Radioactive Waste Management

Use of Natural Analogues in the UK Safety Case*

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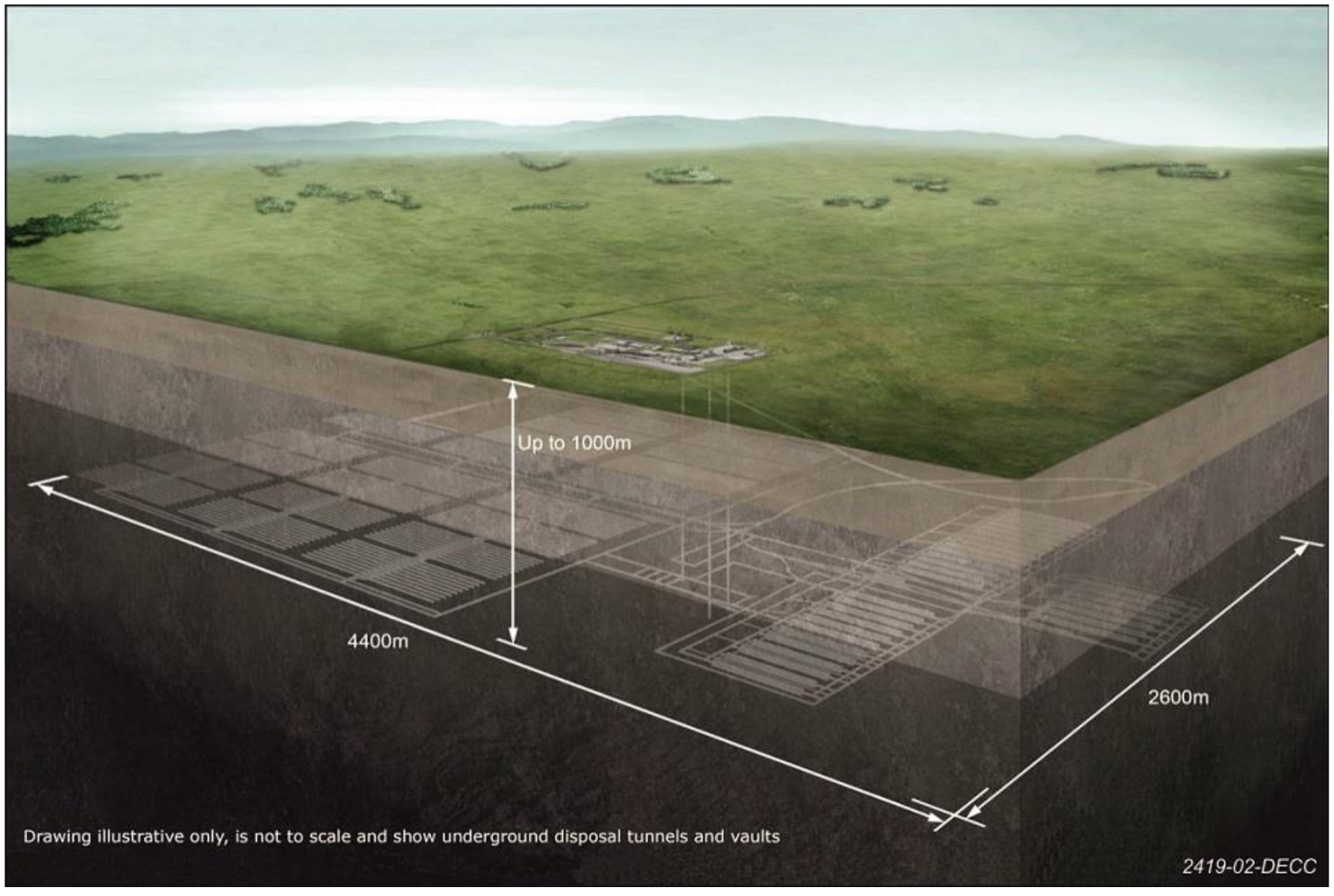
23rd May 2017, Prague

Radioactive Waste Management

***Or should it be "Environmental Safety Case"?**

Geological disposal



- Internationally accepted that the safest option for managing higher activity radioactive waste in the long term is geological disposal
- Solid waste deep placed underground in a specially constructed facilities – a repository
- Facilities contain multiple engineered barriers which work together with the geological environment to contain the radioactive material so that it does not cause harm to people or the environment

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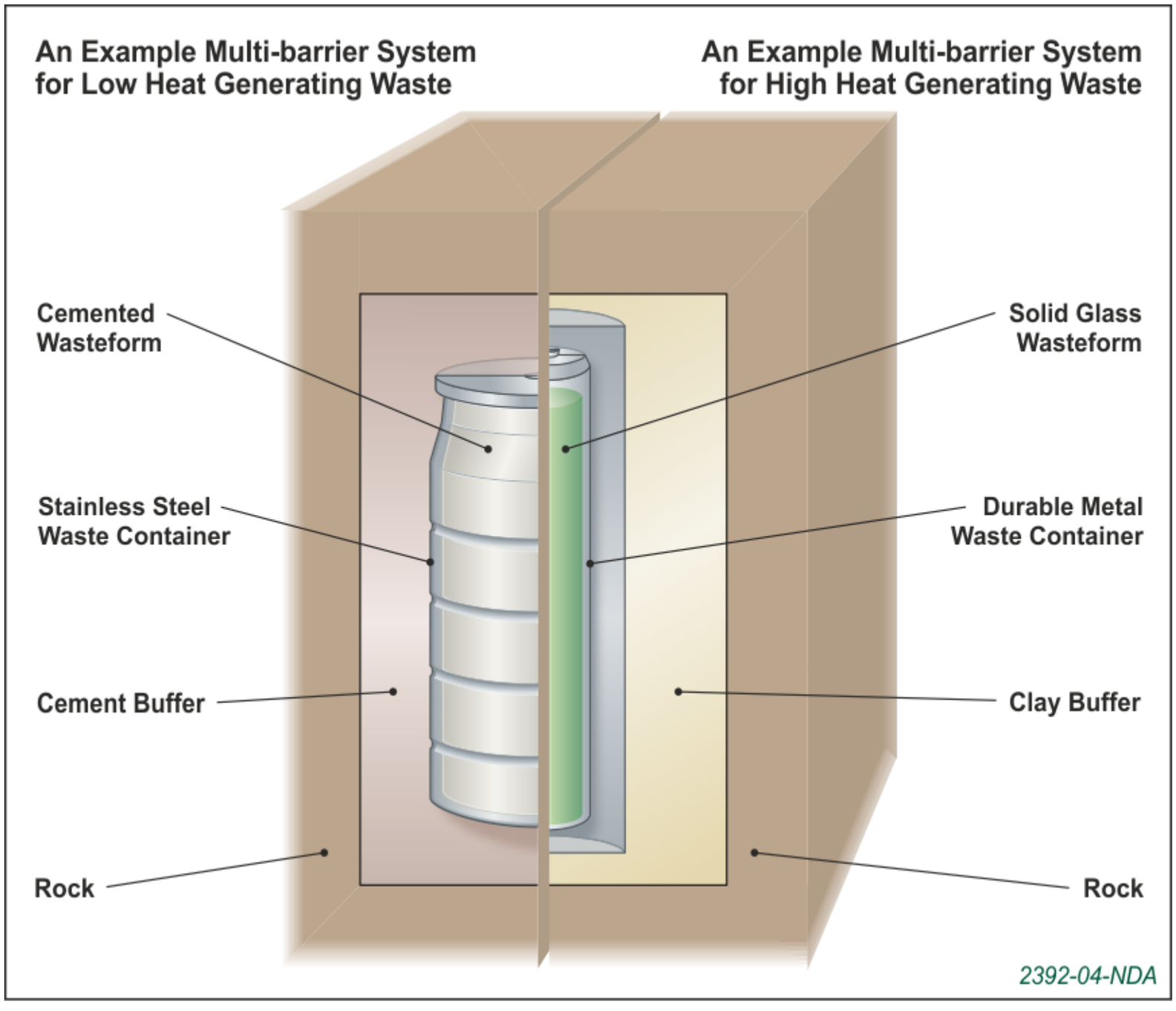
Repository engineered barrier system



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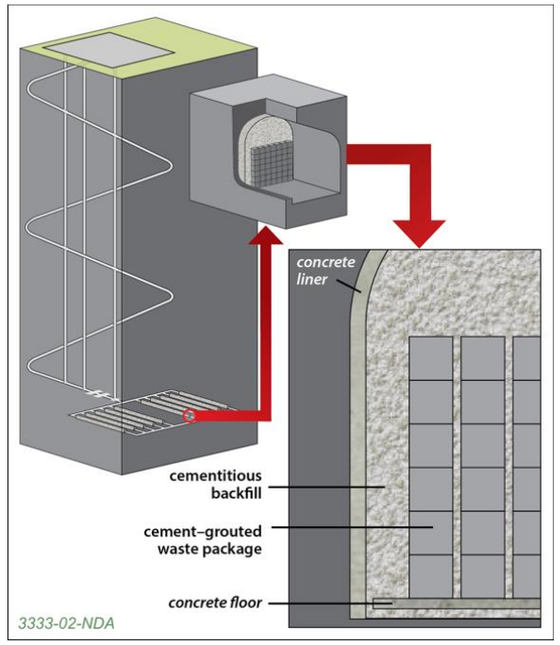
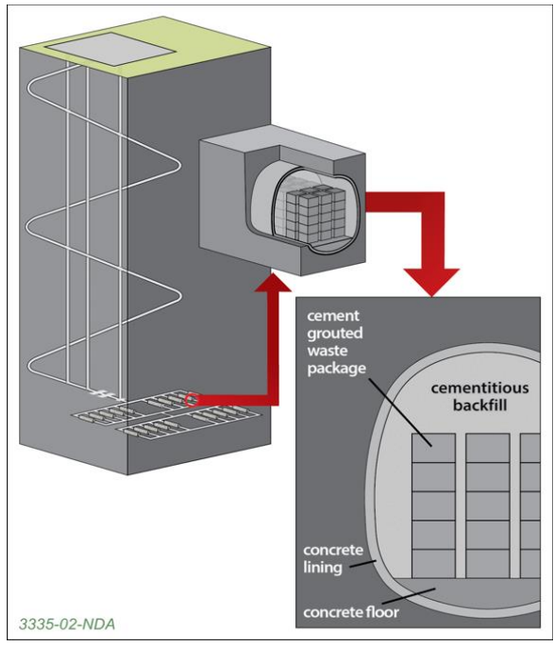
Illustrative disposal concepts

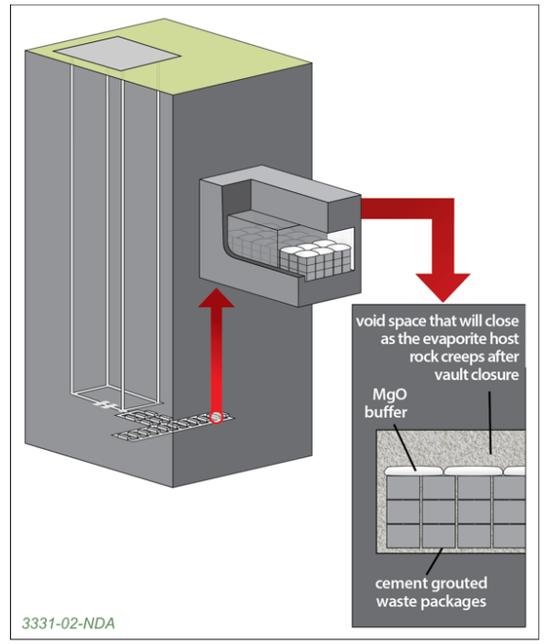
Low heat generating wastes



Crystalline rock

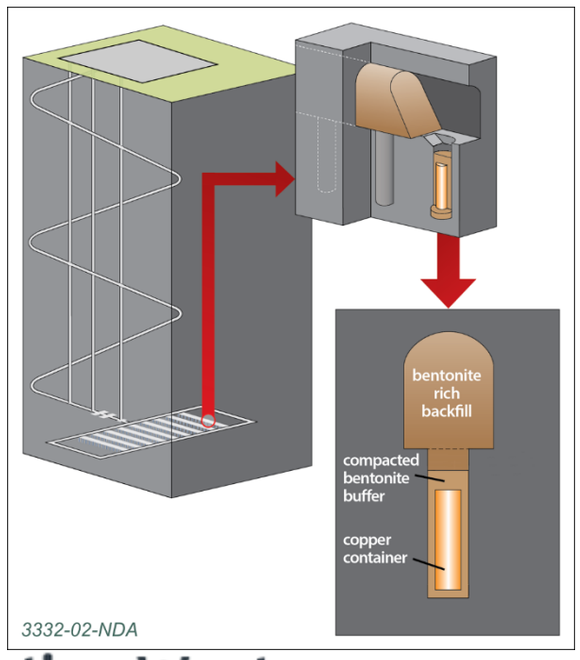


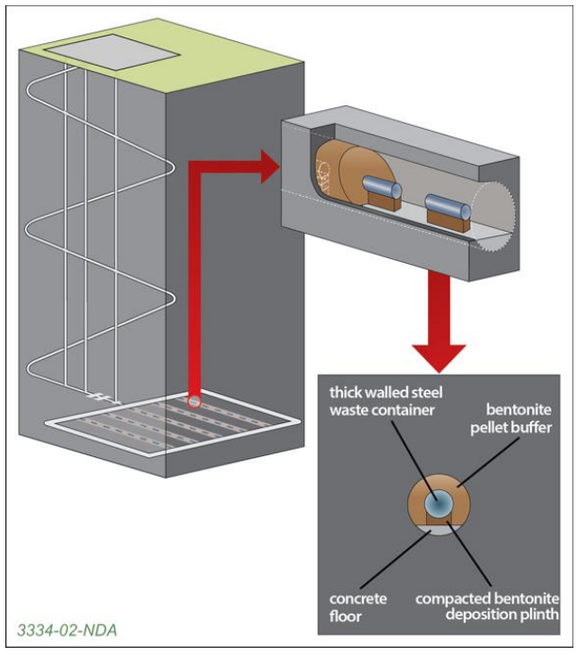
Sedimentary rock (clay)

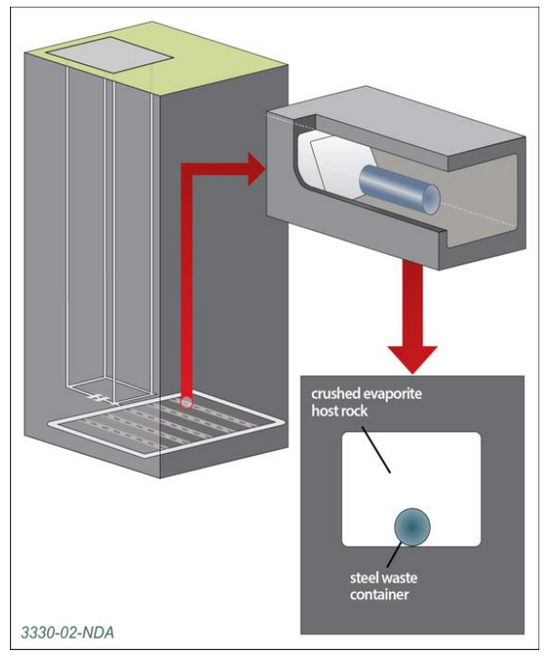


Evaporite rock (halite)

High heat generating wastes







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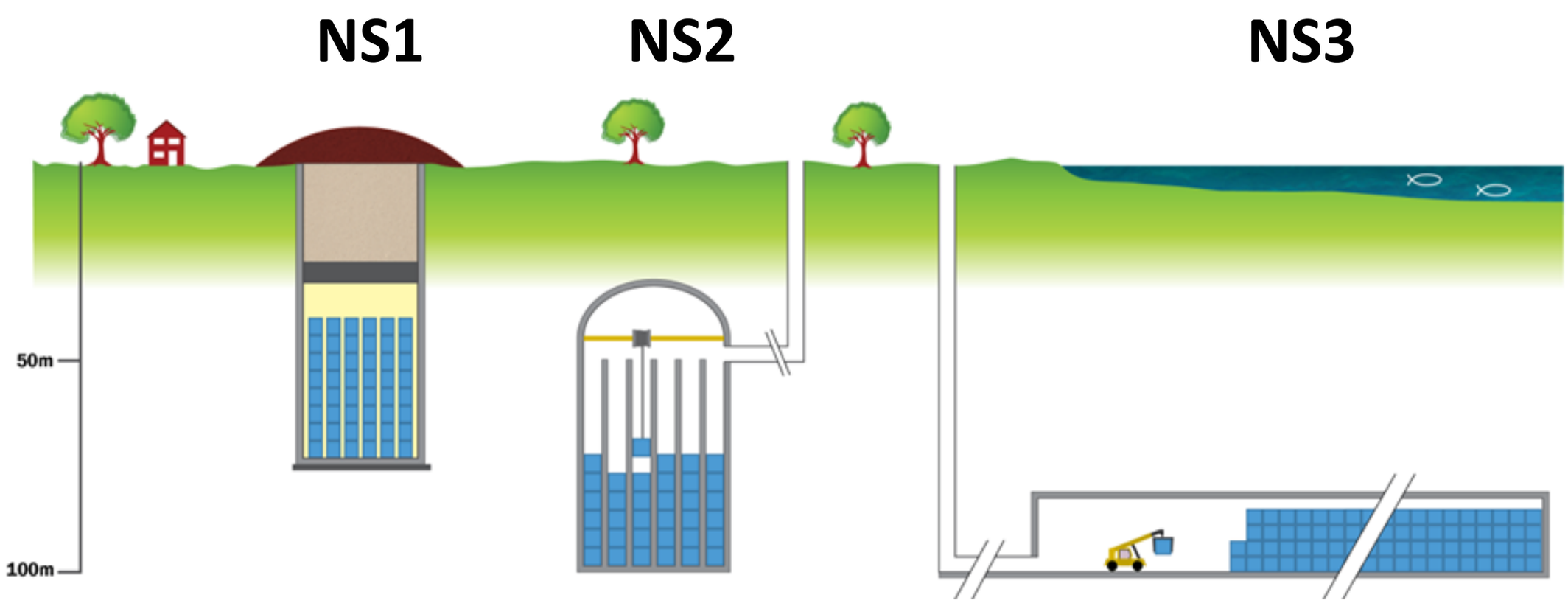
Near surface disposal facility concepts

- Direct access silo (example: Hunterston Pathfinder)
- Underground silo (example: SFR ILW Silo, Sweden)
- Vault facility (example: SFR L/ILW Facility, Sweden & Rokkasho, Japan)



Galson Sciences Ltd (2015), Integrated Project Team on Uranium: Phase 2 [Task ASS-3]; Feasibility of Nearer-Surface Disposal of DNLEU, Report for RWM, Report No. 1207-ASS-3-1, October 2015

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Role of natural analogues in radioactive waste management (I)

- It is not possible to simulate in, or extrapolate from laboratory studies, all of the very long-term processes that might affect the safety performance of a repository for radioactive waste
- Furthermore, it is necessary to address processes which are influenced by natural heterogeneities, which include large degrees of uncertainty and which operate over very long timescale
- It is therefore necessary to supplement laboratory data with information from in situ underground research laboratory experiments and natural analogues (including archaeological and industrial analogues)

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Role of analogues in radioactive waste management (II)

- Analogues – systems that have similar properties to components of repositories – have a unique role to play in a safety case
  - Demonstrate understanding of aspects of repository performance and provide evidence that certain materials can persist for long periods of time, or that e.g. processes can be inferred to occur at rates that are slow in comparison with timescales considered in the safety case
  - Extent to which natural system evolution in the past can be understood and modelled with existing tools and data, also gives an indication of the ability to determine the future development of a repository
- **Use of analogues is integral to a safety case, providing important arguments and building confidence**

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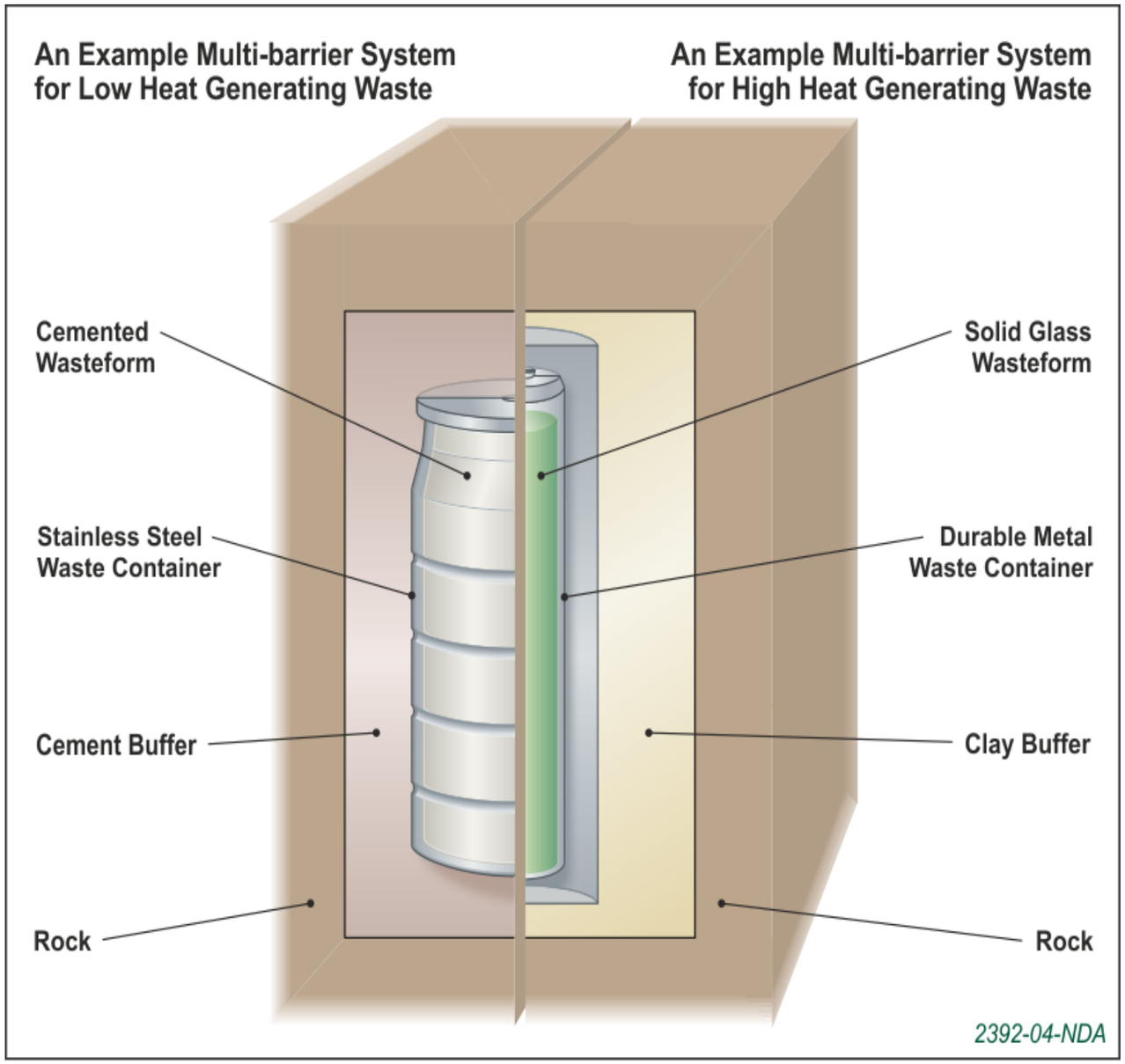
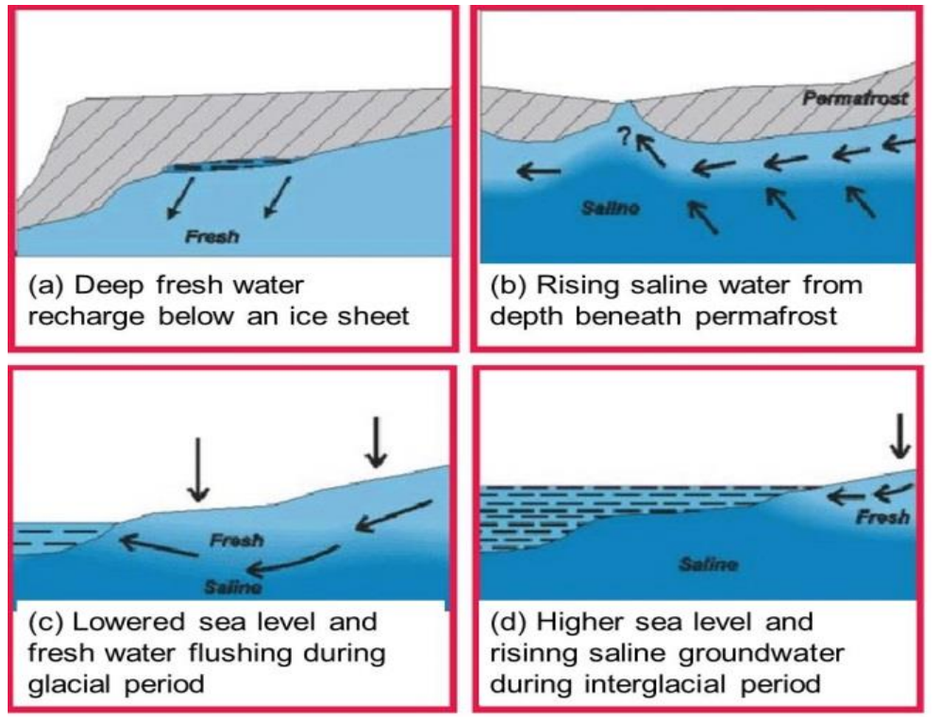
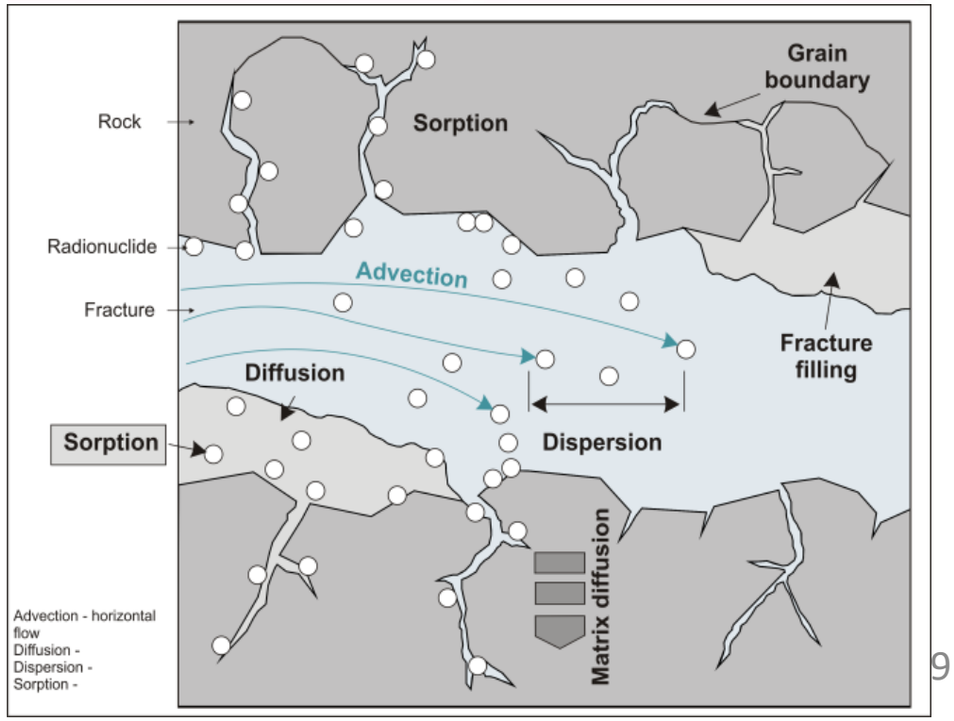
Natural analogues sought for….







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Natural analogues sought for….

Noting role of analogues in RWM's Research programme, current relevant activities include:

- Potential for fractured higher strength rocks to uptake radionuclides from groundwater – a natural analogue study
- Longevity of borehole seals: NA input and open questions
- Palaeohydrology of NW Cumbria

- All to be presented this week!

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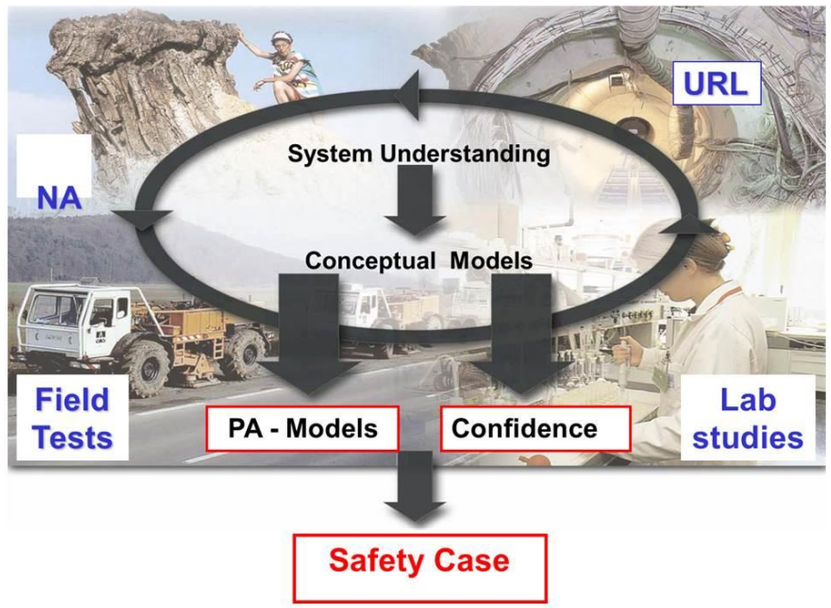
Analogue “topic” areas

1. Engineered Barrier System:
   - Wasteform (e.g. natural glasses as analogues of vitrified high level waste)
   - Container performance
   - Near-field barrier materials (e.g. Cyprus – long term isolation properties of clay)
2. Natural Barrier System
   - Long-term evolution of fractured crystalline host rocks (e.g. palaeohydrogeology / palaeoclimate studies)
   - Long-term evolution of clay host rocks
   - Long-term evolution of salt host rocks
   - Long-term isolation concepts
3. Radionuclide migration in natural systems
   - Retardation in natural systems
   - Colloid migration in natural systems
4. Whole system performance



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Engineered barrier system performance

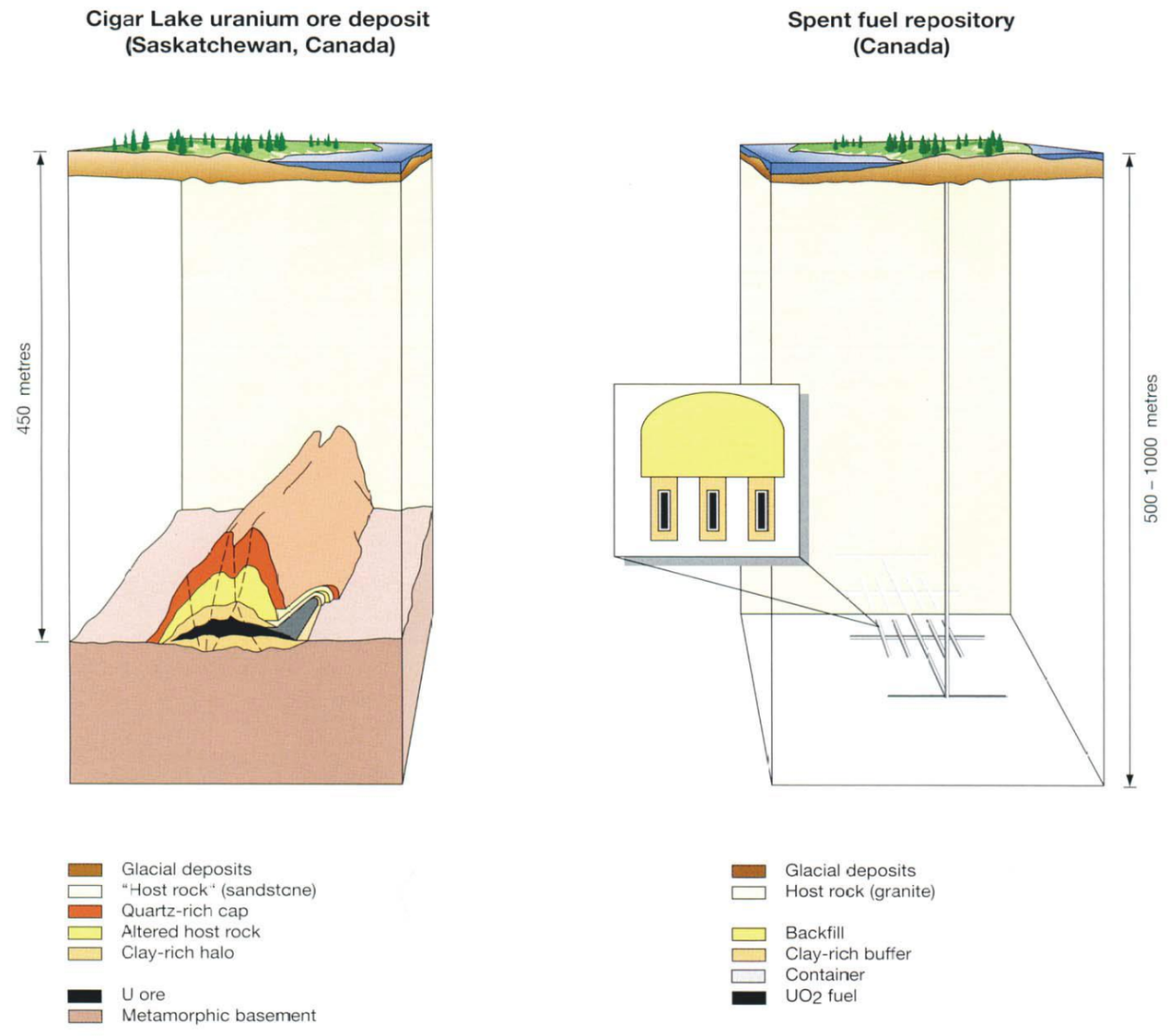
1. Archaeological cements: longevity of cementitious materials
2. Cement from Hadrian's Wall: longevity of cementitious materials
3. Northern Ireland: a cement analogue
4. Maqarin, Jordan: longevity of calcium silicate hydrate phases
5. Maqarin, Jordan: an analogue of the alkali disturbed zone
6. Oman: survival of microbes in cementitious environments
7. Maqarin, Jordan: survival of microbes in cementitious environments
8. The Dunarobba Forest, Todi, Italy: long-term isolation properties of clay
9. The Philippines: long-term isolation properties of clay
10. Cyprus: long-term isolation properties of clay
11. Mudrocks altered by igneous intrusions: thermal stability of clay barriers
12. Engineered barrier system: colloids
13. Bentonite: is erosion possible at repository depths?
14. Radiolysis

Natural barrier system

1. European Commission PADAMOT project: using palaeohydrogeology to predict future climate change impacts on groundwater systems
2. Äspö and Laxemar, SE Sweden: long-term stability of a deep groundwater system
3. Lupin Mine: a natural analogue for a permafrost environment
4. Tono: a natural analogue for host rock stability
5. Natural analogues for a repository in a salt host rock
6. Matrix diffusion: long-term isolation properties of the host rock
7. Poços de Caldas, Osamu Utsumi mine and Morro do Ferro, Brazil - Introduction
8. Poços de Caldas, Morro do Ferro, Brazil – radionuclide migration
9. Poços de Caldas, Osamu Utsumi mine, Brazil – radionuclide migration
10. Poços de Caldas – Osamu Utsumi mine, Brazil – redox fronts
11. The El Berrocal Project - uranium mobilisation and migration
12. Needle's Eye, Scotland - uranium mobilisation and migration
13. Broubster, Scotland - uranium mobilisation and migration
14. South Terras Mine: uranium mobilisation and migration
15. Alligator River, Australia - uranium mobilisation and migration
16. Loch Lomond, Scotland - a study of halogen migration
17. Poços de Caldas, Morro do Ferro, Brazil – colloid transport

Whole system performance

Oklo - a natural analogue for the long-term behaviour of a repository
Cigar Lake, Canada – a natural analogue for an entire repository?



The similarity of the structure of the Cigar Lake ore body (far left) with that of the multiple EBS for a repository for HLW or SF (left) (from Miller et al., 2003)

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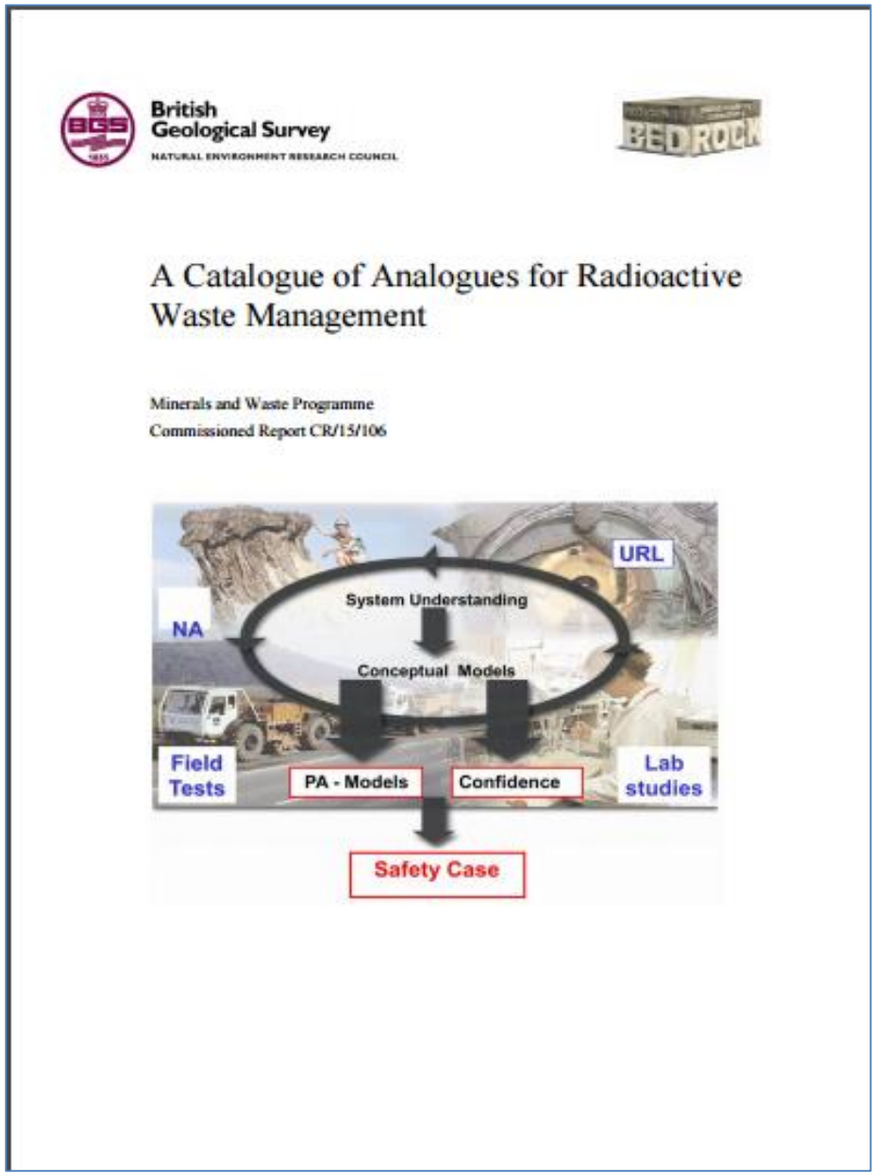
Catalogue of natural analogues for radioactive waste management

- Examples of data from analogue systems that can be used to support a safety case for a GDF.
- Scope includes all aspects of disposal relevant to the UK situation, international usage
- Range of waste types and potential GDF host rocks are considered and examples are grouped into four main sections - the engineered barrier system, natural barrier system, radionuclide migration in natural systems, and whole system performance.
- Published at https://rwm.nda.gov.uk/publication/a-catalogue-of-analogues-for-radioactive-waste-management/
- Extensive reference list, including NA examples discussed in this presentation



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Natural Analogues – proceed with caution!

- Analogues do not provide conclusive proof that materials will survive for the required periods in the environments of a particular repository, as the conditions under which the analogue material has survived may not match those expected to occur or evolve in a repository

- Nevertheless, appropriate analogues can be helpful in providing a long-term practical demonstration to support the theoretical and mathematical safety arguments

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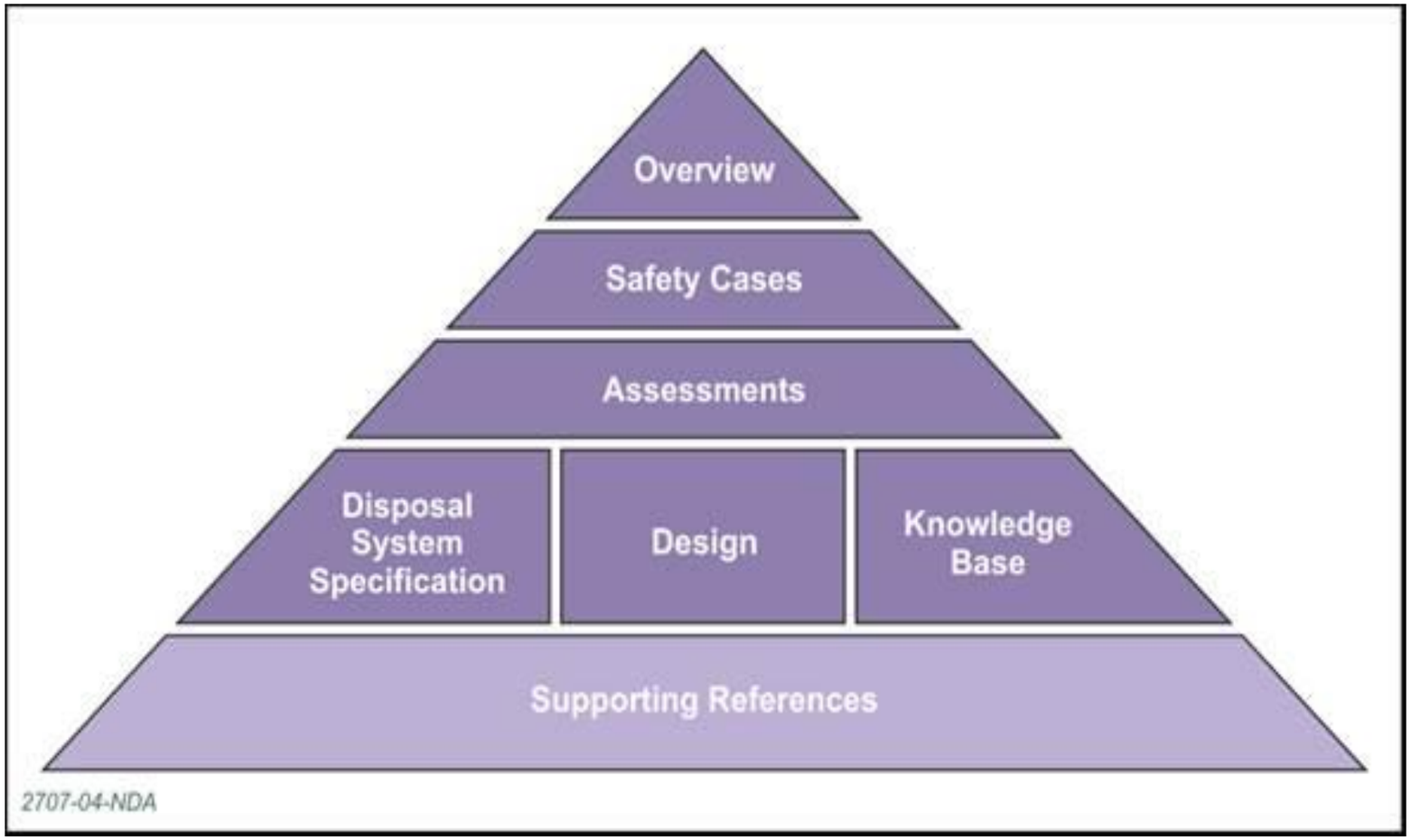
Safety case*

- Implementers of a repository need to satisfy independent regulators of its safety and security before appropriate licences can be issued (covers construction, operation and in the long term after the facility has been closed)
- Safety case gives confidence that a repository can be implemented safely, by describing and assessing the safety and environmental implications associated with all aspects of geological disposal of higher activity radioactive wastes



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*Full title in RWM parlance is “Disposal System Safety Case” (DSSC)

RWM's "Geological Disposal Environmental Safety Case* Strategy"

RWM report NDA/RWM/090 2012

"Analogues can be helpful in demonstrating understanding of aspects of GDF performance and provide evidence that certain materials can survive for long periods.

However, they do not provide conclusive proof that these materials will survive for the required periods in the environments of a particular GDF, as the conditions under which the analogue material has survived may not match those expected to occur or evolve in a GDF.

Therefore, analogues will be used with caution, and can only ever provide supporting arguments in an Environmental Safety Case.

Nevertheless, appropriate analogues can be helpful in providing a long-term practical demonstration to support the theoretical and mathematical safety arguments."

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*Environmental Safety Case (ESC) in UK programme equates to a post-closure safety case in international studies; it considers safety after facility closure, in the UK case to 1 million years in the future.

RWM's "Generic Environmental Safety Case"

RWM report DSSC/203/01 (2016) – approved for publication

- Component of DSSC.
- Discusses how, in each geological environment, the geological barriers of a GDF will provide environmental safety functions that support the isolation and containment of radioactive waste.
- Presents generic understanding of how a suitably sited and designed GDF can isolate and contain the wastes for the required timescales, supported by RWM's knowledge base.
- Given generic stage of the UK geological disposal programme, detailed total system modelling to evaluate base and variant scenarios is not possible. Instead, for this generic ESC, relatively simple total system models have been developed based on illustrative examples of different geological environments and disposal concepts.
- Relationship between stage of national programme and approach to safety case development.

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RWM's "Generic Environmental Safety Case"

RWM report DSSC/203/01 (2016) – approved for publication

- "*It is a requirement of the GRA* that an environmental safety case presents* ***multiple lines of reasoning*** *to support its evaluation of safety. The use of* ***safety arguments*** *based on the understanding of the* ***environmental safety functions of the GDF and their evolution*** *represents an* ***important line of reasoning****, which can be developed at this generic stage for the illustrative disposal concepts and can continue to be applied in the context of a site-specific ESC. Insight modelling and more detailed numerical modelling to understand how radionuclides are contained by each component of the GDF's multi-barrier system constitute further lines of reasoning*."
- **Question - level of detail issue regarding prominence of "the quantitative" versus "the qualitative"?**

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*Environment Agency and Northern Ireland Environment Agency, *Geological Disposal Facilities on Land for Solid Radioactive Wastes: Guidance on Requirements for Authorisation*, February 2009.

RWM's "Generic Environmental Safety Case"

RWM report DSSC/203/01 (2016) – approved for publication

- Other lines of reasoning may also be used to support an evaluation of post-closure safety. These include the use of **complementary indicators and natural and archaeological analogues**.
- For example, complementary indicators include measurements of groundwater age (by comparisons of oxygen isotope concentrations) that can give confidence in calculated groundwater flow rates.
- **Archaeological analogues** include studies of materials proposed for use in the engineered barriers of the GDF to give confidence in calculations of barrier performance.
- **Natural analogues** can include comparisons with geological sites that have similarities to one or more components of the GDF.

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RWM's "Generic Environmental Safety Case" – Use of Analogues

RWM report DSSC/203/01 (2016) – approved for publication

- "*Observations of **natural analogues** support the view that, in suitable geological conditions, **copper can remain stable for very long timescales**. As discussed in the **Waste Package Evolution Status Report**, there are many cases of native copper deposits around the world, including extensive deposits in Michigan, USA and the UK. Also anthropogenic analogues of copper stability are available that date from the Bronze Age (as early as 3000 BC)*."

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RWM's "Generic Environmental Safety Case" – Use of Analogues

RWM report DSSC/203/01 (2016) – approved for publication

- "*Thick-walled carbon steel and cast iron containers are also likely to provide very long periods of containment in both alkaline and near-neutral pH conditions. For example, 10 mm of carbon steel may not be perforated by corrosion for up to around 100,000 years in alkaline conditions and 10,000 years in near-neutral pH conditions.* ***Confidence*** *in the expected* ***durability of steel*** *in near-neutral pH conditions is provided by* ***anthropogenic analogues****. In these conditions, the large majority of observations indicate corrosion depths of less than 10 mm in 1,000 years. Examples of well-preserved iron artefacts from the Roman era include a* ***large hoard of iron nails*** *buried in clay soil in Scotland almost 2,000 years ago.*"

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RWM's "Generic Environmental Safety Case"

RWM report DSSC/203/01 (2016) – approved for publication

Two key messages:

- Underpinning the ESC is an approach to safety assessment based on multiple lines of reasoning, involving both qualitative and quantitative analysis. Total system modelling has been used to develop an understanding of how different components of the engineered and natural barrier system contribute to environmental safety. Qualitative analyses have included the use of **archaeological and natural analogues** of material behaviour.
- The gESC (2016) provides a demonstration of RWM's capability to evaluate the environmental safety of geological disposal, including through quantitative assessment of contaminant transport and with reference to **natural and anthropogenic analogues of material behaviour**.

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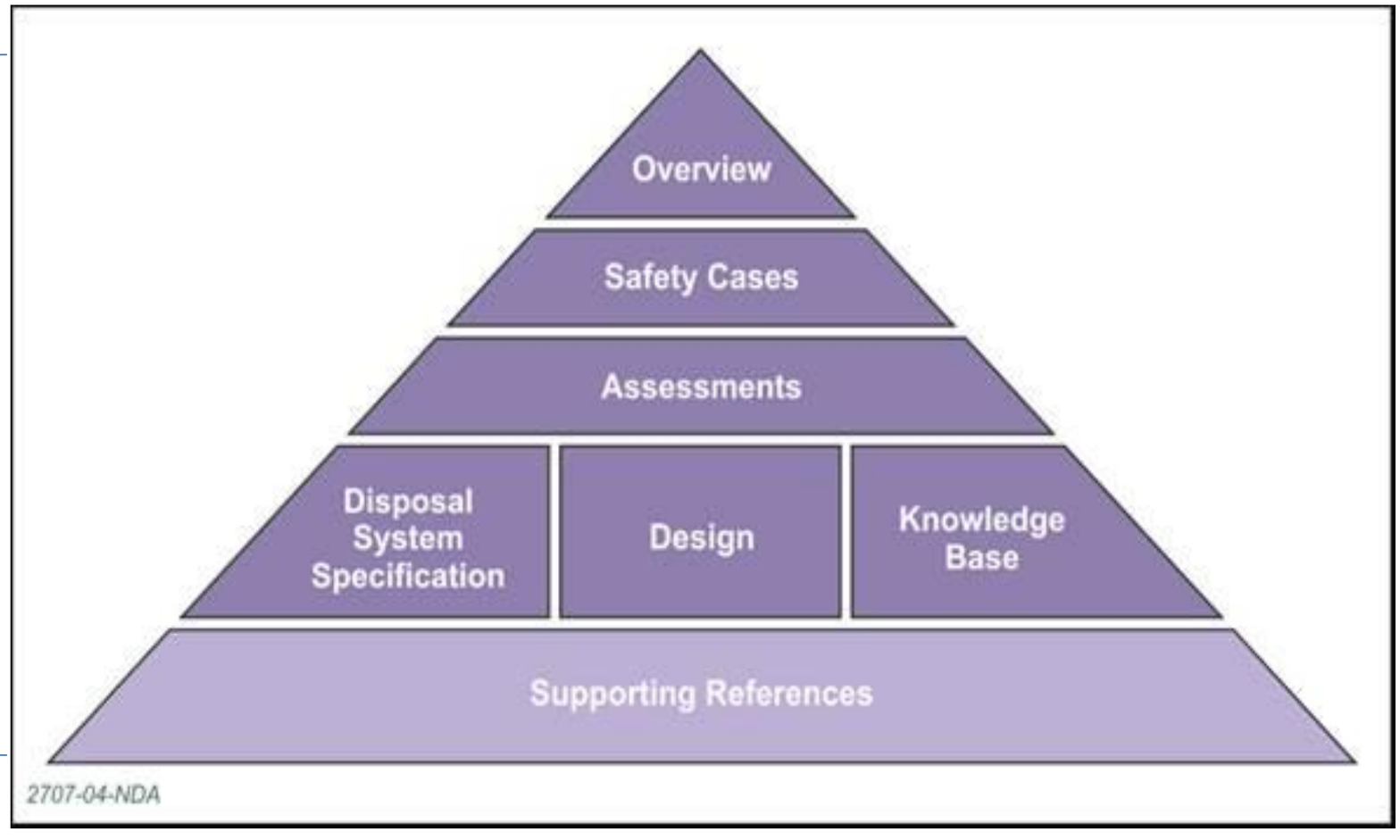
RWM's Utilisation of Analogues in 2016 Generic Disposal System Safety Case

gDSSC



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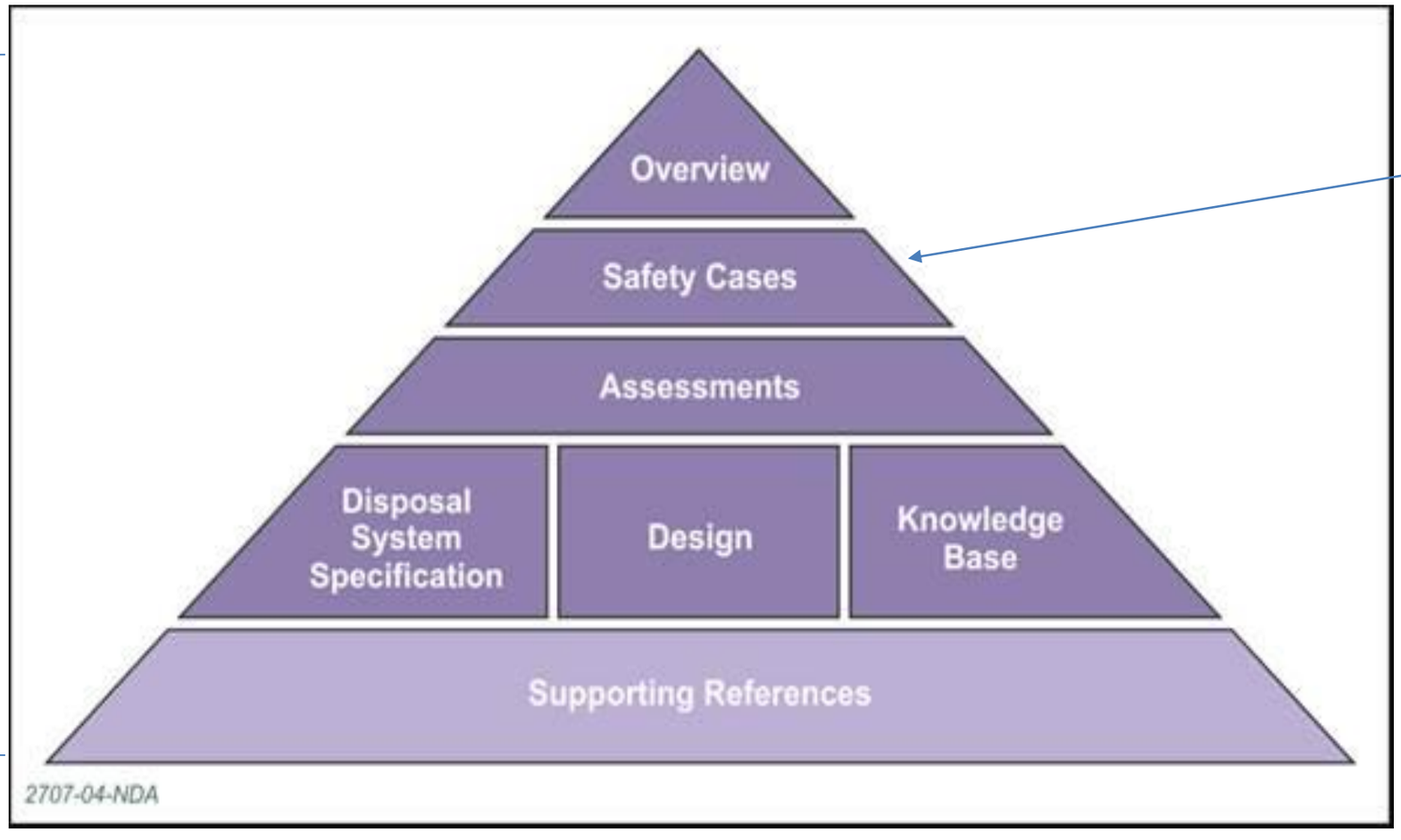
RWM's Utilisation of Analogues in 2016 Generic Disposal System Safety Case

gDSSC



Generic Environmental Safety Case, OSC and TSC

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RWM's Utilisation of Analogues in 2016 Generic Disposal System Safety Case

- Knowledge base contains information on a lot of analogues, see e.g. ***A Catalogue of Analogues for Radioactive Waste Management,*** *A.E. Milodowski, W.R. Alexander, J.M. West, R.P Shaw, F.M. McEvoy, J.M. Scheidegger and L.P. Field, British Geological Survey Report CR/15/106 to RWM, 2015.*
- Utilised / referred to in RWM Research Status Reports.
- So, it is true to say RWM's generic Disposal System Safety Case utilises a range of analogues.
- Explicit reporting of use of information based on analogue studies is arguably at a lower level in the generic Environmental Safety Case, although this document itself is fully supportive of the relevance of analogues to a safety case.
- Real issue? Reasons? Importance / significance?

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RWM's Utilisation of Analogues in 2016 Generic Disposal System Safety Case

- The use of understanding derived from studies of suitable analogues in the context of aspects of the GDF is embedded in the approach to developing the gESC.
- Use of analogues is likely to vary on road from a generic to a site-specific programme basis.
  - "Lag" in deployment of a more extensive knowledge base on analogues in a developing ESC to be expected?
  - Research in respect to enhancing knowledge base and authoring of ESC may be undertaken by different teams in an organisation (likely to vary organisation by organisation); different technical background / approach?
  - Issue cannot just be one of communications (itself rather readily resolved)
  - Preconceptions of e.g. how to develop an ESC / Effect of precedence akin projects has accidental side-effect of not appreciating or understanding how use could be made of analogues?

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RWM's Utilisation of Analogues in 2016 Generic Disposal System Safety Case

- Unlikely that a company starts developing an ESC from a blank piece of paper; often it is the case that 'something' exists before to build on 'next time around'.
- Does "*we've always done it this way*" approach to ESC development allow information from analogues to be most appropriately considered? (that said, availability of analogue studies is hardly new!)
- Is there an implicit preference when developing an ESC to strongly prefer a quantitative approach over a more 'woolly' qualitative one? Does this affect the role that can be afforded to analogues throughout the development of an ESC?
- A case of not quite sure what to make of analogue information or how it could used in an ESC, given the associated caveats and uncertainties – out of sync with the approach to quantitative modelling?
- Is information / additions to the knowledge base as derived from an analogue study actually being presented in a manner that is 'sympathetic' to the modus operandi of the production of an ESC?

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RWM's Utilisation of Analogues in 2016 Generic Disposal System Safety Case

- Analogue community / ESC community joint resolution?
- Some 'frustration' exists! Perception that some ESCs not as robust as could be, for lack of thoroughness of approach in relation to use of analogue-derived knowledge base.
- Shared by regulators?
  - Nothing in it for an implementer to produce an ESC that is not as thorough as it could have been in consideration of attaining regulatory requirements; ongoing 'campaign' to sell the benefits of analogues.
  - Pushing on an open door, but sometimes time is needed for message being delivered to be appreciated (in the first instance), then acted upon when it is timely to do so in any one particular national programme.
  - Key role of NAWG in ensuring message isn't either "lost in the post", or "lost in translation" from acquired science to deployment as part of ESC (or DSSC) and equivalents thereof.

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Setting Ourselves a Test….

- For current activities involving NA at RWM:
  - Potential for fractured higher strength rocks to uptake radionuclides from groundwater – a natural analogue study
  - Longevity of borehole seals: NA input and open questions
  - Palaeohydrology of NW Cumbria
- Adequate thought given to communication of key messages, in terms that relate / ‘speak’ to gESC approach / personnel responsible for gESC?
  - Meaningfulness of above question, site-generic versus site-specific?
  - Is it inevitable that the knowledge base relating to analogues will be more thorough and detailed than the ESC?

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Analogues in a safety case

Analogues can be used in support of a safety case in several ways, with the input ranging from qualitative to quantitative.

- Analogues can increase our confidence in the safety case by identifying mechanisms or processes that could be relevant to the repository and its long term evolution
- Analogues provide understanding of the impact of processes that may occur over long (geological) time scales but which cannot be readily studied under laboratory conditions or within laboratory experimental timescales
- Analogues can be used to test model predictions or extrapolations from laboratory experiments, in regard to the performance of the repository host rock and engineered barrier materials over long timescales

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Analogues in a safety case II

1. Analogues can be focussed on **improving understanding** of key processes and model / database testing
2. **Significant role in public communications and staff training**
3. **Increase confidence** in extrapolating results from laboratory and field experiments to the repository environments
4. Broad deployment – use not restricted to limited number of components of safety case
5. Engineered barrier system isolation and containment safety functions, and evolution over repository-relevant timescale
6. Understanding evolution of geological barrier, and how this might be affected by future long-term natural processes
7. **Key role in integrated safety case that draws on all of laboratory experiments, testing in underground laboratories, modelling and natural analogues – more than 'nice to have'**

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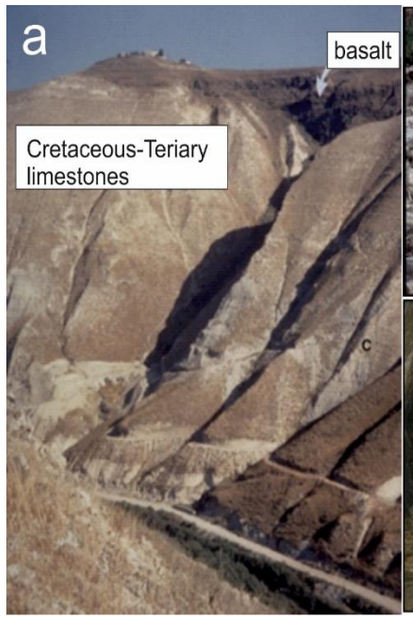
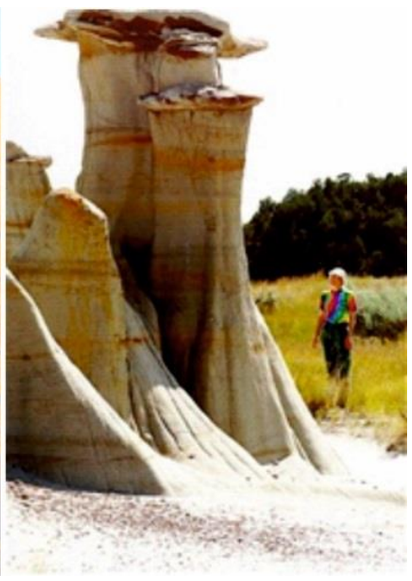
Excellent international collaboration and cooperation opportunities…





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