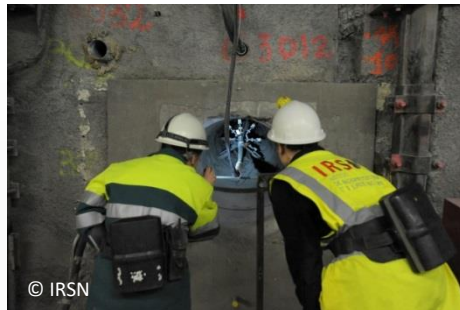




DEEP BOREHOLE REPOSITORY OF HLW AND SF - STATE OF KNOWLEDGE BY SITEX.NETWORK

Muriel Rocher - IRSN, Nadja Zeleznik - EIMV, Colin Wales - NTW, Frédéric Bernier - FANC, Doncho Karastanev - GI-BAS, Wilfried Pfingsten - PSI

EGU General Assembly 2021 – ERE4.3, April 2021



Introduction

- Deep Borehole Repository (DBR) is seen either as an alternative or as an unappropriated option for management of High-Level Waste (HLW) and Spent Fuel (SF).

- Investigate the main outcomes from previous DBR concepts.
- Provide an overview of the new DBR concepts for 4 areas:



Safety of DBR



Answers to social concerns



R&D needs



Regulatory needs

- Discuss the advantages and disadvantages of DBR with different actors in comparison with deep geological repository (DGR) concept.

Introduction

- SITEX overview report

- **Collection of studies and articles → 62 papers**

- Not exhaustive, but representation of the diversity of contents

- **1st sorting by relevance:**

- Out of scope or of poor interest
- Interest for “historical review” of borehole disposal ≈ 26 papers

- Relevant for this study → ≈ 22 papers

[IRSN Report/2019-00318](#)

[International panorama of research on alternatives to geological disposal of HLW & LL-ILW](#)

- **Relevant paper reviewed by SITEX**

- Same form for all reviewers
- Various kinds of RWM actors (FANC, GI-BAS, IRSN, EIMV, NTW, PSI)

- **draft report for the discussion with actors... This overview is a synthesis of the papers = Not intended to be exhaustive and to provide SITEX point of view! → final version of SITEX.Network DBR**

References for “historical review”:

- Angelo 1976. Ph.D., Dep. of Nuclear Engineering, Univ. Arizona, Tucson, AZ; University Microfilms, Ann Arbor, MI, USA
- Attrill & Gibb 2003. *Lithos*, Volume 67, Issues 1–2, p. 103–117, p. 119–133
- Bertram 1976. SNL, Albuquerque, NM, USA, SAND-76-007
- Chen et al. 2013. Science and Technology of Nuclear Installations, Volume 2013, Article ID 184757, 6 p.
- Cochran et al. 2018. 18545. WM2018 Conference, March 18–22, 2018, Phoenix, Arizona, USA, SAND2017-13052C
- Cohen & Steinborn 1979. In: G. J. McCarthy et al. (eds.), Scientific Basis for Nuclear Waste Managt, Plenum Press, New York, p261–264
- Cohen et al. 1972. *Nuclear Technology*, 14:1, p. 76–88
- Compton et al. 2000. Vol. I. International Institute for Applied Systems Analysis, Laxenburg, Austria, RR-00-1, Feb. 2000, 113 p.
- CoRWM, 2004a. CoRWM Document 623, NNC Report prepared on behalf of CoRWM, August 2004
- Finsterle et al. 2019. *Energies* 2019, 12(4), 596
- Gibb 1999. *Waste Management*, 19, p. 207–211
- Gibb 2003. *Geology*, 31, p. 657–660
- Hardee & Sullivan 1974. SNL, Albuquerque, NM, SLA-73-0931
- Heuze 1981. Lawrence Livermore Lab., Livermore, CA, USA. UCRL-53183
- IAEA, 1983. IAEA Technical Report Series n°232
- Juhlin et al. 1998. SKB Technical Report 98-05, Stockholm, Sweden
- Kascheev et al. 1992. *Atomnaya Energiya* 73, 215–221
- Klett 1974. SNL, Albuquerque, NM, USA. SAND-74-0042
- Logan 1974. *Nuclear Technology*, 21:2, p. 111–124
- NAS, 1957. Publication 519, Appendix C: Committee on Deep Disposal
- Nirex 2005. Review of CoRWM Document No. 623 - Direct injection. 472939, April 2005, 23 p.
- NRC, 1972. National Research Council
- Savaleva et al. 2017. *Radioactive Waste* N°1, 2017, p. 37–43
- Schwartz et al. 1978. Peaceful Nuclear Explosions V, IAEA-TC-81-5/4
- SKB, 1992. SKB Technical Report TR 93-04. Sweden: SKB Stockholm;1992. p. 14
- Sun 1980. USGS, Open-file Report 80450 US GS, Reston, VA.
- Tollefson 2014. *Nature*, 507, p. 15–16
- Voosen 2016. *Science*, Sep. 27, 2016
- Weeren et al. 1982. Oak Ridge NL, Oak Ridge, Tennessee - May 1982

Relevant references (for the concepts currently developed):

Arnold et al. 2011. SAND2011-6749. Report for the US DOE, Albuquerque,	USA	operator
Beswick et al. 2014. <i>Energy</i> , 167 (2), p. 47-66	UK	private companies, universities
BGE, 2018. CREATIEF. BGE TECHNOLOGY GmbH, TU Bergakademie Freiberg	Germany	WMO, universities
Bracke et al. 2017. <i>Geosciences</i> 2017, 7, 58, 17 p.	Germany	TSO/research entity
Bracke et al. 2019. <i>Energies</i> 2019, 12(13), 2580.	Germany	TSO/research entity
Brady et al. 2016. Geological Repository Systems for Safe Disposal of SNF at	USA	operator
Brady et al. 2019. <i>Energies</i> 2019, 12(11), 2180	USA	operator
Chapman 2019. <i>Energies</i> 2019, 12(8), 1542	UK	university
Collier et al. 2019. <i>Energies</i> 2019, 12(12), 2393	UK	university, private company
Cornwall 2015. <i>Science</i> , 349, p.132–135	USA	journalist
GRS, 2016. Tiefe Bohrlöcher. GRS – 423, Februar 2016, 337 p.	Germany	TSO/research entity
IAEA 2017. Selection of Technical Solutions for the Management of Radioactive	IAEA	International agency
Muller et al. 2019. <i>Energies</i> 2019, 12(11), 2052	USA	private companies, universities
National Academy of Sciences 1957. NAS, National Research Council, Publ	USA	science related authority
Nirex 2004. Nirex report no. N/108, Nirex (UK Nirex Ltd), UK	UK	WMO
NWTRB 2016. Report to the U.S. Congress and the Secretary of Energy. U.S.	USA	regulatory authority
Payer et al. 2019. <i>Energies</i> 2019, 12(8)	USA	private companies
Sandia, 2013. Sandia for U.S. DOE, FCRD-USED-2013-000409, SAND2013-9	USA	operator for Regulatory authorities
Schwartz et al. 2017. Invited Paper, J. Nucl. Fuel Cycle Waste Technol 2017	Korea, USA	universities
SKB 2013. Niko Marsic, Bertil Grundfelt, Kemakta Konsult AB, September 2	Sweden	WMO
SSM, 2018. Report 2018:04. 146 p.	Sweden	safety authority
Vate et al. 2018. The Netherlands, Laka Foundation	Netherlands	citizen association
WNN 2019. <i>World Nuclear News</i> , 18 January 2019	UK	association of industries
Yang et al. 2019. <i>Materials Chemistry and Physics</i> , 221, p.178–187	USA	operator
...		

Introduction

- Historical review of borehole disposal

3 types of borehole disposal concepts according to the type of waste:

- **Embedding of exothermic waste (vitrified waste, spent fuel) in a vitreous gangue resulting from melting of host rock**

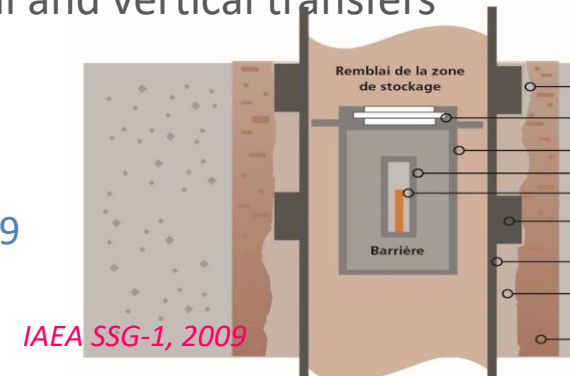
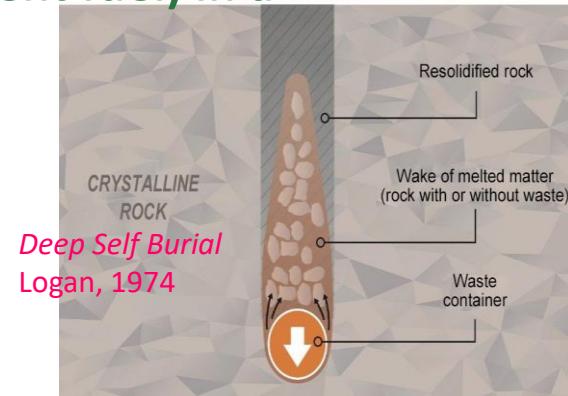
- granite: dissipates little heat and melting temperature
- favoured at great depths (increasing temperature)

- **Injection of liquid waste directly into the rock**

- Host rock chosen for its injection capability (porosity)
- Site hydrogeological characteristics that limit horizontal and vertical transfers

- **Stacking of solid waste packages in a borehole**

- at a depth that depends in particular on its nature:
 - IAEA SSG-1 guide for disposal of SRS in borehole >30m, 2009
 - US. Nat. Academy of Sc., 1957: 5000m borehole
- then the borehole is sealed



Deep borehole repository (DBR)



Safety of DBR



Answers to social concerns



R&D needs



Regulatory needs



Safety of DBR



Answers to social concerns



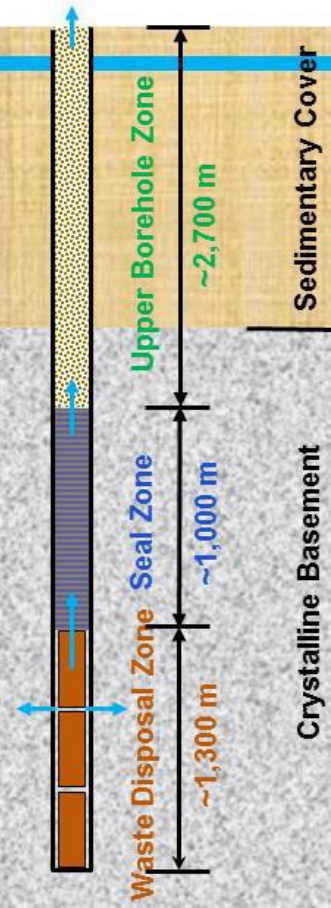
R&D needs



Regulatory needs

Safety

- DBR overall reference design



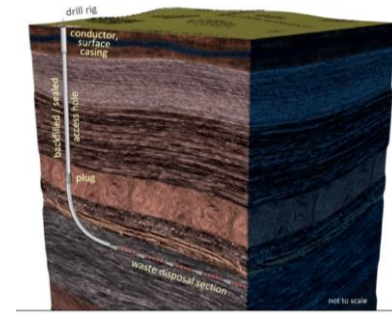
- **US. NAS 1957 concept: a borehole reaching crystalline basement at ≈ 5 km depth, with waste packages placed in the ≈ 2 km lower section, and then sealed...**

- Alternatives:
 - sedimentary host rock
 - horizontal disposal after a vertical drillhole

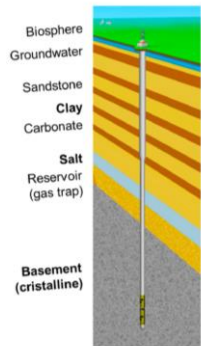
- **Safety concept = mono or multibarrier?**

- based almost entirely on containment in the natural geological barrier
 → zero release of RN by groundwater for ≈ 1 Ma

- Alternatives:
 - multiple engineered barriers
 - role of seal material in post-closure safety (heat phase...)
 - Several geological layers \approx multiple natural barriers



Muller et al., 2019



Bracke et al. 2019

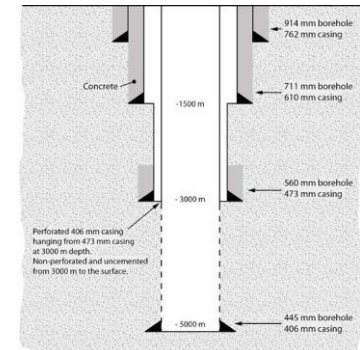
(not to scale) *Freeze & MacKinnon*

Safety

- DBR design

■ Drillhole with a telescoping design

- casing in carbon steel (to protect groundwater and facilitate emplacement), emplaced and cemented after drilling of each section
- Potentially, backfill between casing & drillhole wall (cement), to stabilize the casing



Odén 2013

■ Solid waste with packaging

- put in corrosion-resistant alloy canisters
- must withstand the bottom hole hydrostatic pressure and stacking loads from packages emplaced over
 - 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 emplacement (in an oil-based fluid with bentonite)

- lowering strings of waste packages on drill pipe
- stacking packages in a conveyance casing and lowering that on drill pipe
- lowering one or a few packages at a time on coiled tubing
- one package at a time pushed with an oilfield-type electric wireline tractor
- dropping packages one at a time for free fall to the bottom of the borehole

Safety

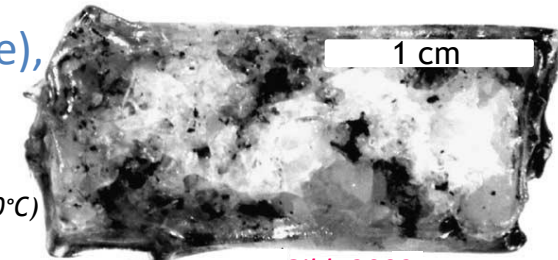
- DBR design
 - Targeted radioactive waste
 - USA:
 - generally studied for the Cs/Sr defense waste
 - granular solids of calcined HLW (Idaho NT&EC), borosilicate glass of vitrified HLW (Savannah River Site), salt waste from electrometallurgical treatment of sodium-bonded fuels...
 - SF from commercial nuclear reactors
 - other military waste types, including plutonium
 - UK: SF, reprocessing HLW and plutonium
 - German studies for HLW
 - Swedish and Korean studies for SF
 - Large variety, even waste that is causing technical problems for storage
 - allowing relatively early disposal of heat-generating waste
 - ... but volumes of 1 000s m³ would require many boreholes

Safety

- DBR design

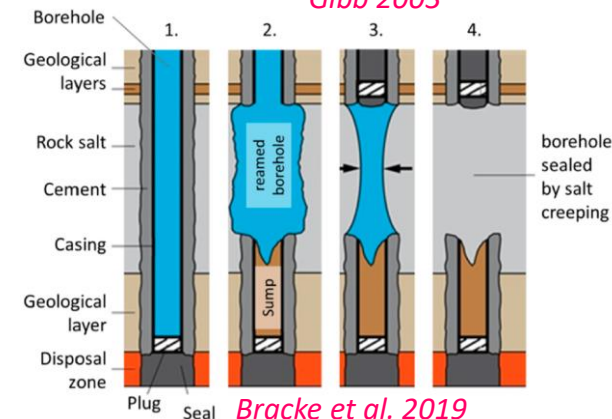
▪ Closure

- the casing should be removed in the disposal section (corrosion)
- plugs that seal the vertical access hole, for limiting vertical fluid movement
 - Traditionally: bentonite, cement (ex. bentonite seals, bridge and cement plugs)
 - Rock welds (resistance heater to melt crushed granite), thermite (ignition of an Al-Fe metal-oxide charge)
 - Partial melting
 - in salt rock, crushed salt and self-sealing
- then, backfill materials (rock, bentonite...)
 - between canister & casing → material providing
 - stability and mechanical protection
 - increased heat conduction
 - reduced fluid flow
 - inhibiting corrosion
 - increasing adsorption
 - And finally along the access sections



Granite partially melted (570h - 800°C)

Gibb 2003



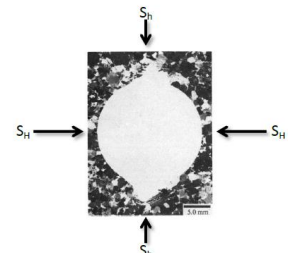
Bracke et al. 2019

Safety

- DBR design

▪ Targeted site (first selection guideline)

- plutonic rocks, large felsic igneous intrusive rocks
 - more homogeneous and fewer pathways 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
- Favour 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



Lee & Haimson 1993

Safety

- DBR construction and operation

▪ Operational safety

- no humans underground:
 - near field much less disturbed, no human radiation hazard at depth...
 - but requires remote transfer and handling of canisters/containers
- Events to consider during handling:
 - canister stuck above disposal zone
 - canister falling in the vertical section
 - mechanical breaching of a canister
- External events: earthquakes → reduce probability & effects by site selection
- Internal events: criticality → limit quantity of fissile material by borehole
- thermal heat transient
- Retrievability, readmission and reversibility
 - Recoverability is required for safety purposes
 - Retrievability requirement (and until when) depends on the National law

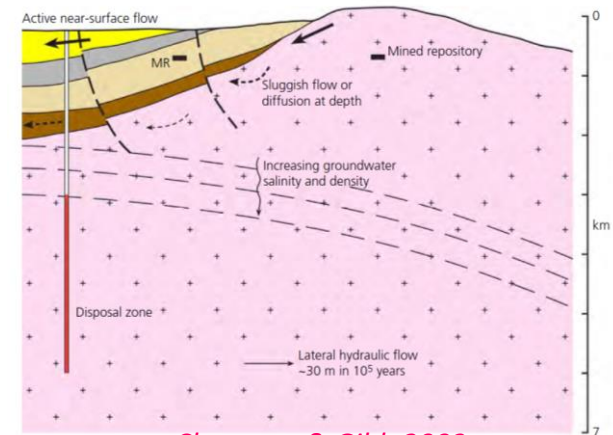


Safety

- DBR post-closure phase

■ Post-closure safety procured by great depth!

- Isolation, multiple layers
- reduced probability of Human intrusion (difficult+ well below potable water resources)
 - avoids many of the proliferation-prone steps involved with recycling fissile material as the retrievability is very difficult and expensive
- Decreased surface effects: groundwater infiltration, effects from climate change (glaciation, sea-level rises...), earthquakes
- Groundwater mainly stagnant; dense, saline brines, stratified and no replacement with superficial groundwater
- Geochemically-reducing conditions, slow diffusion-dominated RN transport
- **Low permeability of crystalline and saline host rock** (if not fractured...)
- **Small diameter holes** → small rock THM damage, easier sealing
- **...but impact of events occurring during operation?** waste package stuck in borehole and abandoned, H₂ from metal corrosion, efficacy of borehole seals & plugs
- **Role of seal materials = Multi-barrier design?**



Chapman & Gibb 2003



Safety of DBR



Answers to social concerns



R&D needs



Regulatory needs

Social concerns

- Social aspects of safety

Payer et al, 2019

- the reference design seems simple, easy to understand,
- built using conventional materials and construction practice, i.e. oil and gas industry,
- small excavation disturbed Zone, fully saturated rock yield to uniform environment along the horizontal disposal sections,
- not boiling due to the hydrostatic pressure at drillhole depth,
- considered canisters of Ni-Cr-Mo alloys would resist corrosion,
- Both, Ni-Cr-Mo alloys and steel, have strong mechanical properties to temperatures well above those experienced in the EBS, and they can be fabricated and sealed by conventional processes.
- → all these attributes contribute to the safe and reliable disposal of nuclear waste in deep horizontal drillholes, also because of “simpler processes” taken into account compared to conventional GDFs, reducing uncertainty in the supporting safety case.

Social concerns

- Lower costs

Nirex, 2004, Brady, 2016, Chapman, 2019

- disagreement in the comparative costs of DBR and GDF, the DBR seems less expensive for small amounts of waste,
- immediate closure of the boreholes, thus reducing the considerable costs for interim storage and operation of an open repository, Muller et al, 2019
- a small-diameter access hole drastically reduce the excavation volume.
- concept has generally been considered to be an expensive option for large volumes of wastes, WNN, 2019
- drilling cost of large diameter 4 km deep borehole yield about £1 million/km, together app \$40M for drilling, completion, and waste emplacement, or \$45 - \$191/kgHM³ - similar assessment from different studies (Germany, Netherlands)
- R&D needed → + £300 M to bring DBR up to the level of KBS-3 concept
- Assuming a continuous operation, the total time per borehole, from drilling to abandonment, is below 200 days. Brady et al, 2016

Social concerns

- Modularity

- DBR is generally considered as a ‘pay as you go’ scheme:
Brady, 2016, Beswock, 2014, Arnold, 2011, Beweck, 2014, Vate, 2018, Muller 2019
 - allows a small disposal programme to be expanded as required or
 - large one to be terminated at any point without any significant further cost,
 - speed of implementation.
- Heat flow modelling of DBR (high heat-generating wastes) has shown that boreholes need be only a few tens of meters apart:
 - many small sites with only one or a few boreholes each, even extending to individual nuclear power plants disposing of their own wastes on or near site,
 - decentralized to achieve a greater degree of geographic, political equity and reduce transportation.
 - faced also with social acceptability ? Chapman 2019
- Modularity may offer a strategic opportunity to make a political statement by early disposal Champan 2019
- 4 km-deep borehole with a useable diameter of app. 0.5 m could be drilled in under a year and filled and sealed in another 2 or 3 years – challenged due to licencing requirement (U.S. NWTR Board).

Social concerns

– Simpler operational activities

- Several papers indicate that the concept:
 - posing fewer risks from the disposal of radioactive materials (Schwartz et al. 2017),
 - waste emplacement and site closure activities are simpler,
 - require fewer workers and
 - no additional infrastructure is needed to support underground work (Muller et al 2019).
- Findings of the U.S. NWTR Board, 2016 were contrary:
 - complex system, not substantially simpler than a mined, geologic repository,
 - less mature concept for waste disposal, compared to mined, geological repositories,
 - Many R&D should be solved before safety case could be prepared.

Social concerns

- Larger availability of suitable sites vs. public acceptance
 - Relatively easy to finding crystalline basement at great depths, but site identification, with all socioeconomic–political aspects, would most likely cause delays.
 - Several authors consider that the greater depth of burial, safety and availability of technically suitable sites for DBR could facilitate public and political acceptance (Beswick et al., 2014; Brady et al. 2016).
 - Though a DBR provides an apparently higher level of isolation, is much more remote from the surface and has smaller environmental impacts (e.g., spoil, operational period) than a GDF, there is little reason to believe that a DBR facility would be any easier to site than a GDF.
 - In several countries, society is also now sensitized to activities in deep boreholes (e.g. fracking for natural gas). Siting a centralised national DBR facility using a nationwide screening and volunteering approach—now the common practice for GDF siting—would likely encounter exactly the same problems as siting a GDF (Chapman 2019).

Social concerns

– The tricky question of retrievability

- Whatever the safety or social reason for retrieving waste almost all authors agree on the fact that once waste is buried, it would be hard to get it back (Beswick et al., 2014; Cornwall 2015; Schwartz et al. 2017).
- Such irretrievability is even seem as a guarantee against proliferation: boreholes could be an effective way to put it far out of the reach of anyone trying to lay their hands-on bombmaking material (Cornwall 2015; Schwartz et al. 2017).
- For some authors, it is difficult to demonstrate that any waste package could be retrieved even before closure of the borehole. For others, retrievability seems to be manageable once the borehole and casing exists, recoverability from deep boreholes needs some R&D to show if it is feasible (Bracke et al. 2017).
- The question of retrievability should be further assessed and looked in the regulatory requirements.



Safety of DBR



Answers to social concerns



R&D needs



Regulatory needs

R&D needs

it is not guaranteed that R&D could solve these questions, inherent of the concept because of the importance placed on extreme insulation

- Site characterization and its long-term evolution

■ deep salty groundwater properties

- Uncertainties associated with the determination of their age
- hydrogeological and geochemical conditions at great depths: chemical factors that influence RN migration (adsorption, valence state, cation complexing...)
- Variation with depth, density stratification
- Driving forces for flow

Are these likely favourable properties of host rock and groundwaters independent of each other?

■ Persistence of isolation and long residence time

- Long-term evolution of brines
- Effect of glaciations, topographic driving forces, tectonic movements...

■ How to characterise at 5km depth?

- Geometry of layers, faults and fracture network, hydraulic properties of faults
- permeability of crystalline rocks, heterogeneity due to faults and fractures

■ Evolution accounting for THM transients

- Extent of hydrological, thermal, geochemical and mechanical perturbation
- effects of heat on groundwater flow and transport (chemistry, buoyant convection...)
- effects of EDZ, gas (notably H₂) → potential transport paths along boreholes

R&D needs

a full-scale trial borehole that would prove feasibility is essential

- Borehole drilling and equipment

- **drilling at great depth and with large diameter**

- (Typical oil or gas well has an inner \varnothing 14-22 cm, enough for Cs/Sr waste capsules)
- No one has drilled 5 km large holes into solid rock; should be smooth and straight
- Actually for several authors, limit is $\approx \varnothing$ 0.405m \rightarrow increase to 0.48 - 0.66 – 0.90...

Deepest boreholes				Depth (km)	Diameter (cm)
Kola SG-3	Russia	R&D	1970-1989	12.26	21.5
KTB	Germany	R&D	1987-1994	9.1	16.5
Gravberg-1	Sweden	Gas	1986-1987	6.6	16.5
Soultz-sous-F.	France	Geothermy	1995-2003	5.3	24.5
Basel-1	Switzerland	Geothermy	2006	5	21.5
Longest boreholes				Length (km)	
Sakhaline I	Russia	Gas	2017	15.00	
Al Shaheen	Qatar	Oil	2008	12.28	
Largest holes				Depth (km)	Max diameter (km)
Mirny, Siberia	Russia	Diamond	1952-...	0.52	1.2
Bingham, Utah	USA	Copper	1906-...	0.97	4

ment

R&D needs

- Waste emplacement

- **radiation protection (not self-shielding WP)**
- **best deployed method (single, small batches or strings)**
- **mechanism by wireline, drill pipe or coiled tubing**
- **Event of canister stuck above disposal zone:** depending on authors,
 - risk is considered low
 - feasible to retrieve with tools and procedures used for oil and gas operations
 - risks greater than those accompanying mined geologic repositories
- **Event of canister falling in the vertical section**
 - Probability depends on the emplacement method
 - velocity and impact can be limited by presence of fluids in the casing, self-deploying breaking, absorber on the canister...
- **management of borehole fluids**
 - notably in case of crack in the wall or break of a container
 - monitoring fluids radioactivity → provide enough storage and treatment facilities

*The operational safety strategy required for drilling and emplacement operations is very different from that for operations involving non-radioactive material
→ Trial borehole should include remote canister handling*

R&D needs

- Waste retrieval

Difficulty to retrieve waste is one of the advantages of DBR for safeguards

■ Before sealing

- German “*Deep Borehole Container-Retrievable*” (DBC-R)
- U.S. demonstration of retrieval of a dummy canister of Cs/Sr capsule placed in a 690m deep horizontal drillhole (242m vertical, 326m curved, 122m horizontal) → to continue for SF canisters in conditions prevalent in a backfilled, heated, potentially sealed disposal section
- risk that events occurring during the operation lead to difficulties in recovering stuck fuel above disposal zone
- it can in any case only touch the latest submerged canister string

■ After closure

- Germany: 500y after closure... may not be reasonably achievable → change regulation?
- change the concept of retrievability? Wait 50y before sealing?

R&D needs

- Borehole sealing

How to remotely emplace sealing materials and monitor at several km depth?

■ Implementation (bentonite and other clay-based systems)

- methods for the removal and/or cutting of casing
- Management of borehole fluids during sealing
- how to reliably deliver compacted, dehydrated clay down a fluid-filled borehole to an open uncased sealing interval
- bentonite alteration under borehole conditions
- Long-term evolution?

■ Other sealing techniques: implementation and performances

- salt suspensions and eutectic molten salt and barite
- rock-welding
- geopolymers, asphalt, sandaband[®], ceramic...

■ Monitoring: how to check the quality of seals at great depth?



Safety of DBR



Answers to social concerns



R&D needs



Regulatory needs

Requirements

- **Regulatory requirements on site characteristics**
 - **Requirements for generic concept of DBR are given in some legislations (USA, D) but were designed for a geological underground mine and are not specific to DBR,**
 - **Discussions with licensing experts indicated that a licensing regime could be developed, given sufficient time and a suitable mandate,**
 - **Many requirements are the same as for mined-type repositories:**
 - low flow velocity, low permeability of host formation, favourable geochemical environment, geology that provides more predictable structure and lithology, relatively low differential horizontal stress, low seismicity and tectonics.
 - **Additional requirements on site characteristics specific to DBR concept:**
 - depth to crystalline basement of less than 2.000 m, high salinity fluids, low potential for deep circulation of meteoric ground water, thick containment-providing rock zone.
 - **Some issues for site characterisation:**
 - Field investigation for site characterisation,
 - Minimization of gas generation,
 - T conditions,
 - Recovery of waste and long term monitoring.

Requirements

- **Regulatory requirements on DBR equipment and operation**
 - **Waste package requirements:** sustain bottom-hole hydrostatic pressure, assure structural integrity, prevent any leakage of radioactive materials, assure integrated system for connection, preclude any possibility of nuclear criticality.
 - **Borehole and casing:** sufficient stability and durability, sufficient large diameter, controlled deviation, must be designed so that casing can be removed, must allow thermal expansion of fluid and flow, drilling allowing characterization of host rock.
 - **Waste emplacement requirements:** safe handling and emplacement of the waste packages, not getting waste packages stuck in the borehole.
 - **Borehole sealing requirements:** provide a low permeability barrier to fluid flow, relatively straightforward to emplace, providing redundant defense in depth, resist mechanical loads, resistant to chemical alteration, be durable and chemically stable at 100 – 200 °C.
 - **Requirements on non-proliferation control:** deep boreholes contributes to lower the likelihood of unintentional human intrusion and malicious readmission of the fuel is made more difficult.

Requirements

- Inconsistency of DBR with existing requirements on retrievability
 - requirements on retrievability existing in several countries appear impossible to respect for DBR,
 - retrievability is diametrically counter to the concept of DBR, which aims at the maximum isolation possible by specifically making it practically impossible to retrieve waste once a borehole is sealed and decommissioned,
 - if retrievability is an undisputable part of national policy, DBR is not an option for consideration.

Discussion with different actors November 2020 at Topical day:

- In total 49 participants
 - A large variety of different RWM actors
WMOs, regulators (safety authorities, ministries), TSOs, research entities, CSOs (local communities, national or international organisations)...
 - **19 countries with various types and amounts of RW**
Switzerland, Hungary, UK, Belgium, Czech Republic, Germany, France, Slovenia, Czech Republic, Netherlands, Spain, Taiwan ROC, Russia, Sweden, Canada, USA, Finland, Austria, Denmark.
- More information on <https://www.sitex.network/sitex-network-topical-day-2020-on-deep-borehole-repositories-2/>

Some outcomes:

Advantages	Disadvantages
<p>DBR is a kind of geological disposal and all the depths are available, from 500 to 5 000m. There are many options between DGR and DBR, notably in terms of depth. DBR can be applied to any depth, and it's maybe not necessary to go at 5km depth.</p> <p>Of course, it depends on which kind of inventory you have...</p>	<p>If you go closer to the surface (500m) you've to put more importance on the safety functions associated with the confining.</p> <p>Also, you will be able to put less waste because less deep and increase the number of boreholes.</p>
<p>About environmental impact at surface, you can do only one borehole ending as several horizontal boreholes, like a fan-out, or Christmas tree</p> <p>The option is interesting for a country beginning, or with low amount of waste.</p>	<p>The footprint and environmental impact at surface of DBR may be higher than in DGR in case of large amount of waste (lot of boreholes).</p> <p>For countries engaged in a DGR programme , it seems difficult to move towards such DBR options. Much work has already been done for DGR, with knowledge and experience)</p> <p>Restarting from the beginning may be of poor interest (R&D still necessary, waste have to be disposed of....).</p>
<p>Disadvantages may be not so severe at less important depth; at 500m you can use the same technology as in a mined repository, you can retrieve and recover the waste easily.</p>	<p>It's very hard to make good borehole sealing. On one side, sealing seems even more challenging at important depths; on the other side, sealing becomes more important for safety if you go less deep.</p>
<p>Of course, great depth is fine for isolation.</p> <p>There are more chance that we forget the waste (reduce the likelihood of intrusion).</p>	<p>DBR option at 5km have technical challenges: there's a lot of technical issues and needs in R&D.</p> <p>A demonstration of feasibility is still necessary, but the question is even if it can be overcome or not with R&D.</p>
<p>In case of need to retrieve the waste after 2-3 years, it is manageable. Such operation notably depends on the canisters. If canisters are specially designed for that, it could be retrieved...</p>	<p>If a canister get stuck, there could be technological solutions but a lot of pressure on the co-workers to retrieve the package (rather a human factor issue).</p> <p>Retrieval (recovery?) after few years looks tricky, as suggested by those who experimented the retrieval of data equipment from a borehole in regular surveillance borehole, after 20 years... It could be possible in theory, but with another technology; it looks tricky in fact with RW and no one could guaranty it. At several km, it is</p>

Conclusions

- DGR concept, a mined repository with galleries located underground in geological layers, is now under implementation: site selected in some countries.
- Alternative concept with DBR is now again under investigation with new technical developments in the drilling field.
- The SITEX. Network identified main areas where further challenges and research priorities would need to be addressed in order to make such option realistic and to which kind of waste inventory it is most appropriate.



**THANK YOU FOR
YOUR ATTENTION!**