NAWG – the beginnings

- Interest in international coordination of NA work sprung from the initial collaboration between SKB & Nagra that resulted in the first NA review (Nagra NTB 84-41/SKB TR 84-16)


- At the time, there were a few EU groups which were *ad hoc* in nature (e.g. CoCo Club), so NAWG followed suit with an EU secretariat (Bernard) and a chairman (Neil)
NAWG – the workshops

1\textsuperscript{st} NAWG Workshop: Brussels, Belgium, 1985, where the theme was the interaction between modellers and NA experimenters (EUR 10315)

2\textsuperscript{nd} workshop: Interlaken, Switzerland, 1986, where anthropogenic analogues and the role of colloids, complexes and microbes have been reviewed (EUR 10671)

3\textsuperscript{rd} Workshop: Snowbird, USA, 1988, where the application of natural analogues to repository performance assessment was discussed (EUR 11725)

4\textsuperscript{th} Workshop: Pitlochry, Scotland, 1990, was devoted to review 5 years of NA studies and the final conclusions drawn from the Poças de Caldas study (EUR 13014)

5\textsuperscript{th} Workshop: Toledo, Spain, 1992, was held in association with the final workshop of the Alligator Rivers Analogues Project (EUR 15176)

6\textsuperscript{th} Workshop: Santa Fe, USA, 1994, where the intention was to review the "state-of-the-art" of several key issues in near-field and far-field processes and their importance to PA with the intention to provide a consensus view of the remaining areas requiring further research in natural analogues (EUR 16761)

7\textsuperscript{th} Workshop: Stein am Rhein, Switzerland, 1996, where one of the main themes of the workshop was the application of natural analogues to toxic wastes (EUR 17851 EN)

8\textsuperscript{th} Workshop: Strasbourg, France, 1999, was devoted to a presentation of three, major international natural analogue projects, Oklo (II), Palmottu and Pena Blanca (EUR 19118)

9\textsuperscript{th} Workshop: Aarau, Switzerland, 2002, where the theme was the current international status of natural analogues

10\textsuperscript{th} Workshop: Munich, Germany, 2007, where the workshop examined how current and future studies could be better focussed on providing appropriate data for the various end-users of natural analogue data

11\textsuperscript{th} Workshop: Liverpool, UK, 2009, where a short meeting was held at the 12\textsuperscript{th} ICEM (International Conference on Environmental Remediation)

12\textsuperscript{th} Workshop: Larnaca, Cyprus, 2011, where bentonite reaction, cement degradation and PR were themes
In honour of our hosts, an introductory session on natural analogues of issues of direct relevance to Japan (including the study of repository exclusion features, stakeholder communication and Fukushima)

The main thrust of the workshop will be a session on natural analogues of repository systems – where are we now and what remains to be done? This was first tackled in the 6th NAWG in 1994 and is ripe for a reprise today, asking international experts to provide an overview of the main topics and identify those areas requiring further NA-based R&D

The final oral session will cover a wide suite of other topical themes in natural analogues, from examining iodine mobility in natural cements to novel NA studies on evaporates to the recent use of NA data to complement laboratory data in developing the safety case – and much other ground in between

Finally, a field excursion which will include a visit to JAEA’s Mizunami URL
NAWG – more than the workshops

NAWG discussions directly led to the:

- identification of areas requiring NA focus (6th workshop)
- formation of PAIG in Oklo-II
- Cigar Lake retrospective
- Palmotto review
- natural analogues video (Traces of the Future)
- two NA review books
- Nanet (EU programme)

Currently have 21 members from 16 countries around the world – Australia, Canada, Czech Republic, Finland, France, Germany, India, Japan, Korea, Slovak Republic, South Africa, Sweden, Switzerland, UK and USA
Evolution in the study and use of NA

- Simple studies
  - Single processes
  - Single materials
- Multi-process studies
  - Oman
- Total system geological analogues
  - Oklo
  - Cigar Lake
  - Poços de Caldas
  - Maqarin
- Support of the wider Safety Case
  - CCR
  - CNAP
  - Real Materials
Simple studies – single processes

In the early days, most NA studies were of single processes or mechanisms

Matrix diffusion depths in granite

Diffusion rates through clay (Loch Lomond)

- In the early days, most NA studies were of single processes or mechanisms.
- Matrix diffusion depths in granite.
- Diffusion rates through clay (Loch Lomond).
Simple studies – single materials

Artefacts which have been recovered from relevant settings can provide evidence for the longevity of materials used in repositories

- in some cases measured corrosion rates can be compared with PA model predictions
- limitation - analogy constrained by extent of similarity of material and burial conditions
Multi-process studies

- Slowly, they became more complex
  - Oman, study of microbiology and radionuclide thermodynamics at high pH (10 to 11)
  - Mix of microbial population studies and hydrochemistry/mineralogy
  - First time for model testing (and the introduction of BPM)

Limitations

- microbes were incubated at lower pH than in situ, no radionuclide speciation measurements, so all very qualitative
Total system geological analogues - Cigar Lake

Very long term (about 1300 Ma) stability of an extremely rich ore body (containing high concentrations of U and a range of other relevant elements including Ni, Co, Mo and Pb)

Highly effective containment of radionuclides under present conditions with no significant surface radiological signature of the ore, despite the relatively high permeability of the host sandstone formation

No evidence of criticality, but extensive radiolysis of water would be expected within this rich ore body

The protective role of the surrounding clay-rich layer appears to function despite the presence of microbes, dissolved organics and colloids in pore waters
Cigar Lake - Conclusions

- Geological disposal is fundamentally feasible - in a suitably stable setting
- Clay-rich materials may contribute to preservation of U ore even in a rather permeable host rock
- Concentrations of specific elements in porewater generally compatible with predicted solubilities
- Fault movement will not necessarily disrupt an isolation system (self healing)
- Presence of colloids does not necessarily disrupt an isolation system
- No evidence of oxidising conditions due to radiolysis - but microbial activity may be a contributing factor
Cigar Lake - limitations

The analogue does NOT

- Give any indication of feasibility of disposal at a different location
- Validate the longevity or performance of bentonite backfills or buffers
- Allow radiolysis models to be verified
- Validate chemical thermodynamic models or databases (variable agreement can as easily be interpreted as “invalidation”)
- Provide any relevant information on the behaviour of specific radionuclide based on measurements of ultra-trace concentrations

Like Oklo, the Cigar Lake analogy to specific repositories is often exaggerated
# Actual use of analogues

<table>
<thead>
<tr>
<th>Safety Case</th>
<th>Conceptual model development</th>
<th>Data provision</th>
<th>Model validation</th>
</tr>
</thead>
<tbody>
<tr>
<td>KBS-3 (Sweden, 1983)</td>
<td>Radiolytic oxidation of spent fuel against observations from Oklo</td>
<td>Maximum pitting corrosion factor for Cu</td>
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<td>Bentonite stability at $T&lt;100^\circ\text{C}$</td>
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<tr>
<td>Projekt Gewähr</td>
<td>Stability of borosilicate glasses</td>
<td>Long-term steel corrosion rates</td>
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<tr>
<td>(Switzerland, 1985)</td>
<td>Stability and instability of concretes and mortars</td>
<td>Constrain illitisation of bentonite</td>
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<td></td>
<td>Stability of bitumen</td>
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<td></td>
<td>Radionuclide release concepts against Oklo observations</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SKB-91 (Sweden, 1991)</td>
<td>Support of bentonite stability from observations at Gotland</td>
<td>Limit relevance of colloid transport by using data from Poços de Caldas</td>
<td>Radionuclide solubility model testing and comparison with observed solubilities at Poços de Caldas and Cigar Lake</td>
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<tr>
<td></td>
<td>Redox front model supported by Poços de Caldas observations</td>
<td>Demonstrate conservatism in estimating radiolytic oxidation by using information from Cigar Lake</td>
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<td></td>
<td>Inclusion of matrix diffusion</td>
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<tr>
<td>TVO (Finland, 1991)</td>
<td>Use of palaeohydro-geological data in the development of Ice-age scenarios</td>
<td>Matrix diffusion profiles surveyed from various natural analogues</td>
<td>Testing of $\text{UO}_2$ spent fuel dissolution models using information from Cigar Lake</td>
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<td></td>
<td>Observations from Cu-deposits and Kronan canon to support corrosion estimates</td>
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<tr>
<td></td>
<td>Use of colloidal and microbial information from Poços de Caldas and Palmottu to develop models</td>
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<td>Kristallin-I (Switzerland, 1993)</td>
<td>Back-up in scenario development</td>
<td>Bounding conditions on redox front development using information from Poços de Caldas Depths of matrix diffusion penetration</td>
<td>Radionuclide solubility model testing and comparison with observed solubilities at Poços de Caldas, Oman and Maqarin Testing models for redox front development</td>
</tr>
<tr>
<td>PNC 1st Progress Report (Japan, 1993)</td>
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<tr>
<td>AECL EIS (Canada, 1994)</td>
<td>Support development of conceptual models for fuel dissolution, Cu corrosion, clay buffer behaviour and radionuclide retardation, particularly the role of colloids and organics</td>
<td>Geochemical processes and parameter values for redox control on UO$_2$ stability (incl. radiolysis bounding values), Cu corrosion, bentonite-to-illite conversion, and radionuclide retardation (incl. matrix diffusion bounding values)</td>
<td>Testing of models and databases for radionuclide solubility, colloid formation and organic complexation, and Cu corrosion, using observations from Cigar Lake, the Canadian Shield and Kronan cannon</td>
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<tr>
<td><strong>TILA-99</strong> (Finland, 1999)</td>
<td></td>
<td>Support for conservatism in assumptions regarding spent fuel dissolution rate using observations from Cigar Lake; occurrence of matrix diffusion; and canister life time with reference to the Hyrkkölä native copper occurrence</td>
<td></td>
</tr>
<tr>
<td><strong>SR-97</strong> (Sweden, 1999)</td>
<td>Use of permafrost data in development of Ice-age scenarios Use of post-glacial tectonic data in development of Ice-age scenarios</td>
<td>Bentonite stability related to temperature effects; availability of potassium. Clay as a barrier to microbial activity (i.e. Dunarobba) Gas transport in shales Insignificant colloid concentrations at repository depths Bounding calculations supporting reducing conditions at repository depths Incursion of oxidising meteoric waters Lack of mineralogical evidence for Fe(II) oxidation</td>
<td>Justification of model for radiolytic oxidation of UO$_2$ Reference to matrix diffusion data for model testing (Palmottu and Cigar Lake) Testing models of redox front propagation using observations from Poços de Caldas Development and testing of groundwater mixing model (Palmottu and Oklo)</td>
</tr>
<tr>
<td><strong>SFR</strong> (Sweden, 1999)</td>
<td>Support for long-term durability of concrete barrier system using observations from Scawt Hill, N. Ireland, Maqarin and ancient/aging concrete structures Hyperalkaline plume scenario using observations from Maqarin</td>
<td>Hydrogeochemical processes and parameter values for released hydroxides due to leaching; CSH and CASH phases; zeolite phases; pH reduction due to reaction with silicate minerals; and colloids/microbes/organics</td>
<td>&quot;Blind Modelling&quot;: (Sweden, 1999) Testing of thermodynamic databases at Oman and Maqarin</td>
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<tr>
<td>JNC 2nd Progress Report (Japan, 2000)</td>
<td>Range of archaeological analogues to support iron corrosion model / mechanisms Natural bentonite to support longevity assumptions</td>
<td>Matrix diffusion depths from Kamaishi natural series profiles Volcanic glass studies to support corrosion model</td>
<td>Analogue evidence to support solubility data</td>
</tr>
</tbody>
</table>
The most recent integrated SA from Nagra Safety report (NTB 02-05) contains 12 mentions of natural analogues in 472 pages.

Comparisons with natural fluxes to put doses in perspective is considered separately (Appendix 3). Use of natural elemental and isotope profiles and palaeohydrogeology to characterise host rock properties also not considered as analogues.

Applications include:
- natural bentonite analogue to argue for slow rates of illitisation
- slow bentonite alteration at temperatures up to 130°C
- retention of bentonite swelling / plasticity even after alteration
- low permeability and sorption properties of bentonite
- low corrosion rates of glass, copper and steel
- validation of codes and databases, particularly with regard to long timescales
A recent integrated SA from SKB (deep disposal of SF in a crystalline host rock)

Summary report (TR-06-09) contains 12 mentions of natural analogues in 620 pages.

Definition: rather limited

Natural analogues: A natural system studied in order to make it possible to investigate processes that have proceeded for a much longer time than can normally be followed by experiments in the laboratory or in the field.

Most mentions (5) in a single short section (13.3.7) explaining use of analogues and giving examples of:

- support of Cu corrosion rates
- natural bentonite as a buffer analogue
## Abuses of analogues

<table>
<thead>
<tr>
<th>Claim</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{129}$I at Alligator Rivers is relevant to geological disposal</td>
<td>Irrelevant source term, chemistry and concentration range</td>
</tr>
<tr>
<td>Bitumen at Oklo shows that this material could isolate SF</td>
<td>Irrelevant material (graphite), inappropriate conditions</td>
</tr>
<tr>
<td>U migration at Alligator Rivers can be used to test sorption models</td>
<td>Irrelevant source term and conditions, precipitation ignored</td>
</tr>
<tr>
<td>“In situ Kd” derived by interpretation of natural series isotope ratios</td>
<td>Irrelevant chemistry, poor scientific techniques, bad modelling</td>
</tr>
<tr>
<td>Chemical thermodynamic predictions of solubilities validated</td>
<td>Undefined source terms, inappropriate conditions, predicted speciation wrong</td>
</tr>
<tr>
<td>Oklo data support calculated criticality risks for Yucca Mountain</td>
<td>Incorrect interpretation of Oklo data, inappropriate conditions, unjustified extrapolation</td>
</tr>
</tbody>
</table>
Future trends – safety case

The requirements for preparation and presentation of safety cases are becoming more rigorous:

- NA will be expected to play a bigger role in technical support of the assessment - in particular supporting key models
- NA will also be needed to aid communication to a wide range of stakeholders

IAEA: Safety Standards for Geological Disposal
“The safety case is an integration of arguments and evidence that describe, quantify and substantiate the safety, and the level of confidence in the safety, of the geological disposal facility.”
Future trends - focus on project-specific concerns

NA evidence for geo-/hydro- stability in the coastal environment – JAEA, Posiva, SKB, NDA – focus of the Sea of Japan project at Horonobe (Amano-san)
Examples

- TD-KUPP – Potential impact of cementitious grouts on a SF repository (SKB) – Russell

- CCR – Complementary Considerations Report (Posiva) – Heini

- CNAP – Cyprus Natural Analogue Project (NDA-RWMD, Posiva, SKB) – Russell

- Stakeholder communication – Dave

- NA of ‘real’ materials (NWMO) – Russell
Summary

- NA studies fell out of favour for a time, probably because they failed to deliver.

- In part, this was due to naiveté on the part of the NA community and SA modellers.

- Having big, flashy, projects in beautiful and exotic locations did not help either!

- NAWG helped by issuing timely and critical overviews and reviews – tried to keep people realistic and on the ground ("NA should lead SA")
Now much more realism about what NA studies can achieve

This is reflected in projects such as KUPP, CNAP and CCR – even if they are fundamentally different

The swing to more CCR type input is also encouraging as there are still too many bottom-up projects, driven by science, not SA or safety case (because science is sexy) – need to think about this over the next couple of days at the NAWG-13 workshop

Regulator has a definite role here – cf. KUPP, CRR and Real Materials
References


- **Stakeholder communication:**


Perception of analogy

Experts

Cigar Lake uranium ore deposit
(Saskatchewan, Canada)

Spent fuel repository
(Canada)

Public

Glacial deposits
•*Host rock* (sandstone)
•Quartz-rich cap
•Altered host rock
•Clay-rich halo

U ore
•Metamorphic basement

Glacial deposits
•Host rock (granite)
•Backfill
•Clay-rich buffer
•Container
•UO2 fuel

500 – 1000 metres

450 metres