Why was **Sellafield** *rejected as a disposal site for radioactive waste?*

Stuart Haszeldine, David Smythe
University of Glasgow G12 8QQ,
s.haszeldine@geology.gla.ac.uk

March 17th 1997 may be remembered by most people in Britain for the announcement of the general election. But for the nuclear industry in Britain, this was the day that their waste disposal plans fell apart. A planning inspector and his team had undertaken a local planning inquiry, examined the evidence put forward by Nirex for continued development leading towards an underground radioactive waste repository site near Sellafield, and had decisively rejected the Nirex proposals. Amongst the reasons specific to the Inspector's rejection was Nirex's poor understanding of the geology and hydrogeology of its proposed site. How did this come about, and how did Nirex come unstuck so badly, after spending some £400M derived from public companies?

The Longlands Farm site near Sellafield was always a difficult technical proposition. The methods leading to its choice are outlined by Kelling and Knill in this issue of *Geoscientist.* It seems that Longlands Farm was chosen because it is close to Sellafield, where 60% by volume of the present and future wastes are predicted to be generated. The site was acknowledged not to be the best available geology in Britain, but was chosen because of expected support from the local population, and because of its expected cheaper operating costs. Announcement of a Planning Inquiry, to start in late 1995 focused efforts by groups and organisations opposed to waste disposal at this site:- Cumbria County Council, Friends of the Earth, Greenpeace and local groups such as CORE.

Geology, hydrogeology, geophysics and engineering were recognised as areas of expert knowledge, on which the debate would be won or lost. To this end Nirex prepared to release company reports detailing information and interpretation from its site investigations since 1991, in support of its case for development. A senior legal counsel and his team were engaged; even a mock planning Inquiry was held. A budget of £10M is said to have been spent by Nirex on the Inquiry. The objecting groups likewise prepared their cases, by means of seeking consultants to act as expert witnesses, but with a budget some 100 times smaller than that of Nirex. It became apparent that independent experts were hard to find; many technical professionals with specialist expertise had previously been employed by Nirex or its contractor companies, and perhaps perceived a conflict of interest).

The Inquiry was held in two parts; Part A examined issues of surface planning; Part B examined the Science and Policy issues. To discuss the technical geoscience and engineering issues in Part B, Nirex produced 7 expert witnesses. All except one, a member of Nirex's academic review committee, were employed directly by Nirex. For the opponents, Cumbria County Council produced 5 experts (one employed by Cumbria), focusing on site selection, hydrogeology and overall risk. Greenpeace presented 5 experts (one employed by Greenpeace), investigating site selection, geology, hydrogeology, flow modelling, geochemistry, and comparable investigations worldwide. Friends of the Earth fielded 9 experts (two employed by Friends of the Earth), tackling Government policy, geology, site 3-D structure, hydrogeology, fluid flow in fractures, engineering and geochemistry.

The Nirex evidence can be consulted in Whitehaven library, Nirex's Harwell library,and at www.nirex.co.uk. The geoscience setting is summarised in a Royal Society Report of November 1994, and thematic issues of the Yorkshire Geological Society (v50, 1-112), and the Quarterly Journal of Engineering Geology (v29 S1-S107).

The technical geoscience evidence presented against Nirex has been reproduced in a book published by the Geology Department of the University of Glasgow. This also includes the legal statement of case and summing-up by each objecting group. There is no space to itemise all the detailed geoscience objections, but rather we will selectively summarise some of the main themes. Site selection in Britain was proceeding well through the 1980's; regions of suitable generic geology had been identified by the BGS. Several types of site appeared geologically feasible, including large areas of East Anglia, where crystalline basement rocks were anticipated to be hydrogeologically poorly conected to groundwater flow in aquifers of the overlying sedimentary cover. However the Nirex site selection process in 1988 changed such sites of "Basement Under Sedimentary Cover" to "basement adjacent to sedimentary cover", and so managed to include the Sellafield area. Elementary hydrogeology warns us that rain falling on the 1,000m high hills of the Lake District might be driven downwards and outwards by the topographic head. Would the Borrowdale Volcanic Rock (BVG), where the disposal site was planned, be sufficiently impermeable to physically reduce the flow rate of such water? This physical isolation from water flow and human intervention is one of the main reasons for seeking deep disposal. Historical information shows the Triassic aquifers in West Cumbria to be artesian, with flow towards the surface; would any deep flows show the same pattern? By June 1991 Nirex had drilled two boreholes and announced that Longlands Farm was its intended site for a repository. By mid-1992, Nirex had completed three boreholes investigating the deep BVG, for a repository planned about 650m depth below the surface. Hydraulic heads measured at depth confirmed that upwards water flow was probable. Preliminary modelling of the hydrogeology system showed us at Glasgow University that the measured permeability range of the BVG was too wide. Yes, there were low permeability zones, but 10-30% of the fractures were far too permeable. Nirex chose to ignore the higher permeabilities, concentrating instead on the much lower average value to represent the regional rock mass. That was an unfortunate error.

It became apparent that Nirex's strategy was unique in the world. Many other nations have programmes to dispose of radioactive waste, and several have extant underground laboratories, or plans for similar laboratories. However the British plan was unlike any other country: intending to dispose of radioactive waste in fractured volcanic rocks, saturated by moving water. There were no other instances of a research "rock laboratory" such as Nirex's Rock Characterisation Facility (RCF), which were planned to become an integral part of the final repository, and certainly not in such a short timescale.

Uranium, plutonium and iodine need geochemical as well as physical barriers to contain the waste. Nirex engineered and patented an alkaline weak concrete to use as geochemical backfill in its engineered vault. Although this concrete may help to contain plutonium complex ions, it does not reduce the solubility of iodine, nor of the 2,500tons of uranium to be placed in a disposal site. Uranium solubility can instead be lessened by making use of geochemically reducing conditions, rather than oxidising conditions. Nirex had sponsored renovation for tourism of one of the former iron ore mines in West Cumbria, and so must have been aware that this district was the site of 180Million tons of haematite ore, Britain's largest iron oxide deposit. Groundwater conditions in the geological past have thus been abnormally oxidising. The oxidation state (Eh) of present day waters within the BVG was measured in boreholes, and found to be oxidising. Nirex "corrected" these measurements to reducing values by assuming the existence of iron pyrites lining all the fractures within the BVG. In spite of the specific assertions given to the Planning Inquiry by Nirex's managers, no iron pyrites could be discovered to justify a reducing Eh. A geochemical barrier was therefore unlikely to exist.

For the evaluation of fluid geology within a deep rock body, the oil industry has evolved the seismic reflection method as a key cost-effective way of imaging underground structure. Several 2-D seismic lines existed close to the site, and interpretation of these showed significant major and minor faults. Unfortunately the interpretations had changed on a yearly or even on a monthly timescale (Figure 1), so there could be no confidence that a final interpretation had been converged upon. Nirex commissioned a trial survey using the more up-to-date 3-D seismic method, with expertise from the University of Glasgow. This was highly successful. The preliminary results of this were available to Nirex before the Inquiry commenced, and showed that the structure was very complex. However Nirex made no attempt to include the new results in its Inquiry evidence. Even so, independently of the 3-D survey, seismic tomograms were produced as evidence by Nirex, to image rock structure between boreholes. Unfortunately these were mutually contradictory, and were also inconsistent with the location and dip of faults interpreted from earlier seismic data. These faulting effects could have all been anticipated in a site chosen at the edge of a faulted and collapsed volcanic caldera. Field examination of the BVG shows it to be a complex group of rocks, highly faulted and fractured, and extremely difficult to predict in 3-D.

Looking to the future integrity of a disposal site, one or more glacial re-advances can be anticipated in the next 50,000 to 1 Million years. Loading by ice is established in NW Europe to have driven recharge of deep waters; such water pressures may even have been able to hydraulically lift 500m of rock. Melting and unloading of ice in Britain is strongly implicated to have triggered earthquakes up to magnitude 6. The Sellafield coastal fault zone has evidence of earthquakes up to magnitude 5 even in historical time. These can both fracture an engineered structure and pump water from a disposal site to the surface. These risks are still unquantified at Sellafield.

To make predictions of safety into the far future it is necessary to know the present conditions, therefore the hydrogeology and geochemistry at the present day must be well measured for a long enough timescale. These are the baseline conditions. Measurements at the Longlands Farm site did not follow best

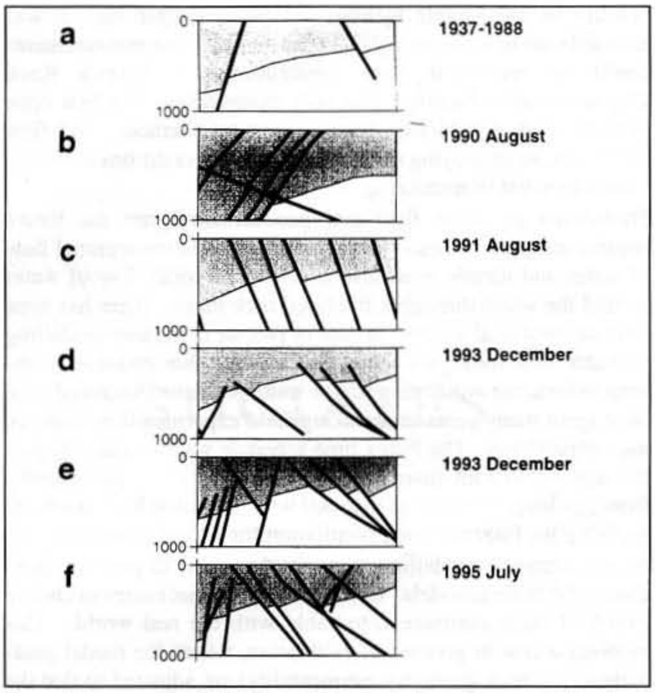

Figure 1 *Cross-sections NE-SW through the proposed repository zone at Longlands Farm, published by IGS and Nirex, compiled by D Smythe. Major faults are black, sedimentary cover is shaded, BVG is white. All these are interpreted from surface mapping and boreholes, with the later addition of 2-D seismic reflection. However there is no consistency of interpretation at different dates.*

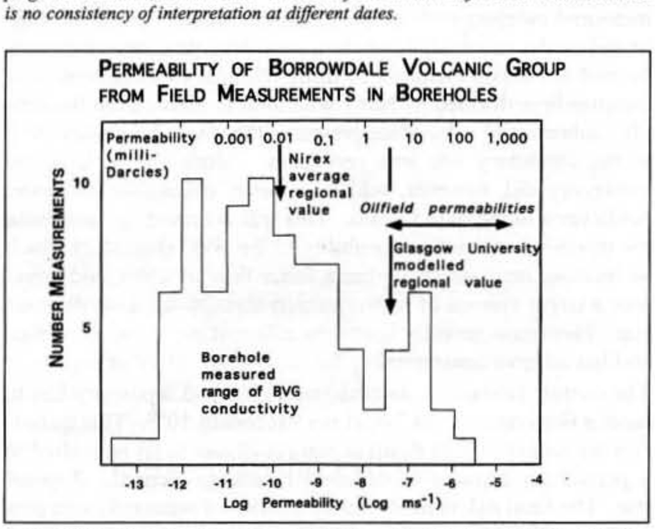

Figure 2 *Histogram of BVG permeabilities in fractures published by Nirex. Overlays by S Haszeldine show the regional value used by Nirex in their fluid flow modelling, this gave a poor match to pressure data measured in boreholes near the intended repository. The value deduced by Glasgow University gives a better match to measured pressure data, but implies that regional BVG permeability is similar to the lower range of producing hydrocarbon fields.*

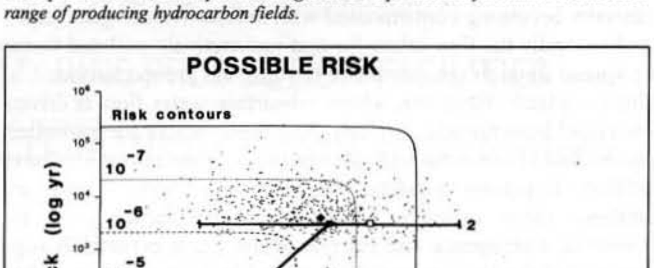

Figure 3 *The overall modelled risk from a repository, adapted by H Wallace from report Nirex 95. Contours show risk of 10-6, 10-5 etc. If BVG is modelled as increased permeability, so both x-axis (time in repository) and y-axis (time in geosphere) values decrease. Consequently the overall risk modelled by Nirex (square) is likely to be too low, and the true risk moves along line 3.*

practice in comparable hydrogeological investigations. It was also difficult to imagine how such natural baseline measurements could be recovered after construction of Nirex's Rock Characterisation Facility. The very excavation of the two open vertical shafts would alter pressures, water chemistry and flow directions, so destroying many of the natural conditions they purported to assist in measuring.

Predictions of water flow and geochemistry into the future require computer models. These must simulate the regional flow of water and ideally must also describe the local flow of water around the waste through a fractured rock mass. There has been little international success to date in precise predictive modelling of water flow through fractured rock, and other countries planning radioactive waste disposal in water saturated fractured rock have spent many years undertaking field experiments to improve their capabilities. The Nirex time schedule was too rapid to permit any significant investigation, allowing only a few months from reaching the depth of disposal with the initial RCF shafts, to applying for final planning permission for a final repository site.

In any computer modelling study, it is possible to generate hundreds of different models. Consequently it is necessary to choose which of these compare favourably with the real world. This involves a crucial process of calibration, where the model parameters (e.g. rock geometry, permeability) are adjusted so that the output from the model fits the measured real-world data. Calibration can then be followed by one or more cycles of validation, when the model is used to predict data points which are measured independently of the calibrated model. Once the calibrated model successfully predicts new data, then that model can be said to contain elements of truth. Neither of these steps was adequately performed by Nirex with their models. Even the simple calibration of subsurface pressures (heads) in boreholes close to the repository site was very poor. Modelling at Glasgow University did, however, achieve a better calibration of model predictions to measured heads. This was achieved by increasing the modelled regional permeability of the BVG (Figure 2). Such an increase necessarily implies a faster flow of water, and therefore a larger volume of water, passing through the deep disposal site. This again severely limits the effect of the physical barrier, and has adverse consequences for the overall safety of the site.

The overall safety of a deep radioactive waste repository has to meet a Government risk target not exceeding 10^{-6}. This quantifies the annual risk of death or serious illness to an individual in a population exposed to radioactive leakage from the disposal site. The final risk is modelled by a series of seemingly complex equations, fed into a statistical Monte Carlo type computer simulation which attempts to combine the many possibilities. These equations are controlled by two simple geological factors:- firstly the time spent by water in the engineered disposal vaults (thereby becoming contaminated with radioactive complex ions), and secondly the time taken for that radioactively polluted water to spread through the geosphere towards the ground surface. In this Longlands Farm site, where subsurface water flow is driven by a head from the adjacent hills, both these factors are controlled by the flux of water through the repository, ie the rate and volume of flow. To present its safety case, Nirex had chosen only the logarithmic mean values of all parameters. Evidence given by Cumbria, Greenpeace and Friends of the Earth experts all suggested that the BVG permeabilities used by Nirex were unrealistically low, and also that many other "non-median" cases should be considered. Consequently, replicate calculations of risk by Greenpeace suggested that the final risk was not 0.5×10^{-6} as proposed by Nirex, but the final risk could equally possibly be 50×10^{-6}, exceeding even the most lax safety regulation by a factor of 50 (Figure 3). Nirex admitted that it had no way of deciding which of these possibilities was more likely.

Following the rejection of their RCF plan on 17 March 1997, Nirex halted all contracts and technical work wherever possible. This even extended to cancelling presentations in late March at the EUG 9 meeting (European Union of Geosciences) in Strasbourg. The Nirex speakers simply did not turn up, leaving ample time for one of us (RSH) to try to present both sides of the debate to the assembled international audience. Media interest has continued regularly since March. Comparisons have been made with the USA radwaste disposal site in New Mexico salt, where the cost started at £2Bn, but to date totals £9Bn. The Longlands Farm site was similarly costed at £2.5Bn, but even the Nirex Managing Director admits the final cost could easily have been £3.5Bn. Attempts have been made to examine "what went wrong" but, surprisingly to many, the Nirex board of management remain intact. In many private industries such a fundamental rebuttal of its core business expertise would necessitate a basic review of corporate culture, and a clearout of management from Chairman and Chief Executive, possibly even down to technical level. In an intriguing development, British Nuclear Fuels Limited (one of Nirex's main funders) has in late April purchased the Canadian underground laboratory at Whiteshell. This raises the possibility that international business interests could overtake Nirex and the search for a British disposal site. Will BNFL simply fund its own commercial studies at Whiteshell, and even apply to dispose of waste at that site? The future of British investigation remains uncertain. There will probably be a review. There is a need to ensure much more public confidence than exists at present. This can only partly be achieved by greater transparency of site selection and investigation. An important lesson from the Longlands Farm experience is that scientific opposition and debate by competing groups is a very powerful method of exposing weaknesses in a technical geoscience proposition. This necessitates funding for some replication of work by active researchers, not simply a rapid critical reading of reports. There seems to be a strong future role here for Universities, consultancies, the BGS and even oil companies, with genuine peer review in open scientific meetings and the normal scientific literature.

On 4-6 July there is an Environment Group meeting on the Quaternary Geology of Sellafield. From Sept 10-13 at Newcastle University the Engineering Group of the Geological Society will examine hazardous and radioactive wastes, including two panelled debates on "the new way forward".

In conclusion, Sellafield was always a long shot. The site was chosen for non-scientific reasons, in a decision-making process which concealed its true geological problems. Results of initial drilling were ignored by the Nirex management, in a culture of speed and over-optimism. As more and more information arrived in the following four years, it seems that there was no holistic critical overview, merely a desire to achieve the drilling schedule and meet the Quality Assurance targets. For this data machine to be halted by a local planning inquiry came as a surprise to Nirex. The Planning Inspector's comprehensive dismissal makes it hard to contemplate a return to this site, even ten years in the future. However this is a success of the British planning system, which enables "the reasonable man" to take a cool and balanced look at the problem, then simply say: "No, not here".

***Dr Stuart Haszeldine** is Senior Lecturer at Glasgow University, and was an expert witness for Greenpeace at the 1995-6 Planning Inquiry.*

***David Smythe** is Professor of Geophysics at Glasgow University, and was an expert witness for Friends of the Earth.*

Research undertaken at Glasgow University by Christopher McKeown was funded by the Greenpeace Environmental Trust. Technical evidence presented by the Objecting groups at the Inquiry is published by the Dept of Geology, University of Glasgow.