



International High-Level Radioactive
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SITEX.Network Analyses on Deep Borehole Repositories

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EMBEDDED TOPICAL CONFERENCE AT THE



SITEX.Network (<https://sitex.network>)

Vision

The SITEX.Network members share the following vision:

To foster a high-quality, sustainable expertise function in the safety of RWM
– independent from organisations responsible for implementing RWM programmes
– through strong collaboration with NRAs and CSOs, and to coordinate and advocate for these goals at the international level within a dynamic network.

SITEX.Network members



Need for a literature study about DBR

- Although originally explored in the 1950s, the DBR concept was largely dismissed for decades. Advancements in drilling technology have revived interest in this disposal route, prompting several countries to re-examine its feasibility for HLW and SF.
- IRSN (now ASNR) published a review study in 2019 *
- SITEX.Network has observed that there are different views on DBR (in the literature and among the stakeholders).
- DBR are seen:
 - either as an alternative to deep geological repositories (DGR), or
 - an unappropriated option for disposal of High-Level Waste (HLW) and Spent Fuel (SF).
- In 2020, following this observation, SITEX.Network started a literature study about DBR: what are pros and cons of DBR, compared to DGR, according to the literature?

Main goals of the study

- To assess the state of technical and scientific knowledge on DBR designs, emplacement techniques, geological settings, and safety features.
- To identify regulatory and societal challenges, especially concerning long-term retrievability, monitoring strategies, and public acceptance.
- To promote inclusive and informed discourse by integrating views from regulatory authorities, technical support organizations (TSOs), and civil society, with a focus on long-term sustainability and ethical waste governance.



Safety of DBR



Answers to social concerns



R&D needs, feasibility



Regulatory needs

Goal was NOT to identify which disposal route is “better”, but to provide elements to all stakeholders to understand the possible pro and cons of DBR compared to DGR.

Methodology for the study

- Collection of studies and articles: 62 papers
 - Papers before 2020
 - Not exhaustive, but globally a representative sample
- 1st sorting by relevance:
 - Out of scope or of poor interest
 - Interest for “historical review” of DBR $\approx$ 26 papers (already considered in IRSN review)
 - Relevant for study $\approx$ 22 papers
- Relevant papers reviewed by SITEX.Network members:
 - Review focused on the 4 topics of the study
 - All types of SITEX.Network stakeholders involved (Regulators, TSOs and CSOs)
- Draft study report discussed with all SITEX.Network members at a Topical Day (Nov. 2020) on pros and cons of DBR compared to DGR.
- Final version of the study report considers reviews and discussions at this Topical Day.

Final report published in 2022

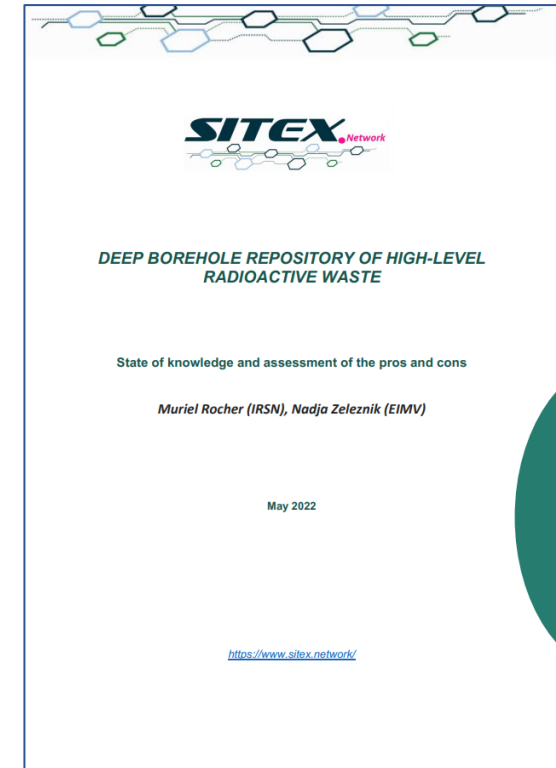
DEEP BOREHOLE REPOSITORY OF HLW - STATE OF KNOWLEDGE AND ASSESSMENT OF THE PROS AND CONS

Editors:

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Contributions:

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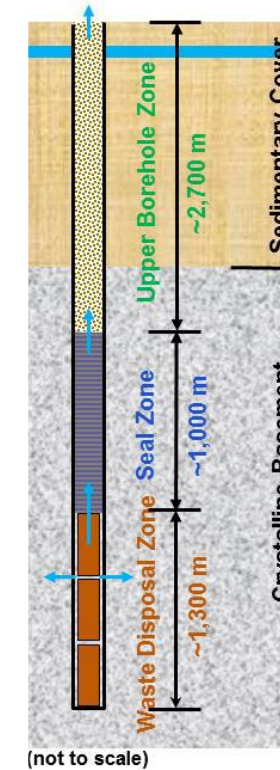


<https://www.sitex.network/deep-bore-hole-repository-for-high-level-waste-report/>

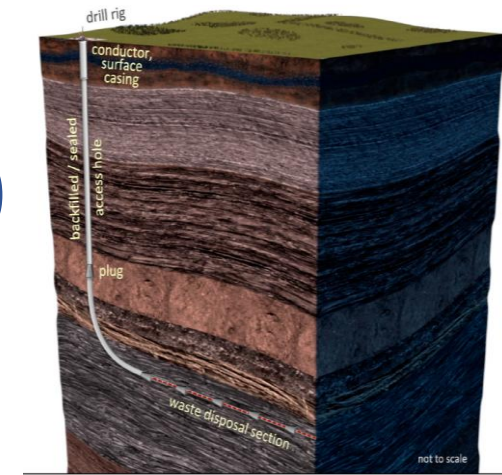


DBR overall reference concept / design (1/2)

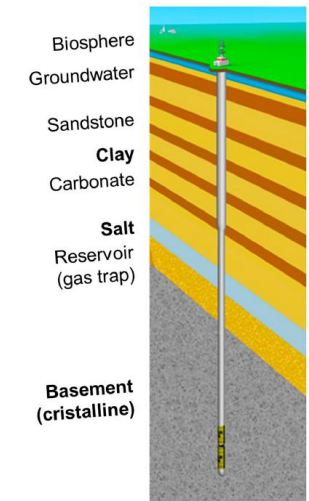
- First concepts:
 - Globally: a borehole of ≈ 5 km depth reaching crystalline basement, in which waste packages would be emplaced in the ≈ 2 km lower section, and then sealed above.
 - Design variants: crystalline or sedimentary host rocks, vertical or horizontal disposal after a vertical drillhole...



Freeze & MacKinnon



Muller et al., 2019



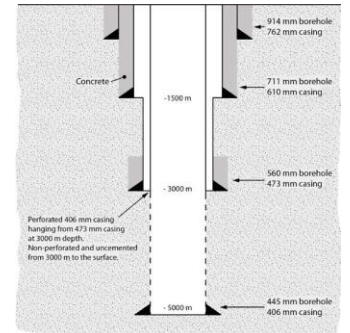
Bracke et al. 2019

DBR overall reference concept / design (2/2)

- Safety concept = mono- (or multibarriers?)
 - Based almost entirely on isolation/containment in the natural geological barrier
 - Design variants:
 - Multiple engineered barriers
 - Role of seal material in post-closure safety (heat phase...)
 - Several geological layers $\approx$ multiple natural barriers
- Recent developments in drilling and sealing technologies indicate that large-diameter boreholes are technically feasible, albeit with challenges in achieving borehole stability, casing integrity, and seal durability.
- Concerns also remained about waste package design, emplacement logistics, and post-emplacement retrieval.

DBR Construction and waste emplacement

- Drillhole with a telescoping design
 - Casing in carbon steel (to protect against groundwater and facilitate emplacement), emplaced after drilling of each section
 - Variant: cement between casing & drillhole wall, to stabilize the casing
- Solid waste with packaging
 - RW put in corrosion-resistant alloy canisters
 - Must withstand the bottom hole hydrostatic pressure and stacking loads from packages emplaced over.
 - variants:
 - Backfill within the canister (suitable material against mechanical damage, increase thermal conductivity, include boron to absorb neutrons, etc.)
 - Installing plugs in the borehole to bear the weight of additional packages
- Various methods for waste packages emplacement
 - In an fluid to counteract stresses & hydrostatic pressure (e.g. oil & bentonite)
 - Remote from surface



Odén
2013

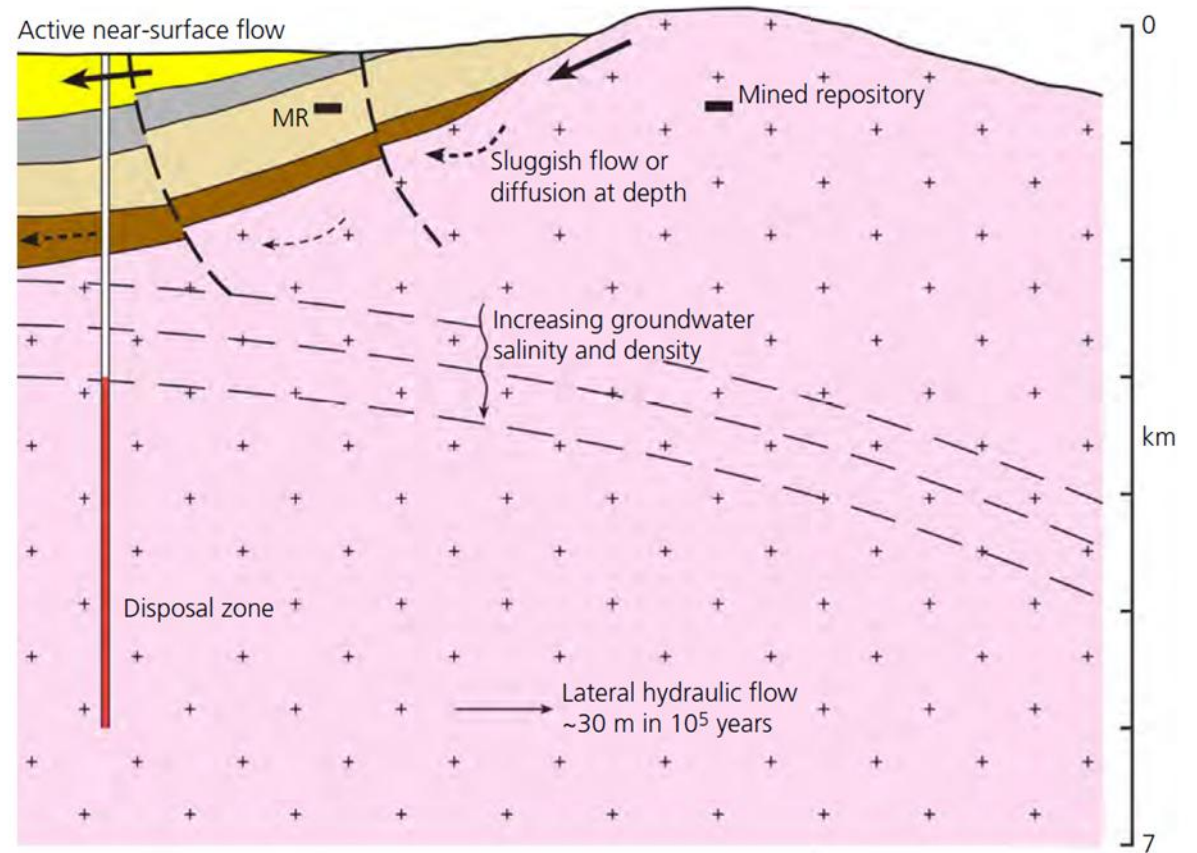


Some considerations for DBR site selection

- Plutonic rocks, large felsic igneous intrusive rocks: more homogeneous than metamorphic rocks or volcanic igneous units
- Depth to crystalline basement $< 2,000$ m: unconsolidated sediments not suitable (earthquake effects)
- Avoid basement structural complexity: drilling difficulties and unfavourable hydrogeological characteristics to waste isolation
- Favor sites with low topographic relief: extremely low groundwater flow rates
- Small differential in horizontal stress at depth: limits borehole breakouts
- Small tectonic uplift: increased risk of seismicity, volcanism, and active faulting
- Minimal faulting or evidence of volcanic activity
- Low vertical temperature gradients
- Reduce vertical flow and instabilities
- Reduced temperature conditions
- Reduce difficulties in drilling and waste emplacement operations: avoid sites with mineral resources or with significant geothermal heat flux
- Reduce likelihood of inadvertent human intrusion

DBR pros and cons vs DGR: 11 criteria

1. Site selection
2. Long-term safety
3. Construction
4. Operational safety
5. Closure
6. Retrievability
7. Flexibility
8. Environmental footprint
9. Costs
10. Required R&D
11. Waste inventory



Chapman & Gibb 2003

DBR vs DGR: site selection

1.Site selection

- 2.Long-term safety
- 3.Construction
- 4.Operational safety
- 5.Closure
- 6.Retrievability
- 7.Flexibility
- 8.Env. footprint
- 9.Costs
- 10.Required R&D
- 11.Waste inventory

Pros of DBR, compared to DGR	Cons
<u>Availability of potential sites</u> : much of the continental crust is underlain at appropriate depths by granitic basement with low hydraulic conductivities	<u>Not all sites are geologically suitable for DBR</u> . Lots of criteria + the depth at which favourable conditions prevail varies according to the geological setting,...
The plurality of potential sites <u>decreases the weight of the socioeconomic–political aspects</u> of the site selection and associated delays	<u>Difficult to obtain data at so great depth</u> : for each site, one must have good information on a lot of specific site data
DBR <u>could be decentralized</u> to achieve a greater degree of geographic and political equity	Dispersion of boreholes in several <u>sites implies several siting processes</u> → higher <u>likelihood of blockage</u> (from society or due to safety)

DBR vs DGR: flexibility

- 1.Site selection
- 2.Long-term safety
- 3.Construction
- 4.Operational safety
- 5.Closure
- 6.Retrievability
- 7.Flexibility**
- 8.Env. footprint
- 9.Costs
- 10.Required R&D
- 11.Waste inventory

Pros of DBR, compared to DGR	Cons
Drilling <u>close to each power plant</u> , so that the waste can be disposed of continuously ('pay as you go' scheme) Eliminates transport issues	It is <u>unlikely that disposal boreholes can be co-located</u> at every RW generating site (depends on the site characteristics)
<u>Short implementation and closure</u> (few years)	
DBR will be forgotten in long term: <u>proliferation</u>	We can be less « careful » with DBR: <u>no attention is expected in terms of monitoring to verify that it runs as expected</u> (negative experiences exist)

DBR vs DGR: required R&D

- 1.Site selection
- 2.Long-term safety
- 3.Construction
- 4.Operational safety
- 5.Closure
- 6.Retrievability
- 7.Flexibility
- 8.Env. footprint
- 9.Costs
- 10.Required R&D**
- 11.Waste inventory

Pros of DBR, compared to DGR

For some stakeholders, a reliable safety case seems possible.

The reference design seems simple, easy to understand

Cons

For other stakeholders, a feasibility demonstration is still needed, illustrating a very theoretical concept.

A lot of technical issues and R&D needs, a lack of proven technology

Even, the question is whether or not this can be overcome with R&D

→ risk to shift the waste disposal even further to future generations

Required research and funding.

Restarting from the beginning may be of poor interest for the stakeholders and difficult to argue to the public after having supported a DGR programme for a long time.

E.g. of R&D: site characterization and long-term evolution

- Deep salty groundwater properties (age, hydrogeology and geochemistry, variation with depth, driving forces...
- Long-term evolution of brines with glaciations, tectonics...
- How to characterize at 5km depth? 3D sedimentary and structural model, hydraulic properties (rocks, faults)
- Evolution accounting for THM transients

Conclusions

- DGR concept for HLW, a mined repository with galleries located app 500 m underground in geological layers, is now under implementation in several countries: sites are selected, licensing processes are progressing, and a first operation of a DGR is close.
- The alternative concept of DBR is again under investigation with new technical developments in the drilling field.
- The SITEX. Network report summarizes (as of 2020):
 - what are pros and cons of DBR, compared to DGR, according to the literature?
 - main areas where further challenges and research priorities would need to be addressed for DBR.
- A DBR option could be of interest for some categories of waste and for small inventories, but intensive R&D should be implemented to provide robust safety cases.