Supplement of Saf. Nucl. Waste Disposal, 2, 31–31, 2023
https://doi.org/10.5194/sand-2-31-2023-supplement

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Supplement of

Deep borehole disposal as a potential solution for high-level waste (HLW) and spent nuclear fuel (SNF) in Norway – current status and a first generic safety assessment

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Deep Borehole Disposal as a Potential Solution for HLW/SNF in Norway – Current Status and a First Generic Safety Assessment

SafeND 2023 – SESSION 04: Activities in international research programs and collaborations

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Outline

1. General information about the Norwegian Program

2. Central aspects of the DBD development
   - General concept development
   - Disposal canister design
   - Sealing of disposal borehole
   - TRL assessment

3. Safety assessment

Radioactive Waste in Norway

- Responsible organization → NND NORSK NUKLEÆR DEKOMMISJONERING
- No commercial reactors, limited waste volume
- Radioactive waste from various industries and research reactors
- Disposal plan is to locate all necessary repository types at a single site:
    - Landfill-type repository for VLLW
    - Intermediate-depth repository for LILW
    - HLW either in DGR-type (similar to Finland and Sweden) or Deep Borehole Disposal

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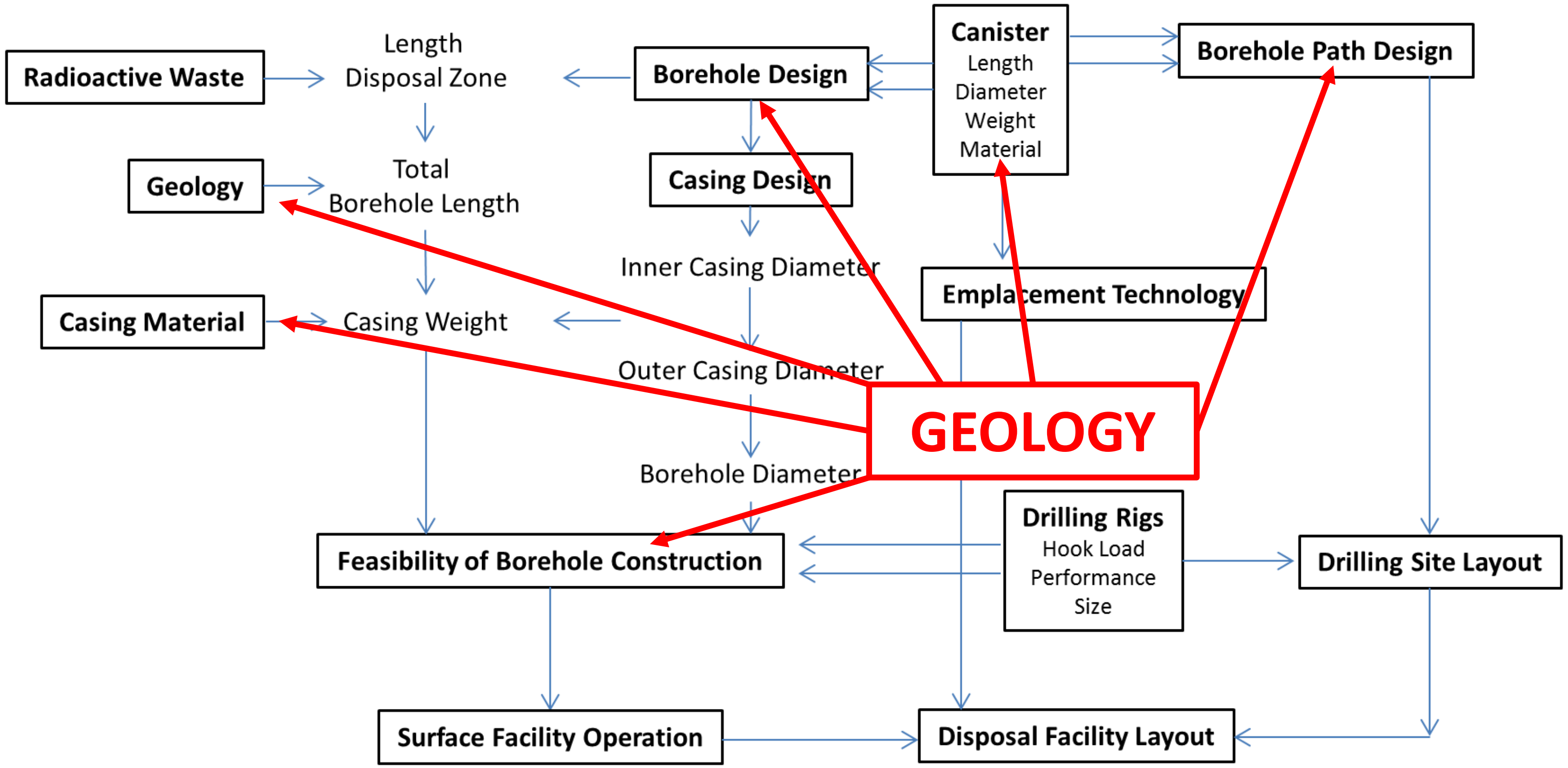
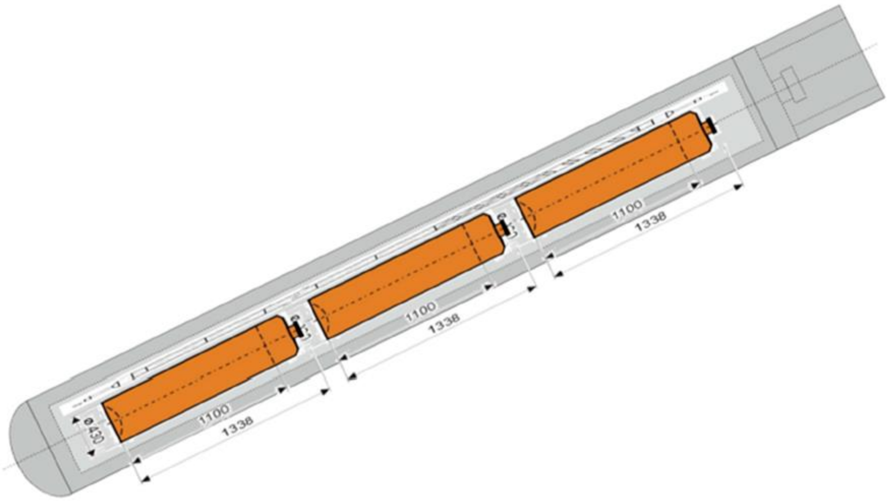
General Concept Development



General Concept Development

- Roughly 70 canisters (DBC-R) for the disposal of all Norwegian HLW/SNF in deep boreholes
  - Considered canister dimensions:
    - Outer length: 5 000 mm
    - Inner length: 4 800 mm
    - Outer diameter: ~ 525 mm
    - Inner diameter: 435 mm

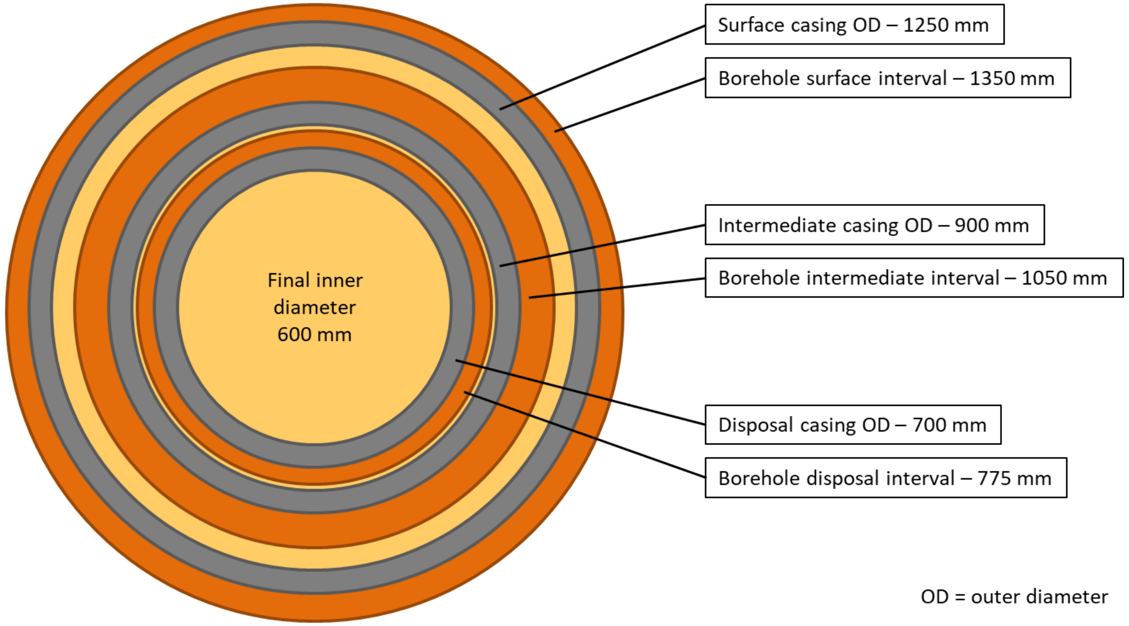


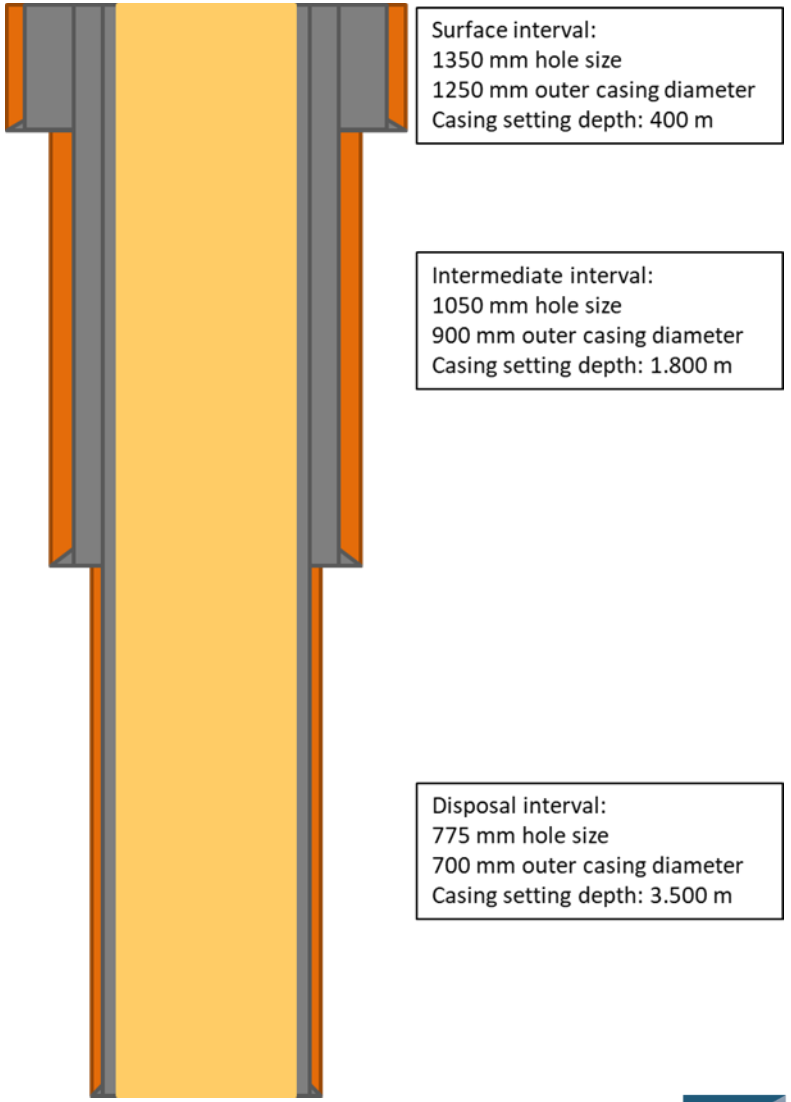
DBC-R container with three assemblies and one fuel rod

from: Bracke, G., Charlier, F., Liebscher, A., Schilling, F., Röckel, T. (2017): About the Possibility of Disposal of HLRW in Deep Boreholes in Germany. Geosciences, 7, 3.

➢ Resulting (preliminary) borehole dimensions:
- Considered borehole depth: 3 500 m
- Required disposal length: 500 m
- Required inner casing diameter (at final depth): 600 mm

General Concept Development





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Disposal Canister Design

Safety functions:
For a radioactive waste canister, in general three major safety functions can be identified:

- **Containment** of the radioactive waste, e.g. as defined in IAEA SSR-5
- **Shielding** of the radiation, e.g. as defined in IAEA SSG-1
- **Absence of criticality**, e.g. as defined in IAEA SSG-15

Additional design- and concept-specific safety functions:

- **Limiting temperature** of the radioactive waste, e.g. as named in IAEA SSG-15
- **Limiting corrosion** and gas production, e.g. as named in IAEA SSR-5
- **Operability**, e.g. as named in IAEA SSG-1

Quantified Safety Functions

Analysis of potential materials and their benefits and limitations

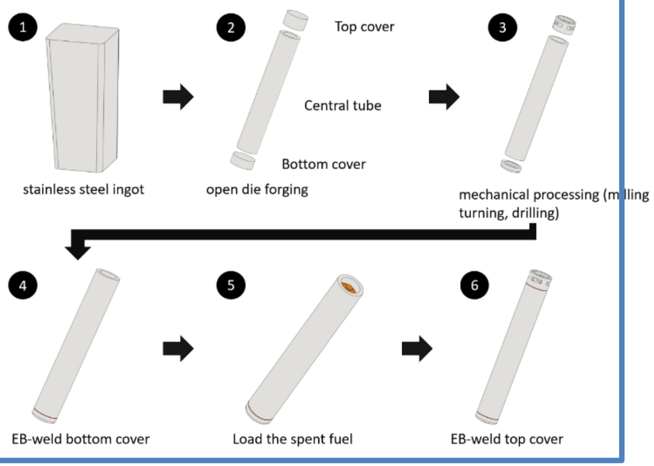
Analysis of material availabilities

Physical design parameters:

- Canister is designed for all waste types
- Dimensions restricted by maximum lengths and diameters of fuel assemblies and waste packages from reprocessing

Analysis of potential manufacturing techniques

Manufacturing techniques:



Physical dimension requirements of the canister

Canister Design

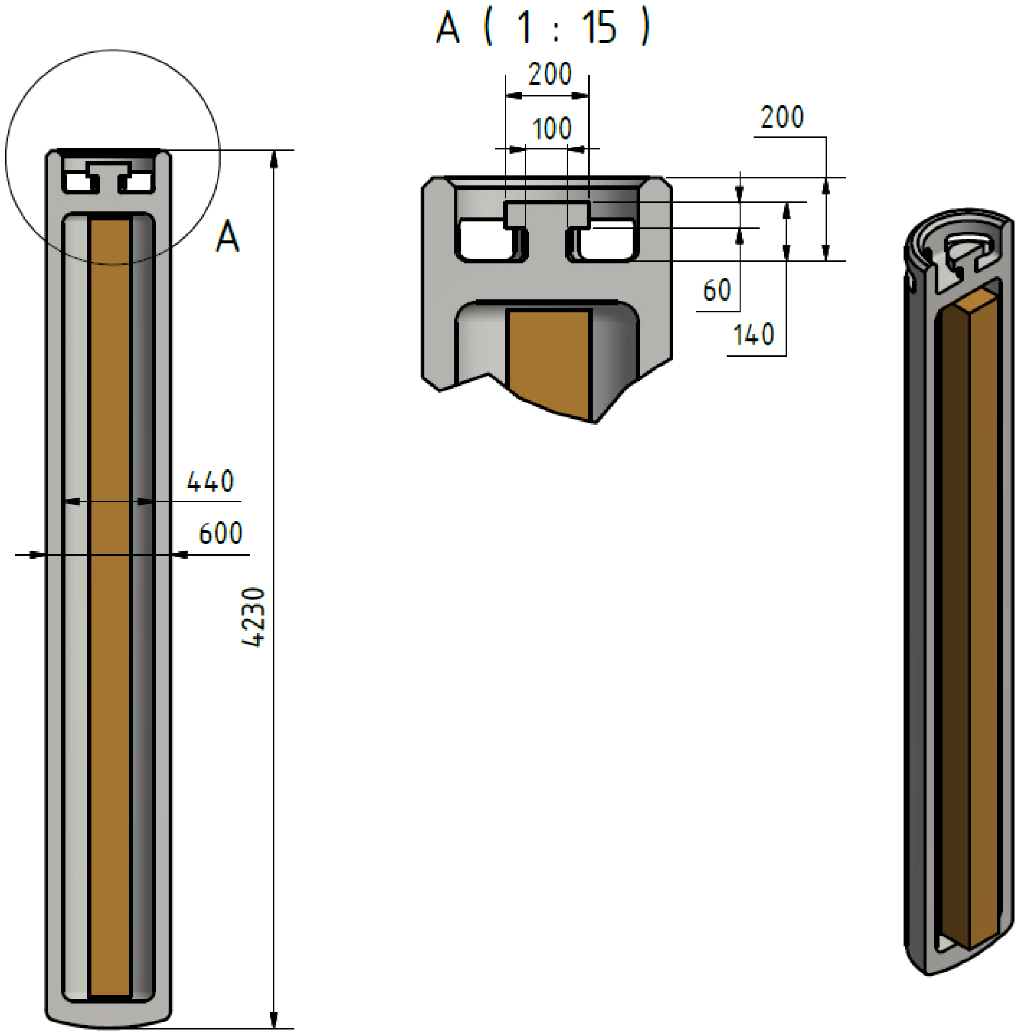
Disposal Canister Design

Canister design for the HLW in Norway:

- Length about 4.4 meters
- Usable inner length ~3.7 meters
- Diameter 60 cm
- Material: Stainless steel

- Weight of empty canister ~4500 kg
- Weight with waste ~6000 kg

- For Norwegian HLW inventory, a total of 90 canisters are needed for a single disposal borehole



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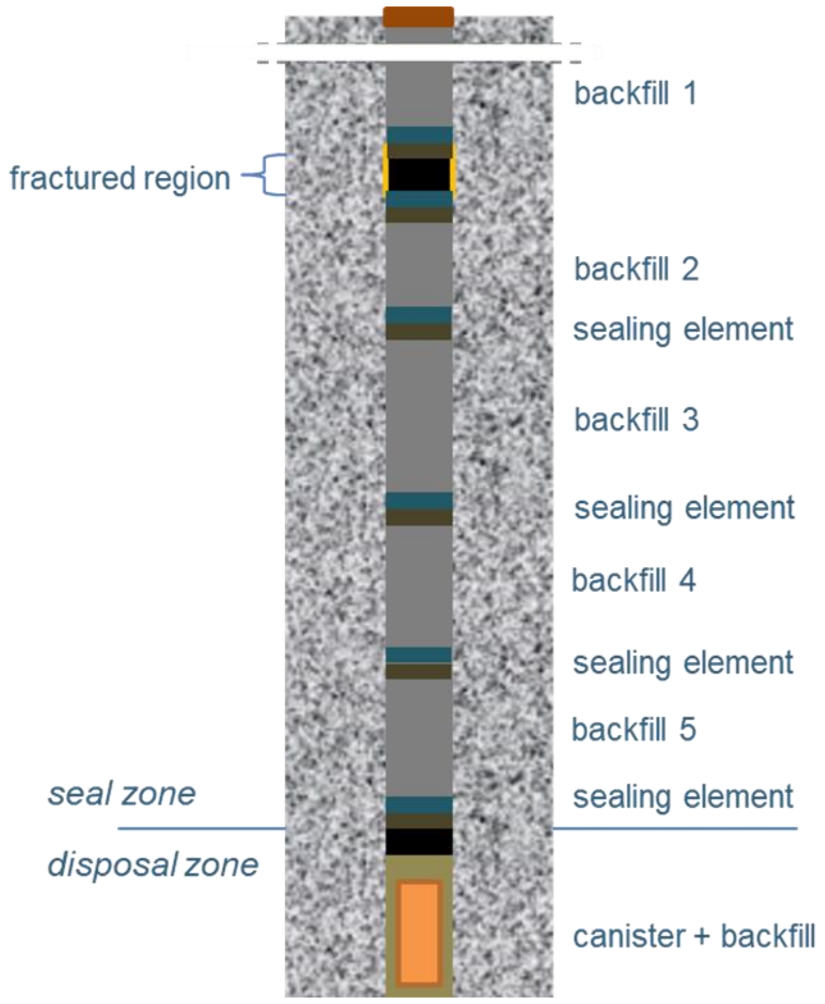
Sealing of a Disposal Borehole

1. Gather information about the geology
   - ➢ Detailed information about formation sequences
   - ➢ Gamma ray-neutron logs
   - ➢ Investigation of cuttings and cores during drilling
   - Borehole pressure tests to identify potential fractures in the formation
   - Seismic surveys to detect faults
2. Gather information about the borehole condition
   - Completion of the borehole
   - Condition of the borehole walls
   - ➢ Prepare the borehole for installation of the sealing elements
3. Select material based on the geological/geochemical information
4. Select emplacement method based on the material selection
5. Determine the exact position of the sealing elements

➢ The main objective is to create a seal that mimics the formation!



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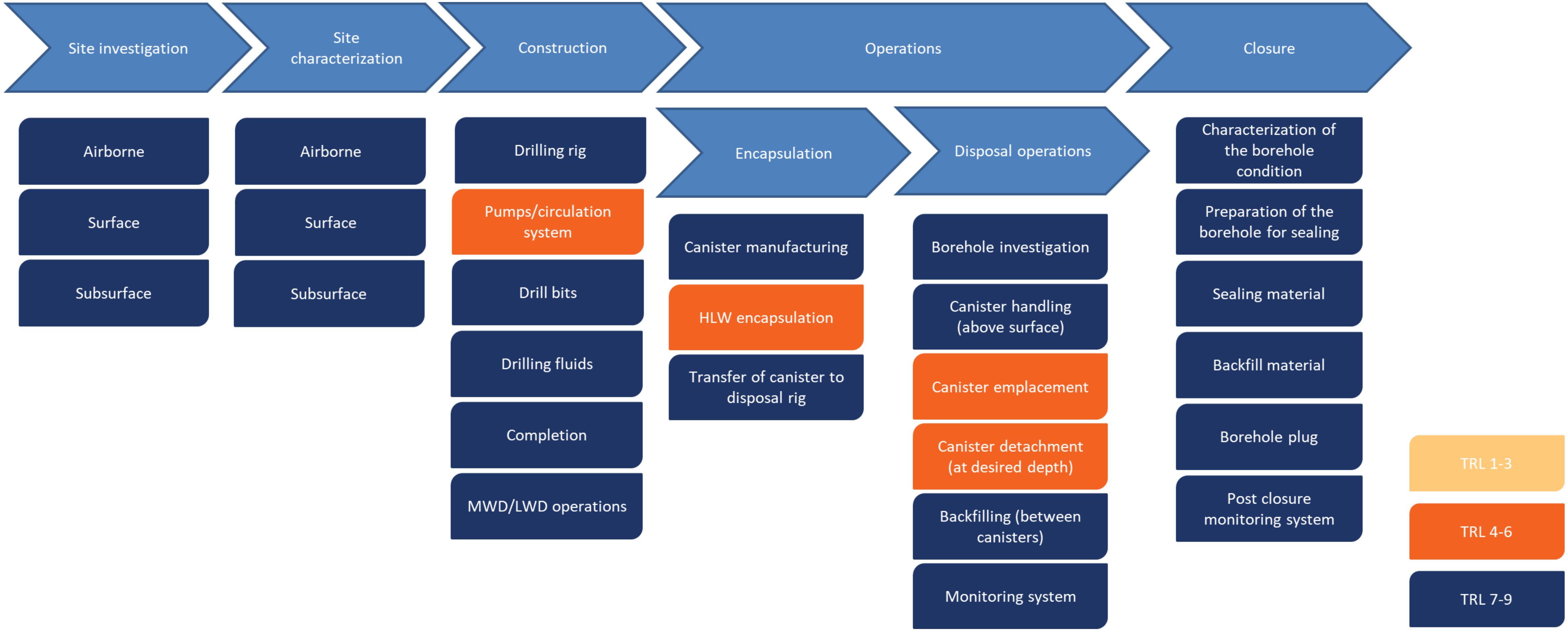
TRL Assessment



- Identification of aspects with the most R&D need

TRL Assessment

- Findings of the first TRL assessment:

  1. Site investigation/identification capabilities are available and applied on a daily basis
  2. Drilling capabilities are in principle available and have proven their usability, however, the "required" dimensions have not/barely been drilled so far

     ➢ When looking at the technical feasibility, availability of the technologies, and statements from drilling engineers, a borehole with the "required" dimensions can be drilled

     ➢ The "right" components need to be put together

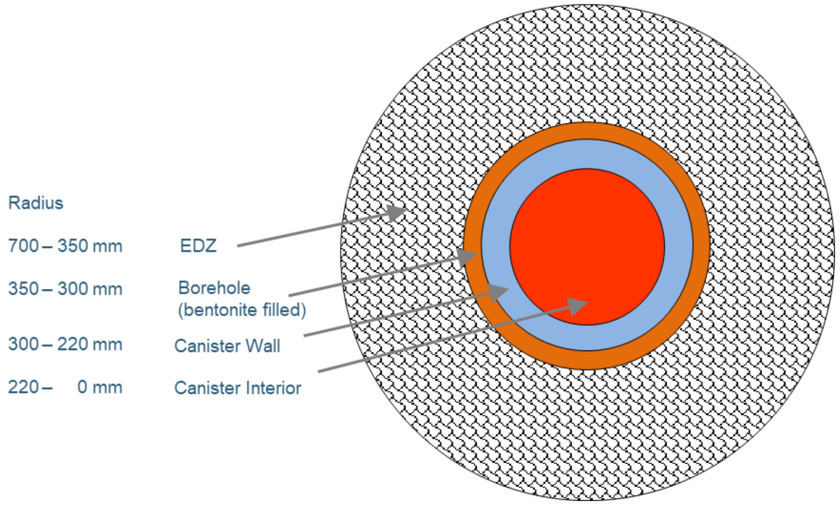
  3. Encapsulation plant, canisters, and emplacement device need to be developed

➢ In principle, all technologies are available and usable, but there is still a need for research to implement the DBD concept.

Safety Assessment

General information for the safety assessment

- Borehole assumptions:
  - Backfill zone length: 2,500 m (backfill material is a crushed rock mixture)
  - Sealing zone length: 500 m (seal consists of bentonite)
  - Disposal zone length: 460 m (88 canisters + 1 m bentonite buffer between the canisters)
- Canisters will fail, once thickness of canister walls has corroded from 80 mm initial thickness to 50 mm
- Calculations carried out with GoldSim



Safety Assessment

- Sealing zone has been divided into 25 segments

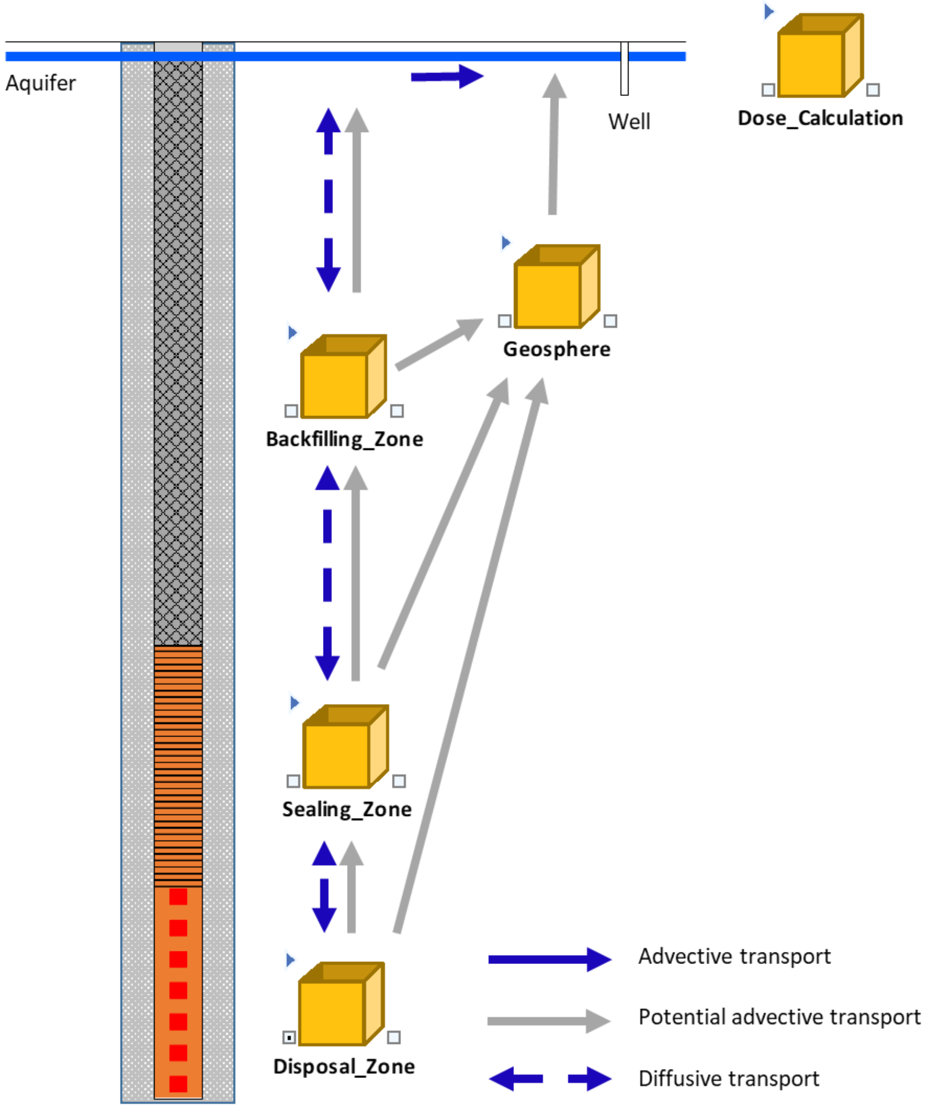
  → Each segment represents a 20-m-section

- Disposal zone has been divided into 22 segments

  → Each segment represents 4 canisters (21 m)

- Backfilling zone has been divided into 25 segments

  → Each segment represents a 100-m-section



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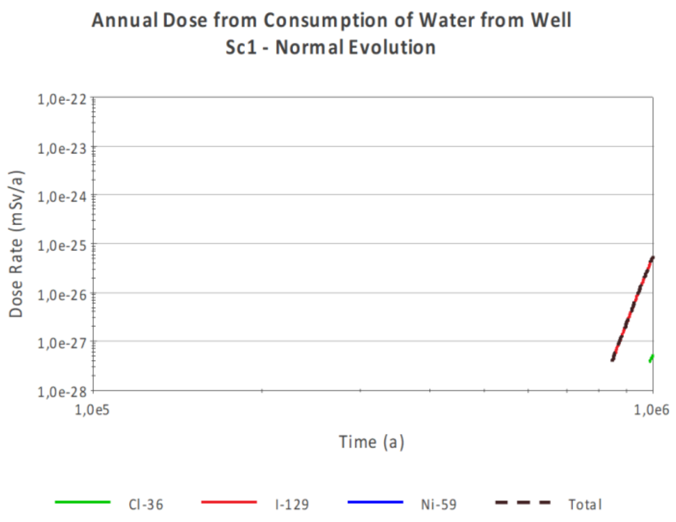
Safety Assessment – SC-1

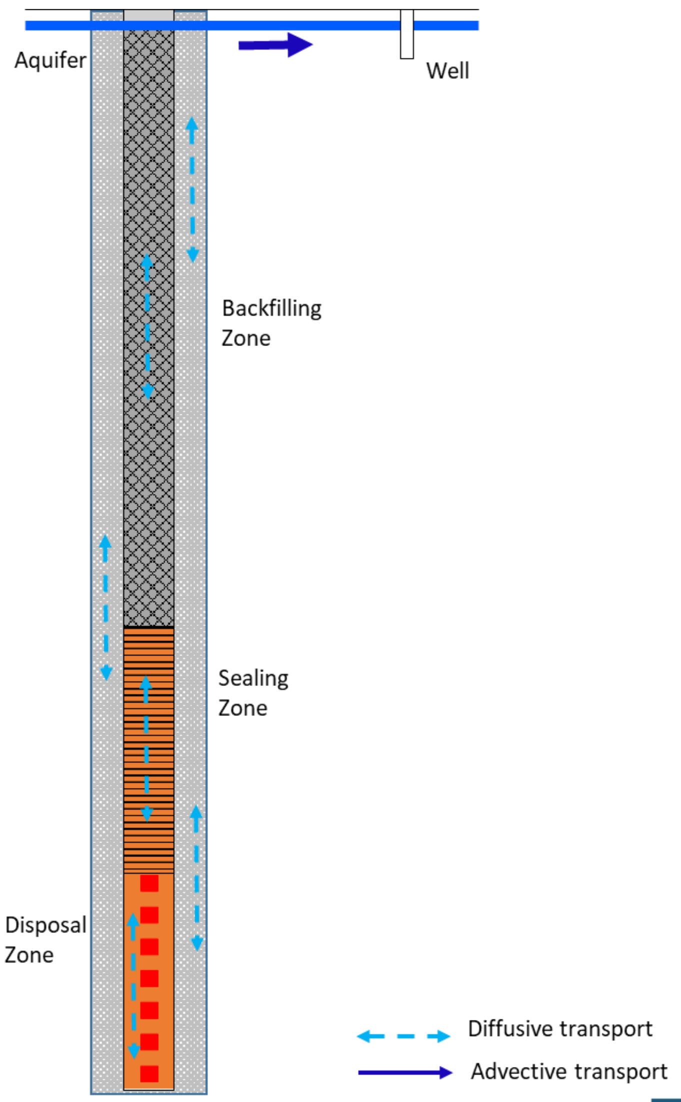
Reference scenario - Normal Evolution Scenario – SC-1

- Only diffusive transport through the borehole and the damaged rock zone
- Advective transport through the groundwater aquifer to a water well

<u>Results:</u>

- Sorbing radionuclides or those with relatively short half-lives do not reach the top of the seal
- Even non-sorbing radionuclides hardly reach the backfilling zone and the aquifer





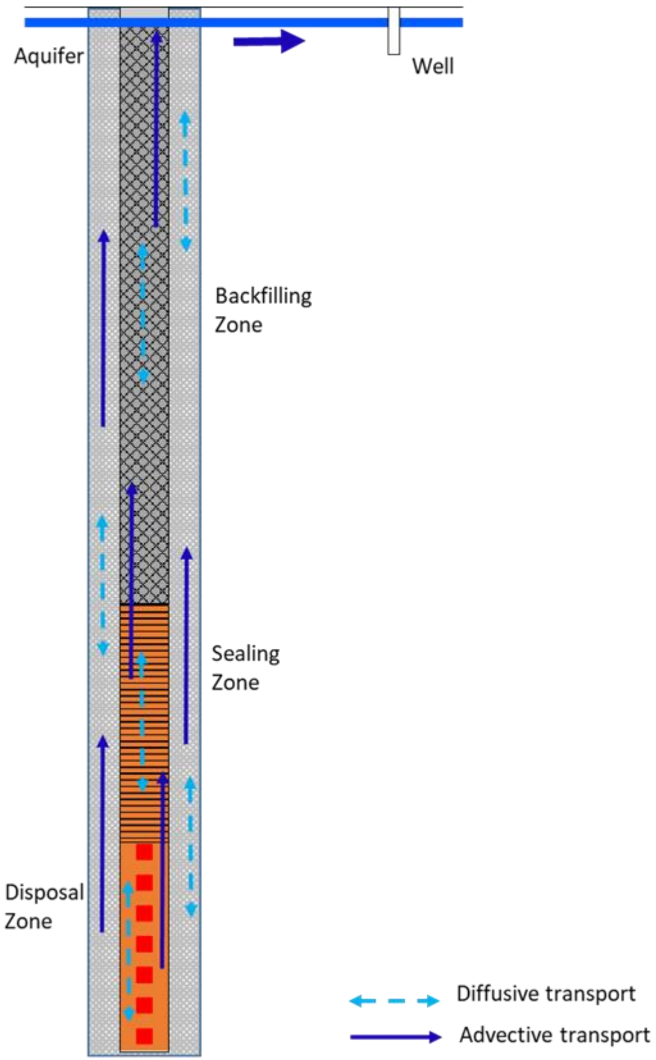
Safety Assessment – SC-2

Alternative scenario – Vertical Flow – SC-2

- Flow through the borehole and the damaged rock zone
- Different sub-scenarios considered
  - No solubility limits
  - No sorption
  - Direct failure of all canisters

Results:

- Compared with SC-1, the total dose rate is larger → advective transport is much more efficient than diffusive transport
- Total dose rate is higher
- Dose rate is still well below the assumed regulatory limit (0.1 mSv/a) even for the pessimistic scenarios



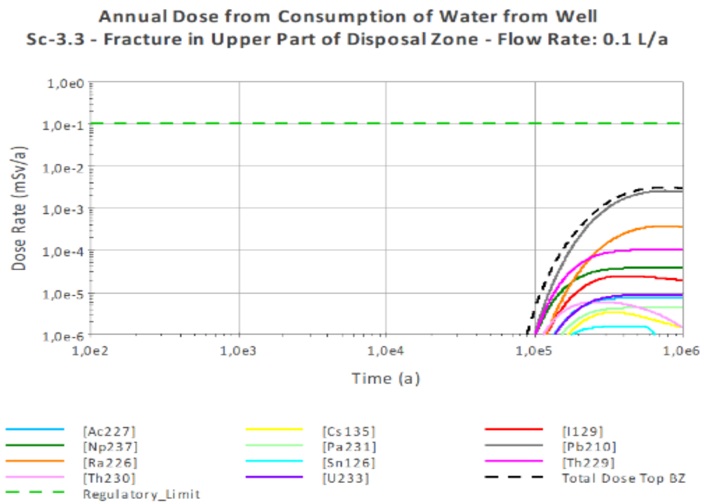
Safety Assessment – SC-3

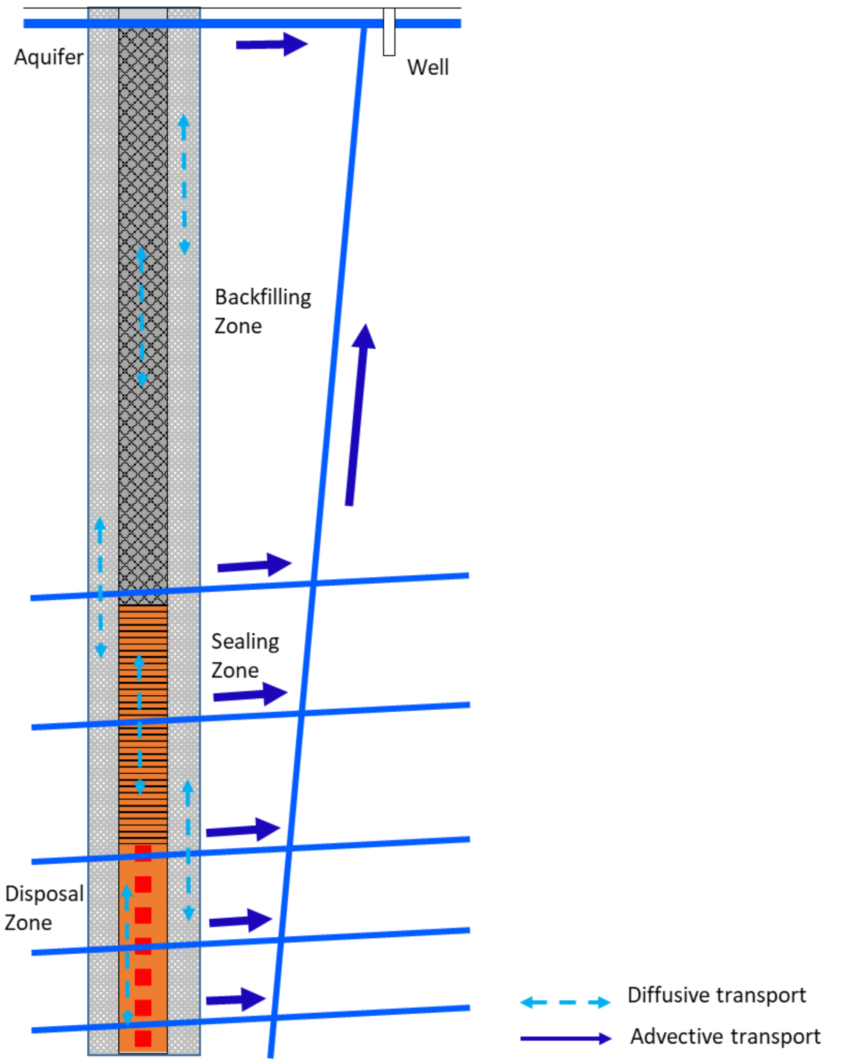
Alternative scenario – Fracture – SC-3

- Flow through fractures
- Intersection of borehole by a highly transmissive fracture
- Fractures at different locations (depths) of the borehole considered:
  1. Bottom/middle/top of the disposal zone
  2. Middle of the sealing zone
  3. Bottom of the backfilling zone

<u>Results:</u>

- Dose rate depends strongly on the location of the fracture
- Higher dose rate than before, especially for fractures through the disposal zone, but still below the regulatory limits





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Thank you for your attention!