex investigations and the practices in the oil industry to seek to demonstrate that the approach and timescales adopted by Nirex are inappropriate (PE/FOE/3, paragraph 7.14 and PE/GNP/3, paragraph 6.3).
- 1.46 The programme presented by Dr Haszeldine for the Nirex investigations is wrong and understates the duration of the Nirex scientific programme. The duration of the Nirex investigations is longer than he quotes for investigations in the oil industry.
- 1.47 The investigation practices adopted by Nirex and the oil industry are substantially similar, the differences reflecting that Nirex is assessing the suitability of a site for a radioactive waste repository and not exploring for oil or gas.

Conclusions

- 1.48 My supplementary proof has demonstrated the inappropriate use by the Objectors of geological and hydrogeological 'criteria' in an attempt to suggest that the Sellafield site has little potential as a repository site.
- 1.49 The results of the investigations carried out by Nirex have been translated through the Nirex 95 studies [COR/522] into assessments of risk that can be compared with regulatory safety requirements. These studies indicate that the site has good potential as a repository site.
- 1.50 I have indicated that those surface-based investigations which are relevant to the assessment of the site to host a repository are planned or are programmed by Nirex either to be completed prior to commencement of the RCF, where necessary or appropriate, or to proceed in parallel with the RCF where this is appropriate.
- 1.51 Baseline hydrogeological conditions have been established and a further two years of monitoring will be completed before commencement of RCF shaft sinking. There is no justification for the duration of monitoring claimed, by the Objectors, as being required before the RCF commences.

2. INTRODUCTION

- 2.1 In this supplementary proof I comment on the proofs of evidence which oppose the planning application for the RCF on the grounds that aspects of the geology and hydrogeology of the Sellafield site have not been adequately addressed by Nirex. I include comments on the proofs and the evidence led by:
 - i. Professor Mather (PE/CCC/4 for Cumbria County Council)
 - ii. Dr Green and Dr Western (PE/FOE/1 for Friends of the Earth)
 - iii. Dr Kokelaar (PE/FOE/2 for Friends of the Earth)
 - iv. Professor Smythe (PE/FOE/3 for Friends of the Earth)
 - v. Mr Reeves (PE/FOE/4 for Friends of the Earth)
 - vi. Dr Salmon (PE/FOE/5 for Friends of the Earth)
 - vii. Dr Hencher (PE/FOE/6 for Friends of the Earth)
 - viii. Dr Allison (PE/FOE/7 for Friends of the Earth) (paragraphs 4.14 and 4.17)
 - ix. Dr Wogelius (PE/FOE/8 for Friends of the Earth) (paragraph 9.9)
 - x. Dr Haszeldine (PE/GNP/3 for Greenpeace Ltd) (except Sections 13 and 14)

Principal Points of Agreement

- 2.2 There are three main areas in which there appears to be substantial agreement between all parties, namely:
- i. the accuracy and reliability of the basic factual data on the geology and hydrogeology as revealed by the investigations carried out so far does not appear to be in question;
 - ii. an RCF will ultimately be required at a potential repository site prior to a decision to propose that site for development; and
 - iii. it is necessary to establish the baseline hydrogeological conditions at the site before construction of the RCF.

Principal Points of Disagreement

- 2.3 The assertions made in the Objectors' proofs, and which form the principal points of disagreement, fall essentially into three categories:
- i. Sellafield is a 'poor' site for a repository and hence there is no need for the RCF;
 - ii. the RCF will not take us significantly forward; and
 - iii. an application to construct an RCF at Sellafield is premature.
- 2.4 These three categories of issues are briefly reviewed in turn in the following paragraphs, the reasons why I disagree with the Objectors are stated and indications are given as to where the individual points of disagreement are addressed in the body of this supplementary proof.

'Sellafield is a poor site'

- 2.5 The assertions by the Objectors that Sellafield is a 'poor' site take a number of forms, which are summarised as follows:
- i. **The site does not conform to generic characteristics of a potential repository site.** This is the assertion made primarily by Professor Mather (PE/CCC/4, paragraph 3.1). He asserts that there are a number of 'requirements' for a potential repository site and that the Sellafield site, by not matching up to these 'requirements', should be regarded as a 'poor' site and abandoned. Dr Salmon (PE/FOE/5) makes similar assertions (paragraph 2.21, page 17). This point is dealt with in section 3 of this supplementary proof.
 - ii. **There are 'better' sites elsewhere in UK at which further investigations should be concentrated.** This is a major assertion by Professor Mather (PE/CCC/4, paragraphs 4.6 and 4.7) which follows from his earlier assertion that Sellafield is a 'poor' site and should be abandoned. Friends of the Earth and Greenpeace, because they adopt the position that further investigations are required at Sellafield before construction of an RCF, only refer in passing to the possibility that there may be 'better' sites elsewhere. Dr Haszeldine (PE/GNP/3, paragraph 16.10) suggests that alternative sites be considered and investigated. Mr Reeves (PE/FOE/4, paragraphs 2.2, 3.2, 4.4 and 8.7) asserts that other sites in the UK should be investigated to provide a basis for selection of the optimal disposal site. Dr Allison (PE/FOE/7, paragraph 4.17) also asserts that alternative sites should be investigated. This point is dealt with in sections 4 and 5 of this supplementary proof.
 - iii. **The site is complex.** Professor Mather (PE/CCC/4, paragraph 5.7), Dr Kokelaar (PE/FOE/2, paragraph 5.1) and Dr Allison (PE/FOE/7, paragraph 4.14), assert that the site is so complex and unpredictable that it will never be possible to characterise it adequately. This point is dealt with in section 5 of this supplementary proof.
- 2.6 I disagree that Sellafield is a 'poor' site for a repository and firmly believe that the results so far of the investigations and studies indicate that the site shows good potential as a repository site. I believe this because:
- i. the results of the investigations carried out so far have provided a good understanding of the geology and hydrogeology of the site; and
 - ii. assessments of the performance of a repository, such as those described in Nirex 95 [COR/522] and in Dr Hooper's evidence (PE/NRX/15), based on site-specific data, provide confidence that a repository could be developed at Sellafield which would meet regulatory requirements.
- 2.7 The Objectors' arguments that Sellafield is a 'poor' site are based on three flawed approaches, as follows:
- i. **the inappropriate use of geological and hydrogeological 'criteria'** for the assessment of site suitability. As set out in [paragraph 6.26](#) of PE/NRX/12/S1, Nirex's view is that the suitability of any particular site must be based on a safety assessment of the predicted performance of the complete repository system at that site. Such an approach is not followed by the Objectors in asserting that Sellafield is a 'poor' site based upon both qualitative 'criteria' which were intended to assist in the early stages of area selection (for example PE/CCC/4, paragraph 3.1; PE/FOE/5, paragraph 2.4) and hydrogeological 'criteria' (for example PE/CCC/4, paragraph 6.2.9; PE/GNP/3, paragraph 12.5);
 - ii. **the selective identification and exaggeration of issues related to the geology and hydrogeology of the site** as a basis for asserting that Sellafield is a 'poor' site (for example PE/GNP/3, paragraphs 7.1 and 8.2); and
 - iii. **the inappropriate treatment of technical issues that are important to the behaviour of the hydrogeological system at Sellafield** and which therefore have significance regarding the performance of a repository at the site (for example, hydraulic conductivity of the BVG (PE/CCC/4, paragraph 6.2.9; PE/GNP/3, paragraph 12.5), interpretation of salinity profiles (PE/CCC/4, paragraph 6.7.1) and patterns of groundwater flow (PE/CCC/4, paragraph 6.6.5; PE/GNP/3, paragraphs 8.1 to 8.4))

'The RCF will not take us forward'

- 2.8 There are two main themes within the Objectors' evidence that can be grouped under this general heading, namely:
- i. **the RCF will not provide sufficient information** to establish whether the site will prove suitable for a repository because it is impossible ever to characterise a complex site to the extent required (for example PE/CCC/4, paragraph 5.7; PE/FOE/2, paragraph 5.1; PE/FOE/7, paragraph 4.14); and
 - ii. **the RCF will not provide important information** (for example, on the regional hydrogeology, PE/CCC/4, paragraph 7.2) needed to assess the suitability of the site.

Sufficiency of Information

- 2.9 I disagree with the first theme on the grounds of a fundamental difference in the apparent approach of the Objectors and Nirex as to how to treat spatial variability (heterogeneity, or 'complexity') in constructing groundwater flow and radionuclide transport models. Whilst the Objectors appear, on the whole, to expect precise deterministic characterisation of the whole flow system to be necessary to build an adequate model, Nirex is adopting state-of-the-art statistical techniques which use a stochastic description of the flow system built on a limited programme of observations and experiments. The Nirex approach is held in common with most organisations concerned with evaluating flow and transport in heterogeneous systems. This is discussed in detail in section 5 of this proof.

Importance of information

- 2.10 A particular issue raised by the Objectors is that the RCF will not provide information on issues of importance to the establishment of the potential of the site to host a repository. For example, the extent to which the RCF will provide information on the regional hydrogeology has been questioned (PE/CCC/4, paragraph 7.2). I do not agree with this assertion and state my reasons in [paragraphs 8.79](#) to 8.88 of this supplementary proof.

'The RCF is Premature'

- 2.11 A consistent theme within the Objectors' evidence is that the RCF is premature. Two main assertions are made, namely:
- i. **Further work is required before an RCF is constructed.** Dr Haszeldine (PE/GNP/3, paragraphs 5.6, 9.8, 14.1, 14.22 and 16.6), Drs Green and Western (PE/FOE/1, paragraphs 9.7 and 10.5), Professor Smythe (PE/FOE/3, paragraphs 7.9, 8.7, 9.10, 10.3 and 10.8), Mr Reeves (PE/FOE/4, paragraph 8.5), Dr Salmon (PE/FOE/5, paragraphs 5.5 and 6.1-6.6), Dr Hencher (PE/FOE/6, paragraphs 6.20, 10.8, 11.8 and 12.3) and Dr Allison (PE/FOE/7, paragraphs 4.43 and 6.20) all assert to varying extents, that additional work needs to be undertaken before construction of an RCF at Sellafield should commence. In asserting that additional work is required to characterise the site prior to construction of an RCF, the Objectors are presumably conceding that the site may hold sufficient promise to ultimately justify construction of an RCF and hence, hold potential as a repository site.
 - ii. **The hydrogeological baseline conditions have not been established.** This argument (PE/FOE/4, paragraph 8.5; PE/FOE/5, paragraph 5.5) is used to assert that additional periods of monitoring are required of 4 or 5 years to establish baseline and therefore, that the RCF is premature. The subject of baseline is addressed in [Appendix 2](#) of **PE/NRX/14** and in section 10 of this supplementary proof.
- 2.12 The RCF is an important part, but nonetheless only a part, of an integrated programme of site characterisation activities. Thus further surface-based investigations, laboratory tests, interpretation and modelling are being undertaken in parallel with the RCF (see [Table 6.3](#), **PE/NRX/14**). Those investigations which are required before the RCF construction starts have either been carried out, are in progress or are planned for completion prior to the commencement of the RCF. There are other investigations which are located outside the area of influence of the RCF which can proceed in parallel with the RCF and do not therefore need to be undertaken before RCF construction commences. These issues are addressed in section 8 of this supplementary proof in paragraphs [8.89](#) to 8.95.
- 2.13 I believe that baseline conditions have been established. This has been confirmed by a review undertaken for Nirex by Professor Lloyd (Professor of Hydrogeology at University of Birmingham) [NRX/14/3]. A further two years of monitoring will be undertaken before RCF construction commences.
- 2.14 Sections 3 to 5 provide my response to the three main areas of disagreement described above in [paragraph 2.5](#). The remaining sections of this supplementary proof (6 to 12) deal with specific technical points surrounding these main areas and are broken down into topical areas, as follows:

Section 6: Geology

- 2.15 The evidence presented by Dr Kokelaar (PE/FOE/2) and Professor Smythe (PE/FOE/3) is reviewed in this section.

Section 7: Groundwater Flow through Fractured Rock

- 2.16 This section of my supplementary proof responds to the points made primarily by Professor Mather (PE/CCC/4, paragraph 6.2.9) and Dr Haszeldine (PE/GNP/3, paragraph 12.5) concerning the treatment of groundwater flow through fractured rocks. Their inappropriate use of hydrogeological 'criteria', their treatment of 'upscaling' and the alternative groundwater flow modelling reported by Dr Haszeldine (PE/GNP/3, section 12) are addressed in this section.

Section 8: Hydrogeological Studies

- 2.17 This section of my supplementary proof addresses a wide range of hydrogeological issues primarily raised by Professor Mather (PE/CCC/4), Dr Salmon (PE/FOE/5), Dr Hencher (PE/FOE/6) and Dr Haszeldine (PE/GNP/3). The section is subdivided into various subsections dealing with:
- i. hydrogeological conceptual models (PE/CCC/4, section 6.6; PE/FOE/5, section 2);
 - ii. patterns of groundwater flow (PE/CCC/4, paragraphs 6.3.5, 6.6.5, and 8.7; PE/GNP/3, section 8);
 - iii. numerical groundwater flow modelling (PE/FOE/5, section 3; PE/FOE/6);
 - iv. hydrogeological information from the RCF (PE/CCC/4, section 7); and
 - v. recommendations for further investigations (PE/FOE/5, section 5; PE/FOE/4, paragraph 8.5).

Section 9: Geochemical Investigations

- 2.18 This section responds to a range of issues related to geochemical investigations raised by Professor Mather (PE/CCC/4, sections 6.5 and 6.7), and Dr Haszeldine (PE/GNP/3, paragraphs 10.3, 11.4 and 11.7).

Section 10: Baseline Hydrogeological Conditions

- 2.19 This section addresses the various points made concerning the establishment of baseline conditions (PE/FOE/5, paragraph 5.5; PE/FOE/4, section 5, paragraphs 7.7 and 8.5; PE/FOE/1, paragraph 9.7).

Section 11: Tectonics and Earthquakes

- 2.20 The issues raised by Dr Haszeldine (PE/GNP/3, section 7) are addressed in this section.

Section 12: Comparisons with Investigation Practices Elsewhere

- 2.21 The comparisons made between the investigation practices in the oil industry and those adopted by Nirex (PE/GNP/3, section 6; PE/FOE/3, paragraph 7.14) are responded to in this, the final section of my supplementary proof.

3. GENERIC CHARACTERISTICS OF A POTENTIAL REPOSITORY SITE

Qualitative 'Criteria' - General

- 3.1 Professor Mather, in paragraph 3.1 (PE/CCC/4, page 5) states that there are "*requirements of a geological barrier*" and lists a series of characteristics which he states are those listed in paragraphs 3.2.6 and 3.2.7 of *PERA* [COR/501]. In fact, his list is his own interpretation of that given in paragraphs 3.2.6 and 3.2.7 of *PERA*.
- 3.2 Dr Salmon (PE/FOE/5) makes a similar point in section 2 of his evidence. At paragraph 2.4 (page 6) he identifies what he states to be "*key hydrogeological criteria for the assessment of environmental suitability for radioactive waste disposal*". He then concludes in paragraph 2.21 (page 17) that "*I consider that the Sellafield site does not satisfy at least two of the hydrogeological criteria previously considered as necessary pre-requisites for the construction of a deep radioactive waste repository*".
- 3.3 The issue of geological 'criteria' is addressed at [paragraph 6.24](#) to 6.28 of Mr Folger's supplementary proof of evidence (PE/NRX/12/S1). As indicated there, the suitability of any particular site must be based on a safety assessment of the predicted performance of the complete repository system at the site, not on criteria for site performance in relation to particular attributes.

Sellafield as a BUSC Site

- 3.4 A similar point arises from sections 3 and 4 of Professor Mather's evidence (PE/CCC/4) in which he indicates that, "*The 'BUSC' concept [low permeability basement under sedimentary cover] (Figure 1c) was identified as providing the best overall performance of land-based options with respect to post-closure*

radiological safety" (PE/CCC/4, paragraph 3.3, page 9), but asserts that the Sellafield site *"has none of the hydrogeological characteristics associated with the BUSC concept"* (PE/CCC/4, paragraph 4.4, page 11).

3.5 Specifically, Professor Mather seeks to cast doubt on the suitability of the Sellafield site generally by claiming in paragraph 4.4 that:

"The geological situation is markedly different in the Sellafield 'variant', where basement rocks crop out some 2.5 km away from the potential repository site. Groundwater recharge to these rocks at outcrop will provide a driving force for groundwater to flow through the repository volume. Thus, from first principles, Sellafield has an inherent flaw in comparison to the original BUSC concept, with a much greater potential for groundwater circulation within the basement rocks. In fact, Sellafield bears no relationship to a BUSC site nor can it be considered as a 'variant'. It has none of the hydrogeological characteristics associated with the BUSC concept, and its designation as a BUSC 'variant' appears to be an attempt to force it to fit one of the hydrogeological environments defined in Nirex Report No 71 (COR/501)."

3.6 The statements made by Professor Mather are contested on three grounds:

- i. he is wrong to rely on comparisons with qualitative, generic site descriptions when quantitative, site-specific data are available;
- ii. in any event he is wrong in claiming that the Sellafield site has none of the hydrogeological characteristics of a BUSC environment; and
- iii. furthermore he is wrong in his interpretation of the information contained in the paper by Bredehoeft and Maini (CCC/4/1) which he quotes.

Point 3.6.i

3.7 In a similar way to that discussed at paragraphs 3.1 and 3.3 above regarding generic characteristics of repository sites, Professor Mather is suggesting that comparison between an actual site and qualitative characteristics of generic sites, in this case the BUSC concept, is an appropriate method of assessing the suitability of the site. For the same reasons as those summarised in paragraph 3.3 above, Professor Mather's approach is inappropriate. Conclusions on the suitability of an actual site must be based on a safety assessment of the complete repository system at the site.

Point 3.6 ii

3.8 In *PERA* [COR/501], Nirex described the geological setting of a BUSC environment as (paragraph 6.3.3, page 42):

"(d) Low Permeability Basement Under Sedimentary Cover (BUSC): groundwater movement will dominantly occur in the sedimentary cover, with little anticipated connection to the basement rocks of low intrinsic permeability."

3.9 While expressing reservations about inter-relationships between flow regimes, Professor Mather at paragraph 6.6.7 of PE/CCC/4 appears implicitly to accept the overall conceptual model of the Sellafield site in which groundwater flow is dominantly in the sedimentary cover with an underlying lower permeability basement through his statement that *"It is concluded that the conceptual model of the hydrogeology proposed by Nirex is a useful simplification"*

3.10 That groundwater flow at Sellafield is dominantly occurring in the sedimentary cover, and there is little anticipated connection to the basement rocks of low intrinsic permeability are both conclusions in my evidence ([paragraphs 6.70](#) to 6.73 on pages 45-47 of **PE/NRX/14**).

3.11 The same conclusions are reached from the modelling undertaken in Nirex 95 [COR/522]. In section 2.1.3 on page 2.5 of Volume 3 it states:

"The largest groundwater flows are in the Near-Surface Calder Sandstone and the Near-Surface St Bees Sandstone.....There are weak fluxes of groundwater between these units and the underlying rocks, which have lower permeability."

3.12 Hence, while suitability of a site is not a question of whether or not it conforms to a particular definition of BUSC, it is the case that Sellafield demonstrates those characteristics identified with BUSC in *PERA* [COR/501].

Point 3.6 iii

3.13 In paragraph 3.4 of PE/CCC/4 Professor Mather indicates that the BUSC concept originates from a paper by Bredehoeft and Maini (CCC/4/1). Bredehoeft and Maini do not use the term 'Basement under sedimentary cover' and therefore do not provide a definition of the term. In fact there is no widely agreed definition. Nirex's view of the key characteristics of the BUSC concept is given at paragraph 6.3.3 of PERA [COR/501] as reproduced at paragraph 3.8 above.

3.14 In paragraph 3.4 CCC/4/1, Professor Mather appears to be incorrect in describing Bredehoeft and Maini's assessment by stating:

"In the example they give the cover rocks are shales with a downward hydraulic gradient isolating groundwater beneath. This contrasts markedly with the situation in which the cover rocks are permeable sandstones used as an aquifer."

3.15 Bredehoeft and Maini give two examples, neither of which matches Professor Mather's description. The first example of a coastal site is a direct analogue of the Sellafield situation; the second example is of an inland site and is similar to Nirex's generic BUSC environment as described in paragraph 6.3.3 of PERA [COR/501]. In both examples, permeable sandstone aquifers are a component of the cover sequence.

i. The coastal site is presented as figure 3 in CCC/4/1. It should be noted that this Figure is simplified and does not show structural features such as the geological faults that cross the strata. Broadly, the coastal site example of Figure 3 of CCC/4/1 is an analogue of Sellafield. Specifically, the following points of similarity refute points made by Professor Mather:

- Basement rocks crop out on land in both Figure 3 of CCC/4/1 and Figure 2b of Professor Mather's proof of evidence (PE/CCC/4) which illustrates the Sellafield site.
- The cover sequence contains permeable sandstones used as an aquifer. Figure 3 of CCC/4/1 shows arrows indicating the movement of fresh water through the permeable strata over the potential mined repository.

ii. The inland site example presented in CCC/4/1 may be the example described by Professor Mather, who states at paragraph 3.4 of PE/CCC/4 that the cover rocks were shales and not permeable sandstones used as an aquifer. In fact, the example given in CCC/4/1 has one of the largest aquifers in the USA in the cover sequence and is explicitly described (CCC/4/1, page 295, paragraph 4):

".....the confining layer, which is Cretaceous shale, overlies a more permeable sequence of Mesozoic and Paleozoic sedimentary rocks. This in turn overlies a less permeable body of rock, the Precambrian crystalline basement."

3.16 As described in [chapter 6](#) of PE/NRX/14 site characterisation investigations have confirmed that at Sellafield:-

- i. Hard basement rocks (BVG) lie under a younger sedimentary cover.
- ii. Groundwater movement is dominantly in the sedimentary cover, particularly the near surface permeable sandstones of the Sherwood Sandstone Group.
- iii. The intrinsic permeability of the basement is low.
- iv. Over the Potential Repository Zone, the groundwater in the sedimentary cover is predominantly fresh and in the basement is saline, indicating little connection.

3.17 These are the characteristics of the sites described by Bredehoeft and Maini (CCC/4/1).

Conclusion

3.18 To summarise, therefore, I disagree with the approach taken by Professor Mather and Dr Salmon in seeking to compare conditions at Sellafield with secondary qualitative "criteria" set up to assist in identifying suitable generic sites for investigation. The appropriate basis for assessing the suitability of a site that has been extensively investigated is by carrying out safety assessment studies and comparing the results with regulatory requirements. Nevertheless, Sellafield does demonstrate the characteristics of a

BUSC environment described at paragraph 6.3.3 in *PERA* [COR/501] and of the examples given in the Bredehoeft and Maini paper (CCC/4/1).

4. ALTERNATIVE SITES

- 4.1 In paragraph 4.6 of his evidence (PE/CCC/4, pages 11 and 13), Professor Mather describes Sellafeld as "*inherently less robust*" than the large area of East Anglia and east-central England identified in *PERA* [COR/501] as potentially suitable BUSC rocks. At paragraph 4.7 he indicates that, "*The Tremadoc rocks in the area of East Central England defined by Chapman, McEwen and Beale (1986) (COR/614) are likely to be far less complex than the BVG*".
- 4.2 In relation to Professor Mather's comparison of the characteristics of the BVG and the Tremadoc rocks, he does not present any evidence to support his view that the Tremadoc rocks "*are likely to be far less complex than the BVG*" and I am not aware that any such evidence exists. Since the compilation of the description of the possible basement geology that underpinned the work presented in *PERA* [COR/501] and COR/614, there has been extensive interpretation of geophysical surveys over the area, and these have indicated more variety and complexity in the nature of the basement rocks than then considered. There has been very limited deep drilling and this has only penetrated a few metres into the basement rocks. It has confirmed their variety and structural complexity. Much of this research has been published by the British Geological Survey and others (see for example, *The contribution of palaeontological data to an understanding of the early Palaeozoic framework of Eastern England* [NRX/14/4]). The main observations are summarised as follows:
- i. Lower Palaeozoic and Precambrian rocks have been proved in the subsurface of East Anglia and east-central England at relatively shallow depths.
 - ii. These rocks comprise mudrocks (mudstones, shales and siltstones), sandstones, volcanic rocks and igneous intrusives. The so-called Tremadoc rocks are the time equivalents of the Skiddaw Group, the volcanic rocks are, in part, time equivalents of the Borrowdale Group. Rocks of similar age and lithology to the Windermere Group have also been proved.
 - iii. The boreholes are insufficient in number to allow confident prediction of the likely basement rock at any one point or to map its lithology in the subsurface. Published subsurface geological maps of the area are generalised and conjectural.
 - iv. The rocks are folded, and metamorphosed, and in terms of their fold structure, cleavage, fracture density and the presence of fault-zones and shear-zones are directly comparable to the similar age Skiddaw, Borrowdale and Windermere Groups of the Lake District or the Lower Palaeozoic rocks of the Brabant Massif of Belgium. NRX/14/4 (published in 1991) describes some of the Tremadoc rocks encountered in the boreholes drilled in the Midlands. The author uses phrases such as "*Dips are steep, between 70° and vertical. The Tremadoc strata are folded and faulted, and high proportion of beds are inverted*" and "*Dips are steep (60° to vertical) and there is evidence of slickensiding [the polishing of faults surfaces due to movement]*".
 - v. Some of the Tremadoc rocks have relatively high organic contents and have been found in boreholes associated with small quantities of methane.
- 4.3 It is unlikely, therefore, that the Tremadoc rocks in the area of east-central England are far less complex than the BVG.
- 4.4 More generally, data on the hydrogeological characteristics of deep basement rocks in the UK are sparse as recognised in a recent report commissioned from the British Geological Survey by Nirex (*Use of a "groundwater return index" in site selection for deep radioactive waste repositories: a review of the RWMAC/ACSNI proposal* [NRX/14/5]). The conclusions of this BGS review include the following statements in section 4 on pages 10 and 11:

"(iii) In application to deep, low permeability formations potentially suitable for radioactive waste disposal, values of hydrogeological indices are particularly difficult to estimate because of the scarcity of reliable data, especially for hydraulic conductivity.

(iv) Hydraulic conductivity data for such formations are particularly lacking (in the UK as elsewhere) and subject to particular uncertainty, because of the difficulties in predicting the influence of faults and other fractures".

- 4.5 In respect of Professor Mather's "inherently less robust" point it is acknowledged that there could be other sites that would offer lower levels of post-closure radiological risk to an individual, but the pursuit of risks below the 10^{-6} design target is not a requirement of government policy or the regulators (see Mr Folger's supplementary proof (PE/NRX/12/S1) [paragraph 6.3](#) to 6.5). However, whereas we now have a very substantial base of knowledge on the characteristics of the site at Sellafield, knowledge of the alternatives described by Professor Mather is comparatively sparse. It cannot be assumed therefore that any specific alternatives would necessarily be more robust in radiological terms.

5. COMPLEXITY

General Considerations

- 5.1 Professor Mather makes repeated reference to the complexity of the Sellafield Site. For example at paragraph 5.7 on page 16 of PE/CCC/4 he states:

"the complex nature of the geology, and particularly the faulting, makes the controls on groundwater flow much more difficult to define."

- 5.2 Similarly, in his conclusions he again refers to complexity. In paragraph 8.6 on page 44 he states:

"The distribution of the various rock types in the BVG show the presence of a complex pile of variably faulted rocks and it is only in a very limited area that any coherent picture has emerged."

- 5.3 In paragraph 8.8 he states that the conceptual model is simplistic and hides the complex inter-relationships between the various groundwater regimes. Finally, in paragraph 8.9 he states:

"The RCF will allow a more detailed understanding of the fracture network in the near-field, but because of the complexity and unpredictability of the hydrogeology, it may not advance the overall understanding of the controls on groundwater flow."

- 5.4 Despite Professor Mather's repeated reference to 'complexity', he neither defines what he means by complexity, nor does he clearly establish its significance.
- 5.5 Dr Allison (PE/FOE/7) at paragraph 4.14, page 20 makes similar statements about the complexity of the Sellafield site.
- 5.6 A simple definition of 'complexity' is something that is complicated or difficult to understand. I believe that any natural geological system, if investigated in the detail to which Sellafield has been investigated, would reveal natural complexity at some scales. The issue is therefore whether this natural complexity can be understood in sufficient detail to enable the suitability of the site to be established. A more complex site may require a more extensive investigation than a less complex site, but providing the site was capable of being understood, complexity would be a matter of resources available for investigation.
- 5.7 Paragraph 4.8 of the HMIP background document submitted to the Inquiry dated 22 September (PE/HMP/1) indicates, *"The proposed RCF site has a complex geological structure and this would need to be addressed thoroughly in any future application that Nirex might submit under RSA 1993"*. This suggests that the regulatory view accords with that expressed at [paragraph 5.6](#) above: that complexity is something to be addressed, not a disqualifier of a site.

Sufficiency of Information

- 5.8 A central difference between the positions of the Objectors and Nirex in respect of complexity and the appropriate response in investigation and modelling is that, whilst the Objectors suggest that very detailed

and specific characterisation of rock properties is essential throughout the system, Nirex, in common with current state-of-the-art practice in addressing flow and transport in deep groundwater systems, has chosen to follow a largely stochastic approach. The arguments which Nirex presents for adopting this approach develop as follows:

- i. All geological systems demonstrate spatial variability the 'complexity' of which may itself vary dependent on the scale at which the systems are viewed.
- ii. It is not possible to characterise this variability in detail in terms of making a complete 3-D model of all features, their size, positions, orientations and properties at all scales (a fully 'deterministic' approach). To do this would involve destroying the rock completely. However, measurements can be made at various scales of observation and within different regions of the body of rock being studied.
- iii. Knowledge of all the properties which display variability is not necessarily important when constructing a safety case as many rock properties need not be considered directly in safety assessment models. For example, very detailed lithological description of the rock may be of minor significance compared to detailed understanding of fracture characteristics, the analysis of which is one of the main aims of the RCF.
- iv. Measurements of fracture characteristics are made at various scales by direct observation and by hydraulic and tracer testing. This allows models of their flow and transport properties at those scale to be developed. Such models use statistical techniques to simulate the properties of the rock volume under study and are conditioned by the observations. The models should have an appropriate level of complexity, sufficient to capture the aspects of interest in the system without unnecessary detail. A number of such 'stochastic' techniques exist for producing realisations of fracture fields (or hydraulic conductivity or transmissivity fields) which replicate the observed behaviour of the system at the scale at which it is being observed and which may also be conditioned to duplicate specific point measurements.
- v. Such models can be constructed and tested in an RCF at a variety of scales (1m, 10m, 100m). The extent to which they are related to each other provides information on the larger scale variability of the rock formation being studied. They can also be used to predict the 'effective' properties of that rock at a much larger scale ('upscaling'). In the large scale model the effects of the detailed structure are taken into account implicitly through the use of appropriate effective properties and the system description is therefore much simpler. These models do not represent the details of flow and transport at the small scale, which do not matter on the scale of interest, but if the upscaling procedure has been developed correctly, they will predict overall bulk fluxes through the system as a whole (e.g. at a regional scale).
- vi. It is important to test the models at various scales in order to be sure that the large-scale effective properties (generally used to underpin safety assessment transport calculations) do not depend on some unobserved variability present at an intermediate scale. The RCF will allow observations and testing at a variety of scales. In addition, some aspects of safety assessment modelling may require the deployment of relatively small-scale models to evaluate specific features of the repository design.
- vii. Where the details do matter, for example in the immediate vicinity of the repository, models can be used in which the features of interest, for example deterministic lithological boundaries and major faults, are represented explicitly.

The rationale developed above has been tested in a number of major programmes in a variety of rock types and at various scales, for example at Stripa at RCF scale, and at the WIPP site in the USA at 100's km² scale. From the above it can be seen that careful observation and experimentation at various scales, combined with model building and testing and a mix of stochastic and deterministic techniques will allow sufficient information to be gathered to allow an adequate level of site description at the scales required for safety assessment modelling.

Finally, I point out that the RCF will not be the only source of information used to develop and test the flow and transport models discussed. The programme of regional investigations will continue in parallel with the RCF and will provide additional information.

6. GEOLOGY

6.1 Two of the Objectors' proofs deal primarily with geology and geological investigations. These are the proofs by Dr Kokelaar (PE/FOE/2) and Professor Smythe (PE/FOE/3). These proofs are reviewed in turn in the following paragraphs.

Dr Kokelaar (PE/FOE/2)

- 6.2 Dr Kokelaar states his view (paragraph 5.1, page 11, PE/FOE/2) that the *"Borrowdale Volcanic Group has exceptional geological complexity that renders prediction of its 3D distribution of rocks and fractures extremely difficult"*. From this he concludes (paragraph 5.2, page 11, PE/FOE/2) that:
- "Accurate characterization can only be derived by drilling boreholes so closely that the drilling would constitute substantial interference with the system."*
- 6.3 He states in paragraph 4.7, page 9 of PE/FOE/2 that:
- "Observational data from a sub-surface facility, such as the proposed RCF, could be obtained directly through observation of the rock exposed through excavation or indirectly through boreholes drilled from the sub-surface."*
- 6.4 Dr Kokelaar adds in paragraph 4.8 on page 10 of PE/FOE/2 that access at depth will not resolve the difficulties associated with the high level of complexity of the Borrowdale Volcanic System.
- 6.5 Thus, Dr Kokelaar appears to be stating a view that the geology of the BVG cannot be adequately characterised except by closely spaced boreholes.
- 6.6 Dr Kokelaar, while having substantial experience of studying volcanic rocks and the BVG, appears to have used the factual information in a way which exaggerates the complexities. The taking of a variety of features of the BVG in the Lake District and implying that they all apply to the local area of the RCF and PRZ is misleading.
- 6.7 Dr Kokelaar's evidence emphasises the difficulties of obtaining a completely deterministic description of the geology. However, he seems not to have appreciated that such a wholly deterministic description of the geology is not required in order to be able to develop acceptable models of the site for assessing the post-closure performance of a repository (see [paragraphs 5.8](#) to 5.10 of this supplementary proof).
- 6.8 In paragraph 3.3 (page 7, PE/FOE/2), Dr Kokelaar makes generalisations over a large area, states that they apply to the area *"in and around the PRZ"*, and applies them indiscriminately, and without justification, to demonstrate *"extreme 3-D geological complexity"*.
- 6.9 In the first bullet point of paragraph 3.3 on page 7 (PE/FOE/2), Dr Kokelaar refers to *"substantial primary lateral variations of thickness and character"* of the many constituent rock units. This generalisation can be contrasted with the statement made in [paragraphs 5.10](#) and 5.11 of my proof (PE/NRX/14) in which I report the establishment of a subdivision of the BVG *"which can be correlated between boreholes over a distance of several kilometres"*.
- 6.10 Dr Kokelaar's second bullet point states that *"caldera-forming gravitational collapse was incremental and haphazard"*. Leaving aside the issue of whether there is evidence of this on the broad scale, there is certainly no evidence to demonstrate that the RCF/PRZ area is located near a caldera margin.
- 6.11 Dr Kokelaar's third bullet point refers to soft-state deformation being far less ordered and hence less predictable than solid-state tectonic deformation. Indeed, such structures may be abundant. However, these structures are generally healed and are not hydrogeologically significant. Hence, there is little to suggest that such features, and their geological complexity, have any significant influence on the hydrogeological properties of the rock mass.
- 6.12 The statement of fact on faulting which forms the fourth bullet point is not disputed. However, the extent to which such faulting affects the hydrogeology of the site is not addressed at all by Dr Kokelaar.
- 6.13 The final bullet point refers to jointing in the BVG. This has been described in detail by Nirex. Again, Dr Kokelaar appears to be assuming that the description of these features needs to be addressed on a deterministic basis, rather than the stochastic basis that will inevitably apply to such small scale fractures (see paragraph 5.8 of this supplementary proof).

Professor Smythe (PE/FOE/3)

- 6.14 The evidence presented by Professor Smythe (PE/FOE/3) can be summarised as follows:

"An essential prerequisite for hydrogeological modelling is to establish the geological structure accurately both in and around the PRZ" (paragraph 10.2, page 50, PE/FOE/3);

The current geological interpretation is simply not robust, and will therefore not provide a reliable foundation for hydrogeological modelling of the site" (paragraph 10.2, page 50, PE/FOE/3); and

"the 3-D seismic survey should be properly completed or a new survey undertaken, properly validated, and adequately peer reviewed. This work should be undertaken before the hydrogeological modelling work is completed and before the location for the RCF is finalised. The results from the 3-D seismic model and those from the hydrogeological modelling should be demonstrated to be properly compatible before work on the RCF starts." (paragraph 10.8, page 52, PE/FOE/3).

6.15 I disagree with Professor Smythe for the following reasons:

- i. Interpretation of a trial 3-D seismic survey is proceeding. If this technique is shown to be useful, an evaluation will be made of the potential value of extending the survey area. Nirex has already programmed a 3-D seismic survey of the PRZ as stated in [Table 6.3](#) (c) of **PE/NRX/14**. The field acquisition work is provisionally programmed to take place during 1996 such that the results will be available before the RCF shaft excavation commences.
- ii. A detailed deterministic representation of all the small scale structures in the PRZ is not required for hydrogeological modelling. The main structures which are likely to be treated deterministically in the hydrogeological model are robustly defined. Thus, whilst it is not disputed that a 3-D seismic survey will probably provide a greater definition of smaller scale structures within the BVG than is currently available, it is not certain that such added definition will have any relevance to the hydrogeological modelling of the site, and hence justify the environmental impact and high cost of such a survey.
- iii. Professor Smythe has not appreciated that one of the primary reasons why Nirex is interested in carrying out a 3-D seismic survey is to enable the rock properties, not just the geological structure, to be mapped at depth. This is required as part of the production of the three-dimensional model of the PRZ referred to in [paragraph 8.13](#) of my evidence (page 65, **PE/NRX/14**). Final decisions on the 3-D seismic survey are awaiting the results of the interpretation of the results of the trial survey carried out for Nirex with input from Glasgow University and Professor Smythe.

6.16 At paragraph 4.6 (page 20, PE/FOE/3), Professor Smythe states that:

"The advent of two-dimensional (2-D) seismic imaging, together with more drilling, has resulted in a radically improved and more detailed, but not fundamentally different picture of the subsurface."

6.17 Professor Smythe then lists a series of data sources and presents a series of cross sections in his Figure 1. He appears to have selected these sections, which are not all from the same transect, to show the greatest possible differences. Nevertheless, the sections show that broadly the subsurface geology has indeed remained fundamentally similar with more structural detail becoming apparent as additional data have been acquired. However, Professor Smythe, having stated in paragraph 4.6 of PE/FOE/3 that the interpretation has not fundamentally changed, at paragraph 4.8 of PE/FOE/3 states that *"the geological interpretation is being substantially revised every year or so"*. These two statements, in such close proximity, appear to contradict each other.

6.18 Professor Smythe has presented a large amount of detail concerning seismic surveys in his sections 5 to 8 (PE/FOE/3) which appears to be aimed at undermining the quality of the investigation work and the interpretations carried out of them. As such, Professor Smythe's evidence contradicts the statements made by other independent reviewers ([paragraphs 5.5](#) and [5.6](#) on pages 15 and 16 of **PE/NRX/13**).

6.19 At paragraphs 2.13 and 2.18 (PE/FOE/3), Professor Smythe draws attention to inconsistencies between data sets and interpretations presented by Nirex and uses this to justify in paragraph 2.18 the need for 3-D seismic surveys in the Site and even the District areas. In making these assertions he has not taken full account of the work on the structure of the PRZ presented in the summary report {Nirex Report S/95/005} referenced in [paragraph 5.9](#) of my evidence (page 21 of **PE/NRX/14**) or of the detailed underpinning report

on the geological structure of the PRZ {BGS Technical Report No. WA/95/47C, June 1995} referenced in the summary report. The introduction to Report S/95/005 on page 1 includes the following statements:

"1.2 The general structural and tectonic setting of the area around Sellafield was reviewed in Nirex Report No. 520. Nirex Report No. 524, Volume 2 considered the 3D structure of the Region and District. Since the issue of those reports many new data have been acquired. These include the geological data from the RCF, RCM and PRZ boreholes, and the associated geophysical (VSPs, cross-hole seismic tomograms, wireline imagery and other wireline log rock mass property data) and hydrogeological investigations.

1.4 A full account of the detailed GIT (Nirex Geological Integration Team) interpretations underpinning this report is given in BGS Report No. WA/95/47C. The interpretation was carried out in two phases; an initial phase in which individual datasets were interpreted either partially or fully independently of other data, and a second phase in which the primary data interpretations were combined to produce an integrated understanding of the geological structure..."

6.20 Thus, by selectively presenting information, Professor Smythe has sought to undermine the geological interpretations presented by Nirex in order to justify the need for a 3-D seismic survey. Not only is it considered that the claims made by Professor Smythe concerning the interpretations of the structural geology are unjustified, but he has also failed to appreciate that the evidence presented by Nirex already includes proposals, subject to the results of the 3-D trial survey, to carry out such a survey prior to the commencement of RCF construction.

7. GROUNDWATER FLOW THROUGH FRACTURED ROCK

General Considerations

7.1 Professor Mather states in paragraph 6.2.9 on page 21 (PE/CCC/4):

"The results of the hydraulic testing show that 10% of tested zones in the BVG have hydraulic conductivities two orders of magnitude or more above the threshold of $1 \times 10^{-9} \text{ ms}^{-1}$ below which values are normally regarded as impermeable from a waste disposal viewpoint. The fact that the bulk of the BVG has a lower hydraulic conductivity is irrelevant as only one hairline crack in a bottle is necessary for all the contents to leak out. Depending on how the zones are interconnected and the hydraulic gradient to which they are subjected, significant groundwater flow is possible."

7.2 Dr Haszeldine (PE/GNP/3) at paragraph 12.5 on page 36 seeks to make a similar point:

"I attempted to define a limit to regional BVG permeability, above which the ultimate Repository should be considered unsafe. This was arbitrarily defined as being unsafe if water flow could return from the PRZ to the earth's surface within 10,000 yr. It is extremely important to note that this limit is not a statistical distribution as currently used by Nirex, but an absolute limit - if only one fracture has a permeability above this limit, the system is fundamentally flawed. It is difficult to imagine how a small RCF can give site specific measurements of all fractures in the larger region to the required accuracy and precision. Thus the RCF cannot act as an adequate site investigation tool. I find that the limit to BVG permeability is $1 \times 10^{-9} \text{ ms}^{-1}$ ($3 \times 10^{-2} \text{ ma}^{-1}$). This is at least 40 times lower than the maximum permeability measured by Nirex."

7.3 The issues identified in the above two paragraphs are as follows:

- i. hydraulic conductivity values have been measured in the BVG by Nirex;
- ii. quantitative criteria have been introduced by Professor Mather (a threshold value of hydraulic conductivity of $1 \times 10^{-9} \text{ ms}^{-1}$ normally regarded as impermeable from a waste disposal viewpoint) and by Dr Haszeldine (a limit to regional BVG permeability of $1 \times 10^{-9} \text{ ms}^{-1}$ defined as the value

corresponding to a groundwater return time of 10,000 years predicted by a groundwater flow model he had developed);

- iii. both assert that only a single fracture is required to render the system flawed;
- iv. Professor Mather adds that "*depending on how the zones are interconnected and the hydraulic gradient to which they are subjected, significant groundwater flow is possible*";
- v. the RCF cannot act as an adequate investigation tool for making site specific measurements of all fractures in the larger region; and
- vi. The limit of permeability defined by Dr Haszeldine as being safe is 40 times lower than the maximum permeability measured by Nirex

7.4 These issues are dealt with in turn in the following paragraphs.

Issue i - Measurements of Hydraulic Conductivity

7.5 There does not appear to be any disagreement over the hydraulic conductivity values measured and reported by Nirex.

Issue ii - Hydrogeological 'Criteria'

7.6 I disagree with the adoption of secondary quantitative criteria for assessment of the suitability of the site. This important issue is discussed further in [paragraphs 7.12](#) to 7.18 below.

Issue iii - Significance of Single Fractures

7.7 I disagree with the statements they make about the significance of single fractures. These may be relevant if one was looking at thin layers, such as liners at conventional landfill sites. They are not, however, relevant to the Nirex situation in which we are considering the large scale properties of blocks of rock many hundreds of metres thick through which water must flow. This point is made in my proof (**PE/NRX/14**) at [paragraph 6.16](#).

Issue iv - Fracture Connectivity

7.8 I agree with the concept that the behaviour of the rock mass and its ability to transmit water are controlled by the way the fractures are interconnected and the hydraulic gradient to which they are subjected. However, it does not follow necessarily that significant groundwater flow is possible. This would only be the case if there was a well connected system of fractures with a high hydraulic conductivity. It is essential to determine the actual characteristics of the rock mass to determine the extent of the flow. This is discussed further at [paragraphs 7.19](#) to 7.27 below.

Issue v - Adequate Characterisation of Fractures

7.9 This statement may be true if the requirement was to make "*specific measurement of all fractures in the larger region*". This is not the purpose of the RCF. This was discussed in [paragraphs 5.8](#) to 5.10 above.

Issue vi - Permeability 'Limits'

7.10 I disagree with this statement for two reasons. Firstly it is inappropriate to adopt a secondary quantitative 'criterion' for assessment of the suitability of the site (see paragraphs [3.1](#) to 3.3 and [paragraphs 7.12](#) to 7.18 below). Secondly, it is inappropriate to use point measurements of hydraulic conductivity as the basis for assessing the large scale hydraulic conductivity of the rock mass. This is directly related to Issue iii above and is further discussed at paragraphs [paragraphs 7.19](#) to 7.27 below.

Further consideration of key points arising from paragraph 7.3 above

- 7.11 Three key points arise from the Issues identified above. These are:
- i. the applicability of hydrogeological 'criteria' (discussed in paragraphs [paragraphs 7.12](#) to 7.18 below);
 - ii. the relationship between point measurements of hydraulic conductivity and large-scale hydraulic conductivity. This is the issue of 'upscaling' (discussed in paragraphs [paragraphs 7.19](#) to 7.27 below); and
 - iii. the validity of the groundwater flow modelling used by Dr Haszeldine for the application of his hydrogeological 'criterion' of site suitability.

Hydrogeological Criteria

- 7.12 Dr Haszeldine in paragraph 12.5 (PE/GNP/3) states that:

"This [regional BVG permeability] was arbitrarily defined as being unsafe if water flow could return from the PRZ to the earth's surface within 10,000 yr."

- 7.13 Having arbitrarily (and without justification) adopted this basic criterion of a 10,000 year return time, Dr Haszeldine then judges the acceptability of the site by comparing the results he has obtained from his modelling for his central case and a number of variants calculations with this criterion. The variant case considered by Dr Haszeldine based on the adoption of the modal values for BVG and sandstone hydraulic conductivity produced travel times of 200,000 years. The case discussed by Dr Haszeldine in which a 10,000 year travel time was obtained was an extreme case in which the regional hydraulic conductivity of the BVG was set to the highest measured value (a factor of 100 times greater than the value used in their other calculations) and the hydraulic conductivity of the Calder Sandstone was set to a low value. Data from Sellafield (Figure 10 on page 17 of Nirex Report 525 [COR/505]) indicates that the combination of these two extremes is very unlikely (see [paragraphs 7.34](#) to 7.38 below).

- 7.14 Using his 10,000 year criterion, Dr Haszeldine derives an 'acceptable' upper bound for the hydraulic conductivity for the BVG. He states in paragraph 12.5 of PE/GNP/3 on page 36:

"I find that the limit of BVG permeability is $1 \times 10^{-9} \text{ ms}^{-1}$. This is at least 40 times lower than the maximum permeability measured by Nirex."

- 7.15 His criterion for acceptability is arbitrary (as accepted by Dr Haszeldine at paragraph 12.5 of PE/GNP/3) and, I would assert, unjustified.

- 7.16 Professor Mather also defines, (Paragraph 6.2.9 on page 21 of PE/CCC/4) a "threshold" value of 10^{-9} ms^{-1} , below which rocks are normally regarded as impermeable from a waste disposal viewpoint. He cites GOV/136, a DoE Waste Management Paper entitled Landfill Design, Construction and Operational Practice. Among other things, GOV/136 gives guidance relating to the selection, properties and performance of low permeability liners that could be installed in landfill facilities. The intention is to promote landfill practices that will achieve stabilisation within one generation (defined as 30 to 50 years).

- 7.17 Given this clarification, it is inappropriate to apply the guidelines quoted to the long term performance of the geosphere of a radioactive waste facility. A more appropriate comparison would be with the performance of the engineered barriers of the Nirex repository system. This is predicted to be significantly in excess of the requirements for low permeability liners installed in landfill facilities [GOV/136].

- 7.18 The likelihood of measured values of permeability (hydraulic conductivity) greater than 10^{-9} ms^{-1} in the basement rocks was recognised in PERA [COR/501] at Table 8.2. Whether such values can be judged as acceptable, or otherwise, can only be made in the context of an evaluation of the overall post-closure performance assessment of a repository. This must include consideration of transport through the geosphere, involving processes such as dispersion and successive dilution, which contribute to reducing the release of radionuclides from the geosphere.

Upscaling

- 7.19 The derivation of effective parameters is described in Volume 2 of Nirex 95 [COR/522]. This is not a new concept within the Nirex investigations. For example, modelling work related to the BVG as a discrete fracture network was described in some detail in section 6.5 of Volume 3 of Nirex Report 524 [COR/517] in December 1993 (pages 6.26 - 6.35).
- 7.20 There are two main ways in which large scale effective parameters can be determined, both of which have been utilised by Nirex:
- i. by the process of 'upscaling' whereby measurements taken over small scales are used to infer large scale effective properties. This is achieved by Nirex through the use of a range of techniques (page 11, Nirex Report S/94/004 [COR/510]). An example is the use of discrete fracture network modelling techniques in which models are produced which reproduce the measurements made in small scale borehole tests and in which the models are then used to estimate large scale effective parameters; and
 - ii. by interpretation of measurements of hydrogeological tests that interrogate a large volume of rock containing the range of natural variability. An example of this is the Borehole RCF3 Pump Test ([paragraphs 6.41 - 6.45 of PE/NRX/14](#)). Also, the drawdown experiment in Phase 1 of the RCF, in which the response of the regional groundwater system to RCF shaft excavation, will constitute the largest scale of testing carried out so far. The drawdowns induced by the construction of the RCF will be significantly greater than those which will have been imposed on the groundwater system by the existing hydrogeological testing ([paragraph 6.88 of PE/NRX/14](#)).
- 7.21 Volume 2 of Nirex 95 [COR/522] presents in detail the methodology used to derive a probability distribution function of effective permeability based upon progressive upscaling from field data. Different categories of flow channels through which groundwater flows within each hydrogeological unit were defined (e.g. paragraph 2.2 on page 2.1 and of Volume 2 on Nirex 95 [COR/522]). The models used to derive the effective parameters are illustrated in Figure 5.3 of Volume 2 of Nirex 95 [COR/522] and the probability distribution functions that characterise the uncertainty in effective permeabilities on a regional scale of the hydrogeological units used in the modelling are listed in Figure 5.1 of the same document.
- 7.22 The base case values of the effective hydrogeological parameters are then summarised in Table 2.1 of Volume 3 of Nirex 95 [COR/522].
- 7.23 The models used in the Nirex 95 [COR/522] calculations incorporated zones of hydraulically connected fractures which extended over scales of 50 metres to 5 kilometres. These are termed Type II features in Nirex 95 [COR/522]. The models therefore explicitly incorporate features which will permit the preferential flow of groundwater over long distances. These features had hydraulic conductivity values which ranged from 10^{-11} ms^{-1} to 10^{-7} ms^{-1} . Additionally, larger scale Type III features were built into the models in the location of known major fault zones. These had generally higher values of hydraulic conductivity than the Type II features. As a result, the Nirex 95 [COR/522] models allow the preferential flow of groundwater along selected features both within the BVG, and cutting across the hydrogeological boundaries between the BVG and its overlying units. The hydraulic connectivity permitted by these modelling assumptions is thus significant.
- 7.24 More recent information on the large scale properties of the BVG are now available. These arise from the Borehole RCF3 Pump Test, which has involved a three month pumping test in a selected zone of the BVG. This zone was located in the Sides Farm Member, between 638.9 metres bOD and 681.6 metres bOD. It contained two identified flow zones. As seen in Drawing No. 10089 in Nirex Report SA/95/002 [COR/518] and [Figures 6.2 and 6.5 of PE/NRX/14](#), the zone selected is one of the most productive sections within Borehole RCF3 and contains the principal flow zones in the BVG encountered in this borehole.
- 7.25 The models used for upscaling in Nirex 95 [COR/522], and a number of alternative conceptual and numerical models of the fracture network in the BVG, are being tested by comparison of model predictions with the results of the Borehole RCF3 Pump Test. This is a stringent test of the models because three months of pumping on the most productive zone in the borehole tests a much larger volume of rock than the earlier borehole measurements on which the fracture network models were based.
- 7.26 Preliminary analyses of the result of these comparisons suggests that the fracture network model giving the best comparisons is likely to have a lower connectivity within the BVG than that predicted in Nirex 95 [COR/522]. This is because it includes variations in fracture apertures within the Type II features. Such

variations were not included in the parameterisation of Type II features for Nirex 95 [COR/522]. Thus the system may be less well connected than assumed in Nirex 95 [COR/522].

- 7.27 Thus, it is concluded that the approach to treatment of hydraulic conductivity values proposed by Professor Mather and Dr Haszeldine in their proofs, whilst probably appropriate to the consideration of flow through thin layers, such as landfill liners, is not appropriate to flow through sequences of rock many hundreds of metres thick for assessment of the performance of a deep repository.

Alternative Groundwater Flow Modelling

- 7.28 In section 12 of his proof (PE/GNP/3), Dr Haszeldine presents the results of groundwater flow modelling carried out by Glasgow University. The results of this modelling have been published in two papers referenced as GNP/3/4 and GNP/3/6. In paragraph 12.1 on page 35 of his proof Dr Haszeldine claims that:

"My approach and results were significantly different to that pursued by Nirex."

- 7.29 Recognising the statement made by Dr Haszeldine, Nirex has undertaken a systematic review of his modelling work as reported in the two papers cited by him (GNP/3/4 and GNP/3/6) to establish whether and, if so, to what extent, his results are actually significantly different from those of Nirex in a manner which might have a bearing on the potential of the Sellafield site to meet regulatory requirements.
- 7.30 On the basis of a systematic review of the modelling work undertaken by Dr Haszeldine it is concluded that the differences he reports between his modelling and that undertaken by Nirex arise for the following reasons:
- i. the selection of a geological structure and hydraulic parameters by Dr Haszeldine to produce an extreme and pessimistic conceptual model of the Sellafield site; and
 - ii. the failure by Dr Haszeldine to acknowledge the difference between regional effective values of hydraulic conductivity and point measurements made in boreholes.
- 7.31 It is my assessment that if realistic parameters were used, Dr Haszeldine's models would produce results broadly comparable to those presented in much more detail by Nirex in Nirex 95 [COR/522].

Conceptual Model

- 7.32 The conceptual model adopted by Dr Haszeldine could not be fully evaluated due to the lack of detail contained in his published papers. However, although in general the conceptualisation appeared to be a reasonable first attempt at describing the Sellafield regional groundwater flow field, it was noted that the parameters adopted did not accord with those presented in Nirex Report 524 [COR/517]. This is discussed in the following paragraphs.

Geological Structure

- 7.33 The geological sequence used by Dr Haszeldine contains some differences to that adopted by Nirex. His model explicitly incorporates a large conductive feature that originates at the surface and terminates immediately adjacent and down groundwater gradient of the proposed repository. Dr Haszeldine terms this the 'Fleming Hall Fault Zone'. A comparison of the structural cross section used in their work corresponds with interpretations presented in 1992 in Nirex Report 263 [COR/502]. Since the publication of this report in 1992 considerably more information has been gathered and a revised structural interpretation was presented in Nirex Report 524 [COR/517]. As a result of these changes, a structural feature similar to that proposed in Dr Haszeldine's model is not located near the PRZ.

Hydraulic Parameters

- 7.34 The models illustrated in Figures 6a and 7a of GNP/3/4 and which show particle tracks along the modelled faults directly to the surface have hydraulic parameters which are considered unrealistic. Dr Haszeldine and his co-author note in the caption to Figure 6 (GNP/3/4, page 93) that:

"BVG conductivity is the maximum measured in site investigation boreholes...The Calder Sandstone set to low conductivity."

- 7.35 There are also some more subtle, but none the less significant discrepancies between the values for hydraulic conductivity used by Dr Haszeldine and those given in Nirex Report 524 [COR/517] particularly for the Carboniferous Limestone and Brockram Formations. Dr Haszeldine has selected conductivity values approximately one order of magnitude lower than the values reported by Nirex from the field measurements. Because these geological units contribute to the hydraulic separation between the upper sedimentary rocks and the BVG, this discrepancy is significant.
- 7.36 The range of hydraulic conductivity values assigned by Dr Haszeldine to the BVG is a subset of the reported test results in Nirex Report 525 [COR/505] and contains only the high and median values. The selection of fault conductivities and porosities also differ from those in Nirex Report 524 [COR/517]. Values of porosity utilised by Dr Haszeldine are also seen to be different, in some cases by up to 100%, from the reported test results.
- 7.37 Thus Dr Haszeldine has selectively taken data and results from Nirex Report 524 (published in December 1993) [COR/517] and Nirex Report 263 (published in March 1992 on the basis of significantly more limited data) [COR/502].
- 7.38 The values of BVG and Calder Sandstone hydraulic conductivity used by Dr Haszeldine in his central case significantly increase the predicted flow velocity in the repository region, as compared to the median value. The values for the Brockram hydraulic conductivity adopted by Dr Haszeldine would tend to produce lower flow and transport across that formation relative to the median value. These two factors combine together to focus groundwater flow in the model into the imposed fault. Thus, by careful selection of parameters for his central case model, Dr Haszeldine has imposed a particular pattern of groundwater flow.

Regional hydraulic conductivity

- 7.39 There is an important distinction between the hydraulic conductivity values used in the model, which are regional effective values, and the measured hydraulic conductivity values which are essentially point values. The measured values can be expected to cover a wide range and to include some quite high values in the 'tails' of the distribution due to the natural heterogeneity in the rocks (see section 8 of this supplementary proof). However, the regional value, which will determine the overall flow rate, will be some average of the local values depending on the connectivity as well as the conductivity of the individual fractures. Thus the existence of a few high measurements does not automatically imply a high probability that Dr Haszeldine's arbitrary criterion will be breached. This issue has been discussed in [paragraphs 7.12](#) to 7.18 above.

The results

- 7.40 Although the model adopted by Dr Haszeldine for his central case comprises a pessimistic and unrealistic end member of the many models formed by possible geometric aspects and hydrogeological characteristics at the potential repository, this model predicted long groundwater return times of 10,000 to 15,000 years depending on modelled repository depths (Figures 6a and 7a of GNP/3/4, pages 93 and 94). The second set of models illustrated in Figures 6b and 7b of GNP/3/4, in which the BVG conductivity was reduced to $3.8 \times 10^{-10} \text{ ms}^{-1}$, closer to the median value of $1 \times 10^{-10} \text{ ms}^{-1}$ ([Figures 6.1, PE/NRX/14](#)), and hence provided a much more realistic representation of the hydraulic conductivity contrast between the BVG and the sandstone, not only produced a significantly longer estimate of groundwater return time (200,000 years), but also indicated a marine discharge (under current sea level conditions) for the water rather than a terrestrial discharge given by the models which suppressed the conductivity contrast between the BVG and the sandstone.
- 7.41 The selection of a geological structure and hydraulic parameters by Dr Haszeldine has produced an extreme and pessimistic model of the Sellafield site. The model parameters, in particular, suppress the effects of the hydraulic conductivity contrast between the BVG and the sandstone and focus groundwater flow into a geological fault that has been imposed on the model immediately downstream of the repository

represented in the model. Adoption of a more realistic value for the hydraulic conductivity of the BVG reproduces the pattern of groundwater flow shown in the Nirex 95 studies [COR/522] with marine discharge to the west of the PRZ (assuming current sea level conditions).

8. HYDROGEOLOGICAL STUDIES

- 8.1 Section 7 of this supplementary proof has considered the important issue of how groundwater flow through fractured rocks needs to be treated. There are, however, other issues related to hydrogeology that are raised in the Objectors' proofs, particularly those of Professor Mather (PE/CCC/4), Dr Salmon (PE/FOE/5), Dr Hencher (PE/FOE/6) and Dr Haszeldine (PE/GNP/3), that need addressing. These issues are dealt with in this section of my supplementary proof.
- 8.2 This section of the supplementary proof addresses issues related to hydrogeological studies, namely:
- i. hydrogeological conceptual models (paragraphs 8.3 to 8.43);
 - ii. patterns of groundwater flow (paragraphs 8.44 to 8.59);
 - iii. numerical groundwater flow modelling (paragraphs 8.60 to 8.78);
 - iv. the role of the RCF in understanding regional hydrogeology (paragraphs 8.79 to 8.88); and
 - v. recommendations for further investigations (paragraphs 8.89 to 8.102).

Hydrogeological Conceptual Models

- 8.3 Hydrogeological conceptual models are descriptions of system components and the understanding of the processes which will determine how the system behaves ([paragraph 5.7](#), page 16, **PE/NRX/13**). Professor Mather discusses "*The Nirex Conceptual Model*" in section 6.6 of his evidence (PE/CCC/4) and Dr Salmon devotes section 2 of his evidence (PE/FOE/5) to "*Consideration of the Current Hydrogeological Conceptual Model*".

8.4 In paragraph 6.6.1 (page 36, PE/CCC/4), Professor Mather states:

"As outlined in paragraph 6.5.2 and illustrated on Figure 4, a conceptual model has been erected by Nirex which divides the hydrogeology into three regimes."

8.5 He then concludes in paragraph 6.6.7 (page 40, PE/CCC/4) that:

"It is concluded that the conceptual model of the hydrogeology proposed by Nirex is a useful simplification. However, it hides the complex inter-relationships between the various regimes and suggests a predictability not substantiated by a detailed evaluation of the data."

8.6 In paragraph 6.5.2 (page 29, PE/CCC/4) Professor Mather refers to the three groundwater regimes and states:

"The geochemical information has been used to identify three groundwater regimes which rely heavily on the distribution of salinity".

8.7 Professor Mather gives definitions (paragraph 6.5.2, page 29, PE/CCC/4) of the groundwater regimes stating that they are *"as defined in Nirex Report 525 [COR/505]"*. The definitions he then gives are not stated in Report 525, as he claims. Definitions are given in Nirex Report 524 [COR/517] on pages 7-9 and 7-10. However, they are different from those given by Professor Mather in paragraph 6.5.2 (page 29, PE/CCC/4) The statement in paragraph 7.3.2 of Nirex Report 524 [COR/517] on page 7.9 that:

"The interpretation of data acquired since release of Nirex Report 268 has, however, lead to refinement in the understanding of processes occurring within these regimes. It is proposed that the hydrogeological system should be divided into the following regimes;

- (a) *The "Irish Sea Basin Regime", containing evaporite derived brines and saline groundwater, with flow driven by basinal processes.*
- (b) *The "Coastal Plain Regime", containing predominantly freshwater, driven by topographic forces through an apparently porous medium.*
- (c) *The "Hills and Basement Regime", containing predominantly saline water, which is a mixture of evaporite derived brine and meteoric water driven by topographic forces through a fractured medium."*

8.8 Also in Nirex Report 525 [COR/505] on page 20 it states:

"Encouraging progress has been made in determination of groundwater chemistry. The chemical composition of the waters provide an indication of the origin, history and age of the waters. This information helps to confirm the pattern of groundwater flow indicated independently by the information on the groundwater pressures and hydraulic conductivity."

8.9 The statements made by Nirex (see paragraph 8.7 above) clearly indicate that the groundwater regimes were defined on the basis of the processes occurring within these regimes and that the geochemical information has helped to confirm the pattern of groundwater flow. Professor Mather is thus wrong in his paragraph 6.5.2 (page 29, PE/CCC/4) in which he seeks to indicate that the regimes are defined on the basis of salinity. Furthermore, the groundwater salinities quoted by Professor Mather, assigned in that way to the regimes, are not, as indicated by him, taken from Nirex Report 525 [COR/505], nor are they as quoted in subsequent Nirex reports.

8.10 Professor Mather is also wrong in his assertion (PE/CCC/4, paragraph 6.6.7) that the model *"hides the complex inter-relationships between the various regimes"*. Professor Mather confines his attention to a single figure (his Figure 4, PE/CCC/4) which is a schematic representation of the broad features of the groundwater system. He ignores the detailed discussion of conceptual models in Nirex 95 [COR/522] and

of the hydrogeochemistry in Nirex Report S/95/008 [COR/525]. Hence, it is inevitable that he regards the model represented in his Figure 4 (PE/CCC/4) as simplistic. Nirex's description of conceptual models in Nirex 95 [COR/522] is comprehensive and detailed. The hydrogeochemical conceptual model in Nirex Report S/95/008 [COR/525] is able to explain all of the compositions of groundwater and, as stated in [paragraph 6.66](#) of my evidence (page 44, **PE/NRX/14**):

"there are no longer any observed compositions (of groundwater) that cannot be explained in terms of the well defined mixing relationships."

8.11 This is a statement that the geochemical attributes of the site have been understood and described in simple terms, not, as Professor Mather suggests a simplification in which complexities are being hidden.

Dr Salmon (PE/FOE/5)

8.12 In section 2 of his evidence (PE/FOE/5), Dr Salmon raises a number of issues, summarised as follows:

- i. the site must meet hydrogeological 'criteria' to allow repository construction to proceed (paragraphs 2.4 and 2.21);
- ii. certain hydrogeological characteristics identified in the current model *"appear to make the Sellafield site a marginal choice for radioactive waste disposal"* (paragraph 2.18);
- iii. undue reliance has had to be placed on the use of elicited data instead of measured data (paragraph 2.13);
- iv. his interpretation of the hydrogeological field tests differs from that presented by Nirex (paragraphs 2.19 and 2.20); and
- v. there must be some doubt that Nirex will ever be able to predict groundwater flow with confidence (paragraph 2.21).

8.13 I disagree with each of these principal assertions made by Dr Salmon because:

- i. site suitability is assessed in relation to regulatory requirements. There are no hydrogeological 'criteria' (see section 3 of this supplementary proof and [paragraphs 6.24](#) to 6.28 (pages 22-24) of Mr Folger's supplementary proof (**PE/NRX/12/S1**);
- ii. the characteristics described by Dr Salmon do not render the site 'marginal';
- iii. Dr Salmon has misrepresented the extent to which Nirex models are based on elicited data by understating the use of measured field data in current models;
- iv. the interpretation of the field tests presented by Nirex and Dr Salmon do not differ in substance, although they do differ in tone. Dr Salmon does not appear to have taken account of certain information presented by Nirex and has misunderstood other aspects of the information; and
- v. he has presented no evidence to support his assertion concerning the prediction of groundwater flow.

8.14 These five issues are reviewed and discussed in more detail in the following paragraphs.

Issue i - the site must meet hydrogeological criteria to allow repository construction to proceed.

8.15 See section 3 of this supplementary proof and [paragraphs 6.24](#) to 6.28 (pages 22-24) of Mr Folger's supplementary proof (**PE/NRX/12/S1**).

Issue ii - Certain hydrogeological characteristics identified in the current model appear to make the Sellafield site a marginal choice for radioactive waste disposal.

- 8.16 At paragraph 2.18 (PE/FOE/5), under the heading of hydrogeological conceptual model, Dr Salmon lists a series of qualitative hydrogeological characteristics which he considers *"appear to make the Sellafield site a marginal choice for radioactive waste disposal"*. The inappropriate use of hydrogeological 'criteria' has been addressed in sections 2, 3 and 7 of this supplementary proof. However, Dr Salmon lists a series of characteristics of the site which I will deal with in turn:
- i. The site is extensively faulted: the extent of faulting is as described by Nirex. The existence and extent of faulting is only important insofar as it impacts groundwater flow ([paragraphs 6.8](#) to 6.29 of **PE/NRX/14** summarise information on this issue). This faulting, its impact on groundwater flow and on repository safety are addressed in detail in Nirex 95 [COR/522];
 - ii. The site exhibits considerable geological variability: the geological variability of the rocks has been described by Nirex. As already discussed in section 7 of this supplementary proof, it is neither appropriate nor necessary to seek to explicitly define every feature of the site in order to establish acceptable groundwater flow models as the basis for safety assessment studies. Dr Salmon's point is another aspect of 'complexity'. This has been addressed in section 5 of this supplementary proof;
 - iii. The field characterisation of flowing features has been inconclusive: substantial progress has been made in characterising flow zones as summarised in [paragraphs 6.8](#) to 6.45 of **PE/NRX/14**. Remaining uncertainties related to the networks of connected fractures that control groundwater flow are clearly identified in my proof of evidence ([paragraph 6.85](#) on page 49 of **PE/NRX/14**) and the importance of the RCF in assisting in addressing these uncertainties has been stated ([paragraph 6.87](#), page 50, **PE/NRX/14**). The data obtained from the boreholes has been used to generate stochastic fracture network models. Uncertainty in the data, due to the impracticability of characterising all fractures, is reflected in the stochastic nature of the models and the range of conceptual and numerical models which have been explored by Nirex in developing Nirex 95 [COR/522];
 - iv. The potential for groundwater flow is considerable: I disagree with Dr Salmon's statement that the potential for groundwater flow is considerable. The Nirex models recognises that there is a potential for groundwater flow and this is clearly indicated in Nirex 95 [COR/522]. Use of the term 'considerable' by Dr Salmon is subjective and unquantified whereas the results of the Nirex 95 studies [COR/522] provide quantitative estimates of groundwater circulation. Furthermore, they indicate that the site is likely to meet regulatory requirements. Thus, it is considered inappropriate to state that the potential is 'considerable';
 - v. The presence of the Irish Sea Basin brines to the west means that the potential direction of groundwater flow in the site is generally upwards: the main flows are from the high ground towards the coast in the upper layers of the sandstones. The much lower flows in the basement rocks generally have lateral and upward components in the PRZ and to the west of the PRZ. All natural groundwater flow systems will include parts with upward and downward flow; that is the nature of the hydrological cycle. The issue of 'upward flow' is further addressed in [paragraphs 8.45](#) to 8.47 of this supplementary proof. The significance of any upward gradients is only relevant when taken in the context of hydraulic conductivity, in order to make estimates of groundwater flow;
 - vi. Relatively low environmental heads could be attributable to a hydraulic connection with the cover rocks: I do not disagree with Dr Salmon that the relatively low heads in Boreholes 2 and 5 *"could be attributable to a hydraulic connection with the cover rocks"* (paragraph 2.18, PE/FOE/5). I question whether similar low heads are shown by the results of Borehole 4. Dr Salmon does not consider the additional data that Nirex has collected on the structural features that could be associated with the low heads from the cross-hole hydraulic testing and the drilling of Boreholes PRZ1, PRZ2 and PRZ3 (drilled specifically to investigate these features). Again, the possibility of the existence of connections from the BVG to the cover rocks is specifically incorporated into Nirex 95 [COR/522]; and
 - vii. The source of brines in the Hills and Basement Regime is uncertain: the sources of salinity are discussed in Nirex Report S/95/008 (section 4, paragraph 4.2.4, page 25 [COR/525]).

Issue iii - the use of elicited data instead of measured data.

8.17 At paragraph 2.13 on page 9 of PE/FOE/5, Dr Salmon describes the way in which Nirex has conceptualised the fractures within the groundwater flow model presented in Nirex 95 [COR/522]. In the last sentence of the paragraph, in referring to the parameters used to describe the characteristics of these fractures, he states:

"Of these, all except fracture orientations can not be adequately quantified by the field characterisation programme alone, and reliance has instead had to be placed on the elicitation of probability density functions (PDF's) for the uncertainty about the mean and variance associated with the distribution of these parameters {S/95/012}, from a group of experts assembled by Nirex (COR/508)."

8.18 It needs to be emphasised that the elicitation of parameter values for modelling is based on data from the site characterisation programme. At page 5.4 of Volume 1 of Nirex 95 [COR/522], the extent to which field data was used as part of the elicitation process is made clear. It states:

"Information on the orientation of the fractures can be obtained from the field data [5.2]. Of the remaining parameters, it was considered most appropriate to elicit distributions of fracture spacing, fractures length and channelling fraction from the expert group, which were able to make reference, in the course of the elicitation, to observations of the spacing of fractures and flowing zones in the boreholes and to outcrop studies of fracture length".

8.19 As stated in section 4 of Volume 2 of Nirex 95 [COR/522], fracture transmissivities were not elicited, but were derived by requiring models to be consistent with field data. The elicitation process is a structured and appropriate response to dealing with uncertainties in field data.

8.20 At paragraph 2.7 (PE/FOE/5, page 7), Dr Salmon refers to the independent review of the Nirex investigations at Sellafield by the Royal Society Study Group, and provides a quote from COR/605, the Royal Society Study Group Report. The quote he uses is:

"The development of conceptual hydrogeological models and their translation into numerical models (and hence radionuclide transport) are some of the most difficult tasks for Nirex in working towards detailed PCPAs for Sellafield".

8.21 He then states in paragraph 2.8 (PE/FOE/5) that:

"This is because 'tests have shown that the hydrogeological system at Sellafield is complex' (FOE/5/6). This complexity is discussed in more detail below".

8.22 The quotation from the Royal Society Study Group Report is to be found on page 143, column 1, of COR/605 from which it can be seen that Dr Salmon has taken his quote from the summary of section 8 of the report. The section in the main body of the report is found on page 135, column 1, first full paragraph, of COR/605. This paragraph puts a somewhat different complexion on the assertions made by Dr Salmon. The paragraph states:

"Three points need emphasis. First, the development of conceptual hydrogeological models and their translation into numerical models of groundwater flow are among the most difficult scientific problems Nirex have to face at Sellafield. Second, the underlying scientific work has been of high quality. Third, participants in the study had to work with a set of site characterisation data considerably smaller than that available now (mid-1994), and much less extensive than that which will be available when the site characterisation programme is nearing completion, including tracer and other tests in the RCF. We therefore examined the work of the expert group with a view to assessing the methodology rather than the soundness of the results."

8.23 Dr Salmon's subsequent assertion in paragraph 2.8 (PE/FOE/5) that the Royal Society Study Group Report comments were made because of the complexity of the site seems difficult to understand as the statement

about the complexity of the hydrogeological system is not taken from the Royal Society Report [COR/605], instead it is taken from a paper on the design of the RCF.

8.24 Dr Salmon returns to this theme of elicitation at paragraph 3.17 on page 25 of PE/FOE/5, where he states:

"The Royal Society (COR/605) concluded that the elicitation procedure, whereby experts used both limited site data and general data, is 'unlikely to lead to defensible sets of parameter values'.

8.25 The section of the Royal Society Study Group Report [COR/605] that is relevant is section 8.2.4 commencing on page 134. Firstly, in the first paragraph of this section the Royal Society Study Group make it clear that the Nirex study they are referring to was the one carried out in early 1993 and was based on limited data (in effect, although not specifically stated, this was the data in Nirex Report 268 [COR/521] based only on the results from Boreholes 1, 2, 3 and 4). Secondly, in the second paragraph of page 135 (quoted in full in paragraph 9.11 above), the Royal Society Study Group Report makes it clear that more data were available at the time they reported and which had not been available when the elicitation study was carried out. They also made it clear that more data would become available, particularly from the RCF. Finally, in the second paragraph in column 2 on page 135 [COR/605], from which Dr Salmon's quote is taken, the Royal Society Study Group is making the point that elicitation in the absence of site-specific data is unlikely to lead to defensible sets of parameter values, but that *"ideally this would be largely replaced by one of scale-up calculations based on extensive field data"*. This is indeed the approach being adopted by Nirex.

8.26 By the use of selective quotations, and by confusing comments made on a much earlier elicitation study (known to be based on limited data) with his own comments made on the conceptual model development reported in Nirex 95 [COR/522], Dr Salmon has misrepresented the extent to which Nirex 95 has been based on actual field data. He has also apparently ignored the points made both in my evidence ([paragraph 6.83](#) to 6.88 of **PE/NRX/14**) and by the Royal Society Study Group that the RCF has an important role in providing the required additional data.

Issue iv - Dr Salmon's interpretation of the hydrogeological field tests differs from that presented by Nirex

8.27 At paragraph 2.19 (PE/FOE/5) Dr Salmon comments on the results of various hydrogeological testing programmes. Apart from Dr Salmon's discussion of the Borehole RCF3 Pump Test, I do not disagree with the comments he makes and find them to be substantially as given in my evidence (**PE/NRX/14**, [paragraphs 6.35](#) to 6.45). In commenting on the Borehole RCF3 Pump Test, Dr Salmon has confused the borehole interference effects observed in the boreholes with the results of the pump test. These interference effects are described in Appendix 2 to my evidence ([paragraphs B.2.8](#) to B.2.10 on pages B.4 and B.5 of Appendix 2 to **PE/NRX/14**) and illustrated in [Figure B.2.1](#) (Appendix 2, **PE/NRX/14**). They are also described in somewhat more detail in paragraphs 7.21 to 7.29 of Nirex Report S/95/007 [COR/524]. [Figure B.2.1](#) in Appendix 2 of **PE/NRX/14** shows these interference effects and the smooth responses observed in the Borehole RCF3 Pump Test after January 1995. These two datasets have been used in complementary ways to provide information on hydrogeological conditions in the PRZ.

8.28 In paragraph 2.20 of his evidence (PE/FOE/5, page 14), Dr Salmon states that his interpretation of the field tests differ in both substance and tone from those presented in my evidence. I do not agree that the two interpretations differ in substance although they may differ in tone.

Paragraph 2.20 - first bullet point

- 8.29 In the first bullet point on page 14 (PE/FOE/4) Dr Salmon disputes that the fracture network may be less well connected than previously considered. I stand by my original statement and point to the description of the fracture networks as presented in Nirex 95 [COR/522] as justification. It is important to recall that Nirex 95 was based on the data presented in Nirex Report 524 [COR/517] which pre-dates the hydrogeological testing to which we are now referring. (See the third paragraph of the Preface to Nirex 95 [COR/522].)
- 8.30 The extent to which the Nirex 95 models represented fracture connectivity is best illustrated by Figures 2.1, 5.3 and 5.5 in Volume 2 of Nirex 95 [COR/522]. These illustrate the ways in which fractures are represented in the model and show:
- i. the incorporation of Type II features (organised structures of fractures with lengths of hundreds of metres);
 - ii. Type III features with length scales of kilometres;
 - iii. the Brockram, represented as a horizon capable of showing significant flows (paragraph 5.5 on page 5.11 of Nirex 95, Volume 1 [COR/522]); and
 - iv. the Basal Deep St Bees Sandstone containing cross-cutting transmissive features.
- 8.31 Thus, for example, Figure 5.5 in Volume 2 of Nirex 95 [COR/522] specifically shows the way in which the Basal Deep St Bees Sandstone, the section containing the siltstone and claystone bands later identified as the North Head Member, was shown as containing transmissive fractures and major faults cutting it. Thus the model recognised the possibility of connections through this part of the sequence connecting the Brockram to the higher parts of the sandstone sequence. In contrast to this, later work (for example paragraph 8.6 of Nirex Report S/95/007 [COR/524]) has shown that:
- "The North Head Member is identified as an interval at the base of the St Bees Sandstone with distinctive geological and hydrogeological properties from the overlying St Bees Sandstone. The claystone bed at the top of the North Head Member is considered to be a possible low permeability control on flow between the North Head Member and the overlying sandstone."*
- 8.32 The preliminary results from the Borehole RCF3 Pump Test (Brockram Phase) have shown that the North Head Member attenuates the hydraulic responses to pumping in the Brockram. No responses were observed in the sequence above the North Head Member. As a result of this, it is possible to conclude that in the vicinity of Borehole RCF3, any sub-vertical joints and fractures that may occur within the Brockram and extend up into the sandstones do not result in a strong hydraulic connection between the Brockram/ North Head Member, and the upper stratigraphic units of the sandstones.
- 8.33 Further information which helps to confirm this limited connectivity in the vicinity of Borehole RCF3 is provided by the monitoring of salinity in the different stages of the Borehole RCF3 Pump Test. The sandstone test was located just above the saline transition zone; the water pumped from the hole remained fresh. The Brockram test was located immediately below the saline transition zone; the pumped water remained saline.
- 8.34 The basis of my statement in [paragraph 6.70](#) of **PE/NRX/14** is thus the comparison of judgements made in the Nirex 95 models with the observations made in the testing. This enhancement in our understanding of the connectivity within the system will be incorporated into the groundwater models which we will be developing as a next stage from Nirex 95 and as the basis for developing the predictions for the RCF shaft drawdown experiment.
- 8.35 Dr Salmon appears to criticise the Fracture Network Testing on page 15 of his proof (PE/FOE/5, paragraph 2.20). He refers to the *"inability of such testing to identify connections within the fracture system in lateral directions away from a borehole"*. Dr Salmon is correct in recognising that the Fracture Network Testing does not identify lateral connections; it is not designed to do so. It is part of an integrated programme of post completion testing as described in [Table A.8](#) on page A.27 of Appendix 1 to my proof (**PE/NRX/14**). This refers to the fact that the Fracture Network Testing was designed to *"provide complete coverage of the section of the borehole within the Borrowdale Volcanic Group"*. By testing a continuous section of borehole with test sections both containing and not containing identified flow zones ([Figure 6.5](#) of **PE/NRX/14**) it was possible to provide statistical coverage of the BVG. This testing needs to be viewed in association with the other major programmes of post completion testing ([Table A.8](#), Appendix 1, **PE/**

NRX/14) namely the Short Interval Hydraulic Testing, the Cross-Hole Hydraulic Testing and the Borehole RCF3 Pump Test. The Cross-Hole Hydraulic Testing, the Borehole RCF3 Pump test, and ultimately the RCF shaft drawdown experiment are the parts of the testing programme specifically designed to investigate lateral connections.

Paragraph 2.20 - second bullet point

- 8.36 On page 15 of PE/FOE/5, Dr Salmon appears to be confusing the results of the Borehole RCF3 Pump Test with the information from the observation of interferences between boreholes during drilling reported in Nirex Report S/95/007 [COR/524]. The two sets of data are not incompatible, although the Borehole RCF3 Pump Test is able to reveal the connections in a more systematic manner, as discussed in [paragraphs 8.27](#) and 8.32 above. Dr Salmon also comments, on page 15 (PE/FOE/5), that I have failed to explain the existence of the *"unusually low environmental heads"* in the BVG *"which may indicate some vertical connectivity with the cover rocks"*. Reference to the descriptions of the models in Nirex 95 [COR/522] should have indicated to Dr Salmon that the possibility of such connections are explicitly recognised in Nirex 95 by the incorporation of both Type II and Type III features in the model. Furthermore, it should be again pointed out that Nirex 95 indicates that the site is likely to be able to meet regulatory requirements.

Paragraph 2.20 - Third bullet point

- 8.37 The point made by Dr Salmon at the top of page 16 of PE/FOE/5 related to hydrochemistry is dealt with in section 10 of this supplementary proof. However, at the end of that paragraph on page 16, Dr Salmon makes the remark that:

"It is also quite possible that any differences in water quality are lost or reduced as deeper groundwater moves to the surface, via processes such as dilution".

- 8.38 In making this remark Dr Salmon is recognising the favourable characteristic of the Sellafield site in offering dilution of waters which may leave the BVG as stated in [paragraphs 6.71](#) to 6.73 of my evidence (**PE/NRX/14**).

Paragraph 2.20 - Fourth bullet point

- 8.39 On page 16 of PE/FOE/5, Dr Salmon comments that the head distributions are not as consistent as I had implied. He is correct in identifying some heterogeneity in the heads observed in the boreholes. This can be seen by the small-scale variability of the heads in Figure 6.8 of PE/FOE/14 and more clearly by the plots of environmental heads with depth shown for the individual boreholes in Drawing Nos. 100111 to 10131 of Nirex Report SA/95/002 [COR/518]. Indeed, this heterogeneity is a characteristic feature of fractured rock masses.

Paragraph 2.20 - Fifth bullet point

- 8.40 In the final bullet point of paragraph 2.20 on page 17 of PE/FOE/5, Dr Salmon seeks to dismiss the geochemical information on the grounds that there are "*relatively few samples*". He then concludes that "*Therefore the possibility of flowpaths with relatively short travel times cannot be discounted*". There are two points arising from this conclusion. Firstly, the possibility of there being such flowpaths out of the BVG has been specifically recognised by the Nirex 95 models. For example, Table 2.3 in Volume 3 of Nirex 95 [COR/522] shows the travel times for different pathways. Paths B and C show significantly shorter travel times than Path A for flow to the top of the BVG because of the pathline intersecting one of the Type II features. Secondly, as stated in [paragraphs 8.15](#) and [9.9](#) of my evidence (PE/NRX/14) the RCF is required to investigate the nature and distribution of these networks of connected fractures. One of the reasons, as stated in [paragraph 8.15](#) of PE/NRX/14, is to determine the extent to which it might be possible to locate vaults to limit the intersections between the networks of connected fractures and the repository vaults.
- 8.41 In respect of Dr Salmon's comment that relatively few samples have been obtained, [Appendices 1](#) and [2](#) of PE/NRX/14 summarise the substantial programme of geochemical sampling that has been carried out.

Issue v - There must be some doubt that Nirex will ever be able to predict groundwater flow with confidence

- 8.42 Given the substantial progress made so far in understanding and modelling groundwater flow at Sellafield, I cannot agree with the comment made by Dr Salmon in paragraph 2.21 on page 17 (PE/FOE/5) that there must be some doubt that Nirex will ever be able to predict groundwater flow with confidence. He has presented no evidence to support such an assertion. Furthermore, his references to the complexity of the site and 'other site criteria' are reiterations of his inappropriate use of qualitative 'criteria' (see sections 2 and 3 of this supplementary proof).

Closing comments on Dr Salmon's conclusions to his section 2 (PE/FOE/5)

- 8.43 I disagree with the conclusions reached by Dr Salmon on page 18 of PE/FOE/5 (paragraphs 2.22 and 2.23) because:
- i. his assessment is based on the inappropriate use of hydrogeological 'criteria';
 - ii. he has failed to recognise that the characteristics of the site have been incorporated into the Nirex 95 modelling and that this modelling gives confidence that the site will meet regulatory safety targets; and
 - iii. he has failed to appreciate the role of the RCF in helping to address the remaining uncertainties concerning the site.

Patterns of Groundwater Flow

- 8.44 There are a series of references in the Objectors' proofs to the pattern of groundwater flow at Sellafield. These are summarised as follows:
- i. there is a potential for upward flow at the Sellafield site (e.g. paragraph 6.3.5, page 23, PE/CCC/4; paragraph 8.2, PE/GNP/3). Professor Mather also lists this as a "*negative characteristic*" (paragraph 8.7 on page 45 of PE/CCC/4);
 - ii. there is potential for flow from the north west and from the south east into the PRZ (paragraph 8.2, PE/GNP/3) and this is a manifestation of flow running along the structural crest of a fault block (paragraph 8.3, PE/GNP/3), thus "*the PRZ is positioned directly on the main subsurface axis of flow potential of meteoric water moving from the Lake District towards the coast.*" (paragraph 8.4, PE/GNP/3); and
 - iii. "*discharge in the shore zone is a more realistic assumption for modelling purposes than discharge offshore into the Irish Sea.*" (paragraph 6.6.5, PE/CCC/4).

Upward Flow

- 8.45 The existence of head gradients at the site is a feature of the site which has long been appreciated. Paragraph 8.14.5 of *PERA* [COR/501] recognised the possibility of "*the propagation of groundwater heads into the basement.*" Our understanding of head gradients at Sellafield is described in the section of my evidence dealing with 'Groundwater Heads and Gradients' ([paragraphs 6.48](#) to 6.59 on pages 39 to 42 of **PE/NRX/14**).
- 8.46 In just the same way as other hydrogeological 'criteria' cannot be used to assess the site, similarly head gradients cannot be used in this way. However, the impacts of head gradients have been examined in Nirex 95 [COR/522] in calculations that have indicated that the performance of a repository is likely to meet regulatory requirements (see, for example, the variant calculations in sections 7.3 and 7.4 of Volume 3 of Nirex 95 [COR/522]). This is because the low hydraulic conductivity in the BVG, coupled with the potential for dilution in the overlying cover rocks leads to an acceptable performance of the site.
- 8.47 Professor Mather (paragraph 6.7.1, PE/CCC/4) suggests that there is evidence from hydrogeochemical data suggesting upward flow. This is discussed in section 9 of this supplementary proof.

Potential for flow into the PRZ

- 8.48 Dr Haszeldine (paragraph 8.2 and Figures 8.1 a, and b, PE/GNP/3) interprets contours of environmental head to infer potential for horizontal flow. This is incorrect as the potential for horizontal flow is given by freshwater heads ([paragraph 6.8](#), **PE/NRX/14**). This is explained in more detail in section 4.4.3 (page 4-4) and Figure 4.2 in Volume 3 of Nirex Report 524 [COR/517]. Dr Haszeldine has also omitted to record the statement made at the foot of page 4-7 of Nirex Report 524, Volume 3 [COR/517] in which the diagrams that he has interpreted are explained with the comment that they are "*intended to demonstrate only that groundwater heads in this region of the BVG are variable*".
- 8.49 The variable nature of the heads in a fractured rock such as the BVG is a feature of such systems. It is therefore questionable as to whether such local data can reliably be used, in the way Dr Haszeldine has, to infer regional patterns.
- 8.50 A regional interpretation of the head data is presented in [paragraphs 6.58](#) to 6.59 of **PE/NRX/14** which indicates that a consistent pattern of head gradients towards the coast is recognised in the area. A more regional interpretation of data, such as that presented in Figure 8.1b of PE/GNP/3 would indicate flow diverging from the PRZ, the opposite to the pattern suggested by Dr Haszeldine. Dr Haszeldine (paragraphs 8.2 and 8.3, PE/GNP/3) suggests the presence of a 'flow axis' associated with the structural crest of a NE-SW trending fault block. In paragraph 8.4 (PE/GNP/3) this idea is given the status of "*the main subsurface axis of flow potential of (sic) meteoric water moving from the Lake District towards the coast*".
- 8.51 This idea is, of course, only relevant if Dr Haszeldine's assertions about converging groundwater flow are supported, which, as stated above, they are not. In any case, the main sub-surface route for meteoric water flow from the fells towards the coast is in the Sherwood Sandstone Group.
- 8.52 In paragraph 8.4 (PE/GNP/3), Dr Haszeldine claims that the PRZ is in the worst position within the Site from the standpoint of hydrogeological containment. This conclusion is based on the spurious idea of the "subsurface flow axis". The basis for selecting the PRZ is explained in [paragraphs 8.2](#) to 8.10 of **PE/NRX/14**.

Location of Discharge

8.53 Professor Mather states (Paragraph 6.6.5, PE/CCC/4):

"discharge in the shore zone is a more realistic assumption for modelling purposes than discharge offshore into the Irish Sea."

8.54 Professor Mather implies that it was assumed by Nirex that discharge was offshore and into the Irish Sea, and that this assumption was built into the models used, for example, for the calculations of groundwater flow presented in Volume 3 of Nirex 95 [COR/522]. This is not the case. The locations of discharges are predicted as an output from the modelling, they are not an input to the modelling.

8.55 Figure 2.6b of Volume 3 of Nirex 95 [COR/522] illustrates that the models used in Nirex 95 do indeed predict some level of terrestrial discharge under the current groundwater conditions. As stated on page 2.12 of Volume 3 of Nirex 95 [COR/522]:

"the main region of radionuclide discharge is from about a hundred metres offshore to about a kilometre offshore. This region is just beyond the main region of groundwater discharge which extends to about a hundred metres offshore".

8.56 The peak of groundwater discharge from the Calder sandstone and Quaternary deposits is very close to the coast, and the discharge falls off quite quickly with distance offshore.

8.57 These predictions are consistent with a number of observations made at the site, including those quoted by Professor Mather and resulting from the 1977 - 1979 studies of Holmes and Hall [CCC/4/3].

8.58 Nirex has undertaken sampling of freshwater spring discharges from foreshores in the vicinity of the site. This confirms the view that some groundwater from the near surface groundwater flow systems will discharge on the coast.

8.59 However, consideration of the chloride profiles for the two Nirex boreholes drilled near the coast (Boreholes 3 and 13A) (Appendix C, Nirex Report S/95/008 [COR/524]) indicate a substantial (300 - 400 metres) thickness of fresh and brackish waters. This would imply that a fair proportion of the fresher waters moving in the upper part of the sandstones and comprising the Coastal Plain Regime is discharging offshore.

Numerical Groundwater Flow Modelling

8.60 For the Objectors, numerical groundwater flow modelling is primarily addressed by three proofs that I am responding to in this supplementary proof: Dr Haszeldine (PE/GNP/3), Dr Salmon (PE/FOE/5) and Dr Hencher (PE/FOE/6). Dr Haszeldine has presented some of his own modelling; this has been addressed in section 7 of this supplementary proof. Within the following part of section 8, I address the issues raised by Dr Salmon and Dr Hencher on aspects of numerical modelling. I also describe some aspects of the recent and current hydrogeological modelling being undertaken by Nirex, in addition to that described in Nirex 95 [COR/95] to demonstrate the range and extent of the work being carried out.

Dr Salmon (PE/FOE/5)

- 8.61 In section 3 of his evidence (PE/FOE/5) Dr Salmon criticises the modelling work undertaken by Nirex and, in paragraph 3.33 on page 33 recommends that additional modelling work should be undertaken which is likely to take at least another year to complete before the RCF is contemplated. As Mr Folger has stated in his supplementary proof (PE/NRX/12/S1) at [paragraph 4.3](#) on page 6, the revised schedule for the RCF shows commencement of the RCF South Shaft in December 1997, some two years hence. Thus, even if Nirex accepted all the recommendations made by Dr Salmon for additional modelling, the work could be completed well ahead of commencement of shaft sinking. Dr Salmon's argument that the RCF is premature is thus irrelevant.
- 8.62 Dr Salmon's criticisms of the Nirex modelling are summarised as follows:
- i. the only models used are NAMMU and NAPSAC based on a single conceptual model (paragraph 3.5);
 - ii. the models do not fully reproduce observed salinity and head profiles (paragraph 3.13);
 - iii. undue reliance is placed on data elicitation (paragraph 3.16);
 - iv. 'upscaling' is not adequately dealt with (paragraph 3.18 to 3.24);
 - v. there are a series of problems with the Nirex flow modelling (listed in paragraph 3.25); and
 - vi. further model validation is required (paragraph 3.28).
- 8.63 I disagree with Dr Salmon for the following reasons:
- i. he has not recognised the range of modelling undertaken by Nirex. For example, the modelling described in Volume 3 of Nirex Report 524, section 6 [COR/517] includes areal modelling, variable density modelling, 3-D modelling and modelling using a range of codes other than NAMMU and NAPSAC. In addition, current studies used to progress towards an updated assessment of the site, at a regional scale include:
 - 2-dimensional (vertical section and areal) modelling;
 - 3-dimensional modelling;
 - modelling of the evolution of fluids in the East Irish Sea Basin;
 - vertical section variable density modelling (steady-state and transient); and
 - coupled modelling of groundwater flow and hydrochemistry;
 - ii. At the more local PRZ scale, a range of fracture network and continuum (dual porosity) models are being tested in connection with the Borehole RCF 3 Pump Test;
 - iii. the extent to which the models used in Nirex 95 [COR/522] are able to reproduce the observed heads and salinities is referred to in [paragraphs 6.80](#) to 6.82 of my evidence (page 49 of PE/NRX/14). The issue also forms the subject of Chapter 7 of Volume 3 of Nirex 95 [COR/522]. On page 7.1 it states that variant calculations were undertaken to investigate the match between calculated heads and salinity. Current modelling work summarised above is adding to confidence in our ability to match the output of models to observed heads and salinity. The role of the RCF in helping in this process is summarised in [paragraphs 6.80](#) to 6.82 of my evidence (page 49, PE/NRX/14);
 - iv. undue reliance has not been placed on data elicitation. This is explained in [paragraphs 8.17](#) to 8.26 above;
 - v. the whole of Volumes 1 and 2 of Nirex 95 [COR/522] are devoted to the issues of upscaling and development of the conceptual model;
 - vi. all the issues raised in paragraph 3.25 of PE/FOE/5 have been addressed:
 - Borehole 8 is not on the line of section modelled. Areal modelling of the Sherwood Sandstone Group has been undertaken and provides a close representation of groundwater levels in the near surface (Nirex Report 524, Volume 3, section 6.2.1 [COR/517]);
 - three dimensional modelling has been carried out e.g. fracture network modelling and 3-D saline transition zone modelling, both of which are reported in Nirex Report 524, Volume 3, sections 6.4 and 6.5 [COR/517];
 - the evolution of the salinity distribution has been investigated using 2- and 3-dimensional models. Examples are given in sections 6.3 and 6.4 of Nirex Report 524, Volume 3 [COR/517];

- water balance studies have been carried out and are continuing. Key sources of information are included in Nirex Report 233, with additional information in Appendix E to Nirex Report 499 and have formed an input to the sandstone modelling undertaken already. Work is continuing, both in the collection of data and its interpretation;
 - the boreholes have been sub-divided using packers and hence, it is not expected that their effect will be significant on regional scale flow;
 - when the boreholes are no longer required they will be sealed to a standard which will ensure that they will not have a significant impact on the hydrogeology; and
 - it is fully recognised and clearly stated that Nirex 95 [COR/522] predates the field connectivity testing. These data will be incorporated into the next cycle of model development due to commence early in 1996 and which will form the basis for the predictions of shaft drawdown in the RCF;
- vii. model validation forms a central part of Nirex's strategy for the progressive development and testing of hydrogeological models. Dr Hooper's supplementary proof ([PE/NRX/15/S1](#)) provides further details of our approach to model validation.

Dr Hencher (PE/FOE/6)

- 8.64 Although Dr Hencher's proof is entitled 'Fracture Flow Modelling' it covers a wider subject area and raises a series of issues which are summarised as follows:
- i. the fracture network and fluid flow through it are complex and need to be fully understood (paragraphs 4.3 and 4.4);
 - ii. the RCF will only advance understanding of these matters to a limited extent (paragraphs 6.5, 6.10, 6.15 and 6.19);
 - iii. the RCF will cause disturbances to the rock mass that will inhibit data collection (paragraphs 6.20 and 11.9);
 - iv. fracture flow modelling is at an early stage of development and will require 'decades' of research before such models will be validated (paragraphs 7.11, 9.4, 9.7, 9.9, 9.10 and 9.12); and
 - v. Nirex's proposal for an RCF is premature (paragraphs 3.5, 3.6, 11.8 and 12.3).
- 8.65 I disagree with the assertions made by Dr Hencher because:
- i. the fracture network and fluid flow do not need to be "*fully understood*", as claimed by Dr Hencher (paragraph 4.3, PE/FOE/6). They only need to be understood to the extent necessary to represent adequately flow through the system;
 - ii. the RCF will make a significant and essential contribution to the understanding of the networks of connected fracture and to fluid flow through them. This is summarised by Dr Hooper in his proof of evidence, [PE/NRX/15](#), [paragraphs 6.20](#) to 6.27 and in [paragraphs 5.8](#) to 5.10 of this supplementary proof;
 - iii. it is not disputed that the RCF will cause some perturbations and changes to the rocks and groundwater conditions. It is an important function of the RCF to generate these perturbations so that they can be measured to gain better understanding of the way the system behaves. It is, however, disputed that such perturbations will prevent Nirex from obtaining essential hydrogeological data;
 - iv. Dr Hencher appears to have misunderstood the extent to which developments in fracture flow modelling have occurred. His assertion that "*decades*" of research is required (paragraph 11.7, PE/FOE/6) is contested; and
 - v. sufficient work has been carried out by Nirex to justify commencement of the RCF which will itself contribute significantly to our understanding of flow through fractured rocks.
- 8.66 These issues are taken together in the paragraphs that follow.
- 8.67 In section 5 of his proof (PE/FOE/6), Dr Hencher, in paragraph 5.5 on page 11 recognises the importance of a stochastic approach to fracture flow. The role of this in characterising the site is described previously in this supplementary proof (section 5). Dr Hencher states in paragraph 5.5:

"Channel flow generally follows a complex and tortuous path between the two rock walls of a single fracture and along the intersection 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."

- 8.68 This observation contrasts with the themes of the proofs by both Dr Kokelaar (PE/FOE/2) and Professor Smythe (PE/FOE/3) who argue that a deterministic approach is required in which rock units, faults and fractures need to be located individually and precisely as the basis for hydrogeological modelling. Thus, for example at paragraph 10.2 in Professor Smythe's evidence (PE/FOE/3, page 50) he states:

"An essential prerequisite for hydrogeological modelling is to establish the geological structure accurately both in and around the PRZ. Inconsistencies in the current interpretation show that major faults, as well as minor geological structures, are likely to have been misinterpreted and/or not identified."

- 8.69 The Nirex approach is to recognise that characterisation and modelling of the hydrogeology of a site requires a combination of the deterministic and stochastic approach. Thus on page 5-1 of Volume 3 of Nirex Report 524 [COR/517] it is stated:

"A general premise underlies work on the hydrogeology of fractured rocks. It is assumed that water bearing fractures of all sizes exist within a region being investigated. Even though the distribution of fracture sizes may be single or multi-modal (Figure 5.1a) it is further assumed that there are more small fractures than large (in terms of extensiveness). It is often assumed that it is possible to explicitly identify the most extensive fractures, and that they will have consistent assignable properties. This has the effect of dividing the hydrogeological system into a large-scale deterministic sub-system alongside a smaller scale probabilistic sub-system (Figures 5.1b and c). The division is based on the values of fracture extensiveness, fracture transmissivity and the certainty of identification and parameter assignment. The values at which the division is chosen vary from rock to rock, site to site and progress during an investigation. Certain large scale (regional) structural features may influence hydraulic properties as much as lithological variation and these have also to be considered."

- 8.70 This same approach is described in section 1 of Volume 1 of Nirex 95 [COR/522]. On page 1.2 it states:

"All hydrogeological modelling is based on representation, which are usually simplifications (abstractions) of the underlying conceptual model....The numerical models aim to treat the important aspects of the system in a way that is realistic, but is at an appropriate level of complexity, without unnecessary detail. Thus, for example, when groundwater flow in a fractured rock on a regional scale is to be modelled, it would not be practical to represent explicitly the extremely large numbers of fractures such a model would involve. In any case, such a model would provide far more detail than is required."

- 8.71 In paragraph 5.6 of his proof (PE/FOE/6) on page 11, Dr Hencher refers to the heterogeneous response of oil wells. He then goes on in paragraph 5.7 to interpret this observation as being due to *"the complex and variable nature of fluid flow within fractured rock"*. The natural heterogeneity in fractured rocks is indeed a feature of these materials and needs to be explicitly dealt with. This is clearly recognised in the conceptual and numerical modelling work presented in Nirex 95 [COR/522]. Providing such heterogeneity is dealt with in an appropriate manner it can simply be regarded as a characteristic of the system rather than being regarded as a source of particular difficulty.

- 8.72 In heterogeneous rock masses, as stated above, it is not necessary to explicitly characterise and understand each and every fracture in order to understand groundwater flow through the system. It is, however, essential in interpreting the results of small scale observations and measurements made within the system, to recognise that these results will themselves reflect the natural heterogeneity of the system. Statements

made in several of the Objectors' proofs referring to a perceived lack of predictability of the system at Sellafield reflect the lack of appreciation of three important aspects of dealing with low permeability, heterogeneous systems, namely:

- i. the systems generate small scale heterogeneous responses which need not and cannot be predicted in detail in order to understand the overall behaviour of the system;
- ii. it is the larger-scale behaviour of the system and the way in which this affects the performance of a repository which need to be the focus of the studies and which need to be adequately predictable; and
- iii. it is not necessary to understand and predict deterministically every last detail of the natural system to be able to develop confidence in the post-closure performance of a repository.

8.73 Spatial variability has also been discussed in section 5 above.

"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, perhaps irrevocably.

8.74 Dr Hencher does, however, state in paragraphs 3.5 and 3.6 of his evidence (PE/FOE/6, page 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."

8.75 Dr Hencher is proposing an approach to the investigation of the site which is different to that proposed by the Royal Society Study Group. In their report [COR/605] on page 110 they state (emphasis added):

"There are two routes forward and we expect Nirex to pursue both of them: a continued effort to improve physical understanding of the relationship between fracturing and water flow, and how these might change under possible future conditions; and a palaeohydrogeological approach to the problem based on observed present-day groundwater geochemistry and its relationship to historical flow conditions.

The RCF will yield valuable information for the two approaches outlined above, as well as providing data on the potential effects of repository construction on the BVG, and allowing progress to be made on repository design. Construction of the RCF should proceed as soon as is practicable."

8.76 Fracture flow modelling is widely recognised as being an appropriate technique for modelling groundwater flow and transport in low-permeability fractured rocks. It is used within the Swedish, US, Swiss, Finnish and Japanese national radioactive waste disposal programmes, and of course the UK programme.

Summary on Nirex Hydrogeological Modelling Studies

8.77 Several opposition proofs (for example PE/FOE/5, paragraph 3.25) criticise Nirex for not using a wider range of models. In fact a wide range of conceptual and mathematical models are used. Previous work is described in section 6 of Volume 3 of Nirex Report 524 [COR/517] and in Nirex 95 [COR/522].

8.78 Ongoing modelling studies are outlined in [paragraphs 8.89](#) to 8.102 of this supplementary proof. Results from these studies are still being assimilated and have not yet been published. However, preliminary analysis indicates that the models consistently predict low flow in the BVG and further advances have been made in reproducing the distributions of pressure head and salinity.

The role of the RCF in understanding the regional hydrogeology

8.79 In paragraph 7.2 (PE/CCC/4, page 43) Professor Mather states that:

"The RCF will add little to our knowledge of the regional picture fundamental to an understanding of the controls on groundwater flow."

8.80 Professor Mather accepts for the RCF solely that (paragraph 7.2, page 42, PE/CCC/4):-

"The RCF will enable the scale over which these networks are observed to be up-rated from that of the borehole to that of the shafts and galleries constructed within the RCF. Although there is no doubt that the RCF will allow a more detailed understanding of the fracture network than it is possible to obtain from surface boreholes and remote geophysical measurements,....."

8.81 He justifies his claim that the RCF will not assist in understanding the hydrogeology by appealing to his review of the results of the Nirex hydrogeological investigations and continuing that (paragraph 7.2 pages 42/43):-

"..... the complexity and unpredictability of the hydrogeology which has been highlighted in Section 6 of this Proof of Evidence means that Nirex may well be able to get no nearer to obtaining a comprehensive understanding of the networks of fractures and the controls of groundwater flow than they are at present. The RCF will provide data on the near-field and will add little to our knowledge of the regional picture fundamental to an understanding of the controls on groundwater flow."

8.82 I do not agree with the assertions made by Professor Mather that the RCF will not address issues related to the regional hydrogeology and set out in the following paragraphs the reasons why I disagree with him.

8.83 Regional hydrogeology is a term applied to the large-scale (kilometres to tens of kilometres) pattern of groundwater movement in a flow system whose boundaries and driving forces can be reasonably well defined and related to geological and geographical features.

8.84 Our current understanding of the regional hydrogeology of the Sellafield area comes from a combination of hydraulic and hydrochemical data from deep boreholes and studies of both present-day and historic records of surface hydrology and sandstone hydrogeology (see section 10 of this supplementary proof for information on the extent of this historical data). Most recently, this understanding was used to construct the regional flow model which figures centrally in Nirex 95 [COR/522].

8.85 The RCF programme addresses many issues apart from regional hydrogeology, but it will provide four main contributions to the current understanding:

- i. Nirex 95 (Volume 2) [COR/522] describes how regional-scale **effective hydrogeological parameters** were derived for each formation and features in the regional assessment model. This work was based on borehole data. The RCF will allow the validity of the basis on which these parameters were derived by the process of 'upscaling' to be tested by applying the techniques to data obtained at the 10 metre and 100 metre length scale. The RCF experiments provide the means of testing and evaluating the assumptions and models used for upscaling.
- ii. The RCF will allow the investigation of the properties of **features** (such as fracture zones) which contribute to regional flow behaviour in the assessment model at an extended 2-D and, possibly, 3-D scale.
- iii. High quality **hydrochemical sampling** from the Coastal Plain and Hills and Basement regimes will be possible from the RCF. This sampling will be able to use techniques and methods not possible in the deep boreholes drilled from surface, and will therefore be able to investigate specific issues in more detail than previously feasible (see [paragraph 10.39](#) below). Long-term monitoring of water chemistry associated with specific features or fracture sets and specific lithologies can be carried out by collection of inflows to sampling installations in the walls of galleries or shafts or from boreholes drilled out from them.
- iv. The **shaft drawdown data** will allow the comparison and testing of different models of flow in both the BVG and the overlying cover rocks by imposing a hydraulic signal which will affect many hundreds of millions of cubic metres of rock. The information from these tests can be readily scaled

to the regional level. The Borehole RCF3 Pump Test was a smaller scale version of the same concept and tested six alternative models of flow in the BVG and two in the overlying cover rocks.

- 8.86 This latter aspect of the investigations, regarding the shaft drawdown data, is consistent with that recommended by RWMAC in 1991 where they commented on the Nirex site investigation programme that (RWMAC, Twelfth Annual Report, 1991, [GOV/404], page 11, paragraph 2.10):

"However, groundwater flow in basement-type rocks is dominated by flow along fractures and it is unlikely that even several boreholes and the most careful geophysics will be able to locate with any certainty all the important groundwater channels. Better awareness of the extent of the hydraulic coupling between the groundwater in the cover sandstones and the basement below will be obtained from observations of the response of the groundwater system to the progressive stages of excavation of the shafts, and then the tunnels, associated with the repository."

The reference to the repository is because this statement was made by the RWMAC before the decision was taken to break-out the RCF as a separate activity. The comments regarding the usefulness of data from monitoring the response of the groundwater system to excavation of shafts and galleries apply equally well to the RCF as they did in 1991 to the repository.

- 8.87 The RCF is not the only contributor to understanding of the regional hydrogeology. An integrated programme of regional investigations has been underway since 1991. The first two stages of this programme involved collecting historical data and data from the Nirex deep boreholes. This has involved gathering meteorological, spring, river and stream, mine working and pre-Nirex borehole data. The current stage is concerned with setting up automated monitoring networks to collect meteorological, hydrological and groundwater data (see description of Regional Hydrogeological Surveys in [Table A.2](#), Appendix 1, **PE/NRX/14**). These networks will also be used to monitor the impact of RCF construction.
- 8.88 The forward programme of deep borehole drilling and testing ([Table 6.3](#), **PE/NRX/14**) will contribute further to understanding of the regional hydrogeology.

Recommendations for further investigations

8.89 In section 5 of his evidence (PE/FOE/5) Dr Salmon presents a series of recommendations for further surface-based investigation studies and modelling. Mr Reeves (PE/FOE/4, paragraph 8.5) also presents recommendations for further investigations. In paragraph 5.2 on page 46 (PE/FOE/5) Dr Salmon states that:

"The need for further surface-based investigations and modelling has been a central thread of my Evidence."

8.90 Dr Salmon concludes (PE/FOE/5, paragraph 6.1, page 52):

"I consider that a RCF should not proceed until the work that I have recommended has been satisfactorily completed, including a proper peer review and due regard being paid to any subsequent comments".

8.91 In Dr Salmon's final conclusion on page 53 (PE/FOE/5) at paragraph 6.6 he states:

"In conclusion, I appreciate the eventual need for a RCF as part of a repository development programme, but consider that the Sellafield RCF planning application is premature. Given the hydrogeological complexity of Sellafield I also consider that Nirex should commence surface investigations at other, more hydrogeologically favourable sites".

8.92 In his final conclusion, Dr Salmon appears to recognise that the Sellafield site may be shown to be a suitable repository site. He is basing his objection largely on the issue of prematurity. The issue of alternative sites has been addressed in section 4 of this supplementary proof.

8.93 At paragraph 5.3 on pages 46 and 47 (PE/FOE/5) he sets out seven "aims" for this further work that he recommends. In paragraph 5.5 he sets out in more detail examples of the types of investigations he considers are required. He concludes in paragraph 5.6 (PE/FOE/5) that:

"I estimate that these tasks (excluding that for aim 6 which needs to be further defined by Nirex) will take five or six years to complete. Most of this period is devoted to the establishment of baseline conditions."

8.94 I do not disagree substantially with the statements made by Dr Salmon concerning the range of additional surface-based work since all the aims raised by him are already incorporated into Nirex's overall programme as explained below. I do, however, disagree with his views on timing, both with regard to the length of time required to establish baseline hydrogeological conditions and the extent to which the work can proceed in parallel with the RCF. The time required to establish baseline conditions is dealt with in section 10 of this supplementary proof. Much of the other work described by Dr Salmon can proceed in parallel with the schedule for the RCF. These aims are discussed below.

Aim 1: to define further the geological sequence and hydrogeology in three dimensions

8.95 Dr Salmon suggests two further boreholes on land and suggests that there may be a case for one or more deep offshore boreholes to better characterise the main potential radionuclide discharge area (see also Mr Reeves PE/FOE/4, paragraph 7.3). [Table 6.3](#) in my evidence (PE/FOE/14) summarises the planned programme of further surface-based investigations. This includes up to two boreholes to the south of the PRZ in the area between Boreholes 2 and 11. These are shown as 'drilling into the Seascale Fault Zone'. It is anticipated that this work can be carried out by inclined drilling from the Borehole 11 site, but consideration is also being given to whether it would be most appropriate to carry out this drilling from an alternative site. Up to four boreholes (Boreholes 15 to 18) are already planned to investigate the saline transition zone, including in the area to the west of the site on the predicted pathlines for groundwater flow that has passed through the repository. Work on the first two of these boreholes is currently delayed as Cumbria County Council have deferred a decision on the planning application. Drilling onshore is preferred for two reasons. Firstly, it provides easier access for long-term testing and monitoring, and secondly, it is considerably cheaper than drilling offshore. Information from drilling offshore needs to be

shown to have a significant benefit to our confidence in the evaluation of the repository system before a commitment should be made. Currently, such a commitment cannot be justified. Regarding drilling to the north-west of Borehole RCF3, Nirex does not consider that such a borehole is required, given the scope for investigation from the RCF itself. Thus the proposals made by Dr Salmon have been included within Nirex's future programme of work. As the additional boreholes are at some considerable distance from the RCF, in areas unlikely to be influenced by the RCF, there is no reason why this work should not proceed in parallel with the RCF.

Aim 2: to determine baseline environmental head and geochemical conditions

8.96 This issue is dealt with in section 10 of this supplementary proof.

Aim 3: to test further the connectivity of strata and fractures

8.97 Dr Salmon states that the scope for further cross-borehole tests and pump tests is limited. Nirex is currently analysing the results of the Borehole RCF 3 Pump Test and considering tracer tests. The monitoring system installed in the deep boreholes is designed to allow sampling of groundwater for monitoring of chemical variation and detection of tracers. The need for further tests will be reviewed in the light of results to date and further work will be planned to complement testing associated with the phased RCF development. Tests of the connectivity of strata and fractures around the RCF and Potential Repository Zone are best done by monitoring the disturbance due to activities such as the controlled disturbance to the groundwater from shaft sinking. This will particularly measure the connectivity between the fracture networks in the BVG and the porous strata in the cover sequence.

Aim 4 : to refine the model in an attempt to enable it adequately to replicate existing groundwater conditions and the effect of any field testing

8.98 Nirex generally agrees - this is what we are doing with our ongoing hydrogeological characterisation and modelling and the RCF is a further development of this process. We are not just refining one model but are developing and testing a range of models to develop understanding of the hydrogeological system. None of this activity needs to delay RCF construction as the phased RCF activities will help to refine, develop and validate the models and their prediction of responses to RCF development.

Aim 5 : to model the impact of the proposed RCF construction on baseline conditions and the PCPA

8.99 Nirex agrees - such modelling is part of our planned programme. As Salmon accepts, it is part of model development as discussed above. This is programmed in as part of the experimentation and modelling related to the phased RCF development.

Aim 6 : to assess the effectiveness of sealing techniques

8.100 This is part of Nirex's ongoing research. Current laboratory results will be further developed once the RCF is developed.

Aim 7 : to begin to develop more appropriate modelling strategies for determining the long-term safety case of any future repository proposals

- 8.101 The current strategy is an appropriate one for this stage of the investigation (Nirex S/94/004 [COR/510]). However, further developments are planned, e.g. to take account of new data from the analysis of the Borehole RCF3 Pump Test and to investigate particular issues. Such plans are highlighted in Section 3 of Nirex Report S/94/004 [COR/510].
- 8.102 Thus, all the work suggested as being necessary by Dr Salmon, and more, is already in hand or planned by Nirex as part of an integrated programme of site characterisation of which the RCF forms a part. There are no reasons for this work to delay the granting of planning permission for the RCF.

9. GEOCHEMICAL INVESTIGATIONS

- 9.1 Issues related to the geochemistry of the site are raised by the proofs of Professor Mather (PE/CCC/4), Dr Haszeldine (PE/GNP/3), Dr Salmon (PE/FOE/5) and Dr Wogelius (PE/FOE/8). Those aspects of the geochemistry raised by Dr Haszeldine and Dr Wogelius that are related to the near field of a repository and the performance of the chemical barrier are addressed by Dr Hooper in his supplementary proof ([PE/NRX/15/S1](#)). The other issues are dealt with in this section of my supplementary proof.
- 9.2 The principal concerns related to geochemistry are:
- i. The lack of boreholes drilled specifically to obtain hydrogeochemical data is one of the major deficiencies of the current borehole programme (paragraph 6.5.1, page 29, PE/CCC/4);
 - ii. Geochemical information has been used to identify three groundwater regimes which rely heavily on the distribution of salinity for their definition (paragraph 6.5.2, page 29, PE/CCC/4);
 - iii. The nature of the saline transition zone in the PRZ (paragraph 6.5.5, page 31, PE/CCC/4) suggests an upward flow of groundwater from the BVG into the Sherwood Sandstone Group (SSG) in this area (paragraph 6.7.1, pages 40 and 41 of PE/CCC/4);
 - iv. Geochemical indicators of residence time have been overinterpreted (paragraph 6.7.1, pages 40 and 41 of PE/CCC/4; paragraph 11.7, page 29, PE/GNP/3);
 - v. The Nirex conceptual model is simplistic and hides the complex inter-relationships between the various groundwater regimes. It also appears unrealistic with respect to the likely point of discharge of groundwater to the surface (paragraph 6.7.1, pages 40 and 41 of PE/CCC/4);
 - vi. the chemical analyses are suspect because of mixing between water from fractures and from matrix (paragraph 11.4, page 29, PE/GNP/3); and
 - vii. rates of regional flows of subsurface waters in the future could be much more rapid than any inferred today (paragraph 10.3, page 26, PE/GNP/3).
- 9.3 The reasons I disagree with the seven concerns listed in paragraph 9.2 above are because:
- i. rigorous procedures, designed to achieve high quality data, have been applied to the collection of groundwater samples from the boreholes drilled by Nirex to date. The quality of information derived from these boreholes has been reviewed by the Royal Society Study Group (page 105 [COR/605]) and is deemed to be of a high standard;
 - ii. the basis on which the three groundwater regimes are defined is clearly documented and is supported by a range of independent datasets. They are therefore not defined on the basis of salinity, although salinity is a key indicator of the different regimes;
 - iii. the inference of upward flow of groundwater from the hydrogeochemical data is made on the basis of considering a localised dataset (around the saline transition zone in the PRZ) without imposing the context provided by the larger dataset or the knowledge of the prevailing hydraulic conditions;
 - iv. geochemical indicators of groundwater residence times have been interpreted in context with each other to build confidence in overall conclusions despite uncertainties prevailing with any individual method;
 - v. a clear picture of the hydrochemical conditions is represented by the Nirex conceptual model and it has not been necessary to modify this substantially as more data are added to the database;
 - vi. the chemical analyses derived from well tests performed in the boreholes primarily sample from the fraction of the rock mass that flowed under test conditions. These are primarily the more mobile waters contained within the fractures; and
 - vii. the suggestion that rates of regional flows of subsurface waters in the future could be more rapid than any inferred today is based on speculation for which there is no existing evidence.
- 9.4 Our responses to these seven concerns are enlarged upon in the remainder of this section.

Lack of geochemical boreholes

9.5 In paragraph 6.5.1 (PE/CCC/4), Professor Mather states that:

"The lack of a programme of boreholes drilled specifically to obtain hydrogeochemical data is one of the major deficiencies of the current borehole programme."

9.6 Nirex has drilled both deep and shallow boreholes at the Sellafield site to gain a regional understanding of the groundwater flow and hydrochemical patterns across the site. These boreholes have had multiple objectives, as a number of features have been required to be explored by each borehole. The collection of groundwater samples from the Sellafield boreholes, in particular in the BVG, is further complicated by the generally low groundwater flow. This restricts the amount of water available for collection in any given period of time. Rigorous procedures have been applied to the collection and evaluation of groundwater samples, in order to ensure that the best feasible quality has been achieved, and that any contamination resulting from the drilling of the borehole or from other sample collection effects can be assessed and corrected for in determining in-situ groundwater compositions. These issues have been previously discussed in my Proof of Evidence (PE/NRX/14, Appendix 1, [Sections A4.4 - A4.6](#)).

9.7 The subject of the reliability of the geochemical data from the deep boreholes was a matter about which the Royal Society Study Group showed considerable interest. Information was presented to the Study Group by Nirex specialists and, as a result, on page 105 of their report [COR/605] the Study Group states:

"Nirex have thus demonstrated a capability to obtain high quality hydrochemical samples from existing boreholes."

9.8 This information, presented to the Royal Society Study Group, was subsequently written up as a technical report for Nirex {Nirex Report 701} which is referenced in Nirex Report S/95/008 [COR/525]. Professor Mather makes no mention of having consulted this report.

9.9 The second point concerning Professor Mather's comments on geochemical boreholes is that Nirex has applied on 30 May 1995 for planning permission to drill two boreholes (Boreholes 15 and 16). The covering letters to Cumbria County Council (Ref: DB/ah/PZ/PP/225 and 226) that accompanied these applications state *"The primary objective of these boreholes is to extend the current understanding of the geochemical conditions as indicators of past and present groundwater flow and mixing"*. Cumbria County Council has deferred making a decision on this application.

Geochemical information used to define groundwater regimes

9.10 This issue is addressed in section 8 of this supplementary proof in [paragraphs 8.7](#) to 8.10.

The saline transition zone and groundwater mixing in the PRZ

- 9.11 In paragraph 6.5.5 of PE/CCC/4, Professor Mather indicates that the saline transition zone in the PRZ is not sharp and goes on to argue that this is "*clear evidence to support an upward flow from the BVG into the SSG in the area of the PRZ*". The following paragraphs 9.12 to 9.20 establish that the saline transition zone is relatively sharp and occurs in the Brockram and basal sandstones, which may be the result of the proximity to relatively high permeability contrasts between the sandstones and the Brockram.
- 9.12 In paragraph 6.5.5 (PE/CCC/4), Professor Mather questions the statement made in my proof of evidence (PE/NRX/14, [paragraphs 6.67](#)) that the saline interface zone is relatively sharp in the PRZ. He states:
- "However, this is only because of the arbitrary definition of the transition zone as the range over which the electrical conductivity of the groundwater changes from less than 10 to over 17 mS cm⁻¹ (at 20° C) (see paragraph 3.2 of {Nirex Science Report S/95/008})."*
- 9.13 Reference to paragraph 3.2 in Nirex Report S/95/008 [COR/525] indicates that the statement made was:
- "The transition from brackish waters to saline waters is known as the saline transition zone (STZ) and has been defined as the depth range over which the electrical conductivity of the groundwater changes from less than 10 to over 17 mS/cm (at 20° C). The upper value is equivalent to 10 g/l of total dissolved solids or about 6 g/l chloride. Definitions of fresh and increasingly saline waters are given in the glossary."*
- 9.14 The glossary in Nirex Report S/95/008 [COR/525] on page G2 states the definitions used for fresh, brackish, and saline waters, and brines. It is stated that these definitions are based on the published work of Davis (1964) and Carpenter (1978). Thus, the definitions of salinity used by Nirex are certainly not arbitrary and are based on standard texts.
- 9.15 This interpretation of the salinity distribution at Sellafield is presented in section 3 of Nirex Report S/95/008 [COR/525]. The summary, as given in paragraph 3.10 on page 16 states:
- "A unified representation of the saline transition zone and other salinity variations across the site has been achieved and is presented. The saline transition zone in the Potential Repository Zone is relatively sharp and occurs in the Brockram and basal sandstones. This is possibly the result of proximity to the relatively high permeability contrasts between the sandstones and Brockram in the locality. To the south and west of the Potential Repository Zone, the saline transition zone is more diffuse."*
- 9.16 The pattern of salinity in the upper part of the BVG is consistent with the current understanding of the site, which suggests that, in the boreholes drilled in the PRZ, zones of slightly higher hydraulic conductivity are indicated in the upper part of the BVG as compared with deeper BVG.
- 9.17 Professor Mather uses his Figure 3 (page 32 of PE/CCC/4) and states that this "*proves how spectacularly wrong*" Nirex were in refuting his earlier suggestions of estimates of upward flow made in ERM Report ITA/7 [COR/608]. Professor Mather's Figure 3 is a reproduction of Figure 3.1 in Nirex Report S/95/008 [COR/525]. Professor Mather does not point out that the original figure was labelled as a "Composite plot of Cl concentration vs. depth for the PRZ" and that it contained data from a total of nine separate boreholes. He also does not point out that the plots for the individual boreholes are contained in Appendix C to the same report (S/95/008 [COR/525]). Professor Mather is overemphasising the implications of salinity levels in excess of 20 mg/l being observed in the base of the sandstones by not placing these observations in context.
- 9.18 The observations of high salinities in the lower part of the St Bees Sandstone referred to in paragraph 6.5.6 of Professor Mather's evidence (PE/CCC/4) are based on a limited number of samples. The samples showing high salinities are obtained from the North Head Member at the base of the St Bees Sandstone. The chloride versus depth profiles for the individual boreholes in Appendix C of Nirex Report S/95/008 [COR/525] shows how these individual samples relate to the interpreted position of the saline transition zone in each of these boreholes. Examination of the information presented by Nirex indicates that over substantial parts of the PRZ, the saline transition zone is sharp, but is actually located within the North

Head Member of the St Bees Sandstone rather than at the top of the BVG or within the Brockram. The interpretation of this information presented in Nirex Report S/95/008 [COR/525] is that:

"the saline transition zone in the Potential Repository Zone is relatively sharp and occurs in the Brockram and basal sandstones. This is possibly the result of proximity to the relatively high permeability contrasts between the sandstones and Brockram in the locality."

- 9.19 As discussed previously, ([paragraphs 8.32](#)), the inferences drawn in Nirex Report S/95/007 [COR/524] are that the North Head Member has distinctive geological and hydrogeological properties from the overlying St Bees Sandstone and is considered to be a possible low permeability control on flow between the North Head Member and the overlying sandstones. The conclusion is therefore that the North Head Member contributes to the permeability contrast between the upper stratigraphic units of the sandstone and the lower formations, and hence the saline transition zone in the PRZ exists in part within the North Head Member.
- 9.20 Detailed examination of the hydrochemical data, in conjunction with other evidence presented by Nirex therefore indicates that it is inappropriate for Professor Mather to conclude that the observed salinity profiles are indicators of significant upwards flow. At present, although the existence of a groundwater mixing profile is evident, it is not possible to use the geochemical data alone to speculate about the extent of this mixing. Further data, from the RCF Phase 1 work, are considered essential to quantify this rigorously.

Geochemical indicators of residence times have been over-interpreted

- 9.21 In paragraph 6.5.10 on page 35 of PE/CCC/4, Professor Mather states:

"It is my view that the noble gas data are over-interpreted".

- 9.22 Professor Mather makes other comments in section 6.5 of his evidence (PE/CCC/4), as does Dr Haszeldine in section 11 of his evidence (PE/GNP/3) that the information on residence times for groundwater have been over-interpreted by Nirex. At paragraph 11.6 (page 29, PE/GNP/3), Dr Haszeldine states:

"it is difficult to envisage how water samples from these Nirex boreholes can be confidently interpreted to yield single ages."

- 9.23 I disagree with the various statements made by Professor Mather and Dr Haszeldine concerning the use of the residence time information because:
- i. they are wrong to suggest that Nirex is using the data to seek to define single ages for the water. That is not what I have done in **PE/NRX/14**, [paragraphs 6.68](#) and 6.69;
 - ii. Nirex is fully aware of all the interpretational issues and caveats related to the use of the various indicators of residence times; and
 - iii. Nirex stress ([paragraphs 6.69](#) and 6.76 of **PE/NRX/14** and [paragraph 4.3](#) of **PE/NRX/17**) the greater confidence placed on the interpretation of groundwater and solute residence times by exploring consistencies between a range of separate and independent data sets rather than seeking to interpret single data sets, each of which has uncertainty attached to it.

Simplicity of Nirex conceptual model

- 9.24 This issue raised by Professor Mather (paragraph 6.7.1, page 40, PE/CCC/4) has been addressed in section 8 of this supplementary proof.

Mixing between waters from fractures and matrix

- 9.25 Dr Haszeldine in paragraph 11.4, page 29 of PE/GNP/3 states:

"Thus any analysis of water from such a BVG flow system will inevitably analyse a mixed sample, containing an unknown ratio of water from fractures and from matrix flows".

9.26 Nirex is aware of this interpretation and this is why residence times are quoted as mean residence times. A range of sample types are analysed, including core pore fluids and fluids sampled during well testing (Table A4, page A21, Appendix 1, PE/NRX/14). The majority of samples analysed for groundwater residence indicators are those taken from well testing in the boreholes. These sample the flow system around the borehole. In the BVG, these samples are dominated by flow from the fracture system.

Future rates of regional groundwater flow

9.27 In paragraph 10.3 (page 26, PE/GNP/3), Dr Haszeldine states:

"It is possible that rates of regional flows of subsurface waters in the future could be much more rapid than any inferred today."

9.28 This statement is made on the basis that Dr Haszeldine suggests in section 10 of his evidence that data for hydrogen and oxygen isotope and noble gases could be interpreted to suggest that recharge of the BVG was restricted to glacial periods when the regional permeability of the BVG might have been much greater than its present value.

9.29 I disagree with Dr Haszeldine's statement because:

- i. Dr Haszeldine does not accurately describe Pleistocene climate history;
- ii. by his own reasoning concerning mixing processes, he should not expect to find distinct isotopic evidence in the BVG groundwaters for recharge during the brief temperate periods in the Pleistocene; and
- iii. there is, therefore, no evidence from stable isotopes (or noble gases) that would suggest preferential recharge of the BVG during glacial periods, and hence no basis for invoking increased BVG permeability during glacial periods.

9.30 Dr Haszeldine's interpretation differs from Nirex's in two key aspects:

- i. Dr Haszeldine misrepresents (paragraph 10.1, page 26, PE/GNP/3) Nirex's interpretation of hydrogen and oxygen isotopic ratios and noble gas recharge temperatures for Boreholes 2, 4 and 5, by equating cold climates with glaciation. He assumes that the observed hydrogen and oxygen isotopic ratios and low noble gas recharge temperatures indicate that groundwater was recharged under glacial conditions. Nirex Report S/95/008 (paragraph 5.3, page 26, COR/525) refers only to "*colder climatic conditions during the Pleistocene*", which includes periglacial and boreal (cold) climate states, as well as glacial conditions; and
- ii. he asserts (paragraph 10.1, page 26, PE/GNP/3) that glacial periods during the past 1.6 million years (i.e. the Pleistocene) were interspersed with warm periods, giving the impression that warm (temperate) climate states were common in the Pleistocene. In fact, the dominant climate states were colder than today's temperate climate, but only rarely glacial (see Table on page 22 of Nirex Report S/95/003 [COR/527]).

9.31 In paragraph 10.2 (page 26, PE/GNP/3) Dr Haszeldine asserts that:

"it is apparent that there is little evidence for water recharge into the BVG in warm period climates, such as today".

9.32 He then goes on to argue that recharge to the BVG may have been restricted to colder (i.e. glacial) periods, and presents a cartoon in Figure 10.2 of PE/GNP/3 that suggests that this was due both to increased heads under the ice and to opening of fractures due to ice loading. This is how he makes the connection between the stable isotope data and the idea that the BVG permeability ("*transmissivities*") may have been higher during past glaciations.

9.33 His own evidence (paragraph 11.4, page 29, PE/GNP/3) emphasises his view regarding the effect of mixing on isotopic indicators of groundwater age, and stable isotopes are no exception. If the Nirex view

that temperate climate conditions were the exception rather than the rule in the Pleistocene is accepted (see paragraph 9.30 above), we would not expect to find spatially distinct groundwater zones with stable isotopic signatures of temperate recharge events pre-dating the last (late Devensian) glaciation, as Dr Haszeldine seems to expect.

- 9.34 In fact, isotopically heavy water characterises the brine in the BVG in Borehole 3. In Nirex Report S/95/008 (paragraph 5.8, page 28, [COR/525]), it is said that this "*might indicate recharge prior to the last glacial epoch*" i.e. before the Pleistocene, possibly associated with Tertiary tectonic events.
- 9.35 Thus there is no evidence, only speculation by Dr Haszeldine that there was preferential and enhanced recharge to the BVG during glacial periods.

10. BASELINE HYDROGEOLOGICAL CONDITIONS

- 10.1 The need to establish the baseline hydrogeological conditions at the site prior to commencement of the construction of the RCF is not in dispute. The point of disagreement between Nirex and the Objectors is the extent to which this baseline has been established and, therefore, whether any further monitoring, sampling or testing is required to establish this baseline.
- 10.2 The matters related to baseline conditions were addressed in [Appendix 2](#) to **PE/NRX/14**. This section responds to various issues raised in the Objectors' proofs.
- 10.3 The Objectors state that additional periods of time are required. For example Dr Salmon (paragraph 5.5, page 49, PE/FOE/5) states:

"I consider that it would be a sensible precaution to define baseline conditions as being established when relatively stable or predictable heads and geochemistry has been observed over a period of four or five years at all monitoring points."

Groundwater Heads

10.4 Mr Reeves (paragraph 8.5, page 42, PE/FOE/4) states:

"This network should be monitored for a minimum of a further 4 or 5 calendar years to enable an equilibrium condition database to be established over an adequate time frame."

10.5 Similar views are stated by Drs Green and Western (PE/FOE/1, paragraph 9.7).

10.6 The Nirex position, as stated in [Appendix 2](#) of my evidence (PE/NRX/14) is that baseline conditions are already recognisable in all boreholes as shown by constant head with time or systematic seasonal variations ([paragraph B.2.16](#), Appendix 2, PE/NRX/14). It has been further pointed out that monitoring will continue and further baseline data will become available prior to commencement of shaft excavation (a further 2 years approximately). A review of baseline conditions carried out for Nirex in September 1995 by Professor Lloyd, (Professor of Hydrogeology, University of Birmingham) has confirmed the Nirex view that baseline has been established [NRX/14/3].

10.7 In its report "Review of aspects of the scientific mission and role of the Nirex Rock Characterisation Facility at Sellafield" [COR/414] at paragraph 14 on page 4, the RWMAC indicate that 18 months to two years groundwater monitoring should be carried out subsequent to cessation of drilling and prior to commencement of shaft sinking. They indicate:

"These recommendations over timing are now likely to be met in view of the interpolation (sic) of the RCF planning inquiry into the overall repository programme."

10.8 Further factors that have not been fully recognised by Mr Reeves and Dr Salmon are:

- i. the extent to which historical data, for example that collected by water authorities, BNFL and the National Rivers Authority, provide a record of groundwater heads and levels which supports and complements the data collected by Nirex as part of the current investigations; and
- ii. the technical objectives of monitoring in relation to the natural fluctuations of natural systems, such as the groundwater system.

10.9 Mr Reeves (PE/FOE/4) in section 5 of his evidence has drawn comparisons with seven UK case studies in order to attempt to support his view that an additional period of 4 to 5 years of monitoring of groundwater heads is required.

10.10 I disagree with the statements and assertions made by Dr Salmon and Mr Reeves for the following reasons:

- i. Mr Reeves underestimates the data available to Nirex, which includes a number of data series of greater than 20 years duration;
- ii. inappropriate comparisons are made with regional groundwater schemes whose expected hydrological impact is orders of magnitude greater than is compatible with the RCF, or even with a repository; and
- iii. a scientific review of the technical objectives of monitoring indicates that there is no justification for the arbitrary periods of additional monitoring suggested as being required by Mr Reeves and Dr Salmon.

10.11 These issues are discussed in turn below.

Data availability

10.12 At paragraph 7.7 (page 31, PE/FOE/4), Mr Reeves comments on the extent of the data available in the sandstones and drift. He is incorrect in his assertions concerning the limited amount of data. There are 16 boreholes with data from 1974 and there are at least 17 drift boreholes with more than 9 years of data {Nirex Report 233, Table 2.11}.

10.13 In the early 1980s extensive investigations into the water resources of west Cumbria were conducted by the North West Water Authority, and subsequently by BNFL. As a result of this there are 41 observation wells with more than 10 years records, and 24 observation wells with more than 5 years records. The results of 13 aquifer pumping tests are available from this investigation, which included monitoring the effects of the development on water levels in the Drift, and on flows from springs and in the River Calder

{Nirex Report 233, Table 3.2}. It is noted that the hydrographs presented by Mr Reeves from Cumbria (Figure 5, PE/FOE/4) display substantially the same pattern of water levels as the hydrograph he presents for Shropshire (Figure 1, PE/FOE/4), except the 1976 drought was less intense in coastal Cumbria than it was in the Midlands. This demonstrates that the Cumbria hydrographs are comparable to the national trends in water level changes.

- 10.14 As part of the development of nuclear facilities in the area, investigations of the relationships between water levels in the drift and underlying sandstone were conducted at Drigg and Sellafield. Professor Mather refers to the Sellafield investigations in CCC/4/3.
- 10.15 The above data show that the investigations of groundwater conditions in west Cumbria, although not performed specifically in connection with the Nirex work, were of a duration and intensity that bears comparison with investigations for groundwater schemes elsewhere in the UK and is greater than suggested by Mr Reeves.

Comparison with regional groundwater schemes

- 10.16 In section 5 of his evidence (PE/FOE/4), Mr Reeves draws comparisons between the Nirex data acquisition programme, and a number of data acquisition programmes associated with different projects. In particular, three groundwater schemes are cited: Thames, Shropshire and the Fylde, the latter two exploiting the Sherwood Sandstone Group, as found at Sellafield. All three of these schemes are very large, designed to impact water resources on a regional or national scale. They involve groundwater abstractions rather larger than the total flow of the River Calder in west Cumbria. The likely scale of impact can be expected to be much greater than the groundwater impact of the RCF, yet it can be seen that the number of observation wells and the timescale of observations are in fact similar to those for the Sellafield area, as described above.
- 10.17 Thus compared with other investigations of comparable scale, Nirex has a comparable amount of data from many of its monitoring installations. As stated in my evidence (Appendix 2, [paragraph B.2.16-17](#), **PE/NRX/14**) the baseline has been established and a further two years of monitoring will be available before excavation of the RCF South Shaft is due to commence. As far as we are aware, there is no tradition of requiring five years data from specially installed monitoring.

Objectives and Duration of monitoring

- 10.18 Natural systems are seldom static, but exist in a state of fluctuation. The objective of monitoring over a period of time, rather than taking just a single measurement, is to characterise this fluctuation with time.
- 10.19 Natural changes to groundwater systems occur over a complete spectrum of timescales. As described in Appendix 2 of PE/NRX/14 ([paragraph B.2.11](#) to B.2.15 on pages B.5 and B.6), Nirex has already characterised gravitational effects (occurring on cycles of 12 hours 25 minutes), barometric effects (24 hours to several days), seasonal effects (1 year), synoptic effects (occurring over several years) and has possibly identified solar effects (22 years). In addition, there is evidence for long-term synoptic effects (about 50 year cycles), climatic effects (100 years to 100,000 years), and tectonic effects (100,000 years plus), all of which are applicable on a much larger scale than just west Cumbria.
- 10.20 Given this continuous spectrum, there is no clear point at which to stop monitoring and it is therefore necessary to form a judgement as to what is sufficient. Some fluctuations can be directly measured and determined on a site specific basis, others, such as, for example, climatic effects and tectonic effects must be established by other means and the uncertainties associated with such estimates taken account of in the safety assessments of the site.
- 10.21 There are two clear uses for the variability recorded in long-term monitoring data:
- i. the characteristics of the variations can be interpreted in terms of the hydrogeological properties of the site; and
 - ii. the natural variability needs to be subtracted from artificially induced changes, such as pump testing and the drawdown caused by RCF shaft excavation, in order to measure correctly the size of these changes.
- 10.22 In terms of hydrogeological properties it can be shown by consideration of the diffusion equation that longer timescale fluctuations directly increase information on hydraulic conductivity. In progressing from daily fluctuations to annual fluctuations there is a significant gain in information of around 2.5 orders of magnitude, whereas further progress to short-term synoptic fluctuations gives a further increase of only a further 0.5 orders of magnitude. In order to characterise cyclic fluctuations, it is necessary to observe one cycle if the period is known, rather more cycles if it is unknown.
- 10.23 In terms of correcting observations for natural fluctuations, if the fluctuations have been explained in terms of hydrogeological properties, the corrections can be made on this basis alone. Otherwise, it will be necessary to measure the natural fluctuations in their own right. It is helpful if the trend can be correlated with trends in boreholes independent of the imposed disturbance. For the longer term effects, which are of more than local significance, the correlation boreholes need not be local. The good correlation of water levels between Cumbria and Shropshire ([paragraphs 10.13](#) above) is an example of this.
- 10.24 Mr Reeves' assertion that at least five years' data are necessary can be examined in the light of the above discussion. Five years' data are clearly more than adequate to characterise fluctuations up to the scale of annual fluctuations. Nearly all the likely information on hydrogeological properties can be extracted from annual fluctuations. Five years' data are inadequate to characterise synoptic variations; this can be seen clearly by moving a five year window over the hydrographs presented by Mr Reeves (Figures 1 and 5 in PE/FOE/4). To characterise such variations, of the order of twenty years' data are required. However, this yields little extra hydrogeological information, and the trends within this can be characterised by less than five years' data. Correlations with other boreholes can also be used.
- 10.25 It is also relevant to consider the use that can be made of long-term monitoring data, for example that presented by Mr Reeves (Figures 8 and 9 in Appendix 1 to PE/FOE/4). Figure 9 shows a fairly consistent mean head, about which annual fluctuations occur. The only major excursion is in 1988. The long record has increased confidence that there are no long-term trends in this dataset, but has added little information beyond that captured by the first one or two years' data. The hydrograph in Figure 8 (Appendix 1, PE/FOE/4) shows the impact of shaft sinking followed by an almost straight line recovery onto which is superimposed the annual fluctuations. These annual fluctuations are rather larger than in Figure 9. The excursion in 1988 is clearly visible. The record prior to shaft sinking is only about 6 months in duration in Figure 8 and is too short to establish whether the amplitude of annual fluctuations has been changed by the shaft sinking. However, it is not clear that the long record of data post-sinking has added much information over that gained in the first one or two years.

Conclusion

- 10.26 The baseline groundwater conditions have been established at Sellafield. A further two years of monitoring will be available before commencement of the RCF South Shaft excavation commences. There is no justification for the arbitrary assertions by Dr Salmon and Mr Reeves that a further 4 or 5 years of monitoring is required before commencement of the RCF.

Geochemical Conditions

- 10.27 At paragraph 6.5.1 (PE/CCC/4), Professor Mather states:

"The lack of a programme of boreholes drilled specifically to obtain hydrogeochemical data is one of the major deficiencies of the current borehole programme."

- 10.28 Dr Wogelius (PE/FOE/8) makes a related assertion at paragraph 9.9:

"Many aspects of the geochemistry of the site as it stands are currently poorly understood."

- 10.29 However, he does not go on to say what these are or why he believes they are poorly understood.

- 10.30 These witnesses call into question whether sufficient geochemical information has been collected prior to RCF excavation. In the following section I explain why baseline hydrochemical information is only required for certain purposes, why sufficient geochemical information, of sufficient quality, is already available for these purposes and why further planned work to improve the baseline will be unaffected by the excavation of the RCF. I also explain why the RCF offers the only means to obtain baseline hydrochemical data relevant for other purposes.

Objective of Hydrochemical Observations

- 10.31 Hydrogeochemical baseline information is required at the current stage of investigations principally to assist with the development of the regional groundwater flow model. The main components of the hydrogeochemical data used to do this have been salinity and other major chemical component data (to help identify the processes leading to the distribution of the main bodies of water present) and isotopic data (which give indications of origins and movement of these waters; so-called palaeohydrogeological information).
- 10.32 At later stages in the programme, requirements for hydrogeochemical data will become more specific in terms of targetting hydrogeological features or regions of interest or in terms of evaluating specific mechanisms and pathways.

Data used in Current Regional Model

- 10.33 The principal source of data used to draw the current hydrogeochemical baseline has been water samples taken from cores and during hydraulic testing of the deep boreholes. These samples were all contaminated to varying extents by drilling fluids but it has been possible to make analytical corrections to provide good quality data which are 'fit for purpose'. This is described in detail in Appendix 2 (B.3) of my Proof of Evidence (PE/NRX/14) and the views of the Royal Society Study Group on data quality were stated earlier, at [paragraph 9.3](#) of this proof.
- 10.34 The information is 'fit for purpose' for the following reasons:
- i. it has allowed a clear picture of hydrochemical conditions to emerge which it has not been necessary to modify substantially as more data are added progressively to the database; in other words, the hydrochemical understanding is robust.
 - ii. thus, it has permitted the construction of a regional hydrogeological model which has met with broad acceptance as a useful representation of the system (e.g. PE/CCC/4 at 6.6.7; Royal Society Study Group [COR/605] at p 107 "*A relatively robust description of the present-day generalised flow in an east-west plane is emerging.*").
 - iii. it has identified areas within the region where further investigations could be focussed to refine the regional model.
- 10.35 The hydrochemical data, whilst fit for current purposes and equalling or exceeding those of comparable international programmes, are of variable quality. For further developments of the assessment work, it will be necessary to increase the quality and spatial density of some of the information. This is discussed below.

Future Programme

- 10.36 Specifically 'geochemical' boreholes (currently, boreholes 15-18 into the sandstones), in which collection of hydrochemical data takes precedence over other measurements, are planned to enhance understanding in volumes of rock where the conceptual regional hydrogeological model is sensitive. These may include the saline transition zone, other regions of groundwater mixing and discharge zones.
- 10.37 Continued sampling of existing and planned deep boreholes will provide progressively less contaminated samples for isotopic analysis which will enable the construction of a model of regional palaeohydrogeology. This will considerably strengthen the regional flow model. At present, this work is in its early stages.
- 10.38 Sampling of entirely undisturbed conditions within the PRZ will not be possible after construction. However, this is not considered to be a significant issue for the following reasons:
- i. A baseline of 'major variables' for the region as a whole, including the PRZ, already exists. This is adequate for constructing the current regional flow model (as discussed above). In this context, hydrochemical data from the PRZ are simply one point in the much broader regional picture which can be built even without data from the PRZ itself.
 - ii. Very detailed hydrochemical characterisation of undisturbed PRZ groundwaters with a view to evaluation of their impact on the proposed repository system is of limited relevance as the actual behaviour of the repository near-field hydrochemistry will be dominated by the presence of the repository excavations themselves (to which the RCF is analogous). In particular, the evolution of pore-waters in the cementitious engineered barriers and the wastes and the interactions of the consequent chemical 'plume' with the rock will need to be demonstrably understood. Monitoring of the hydrochemical disturbance caused by the excavations, such as the RCF, is of considerably greater significance in evaluating the future behaviour of the PRZ than is information on its undisturbed state.
- 10.39 In addition to these points it must be stressed that the RCF offers the only practical means to collect other 'baseline' hydrochemical data which will be important to the future assessment work:
- i. Collection and long-term monitoring of inflows to the shafts and galleries of the RCF as drawdown proceeds using specially designed sample installations which penetrate a few metres out from the excavation disturbed zone will provide high-quality uncontaminated samples from zones of rock or specific features which are intersected. Monitoring of changes in water composition of more

transmissive features/regions as the drawdown progresses will provide valuable information on flow patterns in the PRZ region. This latter approach has been used successfully to study the impacts of major fractures on flow and deep hydrochemistry in the Äspö underground research laboratory in Sweden.

- ii. The RCF itself allows the best practical means of access to neighbouring volumes of rock in the BVG via sub-horizontal boreholes drilled out into the surrounding rock. It is expected that hydrogeochemical conditions analogous to those existing prior to disturbance by the RCF will be encountered. It must also be borne in mind that the response time of the hydrogeochemistry to drawdown and excavation will vary depending on the hydraulic properties of the rock or of the feature intersected. Low transmissivity parts of the deep BVG are expected to remain essentially unaffected chemically and be accessible for sampling for a considerable period.

11. TECTONICS AND EARTHQUAKES

- 11.1 Dr Haszeldine makes a number of statements and assertions in section 7 of his evidence (PE/GNP/3) and seeks to demonstrate that the level of seismic hazard at the Sellafield site is higher than presented in [paragraphs 7.14-7.25](#) (commencing on page 55) of my evidence (PE/NRX/14) He states:
- i. *"a potential hazard exists in the "Site" and "Region" areas of the Nirex investigation which has not to my knowledge been systematically addressed by Nirex work published to date."* (paragraph 7.1, page 18);
 - ii. the Lake District Boundary Fault has been active sometime during the last 60 million years and it is an extensional fault (paragraph 7.2);
 - iii. unconformities and discontinuities within the glacial sediments are indicative of tectonic activity within the last 100,000 years (paragraphs 7.3 and 7.4);
 - iv. Britain is in an extensional tectonic regime (paragraph 7.7);
 - v. large earthquakes in extensional tectonic regimes can pump large quantities of water to the surface (paragraph 7.5); and
 - vi. earthquakes of this extensional fault type and magnitude could easily influence subsurface water flows at Sellafield up to 50 kilometres from the site to produce several cubic kilometres of water discharges (paragraph 7.6) The Rampside earthquake occurred on one part of the Lake District Boundary Fault and may have effected discharge of 100,000 m³ water (paragraph 7.7).
- 11.2 In paragraph 7.8 (PE/GNP/3), Dr Haszeldine draws the conclusion that:
- "It would appear possible that the Sellafield "Region" is unique in Britain in having a combination of:-*
- *Evidence for geologically recent fault movement;*
 - *Theoretical pre-disposition to modern fault movement;*
 - *Historical evidence of a fault event pumping subsurface water."*
- 11.3 Dr Haszeldine refers to four references: Nirex Report 524 [COR/517], the Royal Society Study Group Report [COR/605] and two publications for which Dr Muir-Wood was the lead author [GNP/3/7 and GOV/613].
- Dr Haszeldine's statements and assertions are flawed in several ways, namely:
- i. the evidence quoted by Dr Haszeldine (paragraph 7.5, PE/GNP/3) for major expulsion of water during earthquakes is from large earthquakes of a size far greater than those observed in Britain;
 - ii. the extrapolation of the 'radius of influence' of such a large earthquake to west Cumbria in the way done by Dr Haszeldine is questionable;
 - iii. recent research is indicating that hydrogeological changes produced by earthquakes are typically associated with small enhancements in shallow permeability of the ground, not with expulsion of water from depth;
 - iv. the tectonic regime in the UK is not extensional;
 - v. the last stage of movement on the Lake District Boundary Fault Zone was not extensional, even though the fault originally developed as a 'normal fault' in an extensional regime; and
 - vi. the Rampside earthquake was associated with shallow liquefaction of beach sands. There is no evidence to suggest that it was associated with ejection of deep groundwater.
- 11.5 These various issues are responded to in more detail in the subsequent paragraphs.

Extent of Nirex Investigations

- 11.6 Nirex has initiated studies to evaluate the nature of the tectonic and seismic disturbance which could affect a repository at Sellafield in accordance with international guidelines ([paragraph 7.21](#), page 57, PE/NRX/14).
- 11.7 Nirex is adopting a balanced and scientific approach to evaluating seismicity and any associated hazard in which the scientific evidence is assessed and subjected to wide and critical review before incorporation

into our performance assessments of the site. We are currently obtaining reviews of aspects of the seismicity studies from two international experts in line with the recommendations of the Royal Society Study Group contained on page 160 of their report [COR/605] that the work should be exposed to the widest possible international peer review.

- 11.8 Nirex has recently published a four volume report on the seismological database for Sellafield {Nirex Report SA/95/003} which is referred to in [paragraph 7.23](#) of my evidence (**PE/NRX/14**, page 57).

Lake District Boundary Fault Zone

11.9 In paragraph 7.2 of his evidence (PE/GNP/3), Dr Haszeldine comments on the map presented by Nirex as Figure 6.2 in Volume 1 of Nirex Report 524 [COR/517]. Dr Haszeldine makes the comment:

"In terms of possible uplift, the most important part of this map is the abrupt change in the orientation of uplift contours as they cross a line running sub-parallel to the present coastline. The only way to resolve these changes of contour direction, is to infer that a discontinuity has occurred between the two sets of rocks, i.e. that a fault has been active sometime during the last 60Ma."

11.10 Nirex has presented evidence (Nirex Report 524, Volume 1, page 38 [COR/517]) in its published discussion of Figure 6.2 that:-

- i. The change in the orientation of the contours of uplift across the Lake District Boundary Fault Zone in south Cumbria is largely an artefact of the sparse data offshore. There are only two data points offshore, both on the other side of the East Irish Sea Basin.
- ii. Faulting that has been active during the past 60 million years is not the only explanation for the change in orientation of apparent uplift contours. Expulsion of warm mineralised fluids at the basin margin is a more likely explanation for locally enhanced values of apparent uplift - and the process is as proposed by Dr Haszeldine and others for the origin of the hematite ore bodies of the south Cumbria area.

11.11 Nevertheless, Dr Haszeldine associates this apparent discontinuity with the Lake District Boundary Fault, comments that this structure is an extensional fault and, subsequently, (paragraphs 7.5 to 7.7, PE/GNP/3) draws an association between extensional faulting and groundwater expulsion.

11.12 The evidence for regional uplift in the Lake District is not disputed. Nirex has presented this information in a number of reports. However, Dr Haszeldine fails to make the point that uplift occurred everywhere else in Britain. Section 6.1.4 of Volume 1 of Nirex Report 524 [COR/517] on page 37 states:

"Uplift at about the Cretaceous-Tertiary is ubiquitous in Britain."

11.13 Dr Haszeldine also fails to recognise that this latest period of movement on the Lake District Boundary Fault, would not have been extensional, as he implies, but compressional. This is explained on page 38 of Volume 1 of Nirex Report 524 [COR/517] where it is stated:

"Further evidence of basin inversion superimposed upon a broad, regional uplift is provided by the seismic reflection data with examples of fault reversal and local anticlinal folding. Compression, orientated roughly N-, is consistent with the fact that NE-trending structures, such as the Maryport and Lagman faults, were preferentially reversed. This resulted in inversion of the Solway Firth Basin and northern part of the Langman Basin which appear to have been buttressed against the Ramsay-Whitehaven Ridge. In the vicinity of Sellafield, any displacements on the LDBFZ would have been markedly transpressional."

11.14 The 'LDBFZ' is the Lake District Boundary Fault Zone. 'Transpressional, as stated in the Glossary of Volume 1 of Nirex Report 524 [COR/517] means "Action of compressive stress oblique to the trend of a fault. Results in oblique-reverse displacement of the fault." In other words, it is not extensional.

11.15 Thus, Dr Haszeldine is being somewhat misleading in stating that the Lake District Boundary Fault is an extensional fault. Whilst it formed originally in an extensional regime, its latest movements were not extensional.

Features within the glacial sediments

11.16 Nirex is investigating possible neotectonic features and attempting to distinguish such evidence from the relatively common glaciectonic structural features due to internal deformation of the Quaternary by the movement across it of ice sheets. These have produced compressional and extensional dislocations. The section in Volume 1 of Nirex Report 524 (page 11) [COR/517] to which Dr Haszeldine may be referring in

paragraph 7.4 (page 18, PE/GNP/3) is comprehensive and sufficient to show that we are addressing the subject and it is not a major omission as he claims:-

"2.5 Neotectonics and seismic hazard

Since the preparation of Nirex Report Number 263, there have been further investigations of seismological, geophysical, geological and remotely sensed features, to determine whether they may indicate neotectonic activity. In particular, potentially faulted offsets of rockhead and Quaternary sediments have been interpreted from onshore and offshore seismic reflection data. No firm field evidence of neotectonic activity has been found in the onshore district although sites which might be the most likely to reveal such evidence have been identified for further study."

Tectonic Regime in the UK

11.17 Dr Haszeldine states in paragraph 7.7 (PE/GNP/3) that Britain is in an extensional regime. He is incorrect in this assertion. His mistake may have arisen from misleading statements in the references he quotes (GNP/3/7 and GOV/613).

- 11.18 In the 1992 HMIP Report (page 30, section 2.7.2, British Earthquakes, paragraph 1 [GOV/613]), Dr Muir Wood is initially definitive that Britain, in contrast to other intraplate regions, is in an extensional regime but, on referring to section 3, the evidence for extension is admitted to be minor with evidence for strike-slip faulting predominant (page 63, section 3.2.5 [GOV/613]). More specifically, for western Britain, including the Sellafield area, it is accepted that the regime is not extensional.
- 11.19 By the early 1990's, observations of present day stress fields by earthquake focal mechanism studies, *in situ* stress measurements and borehole break-out analyses had shown that the European stress state was generally not extensional, but in a similar compressional state to other intraplate areas. In a summary paper on "Regional Patterns of Tectonic Stress in Europe", Muller *et al.*, 1992 (Figure 3, page 11,787 [NRX/14/6]) provided maps of stress indicators. On a generalised stress map they classified these as compressional or extensional. *"Inward directed arrows indicate the maximum horizontal compression directions in regions of dominantly compressive stress regimes (either thrust or strike-slip faulting). Outward directed arrows indicate the least horizontal stress in regions of extension."* Areas of dominant extension were only present in Italy, Greece and Turkey. All other areas were dominantly compressional, with a limited number of local extensional zones as in the Rhine graben and in uplift zones following melting of thick ice sheets. Even basins formed in an extensional regime, such as the North Sea, were generally in a situation of present-day compression. All but two of the many stress indicators in Britain were compressional. One of these extensional indicators was in eastern England near the Wash, the other was in the SW Scottish Highlands, in the area of maximum ice load during the Pleistocene.
- 11.20 In the HMIP report [GOV/613] reference is made to an article (King, page 90) on fault plane solutions for the 1979 Carlisle earthquake. This was not discussed in detail but is relevant to Sellafield as the nearest earthquake of moderate size that had been instrumentally monitored in detail and results analysed to determine the stress pattern. One mechanism was thrust/reverse faulting, the other mainly strike-slip, i.e. neither were extensional. King favoured the reverse faulting solution but later more detailed analysis by the BGS {SA/95/003}, including the aftershock data, preferred an oblique strike slip mechanism.
- 11.21 Subsequently, as part of the Nirex Seismic Hazard Assessment, [SA/95/003], the data for the 1979 Carlisle (Longtown) earthquake were re-analysed and confirmed the strike slip solution. Additionally, analysis of the 1993 Grange-over-Sands earthquake, at $3.0 M_L$ the largest earthquake recorded by the BNFL/Nirex monitoring and the closest earthquake of moderate size to Sellafield, indicated strike-slip with a small component of reverse movement. Such a mechanism was found to generally apply to the great majority of earthquake fault plane solutions in the area. Pure reverse or normal faulting is minor and associated with the smaller earthquakes. It was noted ([11] p 48 paragraph 2) that: *"At or above this magnitude ($3M_L$), focal mechanisms elsewhere in Britain invariably appear to be strike-slip"*.
- 11.22 Therefore, earthquake analysis confirms that the stress regime at seismogenic depth in the Sellafield area is not extensional but generally strike-slip and similar to that in the majority of Britain and north-west Europe. Thus, Dr Haszeldine is incorrect in stating that the tectonic regime in Britain is extensional.

Effect of Earthquakes on Groundwater

- 11.23 Dr Haszeldine (paragraph 7.5, PE/GNP/3) states that earthquakes can pump water to the surface as a consequence of their aftermath. He quotes information from GNP/3/7 in support of his statements. He then extends his argument to the UK quoting information from GOV/613 in his paragraph 7.7.
- 11.24 In the 1992 DoE/HMIP Report [GOV/613], Muir Wood and Woo suggest that normal fault earthquakes can have a major effect on groundwater whereas reverse fault earthquakes do not produce significant effects. Strike-slip earthquakes were found to produce a variety of responses and this was considered to be due to the associated component of normal or reverse faulting.
- 11.25 The relevant extract for strike-slip earthquakes is (page 16 [GOV/613]):

"2.4 Strike-slip Faults

2.4.1 General remarks

As might be predicted from the findings concerning normal and reverse fault earthquakes, strike-slip fault displacements are found to cause a diversity of responses. Many strike-slip faults are accompanied by some component of normal or reverse displacement, and it is evident that this can be of particular importance in dictating the resulting hydrological signatures."

- 11.26 Dr Haszeldine draws an analogy in paragraphs 7.5 and 7.6 (PE/GNP/3) between the reported effects of the 1959 Hegben Lake earthquake and the 1983 Borah Peak earthquake. His diagrams (7.5 and 7.6) both, however, refer to the Hegben Lake event. He does not mention that both events were large earthquakes on normal faults in an extensional regime and were therefore not analogues for potential effects at Sellafield. Section 2.2 on page 5 of GOV/613 is headed "Normal Fault Earthquakes" and contains the quote:

"In the past 35 years there have been three major onland normal fault earthquakes in countries with a well developed programme of hydrogeological monitoring: the two most recent large normal fault earthquakes in the USA (the 1959/8/17 Hebgen Lake earthquake (M7.3) in Montana, and the M_s 7.0 1983/10/28 Borah Peak earthquake 250 km away in Idaho), and the M_s 6.9 1980/11/23 earthquake in southern Italy."

Hydrogeological effects of UK Earthquakes

- 11.27 Reference to [paragraphs 7.14](#) to 7.25 of **PE/NRX/14** indicates that the seismicity of the UK is low and that over the last few hundred years has only been subjected to moderate or small earthquakes (up to about magnitude 5.5). Thus, it is scientifically questionable to suggest that the effects of a magnitude 7.3 earthquake can be realistically mapped onto Cumbria in the way that Dr Haszeldine has sought to do in his Figures 7.5 and 7.6 (PE/GNP/3).

- 11.28 Dr Muir Wood and G Woo in a 1992 report for DoE/HMIP [GOV/613] stated in the abstract that:

"Britain is shown to be a slowly deforming region of active crustal extension, in which increases in springflow and rises in the water-table have been noted following even relatively small earthquakes of the past 150 years. Hence earthquake-induced changes in hydrology will need to be accounted for in estimating the performance of proposed British radioactive waste repositories."

- 11.29 They applied their analysis to the Sellafield site and concluded that ([GOV/613], page 79, section 4.5.1, paragraph 5):

"Hence there are tectonic arguments for suspecting that faults of the LDBFZ may currently be active. The hydrological signature of the 1865 Rampside earthquake provides further corroboration that at least some faults of this system are liable to undergo shallow normal fault displacements."

and that (page 80):

"However current evidence suggests that the fault-bounded West Cumbrian coast may be tectonically active, and that seismic pumping of groundwater may occur around Sellafield."

11.30 As Britain is not in an extensional regime, the claimed mechanism for significant hydrogeological effects predicted by Dr Muir Wood's hypothesis will not apply. The examples he presents, [GOV/613] Appendix B, of British earthquakes that affected the hydrogeological regime are:

- i. Rampside, 1865 (near Barrow in Cumbria)
- ii. Colchester, 1884
- iii. Hereford, 1896
- iv. Stafford, 1916
- v. North Sea, 1931

11.31 Of these, only the Rampside and Colchester events produced significant effects, and these effects themselves were limited in extent.

Rampside, 1865

11.32 The Rampside effects were not of deep groundwater expulsion, but of near surface effects due to beach sand liquefaction.

Colchester, 1884

11.33 After the Colchester earthquake ([GOV/613] B2), there were limited short term effects in the immediate area but also more widespread and long-lasting hydrological changes up to 25 km away. Water levels within the Chalk rose by up to 7.5 feet in wells to 420 feet depths over periods up to 40 days following the earthquake. The majority of changes in water level were rises but the level fell in one well. The widespread nature of the changes probably does reflect earthquake strain effects on the fissured Chalk aquifer. The Colchester earthquake was in SE England adjacent to the southern North Sea basin and so there could be an extensional component to the local stress regime. Therefore the changes to the local water table following the Colchester earthquake probably indicate effects that would not apply to the Sellafield area.

Recent Review of earthquake effects on groundwater

11.34 A recent study (Rojstaczer, Wolf and Michel; Nature, 373, pages 237-239, 1995) has concluded that earthquakes do not expel water from depths of several kilometres. Instead earthquakes can cause near-surface permeability enhancements that produce persistent and widespread changes to the groundwater. These include changes to the water table and groundwater outflow to streams. Measurement of the groundwater chemistry after earthquakes in California showed that near surface water was involved in changes to the stream and spring flow.

11.35 Inferred changes to the permeability were about one order of magnitude. Measurements of the permeability of all the hydrogeological units at Sellafield have indicated a range of values over several orders of magnitude. Modelling of the groundwater pathway for the post-closure performance assessment (Nirex 95 [COR/522]) has used a range of permeability values. A general increase of one order of magnitude in the average near surface permeability was not found to produce significantly different results.

Conclusions

11.36 The following conclusions are therefore drawn:

- i. As indicated in **PE/NRX/14** ([paragraph 7.26 iv](#), page 59) earthquake activity in the UK is low and is not expected to have a significant effect on the physical stability of the site in terms of its potential to host a repository.
 - ii. The Sellafield area does not lie in an extensional tectonic regime in which earthquakes would produce significant effects on the groundwater.
 - iii. Earthquake effects on the groundwater are likely to be small, indirect and near surface with no direct expulsion of groundwater from repository depth.
- 11.37 Dr Haszeldine, by selectively quoting information from a limited number of sources has sought to draw conclusions about the tectonics of the Sellafield area and concerning possible impacts of earthquakes on the hydrogeology of the area. In doing this he has failed to take account of the published information and has misrepresented information, for example, by seeking to draw a comparison between large, normal fault earthquakes in the USA and small earthquakes in the UK in a compressional stress regime.

12. COMPARISONS WITH INVESTIGATION PRACTICES ELSEWHERE

Comparisons with the Oil Industry

- 12.1 Several Objectors' proofs draw comparisons between the Nirex investigations and the practices adopted within the oil industry. Dr Haszeldine (PE/GNP/3, section 6, pages 15-17) draws comparisons in terms of timescale and approach. A similar theme relating to approach to investigations is picked up by Professor Smythe (PE/FOE/3, paragraph 7.14).
- 12.2 Professor Smythe and Dr Haszeldine both seek to criticise the Nirex approach to investigations claiming that it does not follow oil company practice which they regard as a model for Nirex to emulate (PE/FOE/3, paragraphs 7.14 and 9.6; PE/GNP/3, paragraph 6.3).
- 12.3 The first point that must be made is that Nirex is not exploring to identify and exploit an oil deposit. The oil industry seeks to locate oil and gas deposits which are confined to specific locations dependent upon very specific combinations of geological features and processes. Nirex, on the other hand, is exploring a specific location to determine its suitability to host a repository. Fluid flow technology for the oil industry tends to be aimed at high flow rates and high permeability rocks. Nirex, on the other hand, is looking primarily at low flow rates in low permeability rocks. In these respects, the oil industry is not a direct analogy to the work being undertaken by Nirex.
- 12.4 Nevertheless, the Nirex approach has drawn on a wide range of expertise and experience from the hydrocarbons industry, notably through such contractors as British Geological Survey, GeoScience Ltd, J. Arthur and Associates Ltd, Schlumberger GeoQuest Ltd and others, all with direct experience of working in the hydrocarbons industry. Meetings have been held with both Shell and BP to exchange technical knowledge and experience, and this information exchange continues.
- 12.5 At paragraph 6.7 of his evidence (Pages 16-17, PE/GNP/3), Dr Haszeldine states that:
- "Choice of site and Planning Application for the RCF could be considered analogous to deciding to proceed with oil field development in a particular location."*
- 12.6 The only decision Nirex has made is to apply to construct an RCF. In terms of the exploration analogy that Dr Haszeldine persists with, this may be seen as just another tool for obtaining data and testing predictions analogous to the change in the hydrocarbons industry from drilling exploration wells to an appraisal well - it is definitely not analogous to a decision to proceed with the development of an oil field. This would be equivalent to commencement of construction of a repository and first oil would be equivalent to first waste emplacement in a repository.
- 12.7 Dr Haszeldine's presentation of the Nirex programme is wrong (his Figure 6.7, PE/GNP/3). He shows the boreholes starting in late 1992. The borehole drilling started with Borehole 1 in mid 1989. The RCF programme described by Dr Haszeldine is not the same as that presented as [Figure 5.1](#) in Dr Mellor's evidence (**PE/NRX/16**). Dr Mellor shows the RCF programme commencing in mid 1996, seven years after the start of drilling as compared to the 15 months shown by Dr Haszeldine. Dr Mellor shows the RCF science programme completed in early 2006; Dr Haszeldine shows it to be completed by the end of 2001.

The programme shown by Dr Haszeldine for the development of a complex or difficult oil field concludes with first oil production some 18 years after start of work. The equivalent end point for the Nirex programme is first waste emplacement in a repository. Mr Folger's evidence (**PE/NRX/12**, [paragraph 9.22](#), page 61) states that this may be possible in the first half of 2011. Mr Folger's supplementary proof ([paragraph 4.3](#), page 8, **PE/NRX/12/S1**) presents a revised programme indicating the earliest date for first waste emplacement as the first half of 2012. This is 23 years after start of drilling. This is longer than the 18 years quoted by Dr Haszeldine for an oilfield and substantially longer than the 9.25 years he shows in his Figure 6.7 (PE/GNP/3) for the '*Nirex drilling plan*'.

- 12.8 Detailed examination of the Nirex investigation programme reveals close similarities with the practice in the hydrocarbons industry. The adoption of a progressive, step-wise methodology from the regional reconnaissance scale towards the District and then the Site and finally the PRZ is a clear example.
- 12.9 The acquisition of seismic reflection data similarly followed standard exploration procedures. Hydrocarbon exploration normally begins with wide ranging 2-D seismic reflection surveys and exploratory drilling, moving later, where justified, to development drilling and, in many, but by no means all cases, to targeted 3-D seismic surveys.

REFERENCES

COR/502

Nirex Report 263, The Geology and Hydrogeology of Sellafield, March 1992, (Vols. 1-2)

COR/508

Nirex Science Report S/94/002. Post Closure Performance Assessment, Information Management, October 1994

COR/510

Nirex Science Report S/94/004. Post Closure Performance Assessment, Modelling of groundwater flow and radionuclide transport, January 1995.

COR/524

Nirex Science Report S/95/007. Sellafield Geological and Hydrogeological Investigations. The 3D Geology and Hydrogeology of the RCF South Shaft Location: Summary Report, July 1995.

COR/525

Nirex Science Report S/95/008. Sellafield Hydrogeological Investigations. The Hydrochemistry of Sellafield: 1995 Update. July 1995

COR/527

Nirex Science Report S/95/003. Nirex Safety Assessment Research Programme: Nirex Biosphere Research: Report on Current Status in 1994. July 1995

COR/602

Bath, A.H., 1995. Groundwater geochemistry in the potential repository zone and surrounding rocks at Sellafield, in "The Geological Disposal of Radioactive Waste" IBC Conference, London, 27/28 March 1995.

COR/608

Environmental Resource Limited (ERL). 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, December 1992.

COR/614

Geological Environments for Deep Disposal of Intermediate level wastes in the United Kingdom. Chapman, McEwen and Beale. IAEA-SM-289/37, 1986

GOV/404

The Radioactive Waste Management Advisory Committee, Twelfth Annual Report, HMSO, 1991.

GOV/613

Tectonic Hazards for Nuclear Waste Repositories in the UK. Muir Wood and Woo, HMIP Report No 92.070, 1992.

GOV/627

The Nirex Sellafield Site Investigation: Structural Characterisation of Hydrogeology. Muir Wood. HMIP Report No. 93/076, 1993.

NRX/14/3

Hydrogeological Baseline Conditions. Review of Groundwater Pressure Distribution (September 1995) by Professor J.W. Lloyd.

NRX/14/4

The contribution of palaeontological data to an understanding of the early Palaeozoic framework of eastern England. S.G. Molyneux. Annales de la Societe Geologique de Belgique, T. 114 - 1991, pp 93-105, December 1991.

NRX/14/5

Use of a "Groundwater Return Index" in site selection for deep waste repositories: a review of the RWMAC/ ACSNI proposal. A report prepared for UK Nirex Ltd by British Geological Survey, May 1995.

NRX/14/6

Regional patterns of tectonic stress in Europe. Muller et al. Journal of Geophysical Research, Volume 97, No. B8, Pages 11,783-11,803, July 1992

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