6C. SCIENCE & TECHNICAL PROGRAMMES

6C.1 The science and technical programmes are designed to enable the production of a safety assessment within regulatory guidelines. Sufficient understanding of the geology and hydrogeology of the site is needed to provide an input to the conceptual and mathematical models and hence lead to a reliable probabilistic safety assessment for the DWR as designed. Good engineering, good science and best practicable means are required to be employed [GOV/208, paras.75 & 78]. Decisions should be based on the best possible scientific information and analysis of risks [idem, para.50]. The precise timetable will depend on the granting of planning consent and compliance with regulatory requirements, including the establishment of a sound safety case [idem, para.101]. This Chapter describes progress to the time of the inquiry, and considers whether it has been good enough for the RCF to start.

The Multi-Barrier Concept

6C.2 The programmes are based upon Nirex's disposal concept of a multi-barrier containment system, briefly outlined at 6A.2 above. The components of the concept are the disposal inventory, physical and chemical containment and the natural barrier [explained in COR/528, Chapters 2 & 3].

6C.3 Nirex regard the disposal inventory referred to at paragraph 6A.4 above as being broadly subdivided into relatively short lived fission products (eg ^{90}Sr and ^{137}Cs) or neutron activation products (eg ^{63}Ni), having radioactive half lives of around 100 years or less (as distinct from the GOV/507 Glossary definition), and the long-lived radionuclides [see para. 6A.4]. The latter are of great importance to DWR performance, especially some `daughter' radionuclides (eg $^{226}$Ra of `parent' ^{238}U).

6C.4 Potential waste streams have been identified as the source of radionuclides. About 65% of the total 16.6 TBq of ^{36}Cl (50,000 m^3 approx) are calculated to arise from 7 streams with small quantities likely in many other waste streams. ^{129}I from nuclear fission would be present in small quantities in a wide range of wastes but 4 waste streams are estimated to contribute some 50% of the projected total of 0.92 Tbq (500 m^3 approx). ^{238}U from reactor fuel is expected in seven waste streams contributing about 55% of the total 36 Tbq (37,000 m^3 approx).

6C.5 Most ILW would be packaged in unshielded stainless or carbon steel drums or boxes, immobilised by a cement-based grout. Shielded ILW would be principally packaged in concrete boxes and similarly immobilised. LLW would make a very small contribution to the radioactive content of the DWR and would be packaged, but not immobilised, in carbon steel boxes. 99% of the radioactive disposal inventory would be unshielded.

6C.6 Physical containment of the wastes is intended to be achieved by the initial prevention of access of groundwater to the radionuclides in the wastes and subsequent limitation of the movement of groundwater containing radionuclides away from them. The integrity of the containers is to be the principal containing feature coupled with the immobilising grout. Corrosion of steels is expected to be reduced by the presence of alkaline water chemistry and the anaerobic conditions prevailing once the initial volume of air has

been displaced by inflowing groundwater, organic matter in the wastes degrades, and the residual oxygen has been consumed by aerobic corrosion. Research work has indicated to Nirex that the average time for a metal container to be corroded through at Sellafield ranges from 9,000 to 16,000 years [NRX/15/1, p.16]. More than 95% of the radioactivity is predicted to have decayed after 300 years and about 99% after 1,000 years [NRX/15/43/Fig.5.1] and it is the 1,000 year figure which Nirex assume for design purposes at present although not for the risk assessment in Chapter 6E.

6C.7 Chemical containment would be principally achieved by the Nirex Reference Vault Backfill (NRVB) surrounding the emplaced waste containers in the disposal vaults but leaving a crown void. High integrity seals would be located in access tunnels and shafts [COR/528, p.4]. Rock fissures would be pressure grouted to inhibit water flow into, or out of, the DWR. The NRVB is designed by Nirex to achieve long term maintenance of both a high alkalinity (pH) in the groundwater chemistry and a high active-surface-area for sorption of radionuclides, together with relatively high permeability and porosity for homogeneous performance and to permit gas escape. Thus the effects of leaching of reactive components by groundwater flow and reactions with groundwater constituents are important to DWR performance.

6C.8 Nirex seeks to maintain the NRVB porewater at a pH value above 10 to achieve extremely low solubilities of several important radioelements, such as plutonium, in the conditions of the DWR which Nirex believes are chemically reducing ("low Eh"). Calcium hydroxide in the NRVB is calculated by Nirex to maintain the required pH conditions for many millions of years and conservatively for one million years [COR/522/Vol.3, sub-section 2.3, p.2.12]. During this period the chemical barrier is estimated to contain 99% of the 1% of the radioactive waste inventory not contained by the physical barrier [NRX/15/43/Fig.5.1].

6C.9 Experiments suggest to Nirex that the NRVB has high sorption capacity due to its favourable pore surface area. Chemical containment of some radionuclides by reduction of solubility and by sorption is calculated by Nirex as being good [eg ^{239}Pu - NRX/15/43/Figs.5.2]. On the other hand, ^{36}Cl, ^{129}I are considered by Nirex to be highly soluble and not subject to a high degree of sorption in the DWR near-field and ^{238}U half life is very long at some 4,500 million years so raising uncertainties. It is these 3 radionuclides, the last of which is particularly active, which Nirex calculates are likely to be released, despite the engineered physical & chemical containment, in quantities that result in significant contributions to the peak risk either from natural discharges or from well abstraction.

6C.10 Nirex thus needs the natural barrier afforded by the BVG rocks in the PRZ as well as the engineered containment in order to ensure a very low fractional, and radiologically insignificant, release of most of the surviving radionuclides. Then the most significant component of the residual risk is from the small number of longest-lived radionuclides as they find their way through the geosphere into the biosphere and eventually enter the food chain.

6C.11 Groundwater flow models predict extended timescales for groundwater to return to the surface in the sediments below the Irish Sea, or to a terrestrial environment if climate change has caused a lowering of the sea level [COR/522/Vol.3, Sub-section 9.1(d)-(h), pp.9.1-9.2]. Nirex estimates that radionuclides would be considerably diluted and dispersed by the groundwater flow and geosphere spreading [eg idem, Sub-section 2.3, p.2.12] and,

perhaps, further diluted by streams, lakes or the sea [idem, Sub-section 9.1(f)-(g), p.9.2]. They would also be subject to sorption and rock matrix diffusion in the geosphere. Low flows of groundwater are necessary through the DWR so that the physical and chemical barriers can operate to retain short-lived and most long-lived radioactivity, yet high dilution is required in the overlying rocks of those radionuclides that escape into the geosphere in order to limit concentrations reaching the surface and so meet regulatory requirements. The groundwater pathway is thus central to the DWR system and requires to be well understood.

6C.12 Nirex calculates the greatest risk from gas migration to arise from the incorporation of ^{14}C from the disposal inventory in methane from microbiological degradation of wastes in the DWR and subsequent entry of the methane into the food chain [COR/509, Section 4.1, p.20]. After extensive local investigations on mineral resources [NRX/15/2, Sub-section 3.1, pp.9-12], and on the basis of the scenario of borehole drilling at some time in the future when records of the DWR no longer exist [COR/501, paras. 5.6.11 to 5.6.14], risks from inadvertent human intrusion are considered by Nirex to be low.

Main Components of Programmes to the Time of the Inquiry

6C.13 In 1989 preliminary drilling investigations were commenced at Dounreay [COR/506] and Sellafield but from 1991 efforts of the Nirex Science Programme have been concentrated at Sellafield alone. The programme has obtained basic geological, hydrogeological and hydrochemical data on the Sellafield area from surface-based and laboratory studies as part of Nirex's site characterisation and safety assessment research programmes (NSARP) [eg COR/500 series]. It will also assist in locating the RCF development, establishing baseline conditions and monitoring perturbation effects [paras.2B.5 & 6 above].

6C.14 At the time of the 1989 decision to focus attention on Dounreay and Sellafield there was confidence that a limited drilling and testing programme, supported by geophysical work, would be sufficient before a repository planning application could be made, based on a preliminary safety case. After the first few drill-holes and 2-D geophysical surveys had been completed, Nirex considered there was already sufficient information to make a preliminary safety assessment but anticipated that its continued geological investigations would involve approximately 20 deep boreholes (up to 2,000 metres deep) plus shallow groundwater investigation holes, geotechnical boreholes and a 3-D seismic survey [NRX/12/2, paras.4,6,7]. A PCPA was voluntarily submitted to HMIP in 1992 for a DWR in the current PRZ [COR/120, para.3.1].

6C.15 The scope of investigations since then has however been much more extensive than that anticipated earlier. Geological, hydrogeological and hydrochemical results are summarised in COR/517 (1993), COR/518 (1995), COR/525 and in NRX/14/13/Tables A.1-13. The investigations have included geophysical surveys, regional surveys, deep boreholes, core description and characterisation, borehole geophysics, hydrogeological testing, geochemistry studies, groundwater pressure monitoring, acoustic emission monitoring, earthquake, fracture and geotechnical studies and interpretation and modelling [NRX/14/13/Appendix 1].

6C.16 During and since the compilation of the preliminary PCPA [COR/522], for which COR/517 (1993) was the starting point [COR/522, Vol.I, Preface], further information

resulting in revisions of the geological interpretation of the PRZ has been acquired in the form of modelling studies, geochemical and other data from boreholes including from testing programmes, 2-D PRZ surveys, regional surface mapping and hydrogeological studies of the BVG, seismic tomography and vertical profiling.

6C.17 Site Characterisation. The main effort in the site characterisation programme has been directed towards achieving an understanding of groundwater flows and conditions in the fractured rocks essential to support a PCSA/PSA. The establishment of baseline conditions prior to development of the RCF is a necessary element of this work. Geological and hydrogeological surveys have been made using a range of surface based techniques within an area of about 60 km by 65 km centred on Sellafield [NRX/14/12/Fig.4.1]. The investigations have comprised studies at regional (about 4,000 sq.km), district (about 600 sq.km) and Site (about 50 sq.km) scales. Observations have been ground-based and made from the air, on and off-shore.

6C.18 Surface and airborne geophysical surveys have been extensive using conventional and new techniques including a 3-D seismic reflection trial over the PRZ to achieve detailed interpretation of the deep geological structure [NRX/14/13/Table A.1]. Deep drilling has been carried out in 22 locations, 12 of which are in the PRZ, to obtain mostly NE/SW and NW/SE cross sectional geological and hydrogeological data [NRX/14/12/Fig.4.2]. Rock core samples have been analysed to determine rock types and their properties and cross hole seismic tomography undertaken [NRX/14/13/Table A.6]. Hydrogeological testing has been undertaken to gain data on groundwater pressures and hydraulic conductivity of the rock including testing of fracture networks [idem/Table A.7 & 8, COR/517, COR/518 & COR/518A].

6C.19 Regional surveys have included studies of the catchments of the Rivers Calder and Bleng extending to old mineworkings [COR/521/Figs.3.6 & 4.12]. Watercourses have been monitored and data collated from many old boreholes [NRX/14/13/Table A.2; NRX/5/1] and from information on water abstractions [COR/521, p.4-14] and water resource investigations over several years including aquifer pumping tests [COR/501, paras. 4.4.1-4.4.5]. The NRA have also supplied information on the quality of shallow groundwaters at a number of observation boreholes (all less than 150 metres depth) and a spring in the vicinity of the RCF [NRX/5/2]. Data on deeper groundwaters (200-1600 metres) have come from the Nirex drilling programme [COR/101].

6C.20 Groundwater samples have been comprehensively analysed for their chemistry [NRX/14/13/Appendix 1, Section A.8.1 & Table A.9]. Of particular note are the isotope and inert gas studies, relevant to estimations of the residence time or 'age' of the groundwater [NRX/17/1 (extract from COR/525), 5.2], and the reduction-oxidation potential ('Eh' or 'redox' potential) of the groundwater, relevant for its control over chemical reactions within the water system and its effects on sorption.

6C.21 The presence of drilling fluids in borehole water samples inhibits reliable determination of the Eh in the laboratory although the use of chemical tracers in the drilling fluids has allowed some correction to be made for contamination. Noble gases (neon, argon, krypton & xenon), indicating the climatic and/or altitude effects at the time of recharge, have been sampled, measured and plotted [COR/518, Drgs.010180-010195]. Helium (^{4}He)

abundances, produced in the rocks through the radioactive decay of naturally occurring uranium and thorium minerals, have been determined for borehole water samples [COR/518, drgs.010180-010191; NRX/17/1, paras 5.7 & 5.10]. Water salinity and density measurement has been carried out in order to identify and characterise the Saline Transition Zone (STZ) in the Sellafield area and assess its implications for groundwater flow.

6C.22 Safety Assessment Research work has included the development of NRVB [COR/529], preliminary design of DWR storage vaults and packaging [idem], modelling [COR/528, COR/529 & COR/522] and elements of the preliminary PCSA, "Nirex 95" [COR/522 (1995)]. These studies involve prediction of climate states, landform evolution, radionuclide transport, uptake by plants, identification of local communities and critical groups and a wide range of models [COR/526 (1994) & COR/527 (1994)].

6C.23 Conceptual and numerical models have been extensively used in Nirex's evaluation of post-closure safety performance (see Chapter 6D). This has involved application to biosphere assessment, chemical processes, geological structure and hydrogeology facilitating the preliminary analysis of the groundwater pathway for a DWR at Sellafield [COR/522]. Considerable quantities of field and laboratory monitoring and test data are required in order to develop models and validation of the models requires additional independent field and experimental data against which model predictions can be systematically compared.

6C.24 Research on radionuclide transport includes investigation into radiolytic reactions due to irradiation of water [COR/528, p.12]; slow recrystallisation and other ageing processes affecting the retardation or immobilising performance of NRVB [COR/528, s.3.2.2(b) & COR/529, p.19]; solubility and reactions of radioelements at high alkalinity [COR/529, s.3.2]; the process of colloid formation and stability and their effects [COR/528, s.3.2.3]; and effects of gas generation and migration of ^{14}C in methane and of gas-water interactions [idem & COR/509, s.3.3, p.16].

6C.25 Biosphere Research databases are large and the existence of well-established values for many parameters means that fixed parameters have to date been used in the biosphere part of PCPA calculations rather than sampling from Probability Density (or Distribution) Functions (PDFs) mentioned further below [COR/605, s.9.2], however, work is progressing to refine and validate these modelling inputs.

6C.26 Local earthquake data have been intensively researched and documented by Nirex from historical records together with data from studies of mineralogy, stratigraphy and structural geology. A continuous flow of new data is coming from Nirex's ongoing instrumental monitoring; from the network of seismographs in Britain and NW Europe; and from the BGS Cumbrian Microseismic Network capable of recording very small events within a radius of about 60 km of Sellafield [NRX/14/13, Appendix 1, s.A.11].

6C.27 Future climate states and land form evolution studies [COR/527, s.2 & 3] have resulted in the formulation of 4 representative conditions for the purposes of the preliminary PCPA involving either terrestrial or marine discharge from the DWR over a period of 10^8 years as sea levels change [COR/522, Vol.3, s.6.36. & Figs. 6.6-6.18]. These studies cover such effects as glaciation and global warming and the predicted consequences for changes in topography, climate, and patterns of human and animal habitability and alternative scenarios

are being worked up [COR/527, p.23]. A fifth (Mediterranean) state is predicted as possible in the event of global warming. Of particular note is the predicted scenario where Sellafield is occupied by a self-sufficient subsistence community under Boreal and Temperate conditions [idem, s.5].

International Co-operation

6C.28 Nirex plays a leading part in international research into aspects of radioactive waste disposal of which climate change is an example [COR/527, Box 6]. The work falls into 2 broad categories: firstly, practical investigations, mainly underground, predominantly in generic rock laboratories or mine-like excavations, with development of logging, sampling, in situ testing together with associated mathematical modelling; and, secondly, laboratory based and surface experimental work and testing, much of it related to fundamental chemistry, geochemistry and hydrochemistry.

6C.29 Nirex is a participant and financial partner in several of the principal international underground research facilities. It participated in the 13 year Stripa Project in Sweden in which useful experiments were performed in a disused iron ore mine to develop techniques for investigating deep crystalline rock and to study engineering means of enhancing the post-closure safety of deep repositories. The principal achievements at Stripa have been to provide experience for new methods, characterisation strategies, modelling and data on rock properties that could be applied to further rock laboratory work [FOE/6/15, Ps.29 last para.& GNP/4/10, s.3.1].

6C.30 It is closely involved in the ongoing Äspö Hard Rock Laboratory, Sweden, and in the underground rock laboratories (URL) at Grimsel, Switzerland and Lac du Bonnet, Canada, all in saturated fractured granites. Experiments at Äspö include comparison of rock disturbance produced by tunnel boring with that by drilling and blasting; characterisation of the zone of excavation disturbance (ZEDEX); performing multiple well tracer tests (MWT); and investigating the effect of air on the geochemistry of the surrounding rock [COR/605, s.4.3.1-4.3.4].

6C.31 International projects promoted by the EU include a general programme on migration of radionuclides through the geosphere (MIRAGE); specific research on basic validation of geochemical codes (CHEMVAL) and on colloids and complexes (CoCo); a project on gas generation and migration from underground storage facilities (PEGASUS) [COR/605, s.4.2.3 & COR/529, pp.62, 64 & 66]. DECOVALEX is an important collaborative project to develop coupled thermo-hydromechanical (THM) models [COR/605, s.8.2.5].

6C.32 A number of international collaborative studies have been funded by Nirex and their Swiss and Swedish counterparts (Nagra & SKB) on natural analogues, that is to say occurrences of materials or processes which resemble those expected in a proposed geological waste repository and which can be studied to give useful indications of the possible properties and behaviour of parts of the disposal system over long timescales. These include, for example the Oklo uranium deposit of Gabon [mentioned in 6A.46 above], and the highly alkaline groundwater system at Maqarin in Jordan which is in near equilibrium with naturally occurring cementitious minerals at a Ph of about 12.5, comparable to that planned for the

Sellafield repository [COR/529, pp.62 & 65]. HMIP has helped with some funding of international programmes [GOV/630].

Data Availability & Elicitation

6C.33 Data elicitation is achieved by the formal application of expert judgement to arrive at quantitative input parameters for use in repository performance assessments and in preliminary numerical models [COR/529, section 7]. Safety assessment parameters whose values are uncertain are expressed as PDFs rather than individual fixed values. The PDFs are then sampled randomly in, for example, the MASCOT computer analysis.

6C.34 Some parameters relating to the physical properties of the geology are derived from measurements & others by elicitation [COR/522, v.1 tables 5.1-5.19]. There are up to 14 parameters expressed as PDFs for each of the geological units used in the Nirex 95 groundwater flow modelling. Fracture orientation was characterised by field data and elicitation of PDFs was used for parameters such as fracture spacing, fracture length and channelling fraction, taking account of borehole observations and outcrop studies. However, fracture transmissivities were derived by requiring models to be consistent with field (environmental pressure) data [idem, v.1, p.5.4, 1st & 2nd paras.].

6C.35 In the near-field, formal elicitation was undertaken to derive PDFs for parameters used in source term calculations such as solubility limit (in the repository pore water) and sorption distribution ratio (in relation to repository materials) of several elements [COR/529, s.3.3 & s.7.2], including the solubility of key radionuclides [idem, s.3.2.1 & Box 13].

Transparency, Quality & Peer Review

6C.36 Nirex has published over 500 scientific reports and papers and has made many more available for reference after application of its quality assurance process [eg those listed in NRX/12/7]. Many of the reports which Nirex has submitted to the inquiry [Appendix 3 - COR/500 series; FOE/5/19] were not published until 1995.

6C.37 Nirex has used a selected group of experts as a Review Panel to periodically review selected parts of their work prior to publication, advise on strategy and approach for geological characterisation of Sellafield as an input to the PCSA and to provide ad hoc specialist advice [COR/516, para.1.2]. The RWMAC has maintained surveillance of progress of DWR development, as part of its terms of reference to advise the Secretaries of State [GOV/407/Annex 1], issuing a series of Annual and Special Reports [GOV/401-415]. The Royal Society responded to Nirex's invitation in 1993 to review the scientific aspects of assessing the likely long-term performance of a DWR, focusing upon work at Sellafield, in its 1994 Report [COR/605].

6C.38 The **RWMAC** recommended independent peer review of the safety case as a standard practice in 1989 [GOV/402, para. 2.26] and has maintained that view [GOV/407, para 4.22]. It regards the field work and interpretation of site data being carried out by Nirex and its contractors as being of the highest quality [GOV/407, para.4.6]. The RWMAC (May) 1995 Annual Report suggests that attention be paid, inter alia, to the time necessary for establishment of base hydrogeological conditions, the monitoring of microseismic activity,

natural gases, and thermal regime [idem, para.4.12]. It emphasises issues highlighted by the Royal Society which the RWMAC have also raised such as the complexity of the hydrogeological conditions at Sellafield, the limitations of the groundwater modelling programme, the important role of groundwater geochemistry, gas generation and the significance of chemical containment within the multi-barrier approach [idem, para.4.22]. These matters were aired in the RWMAC 1994 Report [GOV/406, Chapter 3] where it noted indications that upward groundwater flow takes place in the PRZ and concluded that inconsistencies between computer-based modelling and observed groundwater flow systems need removal. Also, it considered that a very significant amount of work needed to be done before the state of knowledge of the Sellafield area could be sufficient to provide a confident basis for a PCSA [idem, paras.3.34 - 3.36].

6C.39 In its 1994 Report [COR/605], The Royal Society identified 3 concurrent operations in preparing for the DWR at Sellafield, namely:

a. characterising the site to establish relevant geological, geochemical and hydrogeological features;

b. developing appropriate engineering designs for the DWR;

c. undertaking studies to assess potential leakage of radionuclides from the DWR to the surface [idem, s.1.2, p.2].

6C.40 It pointed to the need for quantification of uncertainties and for elicitation. Key scientific issues it identified were groundwater flow, gas generation and migration, long-term evolution of geosphere and biosphere conditions including climate change, and chemical containment [idem, pp.3-5].

6C.41 The Royal Society expressed the widely held view that, although Nirex participates in underground research in other countries, none of the sites is very similar in geological setting to Sellafield [COR/605, s.4.4].

6C.42 Observing that much background information was becoming available, the Royal Society study group commented that Nirex had not yet published details of the assumptions, site specific models and input data used in the Sellafield PCPAs, nor of the actual results and sensitivity analyses. In consequence it was unable to judge the adequacy of Nirex's synthesis and use of research and site characterisation findings, or to appreciate fully the importance of any scientific issue to the PCPA. [COR/605, s.5.9].

6C.43 On elicitation, the Royal Society noted that because the number of sorption distribution ratio (Rd) values required is large (at least one for each radionuclide and geological unit, making over 100 in all), Nirex have tended to elicit PDFs of Rd values only for some radionuclides and units, and derive the remainder directly by judgements from one or two scientists [COR/605, s.8.4.1].

6C.44 It foresaw the possibility of programme set back if research and assessment at Sellafield does not provide for early exposure to peer review.

6C.45 In relation to technical and scientific achievement, the Royal Society observed that contamination had been reduced to less than 1% in a significant, and increasing, proportion of borehole water samples, which demonstrated the capability of Nirex to obtain high quality samples from existing boreholes [COR/605, p.105]. However, the Report noted that there were no adequate models for 2-phase gas/water movement in fractured rock; no definition of scenarios for future evolution of conditions in and around the DWR; and a lack of truly quantitative predictions of the behaviour of chemical containment [idem, pp.3-5]. It points out that much of the science is new [idem, s.1.6, p.6].

6C.46 The Royal Society comments on solubility and reactions at high Ph that "the design of the near-field, with its high Ph and complex metastable mineralogy poses an extremely difficult problem for the chemist. The thermodynamic properties of many of the phases present are not well known and little information is available for surface properties or reaction kinetics. This means that an experimental approach must be adopted and the number of experiments needed to describe behaviour adequately will be large. Many such experiments have already been undertaken by Nirex and other groups internationally, and these programmes are on-going" [COR/605, p.121, foot of left column].

6C.47 The Royal Society study group noted that the mainland of the UK is not close to an active crustal plate boundary and the historical record is very short in relation to the PCSA timescale for a DWR. It observed that, although only moderate to small earthquakes have been recorded over the last few hundred years, this may not always be the case [COR/605, para.10.1.2].

6C.48 In 1994, the Nirex Review Panel was involved with technical reviews and workshops on geochemistry, hydrogeology conceptual model development, fracture characterisation, validation strategy, RCF structural geology, RCF3 pump test design and assessment modelling [COR/516/Appendix B]. This was supported by visits to Sellafield and site facilities [idem/Appendix C]. It regards much of Nirex's work as being at the leading edge of science [idem/Appendix C, para.4 & Appendix D, para.2.3]. The Panel recommended that the Nirex strategic programme and the results of the scientific work should be subjected to peer review [idem/Appendix D, paras.2.2, 3.3, 5.4 & 5.9]. Ad hoc advice was given through an open approach between Nirex staff and Panel members [idem, para.2.10]. Key issues were identified as being future climate change and changes to the geosphere with seismic risks and earthquakes being of importance though not a major issue regarding safety performance [idem, paras.3.5-3.7].

6C.49 The Panel identified a number of activities which it considered should be included within the forward programme of work. These included correlation between flowing fractures and mineralisation episodes; incorporation of key aspects of structural geology into hydrogeological studies; relating behaviour of smaller scale features into the large scale geological structure; Quaternary, earthquake and seismic studies; improvement in hydrogeological modelling to accurately reproduce the observed salinity distribution and incorporate temperature effects, and scaling effects related to the conductivity of the sandstones and the BVG [COR/516/Appendix D, paras.5.1-5.11]. For 1995, the Panel sought specialist expertise in modelling, early information on the results of studies on ^{36}Cl, thermodynamic geochemistry and Quaternary strategy, and improved communication with the wider scientific community.

Current Understanding of Scientific and Technical Issues

6C.50 Areas of uncertainty still to be addressed with the help of the RCF are groundwater flow & radionuclide transport; natural & induced changes to the geological barrier; and DWR design & construction. Key uncertainties are BVG fracture network flows, the properties of flow channels, rock matrix diffusion, colloid transport & gas migration; and the validation of the stability of the hydrogeological system over extended timescales, plus the effects of both excavation and chemical disturbance. Also identification of geological and hydrogeological features would enable the depth, location, layout and orientation of the DWR vaults to be refined. Sealing experiments in the RCF would assist in satisfying post-closure safety requirements for the DWR and perturbation effects require to be assessed.

6C.51 Groundwater monitoring has yielded evidence of gravitational, barometric, seasonal and synoptic effects and to support climatic and tectonic effects in the longer term [NRX/14/13/Appendix 2, pp.B5 & B6].

6C.52 The STZ represents the boundary between the fresh waters of the Coastal Plain Regime, present in the shallower strata, and either, the deeper saline waters of the Hills & Basement Regime inland, or the hypersaline (brine) groundwaters of the Irish Sea Regime present below the sea and at depth below the coastal plain [COR/507, S.2, Figs.1 & 2]. Since the PRZ is located in the Hills & Basement zone the nature of the contact between the freshwater and the saline waters in that area is of most interest. It is common ground that there are relatively rapid flows in the Sherwood Sandstones.

6C.53 Nirex's most recent flow zone characterisation of the RCF area concludes [COR/523, s.7] that flow zones are not associated with a single, consistent geological signature in the boreholes studied, the strongest observations being that flow zones in the Sherwood Sandstone Group are largely matrix flow with some contribution from bedding-plane fractures. In the Brockram flow zones are associated with either matrix or fracture flow, and in the BVG they are discontinuity dominated, mostly associated with "vuggy veins" or part mineralised fractures. Overall there is a wide variation of orientations observed with a SW dipping tendency in the Sherwood Sandstones and a NE dipping bias in the BVG.

6C.54 Flow zones tend to be associated with distinctive discontinuity characteristics compared with those above and below. In the BVG generally, 20% of the flow zones seem to occur within fault rock and 47% within 5 m of a fault [idem, s.4.18]. However, in deviated boreholes (RCF2 & RCM3) it was found that a far greater (90%) association of flow zones to faults exist in the BVG compared with the 9 boreholes as a whole [idem, s.4.19]. In the BVG fracture flow is thus dominant but a broad relationship between flow zones and ME6 mineralisation is apparent. However, not all mineralisation is associated with flow. Although flow zones are associated with proximity to faults, there is a more variable association between faults and ME6 mineralisation leading to a clustering of mineralisation. A strong relationship was found between flow zones and ME9 late calcite mineralisation, post-dating all observed fault structures observed in borehole cores. The calcite morphology seems to be related to salinity of groundwater. These features suggest to Nirex a conceptual model in which flow in the BVG is related more to the larger-scale distribution of ME6 within the rock mass, rather than type, orientation or intensity of individual candidate flow features.

6C.55 Of the 42% of flowing features in the BVG, 74% are within the Fleming Hall Formation, an association most marked in Borehole RCF3 [idem, para.5.6]. However, flowing zones in Boreholes RCM1 and RCM2 were found predominantly in the Brown Bank Formation in Borehole 2, notably concentrated in the Broom Farm Formation [see COR/518, Vol.2, Drgs.010147-9, left & central columns]. As the relationships are not ubiquitous, Nirex considers it likely that partial correlations exist between many factors rather than that there are any full and consistent correlations. Nirex also considers that the apparent linear relationship between flow zone transmissivities and measured depth requires further investigation.

6C.56 The deep groundwaters in the PRZ appear to contain no significant tritium (hydrogen isotope ^{3}H) and therefore cannot contain any modern (post 1953) water [NRX/17/1, 5.4]. Interpretation of the content of deuterium (hydrogen isotope ^{2}H) and heavy oxygen (^{18}O) is in contention, as is the data on noble gases, ^{36}Cl and ^{4}He, but it is common ground that all the groundwater in the strata relevant to the Sellafield project, in each of the three groundwater regimes, had a meteoric origin because it originally fell as rain or snow. However the stable isotope ratios for groundwater in the deep BVG of the PRZ are lighter than present day rainfall and lighter than water in the overlying sandstones which could indicate a cold temperature of precipitation at the time the water entered ('recharged') the ground. On the other hand, the highly saline groundwaters of the Irish Sea Basin regime have relatively heavy stable isotope signatures, in some instances heavier than modern meteoric groundwater. It is generally accepted that the basinal brine component must be of great age, and probably dates from well prior to the Pleistocene glacial epoch. [NRX/17/1, para.5.8]

6C.57 It is common ground that analyses of borehole water samples are subject to significant uncertainty due to contamination by drilling fluids and other sampling difficulties. However, the samples with least contamination appear to contain no modern carbon, ^{14}C, other than can be accounted for by traces of drilling fluid. If uncontaminated samples can be shown to contain no ^{14}C then the groundwater in the PRZ basement must more than 30,000 years old [NRX/17/1, 5.5].

6C.58 **Potential of Natural Geosphere Barrier.** It is common ground that the host rock is complex.

6C.59 Nirex has been carrying out a range of experimentation both at standard laboratory temperatures and at the maximum anticipated repository temperature of 80°C, into changes in groundwater chemistry, radionuclide solubility and sorption, degradation of organic wastes and metal corrosion. Microbes are expected to survive the period of elevated temperatures and may continue to break down the wastes. Provision for the dispersal of gas arising from accelerated corrosion reactions may need to be considered in more detail [COR/528, p.8 Box B]. However, leaving aside local variations and solubility and reactivity of radionuclides where there is some uncertainty, the general chemical composition and patterns of groundwater are now understood [COR/529] subject to sampling difficulties already mentioned above. This area of experimentation is acknowledged to be difficult and is carried out mainly in the laboratory simulating predicted DWR conditions such as ageing, extrapolated timescales and interpolating results from crushed rock to represent true rock surfaces. Similarly, uncertainties exist in scaling up laboratory results to determine diffusion

coefficients of dissolved radionuclides and the accessible porosity of PRZ rocks for field conditions.

6C.60 **Chemical and Engineered Barriers.** [COR/528 & 529] Interactions of the wastes with the chemical barrier of the NRVB would be complex but, once the integrity of the containers is breached, the alkaline conditions of the NRVB should dominate. Soluble complexing agents produced by degradation of organic materials in the waste can enhance the solubility and reduce sorption of some radionuclides, notably plutonium. The prospective repository waste contains paper, wood and similar cellulosic matter, plus plastics, rubber, resins and other organic wastes which would produce organic degradation products. Such breakdown would also liberate large volumes of gas. A significant programme of research has been started, particularly into cellulose degradation and its effects, and into plutonium solubility and complexation with organic compounds [COR/529, s.4.2.1]. Nirex have been concentrating on what it regards as key compounds and fractions and expects future research to focus on achieving a better understanding of the underlying mechanisms [idem, p.76, (iii)]. HMIP has commissioned its own research into the presence of organic acids in natural groundwaters and the effect of organic compounds in the transport of metals [HMP/1/2]. The physical and chemical characteristics of NRVB require more experimentation. On chemical behaviour, the interrelationship between solubility and sorption behaviour of some of the residual radionuclides and Eh/pH values [COR/529, p.5 Box 2 in brief; COR/528, sections 3.1.1-3.1.3 in more detail] is a novel area with few data previously available at such high pH values since these are very rarely encountered in the natural environment [COR/605, s.7.2].

6C.61 Sealing and grouting experiments have been undertaken as collaborative international URL projects in Canada [FOE/6/29 & FOE/6/30] and in Sweden (Stripa) [FOE/7/20]. However, it is necessary to verify results from generic work in the intended host rocks under conditions comparable with that of the DWR. It is accepted that requirements for repository sealing go beyond standard civil engineering and mining practice. Possible deterioration of seals and sealing materials has not yet been addressed.

6C.62 **Gas Generation and Migration.** Corrosion and decomposition of the waste and containers in the repository will generate substantial quantities of gas, equivalent to many times the volume of the repository. This will be principally hydrogen, carbon dioxide, methane and perhaps hydrogen sulphide, a very small proportion of which is radioactive. [COR/509, section 2] The gas must be released, otherwise the resulting pressure build-up could generate cracks in the repository and surrounding rock which would provide additional groundwater flowpaths. Even in the absence of rock fracturing, gas pressures might speed the movement of contaminated groundwater from the repository. NRVB has been designed to permit the escape of gas and there is an engineered gas vent in some designs of waste container. The surrounding rocks need to be sufficiently gas-permeable to permit its controlled escape but not such that gas could reach the surface in flammable or radiologically hazardous concentrations.

6C.63 **Potential Excavation Disturbance.** A knowledge of the geotechnical properties of the rocks and superficial strata is necessary to assess the ease or difficulty of construction of the shafts and galleries of the RCF and potential repository, their optimum orientation and layout for stability and the effects on groundwater flow and geochemistry. Nirex's

geotechnical studies to date [NRX/14/13, Table A.13], include core testing supplemented by geophysical logging [idem, Table A.4, p.A.21 & COR/518, v.2, drgs 010156 to 010177]. In addition to measurements specific to the Sellafield area, for example measurement of in situ rock stresses, Nirex has made comparison with excavation disturbance measured in mined openings elsewhere, as at the Canadian URL and Stripa [eg. FOE/6/29-31].

6C.64 Uncertainty remains as to scaling up from borehole samples to full size repository vaults and whether the BVG will behave in a similar manner to rocks from other sites.

6C.65 **Physical and Chemical Properties of Individual Radionuclides.** Colloids are taken, in the context of the RCF and DWR, to be mostly extremely fine particles, organic or inorganic, dispersed in aqueous fluid (repository porewater or groundwater) that cannot readily be filtered out like ordinary suspensions [see COR/529, p.39 Box 19]. It is possible that radioactive materials in the waste may form colloidal particles or be sorbed onto other colloidal material and then be transported away by flowing water, particularly by fissure flow in the BVG. Field experimentation is prone to difficulties of achieving uncontaminated groundwater sampling at depth [GOV/630, p.247 1st para.] including during RCF drilling.

6C.66 **Climate & Tectonics.** Nirex's main approach has been of studying past geological and climatic events as a guide to future evolution to investigate whether such effects could adversely affect the DWR over the required period of limitation of risk. Nirex continue to investigate the shallower (Quaternary) deposits for evidence of geologically recent earth movements using pits, boreholes and geophysical methods [NRX/14/12, Table 6.3]. A few possible sites in the onshore district of faults that cut both the bedrock and the Quaternary deposits have been identified for further study.

[Reporting of cases begins on next page]

The Cases of the Participants

6C.67 In its draft guidance, HMIP sets out technical information supply requirements [HMP/1/1, Chapters 7 & 8]. Of particular note are the contingency for an adverse interpretation of an element of the disposal system taken in isolation [idem, para.7.3]; the need for adequate characterisation, understanding and analytical capability of the geological environment, including the potential for seismic events [idem, para.7.6]; the requirement for the limitation of migration of radionuclides by the physico-chemical and geochemical characteristics of the geological environment combined with construction materials of the facility [idem, para.7.7]; the separation from geological media of less suitable characteristics [idem, para.7.11]; implementation of methods of construction of a DWR to avoid undue disturbance of the geological environment and containment properties of the host rock [idem, para.7.12]; demonstration that a criticality incident is not a significant concern [idem, para.7.18]; undertaking monitoring during the investigation and pre-construction phases, without compromising the long term safety of the facility, to provide a baseline for monitoring in later phases - the developer should show that the changes in and evolution of the monitored parameters are consistent with the safety case [idem, paras.7.21-23].

6C.68 In supply of information, treatment of uncertainty would entail maintenance of a detailed audit trail and modelling studies should include continuing peer review [idem, paras.8.17 & 8.19].

6C.69 Nirex would decide when it had collected sufficient data to support the development of a safety case [COR/120, para.4.4]. However the quality assurance regime should meet a national or international quality assurance standard and enable data to be traceable back to source [idem, para.4.7]. HMIP confirms the value of experimental studies in URLs in improving understanding and provision of geotechnical and engineering data for DWR design [idem,para.4.11].

6C.70 HMIP says that Nirex would have to provide a scientifically and technically robust interpretation of the geological and hydrogeological conditions at the site taking account of uncertainties arising from an incomplete knowledge of the full system and its future evolution [idem, para.4.10]. The construction of the RCF would alter the hydrogeological and hydrochemical regime of the site so these effects and consequences must be demonstrated prior to the construction of an RCF [COR/120, paras.4.10, 4.16 & 5.5].

6C.71 HMIP regards the PRZ as having a complex geological structure and the PCSA as relying heavily upon geological and hydrogeological data [idem, para.4.8] and a sound understanding of its behaviour, especially on a regional scale [idem, para.4.9]. This extends from the recharge of the groundwater which passes through the PRZ to its discharge point downstream, likely to be measured in some tens of kilometres from the DWR. HMIP sees a need to reduce uncertainties about the physical and chemical processes which might influence the migration of radionuclides through the geosphere. It has in mind examination of fracture networks, rock permeability and fracture conductivity; experiments on excavation damage, chemical tracer tests, gas migration and colloidal transport [COR/120, para.4.13], on which HMIP commissioned its own research [listed in HMP/1/2]; and gaining a better understanding of the capabilities and limitations of models [idem, para.4.15]. Oxides or metal particles may be transported as well as colloids.

6C.72 Nirex considers that its scientific and technical programmes have yielded sufficient quality and quantity of material through research and investigation to demonstrate that the PRZ holds good promise to host a DWR and has reached the point where an RCF is necessary. It regards comparisons made by FOE and Greenpeace with practices in the oil industry in terms of timescale and approach as misplaced albeit relevant technical experience and expertise is of course used. Nirex's investigative programme is longer in duration to those cited by Greenpeace for the oil industry. It refutes the claim by FOE that the scientific information gained so far, and referred to below, is not "best possible" citing in support the praise given by RWMAC, the Royal Society and from some witnesses for the objectors for the quality of information arising from the programme and the extensive experience of their main contractors. The Nirex 95 PCPA report [COR/522] and supporting documents address the issues raised by the Royal Society Report [COR/605]. Much new information has been brought forward since the publication of the report.

6C.73 International Co-operation. Although there is no substitute for actual testing in an RCF, Nirex regards the results of international research as considerably valuable in generic terms with the Swedish and Canadian rock laboratories having the greatest application to Sellafield. Because the RCF is intended to be site-specific and not a generic facility comparable with a URL there is not proposed to be international co-funding and setting of joint objectives in the project but the same international expertise will be used to devise the science programme.

6C.74 Data Availability & Elicitation. Nirex stresses the importance of a methodical, structured process within a meeting of a group of experts to arrive at a defensible output when dealing with uncertainties in field data and contrasts it with the erratic assessments frequently made by individuals. Formal elicitation has been used to derive data to cover the 21 elements considered to be of greatest interest to PCPAs performed to date [COR/529, p.69]. Within each 'element' there may be many PDFs requiring to be defined. It does not accept that a complete understanding of all processes is essential to assessing system performance but that uncertainty is either dealt with explicitly, within a range of models, or through the use of appropriate parameter distributions in a probabilistic assessment. More data would not necessarily improve modelled predictions in its view.

6C.75 Transparency, Quality & Peer Review. Nirex describes their science programme as being founded on the principles of having a knowledgeable and experienced management team and interdisciplinary teams of specialists; thorough quality assurance procedures; and independent peer review and challenge. Proper independent peer review of all work critical to radiological safety, as required by BS 5882, is carried out by Nirex staff, by contractors, by consultants not engaged on the programme, the Nirex Review Panel, and by publication of reports articles and conference papers. It invited the Royal Society to make its 1994 report. The quality of its work has been widely recognised, for example by the Royal Society [COR/605, Ss.1.9 & 6.8] and RWMAC [GOV/406,para.3.10 & GOV/407, para.4.6]. Nirex regards information made available to the scientific and local communities as being important in promoting public understanding and confidence but complementary to, and not part of, the peer review process required for a nuclear safety case to satisfy the regulators. Nevertheless, noting the Government's wish for transparency of decision making [GOV/208, para.110], a biennial Project Review would be produced in future [NRX/12/6];

and it has been decided to supplement this with daily or weekly releases of site investigation data.

6C.76 Groundwater. Nirex believes that a high level of understanding of the groundwater conditions at Sellafield has been achieved and the favourable prognosis of the site conditions it made in 1989 has been confirmed. It describes the amount of data obtained so far as vast and sees the question of sufficiency of information as being the essential difference between it and objectors.

6C.77 On groundwater monitoring, Nirex points to its own programme of boreholes plus 16 boreholes in the Triassic sandstones and superficial drift deposits with data from 1974 and at least 17 boreholes in the drift with more than 9 years of data. Some data is in excess of 20 years duration. It feels it will be able to distinguish RCF construction from other effects with confidence including using the information to test and develop models of the site and to interpret the properties of the PRZ within the context of regional groundwater flow and hydrochemical models from the database on undisturbed conditions [NRX/14/13/Appendix 2]. It believes that the borehole programme at Sellafield compares favourably with the larger schemes mentioned by FOE.

6C.78 A further 4 to 5 years of relatively stable or predictable environmental heads and geochemistry proposed by FOE is unrealistic and inappropriate in its view particularly bearing in mind that monitoring is continuing. Similarly, it refutes Cumbria and FOE suggestions that boreholes additional to those planned [NRX/14/12/Table 6.3] are required because confidence in the PCSA would not be enhanced. There is therefore no technical objective to increase them further. Observed settle-down effects in several boreholes up to October 1995 indicate that baseline conditions have been established [NRX/14/13/ Appendix 2, para.B2.16]. Nirex points out that RWMAC thought that 18 months was likely to be sufficient time [GOV/408, para.19, GOV/414, para.14] and its own independent expert concluded that a comprehensive baseline pressure head distribution had been obtained [NRX/14/3]. More 3-D seismic surveying may be carried out if the information is necessary and not obtainable from the RCF.

6C.79 It regards the chemical characteristics of the groundwater conditions as being sufficiently well defined and understood to facilitate monitoring and interpretation of RCF perturbation during construction, particularly bearing in mind that a further 2 years results would be available from October 1995 before RCF construction could begin. Information on geochemical conditions is "fit for the purpose" in Nirex's view although Eh and Ph cannot be definitively measured from the surface. Sampling has progressed as far as possible without an RCF and the data have been deemed to be of high quality by The Royal Society Study Group. It has not been necessary to modify the conceptual model of hydrochemical conditions in the light of new data. The BVG groundwater is considered by Nirex to be in a reducing state, buffered (controlled) by a combination of pyrite (FeS_2) and haematite (Fe_2O_3) and dissolved sulphate at a value of about -230mV [COR/525, paras. 6.7-6.9, p.33]. Pyrite remains stable under these conditions, as does haematite, but, unlike haematite, pyrite is likely to lose its stability under oxidising conditions [NRX/15/43/Fig.7.1]. It points out that it is the presence of a mineral that is important in establishing in situ geochemical equilibria and not the amount. Furthermore, redox conditions in the near-field would be controlled by the components of the engineered structure. Also, geochemical modelling has

shown that such conditions are not dependent on the redox condition of the inflowing groundwaters with redox potentials within the realistic range of +400 mV and -400 mV [NRX/15/10, p.19].

6C.80 Nirex identifies 3 regional regimes, namely the Hills and Basement, Coastal Plain and Irish Sea Basin Brines. It suggests a relatively simple pattern inland of the Irish Sea Basin Brines regime and claims that the Saline Transition Zone is relatively sharp, particularly in the PRZ where it is said to be within the lower permeability North Head Member of the St Bees Sandstone. It does not accept that upward flow can necessarily be inferred from the STZ when the PRZ STZ dataset is viewed in the context of the larger dataset and prevailing hydraulic conditions. Although salinity is a key indicator of the 3 different groundwater regimes, the regimes are not defined simply on the basis of salinity but with the support of a range of independent data sets.

6C.81 On an expanded site scale Nirex also recognises 3 layers in the groundwater system from monitoring environmental heads. It concludes that there is an upward though predominantly shallow coastward flow of freshwater in the SSG in and west of the PRZ; a zone in the upper part of the BVG, in the Brockram or the lower part of the SSG with little, if any, vertical gradient; and a deeper zone in the BVG with upward head gradients [NRX/14/12/Fig.6.8].

6C.82 Recharge conditions for BVG groundwaters in the PRZ were colder in Nirex's view than for the fresher waters in the sandstones, and this indicates recharge of the PRZ basement rocks under colder climatic conditions during the Pleistocene, sometime between 1.6 million and 10,000 years before the present, when the climate was predominantly glacial, periglacial or boreal. [NRX/17/1, para.5.3 & NRX/14/12/Table 6.2]. Whilst oxygen isotope ratios could be due to altitude differences, this would not explain the different ratios now recognised in different parts of the Triassic sandstones. This argument also applies to isotopically lighter groundwaters in the lower part of the Permo-Triassic sandstones west of the PRZ (at the base of the Coastal Plain flow regime) in Borehole 10A and perhaps also 11A [NRX/14/13/Fig.B.3.2] which are also interpreted as indicative of recharge more than 10,000 years ago. Groundwater studies of Triassic sandstone aquifers elsewhere in the UK show that lighter isotopic compositions can be specifically associated with the last glacial maximum advance about 18,000 years ago [NRX/17/1, para.5.9]. The noble gas ratios in the BVG of the PRZ are distinctly different from those in the overlying sandstones and support the interpretation of recharge in a glacial period.

6C.83 Nirex considers ^{36}Cl to be a useful indicator of solute residence times because the high salinity of the groundwater means that contamination is not a significant concern. Naturally occurring common chlorine (^{35}Cl) can be converted to ^{36}Cl by neutrons from the surrounding rocks. There is a consistent $^{36}Cl/Cl$ ratio of about 22-28 x 10^{-15} for the BVG water in Borehole 2 [COR/518, v.2, drg.010181], which is what would be expected for water in equilibrium with the *in situ* neutron flux in the BVG. To reach this equilibrium it is necessary for most of the chloride in the groundwater to have been resident in the BVG or host rock with similar high neutron flux for at least 1.5 million years [NRX/17/1, 5.6 & 5.11].

6C.84 By making assumptions, for example about the average abundance of uranium and thorium, rock porosity, and ignoring the possible migration of ^4He gas from deeper in the earth's crust, Nirex estimates that the water at great depth in Borehole 2 in the PRZ could have been resident for 1.3 million years and beyond the PRZ (in either hole 7A or 12A) for up to 1.6 million years [NRX/17/1, 5.7 & 5.10].

6C.85 Whilst it is possible that recharge may have taken place near ice sheet margins where meltwater under the ice may be forced under pressure into the underlying strata, it is only speculation that there was preferential and enhanced recharge of the BVG during glacial periods. The climate at the time of recharge did not have to be glacial, but merely colder than now, as was the case during most of the Pleistocene [see COR/527, p.22].

6C.86 Groundwater residence times have not been over-interpreted, but merely placed in context with each other to build confidence in overall conclusions despite uncertainties prevailing with any individual method. Greenpeace's suggestion that rates of sub-surface flows could be much more rapid in the future than any inferred today is again speculative. Furthermore, the contribution from joints far outweighs that from pores.

6C.87 Potential of Natural Geosphere Barrier. There is no evidence to suggest that the PRZ is located near an Ordovician caldera margin as suggested by FOE, and BVG deformation structures, although abundant, are generally healed and are not hydrogeologically significant. Particular complexity of the rock may add somewhat to the difficulties of characterisation but is being addressed thoroughly by focusing strongly on those features relevant to obtaining a sufficient understanding of the system and a capability to predict its behaviour. The state-of-the-art geostatical techniques using a stochastic description of the flow system built on a programme of some observations and experiments, are generally accepted as appropriate for evaluating flow and transport in heterogeneous systems. The degree of complexity at Sellafield is now sufficiently characterised, including Faults F1, F2, F3 and F202, to be likely to meet the regulatory safety requirements, as demonstrated by the preliminary PCPA [COR/522]. It is the safety assessment which is crucial to site acceptability, not geological or hydrogeological criteria which can be selectively identified and exaggerated. Nirex regards objectors' treatment of technical issues such as hydraulic conductivity of the BVG, interpretation of salinity profiles and patterns of groundwater flow as failing to appreciate this critical distinction.

6C.88 Based on results to date Nirex concludes that in the central part of the PRZ at least there is little connectivity between the BVG and the overlying sandstones and in the RCF South Shaft area hydraulic conductivity shows an apparent linear increase with depth. Head gradients at the site have been recognised for some time [COR/501, para.8.14.5] and have been examined in Nirex 95 [COR/522]. Lateral and upward components of flow are a natural part of the hydrological cycle and are only relevant when taken in the context of hydraulic conductivity in order to make estimates of groundwater flow. 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.

6C.89 When considering large-scale properties of rock, fractures are less significant in the case of a DWR than, say, for landfill sites with a liner. The treatment of hydraulic conductivity in the 2 types of installation is not comparable. For the DWR, fractures would

need to be well connected, with high hydraulic conductivity, to permit significant groundwater flow. Preliminary modelling of the results of the RCF3 Pump Test indicates a lower connectivity within the BVG than that predicted in Nirex 95 [COR/522], because it includes variation in fracture apertures within the Type II features not modelled in Nirex 95.

6C.90 Nirex regards criticisms of its geochemical modelling as being misplaced because the work was carried out some years ago [eg. FOE/8/51, abstract] and recent work is greatly improved in quality. For example, measured data specific to the host rocks are being used for PDFs and with solubility data. Furthermore, sorption is much less important than dilution and spreading effects. Validation of existing modelling work (see further Chapter 6D) is best treated by a programme of laboratory experiments and natural analogue studies integrated with in situ experimentation on, for example, colloid transport and alkaline plume/rock interactions.

6C.91 Chemical/Engineered Barriers. Nirex considers that it should be relatively easy to meet a shaft fill permeability criterion of $10^{-12}/m^2$ and to return the hydraulic conductivities of openings to values equal to or less than those of the rock [FOE/7/20, p.199 mid. para].

6C.92 Slow ageing processes will cause long term transformation of amorphous hydrosilicate matrix minerals into crystalline minerals with probably reduced sorption potential, although in the very long term permanent sorption by 'mineralisation' might immobilise much of the remaining inventory of some long lived radionuclides, allowing them to decay in situ and giving much greater retardation than currently modelled. Rates of chemical reactions at 80^0 C would be speeded up but not to the significant detriment of overall repository containment properties.

6C.93 Gas Migration. Nirex participates in international work on gas migration through rock and its effects [COR/605, 8.2.6] and has been carrying out its own experimental programme at Reskajeage Quarry in Cornwall. It calculates that the risk of release of radioactive gases into the biosphere, principally ^{14}C, is so small as to be of no concern.

6C.94 Simplified calculations on migration of ^{14}C in methane, which Nirex believe are conservative, indicate an equivalent to annual risks to an individual of about 10^{-7}. However, studies continue on the possible significance of gas-water interactions on radionuclide transport [COR/509, Sub-section 3.3, p.16] although Nirex claims that much of the required information is now available.

6C.95 Excavation Disturbance. Nirex considers it has been highly conservative in repository modelling by assuming that excavation disturbance could increase hydraulic conductivity parallel to the excavation walls by up to two orders of magnitude for a distance of up to twice the excavation diameter. The Canadian URL tunnel experiment [FOE/6/29, p.9], for example, showed that the increase in conductivity from excavation extended only 0.26 m into the rock wall [FOE/6/29, p.8]. Excavation for the RCF (Phase I) would adequately facilitate groundwater model validation of perturbation effects for the DWR in the light of experience in the ZEDEX project and contribute to the international DECOVALEX exercise. Nirex Report 560 [FOE/5/19] was simply a preliminary scoping study on RCF impacts. Furthermore, Nirex regards the permeability of the backfilled and sealed shafts as being so insignificant in relation to the scale of the DWR that it could safely be ignored in

the MASCOT modelling for Nirex 95 [COR/522] but would be checked by the regulators in due course.

6C.96 Individual Radionuclides. Nirex says that difficulties of defining uranium solubility and reconciling equilibrium relationships with thermodynamic data are not relevant to the low ionic concentrations of the groundwater in the BVG at Sellafield and that in considering the chemical behaviour of the near field system it is the actual experimental data replicating the anticipated conditions that are important. In any event it claims that more recent research now gives a good definition of U solubility at high pHs [COR/529, p.22 Fig.3].

6C.97 Nirex does not expect significant colloid populations in the natural groundwater and does not believe colloidal transport will be an important mechanism in practice at Sellafield. It expects the NRVB to produce many colloids but anticipates they will assist retention and sorption of radionuclides. It points out that any change to the proposed waste inventory, which was reduced in September 1995, would need to meet regulatory requirements.

6C.98 Climate & Tectonics. In relation to future glaciation, Nirex expects to be able to demonstrate that glacial flushing has not taken place in the past, by the utilisation of 3-D modelling if necessary.

6C.99 Nirex has been looking for evidence of seismic activity in the region in the form of earthquake-induced faulting or slumping of glacial deposits both onshore and in the Irish Sea Basin. It has investigated a number of such possible "neotectonic" features but at present considers all to have more reasonable alternative explanations. It believes that the last major episode of faulting in West Cumbria occurred over 100 million years ago, and there is an absence of evidence for significant perturbation of the site by seismic activity over the last 100,000 years or more.

6C.100 Nirex takes the view that the stress regime at seismogenic depth in the Sellafield area is not extensional but generally compressional or intermediate ("strike-slip") similar to the rest of Britain and NW Europe. It believes that ambiguous references in an HMIP report on tectonic hazards for UK nuclear waste repositories [GOV/613] have misled Greenpeace. The 1979 Carlisle (Longtown) and the 1993 Grange-over-Sands earthquakes were strike-slip, the latter with a small component of reverse movement. Their effects were minor and do not suggest any risk to a DWR in the PRZ as modelled through near-surface permeability changes in COR/522. Similarly, the historical record of British events [GOV/613/Appendix B] reveals limited effects, including Rampside which was not associated with ejection of deep groundwater but shallow liquefaction of beach sands. The examples quoted by Greenpeace of widespread seismically-induced groundwater changes [GNP/3/28/Figs.7.5 & 7.6] resulted from large earthquakes on normal faults in an extensional regime and are therefore no guide to potential effects at Sellafield in a compressional regime [GOV/613, Section 2.2]. In any event, the range of permeability assumed for near-surface strata in PDFs used in Nirex 95 modelling more than covers the enhanced transient values that might result from earthquakes.

6C.101 Moreover, 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 [GNP/3/27], a view supported by the Nirex Review Panel. Nevertheless, Nirex conducts earthquake and acoustic emission monitoring to supplement the accumulated

historical data and seeks access to the rock mass at depth to provide information on how the rock mass is evolving.

6C.102 Nirex says the sharp kink in the contours of estimated regional uplift [COR/517 v1, fig 6.2] is largely an artifact of the sparse data offshore, and also a feature of the method of estimating uplift based on dating using mineral fission tracks. It is not an indication of tectonic activity in relatively recent geological time as claimed by Greenpeace.

6C.103 Further Work. The planned surfaced based programme of further investigations [NRX/14/12/Table 6.3] mostly complements the work in the RCF. More boreholes are intended to obtain a better understanding of the saline interface and its influence on groundwater flow; of groundwater recharge conditions; of the significance of the Seascale Fault Zone; and for monitoring and DWR construction planning. Laboratory testing of rock and groundwater is, and will, continue together with earthquake and acoustic emission monitoring, 3-D seismic, electro-magnetic and other surveys to further understanding of conditions and models. This programme includes most of the recommendations made by objectors and can be scheduled to end before RCF development or work in parallel with it.

6C.104 Of the **Opposing Parties**, **Cumbria** points out that the long, costly and scientifically novel investigative programme prior to development of the DWR is consistent with international experience. The investigation is taking longer than expected and estimates have been dramatically wrong eg in 1989 the DWR inquiry was expected to take place in 1994 [NRX/12/1, p.7 News Release 6/12/89]. On the other hand, Nirex has now acquired so much information about the PRZ that its scientists are already claiming that comparisons with other sites are impossible.

6C.105 **FOE** do not regard Nirex's scientific information as the "best possible" as insufficient data has been gathered, baseline models are not available, perturbation effects cannot yet be assessed, validation and peer review of work have not been properly carried out.

6C.106 International Co-operation. Nirex accepts that the results of the generic underground experiments carried out in other countries are inadequate for a full characterisation of the rock volume under consideration at Sellafield and that there is no substitute for actual testing in an RCF. Unjustified inferences have been drawn from experience gained in relatively massive, uniform and fracture-free crystalline rocks in Canada and Sweden in FOE's view. They have similar reservations particularly at the Grimsel and Stripa Migration Experiments [NRX/15/35 & NRX/15/36] and work at Stripa about the applicability of the effects of mechanical disturbance or stress changes on hydraulic properties [FOE/7/31, NRX/16/11 & FOE/6/31]. Objectors express general concern at a lack of practical progress in generic experimentation in preparation for RCF development.

6C.107 Data Availability and Elicitation. FOE claims that undue reliance has had to be placed on the use of elicited data instead of measured data. For example, in the case of geochemistry Nirex has utilised non-conservative elicited data resulting in serious under-estimation of the doses that would arise from the DWR [FOE/8/27, pp.ii-iii]. Data inputs have been unreliable. Before 1995 the expert elicitation group failed to take into account

the different conductivity of the Brockram from the BVG in their modelling of groundwater. Data have been frequently "adjusted" to make theory and experiment agree and the basis for elicitation of geochemical data is inadequate because, for example, the experimental procedures used to generate data are based on a methodology of uncertain reliability [FOE/8/51, pp.20-21, para.5.5]. Furthermore, the expert group for Nirex 95 preliminary PCPA contains people very close to the project, only one chemist and no geochemist [COR/522/Vol.1, Table A1].

6C.108 Transparency, Quality & Peer Review. Nirex accepts that its experimental programme has not been subjected to rigorous peer review and Greenpeace points to the lack of an open independent review of the overall scientific strategy as being a particular failure. The Rt Hon Dr J Cunningham MP regards open, independent peer review of all scientific papers as appropriate. FOE draw attention to the recent Royal Society paper assessing recent developments in peer review [FOE/1/6] and contend that Nirex's process has been deficient in both its completeness and its independence.

6C.109 Groundwater. FOE assert that a much longer monitoring period is required before baseline hydrogeological conditions will have been established. This is based on experience at other important sites, notably Canada, where insufficient record of baseline climatic fluctuations has been reported [FOE/4/5]. Furthermore groundwater flow in the Sellafield regime discharges on the near offshore area, where there are no boreholes, and key data on groundwater recharge from infiltration are lacking, bringing into question Nirex's interpretation of the hydrogeology of the superficial cover and shallow bedrock conditions as well as the overall regime.

6C.110 FOE define baseline conditions as when relatively stable or predictable environmental heads and geochemistry have been observed over a period of 4 to 5 years at all existing and proposed monitoring points. This would allow identification of natural seasonal and annual fluctuations which may occur. They observe that boreholes in the PRZ continue to exhibit signs of perturbation and instability.

6C.111 Nirex's reliance on the active groundwater system in the overlying sandstones for dilution of the DWR porewater puts the potable water supply at risk [COR/522.Vol.3,Figs.2.7 & 2.12]. FOE point out that derogation of water resources was a matter of concern to the NRA. The FHFZ is within a few hundred metres of the PRZ [COR/518, drg.010067] and Nirex concedes that it may have the potential to operate as a pathway for upward flow [COR/522.Vol.3, Fig.2.6(b)] with a short groundwater return time of 4,000 years [COR/522, Vol.3, p.6.19]. Environmental head measurements, for example in BHs 5, 10C, 11A, 12A, 14A, RCM1 and RCM2, indicate the presence of a strong upward head gradient within the overlying cover rocks and in some sections of the BVG below the proposed DWR (eg BH 2, 4 and 5) where heads at depth are extremely high. The relatively low environmental heads at about 800 m bOD within the BVG at BH 2 and 4 and at 600 m bOD at BH 5 could be attributable to a hydraulic connection with the cover rocks [COR/518A, Drgs.010111-010113], a feature remarked on by RWMAC [GOV/405, para.4.20 & GOV/406, para.3.27], also pointed out by Cumbria and not challenged by Nirex. However, the RCF area also shows inconsistent environmental head profiles in the upper part of the BVG even in adjacent boreholes.

6C.112 FOE regard their hydrogeological concerns as being confirmed by recent testing. They interpret the Cross-Hole Hydraulic Testing as indicating marked connectivity in the upper 200 m of the BVG, immediately above the proposed DWR [COR/518, Vol.1, Drg. 010090]. The RCF3 Fracture Network Testing shows that there is occasional vertical connectivity within the BVG over distances of at least 100 m [idem, Drg. 010089] although in other sections of the BVG little flow and connectivity were observed. The RCF3 Pump Test [idem, Drg. 010092] and groundwater monitoring in the other deep boreholes [idem, Drgs. 010111-010131] reveal definite connections between the base of the St Bees Sandstone, the Brockram and the upper part of the BVG. This view is shared by Cumbria, which points out the connection between the North Head Member (lower part of the SSG), Brockram & the upper part of the BVG, and some correlation with Fault F2 [COR/524, para.7.29]. It regards the evidence of vertical connectivity between the SSG at the surface and the BVG at 750 m in the area of BH 2 as strong [COR/608].

6C.113 Nirex agrees that south and west of the PRZ the Saline Transition Zone is more diffuse than in the PRZ [COR/525, para.3.10]. Cumbria argues that the saline transition is more gradual across the SSG and Brockram into the BVG, and that this clearly suggests an upward flow from the BVG into the SSG. Nirex accepts that mixing between freshwater and brines is taking place over a significantly wider zone than is indicated by its narrow definition of the transition from brackish to saline.

6C.114 Nirex's conclusion that hydraulic conductivity of the BVG is low may be relatively correct from the standpoint of water supply flows but hydraulic testing reveals conductivities 2 orders of magnitude or more above the typical waste disposal permeability threshold of $1 \times 10^{-9} ms^{-1}$. Moreover, the RCF3 BVG pump test was unreliable and insufficiently extensive.

6C.115 Nirex concedes that hydrogeological modelling so far (Chapter 6D) has failed to account for some significant process or feature at great depth below the PRZ, which could be geothermal flux, which is probably affecting system performance. Cumbria submits that Nirex's variants to date demonstrate the great sensitivity of modelling to small changes in hydrogeological assumptions and elicitation, showing the importance of further work in this area.

6C.116 The conceptual model is simplistic in Cumbria's view. It does not account for the complex interrelationships between the various groundwater regimes and ignores the presence of high hydraulic heads at the base of the BVG, the northward hydraulic gradient in the Carboniferous Limestone and the fresher water which occurs within it, the isotopically younger recharge in the upper part of the BVG near borehole 10A and the freshwater/seawater interface along the coastline. FOE find the vertical section model and modelling of fracture flow inadequately validated. Predictions and field data do not match [NRX/15/16]. FOE also suggest that the regional 3-D hydrogeological model should be of a minimum of 10 km x 10 km, with perhaps more for boundary conditions, and faulting modelled to 10m accuracy. Greenpeace points out that the safety case is reliant upon low flux through a DWR but that the information so far available is insufficient to be confident about the assumption. For example, groundwater flow from the fells converges on the PRZ and existing faulting is likely to result in increased flows during future glaciation maintaining the same pathways.

6C.117 Cumbria asserts that the difference in oxygen isotope ratios between the BVG and SSG groundwaters of 1.5 per mil equates to an average temperature difference at recharge of only 2°C and could be explained by a difference in altitude (of about 600 m) between the respective recharge areas rather than pointing to a period of colder prevailing climate. Thus recharge to the SSG may have been by precipitation on the West Cumbria Coastal Plain and recharge to the BVG by precipitation originating on the higher Cumbrian Fells to the east.

6C.118 The difficulty of sampling and measuring noble gases [CCC/4/4, p.216] and the uncertainties in the values actually obtained are reflected in the error bars on the plotted results [COR/518, drgs.010180 to -195]. The plotted graph of estimated recharge temperatures for Borehole 4 [idem, drg.010183] shows no difference between BVG and SSG groundwaters, and there is little difference in Borehole 2 [idem, drg.010181] if the error bars are taken into account. Furthermore, Greenpeace and others contend that borehole water samples from the BVG cannot be interpreted to yield single ages because they must inevitably represent a mixture of water from joints, where water may be flowing, and from pores, where the water may be more or less static. They suggest Nirex recognises this by quoting ages as mean residence times. Greenpeace considers 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 there may have been increased heads under the ice, and the regional BVG transmissivities may have been much enhanced due to opening of fractures under the effect of ice loading. On this basis, future rates of regional subsurface flows could be much more rapid than any inferred today. HMIP's contractors accept that glacial loading has the potential to alter substantially the pattern of groundwater flow [GNP/3/16, p.58 penult.para.].

6C.119 Cumbria says that it is not acceptable to consider ^{36}Cl readings in Borehole 2 in isolation because the data from other holes, namely Boreholes 3, 7A & 10A [COR/518, v.2 drgs.010182, 010185 & 010188] suggest shorter residence times so the overall picture is very difficult to interpret. It also criticises Nirex's interpretation of long residence times from sampling of ^{4}He for the same reason as for ^{36}Cl, pointing out significant variations between holes [see COR/518, v.2, drgs 010180 to 010191]. Nirex accepts the uncertainties inherent in the calculations and stresses that the results cannot be used in isolation.

6C.120 Natural Geosphere Barrier. The objectors, with few exceptions, express serious concern that the region is characterised by heavy faulting [COR/518, Drg.010070], is a complicated volume of volcanic rock by its nature and the PRZ is a poor site for a DWR. 50% of the BVG is potentially within the influence of a fault structure [CCC/4/2] and controls on groundwater flow are inherently difficult to define. Flowing fractures are linked in a complex and unpredictable manner with no exclusive geological control [FOE/2/2, Fig.17 & FOE/2/3, Summary & s.4]. This militates against achieving an overall understanding of groundwater flow in the PRZ. Understanding is far too limited to proceed to an RCF and is likely to remain inadequate for a reliable safety case to be made, even with an RCF, because of the unpredictability and complexity of the PRZ in 3 dimensions. FOE suggest that the PRZ constitutes part of an infill of a complicated topographic depression ("a piecemeal caldera") that formed by the collapse of part of a volcano in response to catastrophic removal of underlying molten rock by eruption and which was then subject to deformation [FOE/2/2 & FOE/2/3]. They assert that the random complexity associated with this phenomenon is not confined to the caldera margin as suggested by Nirex.

6C.121 They point out that there are significant inconsistencies between surveys and between models of the BVG structure and borehole data potentially causing errors in the interpretation of major faulting. An example of this is Nirex's failure to treat fault F2, which is the most prominent fault cutting the PRZ, as a type III feature and to identify and map its important strands in the model. Faults F1,F2,F3 and 202 have not been robustly defined in their view.

6C.122 FOE submit that cooling joints within the ignimbrites in the PRZ have not been recognised but say that even if they could be mapped from an RCF tunnel they could not be predicted probabilistically, as with the structure generally.

6C.123 FOE say that the acknowledged complexity of the behaviour of the geochemical barrier makes prediction of radiological doses arising from a DWR extremely difficult leaving aside the complication of RCF construction impacts which would exacerbate the problem. They point out that HMIP have already been critical of Nirex's geochemical work [FOE/8/27, pp.32-33; FOE/8/51, pp.20-21] and question the cogency of Nirex's geochemical evidence. They estimate that some 5 years of laboratory work will be needed to support field testing of the geochemical barrier. A good understanding of geochemical processes is required in order to establish a sound basis for PDF application. Data are inadequate on temperature, ionic strength effects, precipitation kinetics, speciation of fluids in contact with the DWR and understanding of secondary minerals for example. FOE believe that their view is supported by the qualifications made, and the variabilities contained, in the results of the Grimsel and Stripa Migration Experiments [NRX/15/35, p.770 & NRX/15/36, pp.vii-ix] and in measured sorption coefficients (K_d) [FOE/8/21/Tables A2-A4] and the fact that databases for K_d values are discarding the isotherm approach in favour of thermodynamically modelled values [FOE/8/34, pp.86-88, 93 & s.5.5.1].

6C.124 FOE observe that allowance does not appear to have been made for changes in geochemical conditions in the far-field beyond the alkaline plume. Over long periods of time significant changes in groundwater flow and redox state could occur. Greenpeace points out that a characteristic of the region is the presence of large amounts of iron ore, and sporadic traces of iron pyrites, both affecting groundwater chemistry. Cumbria add that, until recently, Nirex was unable to estimate the composition of in situ groundwater for the purpose of water/rock interactions because of uncertainties over natural temperatures, pH and Eh [CCC/4/7, p.2].

6C.125 Greenpeace submits that the BVG groundwater is likely to be oxidising at DWR depth and not reducing as Nirex suggests, albeit reducing at greater depth [GNP/3/28/Fig.3.8]. As a consequence there would be increases in uranium solubility and NRVB retardation and waste container corrosion would be affected. Nirex has changed its theoretical approach to chemical buffering [NRX/15/10] but this has not been tested by chemical simulations. It points out that Nirex are using a value of uranium solubility in modelling the near-field 4 times higher than in the Nirex 95 base case.

6C.126 Nirex's results in Nirex 95 [COR/522] are within a factor of 2 of breaching the 10^{-6} target, or, actually breach it [COR/522,Vol.3, Fig.6.19], and, amongst other uncertainties, the fraction of the radionuclide discharge going to deep soils in the biosphere assessment calculations [idem, p.6.9] is accepted by Nirex as needing amendment in the light of research [NRX/15/4].

6C.127 Chemical & Engineered Barriers. The degree of uncertainty associated with host rock performance in the PRZ gives extra significance to the performance of the engineered barriers in the view of FOE. They contend that the NRVB concept is fundamentally flawed because it fails to limit groundwater flow; and it is inconsistent with international research [FOE/7/25, pp.7-8; FOE/7/11, pp.13-14] and Nirex's patent description [FOE/7/17]. The high permeability of NRVB could give rise to higher, and more variable, canister corrosion rates and gas generation and migration than those predicted, so increasing the rate of escape of radionuclides. It also makes the chemical barrier fundamental to DWR safety. Leaving the crown area of the waste vaults unfilled could lead to inhomogeneous chemical conditions. They regard the model used to quantify the behaviour of NRVB is unrealistic and unreliable. South Cumbria Citizens emphasise the great complexity of the chemical systems in the DWR and the huge amount of research that would need to be done: they question whether the problems would ever be resolved.

6C.128 Preliminary work at Stripa to verify any link between mechanical disturbance and hydraulic properties was unsatisfactory [FOE/7/31, p.148] and so this remains a fundamental uncertainty, particularly in relation to sealing and grouting.

6C.129 Mrs M Higham expresses great concern about the behaviour of plutonium dioxide particles released from a waste repository. Although she does not regard PuO_2 as a colloid, she maintains it behaves in a similar manner to a stable colloid and therefore can be transported readily through the geosphere with the flow of groundwater. She and others relate this to the risk of a criticality incident [see 6A.46 above].

6C.130 Gas Migration. FOE say there is still only poor understanding of the potential of the geosphere to attenuate hydrogen and methane, both poorly soluble and sorptive gases, on their migration towards the surface. There is also the possibility that gas bubbles can increase the mobility of radionuclides by attracting colloids and other small particles [COR/528, S.3.2.3, p.14].

6C.131 Potential Excavation Disturbance. FOE and others highlight inconclusive and sometimes contradictory results from experiments carried out in other underground rock laboratories to relate excavation disturbance and flow, and also related experiments on the sealing of excavations. They believe there is a significant risk that induced pathways with potential for radionuclide transport will be created by excavation and that proposed sealing and grouting techniques are not reliable. They point to shortcomings in modelling which are purported to justify inadequacies in construction standards. Of particular note is the failure to account for transmissivity at the interface of fill and lining, possible extent of rock disturbance, backfill permeability and effects of vault voids. FOE regard it as essential for Nirex to have a proper understanding of the impact which the RCF would have on the PRZ, on the region, and on the long term performance of any future DWR, before RCF development commences.

6C.132 By way of example, although theoretical predictions might show a regular relationship between stress changes and rock mass hydraulic conductivity [NRX/16/11, Figs.A1.1 & A1.2], experiments at Stripa, where boreholes were pre-drilled into an area that was then tunnelled out by extremely careful blasting, gave unexpected results, notably a significant permeability reduction akin to a skin forming around the drift but of unknown

cause [FOE/6/31, p.296 last para.]. Possible explanations were shearing of the rocks, blast damage, drilling debris, gas entering the water flow system, and chemical precipitation [idem, pp.290-295]. Similarly in the Canadian URL attempts were made to measure increased fracture flow as result of excavation disturbance surrounding a shaft and narrow ventilation shaft using groundwater tracer tests [FOE/6/30, Figs.3 & 4] but the results were erratic, especially in Fracture Zone 3 where the flow reduced [idem, s.3.1.3 1st para; B12 1st full para & last; B15 1st para.]. Likewise the results of excavation disturbance around a horizontal tunnel in the URL found little direct correlation between hydraulic and mechanical properties [FOE/6/29, Conclusion p.9].

6C.133 Nirex Report 560 (1994) [FOE/5/19] assessed the impact of the RCF on groundwater flow, indicating that it could be significant. In the light of this scoping study, FOE are concerned that the impact of the RCF on baseline conditions has not been rigorously modelled and suggest that impact prediction can only be reliably undertaken once baseline conditions have been re-established. Moreover, unless construction impacts are clearly understood and dealt with, the RCF could provide misleading data and compromise a reliable PCPA. They see sampling of entirely undisturbed conditions as impossible after construction of the RCF. Also the backfilled RCF shafts could provide an express route to the surface for radionuclides. Fresh fractures may dominate absorption for up to 1,000 years. In addition, Greenpeace submits that the collection of data to demonstrate that glacial flushing has not taken place in the past would be compromised by RCF construction.

6C.134 FOE and Greenpeace suggest that the RCF should be sited and designed as an integral part of the final DWR in order to limit excavation disturbance effects and optimise groundwater flows through the DWR. Although Nirex accept that there should be some commonality in the shafts and galleries to minimise disturbance and costs, and best practicable means would be applied to engineering and chemical barriers, FOE and Greenpeace say the RCF is not currently so designed; the engineering standards applied to it by Nirex are inadequate and not best practicable means for a DWR; optimisation of shaft location needs a validated regional hydrogeological model which is absent; and Nirex fails to recognise the significant risk of damage to the PRZ. Best practicable means and quality objectives should be applied at every step in the view of Greenpeace and FOE, and not just to the final safety case.

6C.135 Properties of Individual Radionuclides. FOE point out a number of examples of difficulty in the physical and chemical properties of individual radionuclides. Discrepancies between predicted solubility and experimental results for uranium (U^{VI} & U^{IV}) [FOE/8/31, figs.7 & 9] led to adjustments being made to the HATCHES database to match the experimental results, yet this was regarded as the definitive data source for thermodynamic modelling [idem, S.3.13.1 & 3.13.2, last paras.]. Greenpeace adds that chemical containment is crucial to providing a sufficient level of safety for uranium yet Nirex may have underestimated its solubilities and there is no long term natural barrier to higher solubilities should the chemical conditioning of the DWR fail. Some written representations also express concern that the waste inventory could be altered to include other waste such as MOX plant arisings [WR/MED/2] which would produce actinides with even longer half lives than plutonium (eg ^{239}Np) with a greater propensity to escape than others.

6C.136 FOE contend there are inadequate data on equilibrium relationships at different temperatures to allow confident extrapolations to be made from standard laboratory temperatures [FOE/8/31, p.13 final conclusion, and final remarks s.3.8, 3.14 & 3.16] and thermodynamic data from which chemical equilibrium predictions are made are critically dependent on the ionic strength of the system [FOE/8/43, abstract & FOE/8/34, s.3.1 1st para.] but it has been necessary for Nirex to extrapolate from one ionic strength to another and adjust the data. FOE argue this is unsound as there is not a constant relationship between concentration of species and ionic strengths [eg FOE/8/43, fig.1] and there can be great disparity between predicted equilibrium constants and experimental data [eg for $CuSO_4$ & $NpNO_3$ in idem, Table 2].

6C.137 Climate & Tectonics. Although 4 climate scenarios have been postulated, no modelling of the process of climate change has taken place. Cumbria contends that this is an important omission on the basis of trials in "Dry Run 3" [CCC/5/1, p.101, para.7.2]. Nirex concede the importance of future climate change. Greenpeace submits that, as in the past, glaciation and earthquakes could each increase the groundwater flow rate through the BVG and so could adversely affect safety of the DWR. Nirex do not preclude the possibility of recharge of deeper waters during a glacial period and accept that future glaciations are expected to occur over the next 10,000 to 100,000 years.

6C.138 Greenpeace claims the Lake District Boundary Fault zone (LDBFZ) has been active within the last 60 million years. It interprets the sharp kink in the contours of estimated regional uplift [COR/517 v1, fig 6.2] as suggesting differential movement between the Lake District massif and the rocks of the coastal plain during that period. There are unconformities and discontinuities within the glacial sediments indicative of tectonic activity within the last 100,000 years. Nirex identified from onshore and offshore seismic reflection data a number of locations where there may be faulted offsets of rockhead and Quaternary sediments [COR/517, Vol.1, p.11].

6C.139 Greenpeace adds that radiometric dating of minerals in a small number of samples taken from fault rocks gave ages of 118-146 million years, and a single sample from another fault zone gave a minimum age of 212 million years. An estimated age of 60 million years for another sample was ascribed by Nirex to a geothermal episode rather than faulting although this date is about the Cretaceous-Tertiary boundary when Nirex says regional and wider uplift occurred. The HMIP report GOV/613 [p.79], specifically describing the tectonics of the Sellafield site, considers that from regional tectonic evidence the most recent phase of compressional and strike-slip deformation may have been in the Oligocene, 40-30 million years. However, it believes Britain is now in an extensional tectonic regime possibly caused by the effects of isostatic rebound following the last ice age.

6C.140 The Sellafield seismological database [GNP/3/27, sections 4.5 & 4.5.1] shows that the surviving record is limited to about the last 350 years and, despite the large body of data, may provide only a sample of the total number of felt earthquakes that have actually occurred in the region. Greenpeace submits that observations confirm the general impression that the northwest is one of the more seismically active areas of England. New UK seismic hazard maps compiled by BGS [GNP/3/24] show that the areas of highest hazard are western Scotland, northwestern England and Wales, albeit with a 90% probability that Intensity VI MSK will not be exceeded in 50 years.

6C.141 Greenpeace draws attention to the largest and most damaging local event, namely the Whitehaven earthquake of 1786, at Intensity VI, magnitude $4.7M_{SA}$ although there have been other events of comparable intensity (Irton 1755, offshore Irish Sea 1843) [GNP/3/27, pp.22 & 23]. It says these events, observed on a very short timescale relative to geological times, are not a good indicator of what might be less frequent larger movements on the Lake District Boundary Fault. The recent historical record shows that there are likely to be at least hundreds more such events during the lifetime of the DWR on any reasonable interpretation, a view shared by South Cumbria Citizens [SCC/5/1] and many of those writing [eg WR/S/242 & WR/W/155].

6C.142 Greenpeace claims that large earthquakes in extensional tectonic regimes can pump large quantities of water to the surface [GNP/3/7, Abstract; GOV/613, sections 2.2.4, 2.3.3 & 2.4.1]; and 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. The 1959 Hegben Lake, Montana and 1983 Borah Peak, Idaho earthquakes were both large events (Magnitude 7) on normal faults in an extensional regime, and the 1865 Rampside, S.Cumbria event caused water spouts in the beach sand. The 1884 Colchester earthquake changed water levels in wells up to 25 km away and seemed to be in an area of local extensional stress.

6C.143 Nirex concedes that there is no international consensus on hydrogeological effects of earthquakes and that all theories should be taken into account.

6C.144 Further Work. FOE make the following recommendations without prejudice to their doubts as to the site's suitability and susceptibility to reliable characterisation. They estimate the work other than f. (RCF impact) would take 5 to 6 years to complete but that 9 to 10 years should be allowed overall and the work should precede RCF development.

a. A 3-D seismic survey over a minimum 7-10 km^2 as essential to stand the best chance of supplying an adequately predictive 3-D sub-surface model.

b. Up to 3 more boreholes offshore and up to 7 further deep and shallow boreholes in the intermediate areas of the site to further define the geological sequence and hydrogeology in 3 dimensions.

c. Repeat the RCF3 BVG pump test over at least 12 months together with other tests, if feasible, in boreholes 5,7A,8A,11A,12A,14A,RCF1 & 2, and RCM1 to 3, and perhaps tracer testing, to further test the connectivity of strata and fractures.

d. Continue monitoring and sampling until relatively stable or predictable environmental heads and geochemistry have been observed for a period of 4 to 5 years to demonstrate the achievement of "baseline conditions" (as normally understood).

e. Refine the modelling to enable it to adequately replicate existing groundwater conditions and the effect of any field testing.

f. Model the impact of the RCF construction on baseline conditions (once established) and on the PCPA.

g. Peer review of the results of the above work.

h. Assess the effectiveness of sealing techniques before RCF construction.

i. Develop improved safety case modelling (see Chapter 6D).

j. Progress laboratory and field work on characterisation of the geochemical barrier.

6C.145 My conclusions on the current state of Nirex's scientific & technical programmes rely considerably on the Assessor's careful evaluation, and concentrate on what seem to be the most important points highlighted by the parties. Generally Nirex's work so far has been of very good quality, and has made extensive use of the available information. I consider below the significance of any alleged important departures from this generalisation. The
6C.15 expansion in the scope of the work over the last 5 years or so has also been very impressive, but does indicate amongst other things that the practical difficulties of the deep disposal option were originally under-estimated by the international consensus. Also Nirex's emphasis
6C.7-8 on the chemical containment element of the mixed artificial & natural barrier in spite of the relative novelty of the concept rather confirms that a difficulty is perceived in identifying a suitable UK part of the geosphere for the implementation of the deep disposal option.

6C.146 In 1989 Nirex was confident that a limited drilling & testing programme, supported by geophysical work, would be sufficient for the compilation of a preliminary safety
6C.14 assessment which could support a repository planning application. Since this turned out to be far too optimistic, Nirex should have entered into a period of serious doubt about the
3A.11 promise of this location, no later than 1992. However, Nirex is claiming once more that there is sufficient information to show that the PRZ holds good promise, and now that its
6C.72 programmes have reached the point where an RCF is necessary. This implies that any really serious doubts have been allayed: and it is the persistent questioning by others of this implication which to my mind is the issue underlying most of the themes in this Chapter.

6C.17-21 6C.147 The site characterisation programme is of course the main programme which is directly related to the promise of the PRZ: but NSARP is relevant also, for example to any
6C.22-7 evaluation of the robustness of the PSAs. It is also necessary to be clear about the relationship between the RCF and the various components of the programmes, particularly when considering plans or recommendations for further investigatory work. Some work would seem to have little direct connection with the RCF investigation - an example would be establishing the boundary conditions of the hydrogeological region. Other work might appear not to be directly related to the RCF, yet their timings would need to be co-ordinated - for instance, for the drilling & baseline monitoring of additional regional boreholes within the area of possible hydrological influence of the RCF. Further categories of work would rely on the RCF as an integral part or phase of the work - such as model validation, and sealing designs. Then there would be some work which could only take place in an RCF-

type development, since it would basically depend on direct observations of relatively large portions of the potential host rock & associated physical matter.

6C.148 A wide range of disciplines is involved in these programmes. There is some novel & fundamental science: there are taxing problems of complex mathematical modelling: and there are potentially fresh applications for some existing technology. Sometimes there is a tension, both within Nirex and amongst its opposers, between a general academic, theoretical & cautious approach on the one hand and a more practical, pragmatic & venturesome one on the other. This distinction is not to do with quality of, or care over, work, but with basic personal dispositions. However, most approaches have also been conditioned by some preconceptions, which tend to surface in some inconsistent treatment of secondary evidence, such as arguments from first principles, unpublished research, & preliminary scoping studies.

6C.28-32 6C.149 International Co-operation has provided Nirex with considerable amounts of comparative data on rock properties & responses. There are also the benefits of some experience with methodologies, equipment & techniques passed on to help the planning & implementation of the RCF, and of exchange of personnel. Whilst FOE in particular draw
6C.132 attention to the poor or unexpected results from some international experiments and are concerned about possibly misplaced confidence in them, a positive way of looking at such results is that they provide lessons to be learnt. In addition there have been international
6C.31-2 inputs to NSARP on topics like radionuclide migration through the geosphere; validation of geochemical codes; colloids & complexes; gas generation & migration; coupled thermo-hydromechanical models; and natural analogues.

6C.150 However, it is clear that none of the experimental sites in other countries is very
6C.41 & similar in geological setting to Sellafield. This raises yet again a query about the choice of
73 Sellafield; and means that a full characterisation of the rock volume here has really had to start from scratch. In turn, this underlines the crucial importance of the RCF, and I share some of the general disappointment at the apparent lack of progress in applying the results
6C.106 of generic experiments to practical preparations for the RCF.

6C.151 One of the basic problems in judging the promise of the site is that, notwithstanding
6C.34-5 the international input, Data Availability for the relevant scientific & engineering requirements has been notably limited. The juxtaposition of this judgement with expressed concern about the relative amount of data being amassed on Sellafield is not a paradox, in my view, but merely a reflection of the profound novelty & complexity of the deep disposal, multi-barrier concept. In any event, although data on Sellafield continue to be accumulated from other site-based studies & experimental work, the RCF itself would of course be a large & crucial stage in data collection.

6C.152 Whilst I appreciate FOE's concerns about some aspects of Data Elicitation, the Assessor advises me that its use has been, and is, proper & appropriate; and that broadly it was the only practical way of carrying out preliminary safety assessments. Seemingly there has been no adequate substitute for relying on human expertise so far. Whereas some of
6C.107 FOE's specific examples are from HMIP's review of Nirex's 1992 PSA, the Assessor has naturally concentrated on the more recent 1995 PSA. Data elicitation has been retained notwithstanding that some experimental values could presumably have been generated by NSARP.

6C.153 Inasmuch as Nirex continues to rely on data elicitation, any more data production
6C.43 by 1 or 2 individuals rather than by a group which is complying with a formal methodology would presumably be unsatisfactory to the regulators. But the fundamental points for the future are that data would remain of variable quality, and that some parameters would always have a wide spread of values. In relation to matters such as the solubility & sorption of radionuclides, these points are more directly relevant to the safety assessment; but the extent of knowledge of geochemical parameters, for instance, could well have a bearing on the detailed timing of, & experiments within, the RCF.

6C.154 Transparency of the scientific & technical programmes has also been a problem in
FOE/5/20-5 the past, with for example HMIP being unable to follow important arguments in the 1992 PSA because of inadequate references & documentation, echoing the difficulties over
6B.65 understanding of the 1988-9 site selection exercise. The Assessor's judgement is that the
& 77 situation is much better now, so that a more integrated & coherent story is emerging, and a good deal of openness is being exhibited in the best scientific & engineering tradition. Nevertheless Nirex's steep learning curve has meant that scientific papers & background
6C.36 documents have become available more recently in an almost indigestible surge. Real transparency is hardly improved, in my view, by flooding people with more information than
6C.75 they can cope with. The proposed Project Review, and rapid release of site investigation data, should both contribute to a better flow of information.

6C.72 & 6C.155 Quality assurance has been rigorously applied, so I am advised; and the
75 consequential delays in publication are warranted by the resultant quality, accuracy &
6C.38 completeness of interpretive reports. Nirex's practice is to classify reports as "Commercial in Confidence" until they have passed successfully through the quality assurance procedures. However, the Assessor's view is that only a small proportion of them would usually be thought of as having commercial value: and consequently I regard the practice as misleading & inimical to Nirex's long-term credibility. If a report is being withheld because it is still subject to quality assurance, then that fact should be simply stated.

6C.156 The kind of Peer Review which is distinct from quality assurance has tended to be treated in this case, wrongly in my view, as a rather amorphous concept. The starting point is that Nirex is essentially a developer, and a developer's work is not normally subjected to peer review, as opposed to quality assurance. The draft regulatory guidance seems to
HMP/1/1 explicitly require peer review only for model development. Nevertheless, Nirex is
6C.48 undertaking much research which is at the leading edge of science, and that would usually go through the standard peer review practices of the scientific community. In the case of learned papers, these take the form of well understood refereeing procedures. For other programmes or aspects of work, there are in fact definitions of peer review in the draft
FOE/1/6 regulatory guidance and in the Royal Society's assessment cited by FOE.

6C.157 The White Paper & the draft regulatory guidance require the employment of good
6C.1 science, and the basing of decisions on the best possible scientific information. In my judgement, science can only be good if it has been subjected to proper peer review. As the Assessor points out, the involvement of so many outsiders in Nirex's programmes does mean that they are being subjected to continuous wide scrutiny. However, I cannot accept the terms of part of Nirex's submission, that some proper independent peer review is carried out
6C.75 by Nirex staff, contractors & the Nirex Review Panel. There cannot be confidence that staff

or contractors would meet the definitive requirements of being experts not directly involved in the work whose judgement can be accepted as impartial & disinterested; whilst the Review
6C.48 Panel has made clear that it does not regard its own contributions as detached peer reviews.

6C.158 Accordingly, I consider that there is an implicit policy requirement that Nirex's
6C.108 scientific work should be subject to peer review, which has not always been fulfilled so far. Therefore I particularly welcome Nirex's assurance to the Secretary of State, reported in full in Chapter 7B, to submit an independently peer-reviewed baseline report to the regulator before RCF shaft sinking begins. To my mind, this would be a good start to settling some
6C.48 of the issues on peer review. However, I would respectfully disagree with the incipient
6C.108 consensus on seeking a peer review of Nirex's overall strategy. For I consider that this should be directly reviewed by the regulators instead. They are unarguably impartial & disinterested; and there could be a more focused review by them than by an ad hoc group,
6B.4 & 7 in the general public interest & in accordance with the spirit of international guidelines.

6C.159 Turning from these procedural matters to crucial substantive issues, I consider that the central question, of the state of Nirex's current understanding of the Groundwater, is a good example of difficulties which may well stem from the lack of strategic guidance, in this instance on the requisite quantity & quality of hydrogeological information. For it is my view, on clear advice, that Nirex has an insufficient understanding of the groundwater
6C.116 conditions for a favourable prognosis to be given. The scientific & technical challenges it
6C.48 & faces in these respects have not been fully appreciated by it. Starting with the data available
71 from monitoring existing boreholes, there is information from a useful number of holes over
6C.19 an extended period, but this is predominantly in the sandstones and drift deposits, with sparse
6C.77 information on the limestones and only recent Nirex data for the BVG. The number &
6C.109 distribution of data points are certainly inadequate at the geological District scale, and may
6C.78 even be so at the geological Site scale at present. Also the monitoring period in the deep
6C.110 BVG has been too short to demonstrate slow trends.

6C.160 Consequently there is considerable uncertainty about flows in the deeper rocks, particularly the BVG. Whilst it is agreed that there are relatively rapid flows in the upper
6C.52 part of the SSG, and that there is a marked tendency for horizontal flow towards the coast, more localised interpretations have been inclined to over-simplify the probable situation.
6C.81 Also Nirex's claim to recognise a 3-layer pattern with depth is still unsubstantiated in relation to the critical middle layer of the upper 400 m of the BVG & above, and its allegedly virtual lack of a vertical gradient.

6C.161 A fundamental point which pervades the hydrogeological assessment, in my view,
6C.50 is that the area is extensively faulted but that there is a considerable amount of speculation
6C.87 as to the influence which any local fault has on groundwater flow. Nirex does not know
6C.120 whether the faults in general or particular increase or reduce or deflect flow. It has simply
6D.10 assumed for the purposes of its PSAs that the major faults conduct flow. An important follow-up point agreed by the Assessor is that, whilst geophysics can give some assistance, there are not enough boreholes in the right places to check for indicators of flows across any of the faults. Thus Nirex not only lacks fundamental knowledge about the relative transmissivity of faults, but also has not taken all of the orthodox steps to find out.

6C.80 6C.162 On the other hand, there seems to be little quarrel with Nirex's concept of the local groundwater as being divided into 3 regimes, comprising the Irish Sea Basin Brines under the sea & deep under the coast; the Coastal Plain Regime of fresh waters in the shallower strata; and the saline Hills & Basement Regime at depth inland. The PRZ appears to be in
6C.52 the Hills & Basement zone, but close to the junction of the 3 regimes. Hence, even though the regimes may have been identified well, again it transpires that there is a complexity, this time in the local hydrogeology, so that the PRZ lacks in another respect the theoretical simplicity of a true BUSC location. Fortunately, the Assessor considers Greenpeace to be incorrect in suggesting that the PRZ is also on the main subsurface axis of potential flow
6C.116 from the Lake District fells to the sea.

6C.163 However, there are further difficulties, in understanding groundwater conditions to the west. At the shallower levels, it seems clear that significant amounts of water flowing
6C.109 through the Quaternary deposits & the upper SSG discharge at the coast or a little offshore. But, in the Assessor's opinion, too little is known about the locations & relative volumes & proportions in comparison with discharges into watercourses or elsewhere. At deeper levels, the Assessor's considered judgement is that, notwithstanding Nirex's views about the boundaries between the hydrogeological regimes in terms of the Saline Transition Zone, the
6C.113 margin of the Irish Sea brine mass is sinuous & irregular, and the vertical distance of transition from fresh water in the SSG to fully saline water in the BVG is 200 m or more. This is another indication of the possible presence of vertical features, in turn suggestive of upward flow from close to the PRZ. Also, whilst the Assessor's views effectively reinforce Nirex's proposals for more boreholes to the west of the PRZ, there is in addition his
6C.78 judgement that further, offshore boreholes not planned by Nirex are in fact required. Thus there is an underlying doubt about the overall utility of the RCF if requisite, complementary investigations further to the west are not to be completed in any event.

6C.164 Moreover, there are considerable uncertainties about groundwater Eh, pH & ionic
6C.79 strength, especially at the preferred repository horizon. I adopt the Assessor's detailed conclusions on the essence of this topic. An adequate working knowledge is to be expected as part of the requisite generic understanding of the PRZ & the geological Site, and at present
6C.125 it is lacking. Some of the deficiency would hopefully be made good by the RCF, but for its investigation to be effective a certain degree of comprehension has to be achieved beforehand. An overwhelming & prolonged effect of the chemical barrier might conceivably make an understanding of the conditions in the near field less important, but the barrier is
6C.7-9 itself an unproven concept. Emphasising a maximum ionic strength in the vicinity of the
Ca.6E repository tends to overlook the 1995 variant cases, plus dispersion & diffusion in the
6C.11 geosphere away from the notional path-line in the base case. The base pathway of a PSA cannot simply be assumed to be representative of the final safety case. The eventual risk assessment will form only part of the overall safety case, together with several other lines of
6A.21 reasoning, and analyses of all significant features of the disposal system. The redox state of the groundwater is fundamentally important because of the control it exerts over chemical
6C.124 reactions within, or equilibrium involving, the water, whether in the natural geosphere or the artificial repository.

6C.86 6C.165 The residence time of the groundwater in the rocks is also important because it can
6C.118 be a strong factor in assessing regional groundwater flow rates. The presence of isotopically
6C.56 lighter waters in the BVG & the lower sandstones is more likely to be due to recharge during

a colder climate than at a higher altitude. Indeed there are a number of indicators which are
6C.82-4 strongly suggestive of a long residence time for the BVG groundwater in the Hills & Basement Regime. This is encouraging for the safety case because it is some evidence of low flows through the potential repository horizons.

6C.166 I consider this to be one of the most promising features of the work at Sellafield; and of course research continues to try to establish a simple & consistent overall picture. However, many more determinations are needed over a wider territory, and yet there seems to be no firm programme to achieve all these. There is also a possible pitfall for the safety case in that an attribution of the long residence time to a previous glacial cycle would favour
6C.118 a hypothesis that another glacial cycle well within the risk assessment period might flush out
6C.98 & recharge the groundwaters. In my view this embryonic hypothesis is no more speculative than some of the scenarios which Nirex wishes to promote on other topics.

6C.167 Moreover, in turning from groundwater conditions to an examination of the Potential of the Natural Geosphere Barrier, there is an immediate reversion to over-optimism in Nirex's understanding of fundamentally important information. Although the bedrock geology is better known now in 3-D as a result of the greater coverage by geophysical surveys, this is at a coarse scale except in the vicinity of the RCF shafts. Also the BVG is difficult to characterise seismically because it has relatively few reflective surfaces. The distribution & variability of faults in the PRZ is obviously great; and it has not actually been possible to identify definitively during the inquiry the location of the fault which is probably the most
6C.121 significant of those traversing the PRZ.

6C.168 The claim that nevertheless the main faults in the PRZ have been adequately
6C.87 characterised has by no means been substantiated either, in my judgement. Although continued data collection & modelling should be gradually improving understanding, Nirex's mapping & interpretation of the faults has been shifting; and the Assessor & I have been given too little cause to believe that this crucial aspect of the PRZ's geology has now been satisfactorily determined. Indeed there is a latent self-contradiction in the argument that it is the latest stochastic descriptions which have resolved the difficulty, since that implies a relative lack of deterministic data. Not every uncertainty can be over-arched by stochastic calculations, for the PDFs must have an initial credibility derived from acceptable data. The probabilistic modelling needs a realistic input of stratigraphic understanding at a relatively fine scale for its output to carry much weight with an impartial observer; and then there are the draft regulatory requirements for multiple lines of reasoning & analysis of all significant features as well.

6C.169 Any lingering doubts that this judgement is too negative are in my view dispelled
6C.120 by a brief consideration of the geological history of the PRZ. BGS has plainly advised, after evaluating a range of borehole information, that the deposition of the BVG is considered to
FOE/2/3 have been within an actively subsiding basin, probably a caldera complex. This is regarded as having had an episodic history, with periods of caldera collapse following eruptions during which an evolving magma chamber was tapped. My distinct impression is that, nevertheless,
6C.87 the implications of this have not fully realised until FOE have elaborated upon them for the
6C.120 benefit of the inquiry. The Assessor's advice, very briefly, is that, in addition to the basic volcanic characteristic of inherent variability, a caldera collapse would have introduced
COR/530, further faulting, slumping & deformation. Whilst some of the super-complexities probably

p.3.14 resulting from this appear to have been observed in the PRZ, they have been categorised as very localised phenomena rather than as typical of the multiple heterogeneity of a caldera.

6C.170 The difficulties in describing the detailed structure of the deep rock could theoretically be overcome to some extent if at least the flow characteristics & conductivity were adequately understood. The Assessor considers that an appropriately wide range of testing & monitoring for a borehole-based investigation of these has been carried out so far.
6D.20 In particular he believes that the results of the relatively recent RCF3 Pump Test tend to
6C.88-9 support the provisional conclusion that there is little vertical connectivity between the rock
6C.114 layers near the centre of the PRZ: but he has some reservations over the period of pumping, and there is a possible anomaly as to a slight response in the BVG some distance away from the RCF3 sandstone pumping.

6C.111 6C.171 Elsewhere, the testing & monitoring has implied in places a direct hydraulic
COR/518A connection between the shallow Sherwood Sandstones and the BVG, with only part-
NRX/14/12 reassurance obtained from extra cross-check boreholes: and other responses have suggested
6C.112 definite connections between the BVG, the Brockram & the base of the SSG, but not the main body of the last. Thus more conclusive information is required; and, although further borehole investigation should assist, one of the main benefits of an appropriately planned RCF would be a powerful indication from its drawdown of the nature & extent of local hydraulic connections between the BVG and overlying strata.

6C.172 The RCF is intended to provide much more information on flow zones too, especially in the BVG, where flow is already known to be principally through fractures but
6C.54 only a small proportion of them. The current explanation is that partial correlations exist
6C.55 between flow zones and many of the geological characteristics. This is the situation to be expected, in my view, with very complex rock; and the relevant RCF observations & experiments would have to be very carefully designed & controlled to pick up the threads. Since there are strong statistical associations between the locations of flow zones and faults, and between the frequency of flow zones and different Members of the BVG, a concentration of activity on the characterisation of the fault systems & on the Town End Farm Member might have been expected.

6C.173 The sorptive capacity of the host rocks is theoretically relevant to the passage of radionuclides; and I consider that the regulators would expect it be thoroughly analysed even
6C.90 though Nirex is currently relying more on dilution & spreading. Sorption behaviour is
6C.123 nevertheless very complicated; and the uncertainties over groundwater regime transitions, redox conditions, & data elicitation are all involved. Sorption processes are very difficult to measure in the field, and the laboratory work programme for the BVG has been rather short
6C.59 so far, in addition to having to rely on artificial ageing. Tracer studies in the RCF on the connected topic of diffusion would be helpful in following up relatively good progress in the laboratory, but again the timescales would be incomparable with the natural system.

6C.3-8 6C.174 The Proposed Chemical & Engineered Barriers are, together with the disposal inventory itself, the artificial part of the multi-containment concept. This implies, of course,
6C.10 that the natural barriers cannot be completely relied on. In the Assessor's judgement, there
6C.6 should be good confidence in the research work into the performance of steel & concrete.
6C.60 Also the processes resulting from corrosion & from the degradation of the waste seem to be

6C.24 fairly well understood, subject to a review of the significance of radiolytic reactions. However, the novelty of the chemical containment concept unsurprisingly throws up a wide range of problems.

6C.175 Notwithstanding the patent on the NRVB, there is a need in the first place for a
6C.60 better understanding of its short-term physical & handling characteristics. Also, in order to support the theoretical estimates of the maintenance of a high pH over a long period, more
6C.127 work is required on the effects of elevated temperatures, particularly in relation to gas
COR/528 dispersal and the survival & activity of microbes. The artificial ageing difficulty also applies to experiments on NRVB's retardation or immobilisation of radionuclides. Another fairly fundamental problem to be addressed is the possibility of cracks forming in the NRVB, with
COR/529 the discovery that the reaction layers within the cracks have different compositions with widely varying effects.

6C.176 This kind of work is partly generic & partly concerned with the natural physical & chemical properties of the PRZ. Consequently, whilst it relates to some extent to the promise of the site and can be assisted by more data from the RCF, it also relates to the practicability of the UK deep disposal concept. Another matter with which both the promise and the
6C.7 concept have to grapple is Gas Generation & Migration, for the gases arising from the
6C.12 degradation of the waste & its containers have to be allowed to escape to avoid serious
6C.62 damage to the DWR; and yet they would form another potential radionuclide transport medium to the biosphere, and may well have favourable or unwelcome inter-actions with
6C.12 other media. The Assessor advises me that there seems to be a good understanding of the
6C.130 production of the gases, but that there is greater uncertainty about what happens thereafter.
6C.50 Apparently some Nirex research on gas-water inter-action is awaiting peer review &
6C.94 publication: but the RCF would be a unique opportunity to experiment with & investigate gas migration through the intended host rocks.

6C.177 The Potential Disturbance from RCF Construction itself is another crucial topic, in
6C.133 my view. The 2 main areas of obvious potential impact are on baseline hydrogeological conditions due to drawdown, and on the long-term safety case due to the introduction of transmissive features through the rock. I regard it as a significant defect in Nirex's case that it has not presented reasoned predictions of these effects to the inquiry. It seems that to date
6C.95 Nirex has only completed a preliminary scoping study, which was left for FOE to draw to the inquiry's attention. However, the Assessor advises me that it is unreasonable for FOE to go on to criticise the study in principle for using a number of different modelling approaches, since that was reasonable at such a preliminary stage.

6C.178 There is also the circular point on the hydrogeological impact that a primary purpose of the RCF is indeed to observe the drawdown as a means of validating water flow models. However, Nirex's preparations should be ready to obtain the full benefits of such
6C.133 observations, and yet neither a calibrated model nor predictions of the drawdown are so far
2B.9 available in anticipation of the start of the shaft sinking, on a tight timetable. This might not have been of much concern if the scoping study suggested that the RCF itself would have
6C.133 only a minor impact. But, on pessimistic assumptions, significant changes in the BVG groundwater were predicted, with a certainty of altering baseline conditions and a probability of drawing into the immediate locality water of a different geochemistry.

6C.179 The study also suggested that the creation of additional conductive features through
6C.131 the rock could be relevant to the safety case. Although it worked on an earlier, smaller design of the RCF than the present one, it included an assumption that drifts would directly
FOE/5/19 connect the RCF and the subsequent DWR. This is further confirmation that the line which Nirex has sought to draw between the RCF and the DWR on the planning merits is untenable
3A.11 as a matter of fact, and therefore in law. Moreover, some of the preliminary indications were that variations in the permeability of the backfill in the RCF's drifts & shafts could substantially alter the times of peak annual entry into the biosphere of radionuclides from the
6C.133 DWR. I agree with the Assessor that it would be a fair inference from this work that the RCF could potentially affect the safety case by introducing additional hydraulic conductivity into the hydrogeological regime.

6C.95 6C.180 Nirex's view is that the scoping study showed that if certain permeability levels were achieved in backfilling & sealing then the presence of the RCF excavation would have no detrimental effect on the transport of radionuclides from the DWR. The sealing requirements
6C.91 involved in achieving the requisite permeability are not regarded as onerous, and so the permeability factor was treated as insignificant for the purposes of the latest PSA. The regulator could be satisfied in due course by, amongst other things, the results of the sealing
2B.17 experiments in the RCF itself. However, I consider that whilst this may seem a measured approach towards the final safety case it is really a rather high-risk strategy for coping with
6C.103 the effect of the RCF excavation after the event.

6C.7 6C.181 This is because it is part of the basic containment concept to instal high integrity
6C.59 seals, but it is agreed that possible deterioration of seals and sealing materials, not covered by standard civil engineering & mining practice, has yet to be addressed. Also Nirex has produced no answer so far to FOE's reasoned anxieties in particular about heightened
6C.131 transmissivity at the interface of fill & lining. The presently programmed sequence of events
2B.15-8 would leave open the distinct possibility of Nirex discovering too late that it has not designed
6C.50 the RCF excavations in the most appropriate manner for subsequent backfilling & other sealing. Nirex seems to be under the impression that this would not be detrimental to the final safety case so long as it could continue to show that the sealed excavations were probably not a preferential pathway; but this overlooks the point that regulatory policy
6C.1 requires Nirex both to aim for the risk target and to adopt best practicable means, rather than allows it to choose between the two.

6C.182 On the other hand, the Assessor advises me that Nirex's position is more secure on other aspects of the general topic of Excavation Disturbance, notwithstanding the several
6C.131 kinds of reservations strongly held by FOE & others. Nirex is believed to now have a good
6C.63 understanding of the basic mechanical properties of the Sellafield rocks, adequate to make preliminary excavation designs. Whilst of course there are many uncertainties about the likely extent & behaviour of large & deep zones of excavation disturbance, it is of the very essence of the RCF to explore these by close observation. Also the vertical stresses and directions of maximum horizontal stress seem now to be known with some confidence, with the best preliminary estimate of the latter consistent with published data.

6C.132 6C.183 The erratic or unexpected experimental results elsewhere emphasised by FOE are not really surprising to the Assessor. There is not a wealth of data on the changes to groundwater flow induced by excavation, but the effects are much more variable than those

of mechanical strains. Two basic points are in Nirex's favour. The indications are that any
6C.64 excavation disturbance zone is very site specific, thereby emphasising the crucial role of the RCF in this aspect of the continuing investigations: and, on the other hand, results to date suggest that Nirex's modelling has been very conservative in assuming that excavation disturbance could increase hydraulic conductivity parallel to the excavation walls by up to 2
6C.95 orders of magnitude for a distance of up to twice the excavation diameter.

6C.184 But, in turning to the understanding & modelling of the Physical & Chemical Properties of Individual Radionuclides, Nirex still has a number of difficult problems to surmount. The anticipated post-closure conditions in the engineered repository would greatly affect the solubility & reactivity of individual radionuclides, often beyond the range of
6C.135 conditions for which there are much previous research data. FOE seem to us to have made
6C.136 out their case on discrepancies between predicted solubility and experimental results, and on
6C.46 inadequate data on equilibrium relationships at different temperatures & ionic strengths.
6C.96 Whilst it is appreciated that it is the experimental results which have been used as modelling
6C.59 inputs to date, it appears that there is still relative uncertainty over solubility at fairly standard
6C.60 conditions, let alone more extreme ones. The Assessor & I also feel that Nirex needs to
6C.129 understand too reactions outside the repository, across all the potential salinity variations.

6C.65 6C.185 Although Nirex is fairly sanguine about the low incidence of colloids in natural
6C.97 groundwater, and about the several conservatisms involved in the assumption that radioactivity could be transported on colloids from the DWR to the biosphere, the facts
6C.24 remain that cementitious colloids would be generated by NRVB, and that research in this area
6C.60 is less well advanced than many other lines of study. Understandably Nirex has been concentrating on the behaviour of cementitious colloids in the varying water chemistry of the
6C.59 near-field/geosphere boundary, but it accepts that broader areas need to be investigated.
6C.71 Another series of topics that the Assessor advises should be researched is the possibility of
6C.129 other fine particulates being released from the DWR.

6C.6 6C.186 A significant programme of research has also been started into reactions with organic
6C.8-9 matter, because some of the degradation products would increase the solubility or reduce the
6C.59 sorption of radionuclides. This is a wide field in itself, and much of the work seems to be novel. Due to the many organic species in the waste leachate, the research has to concentrate
6C.60 on potentially key compounds & fractions, and focus on understanding the underlying mechanisms.

6C.187 Recalling the distinctions between various components of the research programmes made in para.6C.147 above, the Assessor remarks in particular that work on the influence of organic matter would be necessary regardless of the location of the repository. Therefore it has little direct connection with the RCF investigation. The same would apply to much of
6C.3-4 the work on fine particulates, assuming that the inventory would remain the same whatever
6C.97 the location; to some of the work on cementitious colloids, presuming that Nirex intends to use NRVB in any location; and to much of the work on solubility & reactivity. However, the RCF should make it rather easier to sample groundwater colloids; and it would improve knowledge of the geochemistry of the local groundwater for the whole range of site specific aspects of the understanding & modelling of the properties of radionuclides.

6C.188 The theme which underlies much of the opposition on this score is scepticism about the pace & co-ordination of Nirex's research programmes. There are doubts that sufficient understanding would have been developed across the full range to obtain the best value from the nature, design & implementation of the observations & experiments in the RCF. There are concerns that the research may be rushed to try to keep up with the RCF project timetable, or, conversely, that the RCF work might be premature and truncate optimisation. My judgement from this brief review of the state of research into the properties of individual radionuclides, and from others of my conclusions in this Chapter, is that there is some cogency in this line of opposition. I am particularly struck by the way in which Nirex may have handicapped itself from the scientific point of view by deciding not to emplace any
3A.13 radioactive waste whatsoever in the RCF for any experimental purpose.

6C.189 In the light of the Assessor's advice, the opposition's similar worries about the evolution of Nirex's understanding of the Longer Term Geological Processes tend to have less
6C.137 force, in my view, with the exception of the possible implications of successive glaciations. The most significant weaknesses of this specific Sellafield DWR project in relation to the long term geological context seem to be to do with the past, albeit that subsequent Chapters of this Section of the report refer to the deep disposal concept's generic difficulties in predicting the distant future. Thus I am advised that this location should not be especially prone to further volcanism, but I have already concluded that past volcanism has made this a very difficult site to characterise because it is very probably within a collapsed caldera complex [6C.169].

6C.190 A less clear-cut matter is that, despite a conclusion in principle that a location along the boundary between the Irish Sea Basin and the Lake District Dome must be questionable [6B.97], the evidence of activity in the LDBFZ within the last 60 million years is apparently
6C.138 weak. However, doubt remains and further research could be done on the dating of faults and the evolution of fracture systems, for example by studying mineral fission tracks & fluid inclusions. But this would require the sampling of fault & fracture infill materials; and the
2B.15 RCF would afford only limited access to fault zones.

6C.139 6C.191 The situation on seismicity is particularly interesting. Surprisingly, there is expert
6C.100 disagreement on the basic tectonic regime of the crustal rocks of the British Isles. The Assessor tends towards the view of Nirex & its advisors that the regime is strike-slip, but suggests that the analogy of a local extensional stress pattern in the SW Scottish Highlands indicates that the Lake District could be similarly affected as a result of glaciation. This is partly a locational point but emphasises that Nirex's research should endeavour to form a
6C.98 clear view of the local effects of glaciation, particularly groundwater flushing.

6C.26 6C.192 Nevertheless, there has been very detailed research on seismicity in the Sellafield region, now with a continual flow of new data from instrumental monitoring. As is to be expected from the structural geological setting, West Cumbria is amongst the more
6C.140 seismically active areas of England. This is understandably a matter of great concern to some of the lay people who have made representations, and seismicity is a topic on which the
6C.47-8 expert groups have called for more research. The period of systematic observation is, however, minuscule in relation to 10^8 years. Whilst the objectors infer strongly that activity
6C.141 could be much worse & of greater magnitude in this much longer term, and an expert group has expressed doubts, I am advised that this is not what the local stress regime suggests inasmuch as it is understood so far. The deep disposal concept would seem to be much more

6C.101 robust against seismic shock waves than surface installations; and the Assessor is not
6C.142 persuaded from the examples given that there could be a large-scale pumping up of groundwater from deep below within the timescale in question.

6C.193 In contrast to the disagreements over seismicity, there is broadly a consensus on what
6C.40 is to be done about Climate Change, albeit that this is another matter on which the expert
& 48 groups have stipulated further research. The importance of specifying the postulated climate state has been acknowledged in the PSAs carried out so far, so that it has been possible to make a basic comparison between the predicted incidence of peak risk and the climate. This is to be enhanced in the form of alternative sequential scenarios for the next 125,000 years, with the probable capability, so the Assessor advises me, of providing a more continuous
COR/527 representation if required. This kind of work, together with the clarification of "critical groups" which must be made to grapple with shorter term problems like the agricultural wells scenario [see Chapter 6E], would enable the plausibility of earlier work such as HMIP's Dry
6C.137 Run 3 to be reviewed. There would of course have to be a different, qualitative approach towards the longer term, but the main relevance of the RCF to this would be in picking up
6C.51 further clues as to what happened in the past.

6C.194 Although it is not possible to come to final conclusions about the Further Work Programme until completing this Section of the report, the Assessor's comments and FOE's submissions are useful indicators for taking stock so far. There is a need to improve the detail & interpretation of geological structure & stratigraphy across the PRZ, and to extend investigations to greater depths. Whilst some of this work could be in parallel with the RCF, some of it would be required before the RCF starts in order to confirm that the RCF is in the best position; in order to be clear as to the impact of the RCF on the important features of its geological setting; and in order that the RCF is implemented in the least harmful & most effective manner. It is apparent that Nirex did not fully appreciate these points when it prepared its application, for example because it is now relying on the delay in the final determination of that application to carry out some of the requisite work.

6C.195 Even though Nirex is planning to sink more regional boreholes, especially along the coast, they would not be enough to obtain a clear understanding of the regional hydrogeology. All the additional regional boreholes would probably be outside the drawdown influence of the RCF, but there would be little point in going ahead with the remainder of the Sellafield DWR programme, including the RCF, until Nirex changes its mind & agrees to remedy the deficiency. Also, in order to end its undue reliance on limited data, controversial interpretations & extreme stochastic modelling of the PRZ, Nirex needs to sink more boreholes in or close to the PRZ itself. Almost certainly all these would be within the drawdown zone of the RCF; and so they should be sunk, monitored & allowed to settle down again before the RCF starts.

6C.196 In relation to this settling down, whilst Nirex is close to establishing baseline head data for existing boreholes, some more years monitoring of trends in the BVG are required. Also general advances need to be made in fields such as the local coverage of hydrochemical data. Investigations like these relate back directly to the needs for more boreholes & monitoring. In turn, there is some work which is particularly important in investigating exceptionally complex rock like the BVG but which must await the RCF, such as the large-

scale drawdown; direct observation & logging of the rock; tracer tests; high-quality groundwater sampling; and experiments on gas migration, excavation disturbance & sealing.

6C.197 In addition much more laboratory work and modelling development are required on matters such as radionuclide solubility, sorption & thermodynamic relationships. These may not seem to be directly related to the RCF, but the experiments must be focused on chemical conditions & temperature ranges relevant to a DWR in this PRZ. For example, sorption data need to be specifically related to the local rock types, and the natural colloids actually in the local groundwater have to be identified. It is not apparent to the Assessor & myself from Nirex's direct evidence on its programmes that all the important deficiencies are to be made good and all the requisite activities properly timetabled. One of the main tasks in the subsequent Chapters of this Section of the report is to conclude whether the requisite remedies can nevertheless be inferred from Nirex's other scientific & technical evidence.

6D. MODEL DEVELOPMENT

6D.1 Modelling is at the heart of any reliable PSA for the DWR, and the conceptual and mathematical models employed require sufficient understanding of the geology and hydrogeology of the site for their input [6C.11]. The assessment identifies and models the processes and pathways by which radionuclides from the DWR may subsequently return to the biosphere and to people. People would be affected by radionuclides entering the food chain through complex pathways, by their consumption in drinking water or by inhalation in dust particles [COR/526, Figs.1 & 3, pp.8 & 12]. Nirex has developed models around transport of radionuclides in groundwater, migration of radionuclides in gases, and return of radionuclides to the environment as a result of natural disruptive events or inadvertent human intrusion and this work continues [6C.103]. Modelling, together with research and investigation work, needs to address the areas of uncertainty in safety assessment [6C.50]; and some of the vital models would undergo crucial tests in the RCF programme.

6D.2 Gases. Modelling of migration of radionuclides in gases has not yet progressed to the stage of assessment of the overall gas pathway [COR/509, s.5]. The GAMMON mathematical model and associated computer program has been developed to model gas generation in the DWR by the coupled processes of metal corrosion and microbial degradation of cellulosic wastes. Further work is addressing the coupling of the operational and post-closure phases, a modelling approach to assess the implications for gas generation rates of an extended aerobic period, the treatment of heterogeneities in the near-field, gas-water interactions on colloid transport, surface gas release and combined theoretical-experimental studies and field work. Once gas reaches the biosphere, the multi-compartment model RIMERS simulates ^{14}C migration into soil [COR/526, s.4.4] and is considered by Nirex to be robust to within a factor of 2 except in respect of the first transit of ^{14}C through the soil-plant system where further studies are being carried out [idem].

6D.3 Human Intrusion/Natural Disruptive Events. The probability of return of radionuclides to the environment as a result of natural disruptive events or inadvertent human intrusion is considered by Nirex to be low, but such risks are being taken forward into future assessments through a combination of deterministic and probabilistic calculations and modelling. Nirex intends that, in performing individual risk calculations for human intrusion scenarios the underlying assumptions and models should, as far as possible, be consistent with those adopted in assessments of the groundwater pathway [COR/526, s.4.5, pp.17-18]. However, direct and indirect exposure gives rise to different assessment modelling requirements. The former, for example the risk from drilled core materials in the DWR, may be derived using exposure models while the latter, such as risk from extracted material then incorporated into surface soils, is modelled within the groundwater pathway. The groundwater pathway includes the definition of potential critical groups and their exposure to contaminated water from wells, irrigation and river augmentation.

6D.4 Nirex regards the main natural disruptive event for a DWR as an impact by a large meteorite, assessed to occur with very low probability [COR/501, para.5.6.16]. Possible hydraulic consequences of seismic events are currently modelled within the range of permeability assumed in near-surface strata in PDFs used in the hydrogeological model employed in Nirex 95 [COR/522] [6C.100].

6D.5 Groundwater. Because groundwater could transport each of the radionuclides in the wastes, Nirex regards it as the most important pathway. Nirex 95 [COR/522] reflects the most recent and comprehensive assessment and state of model development presented to the inquiry [6C.16]. Although later interpretive work has been published in COR/530 (3-D geological structure of the PRZ) and COR/518 & 518A (geological investigation drawings) this is not the result of further model development. Nirex 95 does not purport to be a comprehensive safety assessment but a preliminary analysis of the groundwater pathway for a DWR at Sellafield [COR/522, Vol.1, Introduction para.1].

6D.6 Nirex regards its conceptual model as not just a description of the behaviour of the system, but as including a definition of the processes within the system and the parameters required to model the system. The conceptual hydrogeological model, based on simplifications and other studies, thus provides sufficient information to enable the construction of numerical models. Nirex intends its numerical models to treat important aspects of the system in a realistic way but without unnecessary detail [COR/510, s.2]. Models facilitate cross-checking and sensitivity analyses and provide input for other models.

6D.7 The main tool used by Nirex for calculating radiological risk from radionuclides carried to the biosphere via the groundwater pathway is the MASCOT computer program and its output processor MOP. MASCOT employs the "Monte Carlo" method of random sampling from PDFs of uncertain model parameters, so providing estimates of the mean and distribution of calculated doses and associated risks. Sub-models describe such processes as release of radionuclides from waste packages, their mobilisation and migration from DWR vaults, transport through the geosphere and biosphere and consequent doses to individuals [COR/522, v.3, Figs 1.1 & 4.1 & para.4.4]. Sub-model input data are derived from other more detailed models, from the Site Characterisation Programme [see 6C.17-21 above] and from the Nirex Safety Assessment Research Programme [see 6C.22-27 above].

6D.8 The "source term" sub-model calculates the concentration of radionuclides in solution in the DWR vaults (near-field) groundwater as a function of time. Supporting sub-models such as RARECAN, CRACK 2, CHEQMATE, and HARPHRQ address the key physical and chemical processes of physical containment by the waste packaging, radioactive decay and ingrowth of decay products, solubility limitation, and sorption onto the NRVB backfill. Near-field groundwater is available for transport into the geosphere at a rate dependent on the flow of groundwater through the DWR volume. Work is continuing on the INHOMOG computer program [COR/529, Box 24, p.58] to model the chemical interactions between waste packages and their effect on radionuclide transport [idem, s.5.2.3].

6D.9 The behaviour of radionuclides transported in the groundwater flowing through the fractured rock of the geosphere is described by 2 sub-models, NAMMU and NAPSAC, which provide important inputs to the geosphere spreading term sub-model in MASCOT. NAPSAC also provides input data of DWR through-flow for the source term MASCOT model, and inputs into NAMMU. NAMMU models the flow system at the regional scale (10 km x 10 km [COR/522, Vol.1, s.4.3]) using a continuum porous medium (CPM) to approximate the behaviour of fractured rock larger than the representative elemental/ elementary volume (REV); whereas NAPSAC models use a more detailed local scale of about 3 km x 4 km [idem, Vol.3, s.2.2.1, p.2.7] and a discrete fracture network (DFN) computer code. Reliable geosphere flow path lengths and water transit times are required as

well as the rate of groundwater flow through the DWR volume [eg idem, Fig 2.7]. Two dimensional modelling has been necessarily supplemented by some 3-D characterisation of PRZ fracture flow in Nirex 95 [COR/522, Vol.1, s.4.4 & NRX/14/12, Figs.5.3 & 5.4] although uncertainty remains in the representation of flow zone connectivity. The models take account of radionuclide decay and ingrowth, advection, diffusion, hydrodynamic dispersion, and retardation by sorption and by diffusion into the pore space in the rock matrix [COR/510, p.10].

6D.10 The extent of faulting, fracturing and other discontinuities of the rock has led Nirex to employ stochastic modelling [6C.87; COR/522, Vol.1, s.5.1.1]. In Nirex 95, the conceptual model recognises 4 categories of permeability or organised structures of fractures [COR/522, Vol.2, s.2.2 & Figs 2.1 & 2.2]. Type 0 is the rock matrix porosity whereas Type III fractures are associated with major fault zones and have lengths measured in kilometres. The most recent characterisation of the PRZ has drawn on new data to obtain the currently best possible lithostratigraphic and structural 3-D model of the PRZ [COR/530, paras. 1.2-1.5] to inform further mathematical modelling.

6D.11 The biosphere sub-models of MASCOT are essentially a series of compartments containing soil, sediments and water between which radionuclides become distributed. The biosphere has been modelled as a system of homogeneous compartments assigned time-invariant values based upon assumed environmental characteristics and constant flux of each radionuclide from the geosphere [COR/526, s.4.1]. Flux-to-dose rate conversion factors enable the geosphere calculations of time-dependent radionuclide fluxes into the biosphere to be converted into doses and risks to individuals [COR/507, Fig.3, p.7 & COR/526, Fig.2]. A full probabilistic analysis has not been attempted [COR/526, s.5.5] but a somewhat simplified approach has been taken within a pragmatic strategy [idem, s.3.1]. The NRPB-developed BIOS model has been used to simulate the processes contributing to radionuclide transport and accumulation in terrestrial and marine environments for most radionuclides [idem, Fig.2, p.11] but for some, such as ^{36}Cl, ^{129}I and ^{238}U and its daughters, a more detailed heterogeneous resource area model has been developed. This development has been guided by a more physically realistic catchment model generated by the computer code SHERTRAN-UK which is also able to model mixing processes occurring at depth in the Quaternary sediments [idem, Fig.4, p.13 & s.4.1, p.12 & COR/522, para.5.2.1].

6D.12 Biosphere modelling includes definition of critical groups which have been taken by Nirex as representative of those members of assumed future communities that incur the largest annual Effective Dose from radionuclides present in the environment. Effective dose and potential health risk calculations have been derived from ICRP models. These have resulted in a series of risk calculations in Nirex 95 [COR/522, Vol.3, Figs.6.6-6.19] and its conclusions [idem, Chapter 9].

6D.13 Nirex now sees a need to develop a new dynamic model for the biosphere to replace the compartment modelling based on the BIOS program, allowing for alterations with time according to future evolution and the building of a formal "audit trail" to justify models and scenarios [COR/526, s.5.1 & COR/507, p.9] as required by the regulators [6C.68]. In addition, Nirex intends to develop stronger links between the understanding of biosphere processes emerging from the NSARP, the Site Characterisation programme and the overall groundwater pathway assessment, and address the implications of parametric uncertainty in

biosphere assessment modelling [idem]. This requires development of SHETRAN-UK to provide a suitable tool for use in hypothetical catchment modelling and climatological and landform related studies [COR/526, s.5.2]. The implications of this for groundwater modelling can be gauged from the prediction of a 40 m or more fall in the sea level leaving the entire bed of the eastern Irish Sea exposed [idem, s.5.4]. Nirex regards the removal of the restriction on models to be independent of time as the most important current development of the PSA methodology [COR/507, s.7]. This requires a greatly expanded definition of the system requiring modelling and greater model interface complexity [idem].

6D.14 Radionuclide-dependent parameters are large in number though the general characteristics of many are known from other models. A data-base is being established to facilitate expert elicitation of PDFs for key parameters. However, exploration of the implications of notional PDFs is considered by Nirex only to be capable of being undertaken in the context of specific future assessments, because changes in the near-field and geosphere components of the system can profoundly influence the relative significance of particular radionuclides and pathways in the biosphere [idem, s.5.5].

6D.15 Model Verification, Calibration & Validation. Verification of a mathematical model, or the corresponding computer program, occurs when it is shown that the program behaves as intended by demonstrating that it is a proper mathematical representation of the conceptual model and that the equations are correctly encoded and solved [COR/519, p.11]. The MASCOT program is said by Nirex to be verified [COR/507, p.6].

6D.16 Model calibration is achieved by correlation with a standard [COR/519, p.3] and is carried out by Nirex for each model against a sub-set of the available data prior to making predictions.

6D.17 The IAEA defines validation [COR/519, p.11] as

> "..... a process carried out by comparison of model predictions with independent field observations and experimental measurements. A model cannot be considered validated until sufficient testing has been performed to ensure an acceptable level of predictive accuracy. (Note that the acceptable level of accuracy is judgemental and will vary depending on the specific problem or question to be addressed by the model)."

6D.18 The draft regulatory guidance contains a similar definition [HMP/1/1, p.8 & paras.8.18 - 8.19], and views model validation as an iterative process of building confidence in the fitness for purpose of models used in developing performance assessment for a DWR and in the predictions they make. The process involves testing model predictions against independent observations and evaluating them against a set of performance measures within a peer review framework. Nirex defines validation as a 12 step cyclical process repeated as necessary. It is also used to discriminate between alternative models.

6D.19 Performance measures must be defined on a model specific basis with knowledge of the model's intended use in advance of the tests and must take account of the wide range of possible uncertainties such as those identified in 6C.50. Blind predictive modelling is the favoured technique to match prediction against subsequent observations during repeated cycles

until the addition of new data does little for the ability to make predictions [FOE/6/11, p.290].

6D.20 Current validation cycles of the groundwater flow models are intended by Nirex to build on the understanding derived from regional boreholes and are geared to be completed by the end of RCF Phase 1. Nirex plans a similar process for other modelling such as gas generation [COR/509, p.5]. It regards the initial cycle of validation of groundwater flow to have been completed in 1994, centred on cross-hole testing between boreholes 2 and 4 [NRX/14/13/Table A.8]. The Borehole RCF3 Pump Test is under way, focusing on flow model validation in the PRZ rocks and is a precursor to the RCF Shaft Drawdown Experiments and Sector Tests in Nirex's next validation cycle. The RCF3 Test [NRX/14/13/Table A.8 & A.11] assisted the evaluation of various combinations of stochastic and deterministic properties in the models to assess their capability. Class A, B and C predictions were made. Class A predictions were blind with independent data before the test. Class B predictions were carried out after the start of the test but without knowledge of the outcomes gained to date. Class C predictions are those made after the event.

6D.21 By the end of RCF Phase 1 Nirex anticipates that validation cycles will permit definition of the most appropriate models to apply to flow in each of the formations and selection of preferred models for assessment purposes; definition of tried and tested upscaling rules for the preferred models; and definition of an updated flow model for use in the safety assessment work. Nirex sees forward predictions during the RCF excavation phase as validating modelling of hydrochemistry, excavation damage, rock stress and its distribution, spatial variability in key features of the rock mass and groundwater flow in the BVG and cover rocks.

6D.22 Modelling Uncertainty. Uncertainty in performance assessment of radioactive waste disposal systems could arise in 3 main areas: the choice and specification of scenarios; the formulation and actual computation of the conceptual and mathematical models; and the quality and appropriateness of input parameters used [FOE/7/46]. Nirex has developed the approach to assessment in which acknowledgement and treatment of uncertainty is central [COR/507, p.5] and incorporated into the risk, rather than considered separately, based upon Government endorsed advice [GOV/208, para.76]. As outlined above, probabilistic safety assessment addresses uncertainty by specifying parameter values as elicited ranges (PDFs) rather than exact values; and, in solving equations, values are selected from these ranges by a "Monte-Carlo" sampling technique resulting in a distribution of possible consequences [eg COR/522, Vol.3, Figs.6.11 & 8.3-8]. However, some values of dose or risk are more probable than others and the mean of all the realisations calculated as a function of time is "the expectation value" which Nirex normally compares with the regulatory target. Work is progressing to refine modelling inputs [6C.25, 6C.33-35, 6C.40, 6C.43].

6D.23 This technique was applied in Nirex 95 [COR/522] where calculations were undertaken for a base-case conceptual model of the hydrogeology of the PRZ. The base-case was developed by an expert group judging it to be the most probable model based on the information available at that time. Issues were also identified which were not addressed by the base case model and so were the subject of variant calculations. The group investigated the match between calculated and observed heads and salinity; uncertainties associated with

the representation of type III features; and a number of different representations of the hydrogeology [COR/522, Vol.3, s.7, p.7.1].

6D.24 Variability was experienced between calculated and observed heads and salinity in the base case [idem, s.7.2, p.7.4]. The reason for the high heads was not known and it was considered misleading to take as a base case a model in which heads were artificially imposed [idem, s.7.3]. As a consequence 2 variants were used: imposed high heads and imposed salinity distribution [idem] and a transmissive feature at depth [idem, s.7.4]. Observed environmental head data were not used. Type III feature uncertainty was explored by assuming that the Seascale Fault Zone preferentially diverts flow by increasing fault width [idem, s.7.5] and by representing the fault as being no more permeable than surrounding rocks [idem, s.7.6]. Hydrogeological uncertainties were represented by a less dense network of Type II features in the BVG [idem, s.7.7] and by the basal deep St Bees Sandstone as a barrier to flow [idem, s.7.8]. Some modification was made to variants for DWR performance [idem, s.7.9].

6D.25 Nirex regards the processes and features highlighted by objectors as being adequately addressed for the current stage of development of the programme. It does not accept that a complete understanding of all processes is essential to assessing system performance, and more data would not necessarily improve modelled predictions in its view [6C.74]. Uncertainty is dealt with in modelling probabilistically and with the assistance of an expert group, following regulatory and Government advice by incorporating uncertainty into the assessment of risk rather than dealing with it separately [HMP/1/1, paras.6.7 & 6.10; GOV/208, para.76]. Model uncertainty can be treated as parameter uncertainty. This process led to the base case model in Nirex 95 [COR/522]. Uncertainties are being comprehensively addressed in Nirex's contention. For example, in some instances and pending RCF investigation, a conservative assumption is made, eg sealing and grouting where flowing fractures are assumed not to be sealed in current models [6C.95], and in the selection of PDFs for geochemical processes. Nirex asserts that dealing with uncertainties in this way, together with Monte-Carlo iteration until such time as they can be better resolved, is in line with international practice and this work is progressing well [6C.90]. It has not been necessary to modify the conceptual model of hydrochemical conditions [6C.79].

6D.26 Cumbria's suggestion that errors need to be distinguished from uncertainty is misplaced and fails to appreciate the implications of the probabilistic method. For example, the employment of a pessimistic bounding calculation for sub-surface routing in the biosphere must be weighted for its low probability of occurrence. Similarly, the significance of extreme values of risk [COR/522, Vol.3, Figs.6.9 & 6.10] cannot be assessed without consideration of the low probability of occurrence.

6D.27 Theoretical modelling exercises carried out on behalf of HMIP [GOV/622, GOV/623, GOV/628] had limitations not present in Nirex's programme, such as an irregular mix of borehole data and limited time, undermining the cogency of any lessons learned. Nevertheless, the RCF would complement regional investigations to overcome any shortcomings in data, and models would be validated to achieve sufficient confidence against a range of data and not just hydraulic heads. Careful evaluation of uncertainty would overcome any errors in risk prediction in Nirex's view.

6D.28 Biosphere assessment modelling is designed by Nirex to ensure that there are no important omissions. Criticisms by Cumbria arise because of inappropriate comparisons with HMIP studies [eg CCC/5/1]; overstating the effects of climate change and the results from variant groundwater flow models for Temperate terrestrial discharge; overlooking the modelling of incised rivers and streams already carried out [COR/526/Fig.6, p.16]; and failures to appreciate that there is not strong sorption of significant radionuclides to submerged marine sediments, and that the risk from agricultural wells is not sensitive to the alternative scenarios posed (Chapter 6E). Furthermore, the wide range of radionuclides modelled in MASCOT [COR/522, Vol.3, Table 6.1] extends beyond the 4 which were found to make a significant contribution to risk in the biosphere (^{36}Cl, ^{99}Tc, ^{129}I and ^{238}U and daughters), and objectors have misunderstood the explanations in Nirex 95 (Sections 6 & 8).

6D.29 Nirex regards criticisms of its approach to groundwater flow modelling, the results obtained and features modelled, as indicating that objectors do not appreciate or recognise important aspects of the work [6C.87]. The NAPSAC fracture network code and the NAMMU groundwater flow and transport code are well verified computer programs which are extensively used internationally, including in the Stripa [NRX/16/2, p.47 - NAPSAC] and HYDROCOIN [COR/510, p.6 - NAMMU] Projects. Fracture network models were used in the upscaling process to derive the regional-scale effective hydrogeological parameters for the BVG and the parameter distributions for the MASCOT sub-models of radionuclide transport in the BVG as well as modelling flow and transport through the PRZ. Two dimensional modelling in Nirex 95 has been carried out conservatively and 3-D modelling is intended at an appropriate stage as required by the Regulator.

6D.30 The conceptual model and parameters have been developed carefully to eliminate bias and unquantified uncertainty and to apply the appropriate type of model to the different regimes. Fracture network modelling is widely recognised as appropriate for modelling groundwater flow and transport in low-permeability rock such as the BVG [FOE/6/15, p.S29] and examples of purported shortcomings in DFN models based on earlier experience are misplaced. It refutes the suggestion that no sensitivity analysis of regional flow modelling was performed [COR/522, Vol.3, s.2.4.2], and that the modelled behaviour is suspect as between COR/505 and COR/522 when more site data became available. As regards modelling results, predictions of marine discharge of radionuclides are derived from modelling based on an understanding of the site hydrogeology in current conditions. They are not assumptions made for Temperate conditions where some level of terrestrial discharge is predicted [COR/522, Vol.3, p.2.12 & Fig.2.6b]. Upwelling in the Fleming Hall Fault Zone and reduced permeability across the Seascale Fault Zone are accounted for in Nirex 95 [COR/522, Vol.3, p.2.15 & Fig.2.12 & Vol.2, Fig.5.1 respectively], and the former may be a conservatism. Nirex submits that it is safe to ignore the permeability of the backfilled and sealed RCF shafts in the MASCOT modelling [6C.95].

6D.31 It refutes the suggestion that any physically realistic features have been excluded from the models and points out that Glasgow University's hydrogeological model, relied on by Greenpeace, is limited and does not model dilution. Nirex's predicted flow paths have been determined by the physics of the flow system which have been incorporated into the models representing the current understanding of the site. PDFs for such features as matrix diffusion and effective permeability are assigned probabilities in a structured way [COR/508, p.9, Box D & COR/522, Vol.1, Appendix 1]. The range of dilution factors used in Nirex

95 has been derived from an analytical calculation and only takes account of uncertainty in one of the effective hydrogeological parameters. As MASCOT realisations take account of the uncertainty in many more parameters, the range of effective dilution factors becomes potentially wider.

6D.32 Before construction of the RCF, a new regional coupled model would be available accounting for observed head and salinity distributions probably by incorporating geothermal effects at the bottom boundary of the model. A revised conceptual model of groundwater flow is planned for November 1996 and would be tested using new boreholes drilled prior to RCF sinking. The variants presented in Nirex 95 are not the only set of conceptual models for regional flow and alternative models have been appraised. For example, the RCF3 Pump Test has been used to compare 6 alternative conceptual models of groundwater flow within the BVG. Nirex asserts that its validation tests include comparison of model predictions with measurements of hydraulic properties other than heads [COR/510, s.2.4, p.18].

6D.33 Nirex refutes Greenpeace's contention that it is necessary to narrow the range of fluxes of groundwater through the DWR because the probabilities associated with different values of groundwater flux are sufficiently low for the calculated risk to be acceptable. It points out that lower fluxes are as probable as higher fluxes and that the RCF would test that the expectation value of groundwater flux through the DWR, derived from one or more conceptual models, gives an acceptable risk. The distribution of fluxes considered in the probabilistic calculations is a proper representation of the uncertainty in that parameter; and this distribution is acceptable in the context of regulatory requirements taking account of the probabilities of their occurrence. Furthermore, current modelling does not optimise the DWR location with respect to Type II features in the BVG with consequent reduction of groundwater flux.

6D.34 It regards Greenpeace's suggestion that the source term and geosphere spreading times [COR/522, Vol.3, Fig.8.8] are directly and proportionately linked as wrong because the controls on the flux and geosphere travel time calculated in Nirex 95 are well understood and different. Flux through the DWR is mainly controlled by the horizontal gradient of the freshwater head in the BVG at DWR depth and the horizontal component of the effective permeability of the deep BVG [idem, s.7.9, pp.7.9-7.10 & Table 2.3]. Except for the case of release from the small downstream section of a vault, the travel time in the BVG makes only a small contribution to the overall geosphere travel time. Geosphere spreading time for water leaving a DWR vault would be dominated by the time spent in the sandstone formations overlying the BVG [idem, Table 2.3], controlled mainly by the vertical gradient of the environmental head and horizontal gradient of the freshwater head in the sandstone formations and the effective permeabilities and porosities of the relevant sandstone formations. MASCOT provides a robust interpretation of these independently controlled but correlated parameters [idem, s.8.2.3, p.8.12]. Nevertheless, the RCF would make an important contribution to building confidence in the calculation of the geosphere spreading time in the Shaft Drawdown Experiment and the modelling of Type II features.

6D.35 Nirex proposes an extensive further programme for the cyclical validation of its models, covering a variety of scales including macroscopic, in a multi-staged process involving prediction and subsequent observation in relation to previously identified criteria together with peer review. Validation would focus on key uncertainties with the help of RCF

data and could continue through RCF Phases 2 and 3 if necessary, although it is intended that the regional scale models would be available for RCF Phase 1. The RCF would facilitate 3-D testing at greater length-scales and simultaneous testing and observations on specific features on the larger scale.

6D.36 Reservations about model development prior to commencement of the RCF are unjustified in Nirex's contention. The adequacy of safety assessment models would be a matter for the appropriate regulatory bodies. Also, the RCF is an essential facility for the calibration, validation and improvement of models to be used in PCSA and the validation process would incorporate appropriate peer review. Objectors have misunderstood the process of model validation and the integral role of the RCF in it. The INTRAVAL Project showed general international agreement that models cannot be validated generically but must be site specific [COR/605, p.88].

6D.37 Validation is not a matter of ruling out models that are inconsistent with data but a process of building confidence in the fitness for purpose of models, achieved through their refinement and development [COR/510, p.2] as set out by the regulators [HMP/1/1, para. 8.19]. Rejection of an imperfect model may discard potentially useful information so the results of different approaches should all be considered. At some stage in the validation cycles it may be reasonable to specify quantitative acceptance criteria (as are being considered for the RCF Shaft Drawdown Test). A good outcome of validation testing of alternative models would be increased confidence that the current judgements are correct and that alternative models, not consistent with meeting regulatory requirements, are of acceptably low probability. Uncertainties are not of themselves obstacles to establishing the safety case [idem, paras.8.15 & 8.16].

6D.38 Nirex's validation procedure has incorporated performance measures for some years [NRX/15/39]. The forward predictions for the RCF3 Pump Test to discriminate between, and refine and develop, conceptual models were held independently for comparison with relevant performance measures. Approaches to building confidence in the regional scale groundwater flow model and, in particular, the hydraulic model of the BVG are different, reflecting the different character of both the data and the uncertainties of importance to performance assessment which underlie the system concerned. At the PRZ scale a more detailed understanding and evaluation is required in order to evaluate the behaviour of the engineered barrier system and the source-term spreading time. A less detailed understanding of groundwater flow through the rest of the regional system is acceptable for evaluating larger scale geosphere transport. Predict, perturb and monitor tests are not required at a regional scale where, for example, palaeohydrogeological studies are more appropriate, although wherever possible comparisons of outputs from mathematical models with independent field observations have been used to refine the regional scale models.

6D.39 The application of quantitative performance measures to regional scale groundwater flow modelling has, together with the results from a number of other ongoing modelling studies, not yet been published but has been found valuable to assess the adequacy with which key features or processes are modelled and examine their treatment that may explain discrepancies. Full representation of the increase in hydraulic head with depth in the Nirex 95 base case, treatment of major fault zones as Type III features, the height of the water table to the north-east of the PRZ, the extent of sub-vertical fracture systems and related effective

permeability in the Deep St Bees Sandstone and variable permeability are all refinements likely to be considered to the regional scale models.

6D.40 As to fracture network model validation, in the RCF3 Pump Tests, Class B predictions became necessary for practical reasons, but were independent and are entirely consistent with its validation strategy. Nirex viewed the initial validation cycle involving Borehole 2/4 cross-hole testing as successful in meeting its objectives [NRX/15/16] and in particular enabling the construction of conceptual models for subsequent testing - a more meaningful test of outcomes of validation than adherence to a prescriptive approach as advocated by Greenpeace. FOE's criticism of the Stripa Test [FOE/6/15, p.S28] is misconceived because the test was only used to generate input values to another model using NAPSAC and not to predict flow.

6D.41 Nirex refutes the suggestion by Greenpeace that an assumption of uniform hydraulic properties is conservative in safety terms, pointing out that the inclusion of heterogeneous properties and fracture networks can lead to channelled flow and higher calculated risks than for an assumption of uniform properties [COR/522, Vol.3 Chapter 3]. Furthermore, the reduction with time of the solubility and sorption properties of chemical containment is modelled conservatively in Nirex 95, by assuming a reduction in performance by an order of magnitude from day zero.

6D.42 Cumbria regards the conceptual model as simplistic [6C.116]. It points out that, in Nirex 95, adjustments are required to account for the presence of some process or feature at great depth below the PRZ which has led to a variant model of a transmissive feature at depth with artificially imposed high heads being required in the preliminary safety assessment [6C.115 & 116] which Nirex acknowledges. Cumbria suggests that Nirex is being complacent about the effects of modelling change between climate states, referring to the conclusions of HMIP's "Dry Run 3" that the results of such modelling are unpredictable [CCC/5/1, para.7.2, p.101]. It regards the conclusion as relevant and salutary for the PRZ on this point even though the results may not be transferable from Harwell in other respects.

6D.43 Also, the Nirex 95 deterministic run takes no account of the range of uncertainty over the ^{36}Cl present in the inventory, yet it would be spread widely across a number of waste streams. Cumbria expresses general concern about the large numbers of assumptions and uncertainties in the modelling and emphasises the need to discriminate between uncertainty and error in safety assessment [6C.116-9]. The regulators require reduction of uncertainty [6C.71]. Other participants support the point of principle [6C.107, 6C.121-122].

6D.44 As regards biosphere modelling, the approach of HMIP's consultants suggests that the critical group should be located above the maximum concentration in the plume [CCC/5/6, s.2.5, p.16]. Furthermore, the hydrogeological evidence suggests that upwelling [eg COR/522, Vol.3, Figs.2.6a, 2.11 & 2.12] could result in a significant radioactive plume reaching the surface well before presently predicted marine discharge, especially with landform evolution. Nirex accepts that biosphere assessment calculations need some amendment [6C.126].

6D.45 Greenpeace is concerned that fracture flow and regional models have not undergone blind prediction against quantitative criteria; there are inconsistencies between calculations and observations; and performance measures have not been properly defined or applied. Calibration has not taken place against hydraulic properties other than head data [WR/GNP/3, para.6.6]. The RCF drawdown experiment would be the first validation cycle for fracture flow models. Similarly, regional boreholes planned by Nirex cannot be utilised for model validation until regional flow models are sufficiently advanced to make blind predictions prior to data gathering. It points out that if data used to calibrate a model are not independent they are not appropriate for validation. It regards Nirex's work so far as simply the iterative processes of model calibration and model building, and does not accept that it is yet at the validation stage.

6D.46 It submits that confidence in groundwater modelling is essential in order to derive performance criteria for fracture flow models during validation in the RCF, especially in the light of experience of unexpected results in earlier studies for HMIP [WR/GNP/3, para.4.7]. Neither the fracture flow nor the regional models would have been through rigorous validation cycles before the RCF is built and the large perturbation caused by the RCF would prejudice the reliability of further modelling data. Furthermore, it appears that data from the deep BVG necessary for validation of the fracture flow models would not be available by the time Nirex anticipate submitting the DSA to the regulators; and a macroscopic groundwater model does not seem to be in sight, only component models.

6D.47 The data input to MASCOT [COR/522/Fig.8.8] and the conceptual model of regional groundwater flows in Nirex 95 reveal too many uncertainties in Greenpeace's view. Models inconsistent with data should be rejected. Nirex's models estimate that groundwater fluxes through the DWR could be up to 150 times greater than the central base case value [COR/522, Vol.3, s.2.3, p.2.13], giving rise to corresponding uncertainty in the source-term spreading time. Nirex recognises that the uncertainties about the properties of the BVG that would control the flux of groundwater through the DWR are currently too great to come to a decision whether to propose development of a DWR.

6D.48 In addition, DWR flux and geosphere travel times (therefore source-term and geosphere spreading times), assumed by Nirex to be independent, are more likely to be linked. This would materially affect the safety case, since achieving the risk target is highly vulnerable to even relatively small increases in groundwater flow.

6D.49 Validation necessarily entails narrowing the range of potential conceptual models. Greenpeace contends that, although validation does distinguish between models which do, and do not, agree with data, validation cannot assign probabilities as to whether one model is more realistic than another. Where alternative descriptions are consistent with data, they must be considered equally likely. Thus there is no process by which different probabilities can be attributed to alternative conceptual fracture flow models; and little confidence can be placed in qualitative comparison between model output and observations, except in model development. Over-emphasis on qualitative measures could lead to a model which looks plausible but is not valid. Nirex accepts that it may never be able absolutely to rule out or reject improbable alternative models, the predictions of which are inconsistent with meeting regulatory requirements.

6D.50 Greenpeace submits that the hydrogeological modelling carried out by Glasgow University [GNP/3/4] indicates different flows and a shorter timescale to reach surface than those suggested by Nirex, which would seriously prejudice the safety case [GNP/3/28/Figs.8.1a & b] (see further Chapter 6E). The permeability of the BVG is the controlling parameter. Furthermore, Nirex's models assume all faults to be dormant throughout the modelling period, whereas active faults cause progressive rock displacement which could substantially alter groundwater flows.

6D.51 FOE contend that a single comprehensive 3-D time-variant model of the Sellafield area of 10 km x 10 km minimum (larger if warranted by boundary conditions) [6C.116], supported by extensive sensitivity analysis, is an essential pre-requisite for a representation of the complex groundwater flow regime at Sellafield. Piecemeal modelling cannot be relied on, although sub-models would help. Faults should be explicitly modelled and to within 10m accuracy. Nirex recognises that a more realistic 3-D model needs to be developed.

6D.52 Likewise, the impact of the RCF on baseline conditions needs to be rigorously modelled, in the wake of the scoping study Nirex 560 [FOE/5/19], before RCF development commences, but the baseline conditions themselves first need to be re-established [6C.133]. Baseline conditions are being disturbed by cross-hole testing and the RCF3 Pump Test so Nirex's assessment of baseline establishment [NRX/14/3] was premature. FOE are sceptical that model validation can be achieved for some years, especially with peer review of the results [WR/FOE/24]. Nirex concedes that much of the modelling on which it relies is at an early and unproven stage yet it moves on from objectively unsuccessful experiments, claiming that sufficient has been learned.

6D.53 Models used to quantify fracture flow are in their infancy [eg FOE/6/21, s.6] and have not been validated in FOE's view. Nirex concedes that fracture flow modelling is very demanding, and progress has been limited by absence of data, particularly at the larger scale. FOE contend that upscaling from DFN to CPM models is also problematic. Nirex concedes that NAPSAC was used rather inappropriately in a Stripa test, and that a model relying on some NAPSAC inputs failed to predict a reduction of flow following excavation in a validation test [FOE/6/15, p.S28]. The only cross-hole testing reported by Nirex showed very little correlation with the predicted distribution of likely responses based on detailed assessments of the Environmental Pressure Measurement tests [NRX/15/16, s.6.3, p.136]. In view of the random and extensive faulting of the host rock FOE do not find this surprising and regard the PRZ as a very difficult site to model [6C.120]. They support Greenpeace's proposition that RCF excavation would exacerbate validation problems, citing experience in Sweden and Canada. In its turn, Cumbria doubts that modelling of Type III features would be validated by the RCF because it believes they need deterministic characterisation.

6D.54 FOE criticise Nirex's relative lack of sensitivity analyses and heavy reliance on estimates of parameter values critical to the safety case, suggesting that the modelling is prone to serious error. For example, although the existence of pathways through the Brockram has been considered possible since 1937, in 1994 the elicitation group viewed the Brockram as a low permeability formation in setting conductivity values. Also, the value given to the Latterbarrow Sandstone is below the normal textbook range for sandstones and has only been partly modelled in Nirex 95, and there is a failure to take into account in the base case the dominance of vertical features in the St Bees Sandstone. Modelling at a higher conductivity

would have helped explain the observed high BVG heads at depth, but have increased the volume of groundwater flow through the PRZ [WR/FOE/23]. The potential for additional vertical flow within boreholes themselves is a further omission from the models.

6D.55 FOE emphasise that the hydrogeological behaviour of the PRZ has had to be modelled so far on a base case and on variants, including those where high heads are imposed and a transmissive feature at depth assumed [COR/522.Vol.3,Figs.7.14 & 7.16], in order to reconcile observations and modelled predictions [COR/522.Vol.3,p.7.4].

6D.56 Nirex's near-field modelling is regarded by FOE as very preliminary and unsophisticated in its application to RCF construction and sealing [6C.131-2]. Important phenomena such as interface flow have been neglected and inferences have been unjustifiably drawn from experience in Canada and Sweden where there is a different rock structure [6C.105-106].

6D.57 FOE consider that the model used to quantify the behaviour of the NRVB is unrealistic and unreliable [6C.127]. Modelling, and the concept, have many shortcomings and the model has not been validated. For example, homogeneous chemical conditions are assumed within the backfill yet are unlikely; there are no measures to eliminate interface flowpaths between backfill and rock; the backfill would not impose significant delay in the saturation process or reduce flow through the DWR (eg for ^{36}Cl and ^{129}I); and the assumption that NRVB would retain its anticipated physical and chemical properties over the required timescales is open to doubt. Also HMIP have already been critical of Nirex's geochemical modelling and data [6C.123], and the Royal Society have expressed concern [6C.45]. Some 5 to 10 years of work would probably be required before an acceptable geochemical model could be ready for the next cycle of safety assessment. These doubts are shared by Greenpeace [6C.125] and **Mrs Higham** [6C.129].

6D.58 On uncertainty, FOE point out that for PDFs to be effective the processes underlying the element of the system it is intended to model must be understood. That understanding is open to doubt, for example, in respect of radionuclide transport behaviour in the DWR vaults [COR/529, p.58] [6C.123].

6D.59 **My conclusions** in this Chapter relate to the vital roles played by conceptual &
6D.1 mathematical models in showing that the proposed DWR would be safe at the preferred
6D.25 location. It is agreed that the models must be based on a sufficient understanding of the
6D.58 geology & hydrogeology, and the main issue between the parties on model development is whether Nirex's understanding of these & related matters has advanced far enough to enable it to proceed effectively with the RCF.

6D.60 Most of the items of concern relate to modelling of the groundwater pathway, but it may be instructive first to look briefly at other potential pathways for the transport of
6D.2 radionuclides from the DWR to the human body. The lack of a model for gas migration through the geosphere, and its inter-action there with other media, seems an obvious gap in
6C.50 resolving this key uncertainty. The promised research results on gas-water inter-action would
6C.176 not completely fill that gap. The RCF would be a unique opportunity to investigate gas
6C.71 migration, and this is one of the specific research topics mentioned by HMIP to the inquiry.

6D.20 Yet there is no indication that Nirex would have a migration model, as distinct from a gas generation model, ready for testing in Phase 1 of the RCF. Its evidence to the inquiry has
6C.92-3 relied simply on experiments elsewhere and its scoping studies.

6D.61 On the other hand, human intrusion or natural disruptive events are pathways which I would not expect to be fully susceptible to detailed modelling. In my judgement, they are generally being approached in the right manner by the deployment of a number of techniques
6D.3 whilst being integrated with the main modelling where practicable. Nevertheless, the Assessor advises me that a greater understanding of fracture flow through the BVG is
6D.4 required before serious attention can be given to transient seismic effects or the consequences of more permanent stress changes.

6D.62 Although the RCF should contribute to such understanding, this obstacle is also one
6D.9 of Nirex's basic modelling problems, which frequently recurs in examinations of the core
6D.47 modelling activities and their development for the groundwater pathway. Certainly I agree with Nirex that a complete understanding of all processes is not essential to the assessment
6D.25 of system performance: indeed such an understanding is unachievable because the natural world is so varied & complex. Also I accept that the acquisition of more data does not necessarily improve the predictive ability of models. But this emphatically does not mean that Nirex's model development could successfully proceed without a robust grasp of the fundamental processes or without basic amounts of credible data. I am sure that these would
6C.156 be expected by the continuing peer review which the draft regulatory guidance stipulates
6C.153 uniquely for the model development programme: and the demands of objective data
6C.154 elicitation & transparency would also militate against obscurity of concept or content.

6D.63 Chapter 6E carries forward the discussion on uncertainty, but a few underlying
6D.43 points should made at this stage. In some of the exchanges during the inquiry, one person's
6D.26 error bar has seemed to be another person's uncertainty distribution range. Although this is a semantic point, it emphasises the analytical necessity to be clear about the type of
6D.25 uncertainty under consideration. Nirex's probabilistic assessments & conservative assumptions are of course 2 main ways of treating some kinds of uncertainty, and yet they have their limitations like all such techniques. It seems to me that some of the resistance by other parties to the extent of Nirex's stochastic modelling may be due to a lack of awareness of the recent achievements of such methods in similar disciplines such as epidemiology. On the other hand, Nirex sometimes needs to be reminded of adages such as that the quality of
6D.54 the output depends on the quality of the input, and that different averages should not be
6D.49 averaged. The possibility of further human error should be considered when examining, for
6D.26-7 example, the reliability of an elicited distribution range or occurrence probability value.

6D.64 Similar strictures could be applied to assertions such as that biosphere assessment
6D.28 modelling has been designed to ensure that there are no important omissions. The fraction of the radionuclide discharge going to deep soils is actually conceded by Nirex to need
6C.126 amendment. More generally, even if some of Cumbria's criticisms are over-stated, Nirex
6D.13 also accepts that a new dynamic model for the biosphere needs to be developed. Yet I am advised that time-variant models incorporating climate change & other evolutionary driving
COR/507 forces seem to be still at an early stage, and that the numerical models have yet to be developed. Whilst biosphere modelling is not directly related to the RCF, this situation

should be taken into account when considering claims of the promise shown by modelling work to date, or the realism of the timetable which incorporates the RCF programme.

6D.65 Nevertheless, I also agree with Nirex that some of its opponents have not always
6D.29 appreciated or recognised important aspects of its groundwater modelling work. The
6D.51 promotion by FOE of a unified 3-D time-variant model of the Sellafield area seems to be partly due to such a lack of appreciation, coupled with a counsel of perfection. Nirex is able
6D.5 to produce 3-D digital maps which synthesise available information. But so far as real conceptual & mathematical modelling are concerned, the advice to me is that practicability demands both a multiplicity of models and a frequent preference for 2-D models over 3-D ones. FOE appear also to have confused the development of one comprehensive 3-D model
6D.29 with the several needs for more 3-D modelling of various sorts.

6D.66 However, I am also advised that these needs are very strong. The topics to be covered are familiar ones by now, involving broad-brush 3-D approaches towards
6C.166 investigating the historical evolution of the groundwater system; towards a better
6C.159 understanding of present hydrogeological conditions around the District; towards coping with
6C.193 climate change & other transient driving force scenarios; and towards exploring the effects of varying the location of the DWR within the PRZ. The first 2 topics are indirectly related to the RCF inasmuch as they would enhance knowledge of its setting and might help focus the investigations & experiments within it, whilst the last topic is directly connected to the
6C.194 position & timing of the RCF, in my view.

6D.67 The advice to me adds, moreover, that the characterisation of the PRZ in the vicinity
6C.167-8 of the RCF would require more detailed 3-D representation of the geology & hydrogeology: and this brings us back to the crux of the contentions about the extent of Nirex's
6D.53 understanding of the fundamental uncertainties in both the relevant modelling and the host
6D.47 environment. In the first place there is a generic problem in that most of the fluid flow
6C.53 through the PRZ, especially the BVG, is believed to be through fractures, and yet the physics
6D.31 of such fluid flow is poorly understood. Models of the discrete network type ought to be best
6D.30 for rock hydraulic modelling, but even the sophisticated NAPSAC package cannot
6D.9 meaningfully represent a 3-D geometrical distribution of fractures.

6D.9 6D.68 The similarly advanced CPM model, NAMMU, could be an adequate tool for the investigation of flow in the rock mass, but it cannot on its own determine whether short-cut flow paths to the biosphere are possible nor allow for changes in rock stress or temperature. Moreover, there is a difficulty with scaling up the parameter values of the BVG. Although
6D.20 the REV must always be site-specific, the borehole tests suggest particular problems at Sellafield due to the unusual complexity of the volcanic rocks, for instance the preferential
6C.54 channelling of the flow through only a small proportion of the fractures. The Assessor advises me that this exemplifies serious difficulties in applying NAMMU to the BVG.

COR/510 6D.69 Nirex is developing a linked NAPSAC-NAMMU model, which appears to me to be a significant step forward, but for the moment it seems restricted to a simplistic representation of each individual volume of rock. Another very important advance in multiple models would be the thermo-hydromechanical model which would be able to incorporate deep
6D.32 geothermal effects as well as the heat generated within the repository. Nirex has intimated that the former might well help account for discrepancies with observed head & salinity

6D.24 distributions in its present regional-scale model, which the preliminary assessment modelling in Nirex 95 had to grapple with. However no description of this model was published by the close of the inquiry. Whilst making it available would, so I am advised, entail a revision rather than a replacement of the regional conceptual model, it seems that Nirex may well be
6D.32 unduly optimistic about the work still to be done on such a coupled model and its incorporation into the overall set of models.

6D.42 6D.70 This is particularly important because the inability of the current concept & its
6D.55 derivatives to match observed heads & salinities is a fundamental defect, in my view. The advice to me is that, in a coastal location like Sellafield, calibration of a broad groundwater model is typically based on obtaining the best fit between simulated and measured heads &
6D.15-21 salinities. Debates at the inquiry about verification, calibration & validation have had a large
6D.35-40 semantic element and been subject to preconceptions on both sides, not unlike the discussions
6D.49-53 on uncertainty. But, even when adopting the strictly practical approach of fitness for purpose from the initial calibration stage, there is no escaping the fact that the current conceptual model at the core of Nirex's modelling cannot account for some basic processes & parameters of the hydrogeological system. The new model which is promised in order to cope with this problem is of completely unknown quality. The Assessor also considers that conditions &
6C.194 processes going on at depths well below the proposed DWR are likely to have to be addressed
6D.46 in due course.

6D.71 In my view, Nirex should not be contemplating a start, in the form of the RCF Shaft
2B.15 Sinking, of what may be a long-term perturbation of the centre of the system before resolving
6D.52 this matter. Although baseline conditions are effectively a mere snapshot in time and it is not
6C.78 necessary to know that the system has returned to complete baseline conditions after any particular intrusion, as the Assessor points out, any imposition of stress for model testing
6C.178 purposes must be done in a controlled & measurable way. This would be impossible for
6D.53 other tests in the midst of a large drawdown experiment. Still taking the strictly practical
6D.35 approach towards verification, calibration & validation, but allowing for the necessary peer
6D.32 & 39 review, it is very difficult to see how Nirex would develop its models sufficiently in this
2B.9 regard by the proposed start date. This would be even after delays in obtaining planning
6C.103 permission not foreseen by Nirex until last year. The realisation that before then Nirex was planning to go ahead on a now plainly inadequate timescale for model development is of particular concern to me.

6D.34 6D.72 There are other basic modelling problems too. Although Nirex does appear to have
6D.48 a better understanding than Greenpeace of the controls on flux through the DWR & geosphere
6D.21 travel time, and of course the RCF should make an invaluable contribution to model
6D.36 calibration & validation, Nirex has been evaluating no fewer than 6 alternative conceptual
6D.32 models of groundwater flow within the BVG. This evaluation has been in the course of the
COR/518 RCF3 Pump Test, of which the final peer-reviewed results are not available, even though
6D.53 Nirex has been relying heavily on some preliminary results. The Assessor regards this Test
6D.40 as the first & an imperfect validation exercise for models of the PRZ, in comparison with
6D.50 Nirex's belief that the initial validation cycle was the Borehole 2/4 cross-hole testing.

COR/507 6D.73 It also seems that Nirex has been conducting random sampling from the output of
6D.49 alternative models according to allegedly defensible degrees of belief in the models, but I

share the Assessor's scepticism at such a practice, since in my view that criterion must run a serious risk of being merely circuitous.

6D.74 In fact, difficulties are apparent along the length of the groundwater pathway. In
6D.57 modelling the near field there are simplifying assumptions about the release of individual radionuclides into the groundwater which would need to be refined well before preparation of the DSA, according to the Assessor. A basic point about the geosphere is that the steps
6D.10 being taken by Nirex formally to quantify basic geological uncertainties, such as the precise
6D.53 identification of faults & major stratigraphical units, are not clear-cut. Then again, Nirex's
6C.161 ignorance of the actual conductive properties of the major faults, on which I have already
6D.50 commented, is reflected in its modelling, as noted by the Assessor, who emphasises the great effect on flow path-lines & transit times of the assumptions made about the fault zones.

6D.75 A phenomenon not otherwise emphasised much is the potential for sideways dispersion in the plume of radioactive groundwater. This becomes of importance in Nirex's
COR/522 rebuttal of the worst implications of the agricultural wells scenario discussed in the next Chapter, and the Assessor remarks that there appears to be considerable uncertainty over the effects of transverse dispersion even though it can have a marked effect on safety assessments. Yet other needs, in his view, are for more exploration & modelling to
6B.34 investigate both divergent flow away from the PRZ across the SFZ to the south, and the influence of the Carboniferous limestone to the north.

6D.76 Much of such work would not be directly related to the RCF. However this review of model development indicates that there are many uncertainties yet to be adequately treated both in the modelling techniques and in the features to be modelled. The overwhelming impressions are of a large volume of work to be done and of a powerful drive to speed through it, sometimes without due regard for the chronological or statistical niceties. In turn this haste raises questions about the degree of confidence in the decisiveness of the preliminary modelling work. This rather negative effect is perhaps typified by the final
6C.133 points that the only study submitted to the inquiry on the perturbation & safety assessment
6C.95 effects of the RCF looks distinctly out of date, whereas the various groundwater flow models
6D.32 now under consideration do not appear to be sufficiently well developed yet to credibly
6D.39 predict such effects.

6E. RADIOLOGICAL PROTECTION & SAFETY ASSESSMENT

6E.1 The principal risk posed by a DWR is from the escape of radionuclides from the emplaced waste and subsequent exposure of people [6A.2]. HMIP regards the duration of the risk as being mainly dependant on the rate of decay of the radionuclides in the waste. Potential pathways, namely gas, human intrusion, natural disruptive events and groundwater have been modelled to varying degrees by Nirex [Chapter 6D]. A preliminary analysis of the most important pathway for a DWR, namely groundwater, has been carried out (Nirex 95 - COR/522) as part of the evolving progression of the post-closure performance assessment for the PRZ. Nirex 95 does not purport to be a comprehensive assessment [6D.5] but brings together Nirex's understanding of the processes as at early 1995 and factors which, for the groundwater pathway, determine post-closure safety performance [COR/522, Vol.3, Preface, para.2].

6E.2 Timescale. Radionuclides in the proposed waste inventory have half lives extending to 4,468 million years [6A.4]. In the light of national and international guidelines [6A.7-6A.25], Nirex uses a timescale of 10^8 years for risk calculation in Nirex 95 but, together with the regulators, RWMAC [GOV/409, paras.3.30-3.31] and NRPB [NRX/15/3, Doc.2, paras.84 & 93], believe that quantitative risk prediction is inappropriate for the later parts of this period and particularly beyond 10^6 years [COR/526, s.5.4, p.23]. The very long timescales involved would require multiple and complementary lines of reasoning to support qualitative assessment [6A.21], although the threshold for such a requirement might be as low as a few thousand years [GOV/503, s.6.1]. The Intergovernmental Panel on Climate Change has made predictions for 125,000 years [COR/527, pp.22-23] but more work is being done by Nirex to achieve dynamic modelling [6D.13]. Tectonic stability needs to be related to the duration of risk [NRX/14/2]. HMIP would probably be unable to accept a safety case based on maintaining control of the site for more than a few hundred years, and any post-closure monitoring would be primarily for public re-assurance [HMP/1/1, paras.6.4 & 7.24].

6E.3 Uncertainty. The risk target for post-closure safety is 10^{-6}/y of developing either a fatal cancer or a serious hereditary defect [6A.18] with no upper bound on optimisation [6A.68]. As a matter of policy, where there is uncertainty, and potentially serious risks exist, precautionary action may be necessary [GOV/208, para.50]. However, the lifetime dose threshold entailed in the current risk target errs on the side of caution [6A.18]; and the regulators would require that the safety case takes adequate account of all relevant uncertainties [HMP/1/1, para.8.17].

6E.4 The NRPB and HMIP categorise basic uncertainties in different ways. The NRPB has grouped uncertainties under the 3 main modes of risk assessment - conceptual, modelling & parameter [NRX/15/3, para.43], and Nirex has broadly followed these in terms of model development [6D.22]. However, the Board also sub-divides parameter uncertainty into 2 types - objective uncertainty which exists as a result of the inherent unpredictability of random processes, and subjective uncertainty which arises from the fact that human knowledge of any complex system will be incomplete [idem, para.43].

6E.5 The Board has advised that the 3 main categories of uncertainty be addressed in turn by a series of calculations [NRX/15/3, para.85]. The calculative techniques suggested are

sensitivity analyses, alternative models, and comparisons with field studies & natural analogues; a series of scenarios representing qualitatively different possibilities, with "central value" risk calculations for each; and uncertainty analysis, giving a probability distribution of risks. To provide reasonable reassurance that the target would not be exceeded, the likely parameters of interest would be the central value and an upper percentile of the distribution obtained from uncertainty analysis [idem, para.86].

6E.6 The draft regulatory guidance also regards the treatment of uncertainty as central to the safety case [HMP/1/1, para.8.15]. However, the uncertainties to be assimilated into the structure of the case are categorised not by mode of assessment but by source, to include those arising from natural variability, practical sampling limitations, alternative interpretations of data, and natural events & human activities. In these terms, Nirex has categorised 3 main areas of uncertainty about the PRZ, and encompassing 10 particular key uncertainties [6C.50], on which its case on the need for the RCF is founded.

6E.7 As to treatment, some uncertainties are said by the guidance to be common to all radiological assessments, and so can normally be left implicit [idem, para.8.16]. Others may be eliminated by making simple deterministic assumptions based on reasoned arguments: and some which it is inappropriate to quantify may be treated by exploring variations of baseline deterministic assumptions. Other uncertainties may be quantified and incorporated into numerical assessments of probability or risk. Thus the safety case is expected to include probabilistic risk assessments of the disposal system [idem, para.8.21].

6E.8 The "Critical Group" is intended to typify the people whose health is likely to be most affected by radioactivity from the DWR in any scenario. In 1985, the ICRP specified that the group should display homogeneity in location, habits & metabolic characteristics affecting the doses received, and advocated the use of cautious but reasonable assumptions so that no individual doses are unacceptably high [CCC/5/12, para.46].

6E.9 The NRPB has given a similar definition in its 1992 Board Statement [NRX/15/3, para.28 & p.24]. The NRPB, together with MAFF & HMIP, have also published more recently the results of a 2-year joint study on critical group doses around nuclear sites. This concludes that current critical group methods are generally adequate, but stresses the importance of considering the combination of relevant exposure pathways in assessing doses [GOV/208, p.10, para.38].

6E.10 The NRPB's 1992 advice, however, distinguishes between routine effluent discharges and releases from a solid waste disposal facility, due to the much greater uncertainty in the case of the latter [NRX/15/3, paras.28 & 30]. Thus, for such a facility, there can only be "hypothetical critical groups" who, unlike the group for routine effluent discharges, must exist at the place where the relevant environmental concentrations are highest at any given time in the future. Also the hypothetical groups are the ones expected to experience the highest risk [idem, para.30 & p.24], whereas the critical group for routine discharges is the one that receives the highest doses [idem, para.28].

6E.11 The Board also advises that the habits of the hypothetical critical groups should broadly represent the habits of observed present-day critical groups, but should not be based on the most extreme examples [idem, para.83]. Moreover, for times beyond about 10,000

years, the critical group should be replaced by a hypothetical reference community with habits broadly typical of those of subsistence communities in the present day [idem, para.84]. Again, the reference community is to be located so as to be representative of individuals exposed to the greatest risk, at the point of highest relevant environmental concentrations; and its conservatively chosen habits should be internally consistent [idem, para.39].

6E.12 In compiling Nirex 95, Nirex has generally followed the advice of the NRPB. However, the second version of the draft regulatory guidance [HMP/1/1] introduces some proposed modifications in approach. The concept of the critical group as the one expected to experience the highest risk would be dropped, with the retention of one simple definition identical to that in Cm 2919, namely "those members of the public whose exposure is reasonably homogeneous & is typical of people receiving the highest dose from the given source" [idem, pp.5 & 6]. Nevertheless, whilst the pre-withdrawal radiological Requirement is consequently expressed in terms of the effective dose to a representative member of the critical group, the post-withdrawal Requirement relates to the assessed radiological risk to a representative member of the group [idem, pp.21-22].

6E.13 The radiological risk is in turn defined as the product of the probability that a given dose will be received and the probability that the dose will result in a serious health effect, summed over all situations that could give rise to exposure to the group [idem, para.6.10]. Nevertheless it is made clear that different groups may need to be considered at different times, and also at the same time in order to cater for different possible circumstances [idem, para.6.12]. Whilst for the very near future groups can be based on actual population subgroups expected to receive the highest doses, for the further future the second draft reverts to hypothetical critical groups to typify potentially exposed populations. But the concept of a reference community is specifically dropped [idem, bottom of p.22].

6E.14 Nirex's response to the second draft seeks the restitution of the full ICRP & NRPB distinction between critical groups receiving doses from routine effluent discharges and hypothetical groups located at the highest environmental concentrations & exposed to the highest risks [NRX/12/17, S.2.2 & Annex]. It emphasises the 1992 NRPB comment that, although (by definition) exposure within the hypothetical group is relatively homogeneous in terms of risk, any dose which actually occurred would be confined to a very small number of that group.

6E.15 Nirex proposes an expanded definition within the guidance, to refer to people at risk of receiving the highest exposures, rather than doses; and to say that for solid waste disposal assessments the exposure may be evaluated by reference to an average individual within the hypothetical group. However, its response does not criticise the suggested omission of the reference community.

6E.16 Overview of Preliminary Safety Assessments to Date. The Sellafield location has been assessed for radiological safety on a number of occasions since the MADA exercise. In the 1989 review (Nirex Report 71 or PERA - COR/501), Nirex concluded that the predicted risks would meet regulatory targets [COR/501, para.8.1.6 & s.8.14] although the MASCOT program did not address a number of effects at that time [6B.28]. The next assessment was Nirex Report 337, released in 1992, which was reviewed by independent consultants on behalf of HMIP [FOE/5/20-25, FOE/8/27 & FOE/8/51] and is mentioned in

6C.89, 123 & 154. Assessment capability at the end of 1994 was reviewed in Nirex Report S/94. The overview [S/94/001] illustrated the risk target being met [COR/507, S.6, Figs.5 & 6] and outlined continuing development of models and methodology. Nirex 95 [COR/522] represents the most up to date assessment submitted to the inquiry [6D.5]. Its modelling is summarised in 6D.5-24 and in the Assessor's Report [Appendix 1].

6E.17 Nirex 95 explores both a probabilistic base case with several variants and a base case comparison with 6 variant deterministic calculations [6D.23 & 24]. It concludes [COR/522, Vol.3, s.9] that for discharge of all radionuclides to the marine environment, risks would be at least 3 orders of magnitude below the regulatory target; and for the Temperate climate state, when some terrestrial discharge would occur, there would be a comfortable margin before the risk target was reached [idem, para.(g)]. In the Boreal climate state, with a lower sea level, the peak risks would still be of the order of 1.1×10^{-7} at 20,000 years after closure and 3.3×10^{-7} at 4 million years after closure [idem, para (h)].

6E.18 Nirex 95 calculates that changes in risk from the base case for the deterministic variants range from an increase by a factor of about 2 or 3 to a small reduction [idem, s.9.1, p.9.3]. Its conclusions on the risk control factors are summarised at idem, s.9.2.

6E.19 On the basis of further preliminary calculations, Nirex 95 concludes that, for agricultural wells in the Temperate climate state the preliminary estimate of peak risk to a critical group of about 10 children living in the relevant community resource area [COR/522, Vol.3, p.6.18] is 1.7×10^{-6} on the basis of an assessment for ^{36}Cl and ^{129}I only. ^{129}I is considered by Nirex to be the major contributor, with the peak risk occurring at about 4,000 years after DWR closure from concentrations in groundwater in the region of the Fleming Hall Fault Zone, to which the travel time would be shorter than to the region where radionuclides from the DWR would be naturally discharged [idem, paras.(a) & (b), p.9.2].

6E.20 Nirex submits that Nirex 95 provides sufficient confidence in the potential of the PRZ to justify the grant of planning permission for the RCF. The results of research to date suggest that a very high level of containment should be maintained by the physical barrier for at least 1,000 years during which some 99% of the waste in the repository would decay. Undue reliance is not being placed on the engineered and chemical barriers. Indeed, it is conservatively assumed by the Nirex 95 base case that all radioactivity would be available for release immediately upon closure of the DWR [COR/522, Vol.3 Section 6.1.3 p.6.2]. The chemical barrier would operate for around 1 million years and would act to contain around 99% of the 1% of the long-lived radionuclides not contained by the physical barrier [NRX/15/43, Fig.5.1]. The groundwater flow would then be the main agent transporting the remaining radioactivity through the natural geological barrier. This radioactivity is put at 0.01% of that of the emplaced waste.

6E.21 Nirex regards its probabilistic approach to modelling as unchallenged. The plotting of risk, or expectation value, against time [eg COR/522, Vol.3, Fig.6.7] is the only proper basis upon which to compare outcomes against the risk target, a point specifically conceded by Cumbria. Complexity does not equate to unpredictability. It would be a matter for concern if there were a significant spread of risk values greater than 10^{-5} despite an expectation value of risk below 10^{-6}. In that event remedial measures would be taken unless

the values were an artefact of modelling in the very long term. The precautionary principle would be applied by meeting the risk target and by identifying, and dealing with, all uncertainties in a robust manner and by employing best practicable means.

6E.22 Nirex 95 demonstrates a conservative approach to modelling and safety assessment. This is achieved in a number of ways by the use of appropriate parameter distributions and values [COR/507, pp.3-4] and by conservative assumptions including unrestricted access of groundwater to wastes immediately after DWR closure [COR/522, Vol.3, s.3.3.1(a), p.3.7]; release of radionuclides from DWR vaults to Type II features which are the shortest route across the BVG [idem, s.3.2.4, p.3.5]; the absence of mineralisation as a mechanism for reducing ^{238}U solubility; and reduced sorption in the near-field. In the case of the agricultural wells scenario, the assumptions are of an encased well at the maximum depth consistent with local practice in the subsistence community scenario, and ignoring the likelihood of shallower wells intercepting an adequate water supply [idem, pp.6.18-6.20]; meeting all of a farmstead's water requirements by means of the well; and the absence of recent meteoric water from the well water [idem, p.6.19].

6E.23 Additional examples of conservatism are the reduction of radionuclide sorption in the geosphere by the use of organic enhancement factors [FOE/8/9, s.5.2.2, pp.59-60]; treatment of sorption by use of distribution coefficients (K_d values); the effect of channelling within fractures; the simplifications in the calculation of risk from radioactive gases (^{14}C); and the selection of a factor appropriate to U(IV), by which the solubility of uranium in the near-field is multiplied to take account of organic materials, which gives the highest solubility limits [COR/522, Vol.3, s.6.1.6 (end), pp.6.6-6.7].

6E.24 It refutes the suggestion by FOE that there are errors of 10,000 fold in its sorption database, putting it down to a misunderstanding of the process in question which accommodates uncertainty. FOE's proposition is somewhat equivocal, and they concede that, as understanding improved, the PDFs would become sharper. Moreover, criticisms of various aspects of its understanding of the system, such as modelling of the BVG, do not amount to criticism of the PDFs themselves in Nirex's view.

6E.25 The Nirex 95 base case results in curves of risk against time for appropriate climatic states [COR/522, Vol.3, Fig.6.6] all of which fall within the risk target of 10^{-6} [idem, Table 6.18]. Variant models have been investigated to explore issues that were not identified within the base case model [6D.24]. These variants provide confidence in the preliminary base case risk assessment.

6E.26 The inability of the base case model to fully reproduce the high heads observed at depth in the vicinity of the PRZ was expected [idem, para.7.3, p.7.4] and enabled Nirex to recognise that a feature or process not included in the current model needs to be incorporated, such as a geothermal flux at depth [6D.32]. On the basis of the variants the system is robust to changes in the duration of the release of radionuclides from the DWR if the spreading time in the geosphere is constant and to changes in the spreading time if the duration of their release remains constant, the 2 being independent. Greenpeace's observation that the sensitivity of risk to flow through the DWR should be investigated is precisely the object of the RCF and for which the RCF is essential. The marginal factor for meeting the risk target

of increases above the base case is about 60 or 70 fold but imposed heads only increase flow by a factor of 2.

6E.27 Nirex contends that FOE's view that a time-variant 3-D model of the Sellafield region should exist in order to assess the impact of the RCF misunderstands the requirements at this stage. Some 3-D modelling has been undertaken and the simplification to 2-D models in Nirex 95 has been undertaken conservatively. Three dimensional modelling would be carried out in response to specific requests by the regulators.

6E.28 On geochemical processes, objectors have failed to appreciate the implications of the presence and effects of oxidising or reducing conditions in the groundwater, minerals surface chemistry and sorption. These are all matters being progressed as part of an integrated approach to developing the safety assessment. FOE for example misunderstand the relationship between activity coefficients and ionic strength [NRX/15/30].

6E.29 For colloidal transport of radionuclides to be a problem in the safety assessment, a number of unlikely factors must occur simultaneously. Preliminary investigations suggest the colloid population to be low in the PRZ groundwater and natural analogue studies suggest colloids would not cause difficulty. The issue can only be explored through a combination of continued laboratory studies, natural analogue studies and in situ observations in the RCF. The fact that Nirex 95 does not explicitly take account of the possibility of colloid transport does not therefore render the assessment in any way deficient.

6E.30 Nirex refutes the suggestion that it may have overestimated the extent to which sorption would constrain the transport of radionuclides in the far-field. It points out firstly that no account has been taken of the reduction in transport due to only a fraction of the available sorption sites in the rock being accessed by radionuclides; and secondly that the assumption that organic degradation products would attenuate sorption throughout the BVG at a level fixed by organic concentrations in the DWR is conservative.

6E.31 Criticism of the assessment of the impact of the RCF on groundwater flow and on risk from the groundwater pathway (Nirex 560) [FOE/5/19] is misplaced [6C.95]. Backfilling and sealing qualities to satisfy the safety case are planned for the RCF to satisfy the regulators. Cut-off collars, suggested by FOE, are under active consideration.

6E.32 Although the process of climate change has not been modelled so far, except for biosphere scenarios, Nirex 95 is not flawed because the peak risks from ^{36}Cl and ^{129}I are predicted to occur before any significant climate changes are expected by experts in the field. The effect seen in "Dry Run 3", carried out on behalf of HMIP, was attributable to an implausible treatment of human habits rather than any geological phenomenon.

6E.33 Nirex regards agricultural well calculations as simply scoping studies leading to a preliminary assessment, based upon significant conservatisms and without taking account of the effects of any optimisation opportunities. Optimisation could be achieved by storing wastes so as to minimise their effects. The inventory could be favourably disposed in relation to Type II features; DWR depth could be reviewed; and long lived radionuclides could be placed in a silo away from the main vaults or flow channel, bearing in mind that 50% of ^{129}I, the main contributor to risk, is contained in only about $500m^3$ of waste.

6E.34 Nirex contends that the justification of the choice of the critical group is a matter for the regulators in due course, and it certainly cannot be said that the regulators would be bound to reject its approach since that accords with current guidance. It refutes Cumbria's assertion that the critical group should be placed above the greatest concentrations in the plume. The assumption is that a subsistence community exists in the resource area containing the highest environmental concentrations and then appropriate critical groups are identified within this reference community. This is the smallest credible community [COR/522, Vol.3, p.6.18], and so the risks are calculated across the complete resource area even though only part of it would contain contaminated groundwater. The scenario is an example of individuals with the same habits and behaviour constituting a group which is homogeneous with respect to risk, but not necessarily with respect to dose [NRX/13/5, p.3]. Moreover the exposure to risk which is evaluated is that to an average individual within the critical group [NRX/12/17, paras. 2.2 & 6.5].

6E.35 Cumbria's assertions of increased risks in the agricultural wells scenario [CCC/5/7] are greatly exaggerated in Nirex's view and it contends that they are not supported in terms of factual information or the suggested approach. A more realistic treatment of the scenario is more likely to lead to a significant reduction in risk. For example, in the case of a well assumed to be somewhere within the plume, transverse dispersion should be taken into account, reducing the factor increase suggested by Cumbria from 5 to 2.5 [NRX/15/25, s.2]. In the case of the peak concentration in the plume, at 50 m bOD this is about 2.3×10^{-3} (relative to the initial concentration of 1.0 at the DWR) [idem, Fig.1], compared to the average concentration over the plume of 7.46×10^{-4}. This gives a ratio of peak to average concentrations of 3:1 and not an order of magnitude as suggested by Cumbria.

6E.36 As to well depth and calculated path-line radionuclide concentrations, the steady state calculations [COR/522, Vol.3, Fig.2.11] do not provide as realistic an estimate of dilution of ^{36}Cl and ^{129}I as in the transient case [idem, Fig.2.12], which Cumbria concedes may be so, because the steady state calculations neglect the effects of the finite duration of the source term and spreading in the geosphere which would lead to greater dilution [idem, s.2.3, p.2.12]. Also, the chosen well depth of 88 m (50 m bOD) at the location of the FHFZ is conservative because it is deeper than the most likely well depth needed for this scenario [NRX/15/25, s.4, pp.2-3]. Moreover there is no basis for Cumbria's assumption that the ratios between the base & variant cases for radionuclide concentrations tapped by the agricultural well would be the same as for the respective fluxes in their natural discharges to the biosphere.

6E.37 Indeed, some of Cumbria's mistaken assumptions about the agricultural wells scenario also affect the authority's general critique of Nirex 95. Although some of the variant groundwater flow calculations do give rise to higher risks for natural groundwater discharge, albeit by no more than a factor of 2 to 3, other variant calculations give rise to lower risks. Nirex considers that it is therefore unreasonable to assume that a revised, more realistic hydrogeological model would lead to a higher calculated risk of the order of 3 [idem, s.5, pp.3-4]. A range of models should be considered, especially as some of the variant calculations producing lower risks are more compatible with recent observations than the equivalent part of the base case model. Cumbria cannot say whether higher risks would result from further investigation and assessment; and Nirex rejects the higher risk values given by Cumbria to the preliminary estimate of peak annual individual risk.

6E.38 Nirex also regards objectors' concerns about potential pollution from the marine discharge as unwarranted [3C.16-17]. For example, contamination of coastal sediments would be extremely small [NRX/15/34, paras.9-12]. The further dilution achieved by marine discharge is not crucial to the safety case. On the other hand, a predominantly terrestrial discharge of radionuclides in the location of the exposed sea bed in the base case would be inconsistent with its knowledge of the groundwater flow system. A scoping well calculation for this scenario, as suggested by Cumbria, is not therefore called for in Nirex's view.

6E.39 Nirex refutes Greenpeace's suggestion that solubility of uranium has been underestimated in Nirex 95, resulting in the risk target being exceeded, because it is likely that, if anything, the PDFs are biased towards values which are too high; and, even if the central value for the PDFs should be a factor of 4 higher, the risk target would still not be exceeded [WR/NRX/1(15)].

6E.40 The scepticism of some objectors that long term risks can be systematically evaluated is not borne out by international opinion [WR/NRX/5(15), para.1]. Furthermore, the evidence suggests that the risk of tectonic and seismic disturbance is low and there is no evidence for significant perturbation of the site by seismic activity over the last 100,000 years [WR/NRX/4(14), para.2 & 6C.99-102 above].

6E.41 Windscale and Calder Shop Stewards Committee points out that BNFL, as the probable agent of Nirex for the emplacement of waste in the DWR, has the facilities, experience and skills in place at Sellafield to deal safely with nuclear waste; and so there is an assurance of pre-closure safety at this location.

6E.42 Cumbria points out that the comfortable margin of 3 orders of magnitude below the risk target in the Nirex base case assumes a discharge into the seabed, and yet the geological evidence suggests that this is subject to considerable uncertainty [6C.109 & 115]. It also draws attention to Nirex's reliance in their safety assessment on substantial dilution of the DWR porewater as it joins the active groundwater system in the overlying sandstones, in contrast to the BUSC environment, and on low groundwater flows through the BVG. The dilution occurs in a sandstone aquifer used as a potable water supply making well scenarios a central issue.

6E.43 The modelling of the base case demonstrates some of the characteristics of this heavily faulted general location, and that upward flow is predicted from the FHFZ. Porewater leaving the PRZ would have significant concentrations of radionuclides and flow only a very short distance below the surface. This is an inherent and unavoidable feature of the performance of the site, in its view [COR/522, Vol.3, Figs.2.7 & 2.12]. The path-lines for the high heads and transmissive feature at depth variants are even closer to the surface than the base case [idem, Figs.7.14 & 7.16] and the variants generally demonstrate great sensitivity to quite small changes in hydrogeological assumptions, so affecting DWR performance.

6E.44 Although the imposed high heads variant is artificial, and the transmissive feature at depth is based upon only one possible explanation of the uncertainty which the variants seek to explore, it is the case that the model does require some adjustment to conform with

reality, and Nirex 95 itself states that the variant outcomes need to be considered with the base case for an overall view of system performance [COR/522, Vol.3, p.7.4]. Nirex concedes that some force is creating a driving pressure from below the volume of rock currently modelled in the PRZ [6D.42] and modelling would have to account for it. It also accepts that a variant case with an increased density of Type 2 features, increasing flow through the DWR and having a shorter period in the geosphere, is relevant. Furthermore, it is conscious that more work is needed to develop a more realistic 3-D model of the geosphere. A recent contractor's report confirms the geological importance of F1, F2, F3 and F202.

6E.45 It is a matter of serious concern to Cumbria and other objectors that there is such a small margin between the final results of the deterministic assessments and the risk target [COR/522, Vol.3, Table 7.7]. This is not to require a cushion on the ultimate prediction of risk below the 10^{-6} target, but to provide one in the interim so that the risk target is likely to be met, or is unlikely to be significantly exceeded, as the safety case is taken forward and new discoveries have to be accommodated. In comparison the BUSC sites would probably provide such a prudent margin, with a deterministic central value of risk of about 10^{-9} or 10^{-10} at this preliminary stage, and so show good promise.

6E.46 Although the modelling of climate change in HMIP's exercise "Dry Run 3", in which the results were unpredictable [CCC/5/1], had limitations, Cumbria does not accept that Nirex can preclude the possibility of unacceptable results when the process of climate change is modelled. The small margin on the deterministic assessments provides a tiny cushion if, for example, climate change substantially reduced the volume of water in the sandstone aquifer available for dilution.

6E.47 The fragility of the safety assessment in Nirex 95 is further demonstrated by the values Nirex has chosen for the fraction of radionuclide discharge going to deep soils in the biosphere calculations (value of "S") [COR/522, Vol.3, page 6.9]. Nirex concedes that the pessimistic assumption in the base case of 0.1 is questionable in the light of further research on the aquatic-terrestrial partition for deep groundwater discharge [NRX/15/4]. Cumbria takes issue with Nirex's revised view that PDF sampling of merely up to 0.2 would now suffice since that the research shows an actual ratio of 83% to 17%. But even if the pessimistic parameter value for "S" were merely 0.2, this would double all the risk results, and the highest variants would fail to meet the risk target.

6E.48 Further doubt on the efficacy of the PRZ as host for the DWR is cast by the peak preliminary estimate of risk from ^{129}I and ^{36}Cl versus time for agricultural wells being 1.7 x 10^{-6} [COR/522, Vol.3, Fig.6.19], breaching the regulatory target. It is standard international practice to deal with well scenarios at an early stage because they can be the worst case for groundwater transport. However, in this case they show signs of becoming the controlling scenario for authorisation. The crucial concession by Nirex in describing its subsistence community is that in using local wells for water, the community is presumed to be capable of digging and lining a well down to 88 m (50 m bOD) [NRX/15/25, s.4].

6E.49 Cumbria points out that the peak risk in the agricultural wells scenario, when radionuclides are predicted to be present in the aquifer, would arise after 4,000 years on the assumptions in Nirex 95 [idem, p.6.19]. This is strikingly short when compared with Nirex's

declared requisite attributes which include effectively static groundwater taking hundreds of thousands of years to reach water courses [COR/203, para.3.1.4]. It believes that Nirex's special measures to optimise the DWR would only deal with about one half of the ^{129}I inventory, merely reducing the risk to about the target figure on Nirex's calculations.

6E.50 There is also the question of Nirex's irrational approach to the concept of the critical group upon which the assessment is based. By averaging the risk throughout the resource area, some of which is outside the contaminated plume, and so including members of the reference community who are not exposed to the contaminated pathway (as illustrated in CCC/5/14), the risk is diluted. Cumbria contends that the correct approach is to define the critical group as living above the plume, or perhaps even above the greatest concentrations in the plume. These 2 definitions produce very significant increases in risk.

6E.51 The assumption should be made that there is a well in the plume somewhere and all members of the critical group should at least be exposed to the risk. As the Royal Society observes, the probability of occurrence of a well has been commonly taken to be unity in safety assessments in the past [COR/605, p.164]. The importance of this approach is emphasised by the assessment that contamination would come almost entirely from drinking water, especially for ^{129}I [COR/522, Vol.3, Table 5.9]. The approach accords with the latest draft guidance and the approach of HMIP's consultants [CCC/5/6, s.2.5, p.16]. This produces a risk of 4.25×10^{-6} for the base case in the plume on Nirex's own rebuttal calculations [NRX/15/25], and this is 1.28×10^{-5} when factored by 3 to represent either the highest concentration in the plume or the base case variants and 3.84×10^{-5} for the worst case. Cumbria's figures are 8.5×10^{-6} and 2.55×10^{-5} if the well is assumed to be somewhere in the plume but 8.5×10^{-5} (base case) and 2.55×10^{-4} (variants) if the well is assumed to be at the highest concentration in the plume [CCC/5/7].

6E.52 Cumbria regards Nirex's suggestion that ameliorative factors would significantly reduce the risk as highly questionable. None of those factors is quantified, and they may not transpire at all. To convert the assessment of risk for the variant cases of 1.28×10^{-5} and the base case 4.25×10^{-6} into one which meets the risk target requires a gain of more than an order of magnitude even though every pessimism has not yet been modelled. For example, there are uncertainties over the ^{36}Cl inventory [6D.43], and the risk from radionuclides having very high concentration factors in coastal sediments and seaweed, which then becomes used for agriculture, has not been modelled. It submits that it is not good planning to concentrate a programme of investigations on a site having such performance characteristics as are demonstrated at Sellafield.

6E.53 Copeland and Gosforth consider that radiological safety should be paramount in DWR development and Gosforth is sceptical about the objectivity of any planning decision concerning the DWR. These views reflect the overwhelming concern of those writing, both locally and nationally, who fear that Sellafield does not exhibit the robust characteristics necessary for the long term [eg WR/B/57, WR/C/146, WR/A/75, WR/T/84]. Many suspect that short term expedients will be given unreasonable weight over safety [eg WR/H/179, WR/K/2, WR/A/79, WR/O/32, WR/V/5, WR/POL/2]. Similar scepticism as to the proper application of the precautionary principle to DWR development is expressed by the Irish and Isle of Man Governments [6A.52-53] and FOE. Dr J Cunningham MP feels that the DWR risks should be ALARA. FOE submit that the removal of time pressures on Nirex

through the requirement to observe all the principles of sustainable development is a significant change in policy [GOV/208, para.42], and means that BPM is essential at every step in the process and not just when making design choices for the final safety case.

6E.54 FOE regard the safety assessment as flawed because of Nirex's inability to model such a randomly complex volume of rock as is found in the PRZ and its accompanying region together with its undetermined geochemical character [eg 6D.54, 6C.120-125]. Nirex is not investigating the possibly less complex horizons at greater depth. Lack of understanding of impacts and processes, lack of data, the failure to establish baseline conditions and the shortcomings in modelling all add to the problem for Nirex.

6E.55 The chemical barrier is similarly suspect [6C.127]. Nirex is assuming the effectiveness of the NRVB when uncertainties exist and it is being made to fit a non-validated model. Insufficient experimental work has been undertaken to ensure the safety calculations are robust, and some elicited data are non-conservative. FOE disagree with Nirex that the input into Nirex 95 for ionic strengths, precipitation kinetics and speciation of fluids is conservative [6C.123]. Nirex accepts that reliable data for the sorption coefficient (K_d) are very important in controlling the escape of radionuclides. The failure to heed the recommendations of the HMIP review programme [6C.123] could result in a serious underestimation of the radiological doses that would arise from nuclear waste disposal.

6E.56 The engineered barrier assumes a special significance because of the complexity of the PRZ but key uncertainties exist pertaining to the sealing of the damaged zone, the interface between the excavation boundary and the backfill, and critical aspects of DWR design [6C.131]. Since the RCF has not been incorporated into the design of the DWR, it would form redundant excavations and pathways that would promote radionuclide release [6C.133-134]. Nirex accepts that they should be efficiently sealed. Premature perturbation through RCF construction could compromise future safety assessment, or, more worryingly, could give misleading data. However, FOE believe that further work would still result in difficulties in achieving an acceptable safety assessment at this site. A fully sustainable approach has not been adopted in their view.

6E.57 Greenpeace contends that high groundwater flows through the DWR would lead to unacceptable risks and the site is very sensitive to groundwater flux [6D.48]. Three of the variant calculations [COR/522, Vol.3, Fig.8.8] are already close to the risk target [idem, Table 7.7] and are sensitive to changes in groundwater flux through the DWR [6D.47].

6E.58 The hydrogeological sensitivity analysis carried out by Glasgow University shows that the controlling parameter for groundwater models is the permeability of the BVG and that flow in the Calder Sandstone and BVG are de-coupled but with some connectivity [GNP/3/4/Figs.3(a) & (b), the most realistic representation being shown in Fig.3(a) (note - length scales explained on p.89)]. Nirex is prepared to accept that these representations are not incredible even if it regards them as extreme and pessimistic. The linking of DWR flux and geosphere travel times (therefore source term and geosphere spreading times), assumed by Nirex to be independent, suggests that fluxes through the DWR in any new model would need to be less than about 2 to 5 times the central base case value in order to meet the risk target. This indicates that the range of fluxes currently produced by fracture flow models must be reduced by a factor of 30 to 75 times in order to meet the risk target even if no other

source of uncertainty is taken into account and other models assumed validated. Furthermore, Nirex's safety case appears heavily dependent on a low flux through the DWR, and would not be robust to an adverse interpretation as required by the regulator [HMP/1/1, para.7.3].

6E.59 Nirex concedes that, although best practicable means would be adopted for engineered and chemical barriers, this approach would not be sufficient if high groundwater flows were to be encountered. Optimisation of the DWR location by seeking greater depth, avoidance of Type II features, or other measures could be needed. Nirex accepts that the range of fluxes through the DWR needs to be narrowed, and sensitivity tests would be carried out in 1997 to determine the factors that have a key influence on the safety case. Shortcomings in modelling, science and techniques plus uncertainties [6C.105-6C.144 & 6D.45-6D.50] all serve to undermine the credibility of the preliminary safety assessment, in Greenpeace's view. Wherever the disposal system appears to be sensitive to an adverse interpretation of a single component part it is difficult to conceive of any aspect of the engineered design which could sufficiently enhance safety over the relevant timescales.

6E.60 Greenpeace does not regard the use of upscaled parameters as being necessarily more reliable than point measurements, especially for exploring the effect of the measured range of BVG conductivities on groundwater flows. Nirex's use of BVG conductivities no higher than median values from borehole measurements in flow model simulations contrasts unfavourably with Glasgow University's use of a wide range of hydraulic conductivities. Moreover, because a single connected fracture can have a substantial effect on groundwater flows, highly permeable, well-connected fractures should be modelled deterministically, just as faults are already.

6E.61 A geothermal model better representing heads and salinities would not be robust to groundwater flux through the DWR in Greenpeace's view. It is also of concern that HMIP's preliminary 3-D regional model suggests a predominant flow to the south, with terrestrial discharge near the River Irt increasing the risk. Furthermore, emplacement of radioactive waste near an aquifer does not appear to be consistent with the precautionary principle.

6E.62 Greenpeace regards chemical containment as crucial to providing a sufficient level of safety for uranium yet uranium solubility may have been underestimated by Nirex in Nirex 95, and the natural oxidation state of the groundwater is unlikely to provide a long-term barrier to higher uranium solubilities should the NRVB chemical conditioning fail [6C.135 & 6D.57].

6E.63 Greenpeace is sceptical about Nirex's approach to uncertainty in the safety assessment. On the one hand Nirex suggests that not all sources of uncertainty identified by the developer need to be analysed in the safety assessment [NRX/12/7, para.8.8 & 6A.49], and yet on the other hand it states that it would attempt a comprehensive evaluation of uncertainties. It contrasts the position with the Green Book's statement that risk assessment would cover "exposure pathways and health effects not at present recognised" [GOV/302, para.3.8], noting that the general principles and philosophy of this publication remain valid [HMP/1/1, p.1], but that the burden of demonstration is placed on the developer.

6E.64 Greenpeace and other objectors refute Nirex's suggestion that Sellafield is tectonically stable, asserting that the faults around Sellafield continue to be active [WR/C/146] and are likely to be subject to glaciation effects adversely affecting the safety case [6C.137-143]. The selection of a better site would reduce such uncertainties.

6E.65 As a matter of approach to the safety assessment, and when weighing benefits of the proposed development against detriment, Greenpeace contends that any exposure to radiation should be regarded as a detriment [GOV/506, para.112]. The reduction of radiological risk is therefore no more than a reduction in detriment and cannot be regarded as a benefit.

6E.66 South Cumbria Citizens consider that preferential pathways could bring concentrated parts of the groundwater pollution plume to the surface as local "hot spots" with concentrations of up to 3 orders of magnitude higher than average. They also suggest that the ^{90}Sr dose limit is too high based on epidemiological evidence. They are sceptical about the predictions and assumptions supporting the safety case [6A.55]. They share the concern of the Irish Government, Patricia McKenna MEP and Mr J Fitzsimons MEP that the DWR would further contaminate the marine environment [3C.1-2].

6E.67 Dr P Elliott does not believe that risks from the proposed DWR can be predicted, at least until the research to be carried out in any pilot project is completed [WR/E/1B].

6E.68 My conclusions on the topic of radiological protection & safety assessment relate essentially to conditions after closure of, or withdrawal of control from, the disposal facility. I have already set out in Chapters 6A & B my conclusions on the extents to which existing radiation levels or short-term safety considerations should be utilised as locational criteria for the DWR. It seems to me that safety assessment for the operational & control phases would
6E.12 be very similar to that for other nuclear installations; and the RCF project itself is concerned
2B.15-7 mainly with the long-term safety of the DWR. As to the length of the term, I accept the
6E.2 advice of the Assessor and the consensus of expert groups, that conditions beyond 10^6 years should be regarded as unknown. Assessments for that period can have little scientific credibility, with numerical predictions for 10^6-10^8 years informative & useful only as
NRX/15/3 indicators of general, steady-state trends. In turn, 10^5 years is about the maximum for credible quantitative dose & risk values for the biosphere; whilst 10^4 years is commonly regarded as a significant threshold for comprehensive, site-specific calculations.

6E.69 This last threshold is straddled by Nirex's predicted average times for the corrosion
6C.6 of a metal container. But physical containment would be complicated by various factors such
6C.62 as gas generation, and Nirex has prudently assumed in most of its preliminary assessments
6E.20 that this containment would be ineffective. It has also made some conservative assumptions
6E.22-4 about the effectiveness of the chemical barrier in the near field. Nevertheless, all the calculations in Nirex 95 presume that the barrier would have a very significant retarding
6E.20 effect on the longer-lived radionuclides, principally by reason of the provision of high pH
6C.7-9 conditions by the cementitious NRVB, and of distributions for solubility limits & sorption
6C.35 distribution coefficients obtained by data elicitation.

6E.70 The Assessor advises me that these entail great simplifications and may be non-
6C.174 conservative. I am also reminded that this form of chemical containment is new & untried,

6C.175 with more experimentation & modelling development indubitably required. This work would
6D.74 to my mind be particularly difficult & important because of the problems of meaningfully
6E.55 testing some of the components of the concept. Implicitly Nirex feels unable to credit the
6E.62 notion that this barrier would fail; but the lack of any calculation based on an adverse, as
6C.67 distinct from a conservative, interpretation of this chemical containment seems to me to be
6E.59 an unfortunate omission from the emerging safety case, particularly having regard to FOE's
6C.127 impressive critique of the concept.

6E.71 This serious deficiency exemplifies for me the conundrums posed at this stage of the assessment process by the various kinds of uncertainty, particularly by that which the NRPB
6E.4 describes as subjective uncertainty about the incompleteness of human knowledge, and that which the draft regulatory guidance refers to as uncertainty arising from alternative
6E.6 interpretations of data. Generally, in my view, Nirex is least impressive in addressing these
6E.21 types of uncertainty, and they are still substantial notwithstanding the rapid evolution of base-
6E.14 case models as painstakingly analysed by the Assessor. On the other hand, it is essential to keep a sense of proportion about the relationship of the RCF project to such matters, for the
2B.15-7 project would be in effect a massive field study designed to address principally the kinds of objective uncertainty which arise from natural unpredictability & variability or from practical sampling limitations. For example, there has been some tendency to criticise Nirex 95 for
6E.24 failing to incorporate data which in reality only the RCF could provide.

6C.2-12 6E.72 Moreover, as the Assessor comments, with the multi-barrier concept there are opportunities to feed back lessons from the preliminary assessments into the design of the waste packaging & emplacement and the detailed engineering & layout of the repository, as well as into more basic decisions on its location. These in turn can have implications for the detailed design of the RCF, and the nature & choice of investigations & experiments within
6C.181 it. In addition, the Assessor is firmly of the opinion that, whilst the timing of the detailed
6D.76 modelling & other work on the requisite backfilling & sealing of excavations would be late,
6E.31 it would confirm that appropriate materials & techniques are already available.

6E.73 Furthermore, Nirex does have some cause for optimism in Nirex 95's base-case probabilistic calculations for the 4 climate states of Temperate terrestrial & marine and Periglacial & Boreal terrestrial. The mean risks versus time for them all are always below
6E.25 the 10^{-6} risk target, even when indicated in the far future. Within the meaningful time period,
6E.17 the peak risks calculated for Temperate & Boreal terrestrial are about an order of magnitude
COR/522 below the target, with the Periglacial 1-2 orders smaller and the Temperate about 3 orders smaller still. The upper bound of the 95% confidence interval for the Boreal is still below the target, although it is important to note that this interval is for statistical error in the number of realisations, and not a measure of uncertainty in the input parameters.

6E.18 6E.74 Perhaps even more encouraging is that the base-case best-estimate central parameters
6E.25 for the Boreal terrestrial are within the target too. Even the variant deterministic calculations which attempt to account for the basic deficiencies in the hydrogeological conceptual model, and thereby increase the risk by a factor of about 2 or 3, nevertheless produce results below the target.

6E.75 The Temperate marine discharge is at present regarded by Nirex as the most likely
6E.32 for some thousands of years: and, pending the more sophisticated time-variant modelling,

6E.17 a partial marine discharge is predicted to reduce the full terrestrial discharge concentrations
COR/522 proportionately. Although this predicted marine discharge has attracted objections of
6E.66 deliberate pollution & hence international illegality, as the Assessor points out, Nirex's preliminary predictions of the amounts of marine contamination are relatively very low, and
6E.38 a scoping calculation on radio-iodine indicates that there might be no re-concentration problem.

6E.76 However, contemplating the possibility of marine discharge does also serve as a
COR/522 reminder of the scale & variety of uncertainty faced in this exercise. Whereas Nirex 95 is
6E.38 fairly precise about the location of the zone of predicted natural marine discharge, I have
6C.163 already concluded, on the advice of the Assessor, that not enough is known about present
6E.42 groundwater discharges at or near the coast. Hence we are obliged to add spurious accuracy about the most probable outlet of the natural discharge to the initial undue confidence in the
6E.44 chemical containment. Moreover the variant deterministic calculations are a constant reminder of the inherent uncertainties about groundwater flow & geochemistry, as are
6E.58 Greenpeace's alternative model & insistence on some inter-dependence between source-term and geosphere spreading and FOE's persistent criticisms of the basic hydrogeological &
6E.54 geochemical modelling.

6E.26 6E.77 Whilst I accept the Assessor's reservations about Greenpeace's main points & some
6E.47 of FOE's, I also share those concerns of his which follow up Cumbria's criticisms on well
6E.48 scenarios & terrestrial biosphere modelling. These 2 topics are in my view important tests of the more general Cumbria thesis, which the Assessor also broadly endorses, that the overall margins between the deterministic calculations and the risk target are too close for
6E.45 comfort at this stage of the emerging safety assessment. Certainly the proximity demands a critical review.

6E.33 6E.78 The agricultural wells scenario is a scoping study exploring a form of human intrusion into the radioactive plume before any natural discharge takes place, whether marine
6E.19 or terrestrial. The first point to be emphasised is that, on the basis of the approach in Nirex
6E.48 95 itself, the risk target would not be met. Even if to aim for a margin below the target were to be regarded as too onerous at this preliminary stage, it must be reasonable to expect the
6E.21 target to be achieved, as Nirex itself accepts. This criterion is all the more important, in my view, because the TOR approach does not apply to post-withdrawal risk assessment for a
6A.68 DWR, as Cumbria & Greenpeace have erroneously assumed.

6E.79 Secondly, I consider that Nirex 95 under-states the risk, albeit not to the extent claimed by Cumbria. Both the NRPB advice and the latest draft regulatory guidance effectively recommend that in a scenario for 4,000 years after closure/withdrawal the human
6E.10-3 reference unit should be a hypothetical critical group. Although Nirex 95 does calculate the
6E.34 risk to such a group, it draws the group from a hypothetical, wider reference community,
6E.11 despite the NRPB only introducing the latter concept for times beyond 10,000 years. The
6E.13 latest version of the draft regulatory guidance dispenses with the concept altogether. Also, the NRPB advises that the group be taken to exist at the place where the relevant
6E.10 environmental concentrations are highest, whilst the draft guidance calls for assessment of the
6E.12 risk to people typical of those receiving the highest dose.

6E.80 The straightforward application of such advice means to me that all the group should be taken as drawing water from wells tapping the radioactive plume, unless it is incredible that an entire group could be doing this. This does not appear incredible to me, for, as the Assessor states, even on the Nirex 95 scenario there could be scores of household wells
6E.34 across the community's resource area; and so there could be a considerable number underlain
6E.50 by the smaller, but still substantial, extent of the main concentration of the plume.
6E.35 Therefore, even allowing for the sideways dispersion of the plume emphasised by Nirex, the calculated risk should be multiplied by a factor of at least 2.5 to confine the hypothetical group to the place of highest environmental concentrations or exposure to the highest dose.

6E.81 I regard a conclusion of this nature as partly one of principle on the factors to be
3B.39 incorporated into the risk rather than merely a matter of interpretation of a detailed risk assessment. However, I would not proceed to agree also with Cumbria that the group might be taken to exist at the very point of maximum concentration, since that would in my view be an extreme position which discounted the emphases in the guidance on homogeneity and typifying & representing people at risk. On the other hand, neither do I follow Nirex's argument that another multiplier should not be used to represent the pessimistic variants due
6E.36 to lack of knowledge of the proportionate differences in underground concentrations, since
6E.43 I agree with the Assessor that the pessimistic variants are likely to provide somewhat higher concentrations for interception.

6E.82 Moreover, I am not reassured by that part of Nirex's reaction to this debate which
6E.22 suggests a review of the conservatisms in its scoping calculation on matters such as well depth or dilution by recent meteoric recharge. The original assumptions seem to me to be of the
6E.52 cautious but reasonable nature called for by the guidance. The more constructive response,
6E.33 as the Assessor indicates, would be to consider changes in design. But since Nirex's own list of possible changes includes, for example, changes in the depth of the DWR, such possibilities suggest to me a considerable pause for reflection & revised planning rather than pressing ahead with the RCF. That kind of review might also include devising at least a
6E.42 profile of the actual sandstone aquifer over the timescale in question; and might question too whether an agricultural scenario is the most pessimistic well scenario in the circumstances,
NRX/15/2, having regard to other well scenarios mentioned in the PCPA Report on Human Intrusion &
Box G Natural Disruptive Events.

6E.83 This exercise is also a reminder that Sellafield is not an optimum environment in which the sedimentary layers combine to present a barrier to upward flow, but that instead
6A.66 Nirex is relying on the layers to dilute & disperse the radioactive plume. The theoretical vulnerability of this concept to relatively rapid movement towards the biosphere tends to be confirmed by both the wells scenario and the debate on subsurface routing to the biosphere. Subsurface routing is the pathway by which the radionuclide flux enters a biosphere catchment from below and goes directly to stream channels without interacting with surface soils. Any fraction of the flux which does not do this but is translocated to surface soils
6E.47 instead (denoted in Nirex 95 by the symbol "S") is important because it seems to substantially increase the risk.

COR/522 6E.84 This importance is acknowledged in Nirex 95 by detailed calculations of theoretical values of S, plus a pessimistic bounding calculation in which it is assumed that subsurface routing does not occur in the Boreal terrestrial biosphere. The conclusions of these are that

the S value of 0.1 used in the base case for Temperate & Boreal climates is conservative; and that the increase in risk is directly proportional to the value of S. Nirex has introduced
NRX/15/4 the 1995 paper on 1991-3 Canadian research to confirm its contentions that the probability of no subsurface routing at all (ie S=1) is zero, and that an S value of 0.1 is conservative. But the paper does not confirm the latter. Instead it summarises a finding on its research site of a partition which could be as high as 83% aquatic: 17% terrestrial, and suggests that biosphere models could use in effect an S value of up to 0.2 unless site-specific data are available. I infer that value to be a conservatism and not an extreme of a probabilistic distribution range.

6E.85 As the Assessor points out, substituting 0.2 for 0.1 as the value of S would
6E.47 seemingly take the pessimistic deterministic variants over the target. He describes these variants as the "better match" because they attempt broadly to mimic a transmissive feature
6E.26 at depth and the observed heads & salinities. Clearly more work needs to be done on the value of S. But the Assessor comments further that it is an illustration of the large differences in the estimates which can be brought about by variations in a single parameter:
6E.4 and I would add that it is rather a striking example of subjective uncertainty on the part of Nirex.

6E.86 Thus indications of the tentative state of the emerging safety assessment of the groundwater pathway are reinforced. I do accept that the encouraging base case calculations mean that this emerging assessment cannot reasonably be claimed completely to rule out on its own any promise in the Sellafield site. However, the exercise is still directly over-arching great uncertainties, such as on chemical containment and natural groundwater discharge, which would not by any means be resolved by the RCF. It is also highlighting the vulnerability of relatively rapid transport of radionuclides to the water-bearing sedimentary layers and the biosphere, compared with the slow downward flow of the ideal hydrogeological environment.

6E.46 6E.87 When further uncertainties are added, such as those over the time-variant & other
6E.2 pathway modelling, or the degree of tectonic stability, or the nature of features & processes
6E.54 at greater depth, the overriding conclusion must be to agree with the Assessor that this RCF proposal is premature. This is without taking into account either the central uncertainty of the BVG's hydraulic conductivity or the need to await the results of the major revisions in modelling development discussed in the previous Chapter. At least another cycle of
6E.1 preliminary safety assessment, ending with more comprehensive & definitive conclusions, would be required before this type of RCF project could be effectively carried out so as to confirm, clarify or contradict such findings at this site.

6F. ROLE OF RCF AND PROMISE OF PRZ

6F.1 Further work proposals to provide sufficient understanding to support a robust safety case are outlined above [Ca 6C-E]. Some work, such as aspects of NSARP [6C.22-27] and establishing boundary conditions of the hydrogeological region [6C.147], does not need the RCF. However, Nirex, some of the main parties and of those writing [eg WR/C/147, D/7, H/195, SPC/1, & WMC/1] and external bodies, such as HMIP, RWMAC and the Royal Society [COR/120, s.4; GOV/407 para.4.11 & GOV/414, para.45; COR/605, s.6.6, pp.107-8], regard an RCF as a necessary precursor to a DWR at the appropriate stage. This is in order to investigate the potential host rock in a way, and to an extent, that would not be possible from surface boreholes. Although some of the bodies have reservations about various aspects of the proposals, the primary issue is whether the appropriate stage has yet been reached at this PRZ. A second issue is the degree of benefit that would accrue from an RCF on this site.

6F.2 HMIP considers that the development of an RCF would be broadly consistent with programmes in other countries for examination of the deep geological structure and hydrogeological conditions at potential repository sites [COR/120, paras.4.1-2]. Studies underground could improve understanding of the geological and hydrogeological conditions at depth and facilitate DWR design so as to enable the presentation of a scientifically and technically robust safety case [COR/120, paras.4.1-4 & 4.11]. An RCF would allow a range of tests to be conducted to secure information which is not readily available from other routes, and would gain access to a larger volume of rock than is accessible from boreholes [COR/120, para.4.12].

6F.3 It would also assist studies of the chemical and physical processes which may influence the migration of radionuclides through the geosphere [COR/120, para.4.13-4] and build confidence in modelling [COR/120, para.4.15]. These views were shared by the Royal Society Study Group [COR/605, s.6.6, pp.107-8]. Because such data may be used to support a future safety case for a DWR, HMIP regards it as important for all the activities during construction and operation of the RCF to meet nationally or internationally recognised quality assurance standards [COR/120, para.4.7].

6F.4 HMIP does not regard the RCF as an aid to understanding the parts of the regional hydrogeological system [idem, para.4.9] which are distant from the PRZ, but a scientifically and technically robust interpretation of the geological and hydrogeological conditions at the site would be expected, taking account of uncertainties arising from an incomplete knowledge of the full system and its future evolution [COR/120, para.4.10]. Because the construction of the RCF would alter the hydrogeological, hydrochemical and geochemical regime at the site, a demonstration that any potential perturbation to the site arising from RCF construction would not destroy valuable information or have any consequent effect on the long term performance of any possible future DWR on the site is essential [idem, para.5.5]. This view is shared by RWMAC [GOV/414, para.32].

6F.5 Although the RCF's main purpose is to enable the submission of a post-closure safety case for the DWR ahead of construction, RWMAC sees the RCF as potentially having

alternative functions of generic research; as research dedicated to the DWR at this site; as a means of access to the DWR in due course; and as a component part of the DWR during its operation [GOV/414, para.6]. In particular, it sees the RCF shafts becoming part of the DWR to minimise delay and costs [idem, para.41]. It is also concerned at the optimism of Nirex's programme [idem, para.35 & GOV/407, para.4.22], a view shared by the Royal Society Study Group [COR/605, s.1.6, p.6].

6F.6 The Nirex Review Panel considers that the site has shown sufficient promise to justify proceeding with RCF development [COR/516/Appendix D, para.3.2]. However, it also recognises that the approach for upscaling local predictions into the wider area needs to be addressed [idem, para.3.8].

6F.7 Nirex points out that the RCF programme is planned on a flexible and provisional basis [2B.15-17], to help it address key uncertainties in the 3 main areas of flow & transport, changes to the geological barrier, and DWR design & construction [6C.50]. At the first decision point, about halfway through Phase 1, Nirex must initially judge whether the prospective post-closure safety performance of a DWR in the PRZ would be acceptable, and DWR construction be safe at an acceptable cost. Confidence that the regulator would foresee no impediment to the eventual grant of RSA authorisation would be a prerequisite to Nirex making a DWR proposal.

6F.8 The observations, testing and interpretation achieved from surface observation to date are amongst the most advanced and comprehensive undertaken at any geological site in the world. From a scientific standpoint Nirex believes the results are spectacular and reflect the high calibre of expertise employed. They show that the PRZ has hydrogeological attributes which demonstrate that it has potential to host a DWR. Nirex considers the site to be stable and the degree of complexity to be sufficiently well understood to have predictability which underpins the site's good promise. The necessary scientific tools are available and further work to be carried out in parallel with the RCF is unlikely to change its view of site performance substantially. Investigations from boreholes undertaken and planned take the work as far as it can go without the RCF.

6F.9 Nirex emphasises that its object is to gain sufficient understanding of the geology and hydrogeology of the site to provide input to the conceptual and mathematical models leading to a reliable probabilistic safety assessment. The object is not to collect information for its own sake, as implied by the thrust of objectors' arguments. Their proposals for more investigation are regarded by Nirex as inconsistent with the RCF's basic purpose. There is no contingency to explore different parts of the PRZ.

RCF Programme

6F.10 The RCF Programme timing, revised to the close of the inquiry, extends to the year 2009, assuming a start to construction in July 1997, including site restoration [COR/102D, Drg.008010 amending NRX/16/10, Fig.5.1]. Phase 1 would run from 1997 to 2002, Phase 2 from 2001 to 2003, and Phase 3 from 2003 to 2007. The time taken to bring a DWR into operation is an important influence on total costs. The RCF and other related Sellafield costs are forecast at £348M at 1995 prices excluding interest and inflation [3A.2]. The RCF would

help to assess DWR construction costs. Nirex does not regard the costs of reverting to another site, should Sellafield prove unsuitable, as an obstacle to such reversion - a view shared by the Rt Hon Dr J Cunningham MP. Much of the work completed so far would still be useful to apply elsewhere and, taken in its national context, the cost penalty of failure at Sellafield would not be great.

6F.11 Phase 1 would involve the calculation of the groundwater flow into the DWR and geosphere spreading effects from continuous mapping and hydraulic measurement during construction of shafts and galleries. It would be established whether the Basal Deep St. Bees Sandstone is a barrier to flow rather than being intersected by large scale sub-vertical fracture systems, and whether Type II features extend as preferential flow paths from DWR depth to the overlying sedimentary formations.

6F.12 Targeted sector tests would be carried out [NRX/16/10, Table 7.1 & Figs.7.1-2] together with dyed grout injection [idem, Figs.4.1-2], geochemical sampling [COR/101, para.1.62] such as Eh/pH values (for which the RCF is essential), observation of mineral formation and probe-hole hydraulic testing. These data would provide information on the extent of drawdown, and confirmation of surface drilled borehole core analysis, establishing the geological history of flow patterns over extended timescales, including seismic events.

6F.13 The effect of excavation disturbance on containment performance of the natural geological barrier, in the wake of the ZEDEX project [NRX/16/1], would be measured towards the end of Phase 1. Information on the spatial variability of the rock would be more effectively obtained from the RCF than from drilling Boreholes PRZ 6 to 10 [NRX/13/2, pp.1-2 & Fig.7]. Furthermore, 5 m diameter shafts would provide direct observations at 50 times the lengthscale of the 100 mm cores obtained from boreholes and permit a high degree of observation of fracture networks. DWR design parameters, in particular, depth, location, layout and orientation, would be confirmed by continuing shaft sinking to the optimum point where the decision on DWR depth (equating to RCF gallery depth) would be made.

6F.14 Models would be progressively validated by comparing forward predictions of the expected geological and hydrogeological characteristics of the BVG with observational data subsequently obtained. During shaft sinking simultaneous validation of coupled flow and transport models should be feasible. By the time Phase 1 is completed, 2 more main validation cycles for groundwater flow models would have been carried out, centred around firstly the Borehole RCF3 Pump Test and then the Shaft Drawdown Experiment [6D.20-21, 34-35].

6F.15 Dynamic biosphere modelling would be introduced [6D.13] particularly incorporating the effects of climate and landform change over some 100,000 years, plus more complex 3-D representation of the Quaternary sedimentary cover over the catchment areas [COR/526, pp.20-21] to produce resultant groundwater flows. The RCF programme allows ample scope to build confidence by responding flexibly to the outcome of each cycle of model testing. Nirex refutes suggestions by Greenpeace that the RCF would do little to assist the validation of regional groundwater flow models. Apart from obtaining invaluable drawdown data, upscaling assumptions would be tested and evaluated; regional flow features could be investigated at 2-D or even 3-D scale, linking NAPSAC and NAMMU [6D.29, 35-36]; and high quality hydrochemical sampling could be undertaken. Near-field models would be

improved by the inclusion of time-dependent effects such as corrosion, solubility, sorption and gas migration [COR/528, pp.22-23].

6F.16 During Phases 2 and 3 the Site Characterisation and Demonstration Experiment would characterise the flow of groundwater through connected fractures in a 1,000,000 m^3 region of BVG unaffected by excavation disturbance [NRX/16/10, Fig.5.2]. It is broadly comparable to experiments carried out at Stripa [NRX/16/2] and planned at the Canadian URL [NRX/16/3]. The Ventilation Tunnel experiment, similar to that carried out at Grimsel for NAGRA [NRX/16/4], would measure the hydraulic conductivity of the BVG, including that of the excavation damaged zone, over a lengthscale of about 100 m [NRX/16/10, Fig.5.3]. Laboratory measurements of rock matrix diffusion would be validated by comparison with in situ observations, as would essential geochemical sampling. Colloid transport would be observed within single fractures and fracture zones for the development of simple models. In Phase 3, gas migration would be studied by measuring gas entry pressure into fractures and gas/water flow characteristics within fractures.

6F.17 Natural and induced changes to the geological barrier would be calculated from experiments to measure the effects of the chemical disturbance to networks of connected fractures which arises from highly alkaline fluids, thereby building confidence in laboratory work. Measuring mechanical and hydraulic changes in the excavation disturbed zone would be continued during Phases 2 and 3. These trials include a "Mine Through" experiment near the end of Phase 3 to investigate the extent to which excavating the DWR vaults and access tunnels would induce significant hydraulic and mechanical changes in the rock mass [similar to Canadian URL "Mine By" experiment - NRX/16/3], albeit the feature through which it would pass has not yet been identified. Further cycles of model validation would continue.

6F.18 Experiments relating to the design and construction of the DWR would also validate models from data provided by mapping the galleries and underground drilling from insets within them; from measurements of inflows to the excavations; and from measurements of drawdown effects in the groundwater pressure monitoring system. The final location of the DWR vaults in the rock mass would be confirmed on the basis of underground drilling from the Phase 3 galleries, possibly along the line of the vaults. The required properties of seal materials would be established for the shafts [NRX/16/10, Figs.5.4-5 & 5.7]; for seals in galleries parallel and perpendicular to the maximum horizontal stress direction; for seals in boreholes [idem, Fig.5.7]; and for seals of fractures and the excavation disturbance zone. The RCF would confirm laboratory studies and provide data for the PCSR.

RCF Design & Construction

6F.19 Hydrogeological baseline monitoring would continue during site establishment until shaft sinking begins. Shaft, rather than drift, access has been selected to reach rocks at depth for reasons of economy. A second shaft would provide a separate access for safe working [COR/101D]. It would be required for the Peripheral Drilling and EDZ experiments during Phase 1. The shafts and galleries would allow regular and routine access to the rock mass for scientific measurements and observations for which a cautious "drill and blast method" is a prerequisite [COR/101, paras.2.76-90 & NRX/16/11, Fig.A2.5]. Much has been learned from international experience [eg Canadian smooth blasting experiment NRX/16/5] which has shown that it is essential to retain a degree of flexibility to adapt the layout of the laboratory

and the experiments during the course of development [NRX/16/6, para.3.2.1]. The proposed layouts for the underground excavations are therefore indicative and not prescriptive. One fundamental flexibility is to the gallery horizon which could be between the preferred level of 650 m bOD and 900 m bOD [2B.12].

6F.20 In Nirex's judgement, FOE are wrong to claim that the impact of excavation damage is insufficiently understood to warrant development of the RCF. In any event, it makes a conservative assumption that the hydraulic conductivity within the EDZ may increase by a factor of up to a hundred over a distance equivalent to twice the diameter of the excavation [6C.95]. Measurement methods would be based on international research and delay is unnecessary.

6F.21 It denies the suggestion that drill and blast construction is a questionable method of excavation pointing out that, given care, the extent of blast induced fracturing would be small using the proposed cautious or smooth blasting technique and certainly not inferior to the Tunnel Boring Machine method [NRX/16/11, Fig.3.1]. Shaft boring would suffer from problems of verticality, essential for the RCF shafts, and using an adit for spoil clearance so compromising working safety. Drill and blast is a well proven method used in UK and world wide and Nirex have call on a blast consultant with international experience of cautious blasting. Blast damage could penetrate the rock from the shaft wall some 38 cm for sandstones, 36 cm for the Brockram and 50 cm for the BVG. This is broadly consistent with experience in the Canadian URL [NRX/16/8, p.8] and the ZEDEX project at Äspö. Furthermore, the strength of the cover rocks through which the RCF shafts would be sunk is great, and not relatively weak as suggested by FOE. There would be support trials during Phase 1. The construction would meet civil and mining engineering standards and principles and could be upgraded if necessary to satisfy the requirements for the DWR. Ground freezing may be required for safety reasons during shaft sinking [2B.12].

6F.22 Mr Spendlove's alternatives for shaft location [NRX/16/11, Figs.5.1-2], use of a single shaft, and headgear design [5A.54-58], overlook important factors. The RCF has a man-riding safety requirement for the RCF shafts, and needs both an underslinging allowance for equipment and simplicity in operation. The use of below-ground decking, as in the Alternative DWR option [SPD/1/1], would introduce complications, and so it has been set aside in favour of ground-level decking together with safe overwind protection. The RCF's man-riding and materials conveying capability demands taller permanent headgear (29.2 m) than would be necessary for the DWR Preferred Option (15 m) although construction headgear would be the same for both (25 - 30 m).

6F.23 His alternative location for the South Shaft would place the shafts outside the volume of rock which Nirex seeks to characterise in detail, making continuity of mapping much more difficult. The shafts would also be outside the centre of the groundwater pressure monitoring system, thereby impairing the effectiveness of the shaft drawdown experiment during shaft sinking without further monitoring boreholes. The collar-and-foreshaft construction would be more difficult and expensive in unconsolidated water-bearing ground and either a new centreline borehole would be needed for the south shaft or the shaft sunk without the benefit of one. The proposed twin kibble spoil removal method is more efficient than that using the single kibble. For all these reasons Mr Spendlove's proposals are substantially disadvantageous. Furthermore, the suggestion by Dr Cobbing that the Bleawath Formation

is a suitable alternative host rock sequence to that proposed [WR/C/146] is unsound because it is too deep [WR/NRX/4(14)].

6F.24 Use of the single shaft for Phase 1 would impede progress to Phases 2 and 3 by some 3 years and deny the scientific benefits which the second shaft would provide to Phase 1. Furthermore, Mr Spendlove's presumption that the decision point on whether to abandon or continue the project would be arrived at part-way through Phase 2 would introduce rigidity into an essentially flexible operation.

6F.25 The scope for re-use of the shafts in a DWR would be limited by their design having been confined to the requirements of the RCF's scientific purposes. However, sealing and grouting would be carried out with the DWR safety case in mind. The RCF's location in the PRZ is designed to guard against the possibility of the shafts providing a preferential pathway for groundwater flow which could compromise the containment performance of the geosphere. One element of this is for the shafts to be upstream in terms of flow, and another is to facilitate provision of an inclined drift access to a DWR without going outside the PRZ. If Phase 1 were to be successful, the DWR would probably be located near the RCF. At some distance, extrapolation between them could be less reliable. As a matter of principle, Nirex considers there should be as much physical commonality as possible between the RCF and DWR without significant penetration into the potential DWR location.

6F.26 All the points raised by the RWMAC in its report on the RCF [GOV/414] have been addressed. A hydrogeological baseline has been established and monitoring continues. Nirex intends to publish its predictions of significant findings expected to arise during shaft sinking and the results of Phase 1 sector by sector. Shaft lining would be installed through the sandstones and the Brockram, but not the BVG, and the shafts monitored so that any disequilibrium could be remediated promptly with support should it prove necessary. Microseismic activity, natural gases and geothermal effects are planned to be monitored. Trials are planned for NRVB in a surface-based facility or in the RCF during Phase 1, and then once a DWR vault has been constructed. Drawdown would be monitored during shaft excavation as described above and would continue through all phases as part of other studies.

6F.27 Nirex points out the penalties involved in further delay to the DWR programme. Sinking further boreholes and monitoring for 5 years followed by peer review, as put by FOE, would take to about 2006 and add to costs. The RCF planning permission would then be delayed to 2009/10 with consequent further costs. While the Government lays down no fixed timetable for a DWR, it emphasises the need to avoid unnecessary delay [GOV/208, para.101]. Nirex well knows the consequences of failing to satisfy the regulator of the establishment of baseline conditions and it is in its interests to ensure that it succeeds. This is not a matter for the RCF inquiry. Nirex is negotiating an agreement with the Environment Agency to define submissions by Nirex and responses from the regulators, and there is also its assurance that it would submit a peer-reviewed baseline report to the regulator, in time to receive the regulator's views, before shaft sinking [6C.158].

6F.28 Copeland's view that the Olkiluoto VLJ repository carried out safety studies in situ is mistaken [NRX/13/6]. They were conducted in a laboratory, as is proposed by Nirex in this exercise, so Copeland's reservations about the work programme are groundless. Nirex's programme compares favourably with international experience [NRX/13/7].

6F.29 Cumbria has very substantial doubts that a safety case can be successfully developed at Sellafield because it is such an unpromising site [6E.42-52]. Although the RCF would yield more information than the boreholes, and Nirex concedes that there is much work to do, the present unfavourable level of risk is likely to persist. The host rock sequence exhibits serious deficiencies [6C.120] and was not selected for its promising radiological performance but for other questionable reasons [6B.58]. Nirex concedes that a potential DWR could be so geologically complex that the degree of intrusive investigation could compromise the safety case and it does not claim to be able to engineer a solution to all situations of geological complexity or identify all features in the PRZ with certainty.

6F.30 Allowing further long, costly and complex investigation, and the harm that would result, is not justified in this PRZ. By the end of Phase 1 total expenditure would be £793M (£425M Sellafield specific); by the end of Phase 2 £857M (£463M); by the end of Phase 3 £1018M (£543M); and total cost to waste emplacement £1820M [NRX/12/18, Table 4.2]. Although some work is generic in nature, repeating the exercise once commenced would be very expensive, the pre-commitment being of concern to many organisations and individuals writing [eg WR/SLC/1, ACC/1, ANG/3&4, T/55].

6F.31 Copeland regards the RCF as premature because, leaving aside paramountcy of safety in site selection, the work programme does not go far enough. In situ testing of the multi-barrier system, testing the feasibility of pre-closure retrievability of waste from its emplacement, and preparing for long term pre- and post-closure monitoring of the waste, need to be made systematic in order that the public may be reassured. It cites the Olkiluoto VLJ repository in Finland as an example of best practice [CBC/3/1, p.13 - "safety studies"].

6F.32 Gosforth is sceptical about the promise of the PRZ and sees the chemical and engineered barriers as providing inadequate assurance to compensate for the complexity of the host rock. The wet environment at Sellafield is flawed in its view [WR/GPC/2, p.3], a point supported by Mrs M S K Higham who draws attention to the additional costs involved in overcoming difficulties. Gosforth regards the RCF programme as being rushed with insufficient time for baseline conditions to be properly established and models validated; for results to be subjected to peer review; and for older waste storage plants and associated waste storage facilities to be upgraded [WR/GPC/3, para.7], a view shared by GAG.

6F.33 FOE assert that baseline conditions are far from being established, a point of concern to several parties and many of those writing, and that Nirex does not understand the complex hydrogeology of the host rock or the impact of excavation damage on fluid flow. Information from the RCF would be of little or no value until these problems have been overcome. They cite HMIP's point that failure to properly establish baseline conditions could frustrate the objectives of the RCF. Moreover, because RCF construction is premature, it could also prejudice the achievement of a PCPA and successful development of the DWR [6C.133] - a view shared by South Cumbria Citizens, Patricia McKenna MEP and Mr J Fitzsimons MEP amongst others. A very comprehensive programme of further work is needed, especially for more boreholes, [6C.144] and peer review would extend this

preparatory period. FOE estimate that Nirex's RCF programme is about evenly divided between generic or engineering functions and site specific characterisation.

6F.34 It is essential, as a prerequisite for the RCF, for a robust interpretation of the geology and geochemistry in and around the PRZ to be achieved as a framework for reliable models and to identify the correct location for the RCF. Equilibrium conditions of the hydrogeological regime must be established which, because of complex fluctuations, could take 2 years or more to achieve [6C.109-110]. International experience, particularly in Canada, suggests that a site programme should involve about 5 years testing of about 6 to 12 boreholes over a 10 km^2 area, targeted at conditions known from seismic and geophysical data. Fracture flow must be understood and models validated. The RCF should be planned as part of the staged programme of DWR development so that its location is optimised [6C.134]. RCF experiments should form the culmination of generic and other surface-based research and Nirex should publish a forward programme for the integration of laboratory and field/RCF work which they claim they are going to follow. However, Nirex concedes that the acquisition of more information from surface based investigations would add to its understanding.

6F.35 Nevertheless, FOE doubt that the PRZ is capable of characterisation or of being suitable for a DWR [eg 6C.112 & 120]. The PRZ is lacking a low hydraulic gradient throughout the site, and simple geology and hydrogeology [6C.114-115]. Modelling is still at an early stage [6D.51-7] and unjustifiable inferences have been drawn from experience gained in the relatively massive, uniform and fracture free crystalline rocks in Canada and Sweden [6C.106]. Experience in Sweden and Canada indicates that in situ data would be of little value to flow characterisation and the PCPA [eg FOE/7/20, p.199, lines 39-43 & FOE/6/28, p.7, penultimate para.], and further fundamental research and development in this area is necessary before excavation is commenced [6C.106]. Without the extra boreholes at Sellafield [6C.144], there is a real danger that even a 3-D time variant model would give an inaccurate representation of the flow regime.

6F.36 Similarly, construction impacts are not yet sufficiently well understood, so that data could be potentially misleading and compromise a satisfactory PCPA [6C.133]. Standards of construction, science and engineering appear to be inadequate [6C.131]. In particular, non-conservative assumptions of the impact of the RCF on the PCPA have led to unacceptably low performance objectives for the engineered barriers. Reliance on drill and blast, and failure to examine alternative methods, would not minimise damage to the rock mass, a point also made by **Mr J N Walker**. Although more costly, a cut-off collar may resolve sealing problems and there is a strong case for machine mining the second shaft because it should reduce the EDZ. Nirex concedes that the Ventilation Tunnel Experiments would only produce broad results because of practical problems. In addition, the concept of backfilling and sealing of emplaced waste is presently flawed and needs more generic research before testing in situ [6C.127-8 & 131-4]. FOE also doubts that there is room in the PRZ for the RCF and a DWR.

6F.37 Dewatering as a result of RCF (and DWR) development could be concentrated along the FHFZ and transmitted to permeable superficial deposits to the West in the Newmill Beck valley, and to the exposed outcrop of St Bees Sandstone in the East near Gosforth. More data are needed on this before perturbation by the RCF. Although there are difficulties in

establishing baseline Eh/pH values from the surface, FOE insists that as much progress as practicable should be made before the RCF is excavated. Nirex has not yet published a programme for the integration of laboratory and field/RCF geochemical work and is over-optimistic about the rate of progress which can reasonably be achieved. Progress towards understanding geochemical processes, for which laboratory work is appropriate, is not sufficiently advanced to justify perturbation by the RCF and potentially compromise future geochemical modelling [6C.123, 6D.57], a view supported by South Cumbria Citizens.

6F.38 Potentially serious risks could result from failure to produce a reliable DWR PCPA of which the RCF development is a part. The high degree of uncertainty in this project, and the likelihood of further difficulties ahead, demands a precautionary approach in accordance with the principles of sustainable development [GOV/208, para.50], a point emphasised by The Irish Government [6A.52]. Nirex's proposals would cause grave and demonstrable harm to interests of acknowledged national importance in FOE's view.

6F.39 Greenpeace does not believe that Nirex would ever be able to sufficiently characterise the PRZ to achieve a satisfactory PCPA for the DWR, and so there is no benefit in the RCF. Furthermore, failure to optimise the location of the RCF would have an adverse impact on the DWR safety case and so risks would not be as low as reasonably achievable (ALARA). This is a material consideration and subject to the Euratom Directive's principles of justification & optimisation [2A.2 & 6A.49] and to SP Policy 54(ii).

6F.40 In addition, all Nirex's activities should employ best practicable means (BPM). BPM could not be implemented without a validated hydrogeological model of the region [6D.45-6]. Without such a model the proposed positioning of the RCF shafts is open to question and yet is critical to optimising the DWR because of the likely role of the shafts for ventilation and emergency access and because of the perturbation caused by excavation. Nirex concedes that the radiological performance of the site could be affected by the RCF yet is equivocal about the physical relationship between the RCF and the DWR. On one hand it cites the difficulties in extending the shafts deeper if an unexpected problem is encountered in the galleries, while on the other it emphasises the need for flexibility of location of the DWR.

6F.41 If the RCF is to confirm current understanding, this must be sufficient to determine the optimal DWR location prior to shaft excavation. Nirex concedes that harmonising the locations of the RCF and DWR would minimise perturbation and costs and the regulator seeks to avoid undue disturbance [HMP/1/1, para.7.12]. Perturbation by the RCF could also compromise Nirex's ability to collect suitable data on glacial flushing, and the RCF is unlikely to facilitate such data collection in any event. The OECD advocates the use of long -term monitoring programmes early in site characterisation in order to establish baseline conditions prior to major perturbations and capture them when they occur [GNP/4/7], but that is not occurring satisfactorily here.

6F.42 The lack of understanding of regional hydrogeology also inhibits Nirex's ability to address key uncertainties through RCF data in Greenpeace's view. Narrowing the range of groundwater fluxes through the DWR [6E.59] would be more effectively conducted through further Cross-Hole and Pump Tests than a single, non-repeatable, poorly constrained RCF Shaft Drawdown Experiment, which itself would make a very large perturbation in the natural flow system thus making further regional borehole experiments much more difficult.

world yet shows unfavourable features for a DWR. He also regards the programme as deficient in its failure to carry out in situ trials using radioactive materials. He points out the great evolution of scientific knowledge which is likely to occur, particularly over protracted timescales. The application of new robotic techniques to the disposal of nuclear waste suggested by **Mr J Michael** could be a case in point [WR/M/194].

6F.49 Many of those writing also question the need for the RCF at this stage [eg WR/W/66]. On the other hand **Dr E J Cobbing** challenges the location under investigation suggesting that the deeper Bleawath Formation is much simpler, more determinable and less active than the host rock in the Fleming Hall Formation, and recommends that it be investigated as likely to provide a more reliable safety case than current proposals [WR/C/146].

6F.50 **My conclusions** on the role of the RCF within Nirex's future work programme start
6F.8 by acknowledging once more the general quality & innovation of Nirex's scientific &
6F.1 technical work to date. Moreover, I note the consensus that a facility of the nature that is proposed must form a central part of the subsequent stages of the DWR project. There is no doubt that the detailed excavations, investigations & experiments planned for the RCF would contribute significantly, and in many cases crucially, to the sum of knowledge required to implement the DWR concept at Sellafield.

6F.7 6F.51 Also I accept entirely the principle that the programme for work within the RCF must
6F.15 be flexible, in order to cope with actual conditions as they are revealed, albeit subject to the critical requirement that the relevant baseline conditions must be fittingly established for each piece of work before it is started, whether it is a deviation from the programme or not.
6F.48 Whilst admiring Mr Spendlove's boldness in taking on Nirex's design team single-handedly and thanking him for the intellectual stimulus of his alternatives, I have firmly concluded with
6F.22-4 the benefit of the Assessor's advice that Nirex's twin shafts would be an integral part of the essential flexibility.

6F.52 I have drawn together these generally favourable conclusions at the outset because I do not wish to appear to detract from them, and yet I do consider that as I near the end of this report I must nevertheless concentrate on the drawbacks which the Assessor & I perceive in Nirex's approach. In the first place, Nirex is too optimistic about the situation it has
6C.159 reached. It does not understand the regional hydrogeological system well enough, and it is
6C.163 not planning to give the remainder of its investigatory programme sufficient scope to remedy
6C.169 that deficiency. Secondly, it does not fully comprehend the extreme complexity of the PRZ,
6C.161 and over-estimates its own knowledge & understanding in crucial respects. Thirdly, it is
6F.37 much too hopeful about the speed & confidence with which it could reliably process
6F.44 information and make firm decisions in constructing & operating the RCF.

6F.53 There are 2 general points to be deduced from these propositions, in my view. The first is that Nirex should not be allowed to proceed with the RCF in its current state of inadequate knowledge, for that would cause needless damage to the PRZ; make it very difficult for anyone to predict the consequences of Nirex's actions; and result in a confusing outcome. The second is that it is difficult to credit that Nirex has optimised the location of the RCF, because it has not equipped itself with the knowledge to do this. It does seem

6F.25 expedient to prefer a location in the upstream part of the PRZ; the environmental appraisal
5A.2-3 does suggest that a drift access should be accepted as a design constraint; and there could
6B.101 well be room for a DWR at the preferred location. But, with respect to RWMAC, the advice to me is that it would be physically impossible to characterise the remainder of the PRZ from the RCF, and so those pragmatic parameters would have precluded all other options within
6F.40-1 the PRZ. Except by coincidence, this RCF could not be the confirmation of the suitability of the most stable, understandable & impermeable volume of rock for a DWR. This paradox is redolent of the defects of the site selection exercise.

6F.54 Moving on to give some more detailed underpinning of these general conclusions, the
6F.42 Assessor advises me that the RCF would be unable to provide information on about half of
6F.6 the principal hydrogeological units which make up the current regional transport model.
6F.19 Also, whilst Nirex's choice of excavation method is agreed as the obvious & conventional
6F.21 one, and the shaft drawdown & excavation disturbance experiments should be very useful, there are 2 very problematic points about the early stages of the RCF. The first is that, although flexibility is being retained over the repository horizon, merely digging down to the preferred horizon of about 650 m aOD would not enable a decision to be made about the actual horizon at which the DWR would be constructed. Even to confirm that the preferred horizon would be definitely unsuitable would have to await the results of tests after arriving there. A preliminary decision to stop at that horizon made on surface-based information would by definition be unreliable.

6F.55 The second point is that the Assessor and I cannot conceive that a decision could be
6F.7 made halfway through Phase 1 to proceed with a DWR application. Nirex would not be far enough into the rock nor have enough additional information for such a decision point to be realistic. Further examination of the items in the RCF programme corroborates this
6F.16 judgement. Some of the main experiments in the preferred option for Phase 2 would not actually be to help design the DWR as Nirex's overall scheme suggests, but would really be
6F.14-5 still testing the suitability of the preferred location. In conjunction with this, Nirex seems
6F.17 to remain unduly optimistic about its model development & validation programme. Put broadly, it would in practice be at least one cycle behind what should be the case, so that Nirex would be at serious risk of basing successive predictions on inadequately refined models, in turn producing output of insufficient reliability.

6D.70 6F.56 This sequence of retardation would start with unsatisfactory knowledge of baseline
6F.4 conditions before the RCF begins. This is a matter of particular concern to HMIP, and, according to Nirex's timetable, there might be no subsequent opportunity for hydrogeological
6F.16-8 conditions to recover between the end of RCF work and the start of DWR construction. The baseline should be established across the entire primary network of boreholes for the region:
6C.159 but it would not be established, because Nirex has no plans to sink some of the requisite
6C.163 boreholes, and does not intend with its existing & planned ones to monitor them for long enough for any responses in the deep BVG to annual rainfall trends to become characterisable. Some current fluctuations suggest that there are hydraulic connections which have not yet been identified.

6F.57 Although a backfilled & sealed RCF should recover to its natural state in ordinary restoration terms, I am advised that there would be subtle changes which could affect radiological safety. In my view, no opportunity to detect such changes should be lost, but

on Nirex's favoured timetable, the normally important phase of observing the recovery following cessation of pumping would be omitted, and there would follow instead the even greater drawdown caused by DWR construction itself. This would certainly alter the baseline
6D.71 conditions, including the geochemical ones, so I am advised. Following the sequence of events through in this way emphasises the importance of establishing the baseline conditions as thoroughly and robustly as practicable before commencement of the RCF.

6C.158 6F.58 Although the welcome assurance has been given to submit a peer-reviewed baseline report to the regulator for comments before the development begins, it is now apparent that there are a number of drawbacks to this procedure. The report would not cover all of the conditions which it should, either by way of regional detail or over time. Then I agree with the Assessor that, even on the incomplete basis which Nirex intends to provide, there would
6F.5 not be the time to have the report properly peer-reviewed for Nirex's programmed start to excavations. The regulator would in any event have no statutory standing in the matter - a
3B.39 reminder that under current UK law & policy the planning system is in effect the state's controller of the present stages of the DWR project.

6F.59 I appreciate that Nirex feels strongly that the details of these scientific & technical matters are for the regulators to consider when eventually they do have formal standing in relation to the project. But the fundamental point on this planning appeal is that, to put it at its lowest, the evidence shows to me that to go ahead with the RCF now would be seriously premature. Thus there can be no benefit to be taken into account under SP Policy 54 for going ahead now, and there could well be some harm to the radiological safety potential of the PRZ.

7A. MITIGATION OF ENVIRONMENTAL EFFECTS

7A.1 In the ES [COR/101] Nirex explains various measures intended to minimise adverse effects. However, during the course of the Inquiry, Nirex and Cumbria have agreed a list of conditions [COR/113] to augment, or give precise expression to, the measures in the ES. Many of these have also been accepted by Copeland and Gosforth. This Section of the report is based on COR/113, but also takes account of the variations suggested by other parties [CCC/1/25, CBC/2/6, GPC/4 & 4A, GRY/1/1 & WR/LOW/1]. I have taken account of these mitigation proposals in the course of earlier chapters and my comments below are without prejudice to the views already expressed.

7A.2 The development would be for a limited period of 13 years [idem, Condition 1] and subject to comprehensive landscaping, restoration, replacement and aftercare schemes [idem, Conditions 28-29, 31-35, 38-39]. There is a contingency for early cessation of the development [idem, Condition 30]. The stripping, storage and use of soils and overburden and control of weeds, would be regulated with reference to submitted schemes with some details being left for later determination by Cumbria. All works would be required to conform to approved schemes [idem, Conditions 2, 40-41]. Of particular note is the schedule of approved drawings appended to the list of conditions [idem, s.1], being the subject of Condition 2. These conditions are not in contention, subject to comments below and save for FOE's scepticism that the 13 year period would suffice: and I regard them as crucial.

7A.3 Design and external appearance of the buildings are proposed to be controlled by an amended scheme [idem, Condition 3a with Scheme A]. However, the scope for discretion is limited by the terms of the application [4B.26] and the scheme is not agreed by Copeland or Gosforth, which differ from Cumbria in seeking a treatment much more sympathetic to the vernacular in materials as well as design [5A.43 & 46]. To my mind the colour scheme now proposed for the profiled cladding of the headgear and buildings would help reduce visual impact to a degree. But, bearing in mind that the heapsteads would not be completely screened, I consider it a retrograde step for the earlier proposed brick finish to their walls to have been replaced in the latest plans by profiled cladding [compare Drgs.008019 and 008021 in COR/102A and COR/102B].

7A.4 Supply of electricity, access arrangements (including special measures for construction traffic - idem, s.10, Drg.008916) and dust suppression measures would also be achieved through agreed schemes [idem, Conditions 4, 6 & 15], while the details of freeze drilling arrangements, should they be necessary [2B.12], and external lighting would be subject to the submission of further details and approval [idem, Conditions 3b & 5]. These conditions are generally agreed but Gosforth and Cllr Gray object to night lighting and anti-intruder fencing [GPC/4, s.16, GPC/4A, s.1 & GRY/1/1]. Because of the nature and vulnerability of the RCF and its activities, and the likely value of on-site plant and equipment, I accept the need for lighting for safety and security purposes but consider that the proposed Condition 5 is capable of ensuring that lighting is limited to the minimum necessary. Nirex has significantly reduced the extent of proposed fencing and lighting [NRX/1/5, Fig.2] and it has incorporated this alteration in the amended application plans [COR/102B, eg Drgs.008007B, 008009B, 008014B]. To my mind the amended application approaches the practicable minimum of security fencing for this operation and is commended accordingly.

7A.5 Blasting and noise levels are designed to be controlled within reasonable limits taking account of nearby vulnerable locations during day, night, weekend and holiday conditions through monitoring [idem, Conditions 7 to 13]. The noise conditions are agreed by Cumbria subject to a further condition on hours. Cumbria and Copeland agree with the blasting criteria. Gosforth's contention that blast levels should, in effect, be undetectable by human senses in any part of the National Park and should not, in any event, be carried out between 2200 hours and 0700 hours [GPC/4 & 4A, s.5], seems extreme, in my view, given the low levels of blast stipulated and the effects caused by HGVs on the A595(T) [5D.11].

7A.6 Gosforth's request for investigatory machinery for complaints of nuisance from blast or noise, or breach of planning conditions, is met already under present legislation, and its concern regarding remedies for blast-induced damage is not a planning matter. Its requests for log-keeping and positive control of operations by the Regulating Authority without any breach necessarily having taken place [GPC/4, ss.7 & 8], while understandable, would be unduly onerous upon Nirex and the relevant Authority. However, I entirely support Copeland and Gosforth's point that the regulatory regime must be effective.

7A.7 On noise, I have already concluded that there should be a general night-time limit of 39 Db L_{Aeq} [5D.29], and I consider that suggested Conditions 9 & 10 should be amended accordingly, since I am satisfied from the evidence that Nirex could comply with such a limit. I have also concluded that the site establishment & fore-shaft excavation activities should be prohibited at night [5D.30]. Nirex has accepted without prejudice the description of the activities to be specially controlled as in Cumbria's suggested Condition 14 [CCC/1/25]. However, there is a problem in that Nirex has expressly declined to acquiesce to a prohibition of any particular working on Saturday afternoons, Sundays & holidays, on the grounds that there is no evidence to support such a distinction. This by-passing of national policy [5D.30] applies to suggested Conditions 9 & 10 as well as 14. My view is that the same limitations as at night should be imposed for the normal rest days on a development of this timescale as a matter of policy, although it might be thought necessary to refer the matter back to the parties with an indication that permission would be granted subject to such an imposition.

7A.8 Groundwater resources should be adequately safeguarded by condition after consultations with the Environment Agency [COR/113, Addendum & WR/NRA/1], in Cumbria's view. However, Nirex believes such a condition would be unnecessary because it would duplicate the Environment Agency's power to serve a Conservation Notice [GOV/803, s.30]. Nirex points out that the authorities, including English Nature, are satisfied that pollution would be obviated by conditions attached to any Discharge Consent [CCC/1/27]. The powers available to the EA Regulator under a S.30 Notice do appear to be generally limited [COR/113C, Addendum, NRA letter of 30 January 1996], and indeed I am unsure whether they are applicable at all to the particular circumstances of the RCF. Although I am also doubtful whether the abstraction could cause serious harm, on balance I conclude that the condition proposed through Cumbria [idem, NRA letter of 19 January 1996], substituting the Environment Agency for the NRA, would be reasonable. On the other hand there is no need in this specific case for planning conditions to control pollution of the watercourse [5E.29].

7A.9 Archaeological remains would be safeguarded by submission of a scheme of investigation to be submitted to, and approved by, Cumbria [idem, Condition 18]. Also uncontentious between the parties is the action to protect badgers and conserve part of their habitat by the maintenance of a grass sward, provision of tunnels and a monitoring scheme [idem, Conditions 19-21].

7A.10 The woodlands management scheme in the planning agreement is generally agreed as helping to mitigate the visual impact of the RCF from the many potential viewpoints in the landscape, and I support this view [Ca.5A] as a complement to the landscaping conditions mentioned above. Although the woodlands are largely outside the appeal site [compare NRX/11/18 with COR/101, Fig.3.5.1 & COR/113, Restoration Scheme H, Drg.008046], there is some duplication with Schemes G and H in conditions 28a and 29. In particular there is overlap of the important tree belts which give some protection to the dwellings on Newton Manor Estate Road. Thus there is technically a degree of conflict with Circular 16/91, Annex B, para.B6, that the terms of conditions imposed on a planning permission should not be restated in a planning obligation, because this would involve nugatory duplication and frustrate a developer's right of appeal. However, I consider that this is not important on this occasion.

7A.11 Gosforth's proposals for road improvements by widening the A595(T) between Gosforth and Calder Bridge; by provision of a footpath and cycleway between Gosforth and New Mill; and by construction of a new access onto the Sellafield/Blackbeck road [GPC/4, s.10-12], have been considered in Chapter 5C. I have concluded that the general improvement of the trunk road is unnecessary and may be environmentally damaging. My conclusion on the footway/cycleway is that there is not the physical highway capacity for both that and the RCF project's vehicular traffic, and so it would be unrealistic to require its provision if the RCF is to be permitted. So far as the service road towards Sellafield is concerned, the publication of a detailed feasibility appraisal is the first requirement.

7A.12 I have considered the remaining conditions put forward, including Mrs Lowery's suggestions for speed restrictions and better signposting [WR/LOW/1; also GRY/1/1], but, in my view, they are either unnecessary, do not relate to matters of proper planning control, or are dealt with by those which I am recommending.

7B. ENSURING SCIENTIFIC AND TECHNICAL BENEFITS

7B.1 In addressing the matters about which you particularly wished to be informed during the course of the inquiry [1.5 Matter 6], and bearing in mind the guidance in Circular 11/95 paragraph 2, I have formed the view that the securing of scientific and technical benefits through the imposition of conditions is an option worthy of exploration with the parties [COR/113C, para.1a]. Suggested conditions are set out at COR/113C, Annex A, as a focus for discussion. The aims would be to control the establishment of baseline conditions; and to ensure satisfactory scope & standards of modelling, monitoring, and experimental work.

7B.2 A requirement on the lines of Condition A would lay down the principle of agreeing a programme of work dedicated to the DWR safety case, whilst one on the lines of Condition B would set out the framework of the programme. An assurance on the lines of Condition C would be needed to preclude premature perturbation of the PRZ before the baseline conditions had been properly settled. Further requirements on the lines of Conditions D & E would be necessary for operational control and monitoring purposes.

7B.3 Nirex submits that the suggested conditions seem to be directed at matters appropriate to an eventual determination by the regulator. It would be wrong to place Cumbria in the position of the regulator, particularly as Cumbria is unwilling to adopt that role, and as it is uncertain that the Environment Agency would be prepared to advise Cumbria. In the meantime, there is no formal role for the regulator during the investigatory process.

7B.4 Furthermore, Nirex submits that such requirements would be unnecessary in view of the formal assurance which it hereby gives to the Secretary of State, that:-

(1) work to extend and refine information about baseline conditions continues;

(2) a further independent peer review of the available data, considering both groundwater pressures and hydrogeochemistry, is planned to be carried out by the end of 1996;

(3) the Environment Agency would be provided with a peer-reviewed baseline report for discussion prior to shaft sinking, in order that it may give a view before underground characterisation commences;

(4) Nirex would take account of the Agency's views before shaft sinking begins; and

(5) the baseline report put to the Agency would be published.

7B.5 Cumbria shares Nirex's view that the suggested conditions appear to be unenforceable in practice because the Council does not have the expertise or financial resources to implement & police them. The relevant matters are appropriate for the Environment Agency rather than the County Council. Although Cumbria considers that the conditions are

potentially lawful, it would not wish to see them imposed. It questions the precision of the procedure of peer review and the measurements necessary to satisfy the conditions, both of which could become fertile areas for dispute. In its view, the need for Conditions A, B and C demonstrates that the development is premature because a lengthy period of other site characterisation is required first. Conditions D and E seek to control matters once the RCF is in being, and so their planning purpose is more tenuous than the avoidance of over-hasty excavation of the potential repository site. In any event, because these conditions could take such a long time to satisfy, refusal of permission is the right course.

7B.6 FOE also have misgivings about the absence of regulatory control by the Environment Agency during the investigative stage of the DWR project. This undermines their confidence in the effectiveness of conditions to secure satisfactory RCF development. The only basis on which the RCF could proceed is to meet in full the requirements articulated by HMIP. This would require a further 10 years of work prior to RCF shaft sinking [6C.144], with an uncertain outcome. Such requirements would derogate from the grant of planning permission and be regarded as unreasonable.

7B.7 Without prejudice to this view, FOE regard it as essential to require the provision of a work programme and its results to Cumbria for approval before RCF development commences. The work programme should relate to the establishment of baseline conditions and research [6C.144], including assimilation of international research and a comprehensive programme of work for the RCF. The results of investigation and research should be available to the scientific community for a 6 month consultation period and, like the RCF work programme, be submitted to an independent peer review panel. These results should also be submitted to Cumbria for approval before RCF development was commenced.

7B.8 The need for public reassurance that scientific and technical benefits would be achieved if the RCF were to proceed is generally felt by objectors and specifically articulated by GAG and Mr S Balogh.

7B.9 My conclusions on securing the scientific and technical benefits of the RCF again rely heavily on the Assessor's evaluation. He and I are clear that it is necessary to ensure that these benefits are secured. Otherwise, the DWR project could fail through premature, or ill advised, development of the RCF; and environmental damage would occur without justification. As to the means of achieving adequate control of the scientific & technical aspects of the development, I consider that a binding agreement between Nirex and the Environment Agency could be the most appropriate form in the current legal context [2A.14-7]. The assurance given by Nirex could be deemed to cover the first steps to be taken under such an agreement.

7B.10 However, should planning permission be granted for the development in the absence of such an agreement, Cumbria must perforce regulate all aspects of the RCF as local planning authority; and I believe that most of FOE's concerns could be met in the drafting of precise provisions. But I take Cumbria's point about the shortage of resources necessary for it to carry out this special national task. The inquiry has shown that considerable specialist expertise is essential to fully consider the relevant matters and make competent

determinations. Yet the DWR project has now reached a critical stage where self-regulation by the developer plus summary Ministerial endorsements following reports from advisory bodies might well not suffice in lieu of decisive and authoritative external control. In the absence of direct jurisdiction by the Environment Agency under statute or by agreement, the most expedient action might well be to ask the Agency to advise Cumbria in regulating the development, in parallel with a constructive process of peer review [6C.158].

7B.11 The reservations expressed about the possibly lengthy time delay in meeting requirements on the lines of the suggested Conditions A, C and D have to be weighed against the complexity and national importance of the DWR project, in my view. Although I have not sought to define independent peer review, nor state the requisite measurements and data requirements, the concept of peer review is, I am sure, well understood by the scientific community [6C.156-7], and the measurements and data required would be for Nirex to suggest and for Cumbria, on advice, to specify. Although Cumbria has balked particularly at operational control of the RCF, I consider it as important to supervise work inside the inherently flexible RCF as it is to settle baseline conditions in advance.

7B.12 In short, my view is that controls along the lines which I have canvassed would be necessary, both to ensure that the benefits which weigh in favour of granting permission are actually obtained and to avoid uncalled for harm to the potential DWR location. If it is decided that it would be altogether inexpedient to secure such controls, then I fear that this would reinforce the reasons for refusal.

8. FINAL CONCLUSIONS

These conclusions summarise and draw together the preliminary conclusions from each chapter of my report. The references for the individual conclusions are given in those chapters. This synopsis generally follows the structure of the report, but in some places material on a particular point has been collated from a number of chapters. My final conclusions are given on the matters which I regard as the main considerations in determining the appeal.

Main Considerations

8.1 I regard the main considerations in determining the appeal as:-

(1) the legal and political framework within which the appeal should be decided;

(2) the relevant provisions of the adopted and emerging development plans for the area;

(3) the degrees of adverse visual, socio-economic, traffic and other environmental effects likely to result from the proposed development and any associated development, and the extent to which such effects would involve conflict with the development plan or national planning policy;

(4) the suitability of the appeal site for the development;

(5) the degree of scientific and technical benefits likely to be obtained from the development, to be weighed against the likely adverse effects, as required by the development plan and national planning policy; and

(6) the nature and form of the conditions which should be attached to the planning permission for the development, if granted.

Legal and Political Framework

8.2 The Rock Characterisation Facility (RCF) would be in the form of a deep mine, and there would be no radioactive waste in it. Therefore no authorisation for the disposal of such waste would be required, and the site would not need to be licensed as a nuclear installation. If the RCF were to be followed by a deep waste repository on the site, the law would need to be changed by a statutory instrument for the repository to be required to obtain a nuclear installation licence. It has been submitted that the present law would not require the repository's operator to obtain a waste disposal authorisation either, because the producers of the waste would already have appropriate authorisations. My opinion is that it cannot be

assumed that this would be so, and it is clear that this is not the situation which the Government envisages.

8.3 A more important aspect of this point for me is that no potential regulator of the repository has a formal standing for the time being in relation to the overall repository project. Although the predecessor body responsible for authorisation has been shadowing some of Nirex's work, that has been as informal preparation for the anticipated application for authorisation. A suggestion for a formal working agreement between Nirex and the regulator was under discussion at the time of the appeal inquiry, but the arrangement had not been made by the close of the inquiry. This situation, of the repository project being well under way without any formal involvement of the regulator, is not one which is contemplated by the various international guidelines as I understand them.

8.4 It is against this background that there is a need to resolve the first set of legal issues between Nirex on the one hand and the Irish Government, a joint committee of local authorities and several other parties on the other hand. In my opinion, the work on the repository project is much too advanced for Nirex to be able to claim that the potential repository is merely hypothetical, and that it should be ignored for the purposes of the present appeal apart from reviewing the choice of location. Nirex has been working on the Sellafield repository project for several years: the function of the RCF would be to appraise the suitability of a particular volume of rock as the place for the repository: and parts of the RCF could well be used for repository construction. The connection between the RCF and the repository is direct and obvious, and so cannot simply be set aside in the rest of the appeal determination process. Nirex itself has referred to the connection in some of its other evidence.

8.5 This close association means to me that the potential impact of the repository can be relevant to the determination of this appeal, so long as a judgement on such impact can be informed and measured, and not merely speculative. The most appropriate words to describe this relevance in terms of environmental assessment law, in my opinion, are that some of the repository's impact would comprise indirect effects of the RCF development, either as an obvious consequence of a successful RCF or in combination with some of the impact of the RCF itself. Any doubts about this are resolved by referring to the European concept of the project. The RCF development would not be a project on its own because it would be crucially dependent on the development of a cluster of boreholes on the same site which has already been permitted. Thus the immediate project is the appeal development plus the boreholes. But, equally obviously, this project is just one of a series of Sellafield projects, the next in line of which could well be the repository construction project - and all under the umbrella of the overall repository project. The fact that the whole enterprise could abort does not negate the inter-connections, in my opinion.

8.6 Since the function of the RCF would be to appraise the potential location of a repository, it follows that any alternative sites which have been considered for the repository are alternative sites for the RCF too. There is also a clear public advantage in characterising the rock of the potential location for the national repository. On the other hand, there are plainly some substantial environmental objections to this RCF development. The skills and

other resources required to carry out investigations of this nature must mean that there will only ever be a few RCFs at the most in the UK. Crucially, it is obvious that the appeal site is not uniquely suitable for a repository, and that a variety of potential locations could be chosen depending on the importance attached to different factors. Cumulatively, these propositions make an overwhelming case for examining the merits of alternative sites, in this instance.

8.7 The law, in my opinion, requires these alternatives to be examined by the state sooner rather than later, so that they must be looked at now if that is practicable, instead of waiting for the inquiry into the construction of the repository. Nor is it a matter to be deferred until it can be considered by the regulators, because national policy as I understand it is for the locations of potentially polluting developments to be reviewed by the planning authorities, and not the pollution control authorities.

8.8 It is practicable to compare alternative sites in this case, since Nirex has already done this some years ago, albeit that with the passage of time a review of the comparison is gradually becoming more difficult. The planning authority has already exercised its right to require more information from Nirex about this site selection exercise. It has been dissatisfied with the amount of information supplied in response, but has eventually formed the view that planning permission should be refused in any event. Now that the application is subject to appeal, my opinion is that it is necessary to enforce the authority's reasonable requirement, and not grant permission before outline environmental profiles of the short-listed alternative sites have undergone a public consultation process. Although this procedure would raise some alarm around the alternative sites, this is overridden by the advantage of locating the repository, with its exceptionally long-term potential impact, in a well chosen place.

8.9 It also appears that a locational criterion required to comply with the UK's international obligations has not been applied in the site selection exercise. A repository near the sea would put the marine environment at greater risk of radioactive pollution than an inland site, for instance by means of a groundwater flux from the repository as is predicted by Nirex in this case. In my opinion, the special legal protection of the sea and the modern precautionary principle combine to require both an exceptional justification for locating a repository near the sea and an assessment of potential effects on the marine environment.

8.10 An incidental point on the legal adequacy of the environmental information supplied so far is that it does not cover the environmental effects of abnormal incidents at the RCF.

Relevant Provisions of Development Plan

8.11 The adopted Cumbria and Lake District Joint Structure Plan 1991-2006 applies to the appeal site and is up to date. Its strategic framework policies relate to, amongst other things, the protection of Cumbria's scenic beauty and natural resources from inappropriate development; the protection and enhancement of the essential qualities of the Lake District National Park; the regeneration of the economy of West Cumbria; the improvement of inter-urban communications; and steering the growth of tourism.

8.12 The bulk of the Structure Plan's policies are concerned with either managing the environment or guiding development. The key one for the purposes of the RCF development is Policy 54, applying to major developments which are more national than local in character and have significant environmental effects. This Policy prescribes 4 criteria: the sum of benefits to clearly outweigh any harm or risks; to cause the least practicable harm; to minimise adverse impacts; and not to harm interests of national or greater conservation importance unless the value of the benefits outweighs the value of the interests.

8.13 In my judgement, the first criterion plainly requires a wide-ranging balancing exercise, which cannot be confined to the local environmental impact of the development nor to particular tests or formulae for evaluating benefits, so as to purport to exclude the planning authority's discretion under PPG 23 or consideration of alternative sites. The second and third criteria are of particular interest when examining mitigation measures and proposed conditions. The fourth criterion is agreed to cover any effects of the RCF development on the Lake District National Park, despite the site's location just outside the National Park.

8.14 Policy 57 is another major projects policy which would apply if the development were concerned with the reprocessing, storage or final disposal of radioactive waste. From reviewing the gestation of this policy, I am sure that it is not intended to apply to the RCF: and I consider that it would be unnecessary and confusing to take it into account now even though it would apply to the repository construction project.

8.15 Other relevant Structure Plan policies of substantial importance are Policy 11, which seeks to protect the characteristics and landscape qualities of the National Park, particularly its undeveloped open countryside and the character of land identified on its Conservation Map; Policy 13, which seeks to protect the ordinary, undeveloped open countryside from development not required to meet local infrastructure needs; and Policy 25, which aims for all new development to enhance the visual quality of the existing environment. Although the RCF development as specifically described would last for a maximum of 13 years, these policies do not expressly exempt temporary developments from their constraints. Also, in my view, the appeal site is plainly in undeveloped open countryside, as is the nearest land in the National Park.

8.16 There are other relevant policies in the Structure Plan. Policy 16 relates to woodland tree planting, and Policy 17 to nature conservation. Policy 21 applies to emissions, noise, vibration and risks of accident; Policy 22 to sewage or other effluent discharges; and Policy 24 to flooding. Important archaeological sites, features and settings are normally protected by Policy 26. By virtue of Policy 36, development will not normally be permitted where there is insufficient capacity in the service or transport infrastructure. Policy 60 concerns the effects of waste disposal sites, and is relevant because most of the spoil from this mine would be disposed of on-site; whilst Policy 62 is for the imposition of strict restoration conditions. Finally, Policy 63 includes the A595(T), which runs alongside the site, in a key route for long distance inter-urban road transport, albeit there is no specific improvement scheme for the local length of the trunk road; whereas Policy 70 is for large bulk flows and dangerous materials to be transported by rail wherever possible.

8.17 The adopted Mid Copeland Local Plan also applies to the appeal site, but it is becoming out of date, with some land use policies not in conformity with the new Structure Plan. Policy 6I, for development in rural areas to have regard to traditional design and local materials, is still extant but is, in my view, intended to apply to residential development. Other relevant policies remaining in force are Policy 6J, which seeks to protect the character of listed buildings; Policy 6Q, which relates to the substantial retention of existing trees and woodland; and Policy 6R, for the protection of important archaeological remains.

8.18 There are 7 relevant policies retained for development control purposes from the 1988 Structure Plan, pending the adoption of new local plans. But they do not seem to differ significantly from the policies in the emerging local plans in their approach to any interest of acknowledged importance.

8.19 The Inspector's report into objections to the deposited Copeland Local Plan, which applies to the site, had been received by the close of the appeal inquiry. Further progress will have been made by now towards adopting the Plan, and some policies will have been re-numbered. However, these conclusions can, of course, only refer to the deposited policies as recommended for modification by the Inspector.

8.20 The appeal site is outside any town or village development limits defined by the Copeland Local Plan. The closest village with defined limits is in fact Gosforth to the south-east, but that settlement is just inside the National Park, and so its limits are defined by the deposited Lake District National Park Local Plan. Policy DEV 1 of the Copeland Local Plan is for development outside defined limits not normally to be permitted unless the proposals accord with other policies. The appropriate other policy for the appeal proposals is ENV 33, which is to support the RCF so long as 6 criteria are satisfied.

8.21 The first criterion is for the need to be justified by reference to the national radioactive waste management strategy, bearing in mind the Borough Council's fundamental requirement that safety is paramount. The second criterion requires specific justification of further investigations of the suitability of the site for a repository; whilst the third stipulates that the RCF fits into the overall research programme and contributes to the safety case to be put in due course to the regulators. The fourth criterion requires an acceptable non-nuclear environmental impact. The next criterion is a cross-reference to Policy IMP 1, which in turn sets out in some detail the Borough Council's expectations of agreements under Section 106 of the Principal Act, in circumstances where such agreements would be appropriate. The final criterion is for eventual restoration to agriculture subject to any repository safety requirements.

8.22 Policy DEV 3 sets out 8 design principles, normally expecting a high quality of building design and layout, in order to respect the character of the surroundings and help contribute to a strong sense of place. In pursuance of the Council's commitment to sustainable development, Policy DEV 4 is to have regard to the long-term effects of development proposals on the Borough's environmental, social and economic resources.

8.23 Amongst the Local Plan's transportation policies, TSP 5 requires satisfactory standards of access; TSP 6 normally requires significant traffic generators to have direct access to an appropriate standard of road; TSP 7 is for the needs of pedestrians, disabled people, cyclists and emergency vehicles to be taken into account in design and layout; TSP 8 requires compliance with parking standards; and TSP 13 is to support the transfer of freight traffic to the railway. Policies SVC 1, 5 and 6 deal respectively with effluent water quality and quantity, land drainage, and underground services.

8.24 Policies ENV 1 to 5 relate to nature conservation interests. Policy ENV 1 protects sites of international importance, and Policy ENV 2 those of national importance. Policy ENV 4 is for sound reasons to be shown if locally important sites, or the continuity and integrity of some defined landscape features, would be adversely affected by development; whilst Policy ENV 5 will not permit development which would have an adverse effect upon the conservation interest of any site supporting species protected by law.

8.25 A number of the Copeland Local Plan's other environmental policies are also relevant. Policy ENV 11 gives conditional support to new tree planting, and Policy ENV 13 normally requires landscaping schemes. Policy ENV 14 protects existing rights of way, whilst Policy ENV 15 seeks to protect watercourses and avoid flooding. Policy ENV 23 is to support proposals for the disposal of inert waste, effectively so long as their environmental impact is acceptable. Policies ENV 26, 29, 49 and 50 relate respectively to aerial discharges, noise and the settings of listed buildings and Scheduled Ancient Monuments. Policies ENV 51 and 52 effectively elaborate on the archaeological aspects of Structure Plan Policy 26, in line with PPG 16.

8.26 Although not part of the development plan, the Conservation Map in the National Park Plan delineates some mountain, moor and heath in the foothills to the north-east and south-east, and some coast to the south, of the appeal site. A larger area of the Park to the east of the site is defined by the deposited National Park Local Plan as part of the Park's Quieter Areas, the character and appearance of which are normally to be protected by Policy NE5 from disturbance by development.

8.27 A consultation draft of the Cumbria Minerals and Waste Local Plan has been published. Policy 43 of the draft supports minerals exploration provided that there are no significant adverse effects on local communities or the environment: and Policy 51 permits inert waste landfills next to major projects provided that there are net benefits compared with disposal at existing landfill sites.

Degrees of Adverse Environmental Effects and Extent of Conflict with Policies

8.28 Although the landscape of the appeal site does not have a special quality, its importance is increased to some extent by its sheer proximity to the National Park. Also the site does contain some woodland and a small valley which are attractive in themselves. In the much broader perspective of the sweep down from the Lake District's fells across the coastal strip to the Irish Sea, the opencast coal zone to the north and the Sellafield Works to the north-west are much larger than the RCF would be: but that does not mean that the RCF

and associated development would be trivial by comparison. The mine-head up to 30 m high, on a platform of 4 ha within an operational area of 38 ha, would inevitably have a substantial visual impact, even on this well-wooded and undulating countryside.

8.29 The industrial air of the access to the appeal site has already harmed the countryside on either side of the trunk road there, and the screen planting beside the road is obscuring a public view seawards from this edge of the National Park. Little attempt has been made to design the RCF structures to be in keeping with the local vernacular tradition, with the result that they would look palpably out of place; and their impact would be accentuated somewhat by artificial lighting and security fencing. The interesting little valley would be spoilt by the platform works. Whilst I accept that both shafts which Nirex wishes to sink would be required for the effective implementation of its project, the extensive offices and car parking proposed on site are open to criticism. Although the spoil disposal area would be tucked away from the trunk road, it would be in an otherwise pleasant spot visible from a drive in public use. The design would not minimise environmental impacts despite the good quality of its landscaping, nor would it meet high standards of design, both contrary to Structure Plan Policies 13 and 25.

8.30 The overall development would not remain subordinate to the landscape, but would look incongruous, in my judgement. Also, it would cause visual harm to its setting. Although areas identified on the Conservation Map would be marginally affected at most, the RCF would visually intrude into parts of the National Park which are being identified for special protection of their quiet enjoyment. There would be a similar intrusion into a stretch of undeveloped open countryside in the Park, to the protection and enhancement of which particular regard is to be paid. Moreover, the development would be seen as a distinct, modern protrusion in views of the rising ground of the Park from towards the coast to the south-west. Both the Park's appearance and its local character, as spelt out in Structure Plan Policies 2, 5 and 11, and other Plans, would thereby be harmed, notwithstanding that the site is outside the Park and that Sellafield Works is not far away.

8.31 Although the settings of the nearest listed building and Scheduled Ancient Monument would not be affected, nor the Hadrian's Wall Military Zone, nevertheless the breaches of the various Structure Plan policies bring the proposals into conflict in turn with the last 3 criteria of the key Policy 54. It would have been practicable to cause less visual harm and impact, in my judgement, by making the ancillary development smaller in the first place and by preparing a better external design of the structures. Whilst I would rate the visual harm to the National Park as moderate, that plus the harm to the ordinary countryside do now have to be outweighed by more significant benefits under the first criterion of the Policy.

8.32 There are corresponding breaches of the Copeland Local Plan. The visual impact would be unacceptable, in conflict with the fourth criterion of Policy ENV 33; and the utilitarian and rootless type of external design is at odds with the principles of Policy DEV 3. Moreover, although Nirex has compared the RCF's visual impact favourably with that of the local boreholes, the latter are really part of the same project and so actually exacerbate the adverse visual effects. Looking further ahead, the permanent platform site of the preferred repository design concept on the appeal site would seemingly be less obtrusive and

more sympathetically designed; but there are outstanding points about the visual impacts of any service road from Sellafield and of use of the RCF shafts for repository construction purposes.

8.33 Turning to socio-economic effects, there would be some modest employment and economic benefits from the RCF development, and significantly higher ones from the repository's construction and operation. However, it is now very evident that West Cumbria is too dependent on the nuclear industry, and so it would be an economic detriment, in my view, to significantly consolidate the nuclear industry by establishing the repository near Sellafield. Also, despite relative familiarity with the industry, there is a substantial degree of local apprehension, mainly about health and safety in relation to radioactive waste, which affects residential amenity. Similarly, there could be noteworthy effects on tourism, fisheries and inward investment in business.

8.34 Although these perceptions are connected to the proposed repository, Nirex concurs that they are relevant at this stage. Indeed, some research evidence suggests that the impact is greater during such an anticipatory phase. The point that the effects are largely indirect ones of the RCF does mean, however, that a planning obligation to mitigate them might not be appropriate. Nirex has not offered any such obligation, albeit that it could, in my judgement, have taken formal steps towards a joint venture and trust fund, which would considerably mitigate the social and economic effects of the RCF. As it is, there are socio-economic benefits and detriments to be weighed up under the first criterion of Policy 54, and in the meantime there is some conflict with Local Plan Policy DEV 4.

8.35 The present access to the site is a temporary one, and it is time to settle the principle of its permanent retention, especially because the RCF project would be far too fragmented to be viably served by rail. On the other hand, the feasibility of a service road from the Sellafield Works to the appeal site has not been ruled out to my satisfaction, and so there is a national policy objection to retaining the access onto the A595(T), since that is part of a key long distance route identified by the development plan, and also a primary route onto which direct access should be avoided so far as practicable.

8.36 Looking at the particular circumstances to see whether an exception can be made from national policy, the trunk road's carriageway would have the physical capacity to carry the RCF project's vehicular traffic. That traffic should not in itself increase hazards for pedestrians and cyclists on the main road. However, this is the only public road from Gosforth towards the north-west, and is at present unsuitable for pedestrians and cyclists. I consider that utilising any spare capacity for the project's traffic would preclude making conditions better for them. Also every additional access increases the risks of accidents and obstruction, and this length of road is a vital vehicular link. Moreover, its safety record leaves no room for complacency.

8.37 Therefore my view is that no exception should be made to policy, and that the appeal proposals' infrastructure does not include a satisfactory access, contrary to Structure Plan Policy 36 and Local Plan Policy TSP 6. This would entail in turn another breach of the fourth criterion of Policy ENV 33. I have also noted that the layout of the RCF development

would fail to provide for pedestrians and cyclists, whilst making apparently excessive provision for car parking, contrary to PPG 13 and Local Plan Policies TSP 7 and DEV 3. There would thus be further conflict too with the second and third criteria of the key Structure Plan Policy 54. On the other hand, I cannot agree with the powerful local feeling that the whole length of trunk road carriageway from Gosforth to the next village needs immediate improvement, as distinct from a segregated footway/cycleway and specific safety measures.

8.38 As to other environmental effects, the site's quiet rural setting does mean that lower than normal noise limits should be imposed, despite Nirex's resistance, because in my judgement the RCF's essential work could be continuous whilst complying with such limits. The vibration effects from rock blasting should not cause disturbance, subject to the usual precautions and controls.

8.39 Although the proposed landscaping and restoration should enhance the general nature conservation value of the area in due course, I consider that Nirex and the authorities have made a serious error of judgement over disturbing the local badger clan, which is particularly important because it seems to be the last surviving clan in the locality. The spoil disposal operations would take place on most of the clan's principal feeding ground. The mitigation measures which have been considered and proposed do not go far enough and are untried. This would amount to a serious interference by a waste disposal operation with the core habitat of a protected species, contrary to Structure Plan Policy 60 and Local Plan Policies ENV 5 and 23, in my view. Thus there is yet more environmental detriment to take into account under the key Policies 54 and ENV 33.

8.40 Whilst there is a nationally important habitat of European-protected natterjack toads at risk down the course of the local beck from the appeal site, I accept that the unusual arrangements that have eventually been made between Nirex, English Nature and the Environment Agency to protect the core habitat of the toads from effluent from the development should suffice. But I note that there is an unresolved dispute between Nirex and the Environment Agency over the control of the ingress of underground water into the RCF. A very careful evaluation by Nirex has satisfied me that the part of a recorded Monument which has already been affected by landscape planting very probably does not constitute archaeological remains at all, and that the requisite degree of evaluation of the rest of the Monument has been carried out.

8.41 Other points raised in relation to agriculture, groundwater derogation, air quality, rights of way, recreation and the proposed explosives store I regard as either relatively minor or having been met. However, cumulatively they do confirm the general sense that the appeal development would be out of place.

Suitability of Site

8.42 Although the general international and national criteria for the location of a deep waste repository are merely indicative guidance, 2 overriding principles can be derived from them. One is that the location should be in a region of low hydraulic gradients, so that there should

be slow-moving and long groundwater pathways: and the other is that the geology and hydrogeology of the site and its district should be readily characterisable and predictable. Whilst there has been a shift of focus in the guidance from the properties of the host rock to the wider hydrogeological setting, the requisite features of potentially suitable environments which were identified for Nirex in 1986 complied with both the general principles and the shift in focus. But there now appears to be a fundamental difficulty with some of the choices, in that there was then a preference for maritime locations due to the huge dilution offered by the sea, and yet the reverse preference is suggested by international law, to avoid marine pollution.

8.43 A type of geological environment which eventually scored consistently well in Nirex's site selection exercise, and is favoured by Cumbria, is termed " basement rock under sedimentary cover" (BUSC). This seemingly could offer a range of inland locations. Nirex appears to misunderstand the concept, by claiming that the appeal site is within such an environment, whereas the area has never been so designated by its geological consultants. It seems that Nirex takes the concept too literally, rather than looking for the particular features which led to the environment being identified, such as a minimum scale of hydrogeological system, and a mix of layers in the sedimentary cover to act as a barrier to upward groundwater flow from the basement rock.

8.44 Nevertheless Nirex is right to point out that the ultimate test is whether the preferred host rock has the potential to pass the regulator's safety requirements, regardless of its guideline classification. Also Cumbria and Greenpeace seem to have misunderstood national policy on the safety standards for repositories. There is no risk limit or constraint specified as an upper bound for determining the post-closure safety acceptability of a disposal facility, but there is a risk target as a lower bound beyond which it is not necessary to go. On the other hand, Nirex has failed to appreciate that Cumbria as the planning authority is entitled to its own view about the acceptability of the risk, so long as it does not seek to substitute its own detailed risk assessment for that of the regulators. Cumbria in turn has given no indication of supporting site selection criteria based on existing radiation levels, as suggested in some of the representations.

8.45 However, Cumbria's basic point is that the staged site selection process undertaken by Nirex in 1988-9 was detailed but flawed, and in essence I agree with Cumbria. Although I concur with the exclusion from the initial area of search of designations of national conservation importance, it was in my view premature and excessive to exclude also whole local authority districts on the ground of population density, and tracts of land which might have to be compulsorily acquired. In the later stages of the process, the crucial point is that safety was not treated as the most important discriminative factor. This role was given instead to the costs to be borne by the generations which would utilise the repository, and yet that is contrary to the principle of sustainability, in my judgement. Another fundamental difficulty is that the expert team and the Nirex Board, who should have interacted smoothly in the late stages of site selection, actually used different critical criteria in their final choices - geology for the one and local support for the other.

8.46 I consider that there were 3 crucial discontinuities in what should have been a methodical process. The first was the late introduction of an alternative Sellafield site which was not particularly promising according to the original criteria, and so probably would have been eliminated earlier if it had been included at the start. The second was the inconsistency between the team and the Board, which resulted in this lately introduced site and the doubtful Dounreay being kept in play whilst others with better safety potential were discarded. The third was the subsequent dropping of the alternative Sellafield site when it was realised after all that it is not suitable, and its substitution by the appeal site which, although nearby, had not been through the process at all.

8.47 This cannot justly be described as following a rational procedure, in my judgement. It seems that the process was affected by a strong desire to locate the repository close to Sellafield. Thus my view is that Nirex has failed to make its case on site selection even on its own terms of showing that it followed a rational procedure. Looking at the topic in the wider context which I consider appropriate for a planning authority, it is difficult to see the general public benefit in continuing to concentrate entirely on this site rather than any other. It has not been chosen in an objective and methodical manner, and there are strong indications that there may be a choice of sites in a different part of the earth's crust in the UK with greater potential to meet legal and regulatory requirements.

8.48 Nirex's scientific and technical work since the appeal site was chosen has generally been very impressive. But it does indicate amongst other things that the practical difficulties of the deep disposal option were originally under-estimated by the international consensus, which makes it all the more important to my mind to concentrate on an apparently favourable site. Also I consider that Nirex's emphasis on the relatively novel chemical containment concept in the mixed artificial and natural barrier suggests a lack of confidence in the geosphere. Although international cooperation has provided Nirex with considerable amounts of data on rock properties and responses, none of the experimental sites in other countries is very similar in geological setting to the appeal site.

8.49 All the work and cooperation have not led Nirex to a sufficient understanding yet of the groundwater conditions in and around the appeal site. Another fundamental point is that the area is extensively faulted but there is a considerable amount of speculation as to the influence which any local fault has on groundwater flow. Nirex does not know whether the faults in general or particular increase or reduce or deflect flow, nor does it know where all the faults are. There is a promising feature of the work in that there are indications that the groundwater in the basement rock has been there a very long time, but much more research is required to confirm this, and it would not be a determinatively favourable feature even when confirmed. For the basement rock is volcanic, which makes it inherently variable; and moreover it is very probably within a collapsed caldera, which makes the variability random.

8.50 Nirex does not seem to have fully appreciated these limitations on its understanding of the appeal site, nor the significance of the limitations. Partly in consequence of its undue optimism, it is not planning to take all the steps necessary to put these deficiencies right. This leads to problems in turn with the adequacy of its modelling, in my view. Whilst conceptual and mathematical models have a vital role to play in Nirex's investigations and

preparations for a safety case, the models must be based on a sufficient understanding of the geology and hydrogeology.

8.51 There is no indication that Nirex would have a model of landfill gas migration through the geosphere ready for testing in the RCF. A more fundamental point is that Nirex's regional conceptual model and its derivatives cannot match observed groundwater heads and salinities. This is a failure to account for some basic processes and parameters of the hydrogeological system, and the new model promised to cope with this problem is of completely unknown quality. There are also probably even deeper conditions and processes which have yet to be addressed. Within the basement rock itself, Nirex is still evaluating no fewer than 6 alternative conceptual models of groundwater flow, and typically expressing too much optimism about the results of the evaluation.

8.52 The preliminary safety assessments of the appeal site reflect these difficulties. The last assessment published in 1995 assumes that the artificial chemical barrier would have a very significant retarding effect on release of the longer-lived radionuclides from the repository, and yet the barrier is new and untried and the assumptions in the assessment entail great simplifications and may be non-conservative. Also the assessment predicts zones of discharge to the biosphere even though knowledge about the present groundwater discharges in those locations is inadequate. The results of the main calculations in the assessments which comply with the regulatory target have to be read subject to an appreciation of the uncertainties encompassed in these and similar points. Furthermore the scoping study for agricultural wells reveals and yet understates a potential problem of premature human access to the radionuclide flux. This is a reminder that the appeal site is not in any of the preferred environments: and that far from the sedimentary rocks acting as a barrier to upward flow, Nirex is actually relying on them to dilute and disperse the radioactive plume.

8.53 Whilst this assessment cannot be claimed to completely rule out on its own any promise in the appeal site, it thus directly over-arches great uncertainties which would not be resolved by the RCF, and highlights the vulnerability of the concept of relatively rapid upward transport of the radionuclides, compared with the slow, downward flow of the favoured hydrogeological environments. The indications are, in my judgement, still overwhelmingly that this site is not suitable for the proposed repository, and that investigations should now be moved to one of the more promising sites elsewhere. On this basis, there is really no national or regional benefit to be gained from continuing investigations at this particular site, to be taken into account under the first and fourth criteria of Structure Plan Policy 54. Also, the first two criteria of Local Plan Policy ENV 33 are not satisfied, in that the paramountcy of safety does not justify further establishment of the geology and groundwater flows in the vicinity of the appeal site, nor has it been shown that any further investigations at all of the suitability of the site are justified.

Balance of Benefits and Adverse Effects

8.54 It is necessary finally to consider any generic research benefits from the RCF, and also whether it would actually cause harm to the geosphere. To obtain such benefits, it would be necessary to subject all the work both to independent peer review and to guidance

from the regulator, in my view. The RCF would certainly be essential if the site were promising, to obtain more information for example about geochemistry, conductivity, sorptive capacity, gas migration, colloids and excavation disturbance. But for the RCF to be beneficial, the baselines from which it would start must be clear and comprehensive, and the investigations and experiments must be well focused and designed.

8.55 In order to be sure about the impact of the RCF on its geological setting, and implement it in the least harmful and most effective manner, there is a need to first improve the present detail and interpretation of that setting. There should be more boreholes in or close to the appeal site, and there should be some more years of monitoring trends in the basement rock. Also considerably more laboratory work and modelling development and refinement are required on matters specifically related to the local rock and groundwater before perturbation of the appeal site by the RCF can be justified. Nirex's modelling protocol also need to be generally improved, in my judgement, to recognise the absolute limitations entailed in the quality of input data and the span of human uncertainty and error.

8.56 I consider that Nirex should not be allowed to proceed with the RCF in its current state of inadequate knowledge, for that would make it very difficult for anyone to predict the consequences of Nirex's actions, and result in a confusing outcome. Furthermore, in the eventuality that my conclusion about the suitability of the site is incorrect, to proceed now would cause needless damage and yet very probably could not optimise the repository location. Examination of the details of the RCF programme merely reinforces these apprehensions. The timetable of events is far too optimistic, from starting before baseline conditions are satisfactorily established, through experiments which would still be basic research after crucial decisions had been taken, to restoring the mine without observing the recovery period.

8.57 Therefore I consider that there is no benefit to be obtained on any basis from proceeding with the RCF at present, and indeed it might well harm the potential repository location if it transpires that, contrary to my belief, it is suitable for a repository. The fact that construction of the repository here is precluded on either of the above scenarios has the consequence that its employment and economic benefits cannot be taken into account in the final balancing exercise under the first criterion of Structure Plan Policy 54. My ultimate conclusions are that the modest employment and economic benefits of the RCF itself would by no means outweigh the harm to the appearance and character of the National Park; the encroachment on the open countryside; the detriment to residential amenity and the adverse effects on tourism, fisheries and business investment; the lack of a satisfactory access and of proper provision for pedestrians and cyclists; and the serious interference with the surviving local badger clan. There would thus also be a failure to satisfy the first four criteria of the emerging Local Plan Policy ENV 33.

Nature and Form of Conditions

8.58 My comments on conditions are subject to any further environmental information obtained on the profiles of alternative sites, on the effects of the repository, or on abnormal incidents at the appeal site.

8.59 In relation to the mitigation of environmental effects, I commend the conditions set out in COR/113 subject to the conclusions in my Chapter 7A. Particular consideration needs to be given to the noise controls to be imposed on the permission, having regard to Nirex's reluctance to accept some of them but my finding that it could implement them. Nirex has also expressed reservations about the condition to control ingress of groundwater, but I am clear that on balance this should be imposed.

8.60 As to ensuring scientific and technical benefits, the most practicable solution would be a binding agreement between Nirex and the Environment Agency. The conditions suggested by me in COR/113C, Annex A were as a focus for discussions on alternative control by planning if no agreement is forthcoming. However, I do consider that experience to date shows it would be necessary for some authority to regulate the RCF as it is developed; and so if planning conditions are regarded as inexpedient, this becomes another ground for dismissing the appeal, in my judgement.

8.61 In any event, notwithstanding my comments on deficiencies in the environmental information and on conditions, like the planning authority I consider that the RCF development should not go ahead, for the reasons I have summarised above.

9.0 RECOMMENDATION

9.1 I recommend that the appeal be DISMISSED.

I have the honour to be
Sir
Your obedient servant

C.S. McDonald

C S McDonald