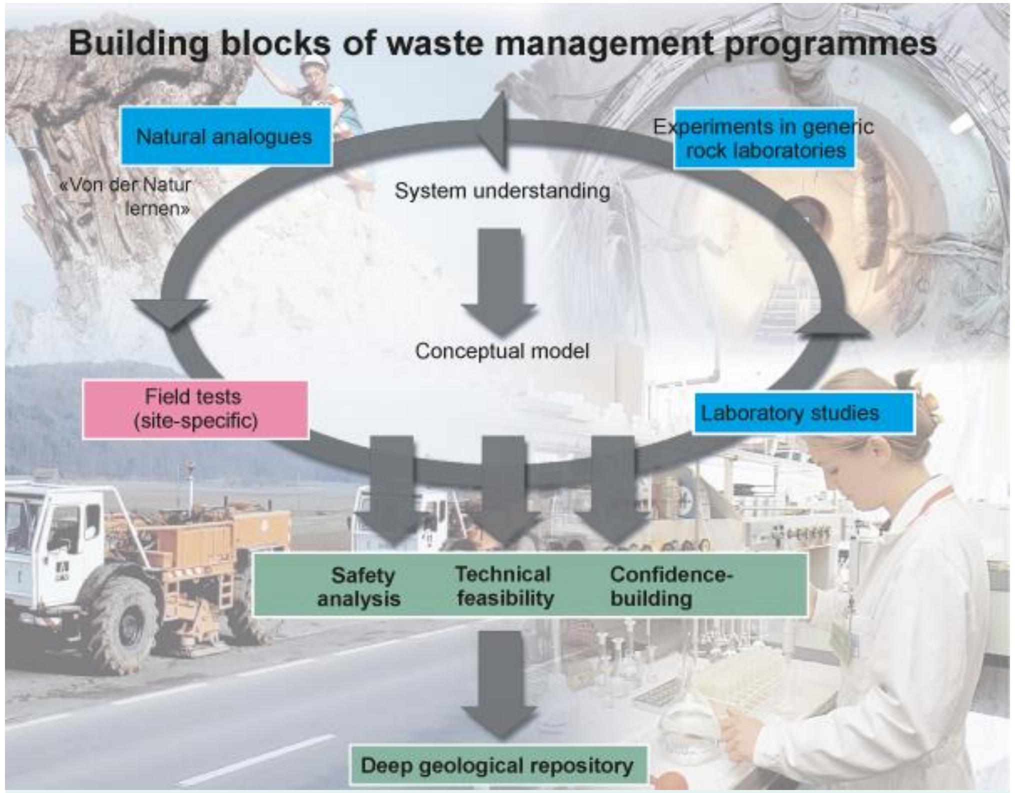
Nuclear Waste Services

Natural Analogues – A proposed strategy for implementation within the Nuclear Wate Services (UK) programme of Geological Disposal

Simon Norris, Heini Reijonen (GTK) , Russell Alexander (Bedrock Geosciences)

Introduction & Background

- Nuclear Waste Services (NWS) UK
  - continuing to move forward with the siting programme for a geological disposal facility (GDF)
  - focus of the programme has shifted from generic stage to a more sites-specific stage
  - Natural Analogues (NA) have been considered in the generic safety case, at general level
  - Use of analogue information can support current programme
- Objective
  - to realize the full potential of NAs for system understanding during the developing GDF project



Example of the role of NAs within geological disposal projects

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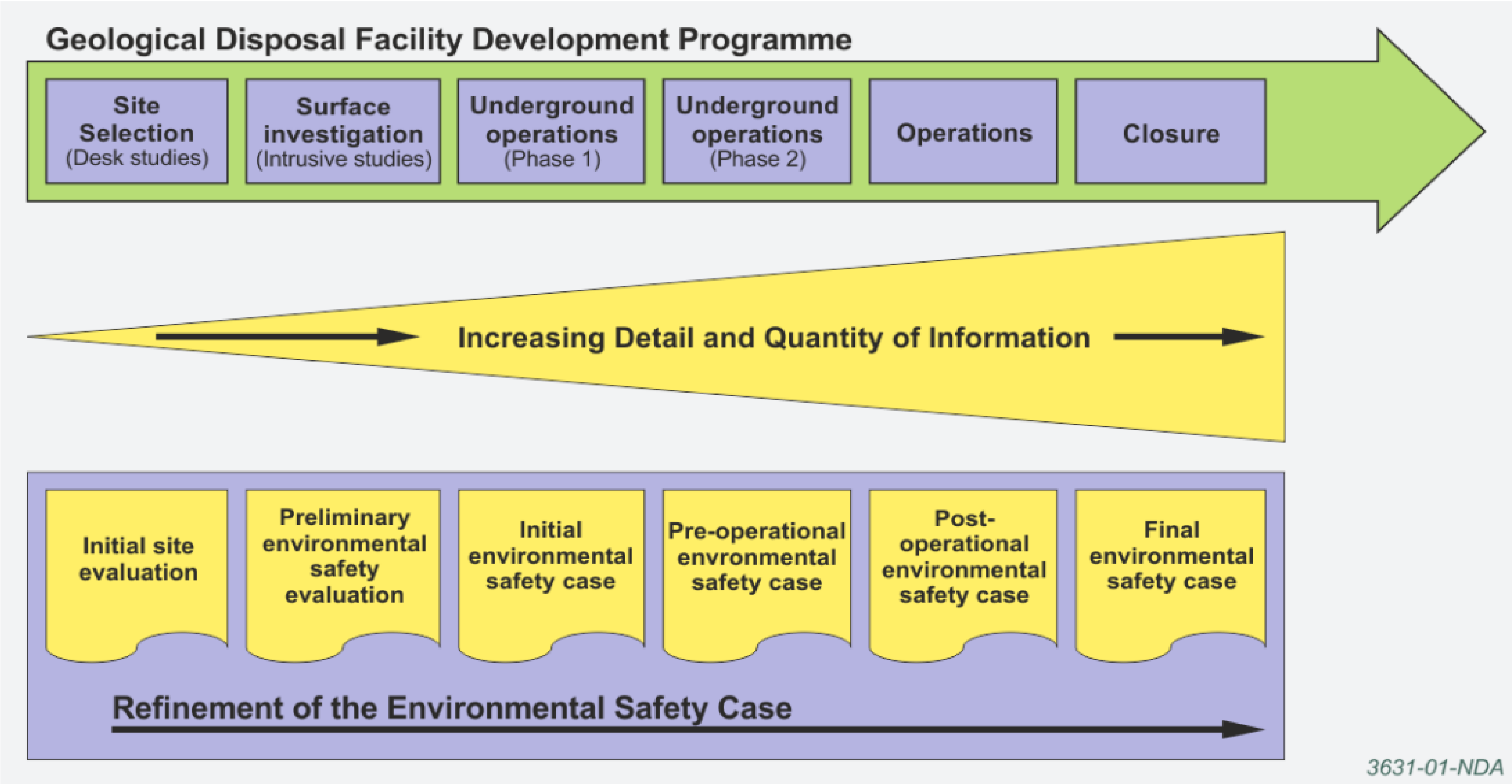
Increasing information within a GDF project



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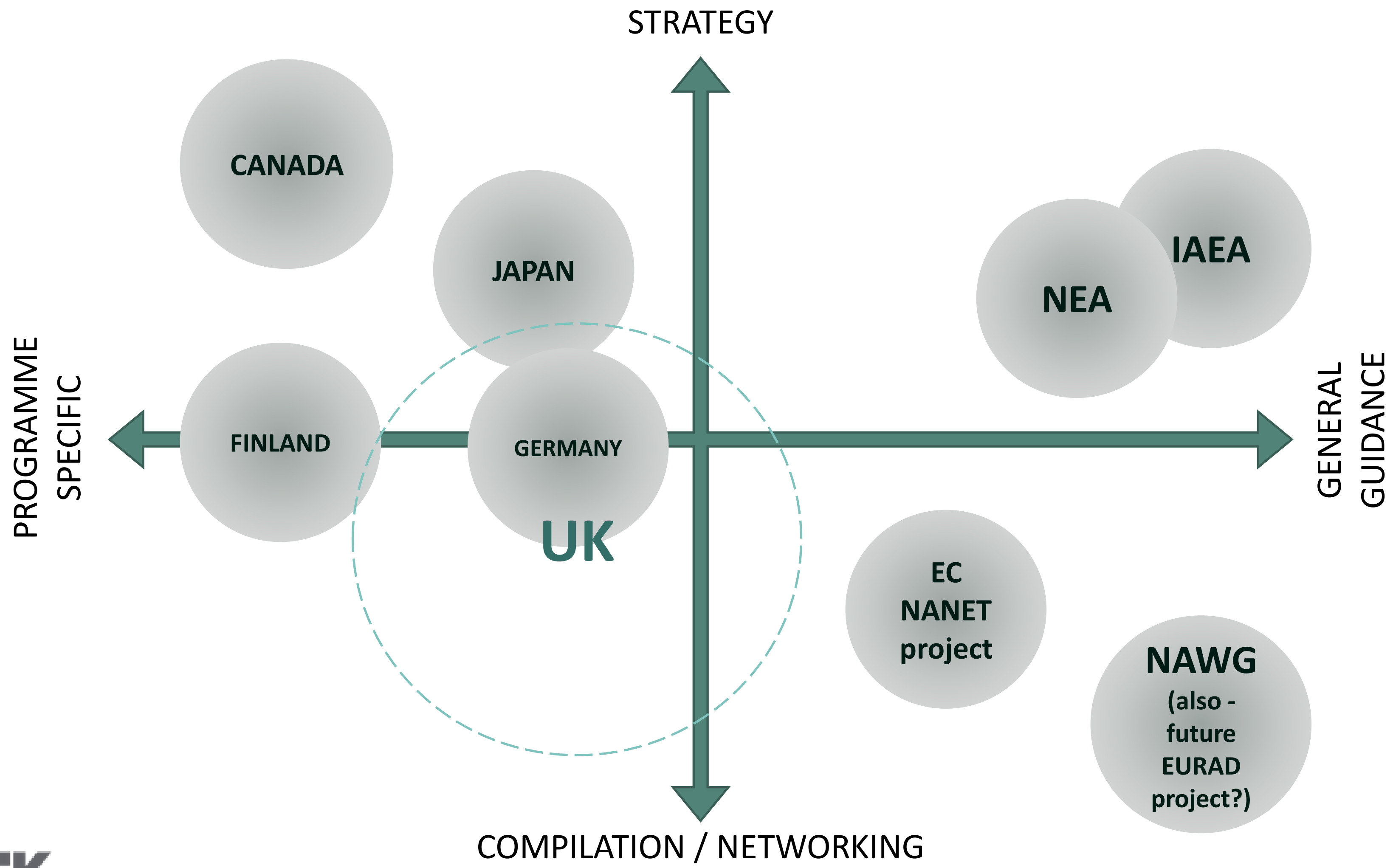
Review of NA strategies

- Several general overviews published over the years
- Few programme-specific strategies regarding the use and development of NAs have been reported
- Inherently included in many programmes, even if not mentioned



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Examples of the use of NA data in safety case to assess long-term safety

Radioactive waste	*Spent fuel (UO_2) corrosion rates*
Waste packaging (copper / steel)	*Maximum rate for pitting of copper / corrosion of steel*
Concrete	*Development of secondary phases due to hyperalkaline leachates*
Natural clays	*Bentonite longevity < 100℃*
Host rock	*Matrix diffusion depths*

Examples of safety cases utilizing NAs

Before 1980
- Nas included in the overall concept for geological disposal
- USE OF NATURAL MATERIALS

1980
- SWEDEN: KBS-3 (SKB 1983)
- SWITZERLAND: Pojeckt Gewähr (Nagra 1985)

1990
- SWEDEN: SKB-91 (SKB 1992); SFR-1, Project Safe (Andersson et al. 1998); SR-97 (SKB 1999)
- FINLAND: TVO-92 (Vieno et al. 1992); TILA-99 (Vieno & Nordman 1999)
- SWITZERLAND: Kristallin-1 (Nagra 1994)
- CANADA: AECL EIS (AECL 1994)

2000
- JAPAN: H-12 (JNC 2000); JAEA (2007)
- SWITZERLAND: Opalinus Clay (Nagra 2002)

2010
- FINLAND: TURVA-2012 e.g. Posiva (2012)
- SWEDEN: SR-Site (SKB 2011); Forsmark (2014) Sidborn et al. 2014
- RWM (2016) – generic safety case

2020
- FINLAND: Posiva (2021) Operational license application SC

Lessons Learned - Research

- What is defined as a NA study is occasionally confusing and literature reviews should ideally cover all relevant publications on the topic
- Critical considerations / reviews are called for in Safety Case application
- In many programmes, NA screening has been done via FEP analyses, but the results may not always produce a state-of-the-art product (see safety culture in next slide)
- **Screening of existing material for both relevance and significance to current sites and designs is required**
- NA studies are most effective when integrated in a combined programme of laboratory, modelling and underground rock laboratory studies (cf. Alexander et al. 1998)

Lessons Learned – 'Safety Culture'

- **There is a lack of critical screening and strategic planning in most programmes**
- Inherited/predefined complementary/alternative status of NA information → risk of detaching relevant information from other evidence (lab work etc.)
- Uncertainties associated with NAs are often overestimated compared to other evidence used in the safety case

Lessons Learned – Programme Level Use

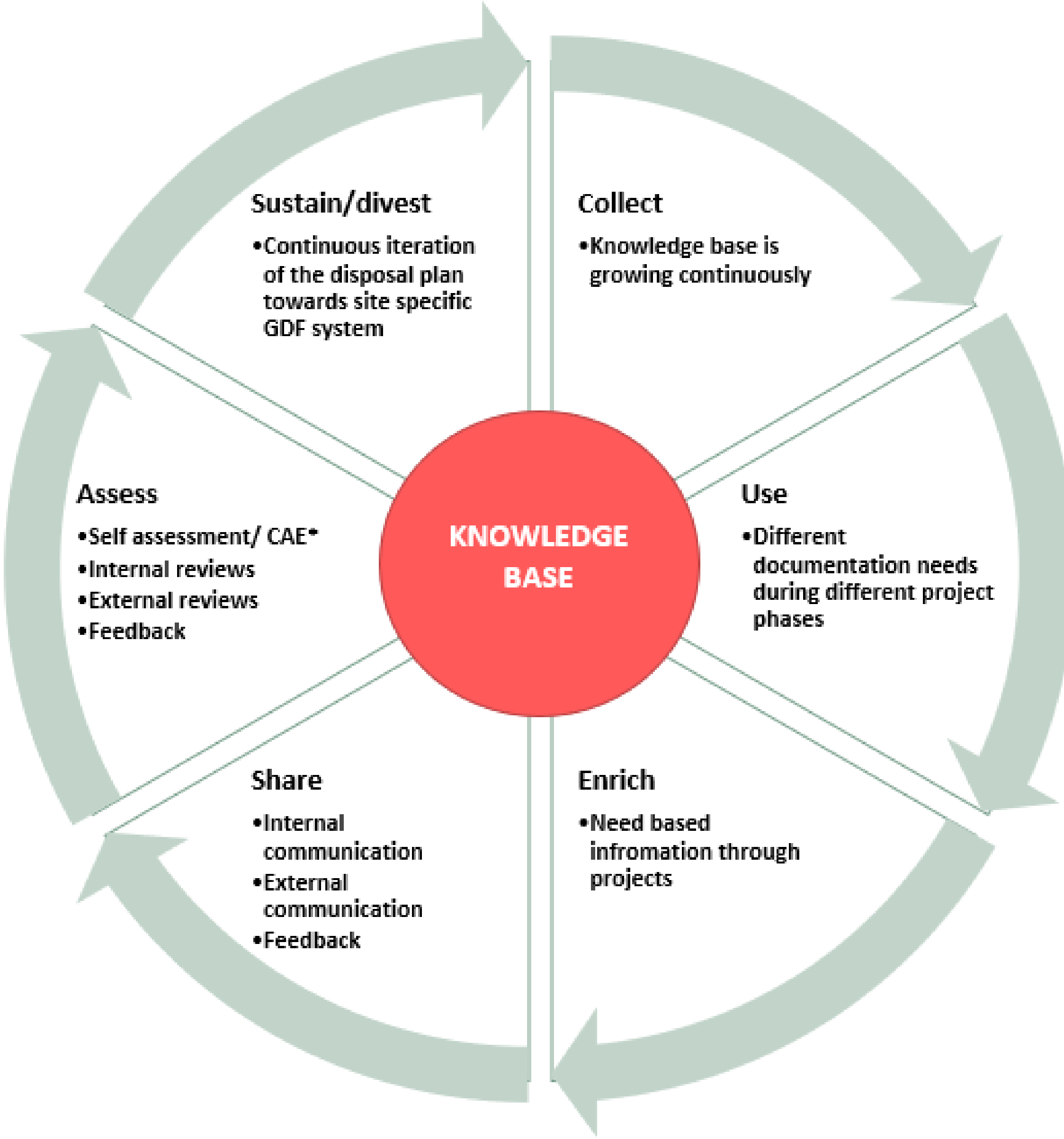
- In addition to more traditional uses (siting, safety case and communication), **NAs have significant potential for use in development of GDF design** (e.g. EBS materials)
- There are differences in degree of success of using analogues depending if they have been directed to communication, siting, design, or safety case etc

Lessons Learned - Communication

- **There are good examples of using NAs in local audience communication**
- Less has been achieved in communicating between scientific disciplines
- Communication aspects utilising NAs have potential to be developed further

Proposed Strategy

- NA catalogue has been updated for NWS (Alexander & Reijonen 2023)
  - Which forms a part of NWS' knowledge base
- Systematic approach to develop the NA catalogue as the GDF programme evolves as a part of NWS' knowledge base
- Linking with digital safety case



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Safety Case Structure

- The Environment Agency Guidance on Requirements for Authorisation Section 6.2.2 defines:

"An environmental safety case is a set of claims concerning the environmental safety of disposals of solid radioactive waste, substantiated by a structured collection of arguments and evidence."

→ Claims, Arguments, Evidence (CAE)

- CAE will need to be updated as the programme advances and arguments/evidence move from the current generic stage ("*we can* …") to site-specific stage (ultimately "*we have* …")
- Office for Nuclear Regulation also describe (and provide guidance for) CAE in its Technical Assistance Guide 51 ('The Purpose, Scope and Content of Safety Cases'), Appendix 4
  - Note however that CAE can mean something slightly different in operational safety contexts…

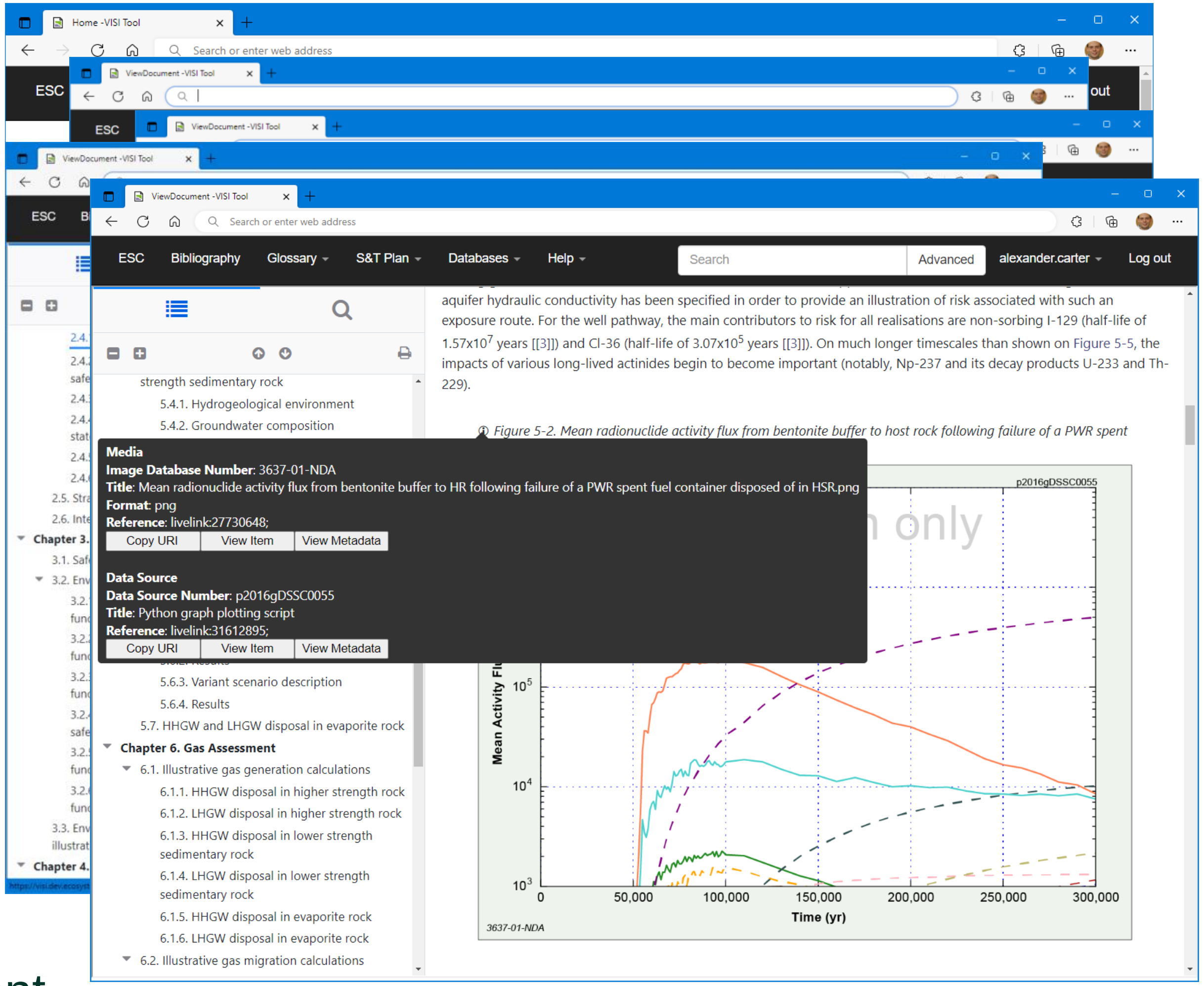
Logical structure – Example

Assessed risks from the disposal facility after the period of authorisation are consistent with environmental safety standards (from Requirement R6)

• GRA (DSS Part A) Requirements	*lead to us making*
• <u>Claims</u>	*on the performance of*
• Barrier system components	*which satisfy*
• Safety functions	*through making*
• Safety <u>Arguments</u>	*which are underpinned by*
• Scientific <u>Evidence</u>	*within our knowledgebase* (and utilise FEPs, models, data etc.)

ViSI (Visualisation of System Information)

- ViSI is a tool developed to store the NWS Safety Case narrative (underlying digital ‘documents’ and associated CAE/argumentation diagram)
- All documents and diagrams are viewable and searchable online, but can still be accessed via PDF
- The system currently contains the
  - **Safety case, safety assessment and status reports**
  - **Bibliographic database**
  - **Glossary**
  - **Science and Technology plan, listing planned future research tasks**
- All content may be hyperlinked to any other content



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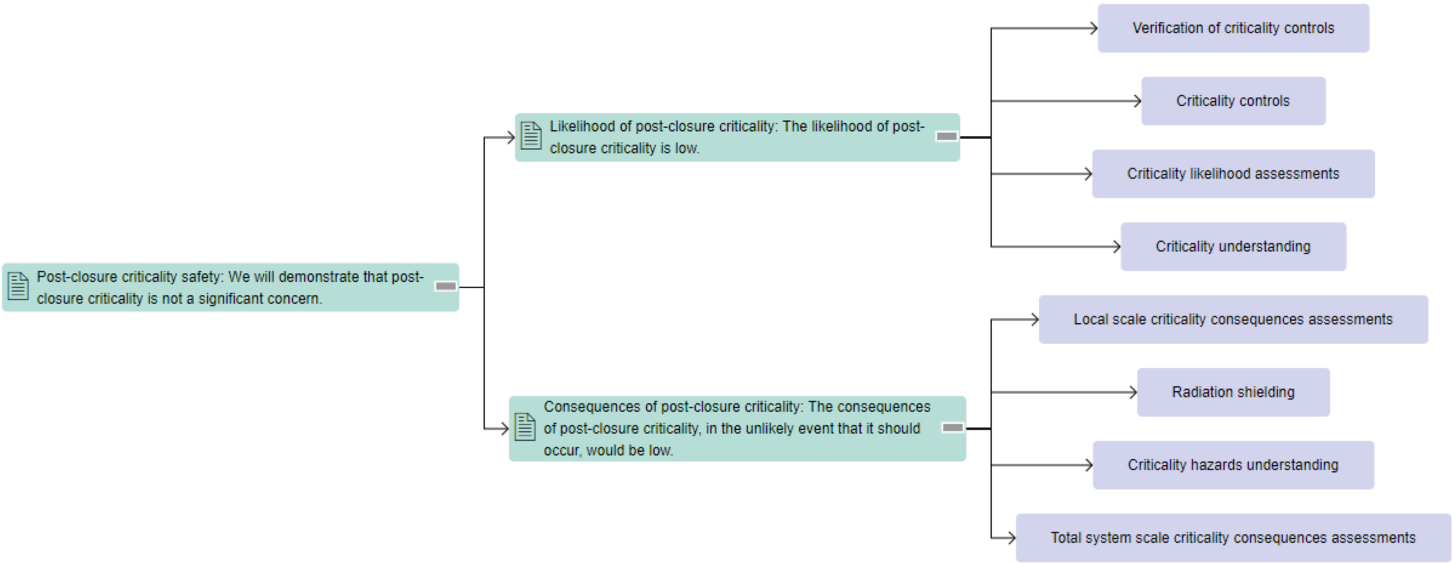
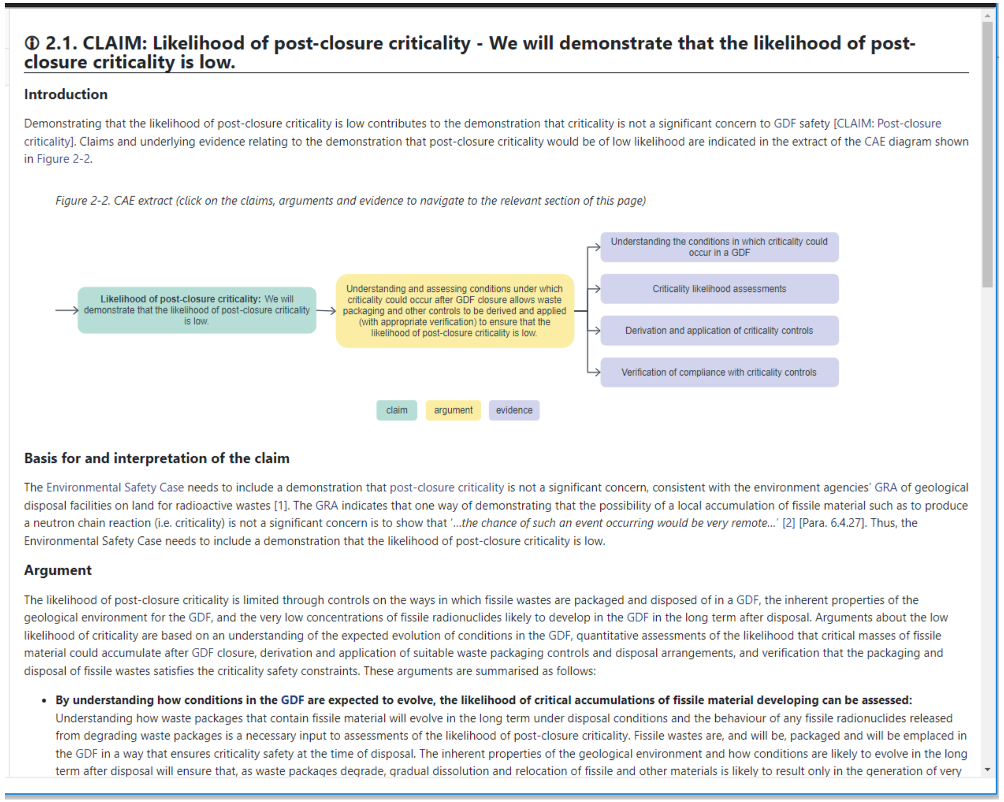
ViSI – Example

- Each claim has a summary sheet which provides safety arguments linking to underlying sub-claims or evidence
- ‘Live’ tasks may be cited from any content in place of evidence (needs-driven research)





ⓘ 2.1. CLAIM: Likelihood of post-closure criticality - We will demonstrate that the likelihood of post-closure criticality is low.

Introduction

Demonstrating that the likelihood of post-closure criticality is low contributes to the demonstration that criticality is not a significant concern to GDF safety [CLAIM: Post-closure criticality]. Claims and underlying evidence relating to the demonstration that post-closure criticality would be of low likelihood are indicated in the extract of the CAE diagram shown in Figure 2-2.

Figure 2-2. CAE extract (click on the claims, arguments and evidence to navigate to the relevant section of this page)

Basis for and interpretation of the claim

The Environmental Safety Case needs to include a demonstration that post-closure criticality is not a significant concern, consistent with the environment agencies’ GRA of geological disposal facilities on land for radioactive wastes [1]. The GRA indicates that one way of demonstrating that the possibility of a local accumulation of fissile material such as to produce a neutron chain reaction (i.e. criticality) is not a significant concern is to show that ‘*...the chance of such an event occurring would be very remote...*’ [2] [Para. 6.4.27]. Thus, the Environmental Safety Case needs to include a demonstration that the likelihood of post-closure criticality is low.

Argument

The likelihood of post-closure criticality is limited through controls on the ways in which fissile wastes are packaged and disposed of in a GDF, the inherent properties of the geological environment for the GDF, and the very low concentrations of fissile radionuclides likely to develop in the GDF in the long term after disposal. Arguments about the low likelihood of criticality are based on an understanding of the expected evolution of conditions in the GDF, quantitative assessments of the likelihood that critical masses of fissile material could accumulate after GDF closure, derivation and application of suitable waste packaging controls and disposal arrangements, and verification that the packaging and disposal of fissile wastes satisfies the criticality safety constraints. These arguments are summarised as follows:

- **By understanding how conditions in the GDF are expected to evolve, the likelihood of critical accumulations of fissile material developing can be assessed:** Understanding how waste packages that contain fissile material will evolve in the long term under disposal conditions and the behaviour of any fissile radionuclides released from degrading waste packages is a necessary input to assessments of the likelihood of post-closure criticality. Fissile wastes are, and will be, packaged and will be emplaced in the GDF in a way that ensures criticality safety at the time of disposal. The inherent properties of the geological environment and how conditions are likely to evolve in the long term after disposal will ensure that, as waste packages degrade, gradual dissolution and relocation of fissile and other materials is likely to result only in the generation of very

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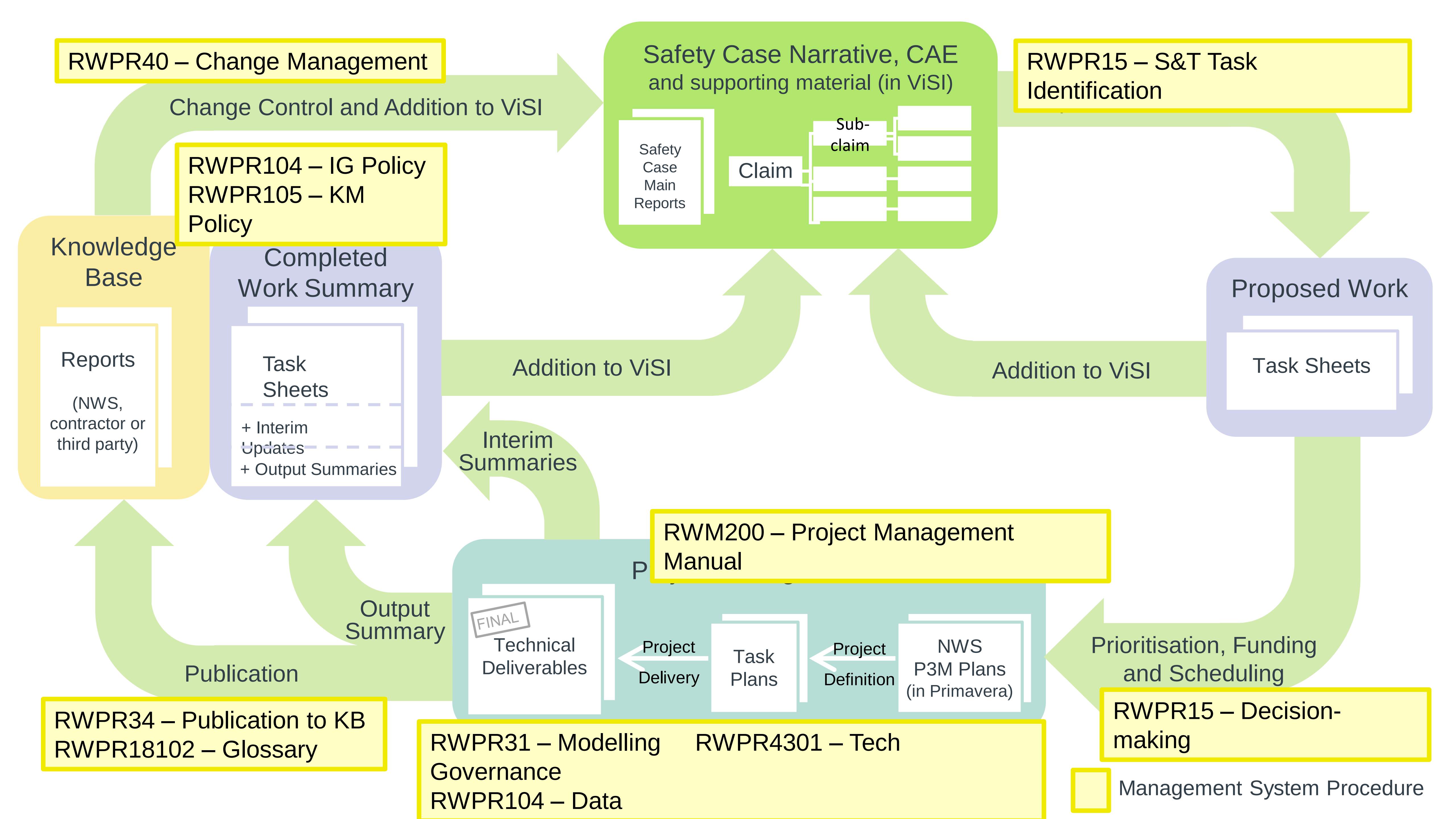
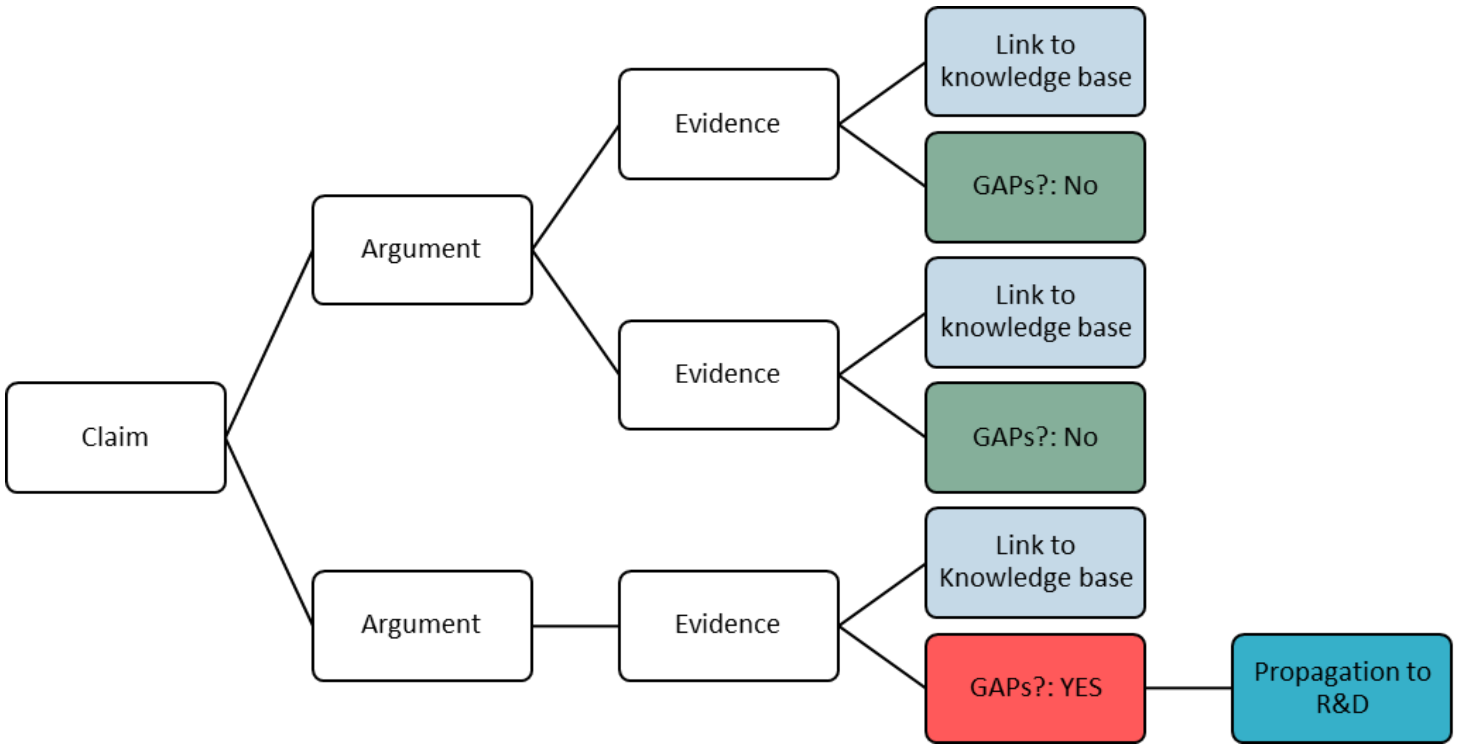


RWPR40 – Change Management
Change Control and Addition to ViSI
Safety Case Narrative, CAE
and supporting material (in ViSI)
Safety Case Main Reports
Claim
Sub-claim
RWPR15 – S&T Task Identification
RWPR104 – IG Policy
RWPR105 – KM Policy
Knowledge Base
Reports
(NWS, contractor or third party)
Completed Work Summary
Task Sheets
+ Interim Updates
+ Output Summaries
Addition to ViSI
Addition to ViSI
Proposed Work
Task Sheets
Interim Summaries
RWM200 – Project Management Manual
P
FINAL
Technical Deliverables
Project Delivery
Task Plans
Project Definition
NWS P3M Plans (in Primavera)
Output Summary
Publication
Prioritisation, Funding and Scheduling
RWPR15 – Decision-making
RWPR34 – Publication to KB
RWPR18102 – Glossary
RWPR31 – Modelling Governance
RWPR4301 – Tech
RWPR104 – Data
Management System Procedure

Connecting with Safety Case

- Connecting with safety case: claims, arguments and evidence (CAE tool)
- Part of GAP analysis, in addition to relevance and significance reviews of existing materials also new studies can be initiated (need based)



Proposed Outlook – Generalised Overview

NWS's evolving programme	Safety Case stage	Objectives (of safety case)	Activities in NA knowledge base	NWS NA research needs	NA research outcomes
Consultation – establishing partnerships with communities **(on-going in 2023)**	Generic ESC	Statement of confidence for long-term safety Stakeholder communication Feedback to design	Compilation of the NA Catalogue Participation in international NA projects Networking Update of the NA Catalogue Integration with the ViSI tool FEP mapping Use of NAs in stakeholder communications	Participation in relevant projects (safety case driven) Additional NA studies relevant to 1. Potential site areas and/or EBS 2.Communication with the local community via NAs	NA Catalogue mapped to the general FEP list allows gap analysis Additional mapping with requirements and arguments Improved understanding on the geological context of potential siting areas
Site investigations	Site specific ESC	As above Screening of FEPs for their relevance to site (and design) specific ESC Stakeholder communication	Screening of FEPs (relevance and significance) Clear indications on keeping / omitting data Gap analysis Project work Use of NAs in stakeholder communications	Additional NA studies relevant to: 1. Site characterisation 2. site selection 3. selected site 4. design 5. operational safety 6. communication with the local community via NAs	Update of the NA database (preferably to NA Catalogue format) Gaps identified Potential new research identified New NA results
Construction	Site specific ESC with increasing detail and monitoring data Potential optimisation of the design	Statement of confidence for long-term safety Stakeholder communication Feedback to design Screening of FEPs complete	Final FEP list, new additions if new processes are encountered State-of-the-art NA update Use of NAs in stakeholder communications	As above	As above
Operation and closure	Periodical ESC including potential optimisation	Checking the robustness of the system Stakeholder communication	As above	As above	As above

Take Home Messages – Handling NA

- NA data can, and should, be handled with the same procedures as any other laboratory-derived and model-derived information, data and parameters
- Systematic knowledge management of NA information (including recording substituted/removed data) is an integral part of the recommended strategic approach
- NWS’ digital environment provides an apt methodology
- Utilisation of NA information successfully is greatly improved when made easily accessible

Take Home Messages – Role of NA

- Recognize potential of NAs - Stop overlooking of NAs over other evidence
- Uncertainties exist in all forms of data:
  - *Uncertainties for NAs are generally related to their less certain boundary conditions (often due to inadequate characterization of the sites)*
  - *Short-term, small-scale laboratory and URL experiments have the biggest uncertainties in extrapolation of the results into the far future*
  - *For a 100,000 to 1 -million- year safety assessment time frame, towards the far future NAs is the key pillar of the safety case*

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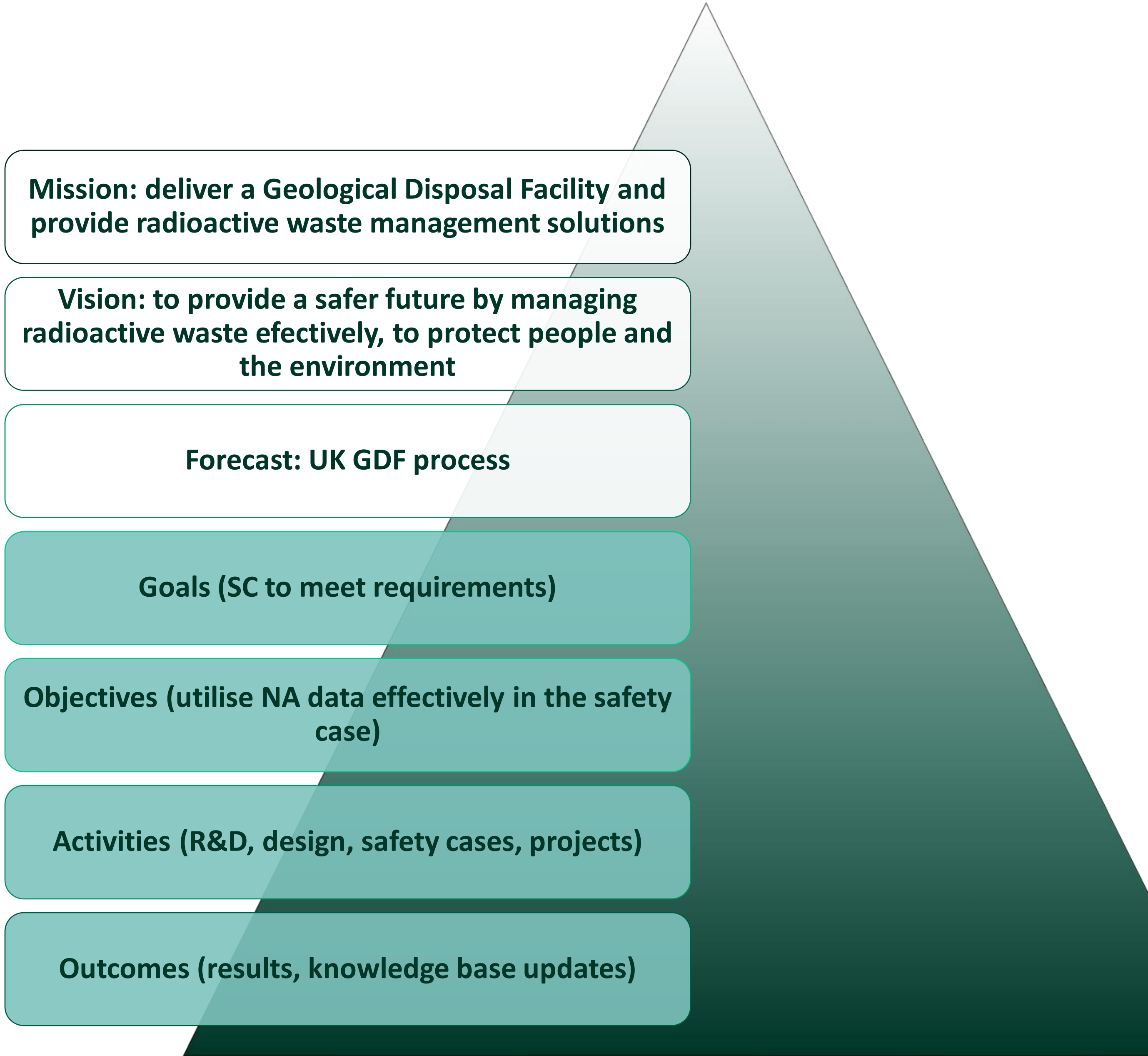
Conclusions

- To realise a full potential of NA for system understanding:
  - A proposed strategy for full integration of NAs in the SC has been developed (Reijonen & Alexander 2023)
  - Proposed strategy report is supported by an update of the NA catalogue (Alexander & Reijonen 2023)



Update on UK GDF Siting Process - Analogues

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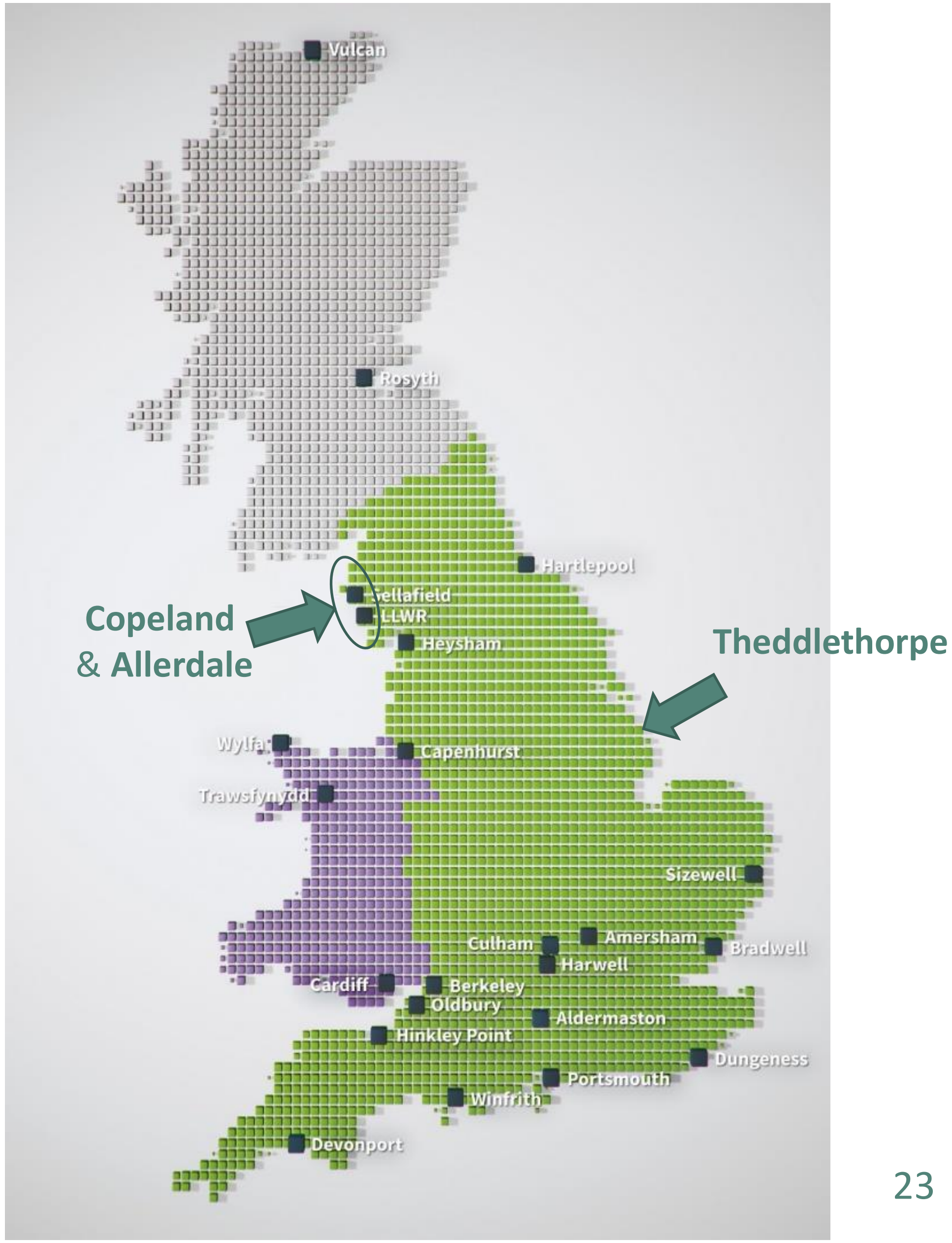
Siting Process

Finding a willing community

We have four communities who want to work with us to explore the implications and benefits of a GDF:

- **Copeland** – two Community Partnerships
  - Mid Copeland formed November 2021
  - South Copeland formed December 202
- **Allerdale** – Community Partnership formed January 2022
- **Theddlethorpe** – Community Partnership formed February 2022



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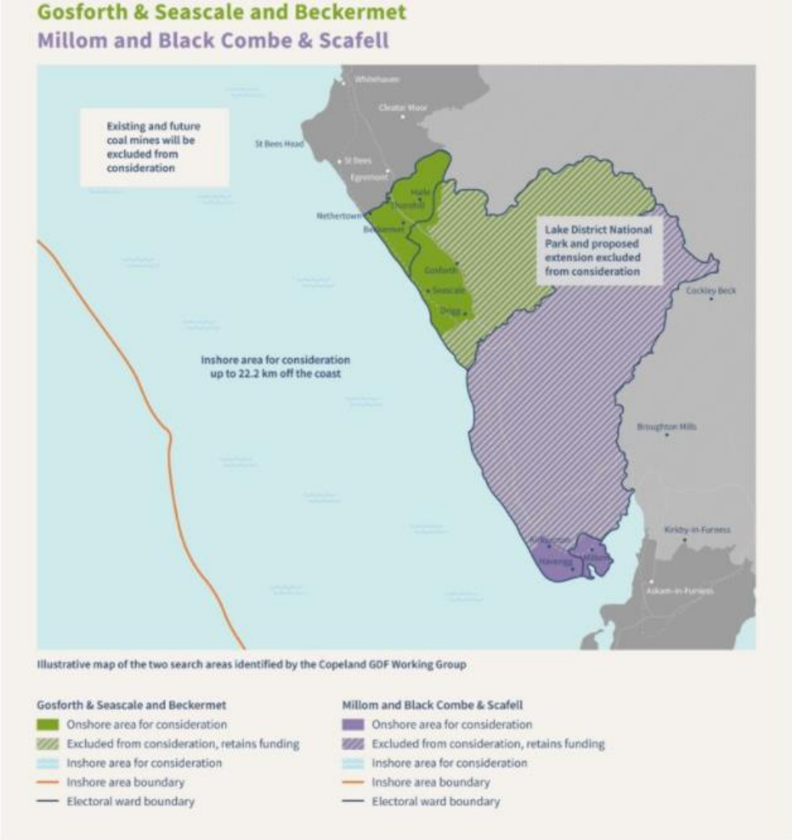
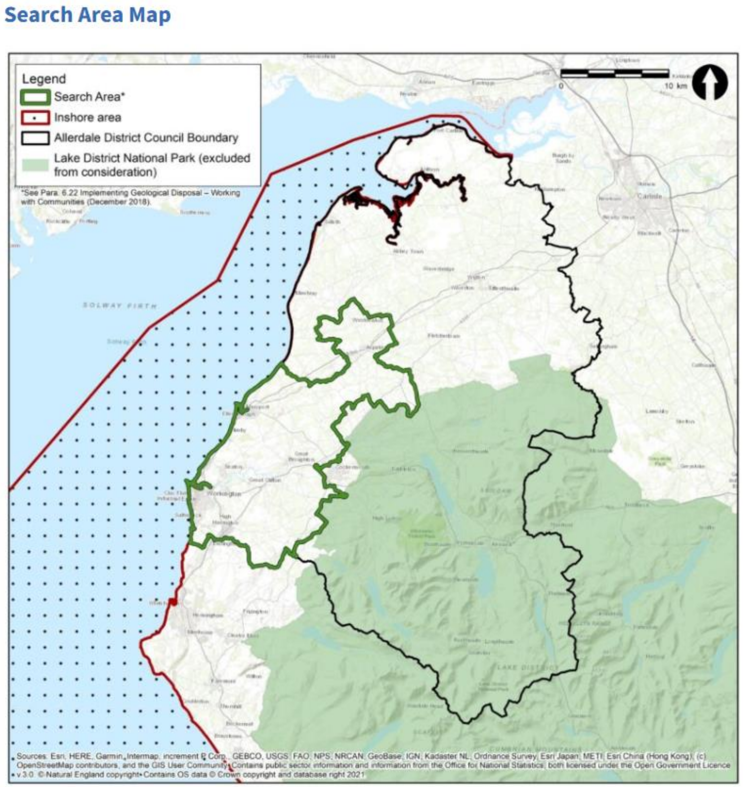
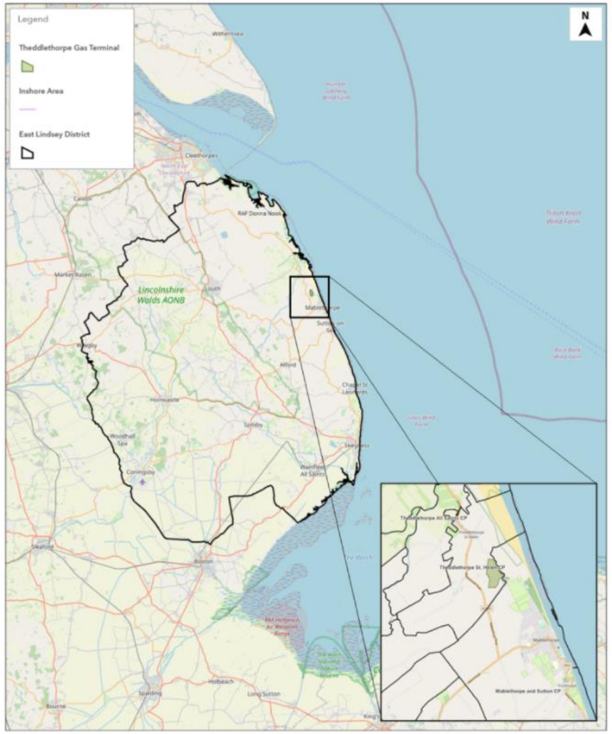
Finding a willing community



Copeland

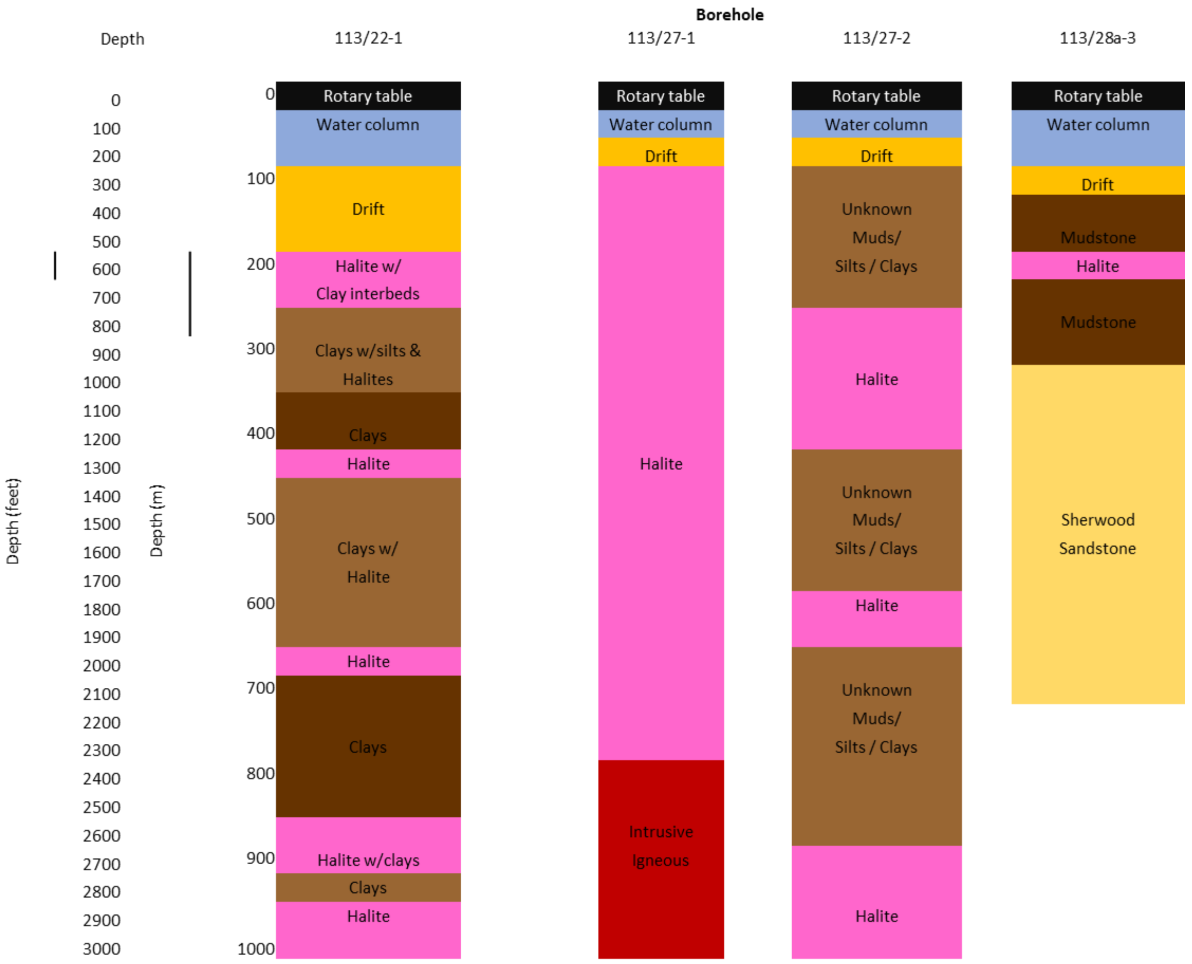


Allerdale

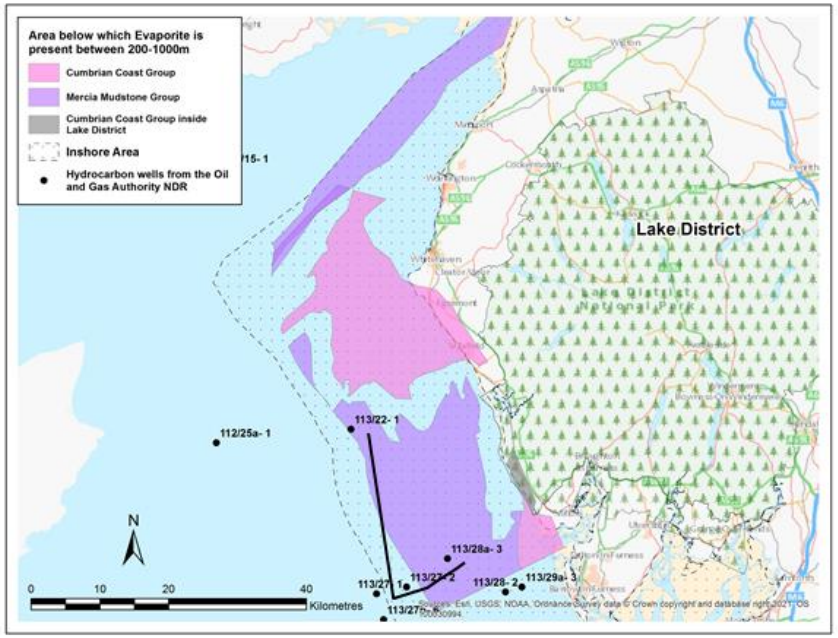


Theddlethorpe

Summary of Existing Information – Boreholes (top 3000ft)



- High lithological complexity
- High lateral variability



Mercia Mudstone Group

(Potential Host Rock in Cumbria - Lower Strength Sedimentary Rock)

- Complex stratigraphy containing mudstones, siltstones, fine sandstones, halites and other evaporites (e.g. anhydrite). Developing understanding via studying other UK MMG deposits:

Hambleton 302-305 m below ground level (bgl) (North Yorkshire)

Thornton Clevereleys 276-277 m bgl (Blackpool)

Northwich Victoria Infirmary 1 118.3-119.8 m bgl (Cheshire)

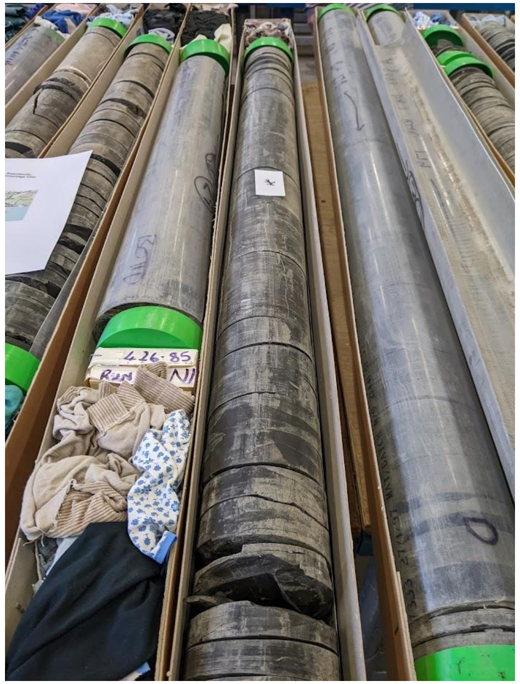
Ancholme Group

(Potential Host Rock in Lincolnshire - Lower Strength Sedimentary Rock)

- Simpler stratigraphy containing mudstones/siltstones. Potential for high organic content in the Kimmeridge Clay Formation. Developing understanding via studying other UK Jurassic Clay deposits:

Oxford Clay Formation
Marchwood 1 ca. 1000 m bgl (Southampton)

Kimmeridge Clay Formation
Elm Tree Farm, Kirby Misperton 128.75-129.5 m bgl (Yorkshire)



Kimmeridge Clay Formation
Swanworth Quarry 425.5-426.8 m bgl (Dorset)

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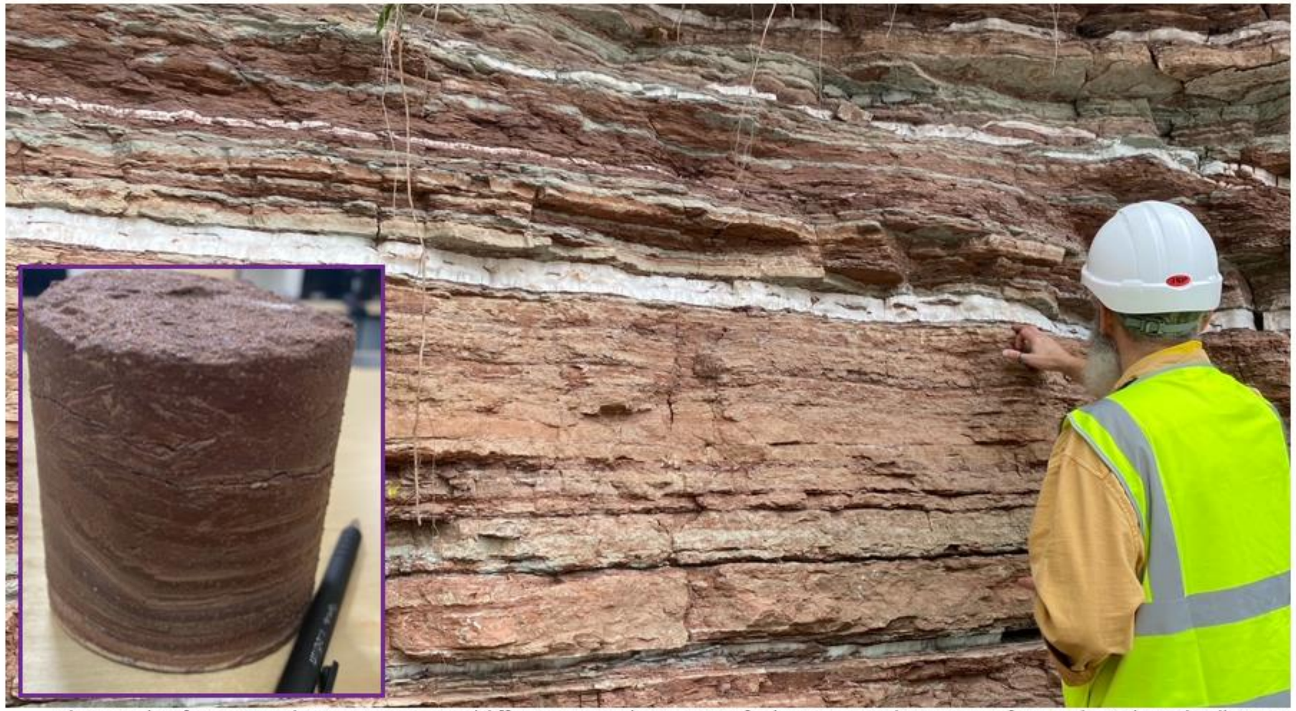
'LSSR subsurface characterisation and conceptualisation of complexity and heterogeneity at multiple length scales in LSSR systems'

Research Support Office



Photographs of Mercia Mudstone Outcrop at Radcliffe on Trent and core at BGS facilities, Keyworth, Courtesy of Drs Andy Cooke and Will Bower

OFFICIAL

Dr Simon Norris, NWS Principal Research Manager, answers residents' questions about geology at our first Big Picture engagement event in late 2022

Is our local area really a suitable home for a GDF?

MEMBERS of the community often ask why this area is being considered as a potential home for a GDF.

This could be a suitable setting thanks to the clay-rich rock layers found in this region of England.

The host rocks in which a GDF will be constructed need to have little or no groundwater movement through them, and have properties that allow for the construction of tunnels and caverns. They also need to provide a stable environment over the long lifetime of the site.

Clay-rich mudstone rocks in this area provide natural containment. Groundwater and gas cannot move through this type of rock quickly, if at all.

ASKING THE EXPERTS

Determining whether an area is suitable to host a GDF comes down to many factors, including local geology.

So what do we know about the rocks under our feet and why is this area being considered as a potential site?

Dr Jonathan Turner, Chief Geologist for developer Nuclear Waste Services (NWS), and **Dr Simon Norris**, NWS Principal Research Manager, explain more…

WHY IS GEOLOGY SO IMPORTANT FOR A GDF?

JT: Our priority in delivering a GDF is safety. The geology is a really important barrier for long-term safety.

When we say long-term, we are talking about hundreds of thousands of years – some radioactive waste has a very long 'half-life' (the time it takes half of the radioactive atoms to decay).

We are looking for two things to give us long-term safety – isolation and containment of the radioactive waste.

Isolation is about putting the waste into solid rock – at least 200 metres, but up to 1,000 metres, deep below the surface.

In terms of containment – preventing radioactive materials making their way back to the surface environment – the geology, along with a series of engineered barriers, works to keep the radioactive materials within the deep geology. This is called the multi-barrier concept.

We're looking for a stable geology and there are some potentially suitable rocks through this area of Lincolnshire.

WHAT PROPERTIES MAKE THE LOCAL CLAY ROCK IN THE THEDDLETHORPE AREA POTENTIALLY SUITABLE FOR A GDF?

SN: The rocks, as we understand them, are a few hundred metres thick, with little variation from borehole to borehole, and are therefore predictable, with very low permeability.

Boreholes are holes driven into the ground to obtain specific geological information, often made when investigating for the presence of oil, gas or minerals.

Low permeability means water or gas can only move very slowly, if at all, through the rock over time and waste placed in a GDF in this type of rock will be contained at or near the place of disposal, even up to one million years in the future.

We need to undertake a lot more research so we can demonstrate the safety of the rocks in the region.

HOW WILL THE DEVELOPER FIND OUT MORE ABOUT THE CLAY ROCK TYPE IN THIS AREA?

SN: It will involve gathering information from existing 2D seismic surveys and boreholes.

We would also look to drill our own boreholes and this will provide site-specific information on clay rocks in the Theddlethorpe area.

We will learn from international expertise, as the French and Swiss waste management programmes are both intending to use Jurassic clays, similar to the clays at Theddlethorpe, and from national expertise available to NWS through the British Geological Survey.

SEE THE BIG PICTURE – PAGE 8

For more information, please visit **bit.ly/3I9BedB** and **theddlethorpe.workinginpartnership.org.uk/finding-a-suitable-site**

British Geological Survey (BGS) findings...

This map on Ancholme Group thickness indicates the clay units in the region have an overall thickness of many hundreds of metres. Surrounding geology is of major importance to the safety of a GDF. Red and orange areas indicate the thickest clay.

Existing boreholes...

This chart shows boreholes with geophysical logs investigated as part of BGS research. Such pre-existing information can be used by NWS.

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