Interplay between research and safety assessment in the Swedish SNF programme

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- With SKB since 1994
- Responsible for assessment of post-closure safety for SKB's planned spent fuel repository

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SKB's expert on clay materials

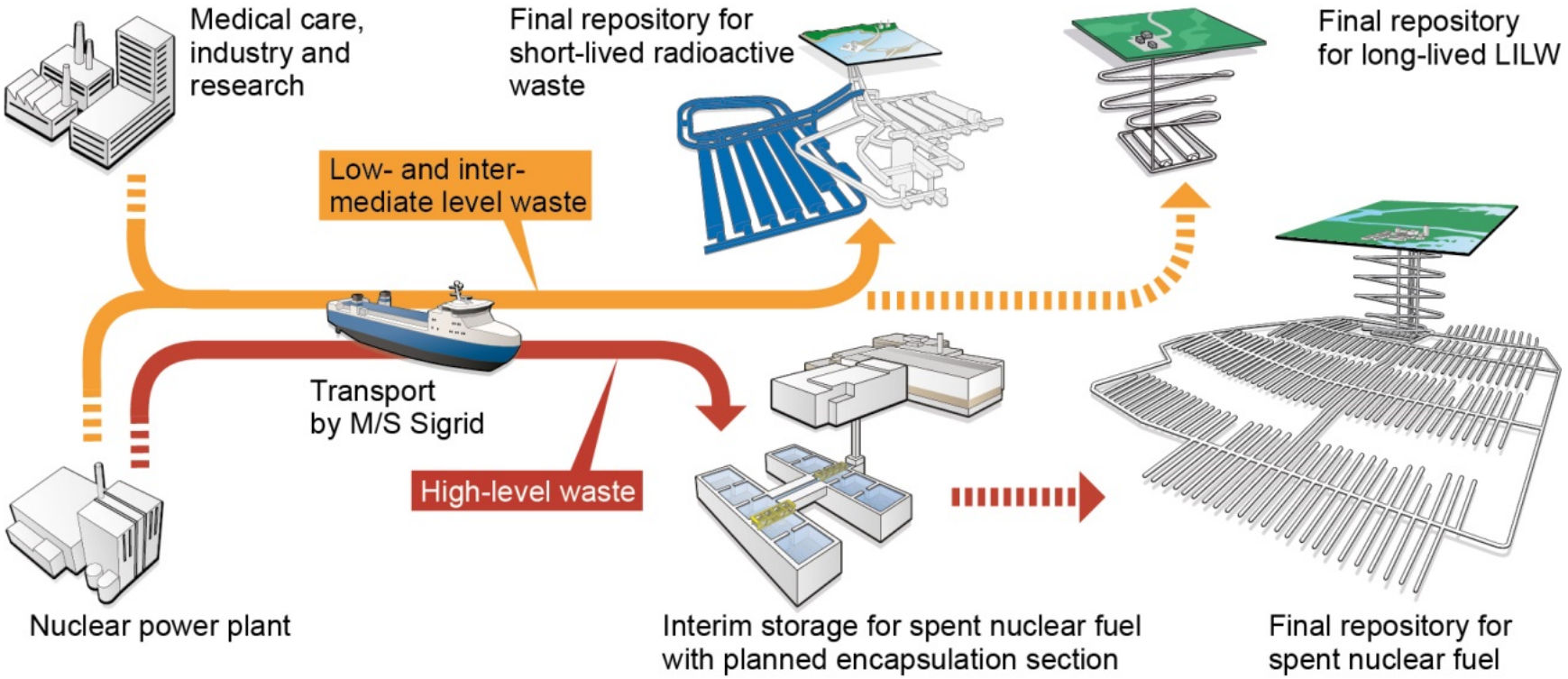
Outline

- General
  - About SKB
  - The KBS 3 concept for spent nuclear fuel (SNF)
- Recent developments in the Swedish SNF programme
- Interplay between R&D and safety assessment – the example of buffer erosion

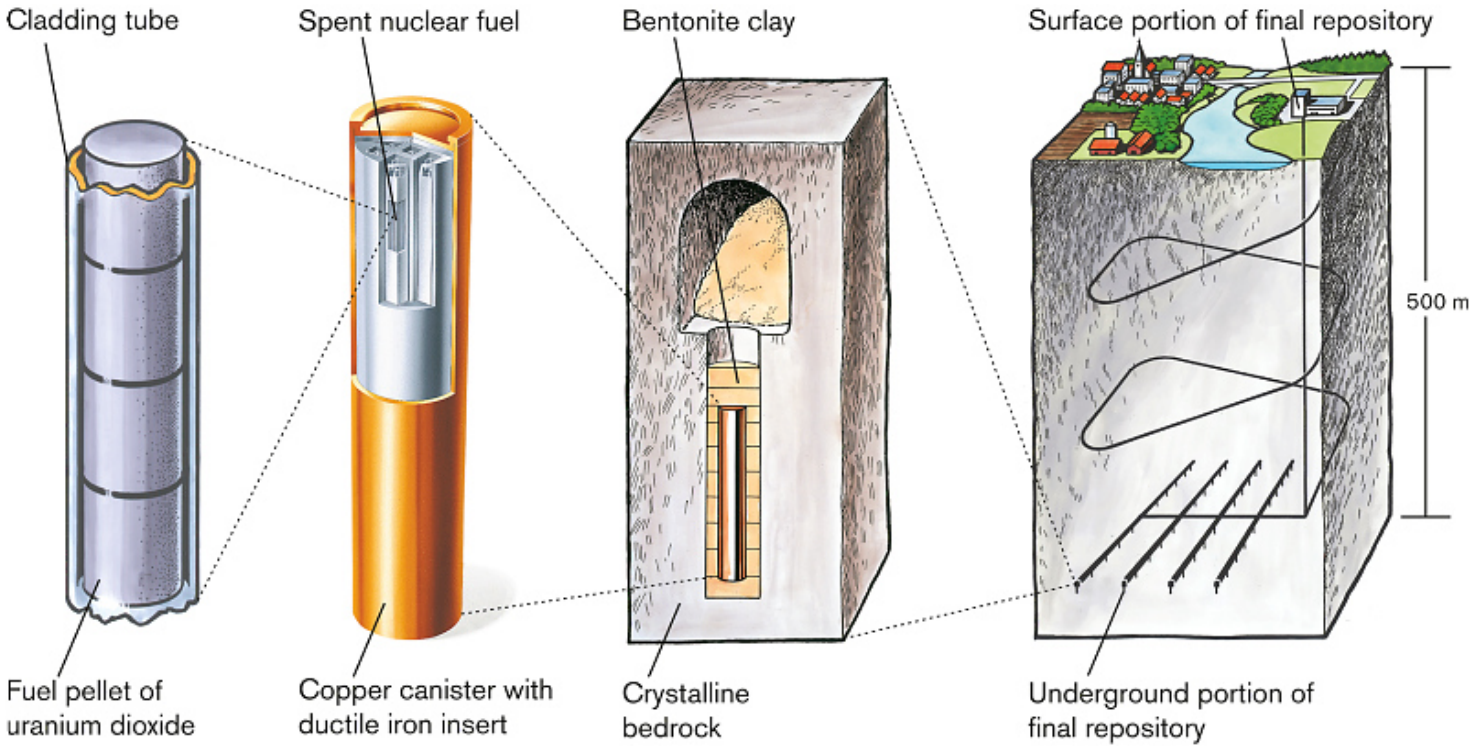
General – about SKB

- The Swedish Nuclear Fuel and Waste Management Co., SKB
  - Owned by the licensees for the Swedish nuclear power plants
  - Responsible for management and disposal of nuclear waste and spent nuclear fuel from the nuclear power reactors
    - Includes RD&D, safety assessments and licensing, construction and operation of facilities
- RD&D
  - Under the Nuclear Activities Act, SKB every three years submits a programme for the R&D and other measures needed to manage and dispose of nuclear waste and spent nuclear fuel and to decommission nuclear power plants.
  - Most recent: RD&D programme 2019; https://www.skb.com/publication/2494395
- SKB's activities financed by tax on nuclear electricity production, generating a nuclear waste fund
  - Tax decided by government, currently around € 0.003/kWh

The Swedish system



General – The KBS-3 concept for spent nuclear fuel



Primary safety function: Complete containment in copper canisters

Secondary safety function: Retardation of releases should the containment fail

Recent developments in the Swedish Spent Nuclear Fuel (SNF) programme (1/2)

- License application submitted by SKB in 2011
- Two facilities, at two sites
  - Final repository at Forsmark (Östhammar)
    - Supported by post-closure safety assessment SR-Site (SKB TR-11-01)
  - Encapsulation plant (extension of existing interim storage Clab) at Oskarshamn
- Tried according to two laws, in parallel
  - Nuclear Activities Act – handled by SSM (the Swedish Radiation Safety Authority)
  - Environmental Code – handled by the Land and Environmental Court
- Long period of supplementing application (2011 – 2016)
- Main hearing with Environmental court September – October 2017

Recent developments in the Swedish Spent Nuclear Fuel (SNF) programme (2/2)

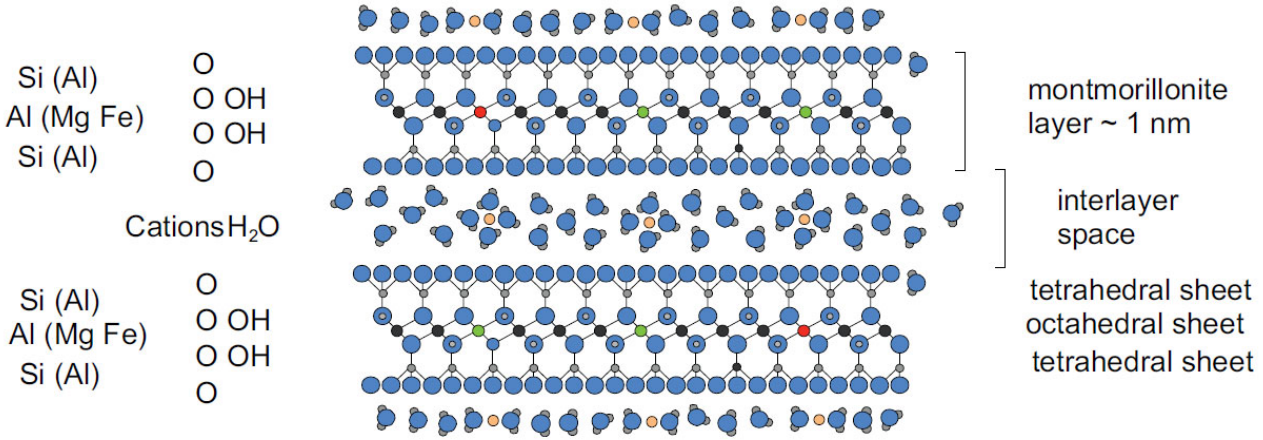
- SSM and Environmental Court each issued a statement to the Government in January 2018
  - SSM: Recommended Gov't to grant license
  - Environmental Court: Recommended Gov't to obtain supplementary information from SKB on five canister integrity issues prior to considering license, approved of other parts
- SKB submitted requested info to Gov't in April 2019; SKB Technical Report TR-19-15
- Reviewed by all stake holders (EC no longer involved in process)
  - SSM: Strengthened support for safety, recommends licensing
  - A few researchers and NGO:s still critical
- The Government may now decide on the application, having first consulted with the two municipalities involved
  - Municipality of Oskarhamn (encapsulation plant) approved in 2019
  - Municipality of Östahmmar (final repository) to decide **October 13**, 2020
  - Decision by Gov't in 2020/2021?

Interplay between R&D and safety assessment – the example of buffer erosion

- – 2000; the issue & “early” history
- 2000 – 2006; literature study and the SR-Can assessment
- 2006 – 2011; research and the SR-Site assessment (license application)
- 2011 – ; further research, preparing the PSAR assessment (construction license)

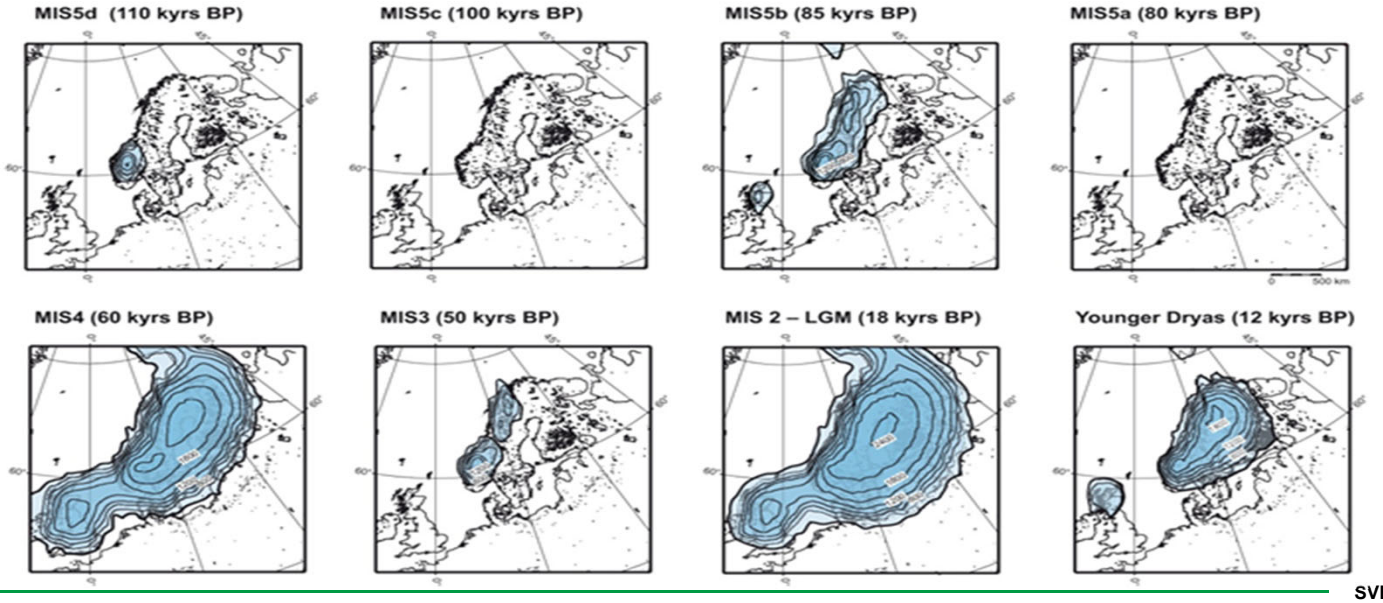
Buffer erosion – the issue and “early” history

- Montmorillonite is the key component of the bentonite buffer
  - Montmorillonite layers held together by cations in the clay material
- Generally, the bentonite buffer is stable in granitic groundwaters
- However, if contacted by groundwater of very low salinity
  - the distance between the individual montmorillonite layers may increase so much that the clay/water system becomes a sol,
  - single or small groups of montmorillonite layers then behave like colloidal particles
  - These colloids may be transported away by the flowing water, thus eroding the buffer



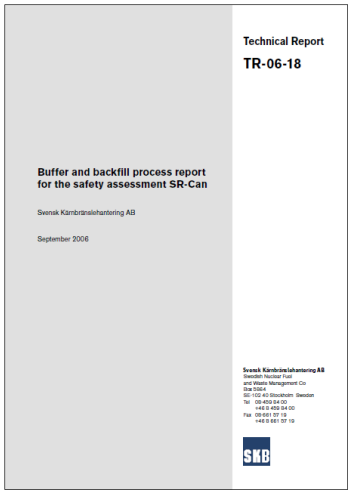
Buffer erosion – the issue and “early” history

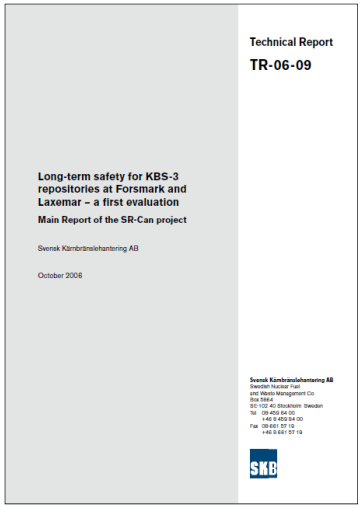
- The issue was identified in KBS-2 (1978), with the conclusion that colloids were unstable in present day Swedish groundwater; future dilute waters were not assessed
- The safety assessment SR 97, published in 1999
  - Seen as extreme conditions (very low ionic strength groundwaters) required at repository depth; could possibly arise far into the future for glacial conditions
  - “*The above discussion suggests that erosion of the buffer is not of significance for the long-term performance of the repository. The process is neglected in SR 97 but should be further studied*.”



2000 – 2006

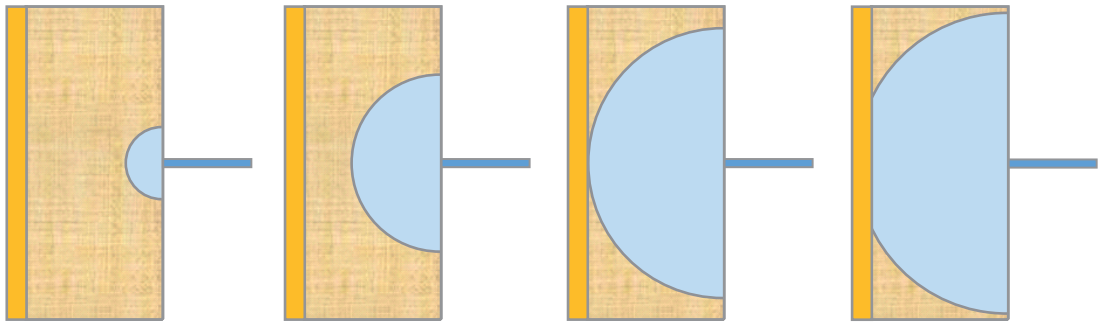
- Extensive literature study
- Formulation of a first very crude model for buffer loss
  - Preliminary threshold value of groundwater ionic strength below which erosion occurs
  - Simple, pessimistic expression for loss rate as a function of water velocity and fracture aperture
- Safety assessment SR-Can, 2006
  - Data from initial stage of site investigation at Forsmark
  - Phenomenon could not be excluded for periods of dilute water intrusion at repository depth
  - Included a scenario where the buffer is gradually lost, such that advective, rather than diffusive, transport conditions arise in the most exposed deposition positions (a few percent of the 6000 positions)



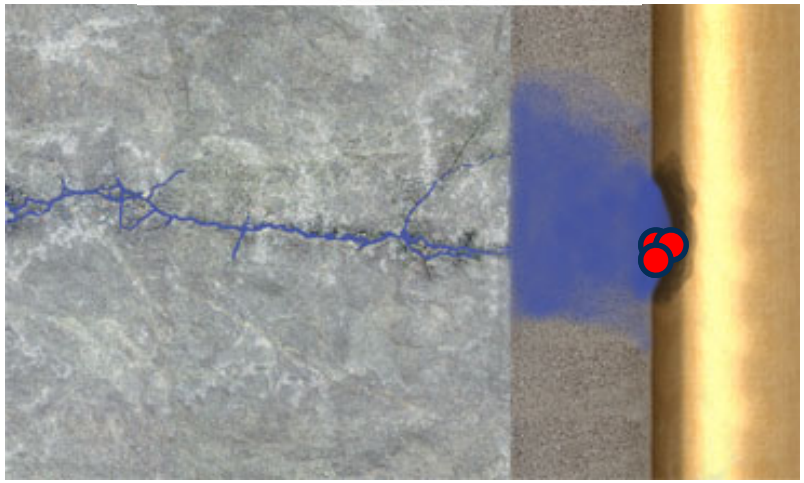


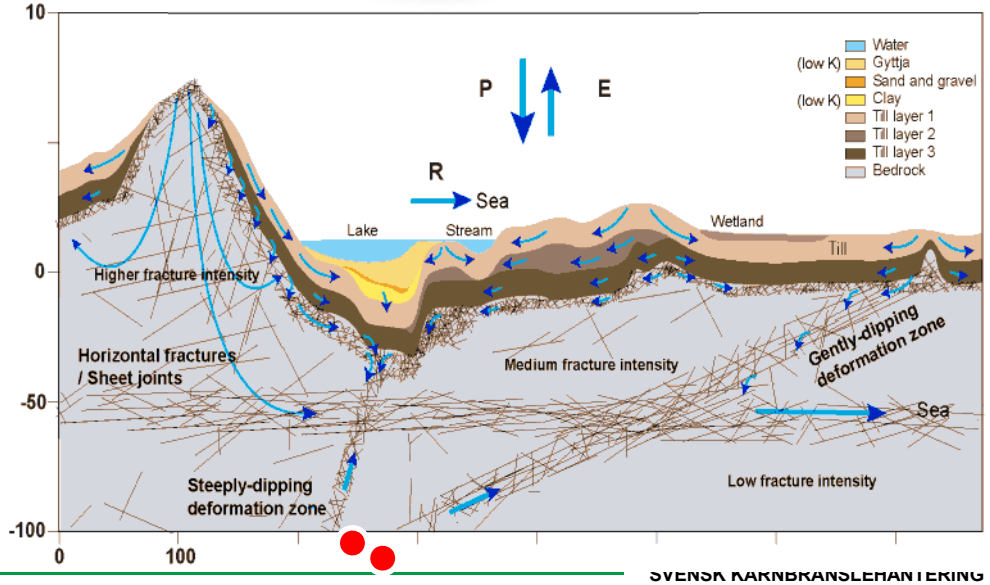
2000-2006; erosion/corrosion scenario in SR-Can

- The canister will then be directly exposed to corroding agents (sulphide) in the groundwater
  - Tens of thousands of years for this to arise – and then only in canister positions with highest flow
  - Results in increased corrosion rates
- After additional typically hundreds of thousands of years, canisters in most exposed positions may be penetrated by corrosion, leading to release of radionuclides to the groundwater



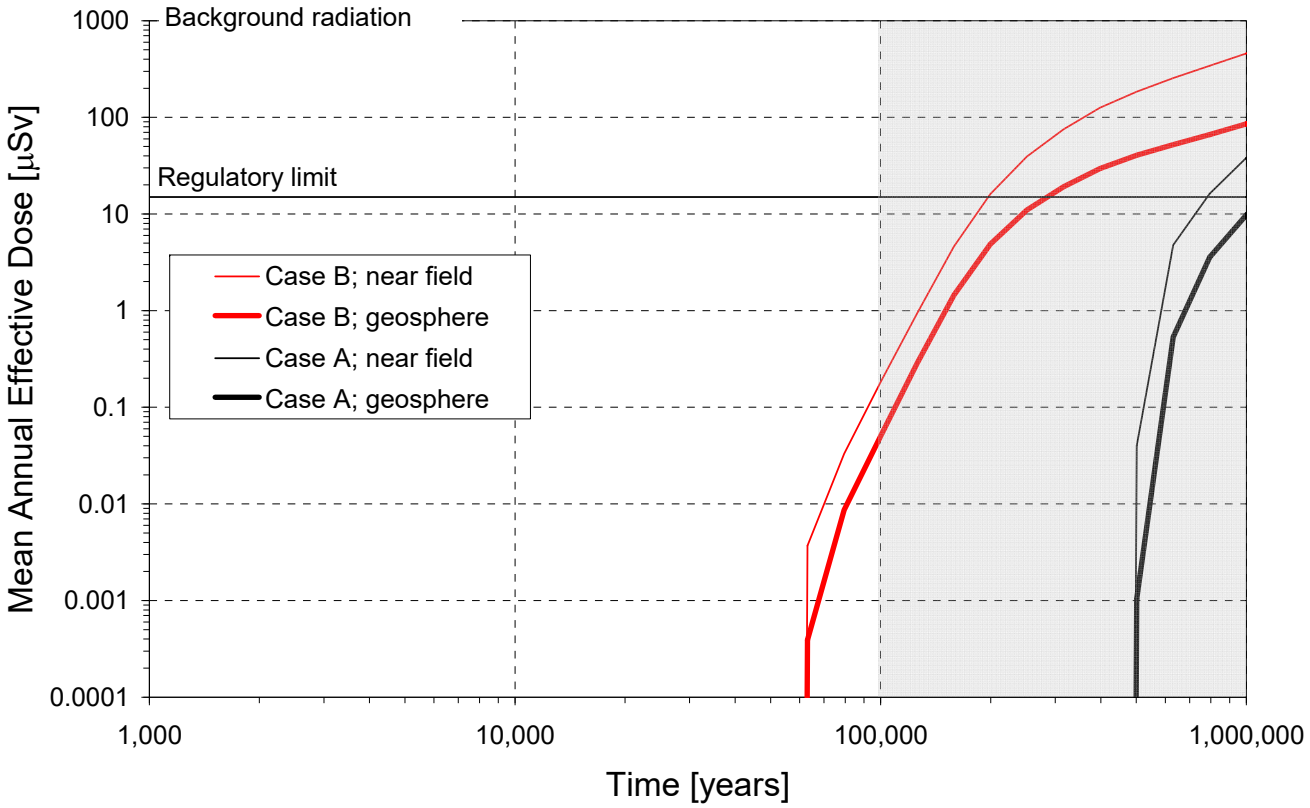
200-2006; erosion/corrosion scenario in SR-Can





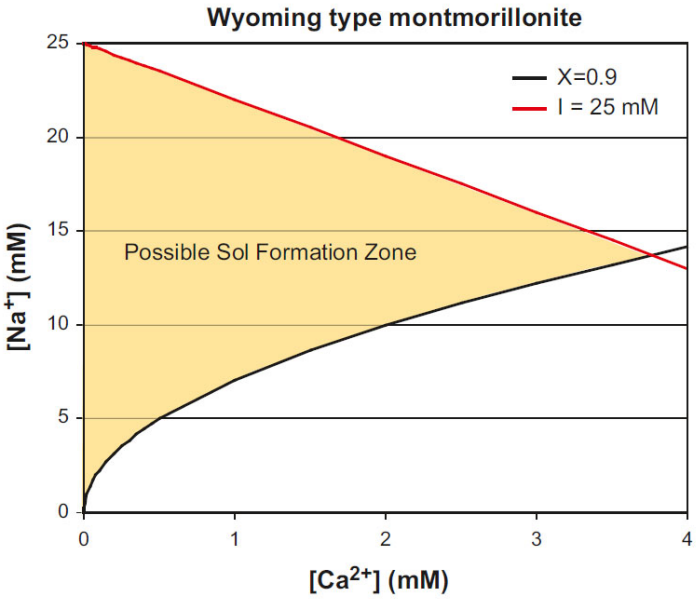
2000-2006; erosion/corrosion scenario in SR-Can

- Dose dominating scenario for Forsmark site in SR-Can
  - Site data from preliminary stage of site investigation



2006 – 2011 R&D

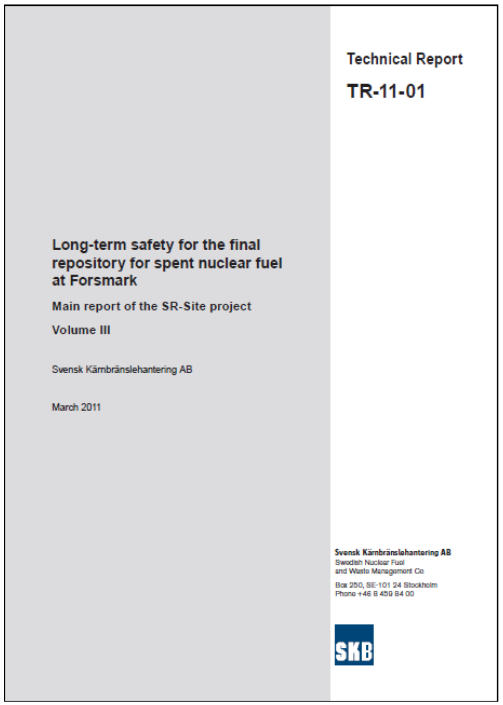
- Recognised that substantial experimental and theoretical work needed
- Under what conditions are bentonite colloids stable?
- If they are stable, what is the mass loss?
  - A large body of experimental studies of dependence on groundwater velocity and ionic strength, type of clay, cation species in clay, etc
  - Led to an improved experimental and theoretical understanding, a more specific threshold and a less pessimistic model for the safety assessment SR-Site



$$R_{\text{Erosion}} = A \cdot \delta \cdot v^{0.41}$$

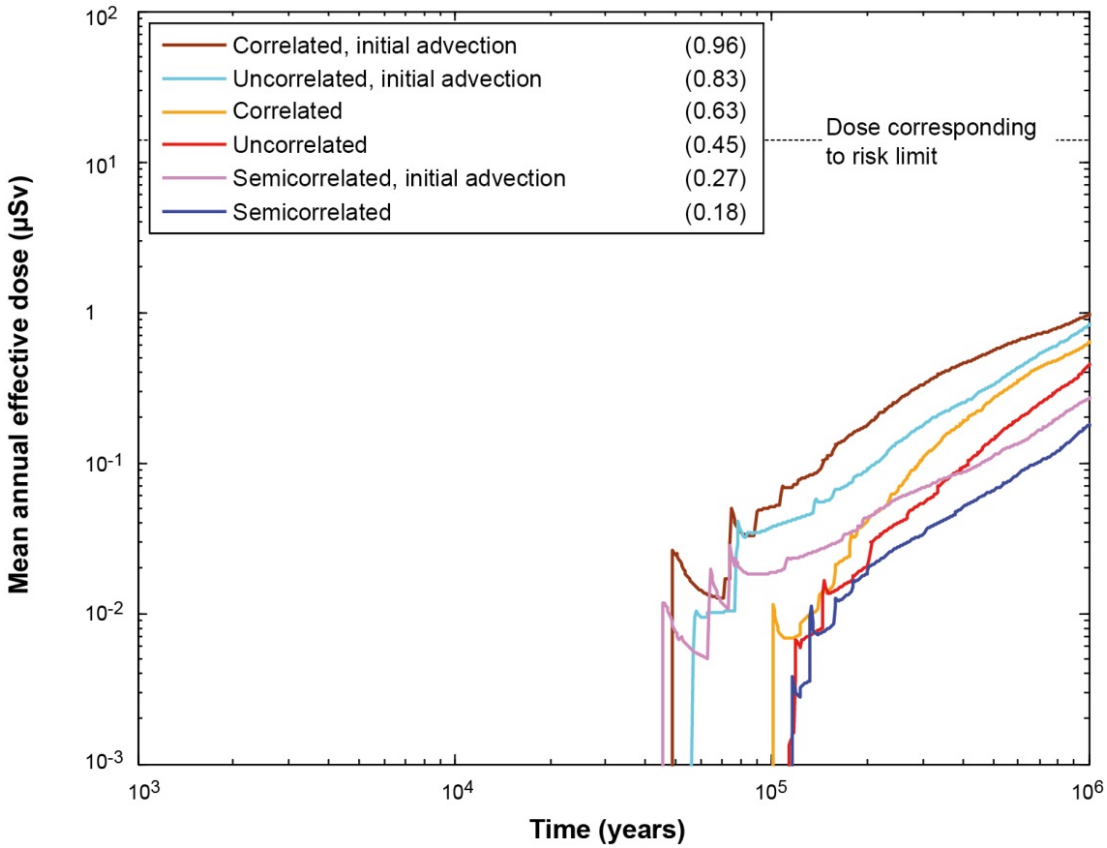
2006 – 2011; erosion/corrosion scenario in SR-Site

- Safety assessment SR-Site, 2011
  - Basis for license application
  - Erosion/corrosion scenario still dose dominating with new model
- Many uncertain aspects of repository evolution affect evaluation
  - Groundwater flow and salinity
    - for current, temperate conditions and future periglacial and glacial conditions
  - Need to consider distribution of conditions over 6000 positions
    - At the Forsmark site, typical deposition hole never expected to see conditions causing buffer erosion/sedimentation
  - Used bounding case with buffer lost initially in all deposition holes to demonstrate compliance
    - Bounds effects of virtually all uncertainties related to erosion
    - Very low probability of canister failures also for this case since flow and geochemical conditions favourable



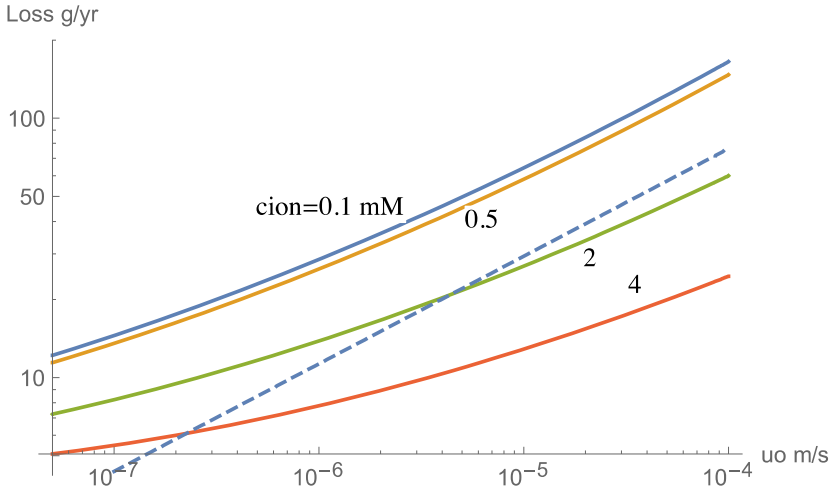
2006 – 2011; erosion/corrosion scenario in SR-Site

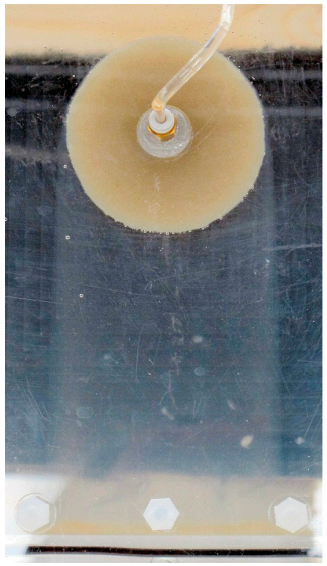
- Dose dominating scenario for Forsmark site also in SR-Site
- Several cases to cover uncertainties in flow conditions, salinity, basic understanding of erosion
- All cases yield consequences well below dose corresponding to regulatory risk limit
- Lower consequences than in previous assessment primarily since “better” site data

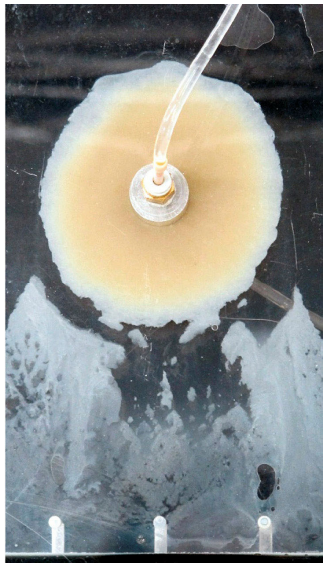


2011– R&D

- Still need for further research, now recognised by several organisation
- EU project BELBaR 2012-2016
  - Experimental and modelling work
  - Improved understanding of buffer erosion
    - More comprehensive data
    - More differentiated model taking ionic strength of groundwater into detailed account
  - However, also recognised that related phenomenon, sedimentation of buffer in sloping fractures, may be non-negligible
    - Preliminary experimental results must be handled pessimistically and then suggest more buffer loss than due to chemical erosion
- Present R&D is strongly focussed on the effect of sedimentation and the role of friction between the expanding clay and the rock in the fractures







2011– Safety assessment PSAR

- SKB's forthcoming safety assessment, supporting a construction license application, planned to be submitted in 2022
  - Will build on essentially the same evaluation cases as in SR-Site, using new, differentiated model, but quite similar consequences
  - Still necessary to include pessimistic, bounding case, now also to address sedimentation

Concluding remarks

- The issue of buffer chemical erosion has been a prominent feature in SKB's research programme and safety assessments for two decades
- Scenario with buffer loss and enhanced corrosion dominating risk contribution
- Identified as unresolved issue in late 1990'ies – led to large and still ongoing R&D efforts
- Gradually improved understanding has led to improved, more realistic modelling in safety assessments
  - But still a scenario with buffer loss/enhanced corrosion dominates
- Lately also buffer sedimentation has emerged as a potential issue
  - At least when early data from lab experiments are extrapolated to repository conditions
- The favourable flow and transport conditions and low sulphide concentrations at the Forsmark site in combination with the canister's 5 cm corrosion barrier implies compliance with risk constraint even without the buffer
  - But need also to be able to argue that we have a robust multi-barrier system
- SKB aims to include staff responsible for research programme in safety assessment team
  - Fosters appropriate representation of research results in safety assessment and efficient feedback of SA results to research programme


Thank You!