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)**
- **Led to first meeting - *Natural analogues to the conditions around a final repository for high-level radioactive waste. Lake Geneva, Wisconsin, U.S.A., 1–3 October 1984. N.A. Chapman & J.A.T. Smellie (eds). Chem. Geol. 55, 167-388 (1986)* – which led to NAWG (Neil Chapman and Bernard Côme)**
- **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 secretairiate (Bernard) and a chairman (Neil)**

NAWG – the workshops

- **1st NAWG Workshop: Brussels, Belgium, 1985, where the theme was the interaction between modellers and NA experimenters (EUR 10315)**
- **2nd workshop: Interlaken, Switzerland, 1986, where anthropogenic analogues and the role of colloids, complexes and microbes have been reviewed (EUR 10671)**
- **3rd Workshop: Snowbird, USA, 1988, where the application of natural analogues to repository performance assessment was discussed (EUR 11725)**
- **4th 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)**
- **5th Workshop: Toledo, Spain, 1992, was held in association with the final workshop of the Alligator Rivers Analogues Project (EUR 15176)**
- **6th 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)**
- **7th 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)**
- **8th Workshop: Strasbourg, France, 1999, was devoted to a presentation of three, major international natural analogue projects, Oklo (II), Palmottu and Pena Blanca (EUR 19118)**
- **9th Workshop: Aarau, Switzerland, 2002, where the theme was the current international status of natural analogues**
- **10th 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**
- **11th Workshop: Liverpool, UK, 2009, where a short meeting was held at the 12th ICEM (International Conference on Environmental Remediation)**
- **12th Workshop: Larnaca, Cyprus, 2011, where bentonite reaction, cement degradation and PR were themes**

NAWG – 13th Workshop

- **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 repraisel 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

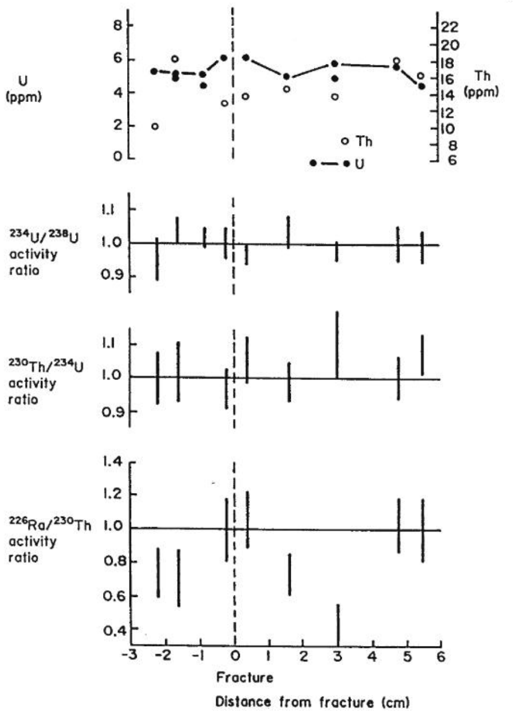
- Simple studies
  - Single processes
  - Single materials
- Multi-process studies
  - Oman
- Total system geological analogues
  - Oklo
  - Cigar Lake
  - Poços de Caldas
  - Maqarin
- Support of the wider Safety Case
  - CCR
  - CNAP
  - Real Materials

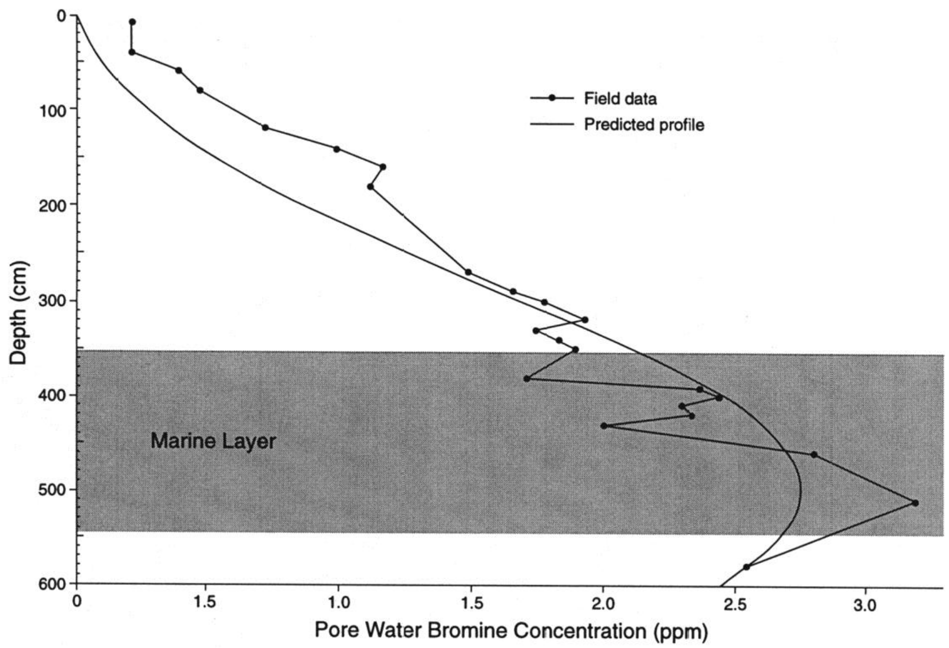
Simple studies – single processes

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

Matrix diffusion depths in granite (Grimsel)

Diffusion rates through clay (Loch Lomond)

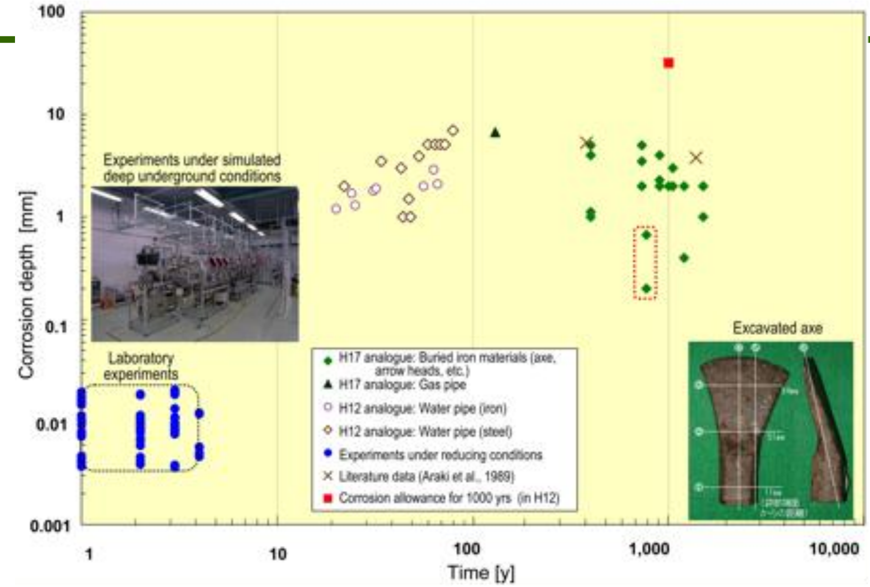




Simple studies – single materials

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



Inchtuthil nail

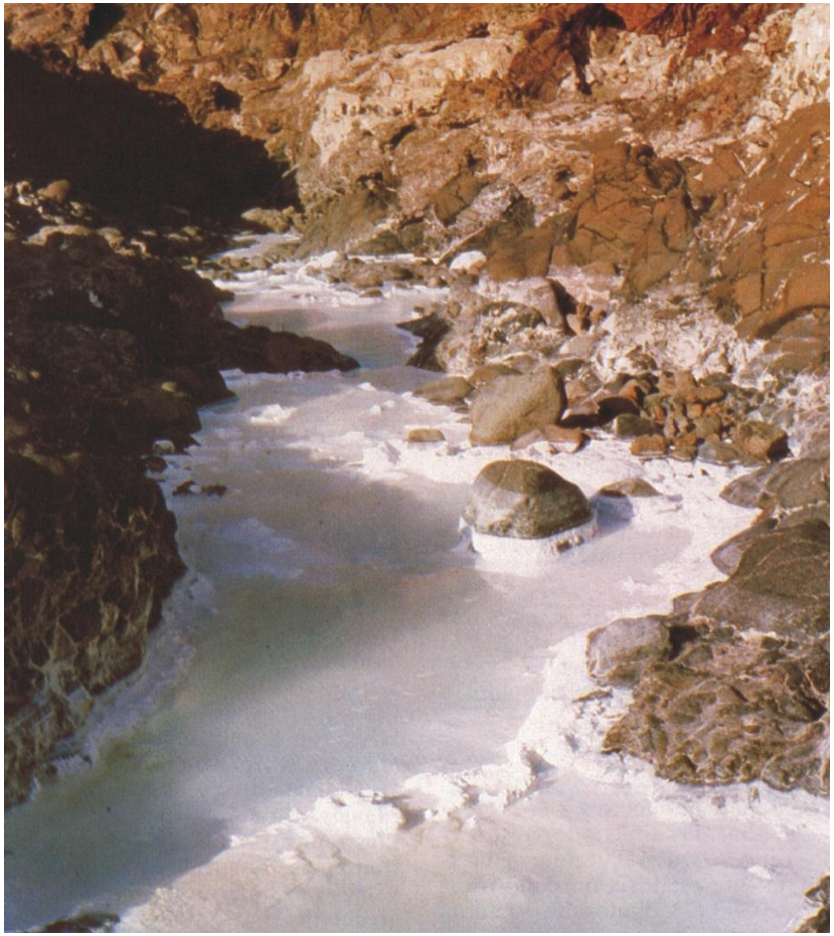
Kronan Bronze cannon

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



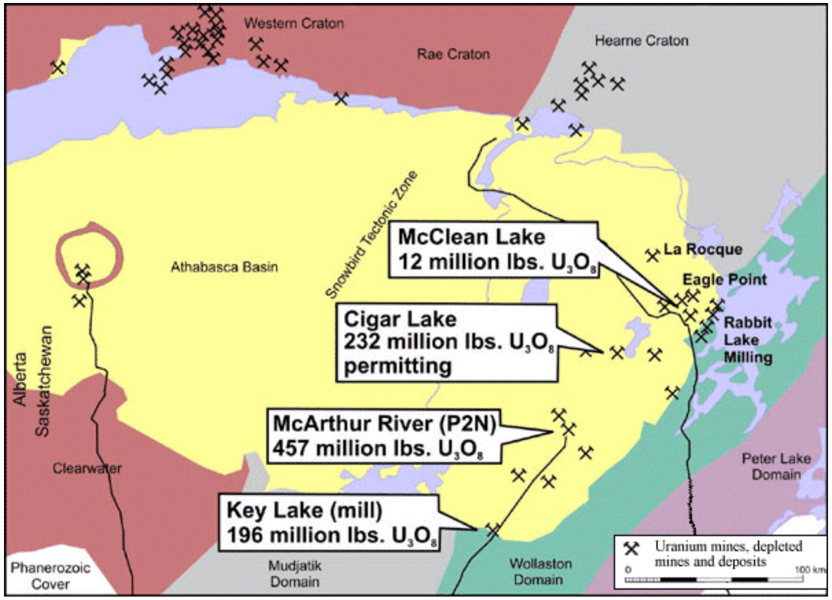
Total system geological analogues - Cigar Lake

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

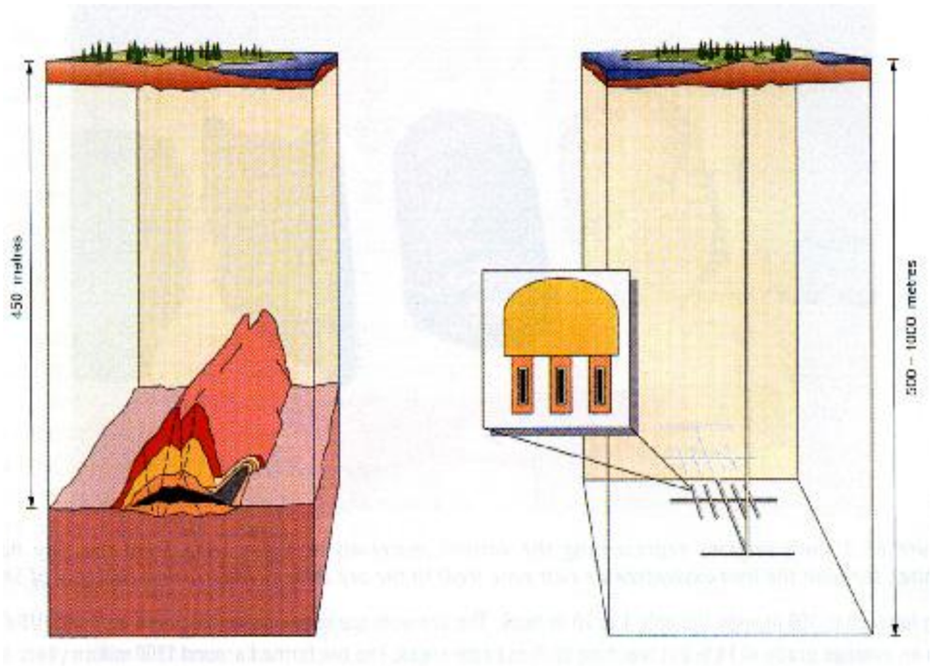
The protective role of the surrounding clay-rich layer appears to function despite the presence of microbes, dissolved organics and colloids in pore waters



Athabasca Basin
courtesy of JNR Resources Inc.

Cigar Lake - Conclusions

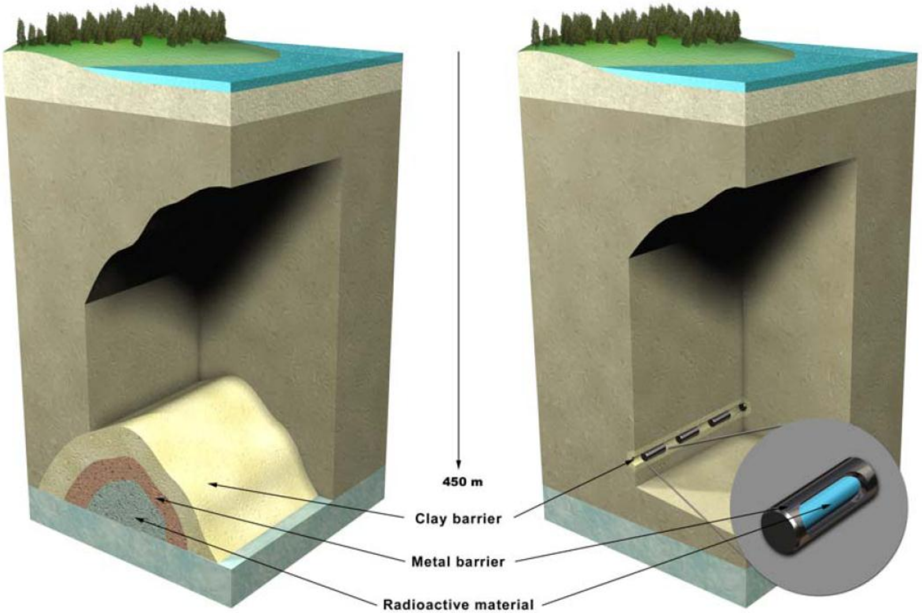
- Geological disposal is fundamentally feasible - in a suitably stable setting
- Clay-rich materials may contribute to preservation of U ore even in a rather permeable host rock
- Concentrations of specific elements in porewater generally compatible with predicted solubilities
- Fault movement will not 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

Safety Case	Conceptual model development	Data provision	Model validation
KBS-3 (Sweden, 1983)	Radiolytic oxidation of spent fuel against observations from Oklo	Maximum pitting corrosion factor for Cu Bentonite stability at T<100^{oC}	
Projekt Gewähr (Switzerland, 1985)	Stability of borosilicate glasses Stability and instability of concretes and mortars Stability of bitumen Radionuclide release concepts against Oklo observations	Long-term steel corrosion rates Constrain illitisation of bentonite	
SKB-91 (Sweden, 1991)	Support of bentonite stability from observations at Gotland Redox front model supported by Poços de Caldas observations Inclusion of matrix diffusion	Limit relevance of colloid transport by using data from Poços de Caldas Demonstrate conservatism in estimating radiolytic oxidation by using information from Cigar Lake	Radionuclide solubility model testing and comparison with observed solubilities at Poços de Caldas and Cigar Lake
TVO (Finland, 1991)	Use of palaeohydro-geological data in the development of Ice-age scenarios Observations from Cu-deposits and Kronan canon to support corrosion estimates Use of colloidal and microbial information from Poços de Caldas and Palmottu to develop models	Matrix diffusion profiles surveyed from various natural analogues	Testing of UO_2 spent fuel dissolution models using information from Cigar Lake

Actual use of analogues

Safety Case	Conceptual model development	Data provision	Model validation
Kristallin-I (Switzerland, 1993)	Back-up in scenario development	Bounding conditions on redox front development using information from Poços de Caldas Depths of matrix diffusion penetration	Radionuclide solubility model testing and comparison with observed solubilities at Poços de Caldas, Oman and Maqarin Testing models for redox front development
PNC 1st Progress Report (Japan, 1993)		Bounding values for metal corrosion (archaeological analogues) and bentonite longevity)	
AECL EIS (Canada, 1994)	Support development of conceptual models for fuel dissolution, Cu corrosion, clay buffer behaviour and radionuclide retardation, particularly the role of colloids and organics	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)	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
NRC IPA (USA, 1995)	Disruptive scenario development (volcanism) Back-up source term conceptual model from Peña Blanca Relative importance of meso-microfracture and matrix transport at Peña Blanca Back-up for vapour phase transport from Valles Caldera Back-up conceptual model for transport in fractures	Identification of secondary phases for long-term release at Peña Blanca	Model testing for elemental transport in unsaturated media at Akrotiri

Actual use of analogues

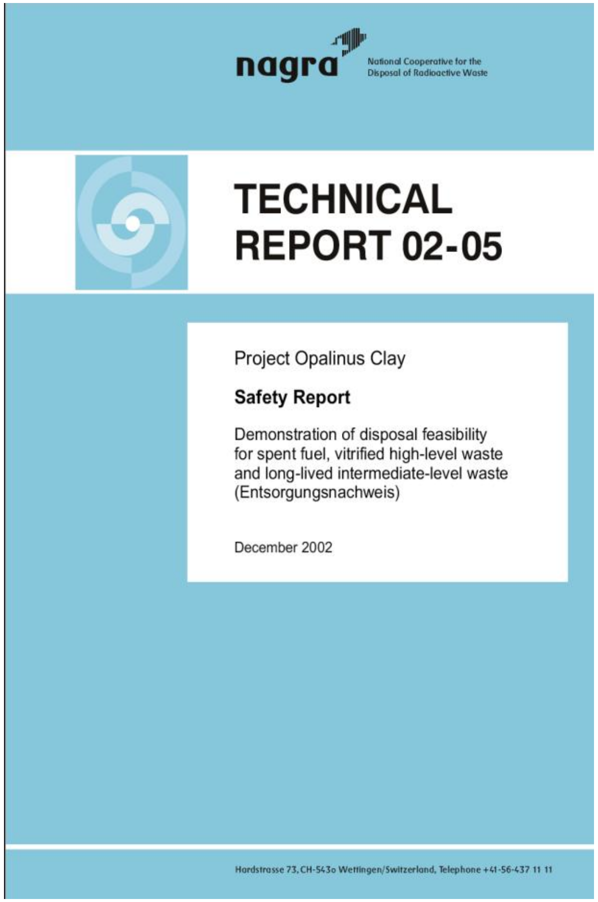
Safety Case	Conceptual model development	Data provision	Model validation
TILA-99 (Finland, 1999)		Support for conservatism in assumptions regarding spent fuel dissolution rate using observations from Cigar Lake; occurrence of matrix diffusion; and canister life time with reference to the Hyrkkölä native copper occurrence	
SR-97 (Sweden, 1999)	Use of permafrost data in development of Ice-age scenarios Use of post-glacial tectonic data in development of Ice-age scenarios	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	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)
SFR (Sweden, 1999)	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	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	'Blind Modelling': (Sweden, 1999) Testing of thermodynamic databases at Oman and Maqarin

Actual use of analogues

Safety Case	Conceptual model development	Data provision	Model validation
1st TRU Progress Report (Japan, 2000)	Maqarin used for high pH plume concept development	Matrix diffusion depths (from H12 database)	Longevity of concrete with archaeological analogues
JNC 2nd Progress Report (Japan, 2000)	Range of archaeological analogues to support iron corrosion model / mechanisms Natural bentonite to support longevity assumptions	Matrix diffusion depths from Kamaishi natural series profiles Volcanic glass studies to support corrosion model	Analogue evidence to support solubility data

Entsorgungsnachweis

- 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


nagra
National Cooperative for the Disposal of Radioactive Waste

TECHNICAL REPORT 02-05

Project Opalinus Clay

Safety Report

Demonstration of disposal feasibility for spent fuel, vitrified high-level waste and long-lived intermediate-level waste (Entsorgungsnachweis)

December 2002

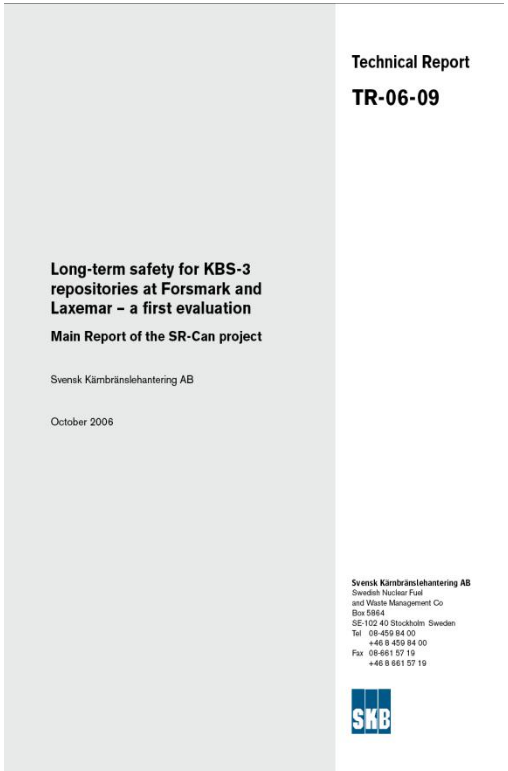
Hardstrasse 73, CH-5430 Wettingen/Switzerland, Telephone +41-56-437 11 11

SR-Can

- 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



Technical Report

TR-06-09

Long-term safety for KBS-3 repositories at Forsmark and Laxemar – a first evaluation

Main Report of the SR-Can project

Svensk Kärnbränslehantering AB

October 2006

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SKB

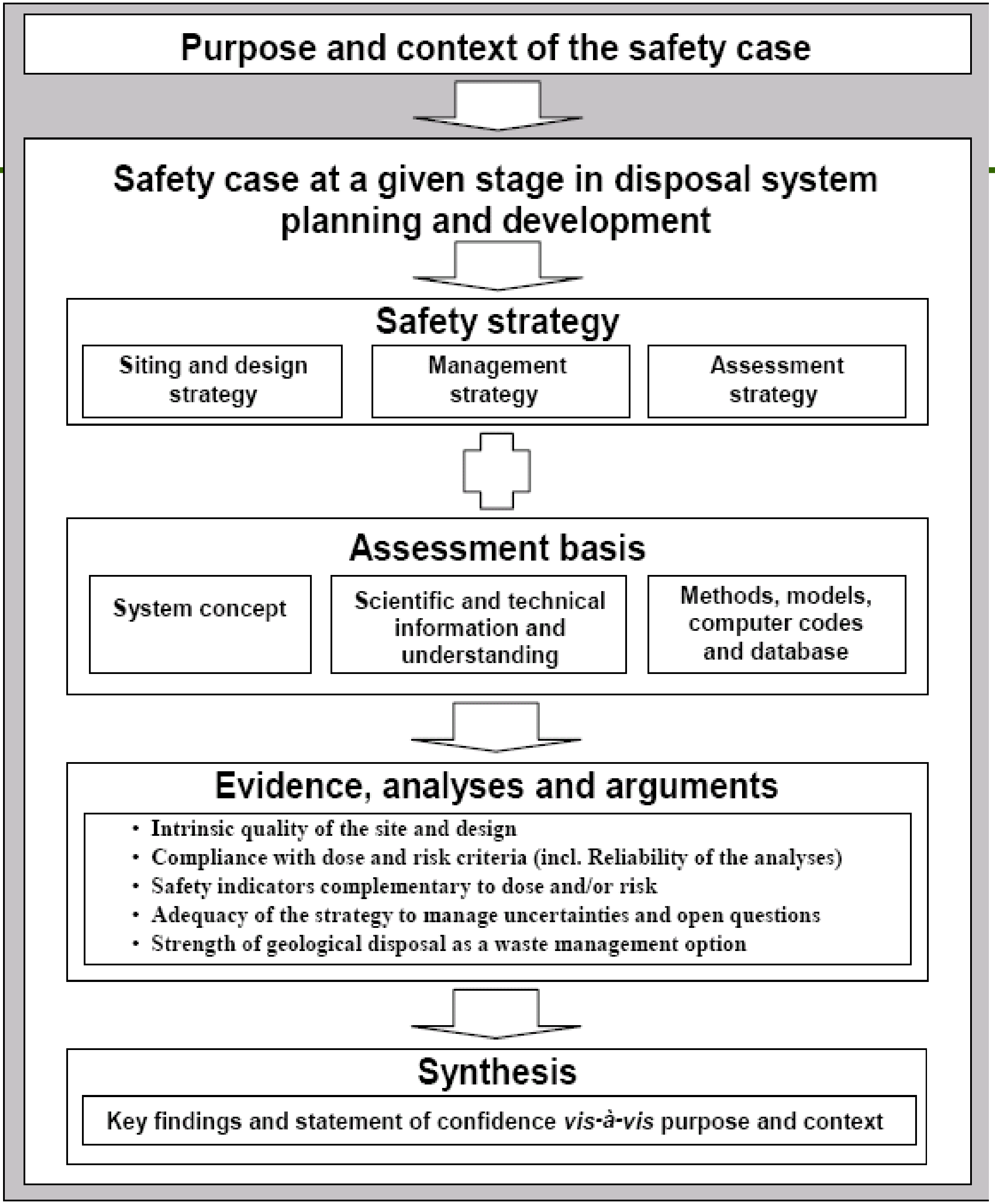
Abuses of analogues

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

Future trends – safety case

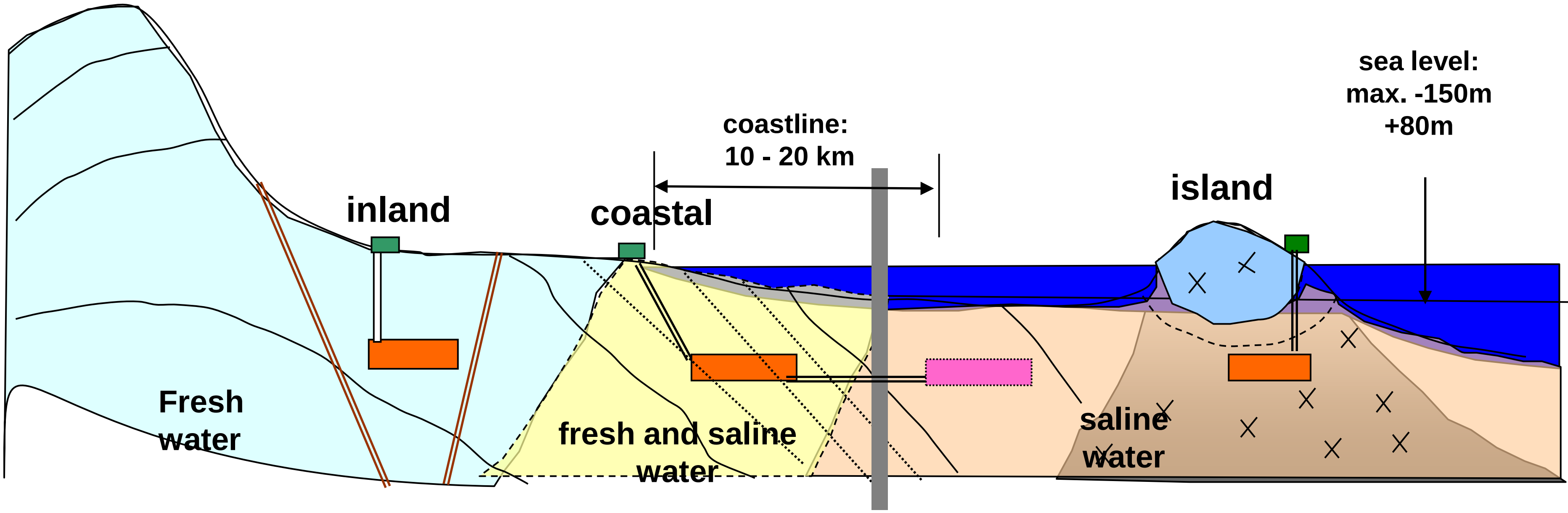
The requirements for preparation and presentation of safety cases are becoming more rigorous:

- 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 naïvity on the part of the NA community and SA modellers

- Having big, flashy, projects in beautiful and exocitic 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")

Summary

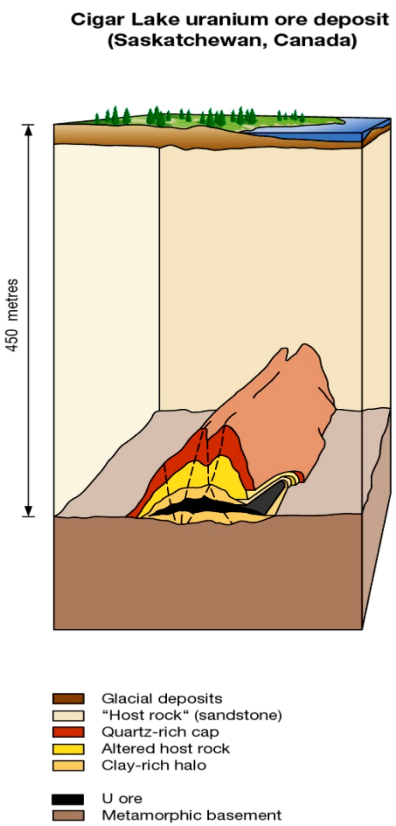
- Now much more realism about what NA studies can achieve
- This is reflected in projects such as KUPP, CNAP and CCR – even if they are fundamentally different
- The swing to more CCR type input is also encouraging as there are still too many bottom-up projects, driven by science, not SA or safety case (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

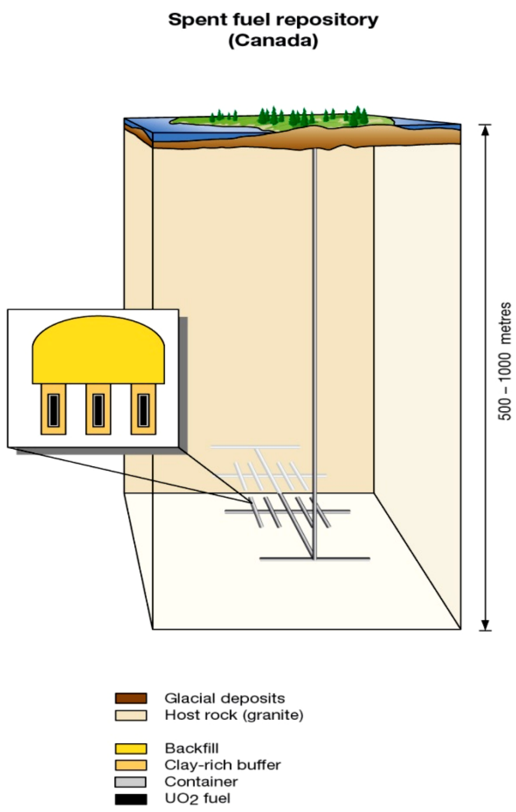
References

- **Overview:** W.R.Alexander, I.G.McKinley and H.Kawamura (2013). The process of defining an optimal natural analogue programme to support national disposal programmes. Proc. NEA-GRS Workshop on natural analogues for Safety Cases of repositories in rock salt. 4 – 6 September, 2012, Braunschweig, Germany. NEA/OECD, Paris, France (*in press*).
- **KUPP:** M.Sidborn, N.Marsic, J.Crawford, S.Joyce, L.Hartley,A.Idiart, L.M. de Vries, F.Maia, J.Molinero, U.Svensson, P.Vidstrand and W.R.Alexander (2013). Potential alkaline conditions for deposition holes of a repository in Forsmark as a consequence of OPC grouting. SKB R-12-17, SKB, Stockholm, Sweden.
- **CCR:** Posiva (2013). Safety Case-2012: Complementary Considerations. Posiva Report 2012-11, Posiva, Eurajoki, Finland.
- **CNAP:** W.R.Alexander, A.E.Milodowski and S.Norris (2013). The contribution of CNAP to the understanding of bentonite reaction with alkaline cement leachates. Swiss Journal of Geosciences (*in prep*).
- **Stakeholder communication**:
- **Real materials:** W.R.Alexander (2013). An assessment of the long-term durability of proposed shaft seal materials under highly saline groundwater conditions using natural analogues. Bedrock Geosciences Technical Report BG13-04 for NWMO, Toronto, Canada *(in press).*
- **NAWG-13 workshop:** W.R.Alexander and H.Yoshida *(eds)* (2013). Natural analogues today. Swiss Journal of Geosciences (*in prep*).

Perception of analogy

Experts





Public