Are we REALLY managing radioactive waste safely?
Geology

Configuration and character of the rocks
-the final, most important barrier

Hydrogeology

How water flows through, potentially carrying toxic waste. Driven by the ‘hydraulic head’-topography

‘Safety’ assessment

Guessing the chances that a person or a population in the future could come into contact with the radioactive waste.
The West Cumbrian recipe

Complex site geology +
High mountains nearby ↓
Fast and unpredictable groundwater flow ↓
Unsafe underground dump
History of search in Britain
  Up to watershed of 1997 Inquiry

International aspects
  Guidelines
  What other countries do

West Cumbria
  Topography
  Geology

Current process
  Political/scientific manipulation
  Safety
History of UK site search up to 1997
Areas almost completely disjoint
Two categories relevant to West Cumbria

Irish Sea  Sellafield  Lake District

Seaward-dipping sediments – hoped for Permian evaporites

Basement under sedimentary cover (BUSC)
Sediments were the only suitable formation identified in Cumbria.
Site search:
‘Coastal sediments’ at Sellafield morphed into a ‘BUSC variant’.

1988 search working maps

List of 437 UK potential sites
True BUSC cross-section at vertical exaggeration x 10

200 km flat coastal plain

Crystalline basement

Sediments

Repository

True slope 0.6°.

So-called ‘BUSC variant’ at Longlands Farm:

- Horizontal compressed by x 20.
- Terrain higher by x 20.
- Dip (tilt) higher by x 40.

Distortion of 20 x 20 = 400.

Result: groundwater flow far too vigorous and complex – this is not a BUSC environment.

Geological cross-section from Windermere to the Solway

Source: BGS
What’s wrong with the Sellafield site (Longlands Farm)

• Not in the list of 437
• Not BUSC (nor any other suitable type)
• Regional topography too severe
• BVG not true hard rock
• Highly complex volcanics
• Highly faulted
• Three-dimensional
• Overlain by aquifers

• Fast, unpredictable flow
• Therefore **unsafe**
After £400M spent in West Cumbria + £10M at the Inquiry itself in 1995-96

The Inquiry Inspector

FINAL CONCLUSIONS

“8.53 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.”

... the end for Sellafield, one might reasonably think.
Evolution of international search criteria

(Summary)

The following organisations agree or have agreed on the same set of broad principles:

• IAEA (pre Nirex 1995 Inquiry guidelines)
• British Nuclear Fuels Ltd
• IAEA – new draft guidelines
• European Union
• British Geological Survey
• Finnish Geological Survey

None of them put voluntarism ahead of a systematic geological search.
Search practice abroad

“In 1983 TVO ... drew up a list of 101 potential sites and undertook a consultation process with the affected communities. This resulted in the identification in 1985 of 5 potential ‘volunteer’ sites at which more detailed investigations were carried out ...”

- Insinuating that it was a voluntarist process.

[TVO is Teollisuuden Voima Oy, the company then responsible for nuclear waste disposal]
Site search in Finland started by a systematic search of the whole country.

327 regional bedrock blocks were identified (red areas).
Site search in Finland:

The regional blocks were sieved down to five sites (upper map) which were subjected to site characterisation.

Two sites were withdrawn, but a third added to give four sites (lower map).

Municipal vetoes resulted in the withdrawal of the two most northerly sites. Olkiluoto in Eurajoki municipality was chosen in 2000.
Sweden:

Staged site selection based on **geology**, but with:
- Local veto
- Government right to override the veto.

The geology of both Finland and Sweden is mostly ancient stable low relief hard rock.

Geological search also preceded community involvement in:

France, Belgium, Switzerland*, Canada, USA.

* Switzerland to be shown later
Summary of fundamental criteria

Drawn from research, experience and recommendations here and abroad since the early 1990s:

- The host rock is NOT so important at the first stage.
- The regional setting of the site IS most important.
- Long geological stability.
- Low hydraulic gradients.
- Simple geology.
- Suitable geology precedes community assent / veto.

West Cumbria has a problem with several of these.
Topographic relief

Drives the underground water flow
Why the land surface relief is crucial

Water flow is driven by the elevation of mountains, and inevitably rises to surface as ‘artesian’ springs.

When toxic waste dissolves, there is no natural barrier to pollution entering drinking water and the sea.

All international potential waste repository locations are in flat areas.

West Cumbria looks like this - it has poor site performance.
Topographic relief map showing actual and potential waste repository sites in NW Europe

1. Finland
2. Sweden
3. Wash - Norfolk
4. West Cumbria
Olkiluoto, Finland
Low relief coastal crystalline rocks

Height 125 m

Perspective view looking north-east
Uniform scale and vertical exaggeration of relief

Baltic Sea
Östhammar, Sweden
Low relief coastal crystalline rocks

Height 65 m

Perspective view looking west
Uniform scale and vertical exaggeration of relief
The Wash and Norfolk – a good example of ‘basement under sedimentary cover’ (BUSC)

Perspective view looking south-east
Uniform scale and vertical exaggeration of relief

Height 77 m
West Cumbria: Pseudo-BUSC and high relief crystalline rocks

Perspective view looking south-east
Uniform scale and same vertical exaggeration of relief as previous views

Solway Firth

Carlisle

Skiddaw

Scafell Pike 978 m
Geology
Complexity

in the context of a potential repository:

• Variety of lithologies
• Folding
• Angular unconformities
• Faults cutting both basement and cover rocks
• Faults intersecting the ground surface
• Faults intersecting each other at shallow depth
• Three-dimensionality
Cross-section through Allerdale from BGS screening report.
Vertical scale 3x horizontal.
Sea level – yellow line; base of section at 1500 m.
Faults are denoted by solid lines, unconformities by wavy lines.

- a good Final Year Honours Geology exam question!
Simplicity: the clay layer site in Switzerland

Cross-section from the Swiss HLW site.

Vertical scale 3x horizontal.

Simplicity + clay = security
Geology district by district

Northern Allerdale

Limestone belt

Eskdale granite

Sellafield / Longlands Farm

Southern coastal belt

Already excluded
Sellafield
Longlands Farm
Borrowdale Volcanic Group

£400M spent
Rejected by Inquiry

Can it be revived?
3D model of the structure at base of sediments, looking to the NW. No vertical exaggeration, 5 km x 5 km.

White surfaces are the faces of the faults. This structure is modelled by computer to try to predict water flow and ultimate safety (shown later).
Geology district by district

Northern Allerdale

Limestone belt

Eskdale granite

Sellafield / Longlands Farm

Southern coastal belt

Already excluded
Coastal geology south of Longlands Farm

Coastal sedimentary strip problems:

• Complex, very narrow strip.
• Limestone present.
• Major fault line.

Conclusion: (even) worse than Longlands Farm.
Geology district by district

Northern Allerdale

Limestone belt

Eskdale granite

Sellafield / Longlands Farm

Southern coastal belt

Already excluded
Eskdale granite: summary

Unsuitable because of:

• Extreme topography
• Adjacent to Lake District Boundary Fault
• Oxidising groundwater (old haematite mines, present-day leaching of uranium)
• Heavily faulted internally
• Complex internal structure
• Possible ‘hyperpermeable’ fracture zones (as found in granite below Weardale, Durham)
A cross-section along the purple segment of line AB is shown in the next figure. Complex.
- Complex, 3-dimensional
- No suitable basement-type rocks
- Limestone and Coal Measures present
- Geologically unsuitable
Geology district by district

Northern Allerdale

Limestone belt

Eskdale granite

Sellafield / Longlands Farm

Southern coastal belt
Sediments of northern Allerdale
A cross-section along the red segment of line AB is shown in the next figure.
Mercia Mudstone Group - unsuitable

- Not previously considered as a host rock by the BGS.
- Current hydrocarbon exploration - should be excluded.
- Regional hydraulic gradient is high.
- Undesirably shallow depth of between 200 and 500 m.
- Geology is well understood due to oil industry exploration.
- Haematite-bearing red beds – oxidising environment.
- The groundwater is fresh, and exploited as an aquifer.
- The hydraulic conductivity is 10,000 - 1,000,000 times too high.
- Not a seal for hydrocarbons if less than at least 600 m thick.
- Cut by large faults which may act as water conduits.

The MMG was probably introduced as a debating tactic by MRWS.
The current process
Misinformation
But the government has airbrushed out the history of the 1995-96 Planning Inquiry.

- to put Sellafield back in the frame.
Since 1997 successive governments have:

• Hidden details of 1995-96 Inquiry.
• Done no research to find other potential sites.
• Removed right of Public Planning Inquiry.
• Elevated ‘voluntarism’ as the main selection criterion.

And is now:

• Misrepresenting Inquiry conclusions.
• Presenting Sellafield as ‘potentially suitable’.
• Implying that other countries use voluntarism.
• Inviting volunteer ‘communities’ to come forward.
• Presenting the ‘initial unsuitability screening’ as a pass mark for West Cumbrian geology.
Nirex discussed Sellafield in 2005, asserting:

“It has been argued that the rejection of the RCF planning application indicates that Sellafield was unsuitable as a repository site.

However, we believe that this was never a conclusion from the RCF Local Planning Inquiry Inspector's report.”

“– and can we now add in High Level Wastes as well?”
Letter from Chris McDonald (Inquiry inspector) : The Guardian, 2007

“The relevant geology in west Cumbria is apparently now claimed to be "stable, although imperfect". But 10 years ago the nuclear industry had not found a way of maintaining the stability of that geology when physically exploring the underground site.

… the imperfection consists of simply failing to meet the internationally agreed criteria on the suitability of rocks for nuclear waste deposit.

The site should be in a region of low groundwater flow, and the geology should be readily characterisable and predictable, whereas the rocks there are actually of a complex volcanic nature, with significant faulting.

…the industry was relying on an overlying layer of sedimentary strata to dilute and disperse any groundwater leakage, when the international criteria require such a layer to act instead as a barrier.

The site is not suitable and investigations should be moved elsewhere.

The site selection process was flawed, not treating safety as the most important factor, and irrationally affected by a strong desire to locate close to Sellafield.”
Fibbing

The NDA (Nirex, 2005) claimed support from the BGS for Sellafield:

“Based on the results of this work*, we believe that Sellafield is a potentially suitable site for a repository. This view is shared by the British Geological Survey (BGS) and many other specialist consultants.”

Really?

* The Nirex 97 set of documents

I asked for evidence ...
“the assertion … was based on verbal evidence, as a result of the … Director of the BGS, Dr David Falvey, responding in the affirmative to the (paraphrased) question,

“Does the BGS consider that Sellafield might be a suitable site?” …”
BGS response, January 2012:

[on correspondence] “our radioactive waste expert, Richard Shaw has searched through all relevant material within our archive and confirmed that there is no correspondence between BGS and Nirex … relating to the suitability of the Sellafield site for a radioactive waste repository …”

[on publications] “we have only published factual reports that relate to the Sellafield site and these will not contain the sort of statement you require for your research.”
Flaws in the BGS screening report

1. The screening report

2. Water

3. Oil and gas
Initial Geological Unsuitability Screening of West Cumbria

Why was a full review not done before the screening-out (as specified in the new IAEA guidelines)?

Next: Potable groundwater
<table>
<thead>
<tr>
<th>Former Designation</th>
<th>Environmental Agency (EA) Designation (from April 2010)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Major Aquifer</td>
<td>Principal Aquifer (e.g. Sherwood Sandstone Group)</td>
</tr>
<tr>
<td>Minor Aquifer</td>
<td>Secondary A Aquifer (e.g. Carboniferous strata)</td>
</tr>
<tr>
<td>Non-aquifer</td>
<td>Secondary B Aquifer (e.g. Borrowdale Volcanic Group)</td>
</tr>
<tr>
<td></td>
<td>Unproductive strata (e.g. halite in the Permo-Triassic strata)</td>
</tr>
</tbody>
</table>

From BGS screening report

“The EA aquifer designation shown in Table 4 post-dates the CPG/CRP report which does not provide guidance on which of these categories would be excluded. In this study only Principal and Secondary A aquifers are regarded as exploitable groundwater resources.”

In effect – we are sticking to the old classification

Why not Secondary B aquifers?
The [ … ] and Mercia Mudstone groups are classified as a Secondary B Aquifer (formerly non-aquifers).

These rock units do not represent major exploitable groundwater resources as defined both in the Exclusion Criteria (Defra, 2007) and within the spirit of the EU Water Framework directives. Really?

[… City of Leicester ‘Waterstones’ ]
BGS screening report:

“Some, but not all, of the rock volume in areas where aquifers and shallow permeable formations are present in the Partnership area are excluded.

However, nowhere does the exploitable aquifer rock volume extend over the whole of the depth range between 200 m and 1000 m below ground level and, consequently, the total area is not excluded at this stage.”

( illogical)

So they are asking for the highly improbable – 800 m thick aquifers.

Why ?
... because if the groundwater exclusion had been applied in a rational way ...

the whole of northern Allerdale would have been screened out.

Next: Oil and gas exploration
Medley of maps showing exploration activity at different epochs in Allerdale.

A. DECC map (2011) showing available seismic profiles (green), exploration wells (red and blue dots) and current licensed areas (grey).
B. Historically licensed areas in the north of England (yellow).
C. PESGB map (1994) showing Mustang Resources exploration licence, extending south from Workington into the Sellafield Site quadrant.
D. PESGB map (2007) showing licences (grey).
BGS exclusion area (red hatching) with the total area of former or current hydrocarbon exploration licences superimposed (diagonal ruling).

So why have rational groundwater and oil/gas exclusions not been consistently applied?
Making a safety assessment in complex geology
Analysis of ‘Nirex 97’

– the set of documents that allegedly changes everything.

Trying to make a ‘safety assessment’ to prove that a dump will be safe for $n$ years (the number $n$ varies and is not consistently applied).

Crucial data include **Permeability**

- How fast fluids can flow through the rocks

- First, what about **uncertainty**?
Estimating the uncertainty in data:

We use
Standard deviation ($\sigma$) or
95% confidence limit
This bar through the preferred value of permeability (diamond) shows the 95% confidence limit on either side.
But what if we have no data …

Never fear!
.... We make it up!

Expert elicitation

From Wikipedia, the free encyclopedia

In science, engineering, and research, **expert elicitation** is the synthesis of opinions of experts of a subject where there is uncertainty due to insufficient data or when such data is unattainable because of physical constraints or lack of resources. Expert elicitation is essentially a **scientific consensus methodology**. It is often used in the study of rare events. Expert elicitation allows for **parameterization**, an "educated guess", for the respective topic under study. Expert elicitation generally quantifies uncertainty.

Expert elicitation tends to be **multidisciplinary** as well as **interdisciplinary**, with practically universal applicability, and is used in a broad range of fields. Prominent recent expert elicitation applications are to **climate change**, **modeling seismic hazard and damage**, association of **tornado damage to wind speed** in developing the Enhanced Fujita Scale, and risk analysis for **nuclear waste storage**.
Data elicitation example:

What is the life expectancy of Adele Adkins?

Think of relevant data .....
Amy Winehouse 27
Janis Joplin 27
Cass Elliot 32
Eva Cassidy 33
Billie Holiday 44
Edith Piaf 47
Sarah Vaughan 66
Joni Mitchell 68+
Nina Simone 70
Etta James 73
Ella Fitzgerald 79
Peggy Lee 81
Juliette Greco 84+
Adele 23+ ??
Nirex 97
Life expectancy of Adele – quantified in two ways

(1) From singer sample we get mean of $56 \pm 21$ (s.d.)
56 ± 42 (95% confidence) = 14 to 98

(2) From graph above - all women + Adele’s current age:
82 ± 16 / -36 (95% confidence)

The answer you get depends on your assumptions
This bar through the preferred value (diamond) shows the 95% confidence limit on either side.

Higher permeability

Some permeability values

AGAIN

Near-Surface BVG
Faulted Near-Surface BVG
Undifferentiated BVG
Faulted Undifferentiated BVG
F1-F2 Structure in the Undifferentiated BVG
Fleming Hall Formation
Faulted Fleming Hall Formation
F1-F2 Structure in the Fleming Hall Formation
Bleawath Formation
Faulted Bleawath Formation
F1-F2 Structure in the Bleawath Formation
Moorside Farm Formation
Faulted Moorside Farm Formation
F1-F2 Structure in the Moorside Farm Formation
Near-Surface Latterbarrow Sandstone
Latterbarrow Sandstone
Near-Surface Skiddaw Group
Skiddaw Group - Horizontal
Skiddaw Group - Vertical
Granite
Faulted Granite
Nirex 97

Log$_{10}$ Effective Permeability
Some permeability values

AGAIN

Higher permeability

This bar through the preferred value (diamond) shows the 95% confidence limit on either side

Always read the small print
Plugging the permeability values into a computer model to predict the flow of toxic waste through the rocks.

NB The ‘engineered barriers’ are temporary. The final, most important barrier is the geology.
How the flow is calculated – the regional 2D model

Geology coloured according to hydrogeological properties

Computer grid for calculations
Computer model result:
Pathlines of escaping toxic waste as shown
Travel time about 55,000 years
Exit under sea
- seems not too bad?
BUT

Travel time is calculated using mean values of permeability for each rock type.

10 times higher permeability means 10 times faster travel time.

So 55,000 years could be just 5500 years, still at 95% confidence.
The whole complex of faulted Borrowdale Volcanics at repository level (circled) is assigned just one value of permeability - tantamount to admission of failure.
None of the faults appear to affect the flow – very suspicious.
Can faults be known?

R. Lunn and colleagues (mathematical experts, 2008):

“Faults can be barriers to flow, conduits, or combinations of the two, and their hydraulic properties vary considerably over both space and time”

They say:

• The *micro* properties as opposed to the average hydraulic properties in a fault zone are crucial.
• But these properties are *unmeasurable at depth*.

They conclude that we can never know …
Fault core – could be a barrier; could be a conduit.

Damage zone – a conduit.

But fault zones have been assigned permeabilities similar to, or the same as, the unfaulted rock.
Red arrows show more realistic flow directions. In case you find this hard to believe …
United Utilities, 2011

“Our specialist teams have plunged four boreholes up to 120m deep in fields south of Egremont …

The boreholes have been sited to target geological faults to give the best access to the yields.”
Geology map

Red / orange / buff colours are sediments

NB locations of water wells are secret …

- Possibility of terrorist contamination

- (ironic?)
Conclusions
on Nirex 97 hydrogeological modelling:

• Values fiddled to keep flow lines underground.
• Many values are just made up (‘data elicitation’).
• Mean values picked – not the worst case.
• Faults airbrushed out of the model.

• We should not pretend to know something just because the computer models tells us.

• Faster computers since 1996 will simply make the same mistakes faster.

• Go where the geology and hydrogeology is simple and predictable.
Committee on Radioactive Waste Management (CoRWM)

“… no credible scientific case to support the contention that all of West Cumbria is geologically unsuitable.”

-A good example of agnotology in operation.

It is NOT TRUE:

• We DO know – it’s a highly studied area
• No stone has been left unturned
• NOWHERE is suitable
• MRWS stage 4 has been done
Memo to Councils: once you’re in, you’re in

Decision points – the slippery slope
Each step postpones the real decision: Is the area suitable?

2. Unsuitability screening
3. Decision to participate
4. Desk studies
5. Surface research
6. Underground

Councils locked in from here on

Govt. to BGS: “Within the Partnership area, where are the most promising localities?”

Point of no return - BGS starts drilling

A site is selected
So ... are we REALLY managing radioactive waste safely?
NO

• History of search ignored
• International guidelines ignored
• International practice ignored
• ‘Voluntarism’ the driver
• No independent, funded scientific criticism (e.g. Sweden, Canada)
• No robust independent nuclear safety agency (e.g. France)

- why?
Why?

- The govt. (DECC) wants ‘new build’ ASAP.
- Needs to ‘sign off’ waste disposal problem.
- Agenda – re-start the failed and flawed search at/near Sellafield.
- Using a nuclear-compliant population.

Legal setbacks await if West Cumbria is not dropped.

The solutions ...
Solutions (over 20 years):

• Run down existing reactor fleet
• No new build
• Replace by renewables / efficiencies
• Search for some REALLY safe repository sites
  - (learn from the French / Swiss)
• THEN get the population onside

Reminder of what the Inquiry Inspector concluded:

“investigations should now be moved to one of the more promising sites elsewhere.”

- and he did not mean anywhere else in Cumbria

Thank-you!