Response to westCumbria MRWS Consultation: Geological Disposal of radioactive waste in west Cumbria ? **22 March 2012**

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Identification:
I am Professor Stuart Haszeldine, employed at the University of Edinburgh, UK. This response is prepared in my individual research capacity, and should not be taken to represent the corporate view of the University. I have long-standing research expertise in radioactive waste disposal, commencing during the early 1990's. I undertook independent research on the geology of West Cumbria, and potential radioactive waste disposal sites during the 1990s. I was a witness during the 1996 planning enquiry on Longlands Farm Repository. I have continued to undertake research and teaching related to radioactive waste disposal from that time until the present day. As part of the westCumbria MRWS process, I was engaged to prepare a review of NDA research strategy which was submitted to MRWS. I also volunteered to comment upon past and present evidence relating to the geological, groundwater and geochemical suitability of the West Cumbria region to host a geological repository. This offer was not taken up by MRWS. I have participated in public information meetings, independently organized, in Cockermouth and Keswick on 2 and 3 January 2012, when some of this evidence was presented to an audience including members of the MRWS administration and members of NDA.

Summary
There is an abundant suite of existing scientific work, which has not been presented through the MRWS process, that clearly provides evidence equivalent to the desk studies and subsurface investigations in MRWS Stage 4 and 5. This shows that west Cumbria has very adverse geological conditions to host a GDF, and that these geological conditions extend throughout west Cumbria. Examination of this evidence, and the potential to acquire new expensive and detailed evidence from west Cumbria will 1) end up in a rejection of the region as a siting location – just as this was rejected in 1997 after the evidence was examined, 2) waste money and time, 3) risk Councils being over-ruled by central government to enforce siting of a GDF, once any sort of detailed investigation has begun. Consequently, there is no point in Councils continuing with the MRWS process*.* ***Councils should withdraw at this stage, and a short list of scientifically plausible UK sites should enter into an MRWS process at multiple sites, so that a scientifically defensible, and publicly acceptable. GDF site can be identified elsewhere in the UK.***

Introduction
It is well established through international scientific work, and the examples of geological disposal facilities (GDF) for radioactive waste currently being developed internationally, that accepted informal criteria for long-term secure performance of a GDF include : simple and predictable subsurface geology, simple and predictable hydrogeology and water flow, suitable geochemistry, resilience to radioactive gas generation and retention of radioactive gases, resilience to thermal effects of waste emplacement. In my opinion, the West Cumbria region fails all these criteria, and enough is already known to exclude the region from further investigation for GDF development.

Although the MRWS process specifically evades addressing issues of site-specific repository design, it is well-known that generic issues will affect a GDF. These include the release of radioactive gases during the first tens of years of repository operation. The effect of heat from emplaced waste causing rock to expand and land surface to rise, and new fractures to form and act as groundwater flow conduits. The coupling together of heat effects from emplaced waste, together with natural groundwater flow has not been investigated, and new research evidence appended here shows this to be devastating to repository performance during the first few hundreds of years. For MRWS, I reviewed the NDA plans to undertake research addressing these issues and remain completely unconvinced that these can be solved within timescales proposed for GDF construction. There is no global precedent in any detail for the disposal of spent fuel or plutonium in a repository like that proposed here.

In addition, the process of region identification, by means of community volunteerism being pre-eminent over scientific evidence is unlike that of other nations, and is fatally flawed. The MRWS process includes opportunities for residents to voice opinions, but there is no opportunity for residents to determine the final outcome, that is undertaken by a handful of non-expert councilors, and can be over-ruled by central government. That is a democratic deficit.

The community benefits for accepting a GDF are poorly defined, but available information indicates that employment opportunities are comparable in numbers of jobs with existing styles of development for retail or manufacturing businesses, and so the case is not compelling.

Based on my own knowledge of UK geology, combined with information available from national searches of the UK for suitable repository locations in previous decades, it is clear that several regions exist which are scientifically extremely plausible to host high performance GDF, and which comply with international benchmarks.

West Cumbria investigations should be abandoned immediately, and UK engagement with communities should focus into these more plausible regions, to maximize the opportunity of a repository site being successfully identified and developed.

TECHNICAL EVIDENCE on UNSUITABILITY

1. Regional geology

West Cumbria is known to contain complex geology in the subsurface. Abundant evidence is available, based on work undertaken by Nirex during the 1990s for previous attempts to site a GDF in West Cumbria. From information provided to West CumbriaMRWS by the NDA, it is clear that a GDF will be at least 5 km x 5 km. By analogy with other nations, such as France, Switzerland, Sweden, Finland, who are developing GDF it's necessary to seek a site of this area which is not affected by rapid changes of rock type or abundant geological faulting. An example section of West Cumbria geology is Fig 1, and compared to an example section of a Swiss (Fig 2, 3) and French GDF site (Fig 4). West Cumbria is clearly complex and hard to predict, the French and Swiss sites are clearly simple and predictable.

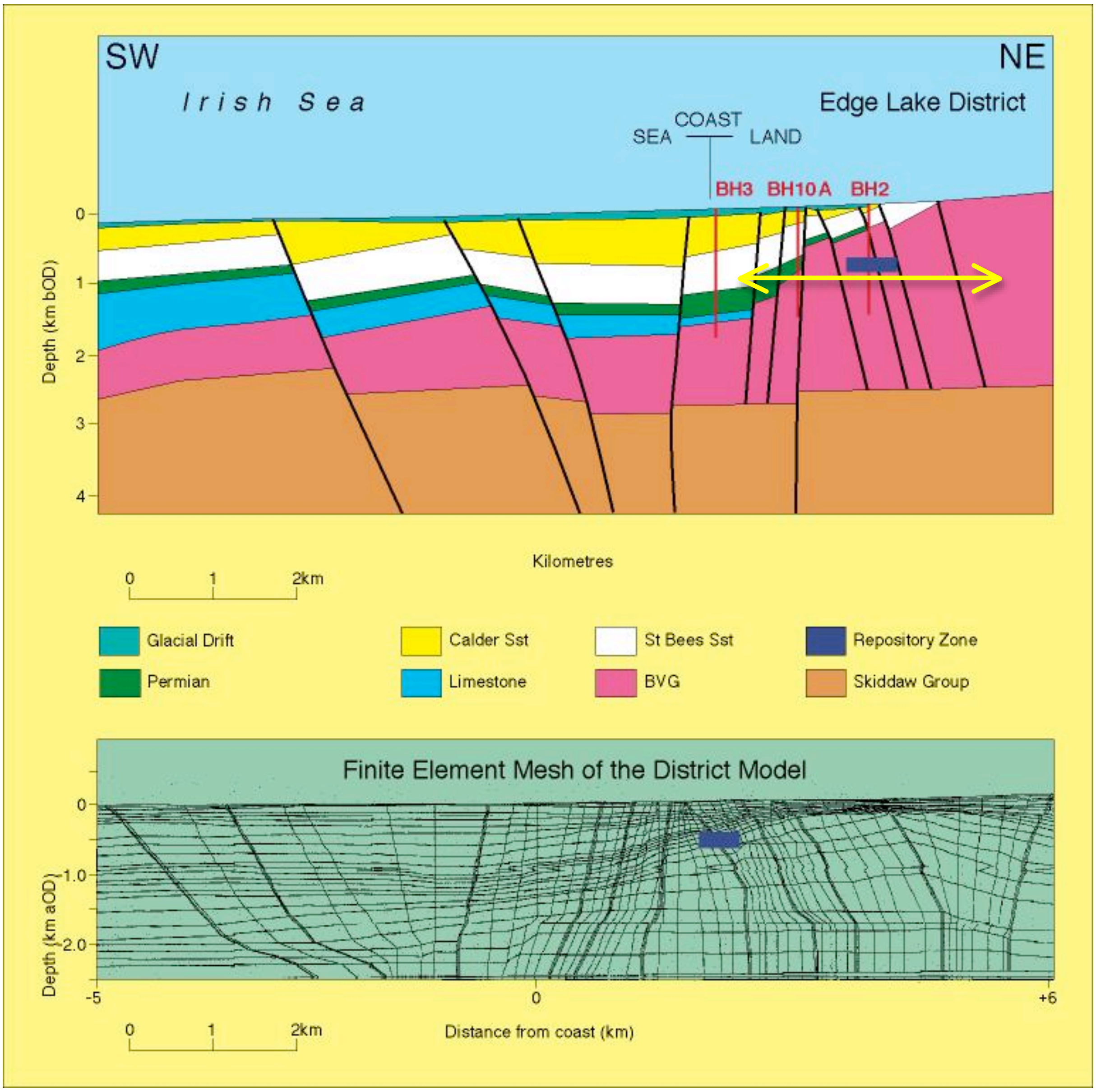


Figure 1 Sections of west Cumbria WNW-ESE through Longlands Farm site. Based on Nirex publications

Arrow shows size on GDF envisaged in 2012, compared to 1996. That cuts across several major faults

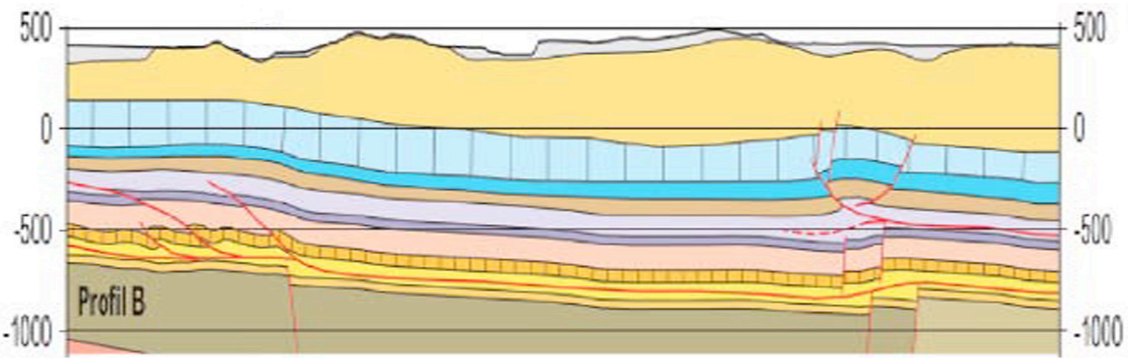
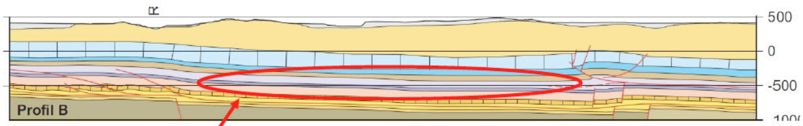
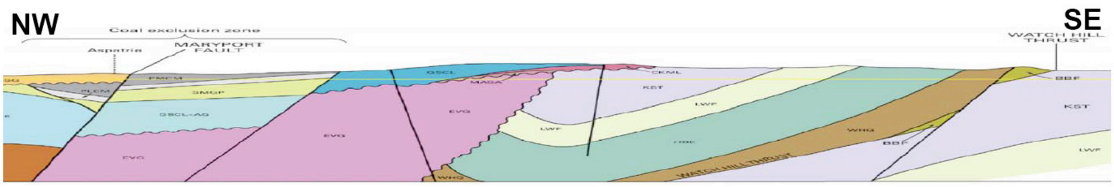


Figure 2 Swiss molasse basin. 30km wide (NAGRA 2008). Proposed disposal site in layer of sediment, overlain by mid Cretaceous Opalinus marl, a mudrock which provides an excellent top seal, isolating the waste from shallow groundwater flow, but also providing a membrane which allows gas to move vertically up and out of the repository to avoid overpressuring

The same sections as in the previous slide, but at a natural scale (no vertical exaggeration)



The Swiss propose constructing a repository here, within a flat-lying layer of clay about 100 m thick. The geology is simple, and therefore predictable.



In contrast, the geology of West Cumbria around the National Park is complex. The great variety of hard and soft rocks is folded and cut by faults with large displacements. The structure is very 3-dimensional – that is, the picture changes rapidly if one moves into or out of the plane of this section.

Figure 3 Comparison of west Cumbria and Swiss sites.
Section length of west Cumbria approximately 22km – taken from BGS (2010) report for MRWS.
Switzerland is much more simple than Cumbria, where a GDF will need to cross several rock layers and potentially cross major faults too.

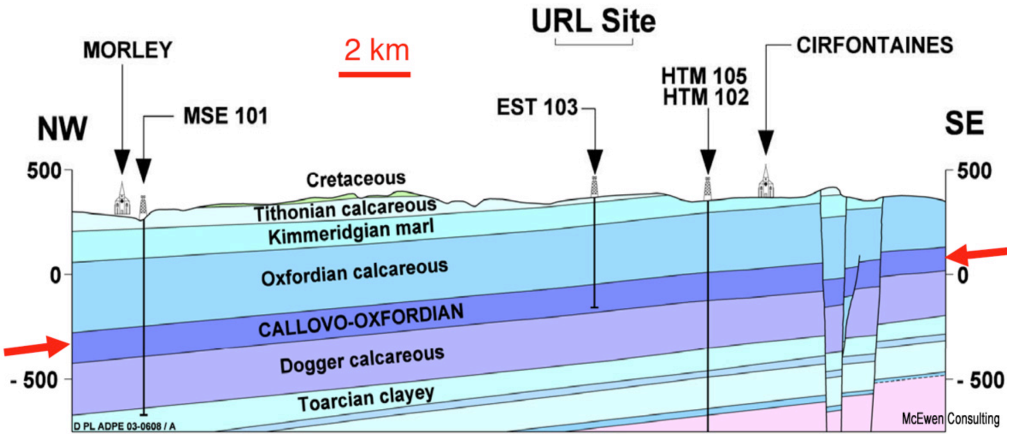


Figure 4 Section through French site at Bure (Andra), where sandstones are sealed by the Oxford Clay. Note simple geology, unfaulted, with ample space for a 5km GDF. Note also that the same Oxford Clay occurs in S and E England (Fig 16), to form a seal above sediments or basement rocks.

SUMMARY; From Fig 1 – 4, it is clear that west Cumbria is geologically complex, compared to other radioactive waste sites

2 Local geology

The rocks of west Cumbria are extensively faulted. This is true of the younger sandstones, and also of the older Borrowdale Volcanic Group.

The complexity of faulting is shown by sections mapped in detail from the Nirex investigations of the mid 1990's.

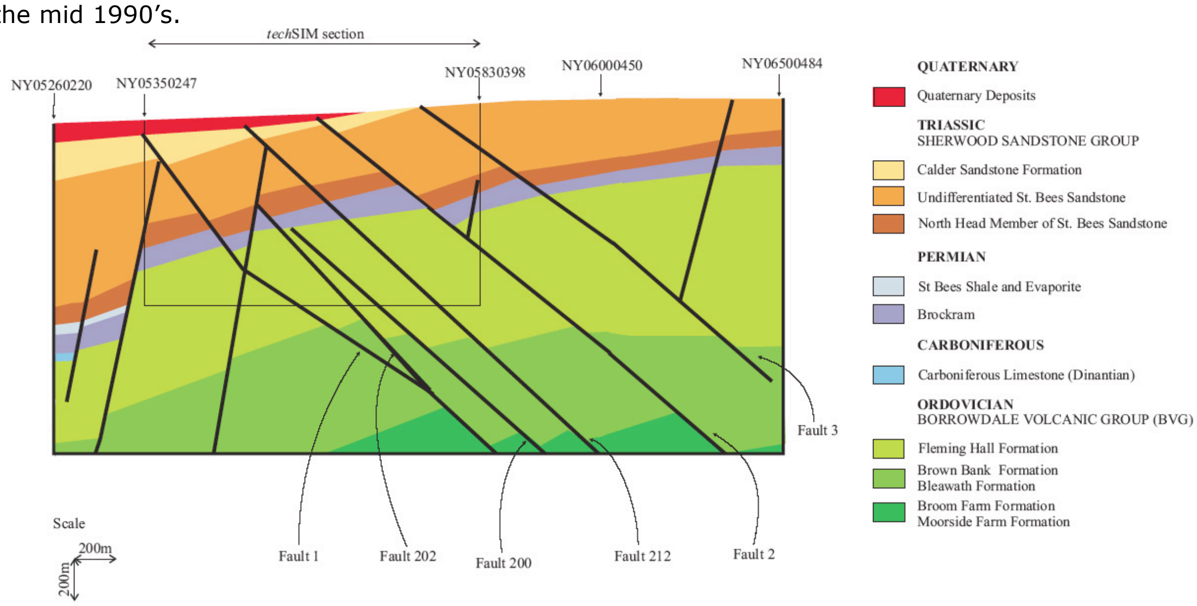
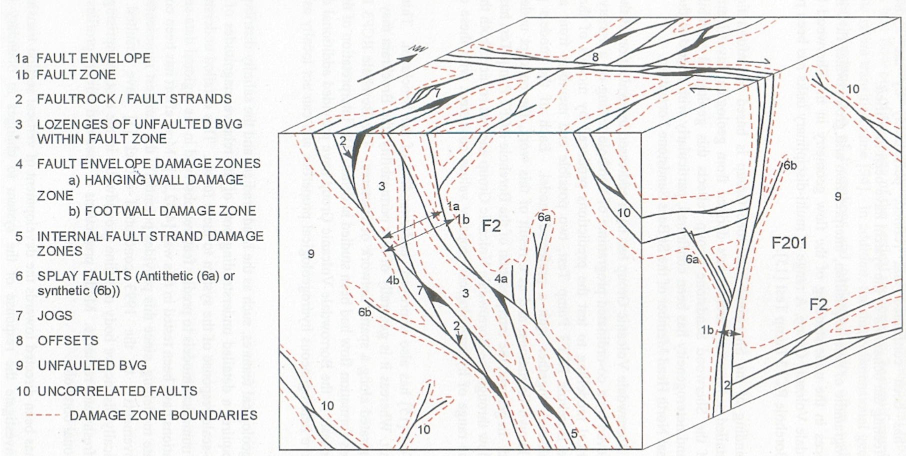


Figure 5 Section of west Cumbria taken from Nirex 97 final report.
Section in detail, through proposed Repository, shows complexity of detailed faults – compare Figure 1, for larger sized contrast. This section is about 3.5km wide. A 2012 GDF, which is 5km on each side, will cut all these faults and will extend beyond the width of this image into additional faults. To map these faults requires a detailed 3D seismic reflection survey, tied to information from drilled and cored boreholes at 0.5 to 1.0km intervals because of the complexity of the geology. All boreholes and fractures and faults will need to be sealed to prevent groundwater circulation. However normal cement grouting will be adversely affected by new fractures, developed during heating, expansion, and uplift of the rock by heat from emplaced HLW, spent fuel and plutonium (Fig 12).

In a detailed example of 3D fault geometry (Figure 6), taken from Nirex hydrogeology update in 1997 (S/97/008). It is clear that individual faults are extremely complex, and are composed of multiple smaller structures, which are very hard to map with certainty in 3D, and impossible to validate, especially where only borehole cores are available, rather than continual rock exposures at the earth surface.



Schematic section of moderate to large displacement faults in the Borrowdale Volcanic Group, and terminology of fault architecture

Nirex Science report S/97/008 Hydrogeology of Sellafield area: 1997 update

Figure 6 Detailed interpretation of connections between faults and fractures within the Borrowdale Volcanic Group. Taken from Nirex hydrogeology update in 1997 (S/97/008). This information is derived two boreholes just 110metres apart, where groundwater was pumped from one, and the pressure effects measured on the adjacent borehole. The connections between the boreholes are best expert guess interpretations, there is no validation possible except by longer duration detailed tests. Nirex hydrogeology update (S/97/008), states that *"The Borrowdale Volcanic Group is highly faulted and it is unlikely that it would be possible to find a block of Borrowdale Volcanic Group with a length scale greater than several metres that does not contain faults. ….. hydraulic test results indicate that, although fault zones appear to have a role in determining the properties of the hydrogeological units, this role is variable."* Ie the faults and connections are un-predictable.

It is clear that for subsurface investigations, even of one small fault, then there is an immense complexity of detailed fracturing, many of those fractures transmit water flow, even under tightly controlled small scale tests, no definitive or no results can be achieved without a different analysis. There is no certainty of producing a result, Research experts on fluid flow in faults have stated that the complexity of flow in subsurface conditions may not be answerable in a unique way, but only in a statistically generic way.

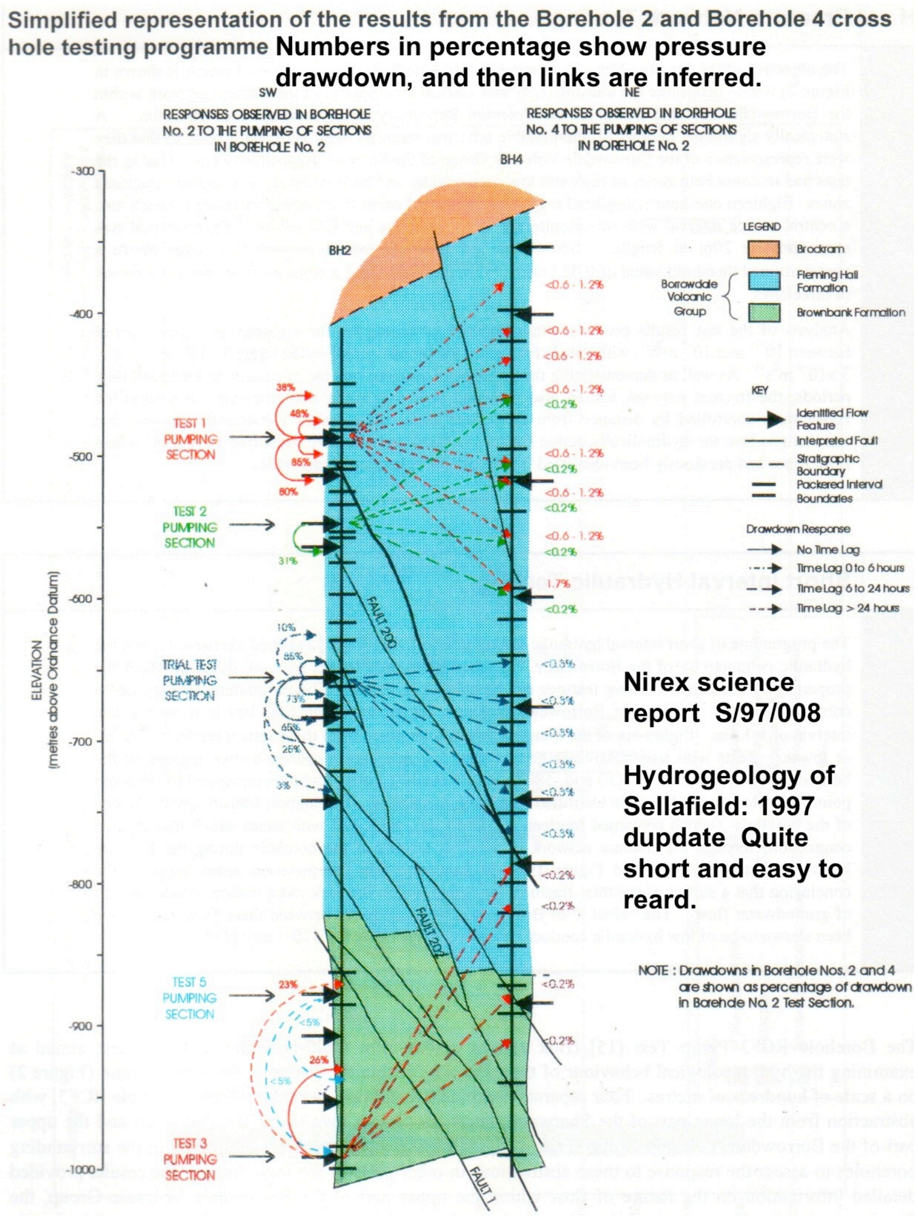
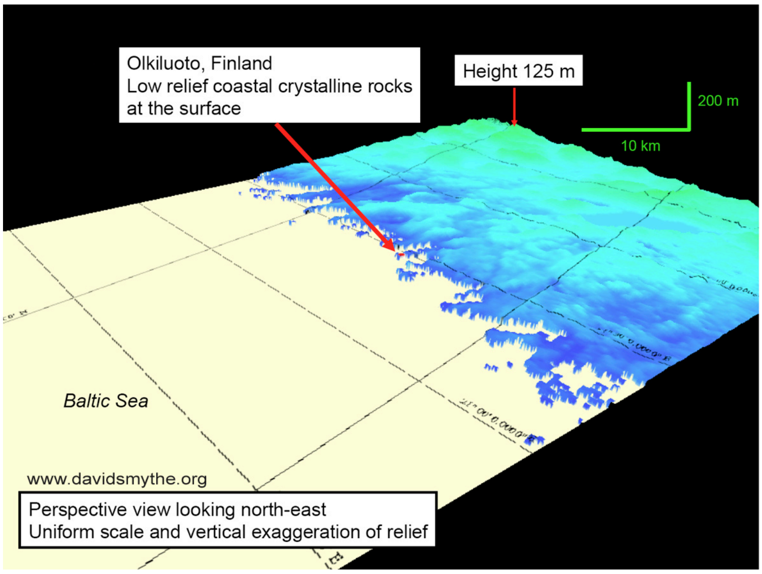


Figure 7 Taken from Nirex hydrogeology update in 1997 (S/97/008). This shows the hydrogeology fluid pressure connections between faults and fractures in borehole 2 and borehole 4, just 110 m apart. These two boreholes are to test if faults and flowing fractures are connected, and if other faults and fractures are not. It is apparent from the data that a single fracture which flows fluid may be connected to one fracture feature in the nearby borehole, or may branch to form several connections into the adjacent borehole. The report states that during a seven-month period throughout the program of testing; *" there is no readily observable relationship between geological structure and responses. Interpretations of the hydrogeological nature of the Borrowdale Volcanic Group from this test are limited to one plane, rather than three dimensions."*

SUMMARY. It is clear from Fig 6 -7, that the hydrogeology connection between faults and fractures in west Cumbria is extremely complex, and unpredictable in any site-specific way. To ensure robust sites performance in retaining radioactive waste into the far future, accurate predictions of groundwater flow through the salt and fracture systems need to be made. That does not appear to be possible.

3. Topography

West Cumbria is a part of the UK where topographic elevations of the present day extend to 1000 m above sea level. That topographic elevation provides an elevated head of groundwater, which drives flow through the subsurface. In West Cumbria this fluid pathway is condensed into the narrow coastal zone between the Lake District and the present-day shoreline. Consequently flows of subsurface water have a large drive, which will not be decreased in the short-term by any geological erosion. By contrast, other sites in Europe proceeding towards development of a GDF have much lesser topographic differentials in their immediate vicinity. Consequently there is minimal drive to promote subsurface groundwater flow. Combined with the complexity of geology, and the complexity of faults and fractures, described above this means that significant drives for rapid flow of induced to take complex and variable pass through the underground geology. These are impossible to predict with any certainty into the near or far future. Thus the westCumbria region is too complex to make simple, secure, and consequently safe predictions of performance.



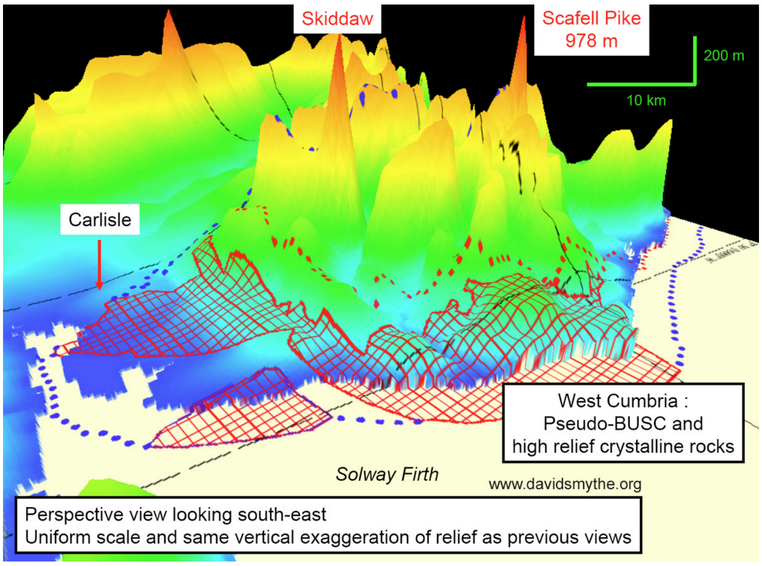


Figure 8 present day surface topography of south-west Finland around the area where a GDF is being constructed.
Figure 9 present-day surface topography of North and West Cumbria, adjacent to the Lake District, where a GPS is proposed as part of the MRWS process.

Computer generated images of topographic elevation (Fig 8, 9), constructed by Prof David Smythe. These are to the same horizontal and vertical scales so can be directly compared. It is clear that the areas which are not excluded by the BGS survey in West Cumbria are close to large topographic elevations, and so will experience intense groundwater drive. That makes the assurance of secure site performance into the far future immensely more difficult. The statements made by Nirex during the site selection process of West Cumbria in the 1990s, implied that these sites along the coastal zone of the Lake District were all considered to be a variant of basement under sedimentary cover, which had been identified by national screening work derived from BGS in the 1980s. In a section below, I demonstrate that is not true (Fig 16). All sites in West Cumbria are subject to this problem, in addition to the complex geology and intense fracturing. These sites are unlike any being developed worldwide as GDF for radioactive waste disposal.

4. Geochemistry
The mix of radioactive waste to be emplaced in a GDF contains many different elements, and compounds of those elements, which have very different geochemical characteristics. The current proposal for this future GDF is that it should include disposal of high-level waste, spent fuel, and potentially plutonium. The first two categories contain large amounts of uranium. The geochemistry of uranium is such that it becomes soluble in chemically oxidizing waters, and is much less soluble in chemically reducing waters. In colloquial terms these equate to more available oxygen, or less available oxygen - but it is important to realize that is an analogy and free oxygen is not required, it is an expression of chemical reactivity.

Although some engineering can be undertaken of the near field of a GDF, the far field of surrounding geology is essential to guarantee secure long-term site performance. That means geochemically reducing groundwater will be more successful at retaining uranium than an oxidizing water. The diagram below is a cross-section through the subsurface of West Cumbria, derived from detailed logging of boreholes by Nirex and its subcontractors in the mid-1990s. This portrays the ground surface, and two boundaries of rock layers below ground, being the base of the Triassic aquifers, and the base of the sediments unconformably overlying Borrowdale volcanic group. Boreholes are shown as vertical red lines, these obtained excellent rock core material, and the fractures in those cores were analysed by BGS geologists. The minerals lining the fractures are in contact with present-day, and formerly past, groundwater. These minerals are a natural record of the oxidation or reduction of the groundwater. It is well known that West Cumbria was the location of the U.K.'s largest haematite deposit, which was about 100 million tonnes of iron oxide. The veins containing the iron oxide occur at the north part of West Cumbria, at the south part of West Cumbria, and throughout the central Lake District. This clearly demonstrates a geochemical homogeneity of groundwater in the entire region through geological time.

It is no surprise, then, that many fractures contain iron oxide minerals. Additional minerals are calcite. Occasionally there are small crystals of iron sulphide. This mineral forms from iron in geochemically reducing conditions, whereas haematite forms in geochemically oxidizing conditions.

In the diagram below, I have plotted the maximum occurrence of any sulphide recorded in fractures. It is clear that sulphide minerals only exist at deeper levels below the ground surface. At shallower levels exist oxides and calcites. This indicates that the shallower parts of the sub surface have been exposed to oxidizing conditions for many millions of years, whereas the deeper parts of the subsurface may have been exposed to some reducing conditions in the geologically recent past.

Siting a GDF (here labeled as PRZ) in the shallower parts, exposes that waste to long-term attrition by oxidizing water, such that uranium and its salts will be prone to dissolution and transport in moving groundwater. Consequently the basic long-term geochemistry of this entire West Cumbria coastal zone is unsuitable for long-term retention of the radioactive waste proposed to be emplaced.

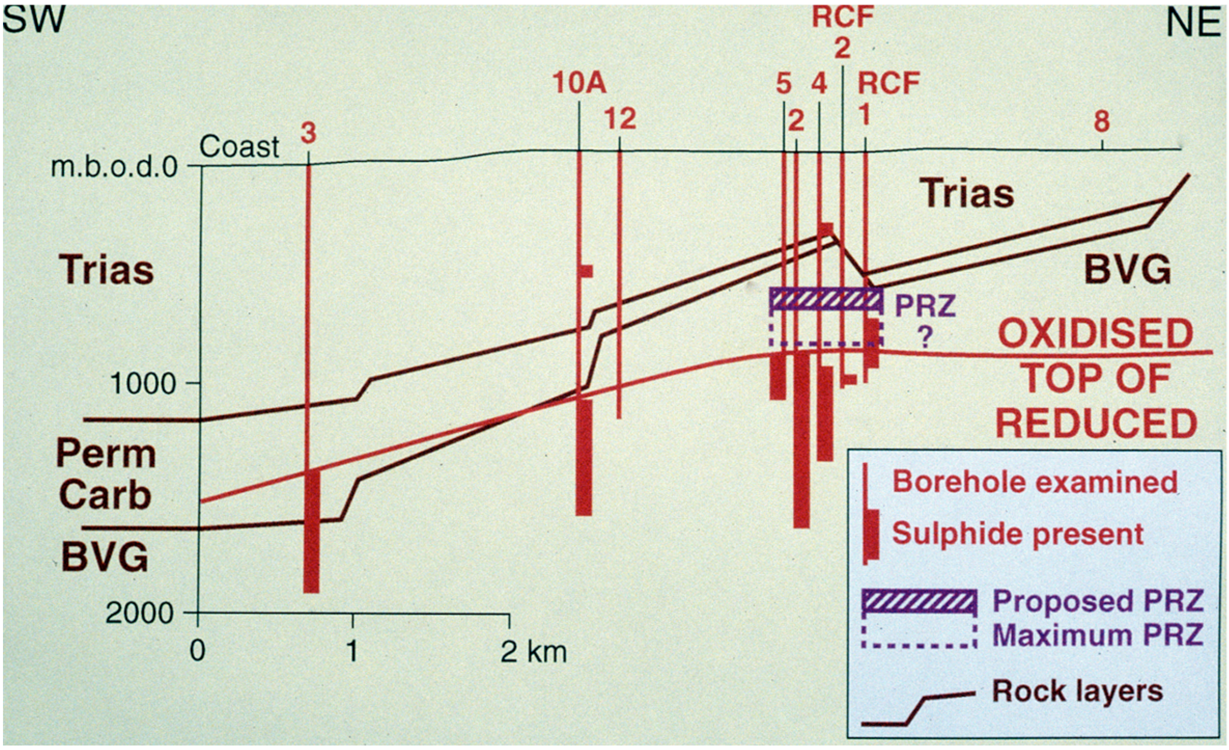


Figure 10 section through West Cumbria, derived from Nirex information. Boreholes with complete rock core are shown as vertical lines. The position of a GDF is shown as PRZ. Minerals lining fractures in the core were recorded in detail by BGS. These minerals are iron oxides and carbonates that shallow depths, indicating geo-chemically oxidizing groundwater. At deeper depths there are occasional minor traces of sulphide minerals lining present-day fracture surfaces. These are indicating geochemistry reduced groundwater. When compiled as a section, it is apparent that the upper 1000 to 1500 m of all rock types are exposed to geochemically oxidizing groundwater, whereas deeper depths have occasionally been a chemically reducing. Uranium is retained by reducing conditions, whereas uranium from a GDF can be made soluble in moving groundwater by oxidizing conditions.

5. Gas leakage

It is well known, since the 1980s, that groundwater exposed to radioactive waste will undergo radiolysis to produce hydrogen. Additionally the carbon content of steel, and any carbon in wastes emplaced will undergo reaction to produce CO2, which may be converted to methane. This has been a subject of persistent research during the past 20 or 30 years. A problem for waste disposal is twofold. Firstly the production of gas in a confined subsurface space increases the pressure, and will eventually result in fracturing the surrounding backfill in the near field, and then the surrounding rock in the far field. Thus, even if natural fractures are grouted and sealed during construction of a GDF, then a suite of new fractures will develop to enable groundwater flow. Secondly the carbon dioxide and methane gases produced within the GDF are mobile, although deeper than 800 m carbon dioxide may be a liquid. These gases contain radioactive carbon-14, and it is well established through scenario modeling of predictions into the future, that movement of this radioactive gas to the surface creates a leakage within a few tens of years (Fig 11).

This problem still remains as a high priority on the NDA research agenda, so has manifestly not been solved. The resolution is indeed difficult, as a suite of retention is needed which can both transmit pressure as a slow bleed off of water or gas, and can also retain radioactive gases. These conflicting aims appear to be resolvable in the settings of the French and the Swiss GDF, because of the natural characteristics of the enclosing mudrocks.

In the West Cumbria region this is a particularly significant problem, because the enclosing rock is known to be extensively fractured, with no natural method of re-sealing. Consequently there is no method to guarantee natural, or engineered, containment of radioactive gases generated during waste storage.

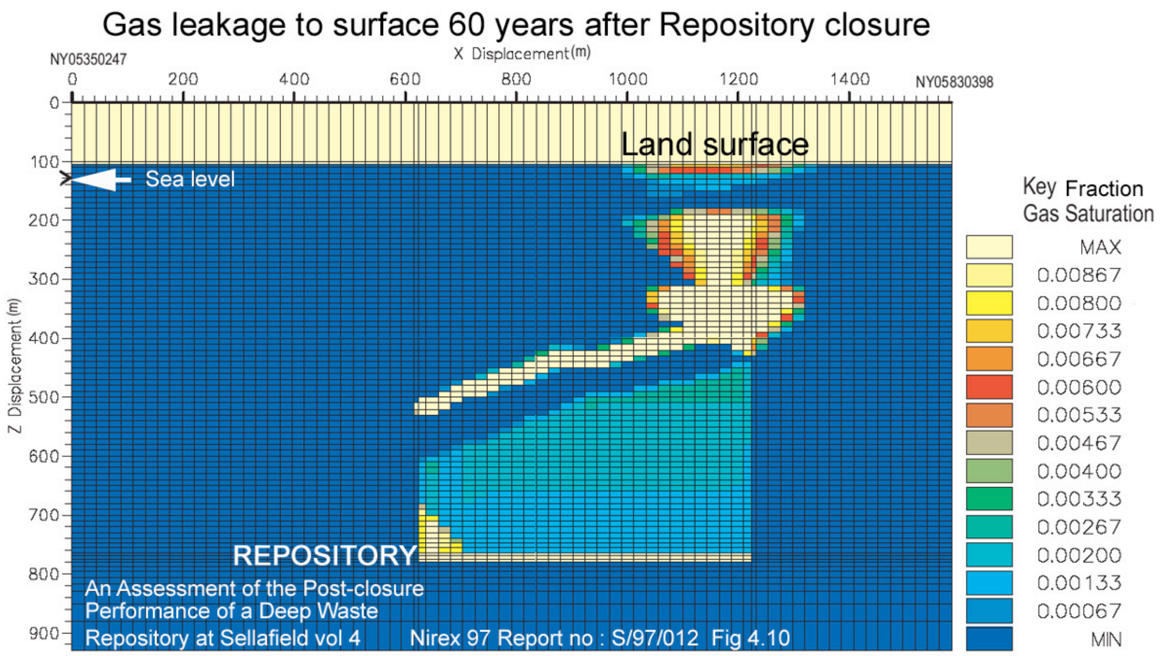


Figure 11. Taken from Nirex 97, S/97/012.

In Fig 11, is a computer simulation of a section through the earth, from land surface, down to a GDF "Repository". A gas leak simulation has been imposed, derived from gases generated within the GDF by radioactive wastes interacting with groundwater and with carbon in steel and carbon in wastes. The majority gases are usually expected to be carbon dioxide and methane. These buoyant gases rise rapidly through near-field seals, and then through fractures in the overlying overburden. This simulation shows a plume of gas (yellow) rising to the surface just 60 years after waste emplacement.

6. Heat from waste: ground surface uplift

Radioactive waste is hot in temperature. And that heat production from nuclear reactions decays exponentially during many hundreds of years. Consequently there is a large additional heat loading on the rock surrounding a GDF, and this heat will ensure that the rock expands. Because natural rocks are confined by other rocks in all directions horizontally, and because rock can only expand downwards in a very limited way because it is not possible to push the deep Earth out of the way, then inevitably a heated rock has to expand upwards.

The effects of such thermal expansion have been modeled in figure 12. This takes a theoretical case of a very small repository at a very shallow depth, but none-the less this demonstrates a very important physical principle. With this small amount of waste, close to the surface, an uplift of 0.85 m occurs. The uplift from a much larger westCumbria GDF has not been simulated.

Because so few nations have elected to co-dispose of high-level waste and the spent fuel and plutonium, all in a similar location to intermediate level waste; then very little research has been concluded on the heat-related problems of radioactive waste disposal and potential leakage.

Nevertheless the principle is clear, and the same effect will occur in west Cumbria, with a much larger GDF. Users of the land, or houses and property on the land above a GDF will inevitably experience uplift. Because of the pre-existing fractures in rock overlying a GDF in west Cumbria, then it is likely that these fractures will re-open, to provide conduits for radioactive gas (Section 5), or flow of groundwater to reach the surface.

SUMMARY: Emplacement of hot wastes will force rock to expand, with the strong probability that new fractures will be created. The fractures can allow radioactive gas to rapidly leak to the surface. Land users and housing at the land surface will be uplifted

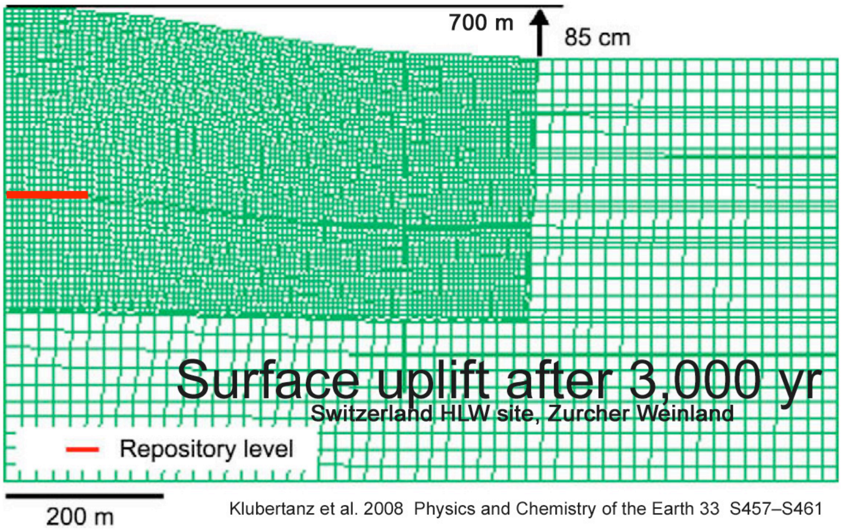


Fig 12 Diagram taken from Kulbertanz (2008). This shows a section through the earth, based on Swiss GDF geology. Heat from the waste makes the surrounding rock expand as it gets hotter, and this produces uplift at the ground surface. This is for a small GDF at shallow depth.

7. Heat from waste: coupling to groundwater flow

It is also possible that emplacing additional heat generation into the subsurface, by means of hot radioactive waste, can interact with groundwater, to disturb the natural steady-state. An analogy may be to place a layer of denser sugar-saturated water or fruit-juice in the base of an electric kettle, and for this to be overlain by a layer of less dense freshwater. The situation is stable, until the kettle is switched on. The additional heat input to the denser lower layer makes this reduce in density, such that the fluid rises and a circulation of fluid ensues.

There does not seem to have been significant research published on this potential for coupling heat and water flowed together. There has been abundant work on simulating the diffusion of heat locally around a GDF. By contrast new research work, currently in progress at University of Edinburgh, has taken a larger view, to emplace the hot waste into the regional groundwater. The example shown below has been constructed using the well measured information on rock and fault geometry, and rock and fault hydrogeology properties of porosity, permeability, and water flow, derived from data measured for Nirex 97.

Although this section relates to a particular location in the former repository proposal (see Fig 5), the generic principles in this modeling apply to anywhere in West Cumbria. This is because the essentials of our model and are a slow but persistent groundwater flow from east to west, trending gradually upwards. The flow passes through rock types which are typical of all of West Cumbria. The faults and fractures are typical of all of West Cumbria.

The routine undertaken in this new research can be summarized as follows: i) construct static framework of rock layers and faults, based on real geological observations. ii) populate these rock layers and faults with values of porosity and permeability which are derived from the final values chosen by Nirex 97. iii) run a fluid flow model simulation, to reproduce natural groundwater flow from east to west, and check the validity of this by reproducing profiles of groundwater salinity and pressure down the borehole sections, which can be compared with natural measured field data. iv) emplace waste in a 5 km GDF, using heat generation, and heat decay through time, values for HLW and spent fuel published by NAGRA (2002), Technical Report 01-04 from Switzerland (although that material differs in detail from the UK waste, there is sufficient similarity to illustrate the processes operating). v) re-run computer flow model, starting from its natural equilibrium position, and ascertain if there is any difference from the natural situation

Results from these simulations show that emplacing waste with heat generation has a catastrophic effect on groundwater circulation. The natural pattern is greatly enhanced, and groundwater circulation is forced to ascend rapidly up faults and fractures above the waste, to produce a surface temperature anomaly. This takes large masses of groundwater past the GDF, potentially carrying radioactive gases and dissolving wastes. These groundwaters ascend into the drinking water aquifer of the Calder sandstone (thereby breaching the site performance standards), and some groundwater reaches the Irish Sea and onshore land surface. These effects are apparent at the aquifer within 200 years of waste emplacement, and continue to supply water from the GDF to the aquifer until at least 3,000 years after emplacement.

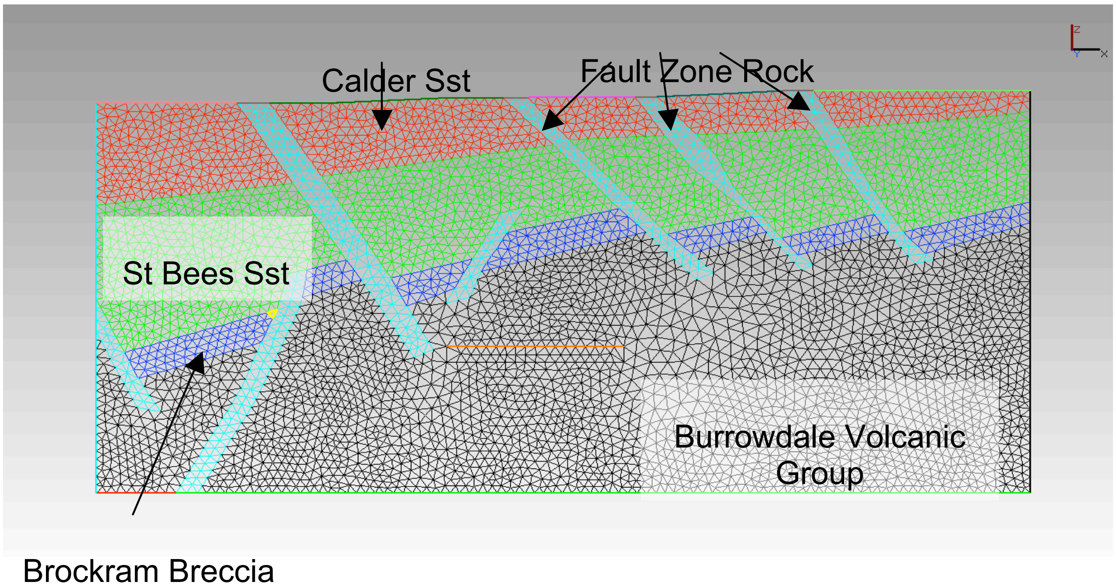


Fig 13 Section prepared by Andrew Harris and Dr Chris McDermott, University of Edinburgh. Scale bars at top left are 200m. Geometry of central part of model as west to east section, focused around Fault 202 (Fig 5) in west Cumbria. The important points are : i) That groundwater flow in steady state flows from east to west, and focuses progressively upwards into the Calder sandstone. ii) this section applied to all of west Cumbria, as the basic relationship is: waste emplaced into a lower permeability fractured host rock, then a short barrier for fluid flow until a permeable fault is reached.

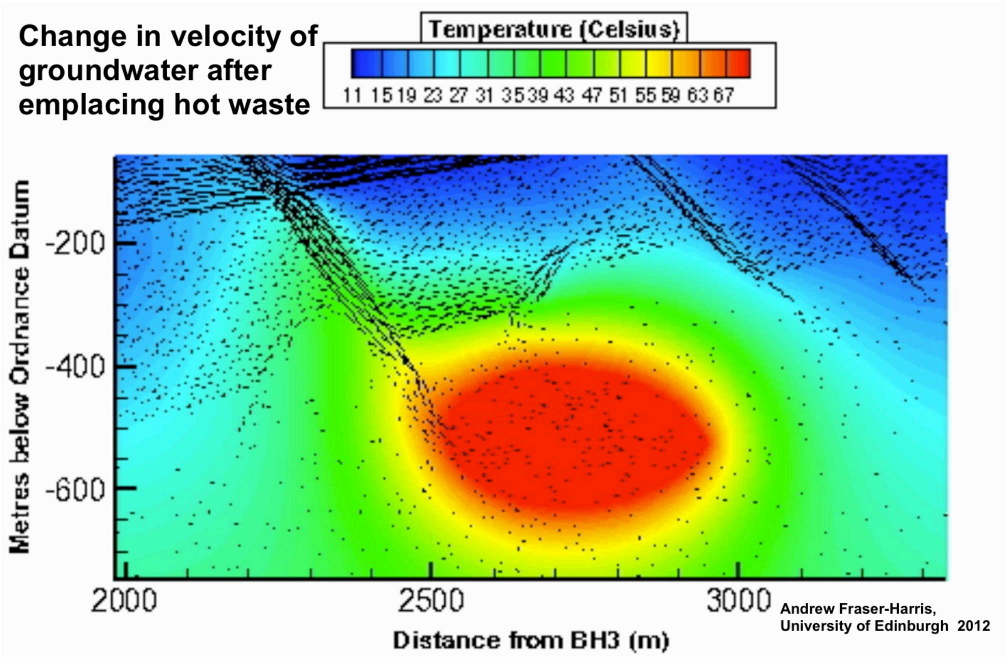


Fig 14 Section prepared by Andrew Harris and Dr Chris McDermott, University of Edinburgh. Slight zoom in to above, showing heat anomaly from waste disposal, after about 800yrs. Groundwater flow paths are shown by arrows, which clearly focus rapid ascent of warm water from GDF up into Calder Sandstone drinking water aquifer.

SUMMARY: This is a highly significant result, which may affect the UK strategy of co-disposing spent fuel with Intermediate Level Waste. Heat accelerates existing groundwater circulation, so that water from GDF reaches surface in 58% less time.

8. Marine flooding

A GDF and associated onshore store will be operational for practical engineering access for 100-200 years. These facilities, and associated nuclear plant and reprocessing equipment along the Cumbria coast, are at risk of flooding and from tsunami. A compilation of data from the DEFRA 2012 report on climate change impacts (Fig 15), shows that much of West Cumbria has at least a medium risk of flooding. These compilations are derived from central case figures in the DEFRA report, and do not reflect the more extreme, but still equally probable, possibility of much larger sealevel rise of 5metres within the next 100-200 years

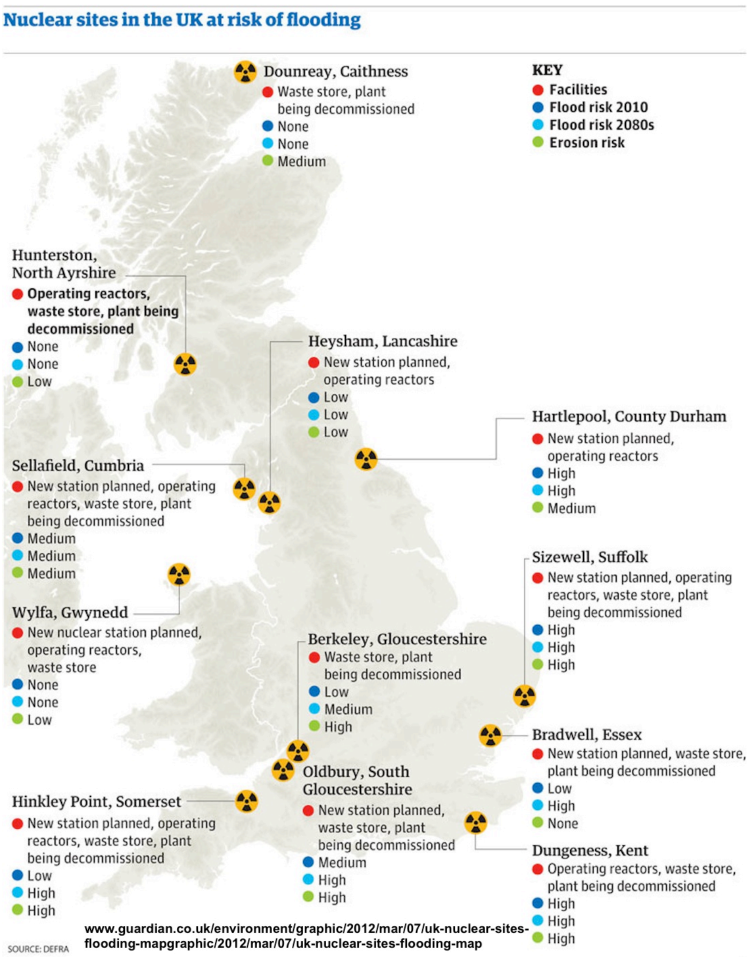


Figure 15 Map published by Guardian, derived from DEFRA 2012. This plots the Sellafield works as being at medium risk from marine flooding in the future

9. Alternative sites

A specification for radioactive storage in the UK which matches international benchmarking, would be Basement Under Sedimentary Cover (BUSC). That was devised by BGS in the 1980's during a national search for sites. Several UK sites exist which fit this criterion. The largest region is East Anglia (Fig 16) showing a very large region of potential suitability, which could be investigated.

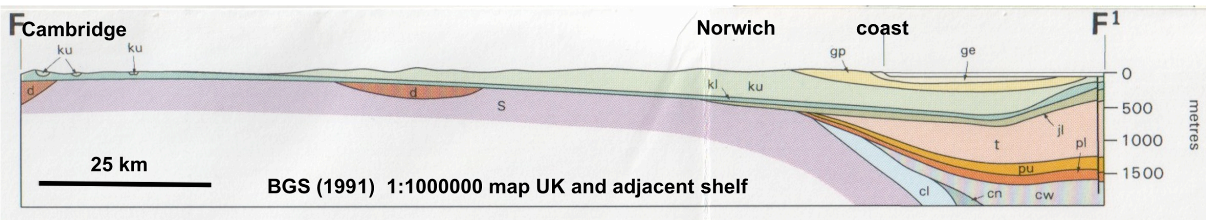


Figure 16 Section from BGS map, along A11 road from Cambridge to Norwich and offshore. This fits the criteria for BUSC sites very well indeed.