Which Processes could define Temperature Limits on the Outer Surface of a Container in a Disposal Facility?

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Site selection act (2017) for disposal of HLRW

- **Draft temperature limit** of 100°C on the outer surface of containers for preliminary safety analyses of disposal sites, § 27 (4)

- Justification as a precautionary measure
Comments on the „draft temperature limit“*

- Temperatures below 100°C are not necessarily advantageous for safety
- Potential sites may be not be considered
- May impede the development and optimization of safety and disposal concepts

Definitions

- **Draft** temperature limit (as given in §27 (4) for container surface)

- **Design** temperature limit (Container surface or other components)
Are there any national regulations on temperature limits elsewhere?

- **No** draft temperature limits were found in other regulations*

However:

- Some general requirements on design temperatures in guidelines!

- **Applied design temperatures** for the surface of containers range between 80 - 230 °C (existing safety and disposal concepts)

* See also: D1016 | EGU2020-20302, State of the scientific and technical knowledge about limiting temperatures in the Repository Site Selection process of Germany with simultaneous consideration to Europe and other European repository concepts, Ute Maurer-Rurack, Axel Liebscher, and Fabien Magri
Temperatures of a POLLUX container of disposal concept for Gorleben

Temperature at container surface [°C]

Design temperature

Peak temperature (disposal area)

Peak temperature (single container)

Temperature limit, §27 (4)

Modified from DBE (2016)
Impact of „design temperature limits“ for generic disposal concepts (DBE 2016)

<table>
<thead>
<tr>
<th></th>
<th>Unit</th>
<th>Rock salt</th>
<th>Rock salt</th>
<th>Crystalline rock</th>
<th>Clay rock</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Temperature limit</strong></td>
<td>°C</td>
<td>200</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td><strong>disposal area</strong></td>
<td>km²</td>
<td>0.80</td>
<td>1.63</td>
<td>2.21</td>
<td>4.87</td>
</tr>
<tr>
<td><strong>additional area for safety distance</strong></td>
<td>km²</td>
<td>0.23</td>
<td>0.40</td>
<td>1.03</td>
<td>1.08</td>
</tr>
<tr>
<td><strong>infrastructure facility</strong></td>
<td>km²</td>
<td>0.25</td>
<td>0.25</td>
<td>0.32</td>
<td>0.63</td>
</tr>
<tr>
<td><strong>Total disposal area</strong></td>
<td>km²</td>
<td>1.28</td>
<td>2.28</td>
<td>3.56</td>
<td>6.58</td>
</tr>
</tbody>
</table>
Building blocks for a safety analysis

- Safety concept and strategy for proof
- Site model and longterm prediction
- Concept for disposal, backfill and closure
- FEP database
- Scenario development
- Safety analysis
Processes in FEP-Catalogues (Features, Events and Processes)

- **Temperature**
  (e.g. structural changes due to illitization, mineral composition, sorption capacity),

- **Hydraulics**
  (e.g. viscosity, density and surface tension; relative permeability),

- **Mechanics**
  (e.g. strength properties; cracking due to drying; swelling capability),

- **Chemistry**
  (e.g. kinetics; diffusion; cation exchange; pH value, reactions)

- **Biology**
  (e.g. growth rate of microbes, population of microbes)
Examples
Rock salt: main temperature-dependent processes for safety concepts

- Microbial Activity
- Thermal Expansion (Host rock)
- Rate of Compaction (Salt grit)
- Creeping (Rock salt)
- Thermochemical Sulfate Reduction
- Thermal Decomposition (Carnallite)
- Release of water (Polyhalite)

Temperature [°C]

Modified from Bracke et al. (2019)
Oedometer tests on crushed salt used for backfill

- Stress versus void ratio (porosity)
- Constant \textit{compaction} rate
- Temperatures 50 – 200 °C
Oedometer tests on crushed salt for backfill

⇒ Higher temperature: Lower porosity at lower stress
⇒ Positive effect!
Clay rock – main temperature-dependent processes for safety concepts

- Microbial Activity
- Thermal...
- CO₂-Desorption from Clays
- Decomposition of Carbonate...
- Smectit-Illit-Reaction
- Quartz-Cementation
- CO₂-/H₂S-Release
- Steam-Bentonite-Reaction
- Thermochemical Reduction...
- H₂-induced Reduction of Pyrite
- Pyrolysis of Cerogen

Temperature [°C]

Modified from Bracke et al. (2019)
Illite-smectite reaction

- Smectite content vs. temperature
- Bentonite rich clay (○) and other clay rock / shale (●)
- Reaction starts at approx. 60°C
- Clay rock / shale losts smectite at approx. 100-120°C
- Difference is negligible at approx 150°C
- Other site specific effects must be assessed
- Lower smectite content with higher temperature

⇒ Higher temperature: Negative effect!
Crystalline rock – main temperature-dependent processes for safety concepts

- Matrix: Consideration of thermal conductivity and heat capacity
- Matrix: High temperatures in history \Rightarrow low mechanical impact by temperature
- However: materials, geotechnical barriers and fissure fillings (e.g. hydrothermal alterations) may be relevant for safety concepts

Three concepts: Overlying CPRZ   KBS-3 Concept   multiple CPRZ
Summary on THMCB processes

- Many temperature-dependent processes and interactions
- Published FEP catalogues list almost all conceivable temperature-dependent processes
- Safety relevance is depending on the safety and disposal concept
Summary and conclusions

- Typical design temperatures - related to the outer surface of the containers and used for design of a disposal facility - are in the range of **80 to 230 °C**.

- Derivation of resilient min. or max. temperature limits for the outer surface of containers should be based on (preliminary) safety and disposal concepts.

- When a safety concept is set and a disposal concept is optimized and approved, "temperature limits" can be justified by safety analyses for a disposal facility.
Which Processes could define Temperature Limits on the Outer Surface of a Container in a Disposal Facility?

Main (many) processes are known.

“Design temperature limits” are derived when safety and disposal concepts are selected.

Therefore:

1. Development of feasible safety concepts and preliminary disposal concepts
2. Preliminary safety analyses to find relevant processes and to optimize concepts and design temperatures
3. Derive resilient and (site-)specific “temperature limits” based on the interaction of all relevant processes.
References (more in Bracke et al., 2019)


End of presentation!

The following slides are extra stuff.
High-level radioactive waste in Germany (heat generating)

- Spent fuel elements (35000 pieces, 10500 Mg - 7600 m$^3$ as fuel rods)
- Vitrified waste (8000 pieces, 2000 m$^3$)
- Spent fuel pebbles (2000 m$^3$)
Design temperatures

- Concepts using clay-based materials
  ⇒ mostly ~100 °C as design temperature limit (container surface)

- The swiss concept considers a design temperature range of 80 – 150 °C on the container surface

- Concepts in rock salt and tuff applied design temperature limits of up to 200 rsp. 230 °C on the container surface

- Mostly based on properties of the rock minerals, water content, … - for a specific safety or disposal concept