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NUCLEAR ENERGY AGENCY
RADIOACTIVE WASTE MANAGEMENT COMMITTEE

Forum on Stakeholder Confidence (FSC)

**Link Between Research, Development and Demonstration (RD&D) and Stakeholder Confidence:
Use of Analogues for Confidence Building**

Proceedings of a Topical Session

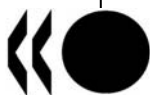
4-6 June 2008, Issy-les-Moulineaux, France.

As part of its programme of work, the OECD/NEA Forum on Stakeholder Confidence continues to investigate the theme of "Link Between RD&D and Stakeholder Confidence". A topical session was held on 4 June 2008 on the use of analogues to help understand and to build confidence in radioactive waste management approaches and safety cases. Case studies were presented from Finland, Spain and Switzerland and from joint international endeavours (EC projects NANET and PAMINA). Input was also received from the Integration Group for the Safety Case (IGSC). These presentations gave a panorama of how natural analogues have been used by technologists, implementers and regulators, in examining the safety case and in communicating with the public about safety. The summary overview offers definitions and recommendations as well as some novel perspectives in this area.

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FOREWORD

As part of its programme of work the OECD/NEA Forum on Stakeholder Confidence continues to investigate the theme of “Link Between RD&D and Stakeholder Confidence”.

Regulators need a technical demonstration to aid in evaluating the safety case. Local stakeholders appreciate the opportunity to visualise technological arrangements. In both cases, demonstration adds to confidence in the feasibility of solutions. Some believe that, if handled with integrity, there is an important role for analogues in both the technical safety case and in communication with stakeholders.

A topical session was held on June 4, 2008 on the use of analogues to help understand and to build confidence in radioactive waste management approaches and safety cases. Case studies were presented from Finland, Spain and Switzerland and from joint international endeavours (EC projects NANET and PAMINA). The results of a questionnaire filled by FSC members in co-ordination with their IGSC colleagues served as the basis of the introductory presentation.

The Chair of the Topical Session, Mitsuo Takeuchi of Japan’s NUMO, told the FSC: “Analogy is a manner very often used in explaining complex things to lay people in a much more understandable way. The expectation behind the use of analogy is to give greater comprehensibility and approachability to repository safety in communication with stakeholders. Implementers want to use analogy, for example, to explain long-term behavior of repository components in order to provide greater confidence in its safety assessment, responding to the regulator’s demands of increasingly more credibility in the safety concept of the repository. It goes without saying that the reference to analogy should be based on sound science. However, when using natural and anthropogenic analogues in communication, we have to carefully consider issues of adaption and then avoid misuse. There is agreement that analogues cannot meet all communication needs.”

This topical session benefitted from input from the Integration Group for the Safety Case (IGSC). Bernard Faucher, of France’s Andra, acted as rapporteur, and summarised the topical session, with input by the NEA Secretariat and review by the members of the FSC. The present, final summary offers definitions and recommendations as well as some novel perspectives in this area.

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**FSC THEME: THE LINK BETWEEN RESEARCH, DEVELOPMENT & DEMONSTRATION
(RD&D) AND STAKEHOLDER CONFIDENCE**

TOPICAL SESSION ON THE USE OF ANALOGUES FOR CONFIDENCE BUILDING

SUMMARY OF PRESENTATIONS AND DISCUSSIONS

Background

In December 2007, the Forum on Stakeholder Confidence discussed its theme entitled “Link between research, development & demonstration (RD&D) and stakeholder confidence”. It was remarked that regulators need a technical demonstration to aid in evaluating the safety case. Local stakeholders appreciate the opportunity to visualise technological arrangements. In both cases, demonstration adds to confidence in the feasibility of solutions. Some believe there is an important role for analogues in communication with stakeholders, if handled with integrity. To explore and benchmark current practices, it was decided to hold a topical session at the 9th regular meeting of the FSC on 4 June 2008 regarding the use of analogues for confidence building.

The session opened with an introductory presentation by the session rapporteur. This incorporated input provided for the purpose by FSC members in cooperation with their country’s representative to the NEA RWMC “Integration Group on the Safety Case”. Three speakers then presented the various uses of analogues by implementers, regulators and scientists to build their own confidence; a fourth speaker dealt with the experience of using natural analogues in public information. The presentations addressed the use of analogues in the field of geological disposal of high-level waste (HLW) and long-lived intermediate level (ILW-LL) radioactive waste. Then the FSC participants split into two working groups for discussion. The outcome of these discussions was reported in plenary on 6 June 2008 and it was agreed to publish proceedings of the session.

The present summary, prepared by the session rapporteur with input from the NEA Secretariat, captures the main points heard in the course of the event. It combines data from the formal presentations and remarks made in discussion. The latter represent viewpoints expressed by a group whose primary focus is not natural analogues but rather stakeholder interests. The summary and viewpoints do not represent an official position of the FSC, but a simple benchmark of current reflection that a wide range of stakeholders may use.

Introduction

To begin with, it is important to understand what is meant by natural or anthropogenic (archaeological and contemporaneous) analogues in the specific framework of radioactive waste geological disposal. The following understanding is typical:

- Natural analogues refer to natural materials or situations whose evolution was not influenced by human intervention.

- Anthropogenic (archaeological or contemporaneous¹) analogues refer to engineered materials, whose evolution was influenced by human actions, engineered conditions and natural environments.

For both the cases above, however, there exist various degrees of similarity to possible situations within a geological repository for radioactive waste or its environment. **According to the degree of similarity to the repository and its environment, the situation or example in question may be considered to be an analogue, an analogy or an anecdote. The FSC used the following definitions to frame its observations:**

When a fairly direct similarity to repository situations exists, the case may be used as an argument to support a phenomenological theory and its modelling: it is an **analogue**. As the degree of similarity decreases (e.g. if relevant chemical or physical conditions do not apply with those of the repository and the consequences of these deviations cannot be quantified; if system boundaries cannot be defined), the case applies more narrowly to the generic feasibility of medium- to long-term safety of geological disposal. When the degree of similarity is quite low, the case may provide a “common sense” rationale supporting the concept of geological disposal as an option that should not be ruled out and could be a relevant solution, providing that adequate research and demonstration are performed to confirm this hypothesis. In the latter cases, the situation is considered an **analogy** or even only an **anecdote**.

The following examples illustrate the FSC definitions of analogue and analogy/anecdote:

- The case of Roman nails found in Scotland can be presented as
 1. An **analogue** for the analysis of corrosion resistance, were it decided to use steels that are viewed to be as corrosion-resistant or more corrosion-resistant than the metal of which the nails were made. Indeed, the evidence of their longevity would contribute to modelling confirmation, despite the related uncertainties.
 2. An **analogy** to illustrate the confinement properties of natural clay over a long time period, as well as their ability to reduce corrosion. We cannot go beyond analogy here because the initial number of nails buried is unknown (we cannot state how many nails corroded away).
 3. An **anecdote**, simply to show that man-made artefacts can last thousands of years underground, if it was used by a programme that is not contemplating the use of steel for containers or clays as a barrier.
- The discovery in a clay formation of a fossilised animal that can be determined to be an herbivore from food remains that were preserved in its stomach over millennia, is an **anecdote**. It illustrates the fact that clay has long-term confinement properties, but as we do not plan to dispose of material similar to vegetarian animals, the degree of similarity is low. Nevertheless, because of the peculiarity of such an example, and because inert materials are much more durable than organic tissue, the anecdote could be used to illustrate the long-term confinement concept.
- With regard to earthquakes, it is possible to compare earthquake damage in a mine with possible damage in a geological repository when affected by a similar event. As such, it is very valuable input for e.g., the design of underground structures and their supports. This situation, which corresponds to a high degree with the modelling and engineering applications expected in a geological repository, serves as a **contemporary analogue**. On the other hand, historical records of earthquakes over a few millennia should not be designated as an analogue. Instead, they would

1. Archeological analogues are those on the order of a few thousand years old, whereas contemporaneous (or contemporary) analogues are those drawn from a period ranging from a few centuries ago until today.

be labelled simply as important data relevant to assessing geological stability and possibly of use for bounding analyses, i.e., for setting limits on uplift or fracturing.

This report focuses mainly on the use of analogues as a line of evidence and as an instrument for confidence-building in safety assessors, evaluators and members of the public.

Analogues: Why, for whom, which ones and how?

Why use analogues?

Timescales relevant to long-term safety of geological disposal (on the order of several centuries, millennia and sometimes more) cannot be attained in experiments. Analogues can provide qualitative or quantitative data in order to illustrate long-term behaviour or conditions and to validate assessment models. They can also provide references and examples, and confirm phenomenological forecasts over long timescales.

Referring to the foregoing definitions, we shall distinguish between natural and anthropogenic analogues. Natural analogues---related to natural materials or situations whose evolution was governed by natural phenomena--- involve very long timescales on the order of geological ones. The conditions of evolution, including the initial state, may not be well known, and we can expect to gain principally qualitative information.

On the other hand, anthropogenic analogues---which involve engineered materials, the evolution of which was governed by both the engineered and natural environments and human intervention---involve smaller timescales, a few thousand years at the most. Such materials are better studied and understood (typically, the more recent the analogue, the better known are the materials and evolution conditions) and are usually more similar to the engineered materials being considered in current repository studies. Therefore, they may very often provide quantitative data. In short, the smaller and more recent the analogue timescale, the more precise and quantitative is likely to be the information it provides.

Apart from the limitations already mentioned---that initial and evolution conditions cannot be always well known and that the materials used may be different from the ones to be considered in a repository---it must also be acknowledged that analogues will never reproduce exactly the possible repository situations such as the coupling of radioactivity, pressure and temperature. Therefore, they can contribute to safety cases as a *line of evidence* in the best case but cannot be relied on as the **sole** line of evidence. For instance, they can provide confirmation, with some associated uncertainty, of particular aspects in broader modelling or can aid in identifying the presence of specific phenomena such as chemical reactions, etc. Overall, it is recognised among the technical community that analogues can not be used as a sole and unique demonstration, but need to stand as one of multiple lines of evidence.

As the degree of similarity with possible repository situations diminishes, examples become analogies or anecdotes and their arguments are more useful in terms of supporting generic and conceptual feasibility of geological disposal.

Analogues for whom? And which ones? How?

We must distinguish between two audiences or stakeholder groups which may be targeted:

- Safety assessors and regulators, who comprise a scientific and technical community;
- Political decision makers;
- The public at large.

While geological disposal is found to be generically feasible and safe by the first group, a less confident attitude on this aspect is to be expected from some members of the two latter groups.

Analogues as line of evidence and confidence-building for safety assessors and regulators

Analogues are considered by safety assessors to be a useful tool, one of multiple lines of evidence used in the safety case to confirm phenomenology and modelling. Analogies and anecdotes are not as important for this scientific and technical community as they present no direct relationship with the phenomena and materials involved in the safety case under review.

Nevertheless, different regulators (whose role is to evaluate the safety assessment) place varying emphasis and value on the use of analogues in terms of confidence-building arguments. Some do not mention them specifically in their basic safety guidelines, whereas others recommend their use and in some cases make their use mandatory when they correspond to possible situations of the repository. For instance:

- In the USA, natural analogues are recommended by U.S. Nuclear Regulatory Commission (NRC) for the Yucca Mountain safety case and identified as **potential elements** of supporting information for models assessing repository performance.
- In Switzerland, analogues are used as general supporting arguments in the safety case and independent evidence for the plausibility of certain modelling results and the underlying parameters. As such, the Swiss regulator makes their use **mandatory** in the safety case.

Some quite extensive studies, such as the Nanet cooperative project of the EC or the compilation coordinated by the Spanish regulator (CSN) with universities (each of which was presented at the topical session), have inventoried and referenced analogues along with their relationship with the various conditions and situations possible in geological repositories. As such databases are an important resource notably for organisations just initiating safety cases or when use of analogues is recommended by regulators, it would be wise to continue such efforts. Nevertheless, it is not realistic to expect a fully exhaustive match between a set of analogues and all repository situations.

The case of so-called “negative analogues,” meaning analogues describing, for instance, a higher corrosion rate than forecast, must be thoroughly investigated and explained. If left unaddressed, a “negative” analogue becomes a counter-example and will challenge the proposed phenomenological theory and its modelling. Thorough investigations must examine whether (and how) such a case is consistent (or not) with the proposed phenomenology and its modelling, and the causes of the supposed initial discrepancy should be highlighted. In fact, “negative” analogues can provide useful information about situations which must be avoided in a repository or can provide a basis to define degraded evolution scenarios, if it is possible for such situations to occur. Therefore, analogues initially considered “negative” can become “positive” analogues and provide an added value to the safety case.

Finally, the dialogue between the implementer and the evaluator is a scientific and technical one, where a comparable degree of specialisation is found on both sides. In this context, there is more likely to be a common understanding of the uses and limitations of analogues. Indeed, there is agreement in this community that an analogue can never be a fully sufficient demonstration; it is only one of multiple lines of evidence.

Analogues as line of evidence and confidence-building for the general public

Although analogues are often described as important confidence-building arguments for the public, most FSC members were not so affirmative in their assessment of this claim. Some typical quotes from the written input by FSC members demonstrate scepticism:

- It is stated that “for **technical specialists, analogues are used**” but the statement is not so affirmative related to the public: “towards **the general public analogues can be used**
- “We proactively use materials found in Japan to provide our **readers** a sense of familiarity. However, since their effectiveness measurement hasn’t been carried out, we haven’t figured out how much they’ve been helpful for confidence building.”
- On one hand, “their main role for **technical specialists is seen** in their support
- ”, but on the other hand, “their major role for the **general public is probably to raise interest and increase** understanding of processes by illustration and showing familiarity to many people”.

Nevertheless, most FSC members have the feeling that analogies and anecdotes could help the public to grasp timescale and understand the basic rationale and principles of geological disposal. They represent concrete examples of important functions such as long-term confinement properties to illustrate potential repository situations which might otherwise be seen as “pure theory”.

The careful statement about the “possible” efficiency of analogues in public confidence-building may originate from the lack of demonstrated evidence of this effect. The presentation of analogues and analogies must be adapted to the audience, using understandable language, and their limitations should be clearly stated. The effort and scale of projects related to the use of analogues for scientific assessors has not generally been balanced by corresponding surveys on the use of analogues aimed at the general public---with the exception of the cooperative project “Traces of the future,” funded by the European Commission. Given that public confidence is the Achilles’ heel of geological disposal projects (and especially of siting decisions) and that it is assumed that analogues do contribute to such confidence-building, it could be worthwhile to develop this line of investigation.

Some FSC members suggested that the use of *national* analogues (i.e. drawn from situations within the host country) may be more effective for the general public than extra-national ones, notably when concerning anthropogenic analogues. Given that analogues are concrete representations of possible repository situations, it seems plausible that the public may be more likely to find a national analogue persuasive and comprehensible, since it is geographically and culturally closer to their own experience and likely to be very concrete, especially in the case of anthropogenic analogues. The familiarity with the case facilitates understanding and may itself provide some reassurance to the public. However, other FSC members suggest that stakeholders in some contexts display more confidence in findings and illustrations presented by international parties who are assumed to be more neutral. Neither position has been systematically demonstrated through societal surveys and each must be considered as hypothetical for the moment.

From the various member contributions it appears that the use of analogues as confidence-building arguments for the general public varies with time and with the stage of programme development and therefore depends on the decision making process and its phases. As the project focuses on progressively more specific sites and more defined concepts, an increasingly closer relationship with the repository situations, for instance in terms of geological formations, engineered materials, etc. becomes possible. Later, as the project is accepted in its principle by local public stakeholders, it seems that the need for analogues, analogies and anecdotes for stakeholder confidence dwindles. This latter statement still remains to be proven valid over the long term of a repository development, though, as it was based only on observations in Finland and France, in which geological repository projects are quite ahead of those in other countries but still in relatively early phases compared to the 100 or more years in which they are meant to be an active presence in the host community.

Possible developments that could be suggested include:

- Continue efforts to build analogues databases such as Nanet, notably for regulators and assessors, but as well in relation to the two following points.
- Use such database matrices to integrate the so-called “negative” analogues and investigate thoroughly the cause of perceived discrepancies to transform the case into an added-value (“positive”) analogue.
- Translate the scientific and technical analogues, as inventoried in various databases, into convincing arguments for the public at large, with specific consideration for national analogues.
- Measure the effectiveness of analogues and related arguments in terms of public confidence-building, in order to improve the tools and techniques of presentation.
- Looking beyond only analogues, investigate the evolution over time (i.e., through the development of a repository) of the type of confidence-building arguments needed for the general public. A first step would be to study whether any evolution has been observed with existing low- and intermediate-level, short-lived radioactive waste repository projects and, by extension, with other controversial industrial projects.

The application of contemporary analogues as input to the design and choice of materials with a view to reversible disposal was not discussed in the working groups, although this was mentioned in the introduction by the session rapporteur. Perhaps this is because analogues have been typically depicted to describe phenomena over timescales beyond hundreds of years. On the other hand, the relationship between repository situations over a few centuries and contemporary analogues, such as tunnels or mines, is very close. Given the relatively early phase of most disposal projects, these analogues might be useful for discussing the concept of reversibility with wider audiences as well as with technical stakeholders. For instance:

- the regulator may find this to be compelling evidence that reversibility is not achieved at the expense of safety;
- the public may be interested in demonstrations of reversibility in engineered system, which could be provided through analogues.

Finally and still in relationship with the project phases, it was reported from Finland and France that current public issues in these countries tend to be socioeconomic ones. The topic of socioeconomic analogues (probably very contemporary ones involving similar projects in terms of investment, running costs, construction, operating life, footprint, etc.), which was not in this session’s remit, could be a future theme of interest for the FSC.

PRESENTATIONS BY PARTICIPANTS

PRELIMINARY REVIEW OF THE VARIOUS CONTRIBUTIONS OF FSC MEMBERS

Bernard Faucher
Andra

NEA FSC June 2008 Meeting

Theme n°1: the link between research,
development & demonstration (RD&D)
and stakeholder confidence

Use of analogues for confidence building
Preliminary report June 4th 2008

Bernard Faucher Andra

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Reminder of the Andra presentation (December 2007) based on Dossier 2005:

- Natural and anthropogenic analogues are used as scientific tools, within the multiple lines of evidence, to confirm phenomenology and modelling; as such they are quite welcome and understood by the evaluators;
 - But why analogues were not used as a major confidence-building argument for public at large? **because they are not so “analogue” to the repository situations;**
 - This may evolve with the reversibility.
-

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Preliminary review of the various contributions by FSC members

Analogues as line of evidence and confidence-building for evaluators:

- Analogues are considered as an efficient tool, within the multiple lines of evidence, to confirm phenomenology and modelling and as such they are quite welcome by the evaluators;
- The dialogue between the implementer and the evaluator is a scientific one, with the comparable level of expertise. Limitations are well understood;
- Nevertheless, use of analogues is not *stricto sensu* a regulatory obligation.

Analogues as line of evidence and confidence-building for public at large:

The use of analogues as confidence-building arguments for the public at large is not so straight forward.

Typical quotes shows that FSC member are less affirmative in their statement:

- “for **technical specialists, analogues are used**” ;
- “towards **the general public analogues can be used**”;
- “their main role for **technical specialists is seen** ...”;
- “but their major role for the **general public is probably to**”.

Specific case of Finland and France.

Other comments:

- In some cases, only “national analogues” are considered;
- Potential drawbacks:
 - **The negative analogue:**
Possible case of misuse of “negative” analogues when, for instance, environmental conditions were not representative of repository ones;
 - **Overstating analogue significance:**
Too much simplification of the analogue case, in order to get it easy to grasp by the layman, may end up with overstating its significance.

Indicating the conditions and limitations of analogues is a must.

USE OF ANALOGUES TO BUILD TECHNOLOGISTS' CONFIDENCE: NANET

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Use of analogues to build technologists' confidence: NAnet

Ulrich Noseck

Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) mbH

9th Session of the FSC Issy-les-Moulineaux, France, June 4, 2008

Outline

- Definition of Analogue
- General information about NAnet
- Different roles of analogues in confidence building for technologists
- Examples of analogue studies for these different roles
- Conclusions

9th Session of the FSC Issy-les-Moulineaux, France, June 4, 2008



Definition

- From NANET: "An analogue is a natural, historical or anthropogenic system that permits a study of repository-related processes, including its surrounding environment and the processes that control its evolution"
- Definition has been extended
- Main reason for use of analogues:
 - cover temporal (and spatial) scales not accessible by lab / field studies
 - Industrial: < 150 a
 - Archaeological: >150 a, <10 000 a
 - Geological: > 10 000 a

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The relevance of analogues to radioactive waste management stems from the long timescales that have to be considered. Periods up to a million or more years into the future need to be considered and these are beyond experimental investigation and human experience.

Within the last years the term "Natural Analogue" has got a much wider meaning and includes man-made analogues as well.

The role of natural analogues in the safety case depends amongst others on the time scale to be covered. Therefore, it is useful to classify them by the time period addressed in the study. Here it is referred to

- industrial analogues, which started earliest 150 years ago and result from "disturbances" of the environment caused by input of constructions, materials, contaminants, etc. produced within the Industrial Age,
- archaeological analogues, which cover time frames between the past 10 000 and 150 years and result from man-made disturbance of the environment with the major difference that the materials do not stem from the industrial epoch, and
- geological analogues, which usually cover time frames of more than 10 000 years and in most cases more than million years. These analogues mostly result from natural changes in the geological environment, e.g. in temperature conditions, in geochemical and/or hydrogeological conditions.

NAnet: Background information

- “Network to review natural analogue studies and their applications to repository safety assessment and public communication”
 - 5th EURATOM Framework of the EC
 - Duration: 01. January 2003 – 31. December 2004

- Partners

- ENVIROS, UK (Coordinator)	- NRI, Czech Republic
- NIREX, UK	- CEA, France
- Conterra A.B., Sweden	- ONDRAF-NIRAS, Belgium
- GRS, Germany	- ENRESA, Spain
- GSF, Finland	- CSN, Spain

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The current interest in analogues in different countries is reflected by several recent review projects with emphasis on the application of natural analogue study results in performance assessment. The most recent international review was performed within the 5th EURATOM Framework of the EC by the NAnet project, a network on the review of natural analogue studies with emphasis on the application of analogues in long-term safety assessment and communication. The project ran from January 2003 to December 2004 and involved a network of European organisations, including both users and providers of natural analogue information. Although several reviews of analogues studies have been undertaken before, NAnet was the first international project to involve participants with expertise in undertaking analogue studies in the field; performing safety assessments and the application of assessment models and codes; regulatory and licensing issues; and public communication.

Details about the goals of this network and all results can be found in:

Miller, B.; Hooker, P.; Smellie, J.; Dalton, J.; Degnan, P.; Knight, L.; Noseck, U.; Ahonen, L.; Laciok, A.; Trotignon, L.; Wouters, L.; Hernán, P.; Vela, A.: NAnet Network to review natural analogue studies and their applications to repository safety assessment and public communication. Synthesis Report. EUR 21919, January 2006.

**NAnet: Goals**

- Critical reviews of a large number of analogue studies
 - not comprehensive but representative
 - no new studies
- Analysis, how far information from analogue studies have been used in performance assessments (PA) and for communication issues
- Compilation of quality-approved analogue information, relevant for typical European repository concepts
- Consideration of potential added value from these past studies that may be applied to future safety cases and stakeholder dialogue programs

9th Session of the FSC Issy-les-Moulineaux, France, June 4, 2008

The overall aim of the NAnet project was to review the past and present use and understanding of natural analogues, and to make recommendations for their future use. The specific goals are listed on the transparency.

The project covered ‘traditional’ natural analogue studies, such as large-scale investigations of radionuclide transport around uranium orebodies, and process or mechanistic analogue studies such as those examining natural glass and bentonite clay stability. To complete the picture, a restricted range of other studies of natural systems which employ a similar philosophy to analogues was also included in the scope. These included studies which have examined radionuclide transport and retardation processes occurring at the geosphere-biosphere interface and in the surface environment.

NAnet: Approach

- Development of a systematic review structure for NA-studies
 - short description, relevance (e.g. repository concept, process(es))
 - previous application in PA, use for communication
 - focusing on PA-relevant information
- Compilation of available studies and prioritisation
- “Classical analogues” and restricted range of other studies of natural systems considered (more than 70 studies evaluated)
- Development of a structure to easily identify relevant NA studies for PA- and communication experts
 - matrices for processes in different environments (near field and far field)

9th Session of the FSC Issy-les-Moulineaux, France, June 4, 2008

One of the primary outputs of the NAnet project has been the compilation of reviews of more than 70 individual analogue studies with relevance for the near-field, far field or biosphere.

Each analogue study review was documented using a standard review template that includes sections concerned with performance assessment relevance and applications, limitations of the analogue (e.g. dissimilar materials and environments compared to a repository etc), a summary of any particular quantitative information derived from the study, an assessment of the uncertainties associated with the qualitative and quantitative information, an indication of the time-scales covered by the analogue and reference to any applications in communication and links to the primary literature.

NAnet: Example of near field matrix



Near-field matrix		Waste form				Package		Buffer/backfill	
		Glass	Spent fuel	Cement	Bitumen	Copper	Steel	Bentonite	Concrete
Mechan. integrity of barriers	Mech. failure		Oklo (Helium pressure)	Roman cements		Archaeol.	Archaeol.	Orciatico	Hadrian's Wall
	Corrosion-chem. alter.	Iceland basalt	Cigar Lake	Hadrian's Wall	DeadSea bitumen	Kronan cannon	Inchtuthil nails	Caborde Gata	Hadrian's Wall
Nuclide release from barriers	Dissolution	Iceland basalt	Pena Blanca	Roman hot spas		Natural copper nuggets	Disko Island		Roman hot spas
	Leaching	Uranium glass studies	U ore bodies	Maqarin	Lower Saxony bitumens				Roman hot spas
Nuclide migration in barriers	Advection			Roman hot spas				Gotland bentonite	Roman hot spas
	Diffusion			Roman hot spas				Gotland bentonite	Roman hot spas
	Two-phase flow								
Nuclide retardation in barriers	Chemical	Iceland basalt		Roman hot spas			Sorption on oxy-hydroxide	Cigar Lake clay layers	Roman hot spas

One general feeling in NAnet project was that natural analogues have not been used to their full potential. The reason for this may be that, because of the large extent of analogue information that exists in technical reports, papers and other publications, for users it is hard to find information that meets their needs from the large body of.

Therefore, a simple referencing system was developed that enables safety assessors and communication specialists rapidly to find all those analogues that relate to their specific issues and interests.

The referencing system that was devised is based on a simple matrix that has on one axis the range of materials and on the other axis the range of processes that can occur in the repository system. Intersections of the axes identify unique material-process combinations and analogue studies can be listed at the appropriate intersections.

Two generic analogue matrices have been developed, one for the near-field and one for the far-field. Exemplarily the matrix for the near field is shown.

Analogue studies complementary to lab / field experiments

Aspect	Analogue studies	Lab and field experiments
Time frame	Very long periods (tens - billion years)	Short-term (weeks - few years)
Boundary conditions	Often poorly defined	Well-defined, set by researcher
Materials	Only approximate repository materials	Materials actually used in repository design
Systems	Complex, involve coupled processes, → realistic but hard to model	Simpler, facilitate modelling → may be unrealistic
Conditions	Natural conditions, partly slow reaction rates	Reactions often accelerated by raising temperature or use of aggressive reagents

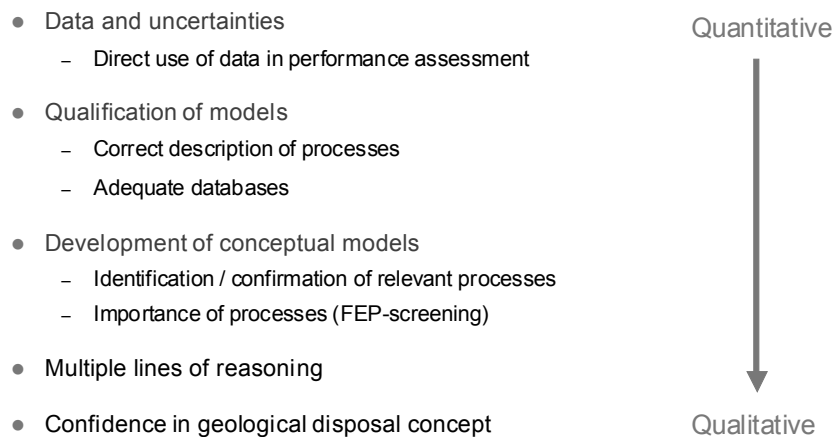
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Although analogues are important for providing realism, it is important to recognise that they do not have a unique role in this regard and should be seen as complementary to other forms of investigations such as field and laboratory experiments. Combining analogue studies with field and laboratory investigations provides a powerful means of investigating the natural processes which will occur in the repository environment because the disadvantages of one method are balanced by the advantages of the other.

As a result, natural analogues should not be viewed in isolation and their key role is to be complementary to other confidence and knowledge building methods such as laboratory studies and modelling exercises. This is one of the main messages from the NANet project: that natural analogue studies should be fully integrated into the mainstream scientific and engineering developmental work in a repository programme, rather than being treated as a separate discipline.

Different roles of analogues

GRS



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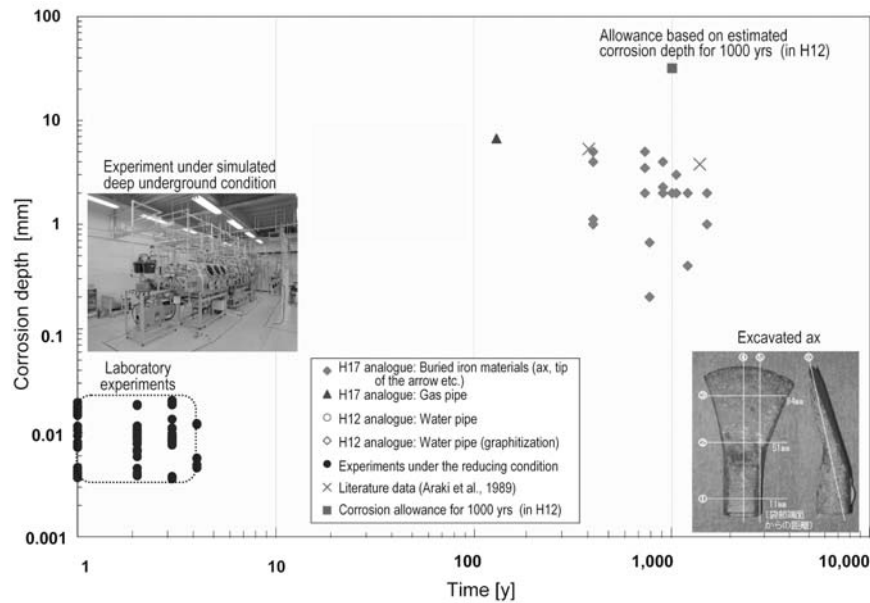
There are different roles analogues can be used for in the safety case. For building technologist's confidence, three roles might be most important.

Data and uncertainties: Approaches to use data, yielded from analogue studies, directly in PA, were only to some extent successful because it proved difficult to extract hard numerical data from complex natural systems where initial and boundary conditions are usually afflicted by a high degree of uncertainty. Nevertheless, there are several examples, where analogue data have been used as upper limits or to confirm results from lab experiments showing the same order of magnitude for the long-term scale.

It is now generally acknowledged that their primary role in support of safety assessment is to provide qualitative information to help develop or qualify conceptual models by identifying which processes are responsible for the evolution of natural systems, how these processes operate and on what spatial and temporal scales, and how these processes are coupled.

In order to illustrate how analogues can contribute to build technologists confidence, examples for the three different roles of analogues are given in the following.

Data and uncertainties: Corrosion of iron materials



Examples where analogue information have been used with respect to data and uncertainties in PA are archeological analogues, in particular those for processes connected with metals used as container material.

The figure shows an example from Japan concerning the corrosion of the container (reference material is carbon steel with thickness 190 mm). The allowance for the corrosion depth in 1000 years is 40 mm indicated by the red dot (from H-12 study). Of course, a lot of investigations are necessary to analyse corrosion processes, which is only possible by lab experiments. Corrosion rates derived from lab experiments are shown in the lower left, covering time scales of four years in maximum. Much larger time scales are accessible by investigation of analogues.

Yusa et al. investigated corrosion of buried gas and water pipes made from various steels and located in a clay-rich burial environment for several hundred up to more than thousand years. The corrosion rate (corrosion depth) estimated from these studies are in nearly all cases equal or below the value applied in the performance assessment study H-12. This analogue gives confidence in the value value for the corrosion rate and therewith in the assumption that container failure earlier than 1000 years after disposal is not expected.



Data and uncertainties

- Only few examples where data can be directly used in PA
 - Scope the boundaries of parameters
 - Problem: high uncertainties in initial and boundary conditions

- Example: Iron/steel corrosion
 - archaeological analogues most useful
 - study of more than 40 archaeological artefacts (Johnson et al.)
 - corrosion rates quite uniform (0.1 – 10 $\mu\text{m/a}$)

Gives confidence, that long-term corrosion rates used in PA models are in the right order of magnitude (e.g. NAGRA, JNC)

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A similar use of such analogues stem from the safety assessment of NAGRA for disposal of radioactive waste in Opalinus clay. Based on the results from lab experiments NAGRA selected for their PA study a rate for anaerobic corrosion of $1 \mu\text{m a}^{-1}$ (Smart et al. 2001). This low long-term corrosion rate is consistent with results from natural analogue studies of more than 40 iron and steel archaeological artefacts (Miller et al. 1994), which yield rates in a quite narrow range of 0.1 to $10 \mu\text{m a}^{-1}$, with the higher end of the range likely to be representative of steels exposed to aerated sediments.

→ This is an example, where a high number of analogues with similar results gives confidence in the results.

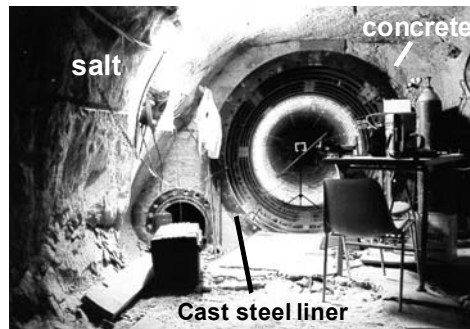
Other examples are corrosion rates for copper derived from ancient native copper at the Hyrkkola site (canister lifetime in POSIVA study) or the penetration depth for matrix diffusion from the Grimsel Test Site, which were used in the Swiss Kristallin-I assessment.

Model qualification: Self-sealing of EDZ in rock salt

PA relevance: increased brine flow through seals via EDZ

- Hydraulic properties (permeability, porosity, ...)
 - Spatial extent
- } Site characterisation
- Development with time → sealing
- } Industrial analogue

Bulkhead drift in the Asse mine constructed in 1914 in 700 m depth



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The second example illustrates the use of analogues for model qualification. The example is an industrial analogue for a repository in rock salt.

Excavation-disturbed zones (EDZs) are formed in all types of rocks as a consequence of the opening of cavities. In salt formations EDZs can extend up to 2 m into the rock salt. These zones represent areas with permeability increased by orders of magnitude compared to that of undisturbed rock salt. In a repository, where low permeable sealings are used as part of a multi-barrier concept, the increased permeability of the EDZ may lead to a reduction of the flow resistance and an increased brine flow through this section. Important for PA are information about the extension and the hydraulic properties of the EDZ and in particular about self healing due to the plasto-viskous properties of rock salt.

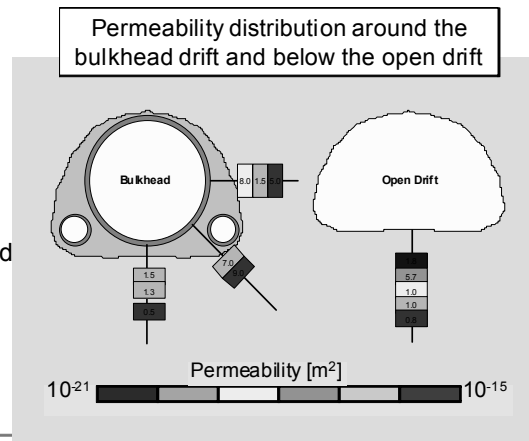
The permeability distribution and the extension of the excavated rock salt was measured at various test sites in the Asse salt mine in Northern Germany, near Braunschweig, by lab and field experiments.

One drift, the so-called bulkhead drift, which was mined in 1911, is especially interesting with regard to the potential long-term behaviour of the EDZ. A 25 m long section of the drift was equipped with a liner of cast steel tubings in 1914, and the void between the liner and the drift surface was backfilled with concrete. This drift can be regarded as a technical analogue for the development of an EDZ in a drift around a bentonite or concrete sealing as foreseen in a repository in salt.

Self-sealing of EDZ in rock salt

Results

- Typical EDZ still present around the open drift after 85 y
 - 1.5 m extension
 - Max. permeability: $2 \cdot 10^{-15} \text{ m}^2$
- EDZ around bulkhead drift sealed to large extent
 - Max. Permeability $< 10^{-18} \text{ m}^2$
 - microfractures closed but not disappeared



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The figure shows the permeability of the EDZ around the bulkhead drift (left) compared to an open, unlined drift (right). Below the open drift, a typical EDZ is present. It extends about 1.5 m into the rock, and the permeability rises above 10^{-16} m^2 . This confirms the results of a great number of permeability measurements at other test sites in the Asse salt mine. At all test sites with open drifts, an EDZ extension about 1.5 m into the floor and not more than 0.5 m into the walls was observed. Tests using various setups for measurements close to the open surface yielded permeability increases up to values from 10^{-16} m^2 to 10^{-15} m^2 , in comparison to around 10^{-21} m^2 of the undisturbed salt.

Around the lined part of the drift permeability is completely different. Apart from the horizontal borehole close to the drift surface, all permeabilities are less than 10^{-19} m^2 and thus considerably lower than the typical EDZ values. These lower permeabilities are due to a self sealing of the EDZ under a stress state with high normal and negligible deviatoric stress components, which is consistent with the results of supporting calculations. The original permeability of undisturbed salt, however, is not yet attained. Microstructural investigations on cores from both the lined and the unlined part of the drift seem to indicate that this may be due to the fact that the existing microfractures were closed by stress-induced plastic deformation, but did not completely disappear.

Self-sealing of EDZ in rock salt

Conclusions

- EDZ permeability significantly decreased within 85 years
 - Even faster at higher temperatures (expected in HLW repository)
 - Process level models to describe self-sealing under development
- (will be) used to give confidence that
 - models are suitable for calculation of self-sealing of EDZ in rock salt
 - extrapolation to longer timescales (several decades)
 - importance of EDZ for performance assessment restricted
 - considerable effect only expected for first decades of post-closure period

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In case of natural dry rock salt in the Asse mine with about 0.02 wt% water, 90 years under high compressive stress and negligible deviatoric stress were not sufficient to completely heal the EDZ around the bulkhead drift. However, this study clearly shows that a partial healing of the EDZ with permeability reduction of more than three orders of magnitude is observed. The permeability decrease in a HLW repository with temperatures of 100 to 150°C above rock temperature will be even faster. Therefore, this study gives confidence, that the importance of an EDZ in PA is restricted to the first decades of the post-closure period. Further, it is currently used in the EC project THRESA for testing and therewith qualifying the constitutive models describing the sealing process.

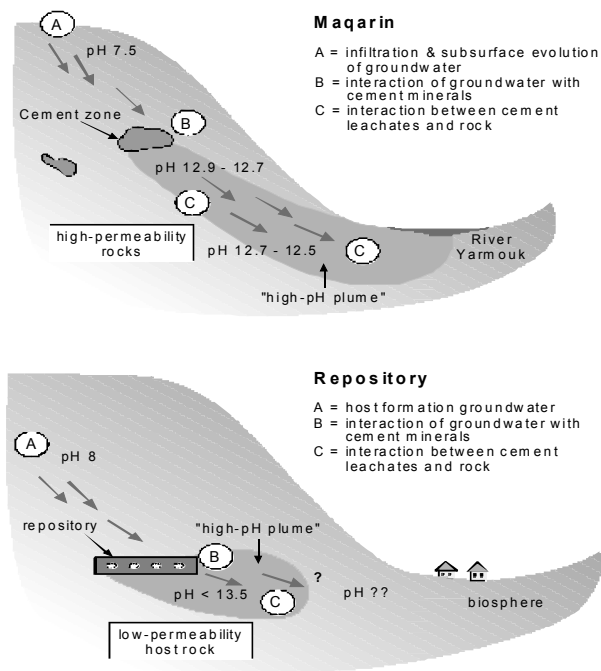
This study shows the worth of an industrial analogue, where the time frame is precisely known and changes of the boundary conditions are of minor importance. It also shows the important complementary role of analogue studies to lab and field experiments.

Other examples are the qualification of thermodynamic models and databases (e.g. in studies from Cigar Lake, Pocos de Caldas, Maqarin) as well as the investigation of natural tracer profiles in argillaceous formations, used for qualification of PA transport codes, showing that the relevant transport process is diffusion. i.e. no significant advective transport on large temporal and spatial scale has occurred.

Development of conceptual models:

Interaction of alkaline waters with host rocks

- Relevant for repositories with cementitious materials
- Analogue site in Jordan (Maqarin)
 - Natural cements from metamorphism of marls / limestone



One nice example where analogue studies have contributed to model development comes from the Maqarin study.

The Maqarin natural analogue site is a unique location for examining the mechanisms of processes associated with cementitious repositories, particularly when cement pore fluids will be dominated by the dissolution of portlandite and calcium silicate hydrate gel phases.

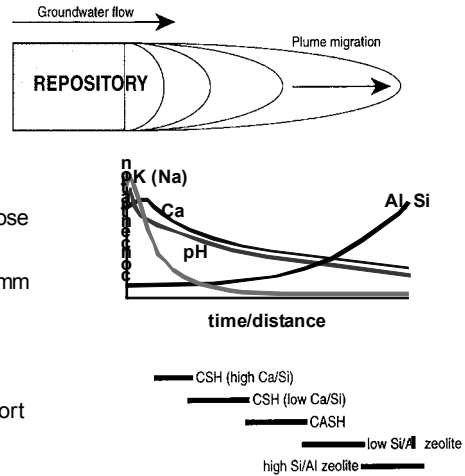
The hyperalkaline groundwaters in the area are the product of low temperature leaching of an assemblage of natural cement minerals produced as a result of high temperature/low pressure metamorphism of marls and limestones.

Interaction of alkaline waters with host rocks



Main Findings

- Conceptual model largely consistent with observations at the analogue site
 - long-lived hyperalkaline fluid conditions (tens of thousands of years)
 - Sequences of secondary minerals very close to those predicted by coupled codes
 - Diffusion-controlled alteration rims: 2 -20 mm
 - mostly positive reaction volumes
→ fractures sealed by precipitation of secondary phases
 - sealing of small fractures occurs within short timescales (years to hundreds of years)



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The Maqarin site now provides a consistent picture explaining the origin of the hyperalkaline waters, the persistence of some of the hyperalkaline springs/seepages, and the sequence of alteration occurring when such waters react with various rock-types. Thus the Maqarin study has contributed to model development, especially by the following observations:

- hyperalkaline pore fluid conditions generated by minerals analogous to those envisaged for cements are long-lived,
- sequences of minerals predicted by thermodynamic and coupled modelling are similar to those observed in hyperalkaline alteration zones at the site,
- diffusion controlled alteration rims occurring in time frames of more than ten thousand years are restricted to only 2- 20 mm, and
- small aperture fractures will be self-healing due to positive volumes occurring by reaction of rock with the alkaline plume.



Interaction of alkaline waters with host rocks

Conclusions

- Increase of process understanding
- Confirmation of findings from experiments and modelling
→ “Demonstration of realism” in the model

gives confidence in

- application of coupled codes to describe transport and interactions of the plume with the host rock
- results used in PA (e.g. reduction of porosity)

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The study has strongly contributed to process understanding, especially on the long-term scale. When the conceptual model for interaction of hyperalkaline fluids with rocks is applied in a safety assessment, confidence in the model is enhanced because the realism in the model can be demonstrated.

This example also indicates that it is largely the qualitative information from analogue studies that is most useful in the development of conceptual models.

Other examples for analogue information used for model development are the improvement of conservative radiolyses models by information from Cigar Lake, the development of conceptual models for glass corrosion, the use of permafrost data in development of iceage scenarios, and the development of a source term conceptual model for YMP from Pena Blanca analogue site.

Overall conclusions

- Increased application range for analogues identified in NAnet
- Multitude of analogue information was structured in matrices
- Approaches and data for integrated level and process level models
 - from laboratory (partly from field) experiments.
 - a number of experiments with well defined boundary conditions necessary
- Technologists' confidence in the adequacy of process-level and PA models underpinned by analogues
- Analogue studies complementary to experimental studies and modelling

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Within the NAnet project an increased application range of analogues was identified. In order to provide analogue information in a most efficient way all analogue information from the review was structured in matrices for the near field and far field of a repository system.

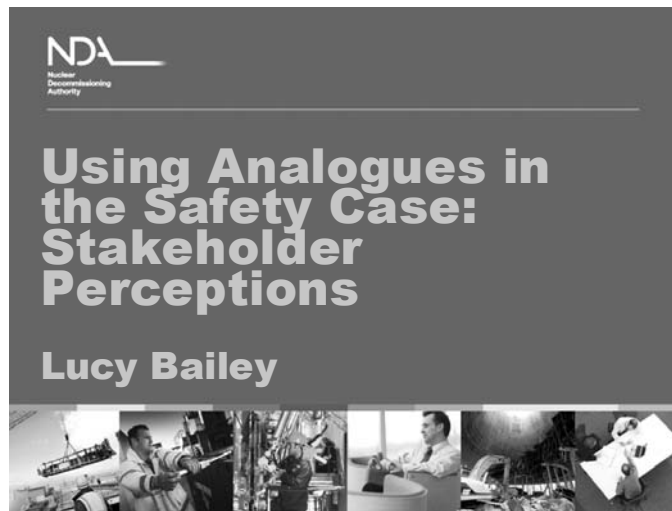
It is clear that approaches and data for modelling of processes on integrated level and process level are derived from laboratory and partly from field experiments. Usually a number of experiments with well defined boundary conditions are necessary. This task can not be done by analogue studies. They should be seen as complementary to experimental studies, because they are important to give confidence that the models are adequate.

Analogue studies contribute to technologists confidence by increasing the understanding of processes that control the evolution of the repository system over time. Qualitative information from analogues is of increasing importance, since it can help to develop or confirm conceptual models by identifying which processes are relevant, how these processes operate and on what spatial and temporal scale.

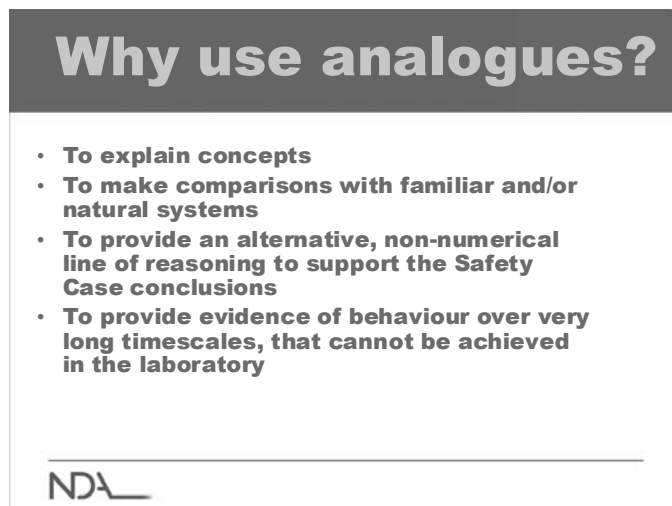
Not always very long time scales are needed. Some processes are only important on time scales of several tens or hundreds of years, which is still longer than the duration of lab and field experiments. Here, industrial analogues, where initial and boundary conditions are rather well known and materials are similar to repository materials, are very valuable.

HOW STAKEHOLDERS VIEW THE USE OF ANALOGUES IN SAFETY CASES: PAMINA

Elizabeth Atherton (NDA) and Lucy Bailey (Nirex)



The aim of this presentation is to provide an overview of some research that has been undertaken in the UK to investigate stakeholders' views of analogues.



There are various reasons for using analogues including:

- To try and explain difficult concepts
- To compare disposal facility features with familiar and/or natural systems
- To provide an alternative, non-numerical line of reasoning to support the Safety Case conclusions
- To provide evidence of behaviour over very long timescales, that cannot be achieved in the laboratory

Potential dangers of analogues

- **The conditions may not replicate those found in a geological disposal facility**
- **There may be negative as well as positive analogues (e.g. artefacts that have completely corroded)**
- **Analogues may be taken too far**

NDA

There are some dangers when using analogues that people should be aware of.

- The analogue conditions may not be the same as those found in a disposal facility, so the analogue may have limited application.
- Some analogues may have negative implications, for example artefacts that have corroded.
- Analogues can be taken too far and used in inappropriate ways to try and support an assumption.
- So it is important to find out how stakeholders view the use of analogues in a safety case.

EC PAMINA Project

- **Performance Assessment Methodologies IN Application**
- **26 partners from 11 European countries, plus other associated members**
- **3 year project: Oct 2006 – Oct 2009**
- **NDA involvement:**
 - **exploring issues of modelling uncertainty**
 - **evaluating the effectiveness of approaches for communicating safety cases with stakeholders**

NDA

NDA is involved in an EC funded project called Pamina. Pamina stands for Performance Assessment Methodologies IN Application.

The project involves 26 partners from 11 European countries, plus other associated members and runs for 3 years from October 2006 to October 2009.

The NDA is involved in several parts of the project.

- Exploring issues of modelling uncertainty
- Evaluating effectiveness of approaches for communicating safety cases with stakeholders.

Stakeholder Workshop: When and who?

- **17th October 2007 in Manchester**
- **14 stakeholder participants, representing...**
 - **NuLeAF (Nuclear Legacy Advisory Forum)**
 - **Nuclear Site Stakeholder Groups**
 - **County and Borough councils**
 - **NGOs (e.g. Shut Down Sizewell Campaign)**
 - **Nuclear workers' union representatives**
- **Led by NDA and facilitated by Galson Sciences Ltd**

NDA

NDA ran a workshop in October 2007 in Manchester.

The workshop involved.

- 14 stakeholder participants, representing:
 - NuLeAF (Nuclear Legacy Advisory Forum)
 - Nuclear Site Stakeholder Groups
 - County and Borough councils
 - NGOs (e.g. Shut Down Sizewell Campaign)
 - Nuclear workers' union representatives

The workshop was led by the NDA and facilitated by Galson Sciences Ltd.

Workshop: Aims

- **Explore how different methods of communicating aspects of a safety case were received by stakeholders:**
 - **examples of different repository concepts**
 - **descriptions of barrier performance**
 - **different ways of presenting numerical results**
 - **use of natural analogues**
- **Used the opportunity to test material that is being developed for our next safety case**

NDA

The aims of the workshop were to:

- Explore how different methods of communicating aspects of a safety case were received by stakeholders.

The workshop presented stakeholders with:

- Examples of different repository concepts.
- Descriptions of barrier performance.
- Different ways of presenting numerical results.
- Use of natural analogues.

The NDA used the opportunity to test material being developed for our next safety case.

Workshop: Structure

- **Highly interactive**
- **Presentations, posters, and showing the Nagra natural analogue video**
- **Asked stakeholders for feedback on our posters....**
- **....then allowed them to cut up our posters and make their own.**

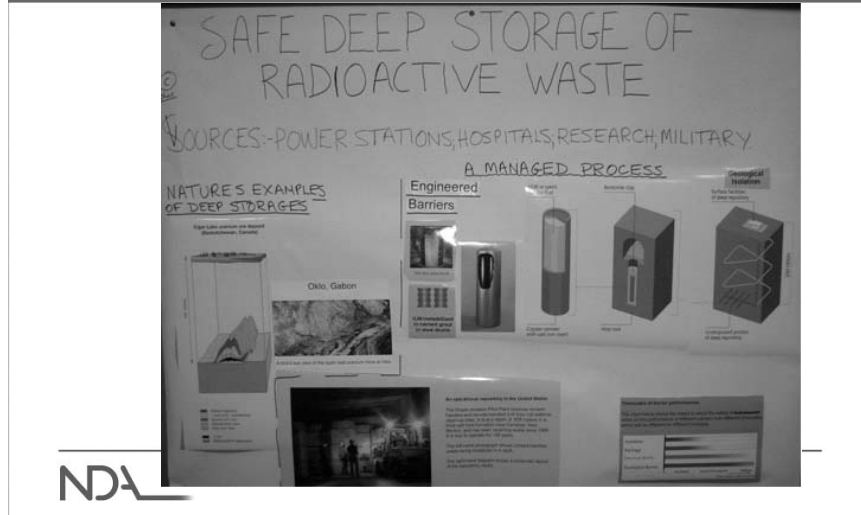
NDA

The structure of the workshop was highly interactive.

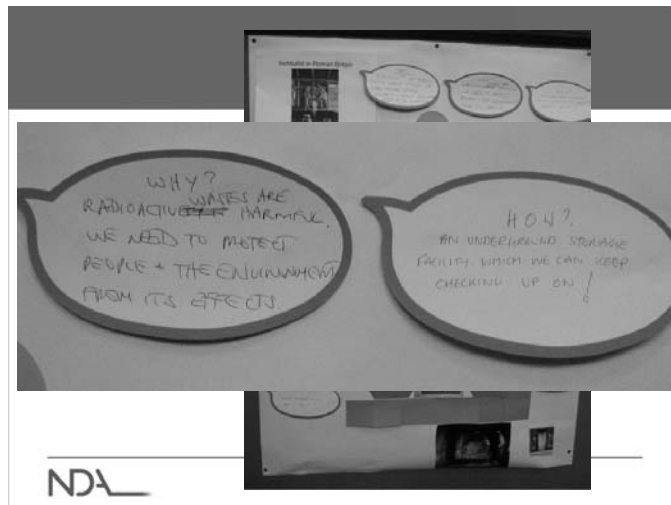
It involved presentations, posters and showing the Nagra natural analogue video.

We asked stakeholders for feedback on our posters and then allowed them to cut up our posters and make their own.

The results....



This slide shows one of the posters the participants made.



This slide shows what messages the participants thought it was important to communicate.

What we learned

- **Get back to basics**
- **Go easy on the graphs**
- **Consider the timescales**
- **Natural analogues may help to explain processes**

NDA

The feedback from participants emphasised several important issues.

- Get back to basics
- Go easy on the graphs
- Consider the timescales
- Natural analogues may help to explain the process.

The following slides explain these in more detail

Get back to basics...

- **We can't assume people will understand concepts such as half-life**
- **We need to explain the basic physics of a repository system**
- **Where possible we should relate the repository and its elements to familiar things, e.g. X-rays – people understand the dangers but accept the benefits**

NDA

In terms of getting back to basics

- We can't assume people will understand concepts such as half-life.
- We need to explain the basic physics of a repository system

- Where possible we should relate the repository and its elements to familiar things, e.g. x-rays – people understand the dangers but accept the benefits.

Go easy on the graphs...

- **Graphical material did not go down well...**
- **...regardless of whether logarithmic or linear axes were used**
- **Pie-charts and bar-charts were also seen as difficult to interpret**

NDA

- Graphical material did not go down well....
- Regardless of whether logarithmic or linear axes were used.
- Pie-charts and bar-charts were also seen as difficult to interpret.

Therefore we need to find other ways to communicate quantitative data.

Focus on timescales

- **One million year timescales are hard to grasp – and people think so many things will have changed that you can't say anything meaningful on this timescale**
- **Much more interested in the earlier timeframes, e.g. the next 100 years**
- **But also want to know the repository won't go horribly wrong in the future**

NDA

One million year timescales are hard to grasp – and people think so many things will have changed over that time period that you can't say anything meaningful over 1 million years

People are much more interested in the earlier timeframes, e.g. the next 100 years and want to know what will happen in this period in some detail

But people also want to know the repository won't go horribly wrong in the future and that if something does go wrong we are able to handle it

Natural analogues

- **Seen as a useful component in presenting a safety case, but not by themselves**
- **More helpful to explain issues, than provide reassurance,**
 - **“...you need to explain why you have confidence in a bunch of rusty nails and an old Roman wall.”**
- **Both groups chose to use natural analogue examples in their posters**
 - **Cigar Lake and Oklo as examples of natural ‘storage’ of radioactivity**
 - **Roman helmet to highlight corrosion**

NDA

Natural analogues were seen as a useful component in presenting a safety case, but not by themselves

People felt they were more helpful to explain issues, than provide reassurance, one participant said,

“...you need to explain why you have confidence in a bunch of rusty nails and an old Roman wall.”

Both groups of stakeholders chose to use natural analogue examples in their posters

- Cigar Lake and Oklo as examples of natural ‘storage’ of radioactivity
- Roman helmet to highlight corrosion

Other key communication issues

Communication should be aimed at all audiences, but particularly young people

- **must be modern and forward-looking**
- **use the latest technology (e.g. interactive CD-ROMS, computer games)**

NDA

There were also some other communication issues that came up as part of the workshop.

The participants felt communication should be aimed at all audiences, but particularly young people they felt it must be modern and forward-looking and use the latest technology (e.g. interactive CD-ROMS, computer games)

**SETTING WASTE ISOLATION TIMES INTO A GEOLOGICAL CONTEXT: SOME
EXPERIENCE WITH NATURAL ANALOGUES IN PUBLIC INFORMATION**

Markus Fritschi
(NAGRA)

Setting waste isolation times into a geological context: Some experience with Natural Analogues in Public Information

Personal remarks based on many discussions with and presentations to the general public ...

Markus Fritschi

nagra.

The question of timescales in public information

The concept of geological repositories:

- Permanent protection of humans and the environment by long-term passive isolation of the radioactive materials from the environment
- Permanent:
until radioactivity has decayed to insignificant levels
- Many tens of thousands of years up to one million years into the future

The question of timescales in public information

Human experience with timescales:

- Personal: Some 10 years ... maybe up to 2 to (3) generations
- “Rapid” (normally experienced as slow) and relevant changes with regard to personal wellbeing during this time span
- 100 years of European history ...
- Human History up to 5,000 years: but relevant to experience?

→ **Complete mismatch of personal experience with the question addressed in the safety case**

3

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How to explain?

Understandable explanation of a geological repository:

- Why is a geological repository *necessary*?
- Why are geological repositories *safe*?
- How can one be sure ... what happens in 100,000 years?



4

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Nuclear Waste Management



Radioactive waste must be disposed of in a way to ensure permanent protection of humans and the environment.

(Swiss Nuclear Energy Law)

→ Containment

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Today's containment (storage) needs maintenance



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Stability of society?



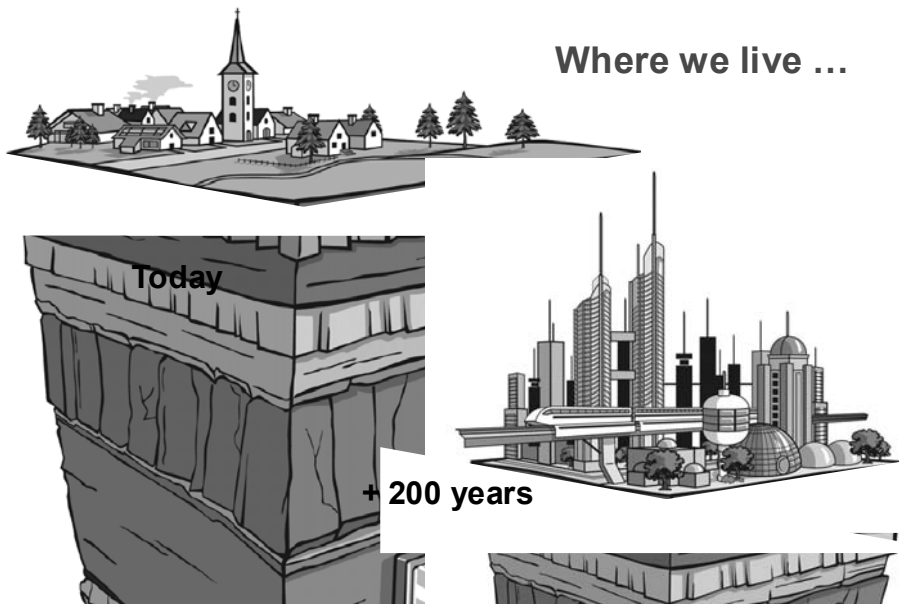
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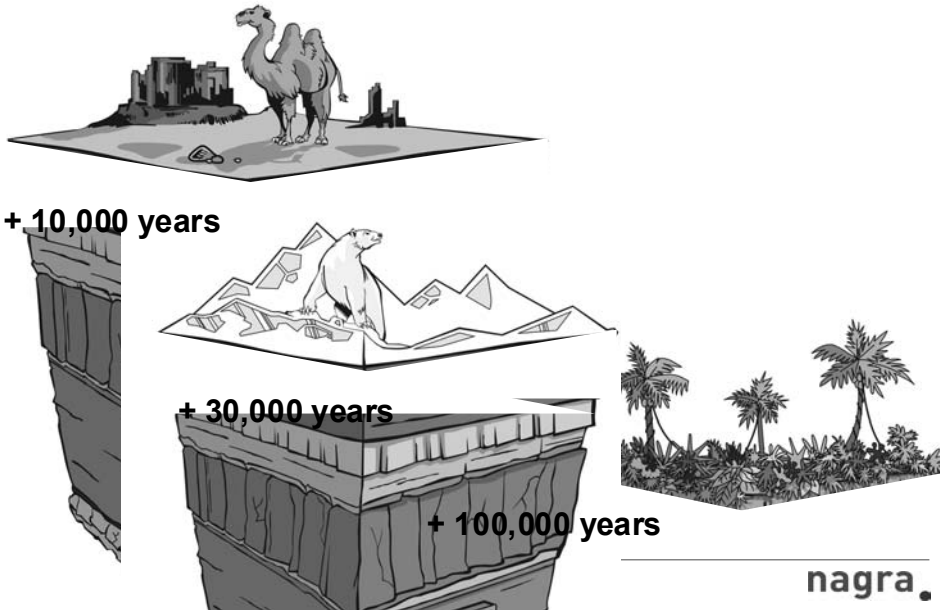
Geological Timescale Figure 5.03

nagra.

Unknown development on the surface ...

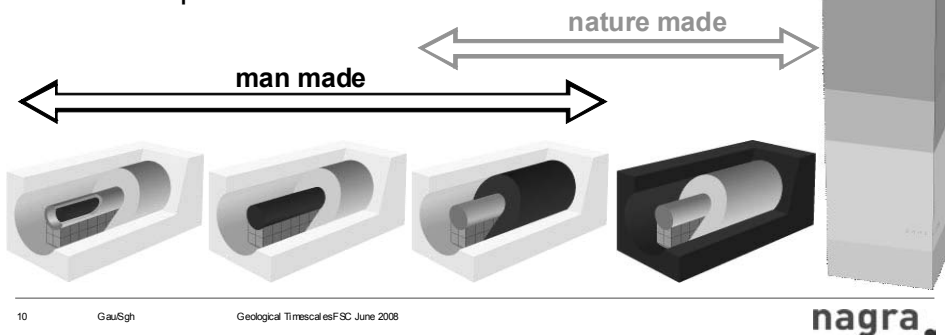


...?



Passive safety: multiple barrier system

- Contribution to safety by different barrier system components → passive containment without the need of maintenance in a geological environment
- Requirements on the host rock and the geosphere
→ Sound science and expertise is available for all the components



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Explaining: The time you have...

- | | |
|----------------------|-------------------|
| ▪ Education | Years |
| ▪ Training | Month |
| ▪ Visits, Excursions | 1-2 Days |
| ▪ Presentations | 30 Minutes |
| ▪ Podiums | 4 times 3 Minutes |
| ▪ Interviews | 3 Minutes |
| ▪ Statements | 30 Seconds |
| | |
| ▪ Persons reached | |
| ▪ Understanding | |

The need for translation

What **pictures** do you use to explain the functioning of a geological repository over long time scales?

The need for translation

What **pictures** do you use to explain the functioning of a geological repository over long time scales?

12

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Translation - some examples

- Pictures
- Symbols
- “Analogues”

... must be adapted to the specific situation in a country.

13

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Grandmother of the Sequoias (Dunarobba, Italy)



Nature demonstrates :

Clay isolates from environmental processes.

Wood has been embedded in clay for 2 M years ...

14

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Analogue of repository material – Clay (bentonite)



... and can still be burned.



15

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Embedded in clay since the Eozän (50 Million Years)



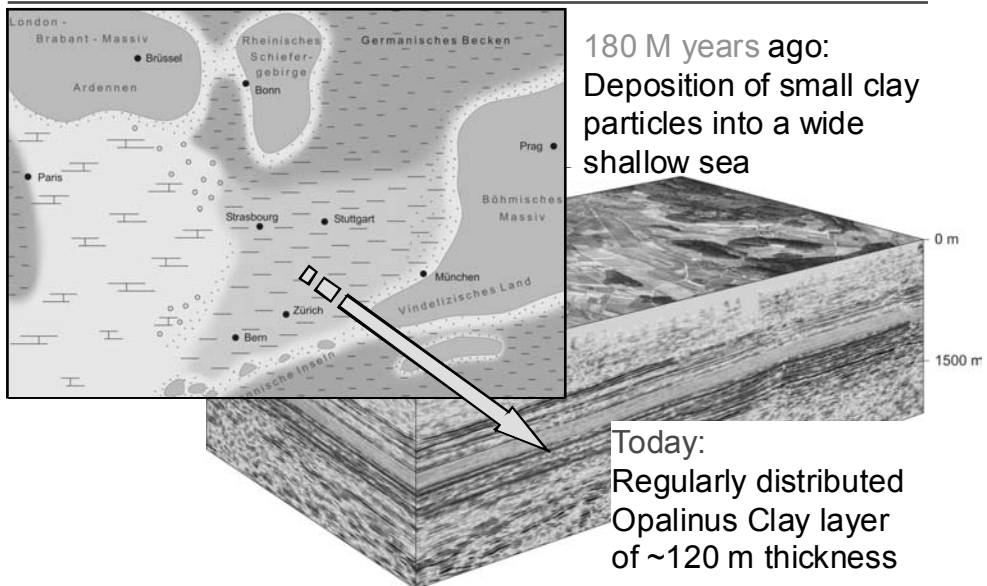
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Opalinus Clay: Depositional conditions



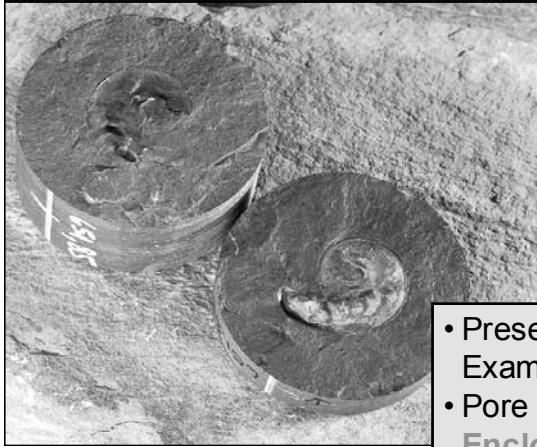
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Opalinus Clay: Outstanding Preservation Capacity



Fossil in drillcore of N-CH
Leioceras Opalinum
 Layer: Opalinus Clay
 Depth: 652 m below surface
 Since 180 M years ago
 embedded in Opalinus Clay

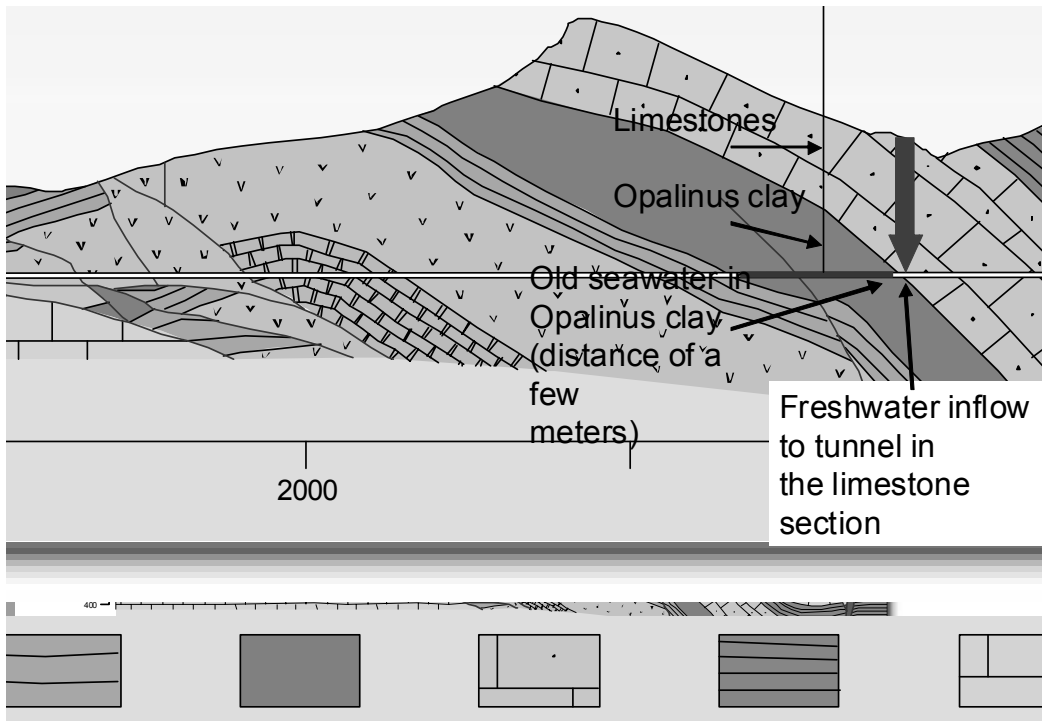
- Preserved mother-of-pearl layer:
 Example of preservation capacity
- Pore water with original seawater:
**Enclosed over 180 million
 years ago → no groundwater
 flow or exchange**

18

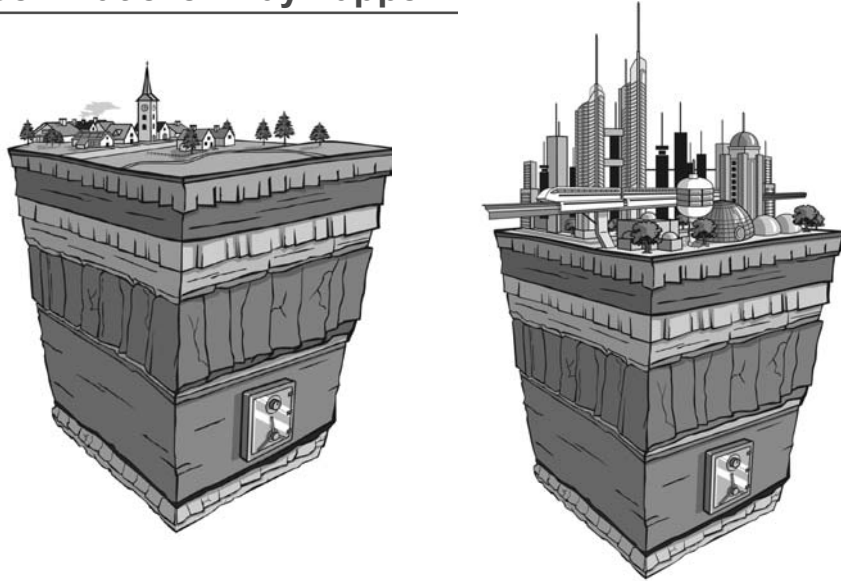
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Geological Timescales FSC June 2008

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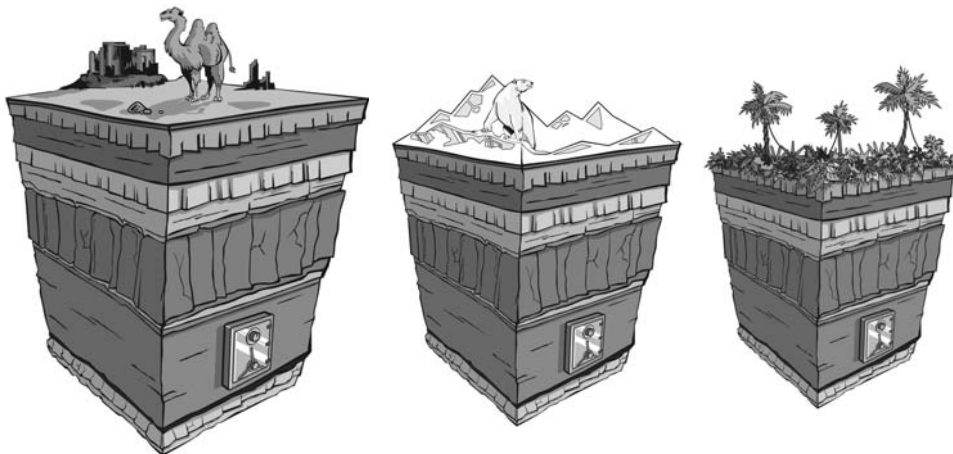
So what ever may happen on the surface



20 GauSgh Geological TimescalesFSC June 2008

nagra.

...over the next one million years:



Time stands still in the underground

21 GauSgh Geological TimescalesFSC June 2008

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Thank you
for your attention
nagra.

NATURAL ANALOGUES IN POSIVA'S SAFETY CASE

Nuria Marcos
Saanio & Riekkola OY

Natural analogues in Posiva's Safety Case

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NEA/RWM/FSC-2008

|| POSIVA



Safety Case vs. Performance Assessment

The SAFETY CASE is a broader concept than PERFORMANCE ASSESSMENT that allows better the use of natural analogues and observations from nature to understand the behaviour of the system and the processes at the site.

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Use of observations of natural systems

- Natural analogues are mostly used to add confidence to the safety of geological disposal with respect to
 - Design (depth and multibarrier system)
 - Materials (long-term durability), and
 - Processes (understanding the long-term behaviour/evolution of the system)

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CONSULTING ENGINEERS

Latest examples – Climate

- Ice ages and erosion
 - largest boulders released and transported by ice during the most recent ice age are well below 20 m.
 - 25 glacial cycles would be necessary to erode in this fashion 500 m of bedrock.
 - During the last million years only about 8-9 glacial cycles are known to have occurred.



Boulder, Sulkavalla, Finland
(www.jukola.com/jukola/kuvat/hiidenkivi)

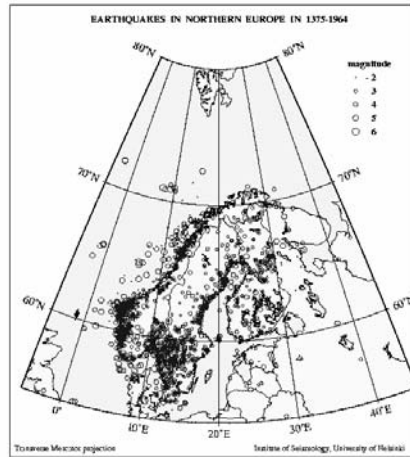
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CONSULTING ENGINEERS

Geosphere stability

- Minor possibility of damaging earthquakes due to the geological position of the Olkiluoto site in the Fennoscandian Shield



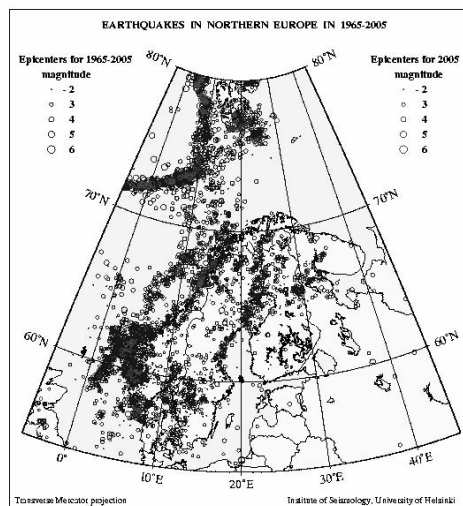
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JSIVA



Geosphere stability

- Magnitudes of earthquakes historically and over the last 40 years have been less than 3 in the area next to Olkiluoto.



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JSIVA



Stability, U, and flow rates at Olkiluoto

- Shallow groundwaters:
 - Assuming a discharge flow rate (DFR) of about 200000 m³/km²/year, the average concentration of U in gw was 3.7 µg/L
 - Depth 375 m
 - Assuming a discharge flow rate of about 1680 m³/km²/year, the average concentration of U in gw was 0.21 µg/L
 - Depth 475 m
 - Discharge flow rate of about 730 m³/km²/year, the average concentration of U in gw was 0.04 µg/L
- [WHO, 2005] Tolerable daily intake of U: 15 µg/L assuming a 60-kg adult consuming 2 L of drinking-water per day.

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POSIVA



References

- IAEA – CRP project
 - Pitkänen, P., Löfman, J., Luukkonen, A., Partamies, S. 2003. IAEA Coordinated Research project (CRP) “The use of selected safety indicators (concentration, fluxes) in the assessment of radioactive waste disposal”. Report 7: Site-specific natural geochemical concentrations and fluxes at four repository investigations sites in Finland for use as indicators of nuclear waste repository. Geological Survey of Finland, Nuclear Waste Disposal Research, Report YST-115. ISBN 951-690-8594, ISSN 0783-3555.
- WHO, 2005. Uranium in drinking water – WHO/SDE/WSH/03.04/118 – Background document for development of WHO Guidelines for Drinking-water quality.

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2008

14 October

POSIVA



**A REGULATOR'S PERSPECTIVE ON THE USE OF ANALOGUES FOR REGULATORY
CONFIDENCE**

Carmen Ruiz
CSN



A regulator's perspective on the use of analogues for regulatory confidence

9th FSC Session, Paris 4-6 June, 2008
Implementing the FSC WoP: Link between R&D and Stakeholder Confidence

M^a del Carmen Ruiz López
CSN

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Outline

CSN 's Experience

- *Study of Natural and Archaeological Analogues: application to safety assessment of deep geological disposal and to public communication (1999-2003), from now " CSN NAA Study"*
- **Illustrative Synthesis Report-Overview**

Review of significant international references

Conclusions: some observation and questions

2

CSN Participants

- The NAA Study, promoted and coordinated by the CSN, was carried out in collaboration with ENRESA by CIEMAT and three Spanish Universities UZ, UDC and UCM
- The 3 year Study, included in the CSN's R&D Programme, started in 1999, is focussed on Deep Geological disposal (DGD)

	Carmen Ruiz Javier Rodríguez	Pedro Hernán	
	<hr/>	<hr/>	
	<i>Consejo de Seguridad Nuclear</i>	<i>ENRESA</i>	
Fernando Recreo Celsa Ruiz Pedro Prado	María J. Gimeno Luis F. Auqué Javier Gómez Patricia Acero Álvaro González	Javier Sarper Luis Monteregro Jorge Molinero Jordi Delgado	Antonio Criado J. Antonio Martínez Susana Ruiz
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CIEMAT	<i>Universidad de Zaragoza</i>	<i>Universidad de La Coruña</i>	<i>Universidad Complutense</i>

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CSN NAA Initiative Background and objectives

- ✓ **CSN motivation** for NA Analogues arose in 1997 as result of the emerging approaches to **increase the confidence** in the Safety Assessment (SA) considering **multiple lines of reasoning** show in:
 - Some international documents (as the IAEA TECDOC 975 "Regulatory Decision Making in presence of uncertainty" and "IAEA Safety Requirements for Geological disposal", in preparation at that date)
 - Some national regulation as the US NRC 10CFR 63
- ✓ After a first preliminary (1997-1998) study, the CSN noticed the **large amount and dispersion of the information** about NNA, and decided to launch a deeper Study with the aims of:
 - **Collecting and reviewing the results** of all the relevant studies on analogues developed in the last decades in systematic way
 - **Reaching a better understanding of their potential and real application to the SA and for communication purposes** (to identify the state of the art , as a basis for potential CSN further positions or activities (e.g. review of SA exercises).

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SNAA Project Development

- Bibliography compilation of NAA studies and considered SA exercises (19)
- Selection of the Analogues to be studied (based relevance for the Spanish geological concept, importance by the quantity and quality of available information, their potential capacity to provide information for different aspects of the SA, disposal components and materials and contribution to consulted SA exercises)
- Identification of the DGD components and processes susceptible of gaining information from analogues.
- Detailed and systematic analysis of the selected analogues (43 natural analogues and 8 archeological analogues)
- Detailed analysis of the contribution of analogues to the SA.
- Analysis of the international and national supporting material for communication purposes.

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SNAA Project's Products

- ✓ **The results of the Analogue Study has been structured in several documents with different levels of detail and technical content addressed to different audiences**
 1. **NAA Catalogue** (detailed description of each analogue), published as CSN I+D Document.
 2. **Contribution of analogues to Safety Assessment** and Communication (detailed study of the potential and real application (edited as internal document)
 3. **Documental Database:** with more of 2000 references on NAA and SA plus references handled during the Project [SOFTWARE]
 4. **Illustrative Synthesis of the Study, published-CSN I+D document 11-2004 (Sp&En), aimed to a wide technical audience not necessary familiar with the matter (Extensively distributed at national level)**

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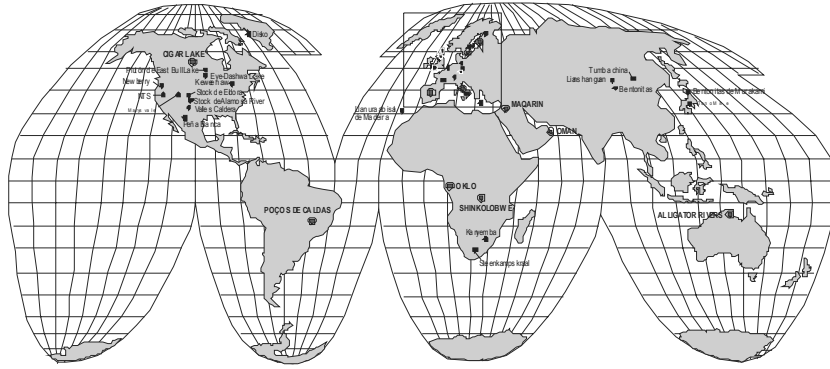


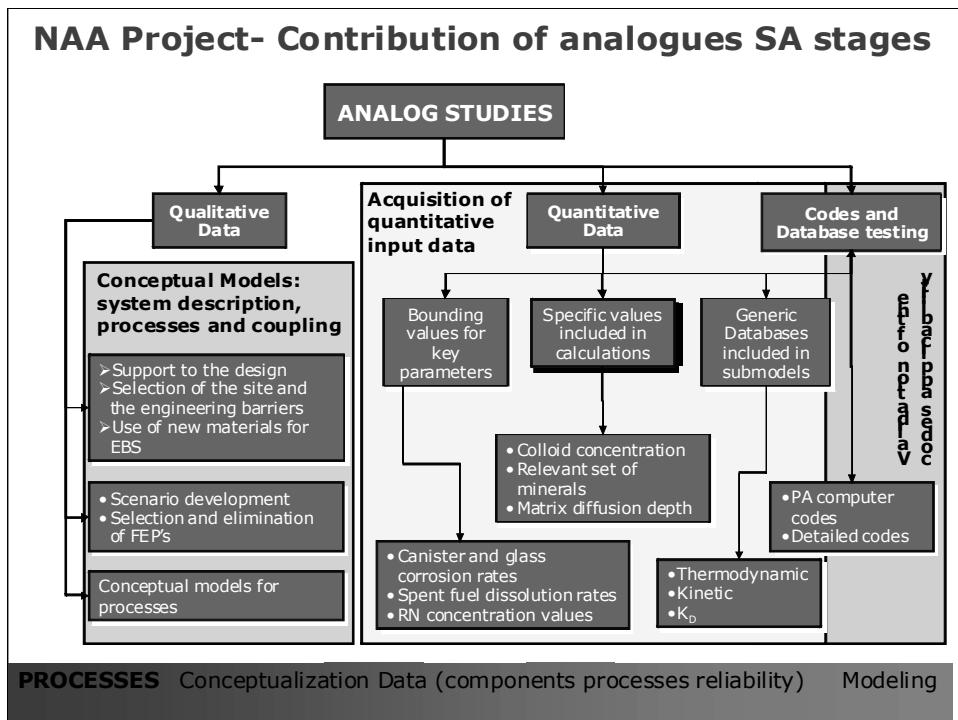
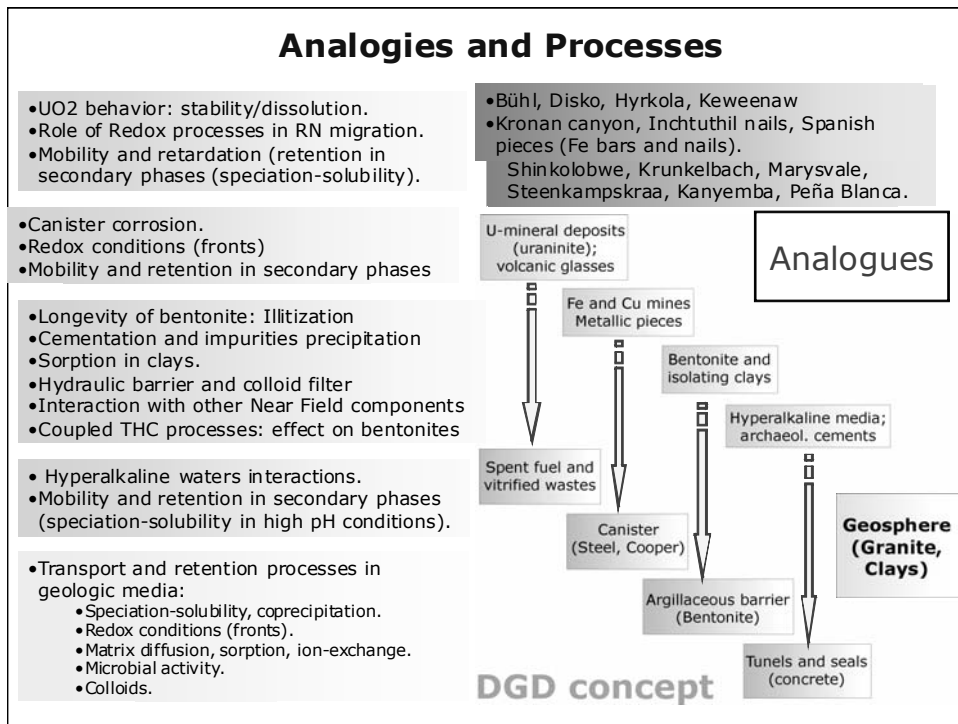
NAA Project A briefing of the Studied Analogues

Natural Analogues:
 Uranium mineral deposits (6+11)
 Clay engineering barrier analogs (2+7)
 Hyperalkaline environments (2)



Archaeological A:
 Metallic pieces (8)
 Cements (3)
 Clays (1)







Conclusions Analogs and PA/SA

- **Analogue studies are a source of knowledge for the understanding of the long-term behavior of DGD systems. They represent a complementary method to increase Confidence Building within PA.**

- They represent:
 - A "Laboratory" to evaluate long term processes.
 - A "neutral field" to check hypothesis and models, and to test codes and databases.
- The reliability on the SA results increases when there are parallel examples to compare with.
- A resource for the communication to different audiences (including non technical audiences and the public)

However

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Conclusions: Observations and Limitations

- The real use of analogs in the 19 consulted SA is difficult to identify:
 - Most of the uses are found in the supporting reports
- Little use of analogue's information due to the early stages of most DGD Programs.

Real sites allow an easier identification of pertinent analogies.

- Limitations of analogues

- **Lack of precision when establishing initial and boundary conditions governing the evolution of the system.**
- **Intrinsic heterogeneity and variability of natural systems.**



Qualitative use of the information

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Contribution of analogue to communication

- **Goal: review the uses of analogues for public communication**
- **Compilation of the available information**
 - divulgation materials: videos, fact sheets, brochures, publications, internet resources (web pages) and other kind of activities perform by regulatory and management organisms (Implementers, International organization, as EC Natural analogues Working group –NAWG-, etc.)
- **The results of the potential and real use of analogues for communication purposes are synthesised in Annex II**
- **In the majority of the cases, analogues have been used to transmit information on generic aspects of the geological concept an easily understood message**
- **The need to simplify the content to facilitate their understanding may imply an underestimation of the audience different information to different audiences**

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NAA Study – Illustrative Synthesis report: Natural Analogues docket

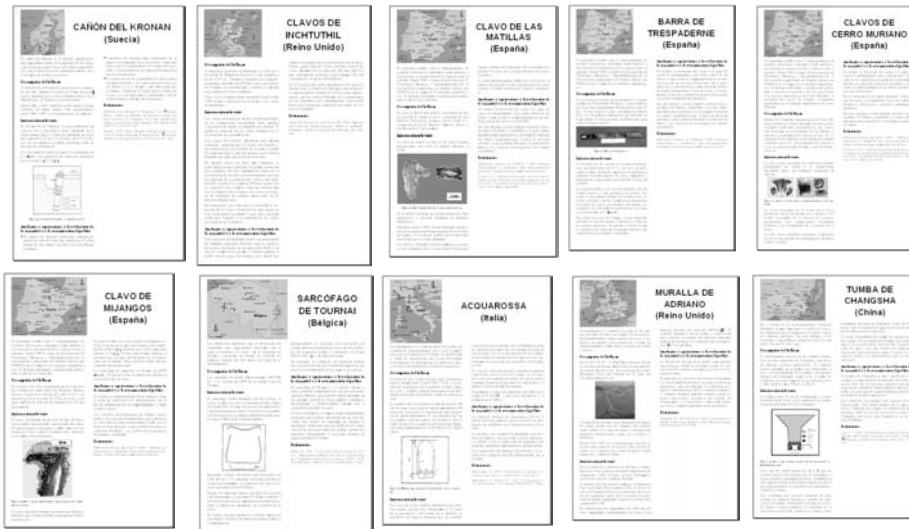
The image displays a collage of pages from a 'Natural Analogues docket' report. The pages are arranged in a fan-like pattern, showing various sections including:

- OMÁN**: A large page featuring a map of Oman and detailed text about its geological context and the use of natural analogues for public communication.
- Descriptores de la...**: Multiple pages with text and small maps, likely describing different natural analogue sites or regions.
- Mapas**: Several pages containing maps of various geographical areas, including Australia, Canada, and parts of Europe.
- Diagramas**: Pages with diagrams and charts, such as a 'Diagrama de flujo' (flowchart) and a 'Diagrama de flujo de la información' (information flow diagram).
- Textos**: Numerous pages of text providing detailed information, including sections like 'Análisis y aplicaciones a la...', 'Descriptores de la...', and 'Descriptores de la...'.

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NAA Study – Synthesis report: Archaeological Analogues docket



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Review of some relevant International references

- **1997-IAEA-TECDOC-975: Regulatory decision making in the presence of uncertainty in the context of the disposal of long lived radioactive wastes**
- **1997 NEA Lessons learnt from Ten performance Assessment Studies (1st IPAG Report) [Q]**
- **1999-NEA Geological Disposal of Radioactive Waste- Review of Development in the Last Decade (Q)**
- **1999 NEA Progress Towards Geologic Disposal of Radioactive Waste: Where Do We Stand? An international Assessment**
- **1999 NEA Confidence in the Long-term Safety of deep geological Repositories: Its development and communication**
- **2000 NEA Regulatory reviews of Assessment of Deep Geologic Repositories. Lessons Learnt (2nd IPAG Report) [Q]**
- **2002 NEA Approaches and arguments to establish and communicate confidence in safety and the overall results of Integrated Performance assessment (3er IPAG Report)**
- **2003 NEA The Handling of Time Scales in Assessing Post-closure Safety of Deep Geological Repositories, Workshop Proceedings, April 2002**
- **2004 NEA Post-closure Safety Case for Geological Repositories - Nature and Purpose**
- **2006 IAEA-WS-R-4 Geological Disposal of Radioactive Waste.**



Review of some relevant International References- Examples

- **1997IAEA TECDOC-975**
- **2006 IAEA-WS-R-4**
- **1999 NEA GD Review of the Last Decade**
- Multiple lines of reasoning: use of natural analogues
- Natural Analogues provide a further component of confidence building process, although enhance integration into PA is still seen as an area warranting further development

➤ **Some other of the above mentioned references develop and even link the type of analogue and the application of natural analogues to specific process or Safety Assessment issues**

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Review of some relevant International References -Examples

1999 NEA Confidence doc:

- ✓ **Use of independent evidence (e.g. natural analogues)**
 - Provides overall confidence in the “reasonableness” of assumptions underlying the calculations (doc- Table 6)
 - To quantify uncertainties related, for example, to the effects of high temperature on host rock (intrusion of basaltic melts into evaporite formation). (Tabl 8)
 - To enhance confidence in, and support assumptions regarding, the operation of key processes that lead to long-term safety

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Review of some relevant International references - Examples

- **2003 NEA, *The Handling of Time Scales*** (Box 5-types evidence that can be used to support arguments for the robustness):
- The existence of natural uranium deposits, and other natural analogues of a repository system or one or more of its components



- Long-term stability of formation, bentonite, used as a buffer material in many repository designs (also the feasibility, in principle, of geological disposal)

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Review of some relevant International references - Examples

2004 NEA Post Closure Safety Case doc. (Pag 22)

- "A safety case intended as a platform for discussion with a broadly based audience, including the general public, may place emphasis on different lines of evidence, arguments and analyses compared to a safety case aimed at regulators and other technical specialists.
- **Highlighting less quantitative evidence for safety, including evidence from natural analogues, may be more accessible, more convincing and of more interest to the public than, say, the results of complex mathematical models"**

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Review of some relevant International references - Examples

2004 NEA Post-closure Safety Case (Chapter 5. Evidence, Analyses and Arguments...)

- Indirect support for the possibility of safe geological disposal also comes from observations of natural systems, including the longevity of uranium ore deposits in many different geological environments around the world.
- Furthermore, there is ample evidence of the importance of the **natural processes** of solubility control, sorption and diffusion in attenuating concentrations of species dissolved in porewater.
- **Archaeological analogues** may also be used to evaluate specific interactions between relevant materials and natural processes.

...

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Review of some relevant International references - Examples

- ✓ **"Some uncertainties can be reduced by methods including site characterisation,demonstration tests, experiments both in the laboratory and in underground test facilities.**
- As a programme matures, studies will increasingly focus on key safety-relevant uncertainties and the specific data and measurements needed to resolve these. For example, *in situ* experiments of radionuclide migration may improve confidence in the migration models or allow their improvement.
 - **In some cases, uncertainty can be managed by seeking multiple lines of evidence for particular assessment assumptions or parameters, including, for example, evidence from natural analogues to support the longevity of engineered materials.**

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Conclusions: some observations and thoughts and questions

Analogue studies are

- **Considered within the multiple lines of reasoning to increase the confidence in the SA**
- **A source of knowledge for the understanding of the long-term behavior of DGD systems.**
- **They represent a complementary method to increase Confidence Building within SA.**
- **There are few examples of the direct use of data from natural analogue projects in the consulted SA**
- **Promoted by International organisations NEA, EC, IAEA, implementers, some regulators...**

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Conclusions: some observations and thoughts and questions

Analogue studies are

- **Carried out by researcher and specialised consulting support a under EC FP.**
- **As a programme matures, studies will increasingly focus on key safety-relevant uncertainties and the specific data and measurements needed to resolve these**
- **Are there a balanced representation of the radioactive waste management community (in particular implementer and regulators)?**

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Conclusions: some observations and thoughts and questions

1997-Regulating the Long term safety of radioactive waste disposal

- **Approaches with multiples lines of reasoning to assess repository performance must be clarified**
- **PA trends: R&D effort may help to reduce some uncertainties**
- **To conduct the Regulatory review process.**
 - **The extent of independent R&D activities or sponsored by regulator in support of their review function depend notably upon the size and development situation of the program**

2



Conclusions: some observations and thoughts and questions

- ✓ **In the last years, it has been progressed in many related areas**
 - Advances in some repository programmes
 - Progress in SA development
 - Recognition of the use of natural analogues in international recommendations, guidance documents and studies
 - Progress in the identification of the role of other lines of reasoning
- **Would be necessary the reconsideration, update and documentation of relevant issues on the use of analogues ? Definition, selecting criteria, analogue role, application**

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ANNEX I: Contribution of Analogues to SA exercises (MR: Main Report, SR: Support Report, PR: Peer Review Reports)

PA Exercise	Country	Organization /Year	Reviewed Information	Cited Analogues
Project-90	Sweden	SKI / 1991	MR, SR, AR	Archaeological analogs, Poços de Caldas
SITE-94	Sweden	SKI / 1996	MR, SR, AR, PR	El Berrocal, Cigar, Poços, generic references to analogues
SKB-91	Sweden	SKB / 1992	MR	Cigar, Hamra, Poços, Broubster
SR-97	Sweden	SKB / 1999	MR, SR, AR, PR	Cigar, Kinnekulle, Poços, El Berrocal, Omán, Maqarin, Krunkelbach, NTS, Broubster, Archaeological analogs (Kronan), Koongarra, Oklo, Palmottu, Dunarobba
SFL 3-5	Sweden	SKB / 1999	AR	Archaeological analogs, Maqarin, Oman.
TVO-92	Finland	YJT / 1992	AR	Cigar, Palmottu, Poços, Kronan Cannon
TILA-99	Finland	POSIVA / 1994	MR, SR, AR	Cigar, Palmottu, Hyrkkölä, Poços, El Berrocal, Omán, Maqarin
KRISTALLIN-I	Switzerland	NAGRA/1994	MR, SR, AR	Basaltic glasses, archaeological analogs, Hamra, Busachi, Poços
GEWÄHR	Switzerland		AR	Archaeological analogs, Oklo

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ANNEX I: Contribution of Analogues to SA exercises (MR: Main Report, SR: Support Report, PR: Peer Review Reports)

PA Exercise	Country	Organization /Year	Reviewed Information	Cited Analogues
ENRESA-97	Spain	ENRESA/1997	MR, SR	Indirect reference to analogues
ENRESA-99	Spain	ENRESA/1999	MR	Indirect reference to analogues
ENRESA 2000	Spain	ENRESA	SR, AR	Generic references to analogues
Mol, Marivoet et al., (1996)	Belgium	ONDRAF / NIRAS / 1996	MR, AR	No references to analogues
NIREX-95	UK	NIREX / 1995	MR	No references to analogues
NIREX-97	UK	NIREX / 1997	MR, SR, AR, PR	No references to analogues
H-12	Japan	JNC / 1999	MR	Basaltic glasses, archaeological analogs, Oklo, Koongarra, Hamra, Busachi, Murakami, Tono Mine, Maqarin, Poços, NTS
AECL-94	Canada	AECL / 1994	MR, SR, AR	Cigar, Oklo, Kinnekulle, Avonlea
NRC-IPA Phase II	USA	CNWSA	MR, AR	Peña Blanca, Valles Caldera, Santorini
TSPA-VA	USA	US. DOE / 1998	MR, SR, AR, PR	Climatic analogs, THC, Peña Blanca, Santorini, Cigar, Poços, NTS, Oklo
TSPA-SR	USA	US. DOE / 1998	MR, SR, PR	Multiple references (analogues review)

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ANNEX II: Potential and real use of Analogues to Communication purposes

ANALOGUE	POTENTIAL CONTRIBUTION TO COMMUNICATION	ACTUAL USE IN PUBLIC COMMUNICATION
Poços de Caldas (Brazil)	<p>–Morro do Ferro: <u>Evidence of the mobility of thorium</u> from the deposit being very low</p> <p>–Osamu Utsumi: Shows the capacity of the redox fronts that may occur in the near field of a repository system to retain and delay radionuclides</p>	–Video “Traces of the Future: Lessons from Nature for Waste Disposal”
Koongarra (Australia)	Illustration of the <u>capacity</u> of the near field and the geosphere of a DGD system <u>to retain radionuclides</u> , even in the case of possible failure of the sealing system	
Cigar Lake (Canada)	<p><u>Illustrative example of a disposal system</u> due to the parallelism between this and the natural geological system</p> <p>Illustration of the isolating capacity of the multi-barrier system for deep geological disposal: uranium deposit of 1,300 million years, with no traces on the surface</p>	<p>–Subject of the video “Nature’s own repository” published by SKB and of the video “Traces of the Future: Lessons from Nature for Waste Disposal”</p> <p>–Websites of Posiva (www.Posiva.fi/englantii/index.htm), SKB (www.skb.se) and NAGRA (www.Nagra.ch/)</p> <p>–SKB exhibition on board the Sygn</p>

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ANNEX II: Potential and real use of Analogues to Communication purposes

ANALOGUE	POTENTIAL CONTRIBUTION TO COMMUNICATION	ACTUAL USE IN PUBLIC COMMUNICATION
Oklo (Gabon)	<p><u>Evidence that radioactivity is a natural phenomenon</u>: even nuclear chain reactions have taken place in nature (natural reactors)</p> <p>Proof that the products of nuclear reactions may be retained in natural systems</p>	<p>–Subject of the SKB video “Nature’s own nuclear waste” and of the video “Traces of the Future: Lessons from Nature for Waste Disposal”</p> <p>–Brochures: “Oklo: natural nuclear reactors” and “Scientists look to nature for insight into how a repository would perform”</p> <p>–Websites of Posiva (www.Posiva.fi/englantii/index.htm), SKB (www.skb.se),</p> <p>–Yucca Mountain (www.ocrwm.doe.gov) and a university (www.curtin.edu.au/curtin/centre/waisrc/OKLO/index.shtml)</p> <p>–SKB exhibition on board the Sygn</p>
El Berrocal (Spain)	<u>Overall and simple example of disposal safety</u> , showing the limited mobility of uranium in the granitic pluton	–Subject of a video published by ENRESA
Palmottu (Finland)	Shows the <u>stability of spent fuel</u>	
Kinnekulle (Sweden)	Evidence of the <u>longevity</u> and maintenance of the desired properties of the <u>clay barrier</u>	

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