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# Radioactive Waste Disposal in Very Deep Boreholes

Observations from Several Studies

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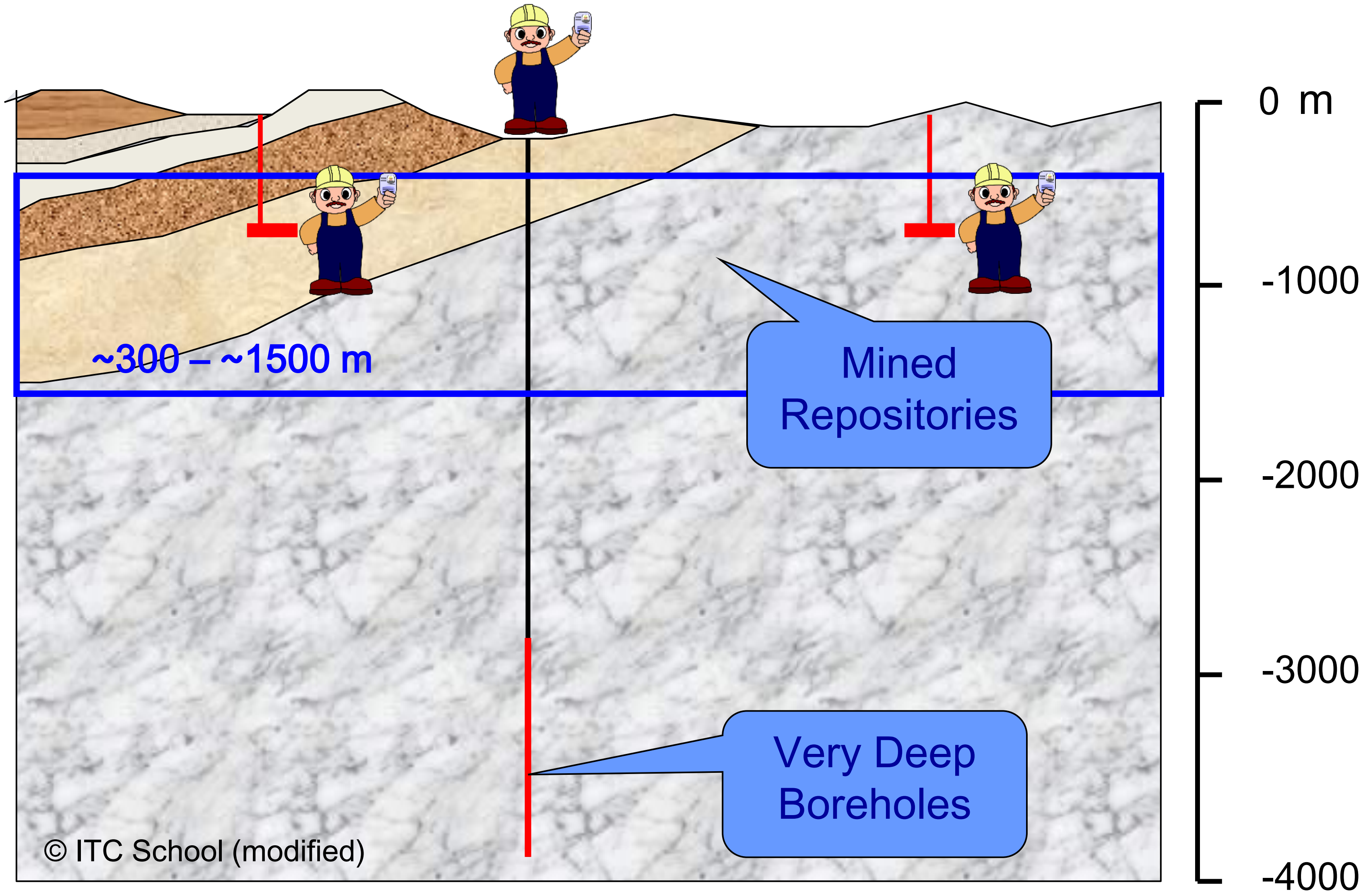
# Outline

- Some general information on in Very Deep Borehole Disposal (DBD)
- The German “case”
- Personal considerations

# What is Deep Borehole Disposal (DBD)?




**What might be the „charme"?**

- Increase distance to accessible environment
- Disposal in geologically „quieter" regions(?)
- No staff underground

# More precisely …

- This presentation: Restricted to emplacement of solid and packaged waste, no account for ideas based on rock melting or liquid injection

- Borehole diameters of about 400 – 900 mm, depths of 3-5 km, multibarrier geotechnical system of seals
- “Strings” of canisters (some 100 m long)
- Mostly considered: crystalline bedrock

- Not to be confused with IAEA’s concept of borehole disposal of sealed radioactive sources at intermediate depth

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# History (see also „State of Knowledge“ report by Rocher, Železnik et al.)

- First concept in the 1950s in the U.S. (National Academy of Sciences, 1957), abandoned due to challenges w.r.t. drilling technology
- “Revival” in connection with the policy re-orientation under the Obama administration, …
- … including a field test (https://www.osti.gov/servlets/purl/1368945) cancelled in 2017 (likely due to lack of appropriate communication and local support)

- Continuously, but with low intensity studied in Sweden since the second half of the 1980s

- Others (UK, Germany, Korea) keeping a watching brief

# What has been investigated / evaluated when comparing DBD with mined repositories?

- Early studies very much focussed on geoscience: geomechanics, hydrogeology, …
- Security / low vulnerability against malicious attacks was seen as an advantage of DBD
- This, however, goes together with lack of retrievablity
(which, according to a Swedish report, was simply „not necessary“)
- Also early recognised: Technical challenges concerning drilling and emplacement
- Sometimes: Claim that DBD might be less expensive than mined repositories

# What has been investigated / evaluated when comparing DBD with mined repositories?

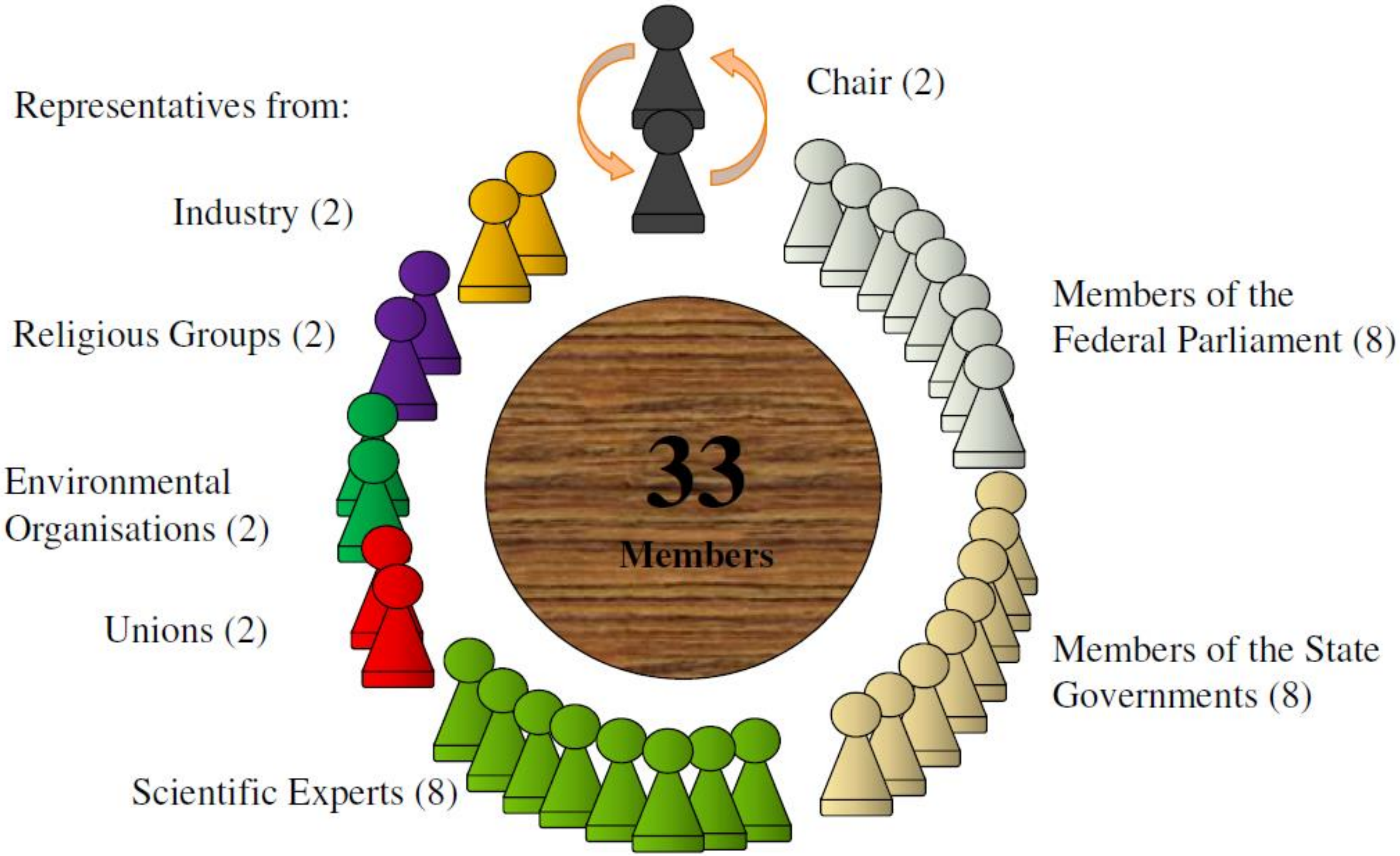
More systematic approach in more recent studies

- Long term safety and its demonstration
- Security / non-proliferation
- Technical feasibility: Drilling, emplacement, sealing
- Costs
- Waste types
- Location

# The German case

- 2013 Site Selection Act
  - Aim to initiate a participative site selection process for SNF / HLW disposal (mined repository)
  - Contained a „self-evaluation principle“:
    Commission („Kommission Lagerung hoch radioaktiver Abfallstoffe“ =
    „Commission on the Storage of High-level Radioactive Waste”,
    shortly: „Endlagerkommission“ = „Final Disposal Commission“ (2014-2016)
    (not to be confused with BMU‘s standing „Entsorgungskommission“ ESK)
    with several tasks, inter alia:
    - Evaluating the Site Selection Act
    - Developing site selection process & criteria
    - Evaluating alternatives to deep („mined“) disposal
  - Final report in German under https://www.bundestag.de/endlager-archiv/blob/434430/bb37b21b8e1e7e049ace5db6b2f949b2/drs_268-data.pdf
    Summary available in English under https://kotting-uhl.de/site/wp-content/uploads/2017/01/2201-16_Gesamt_EN.jpg
- ➢ 2017 Amendment of the Site Selection Act (and other Acts)

# Commission on the Storage of High-level Radioactive Waste



# Commission work: Evaluating alternatives to reversible deep („mined“) disposal

- Outer space
- Polar ice sheets
- Oceans
- Permanent surface storage
- Deep „mined“ disposal without retrievability

➢ Discarded

- Long-term interim storage
- Transmutation
- Deep borehole disposal (DBD)

➢ Watching brief
(note: amongst these three, only DBD can be seen as a real alternative!)

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# Commission work: DBD. GRS expert assessment

(GRS-423, https://www.bundestag.de/endlager-archiv/blob/413166/73c4148a71bb98611305958662204e23/kmat_52-data.pdf, in German)
The reference „Bracke et al. 2017“ in Rocher, Železnik et al. is based on this report)

- Topics according to tender
  - Safe disposal processes
  - Geologic requirements
  - Reversibility and retrievability
  - Drilling technology: State-of-the-art

- Conclusions
  - Boundary conditions
  - Basic concept
  - Drilling technology
  - Costs
  - Disposal, retrieval and recovery*)
  - Operational and long-term safety
  - Site selection criteria and safety requirements
  - Advantages
  - Disadvantages
  - R&D needs

*) Note: German regulations require retrieavabilty until closure and „measures to ease recovery“ for up to 500 a, including canister integrity for this timeframe

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## GRS expert assessment, selected findings

- Boundary conditions
  - Stability requirements: Lining, no „dry“ borehole
  - Minimum borehole diameter determined by flasks for vitrified HLW (not pressure-resistent) plus overpack → 600 mm
  - Container also feasible for disposal of „pulled“ fuel rods
- Basic concept
  - Crystalline bedrock, sedimentary overburden (clay or salt) → two geologic barriers
  - Minimal depth 1500 m
- Drilling technology
  - Lined boreholes to 5000 m depth with diameters up to 450 mm nowadays feasible, for 2000 m depth ca. 650 mm
  - Majority of industrially drilled holes down to 5000 m have diameters of 12¼“ (311,1 mm). Lesser depths → less strict requirements on container stability, higher diameters

# GRS expert assessment, selected findings

- Costs per borehole: Diameter 375 mmm, 5000 m depth → 30 Mio €
- Disposal & retrievability until closure feasible, recovery tricky if not impossible
- Safety:
  - Safe operation incl. radiation protection conceivable
  - Crucial scenario: drilling fluid / defective container → considerable nuclide releases → challenging w.r.t. radiation protection
  - Crucial for long-term safety:
    - transport via EDZ (excavation dammaged zone)
    - Gas-driven migration
- Siting & safety demonstration: Considerable investigation effort

# GRS expert assessment, selected findings

## Advantages

- Diverse geologic barriers
- Long distance of waste to biosphere
- Long combinations of sealing structures
- Less damage to geology
- Lower proliferation risk

## Disadvantages

- Corrosion of containers and lining likely
- Recovery (500 a requirement!) not feasible
- Site investigation effort

# GRS expert assessment, selected findings

R&D needs

- Demonstration tests
- Concept development
- Waiting for developments in hydrocarbon industry appears not to be sufficient!

# The Commission‘s conclusions

- DBD appears in principle feasible
- Long-distance isolation
- Diverse geologic barriers
- High proliferation security

- But technology is not mature, much less advanced than „mined“ disposal
- Extensive R&D needed, outcome unclear
- Lack of recoverability

- ➢ Keep a watching brief
- ➢ Fund R&D
- ➢ But don‘t constrain siting procedure for mined repository!

## Further R&D in Germany: Project CREATIEF (Kudla et al. 2018)

The reference „Bollingerfehr et al. 2018“ in Rocher, Železnik et al. is based on this project)

- Aims:
  - analysis and description of the assumptions made and boundary conditions used in existing research reports / studies
  - description of the key aspects of deep borehole disposal and illustration of potential for improvement
  - conceptual assessment of the opportunities and risks of deep borehole disposal.
- Assessment of regulatory issues (regulations being “tailored” to “mined” disposal!)
- Two generic geologic profiles considered
- Two concepts, both at 5000 m depth: diameters of 445 mm and 900 mm, respectively
- Outline of safety and demonstration concept
- Outline of emplacement and retrieval concept

# Further R&D in Germany: Project CREATIEF (Kudla et al. 2018)

The reference „Bollingerfehr et al. 2018“ in Rocher, Železnik et al. is based on this project)

## Opportunities

- Shielding effect of drilling fluid
- Lower void volume
- 445 mm diameter drilling feasible,
  900 mm drilling requires R&D which will not be performed by raw materials indusry

## Risks

- Diameter 445 mm does not suffice for existing waste
- Corrosion caused by drilling fluids
- Retrieval & recovery requires extensive R&D, recovery most likely impossible
- Challenges w.r.t. safety demonstration (including criticality safety)

# Personal considerations

# Long-term safety, its demonstration and related knowledge

- Possible knowledge exchange due to worldwide occurrence of crystalline basement, but still …
- relatively limited understanding of the nature of deep crystalline rock systems
- ➢ Site investigation much more challenging compared to mined repositories

- Hydrogeology: Long pathways, stagnant (saline) waters, reducing conditions
- Demonstrability e.g. of seal performance?
- More general: Reliable underground testing?

# Security / non-proliferation

- A target conflict which is not specific to DBD: security vs. retrievablity.
- In case of DBD:
  - Apparently higher security, provided that all waste is being emplaced properly
  - Retrievability tricky, even more so in case of stuck canisters

# Technical feasibility

- Deep drilling is feasible, but today only with small diameters
- Challenge: Development of reliable seals

- Perspecives in the rather long run, dependent on technological evolution
- „Wait and see“ what hydrocarbon industry does is not enough

# Costs

- Highly dependent on inventory:
  - Fixed costs possibly lower than for mined repositories
  - Variable costs (per emplaced canister) probably higher

# Waste types

- Decisive: canister diameter, …
  - … which is fixed for existing vitrified reprocessing HLW (430 mm),
  - … as well as for spent fuel elements (e. g. PWR elements 230 x 230 $mm^2$),
  - … which, however, could be disassembled
    (even nowadays, the German concept foresees the disposal of „pulled fuel rods“)
- Sandia: „DOE-specialty wastes rather than commercial spent fuel“

# Location / siting

- De-centralised disposal as an option?
- This would, however, mean multiple surface facilities (waste reception & conditioning), …
- …, which might be ok in case of operating NPPs

- Is this a pro or a con w.r.t. the socio-technical siting process?

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## Regulation

- Adaption would probably be necessary in most countries
- BUT: Does this „just“ concern technical requirements or also underlying principles and, thus, normative issues?
  (cf. the German case: Recovery requirement)

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## (Personal) conclusions:
## Two major issues to be considered when making strategic decisions on DBD

- Normative issues
  - Mainly around the issues of security, retrievability and recoverablity
  - Decisions needed, perhaps with changes in regulations as a consequence

- Technical feasibility, R&D effort and timing
  - …

## (Personal) conclusions:
## Two major issues to be considered when making strategic decisions on DBD

- Normative issues …
- Technical feasibility, R&D effort and timing
  - „Mined“ disposal is close to implementation in some countries
  - Countries in the siting phase: What would be lost, what would be gained?
    - Some potential advantages for DBD, some potential pitfalls
    - To be balanced: Are the arguments strong enough to change direction ar, at least, leave DBD option open? → consequences for budget and time schedule
  - Less advanced countries:
    - „Watching brief“ apparently not enough, R&D investments needed
    - Again: Are the arguments strong enough to justify such investments?
    - Would an international effort be helpful? Another attempt at multinational solutions? Perhaps only for certain waste types, combined with mined repositories in other countries (with advanced programme and / or large waste amounts)?

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# DBD:
# To be discarded?
# An alternative to „mined“ disposal?
# A complement?

# Selected References


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