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SSM's perspective on evaluating safety significance of specific canister degradation processes

KYT seminar on canister integrity
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Outline

- State of the program for a spent nuclear fuel repository at the Forsmark site in Sweden
- Relevant (and recent) lessons learned (pedagogical challenges)
- Basis for SSM's review of specific processes
- System perspective when evaluating significance of a specific process
- A regulatory dilemma – what is the justification for further research if compliance can be demonstrated?

Timeline of events in licensing process

- 2011: SKB submit license application
- 2016: SSM statement to court
- 2018: SSM statement to the government – recommending approval
- 2018: The government invite SKB to submit complementary information
- 2019: SKB report on “Supplementary information on canister integrity issues”
- 2019: SSM completes review
  - (2019: SKB dismantles LOT S2 and A3 experiments)
  - (2021: SSM completes review of SKB’s results and QA work)
- 2021: Government referral on studies related to canister processes (and LOT)
- 2021: SSM answer referral

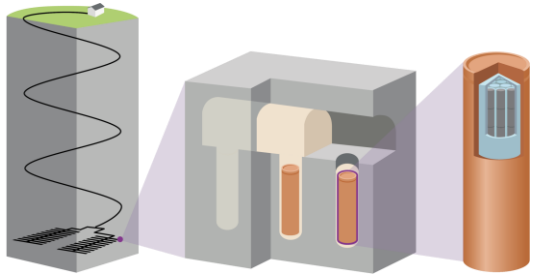
Relevant (and recent) lessons learned

- Recently the Swedish government referred two specific scientific studies regarding specific canister degradation processes
  - Zhang et al. Corrosion Science 184, 109390
    - Sulphide corrosion (authors draw conclusions on implications in terms of SCC and hydrogen embrittlement in copper)
  - Björklund V, 2021, Master's Thesis, Aalto University.

- Pedagogical challenge for the regulator communicating postitive assessment of disposal system robustness when epistemic uncertainty regarding specific processes is discussed

Basis for SSM's review of specific processes (e.g. canister degradation processes)

- SSM's regulatory requirements
  - Requirements on functions and robustness of the barrier system (multiple barriers)
  - Long-term protection of human health and the environment



- Compliance is evaluated based on safety analysis report (SR-Site in SKB's application)
  - System focus – analysis of design criteria for individual barriers (canister, buffer and host rock) to achieve expected functions of the repository
  - Identification and treatment of uncertainties – analyse and limit impact
  - Consequence analysis of reference evolution as well as of less likely evolutions (scenarios)

Criteria on canister function and properties derived from safety analysis report

- Extent of corrosion limited in relation to thickness of overpack (5 cm)
- Canister shall withstand
  - isostatic loads (mostly relevant for insert)
  - smaller shear movements in host rock (< 5 cm)
- Degradation processes considered through appropriate dimensioning and design taking account of overall barrier system performance

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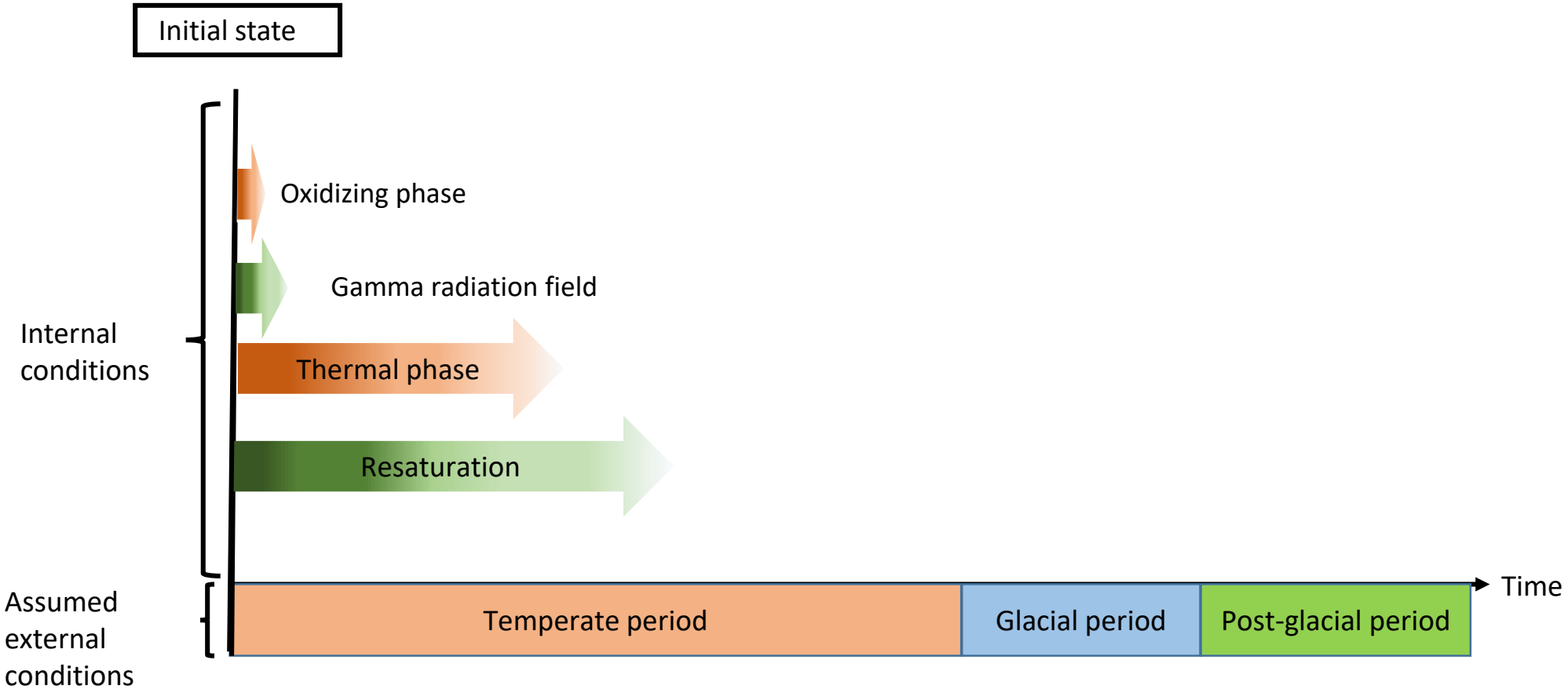
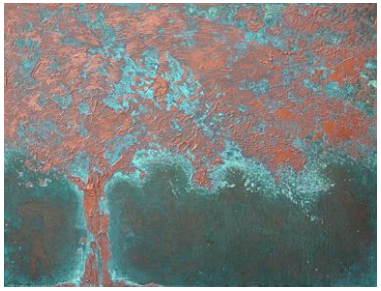
- No regulatory requirement for 100% containment
  - Safety functions in assessment: containment and retardation

Phases in the evolution of the repository



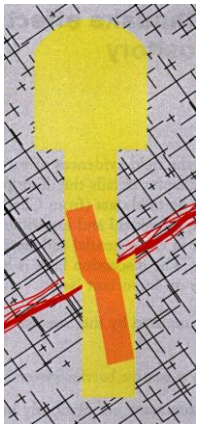
Chemical degradation - Corrosion of copper



- During initial oxidizing phase corrosion occurs through reaction with remaining oxygen
- During persistent reducing phase copper corrosion occurs through reaction with sulfide dissolved in groundwater
  - Against the background of overall barrier system performance
- Robustness: overpack thickness exceeds with margin expected accumulated corrosion attack
- Extent of corrosion: depends on magnitude of groundwater flow in the vicinity of deposition holes and concentration of corroding species in the groundwater
  - Cases with appreciable corrosion attack relative to overpack thickness only after long time and if high concentrations of sulfide are maintained in deposition holes subject to the highest groundwater flow (tail of distribution of deposition holes)

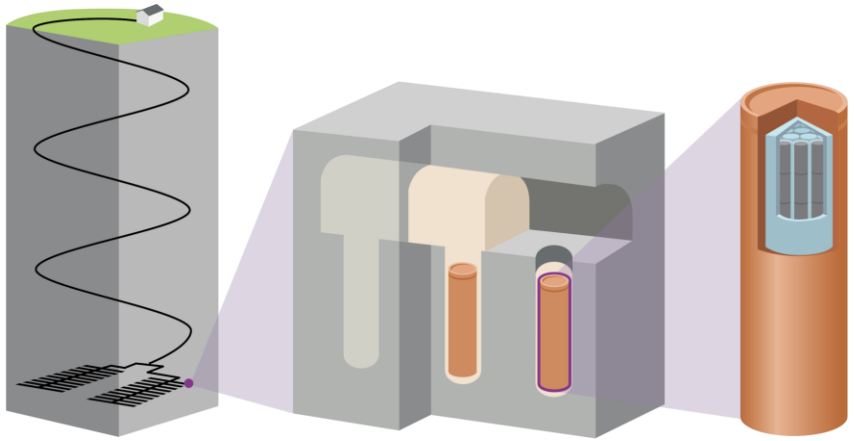
Mechanical degradation - Load cases for a canister in the repository

SKB TR 05-18
Mock-up experiment 140 Mpa to demonstrate safety margin



- Isostatic loads
  - Normal pressure (swelling + hydrostatic): ~ 15 MPa (with max. ice load ~ 45 MPa)
  - Extremely high pressure: canister fails through plastic collaps
  - Set requirement on dimension and material properties of insert
  - Overpack deformed to small extent through creep deformation
- Shear loads (due to large earthquakes in the vicinity)
  - Small displacements are absorbed through buffer (and overpack) deformation
  - Large shear movements (> 5 cm) leads to canister failure and are considered in the risk analysis
  - Factors deciding significance: earthquake probability, distance to epicentre, propagation of rock movements, length distribution of fracture planes, buffer stiffness, and hole selection criteria

A system perspective when evaluating the safety significance of a specific process (e.g. copper corrosion)



- **Understanding of corrosion processes and mechanisms through experimental and theoretical studies**
- Studies of repository environment and evolution – especially groundwater chemistry and hydrogeological transport processes
- Analysis of properties and long-term evolution of bentonite buffer with respect to e.g. transport limitation (corrodant and radionuclide)
- Evaluation of canister long-term integrity with respect to corrosion and relevant loading scenarios
- Risk analysis – under what circumstances can canisters fail and what will be the consequences for human health and the environment?

A perspective on system robustness

- Illustration of system robustness based on hypothetical scenario
- Estimation of dose consequence when hypothetical loss of canister containment function assumed in different given time frames
- Hypothetical canister failure in majority of deposition holes do not contribute to dose – no intersecting fractures

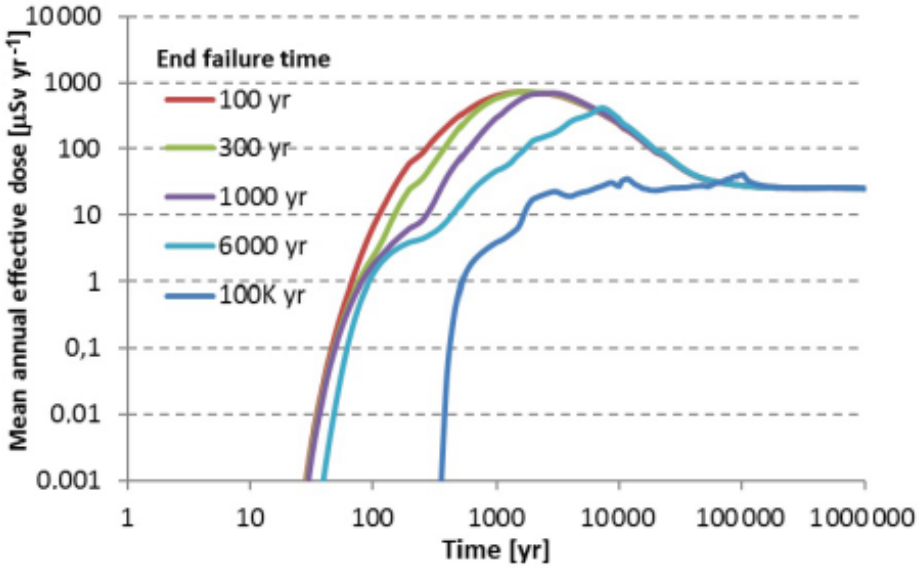


Figure 1. All 6000 canisters fail evenly distributed in different given time frames. Can failures 1–100 years, 1–300 years, 1–1000 years, 1–6000 years and 1–100 000 years. Dose for canisters failure under conditions of intact buffer conditions. Parts of the rock without any intersecting fractures at all do not contribute to dose.

Pensado O., 2017, SSM Report 2017:15

Example: Comment on recent referral

- Zhang et al. 2021
  - Study focuses on corrosion with sulfide (well known and well studied process - sulfide corrosion persistent corrosion process in safety case)
  - Effects observed (with high resolution) have likely occurred in similar studies
  - Conclusions regarding hydrogen loading are authors interpretation and not observations
  - Implications for SCC (which are claimed by authors) difficult to assess – SCC not explicitly studied (not loaded specimens)
  - Safety relevance of specific study? Processes investigated in study are included in SKB's safety assessment, which has been reviewed by SSM.
  - Risk for localized corrosion (e.g. SCC) requires large supply of sulfide, i.e. high concentrations of sulfide need to be maintained in deposition holes subjected to the highest groundwater flow. SCC typically also requires tensile stress. Tensile stresses initially occur in the corner regions near the weld for the canister lid, but in the long-term the canister is predominately exposed to compressive stress after buffer swelling.

Need for further research?

- Today's seminar is focused on on-going research in Sweden and Finland where the regulators have 'approved' DGR concept.

- Dilemma recommending approval of an application and at the same time recommending that additional research should be made?
  - Example: From SSM's review of SKB's supplementary information on canister integrity (e.g. SCC):
    - SSM requests further investigations based on more accurate measurement methods although significance of process deemed small.

- Further research could provide information to:
  - Further motivate design criteria on e.g. barrier components or properties
  - Employ less conservative assumptions in safety assessment
  - Help with optimizing system components