Presentations at NEA IRT hearing
13 December, 9:00 – 12:00

Canister, corrosion of canisters, bentonite buffer,
engineering feasibility

Example question #8

The corrosion behaviour of copper under repository conditions is of concern. Although thermodynamics should prevail ultimately (considering the repository lifetime), it is nevertheless important that the kinetic behaviour of the canisters be investigated in detail. What type of experimental data is SKB planning to produce to assess the corrosion behaviour of the container?

- SKB presentation in two parts
  I. Approaches to predicting the corrosion behaviour of copper canisters
  II. Corrosion experiments

I. Approaches to predicting the corrosion behaviour of copper canisters

General considerations

- Need to consider both uniform processes and localised mechanisms
- Thermodynamics tells us what reactions are possible, kinetics tell us how fast those reactions will proceed
- Because of the timescale of interest, long-term lifetime predictions can only be justified if we have a detailed mechanistic understanding of the corrosion processes involved

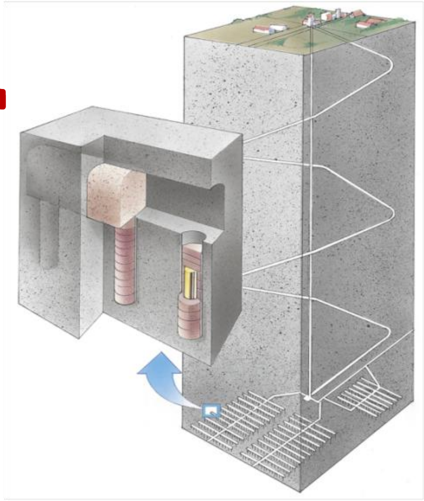
Approaches to predicting uniform corrosion processes

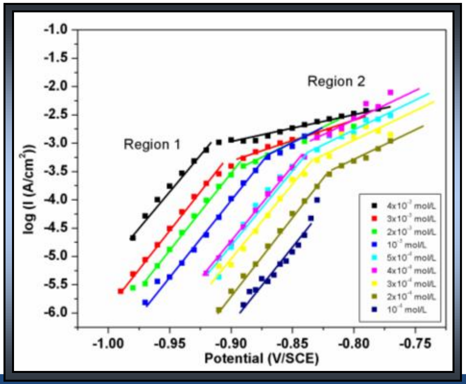
- Different approaches can be taken to predicting the rate of uniform (general) corrosion
  - Extrapolation of empirically measured corrosion rates involves little or no mechanistic understanding
  - Other approaches involve different levels of mechanistic understanding and/or implicit assumptions about the nature of the rate-determining process

Modelling approach	Interfacial reactions	Mass transport
Empirical corrosion rates	-	-
Mass-balance	Fast	Fast
Mass-transport	Fast	Rate-determining
Reactive-transport	Rate-determining	Rate-determining

Approaches to predicting uniform corrosion processes in SR-Site and supporting reports

Modelling approach	Aerobic phase	Sulphide-dominated phase	MIC
Empirical corrosion rates	✗	✗	✓
Mass-balance	✓	✗	✗
Mass-transport	✗	✓	✓
Reactive-transport	✓	✓	✓





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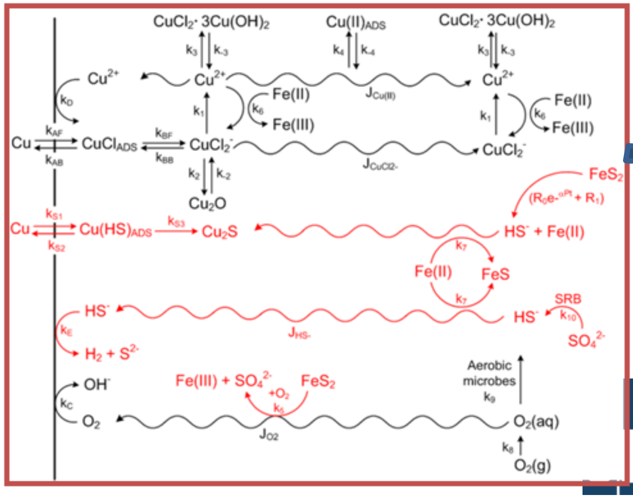


Approaches to predicting non-uniform corrosion processes

- Different approaches have been taken to predicting the rate of non-uniform processes for nuclear waste containers (and for other structures/systems)

Modelling approach	Environmentally assisted cracking	Localised corrosion	MIC
Empirical damage model	✓	✓	✓
Mechanistic model	✓	✓	✓
Exclude from consideration by reasoned argument	✓	✓	✓

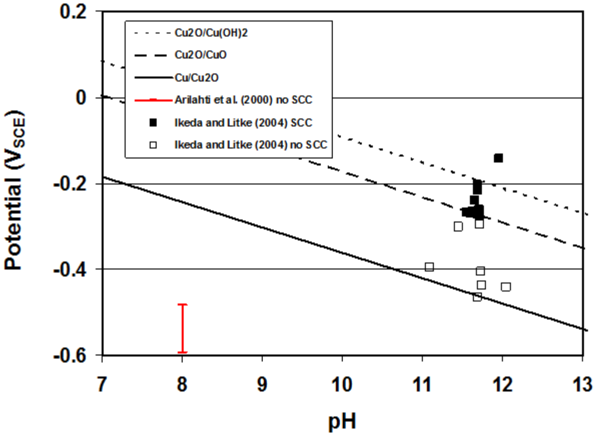
SR-Site approaches to predicting non-uniform corrosion processes

Modelling approach	SCC	Localised corrosion	MIC (non-uniform)	Miscellaneous*
Empirical damage model	✗	✓	✗	✓
Mechanistic model	✓	✓ (conceptual model available)	✗	✓
Process shown not to occur under repository conditions	✓	✗	✓	✓

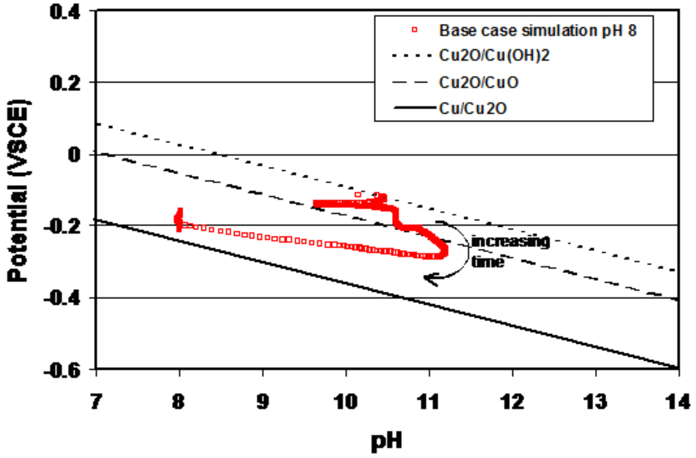
* Miscellaneous processes include: hydrogen effects, corrosion fatigue, galvanic corrosion, radiolysis

Treatment of SCC

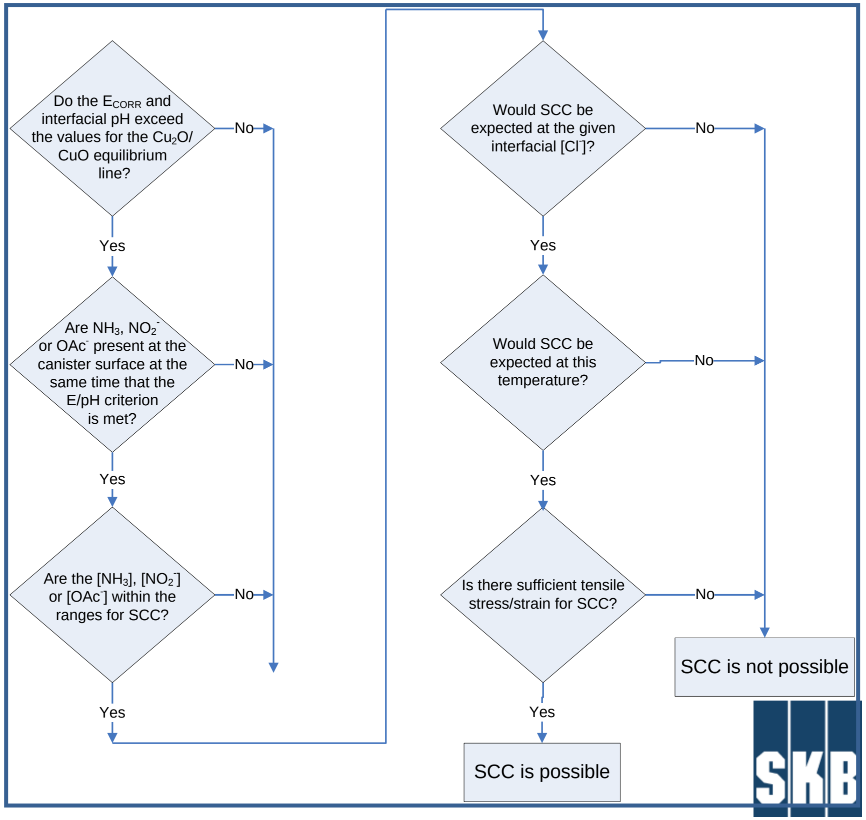
SCC of Cu in ammonia



Predicted time dependence of E_{CORR}/pH of canister



Decision-tree approach to SCC of copper canisters under aerobic conditions



Do the E_{CORR} and interfacial pH exceed the values for the Cu_2O/CuO equilibrium line?

Are NH_3, NO_2^- or OAc^- present at the canister surface at the same time that the E/pH criterion is met?

Are the $[NH_3]$, $[NO_2^-]$ or $[OAc^-]$ within the ranges for SCC?

Would SCC be expected at the given interfacial $[Cl^-]$?

Would SCC be expected at this temperature?

Is there sufficient tensile stress/strain for SCC?

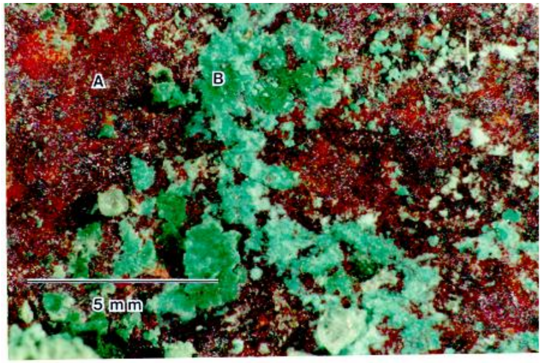
SCC is not possible

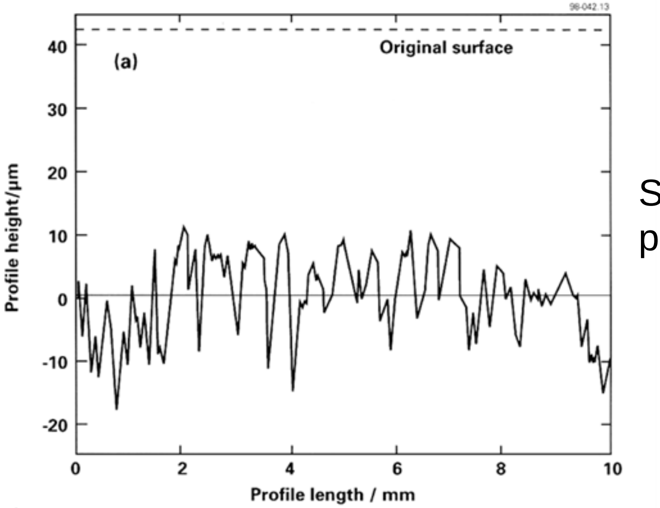
SCC is possible

Treatment of localised corrosion

Empirical localised corrosion allowance

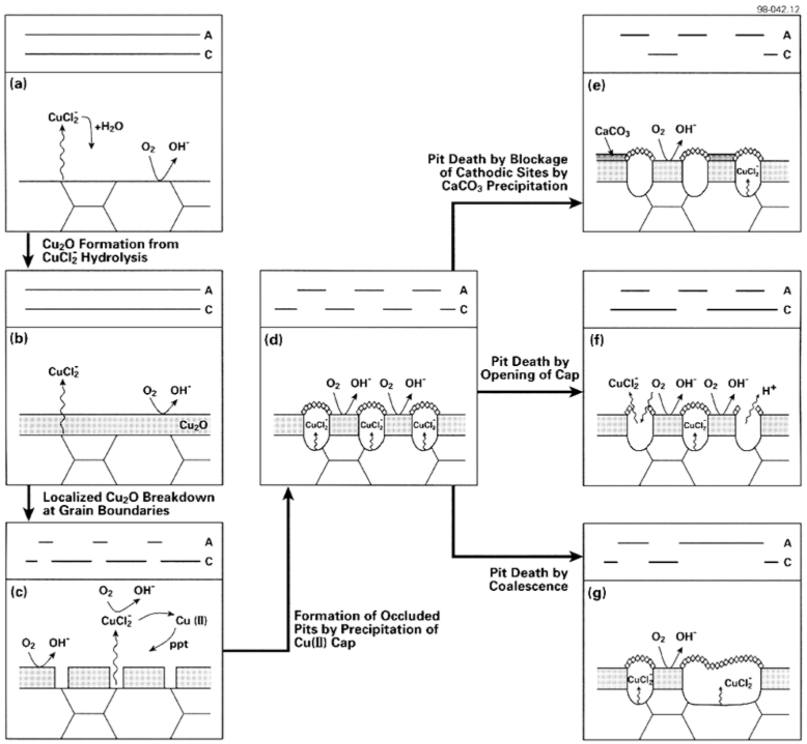
Visual appearance of surface of Cu coupon exposed to simulated repository conditions





Surface profile

Conceptual mechanistic model to explain non-permanent separation of anodic and cathodic sites



Summary

- Approaches to predicting canister corrosion
  - Based on sound corrosion science principles
  - Mass-balance and mass-transport approaches used for SA
  - Different types of models used in supporting studies, ranging from empirical to those based on fundamental principles
- Robustness of predictions
  - Models are either mechanistically based or supported by detailed mechanistic understanding
  - Different approaches give the same result

II. Corrosion experiments

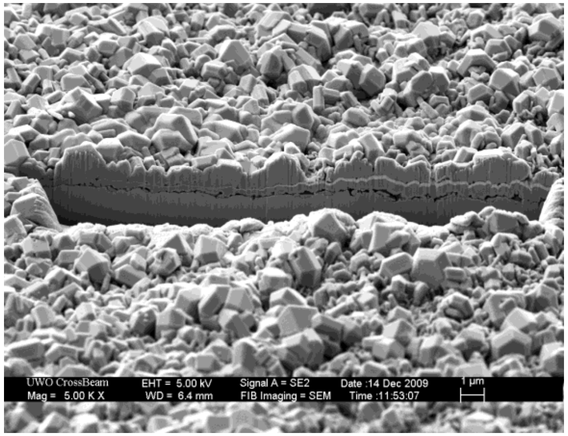
Example question #8

The corrosion behaviour of copper under repository conditions is of concern. Although thermodynamics should prevail ultimately (considering the repository lifetime), it is nevertheless important that the kinetic behaviour of the canisters be investigated in detail. What type of experimental data is SKB planning to produce to assess the corrosion behaviour of the container?

SKB copper corrosion experiments

- Lab experiments
  - controlled
  - to validate kinetic and thermodynamic models and descriptions
  - more detailed knowledge may lessen the pessimisms used in safety assessment
- In-situ experiments
  - to demonstrate system behaviour
  - to validate e.g. reactive-transport and mass balance models (oxic phase) and transport models (anoxic phase)
  - not focussing on exploring or searching for ”unknown” reactions
- Long-term tests
  - data would still not be possible to use for extrapolation
  - natural analogues can give the real long-term comparisons

Ongoing experimental work (I)



- Sulphide environment
  - reactions kinetics (U. of Western Ontario)
  - sulphidation of Cu(II) oxides (Uppsala U.)
- Pure oxygen free water
  - gas tests in ultra-high vacuum (Uppsala U.)
  - copper in test tubes (SP, Micans)
  - electrochemical studies with and without chloride in borate buffer (Bulgarian Hydrogen Society, Sofia)
  - synthesis of CuOH (KTH)
  - copper in E-flasks (VTT)
- Corrosion in gamma radiation field
  - mechanism study (KTH)

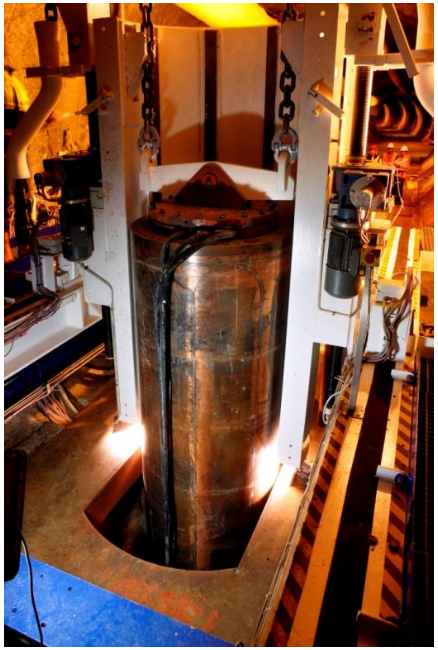
Ongoing experimental work (II)

Äspö experiments – primarily not designed for study of copper corrosion

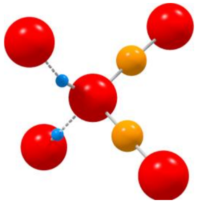
- Minican project: set up as study of iron corrosion in pinhole of copper canister
  - one canister with low density bentonite retrieved
  - analyses ongoing of iron insert, copper canister, bentonite, electrodes, copper and iron specimens
  - still 4 canisters in place

- Prototype (2 full scale canisters retrieved, earlier heated)
  - copper samples taken from canister dh6
  - copper-bentonite samples from upper lid in dh5
  - copper electrodes from dh5 - to help interpreting on-line electrochemical measurements
  - 4 canisters (inner section) still in place

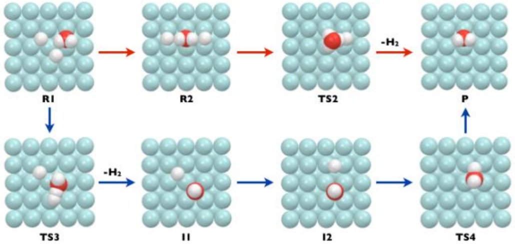
- LOT project (long-term tests of buffer material; heated centre copper tube + copper coupons)
  - revisiting analyses of copper in bentonite
  - 3 tests still running



Supporting theoretical studies



- Stability of copper phases (quantum mechanics calculations)
  - – bulk phases (KTH)
  - – surface reactions (KTH)



- Solubility of pyrite (Integrity Corrosion Consulting)
- Kinetic expressions
  - – pure water (Bulgarian Hydrogen Society, Sofia)
  - – sulphide solutions (U. of Western Ontario)
- Thermodynamics of chloride solutions (Integrity Corrosion Consulting, Posiva)
- Transport equations, concept of equivalent flow (KTH)
- Reactive-transport modelling (Integrity Corrosion Consulting)

Plans for further experiments

- Sulphide environment
  - quantification of microbial activity (SRB) in compacted bentonite
  - cracking at high concentrations
- Corrosion dependence of copper material
  - electrochemical study of corrosion susceptibility for pure copper, canister copper and copper slightly outside specification; starting with aerobic environment
  - possible extension for welded (repetition) and cold-worked material
- Possible further in-situ tests
  - interaction copper – bentonite, especially during early unsaturated phase
  - surface roughness under oxic conditions
  - sulphide transport limitations

Example questions #9 and #10

#9: The canister seems to be capable to bear more than twice the original design load (100 MPa collapse load vs. 45 MPa design load), and the safety margin between design load and possible isostatic loads is considered to be small. Can SKB assess whether a stronger commitment towards the capability of the canister to withstand a much higher load could contribute to confidence in the safety case, especially if combined with a demonstration that a higher design load (for example 75 MPa) can be guaranteed by means of adequate QA procedures?

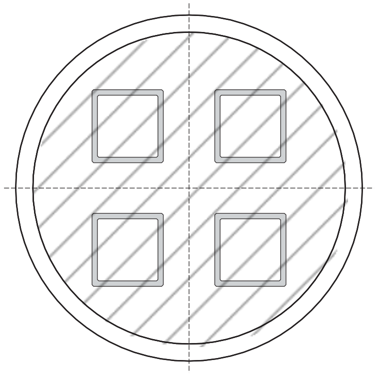
#10: According to the information provided so far it seems that currently there is no valid safety assessment for the disposal of PWR spent fuel in the planned repository. Are complementary analyses for the PWR insert planned to fill this gap in the licensing information?

- SKB presentation
  - Introduction: Verification of mechanical strength of the inserts
  - Response to example question #9
  - Response to example question #10

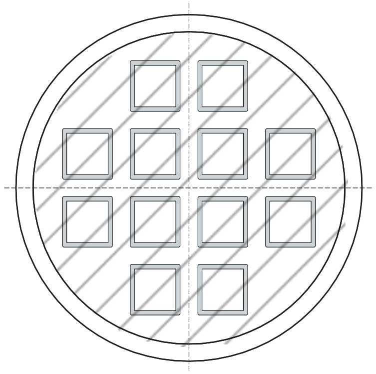
Verification of mechanical strength of the inserts

- Deterministic analysis
- Damage tolerance analysis
- Probabilistic analysis

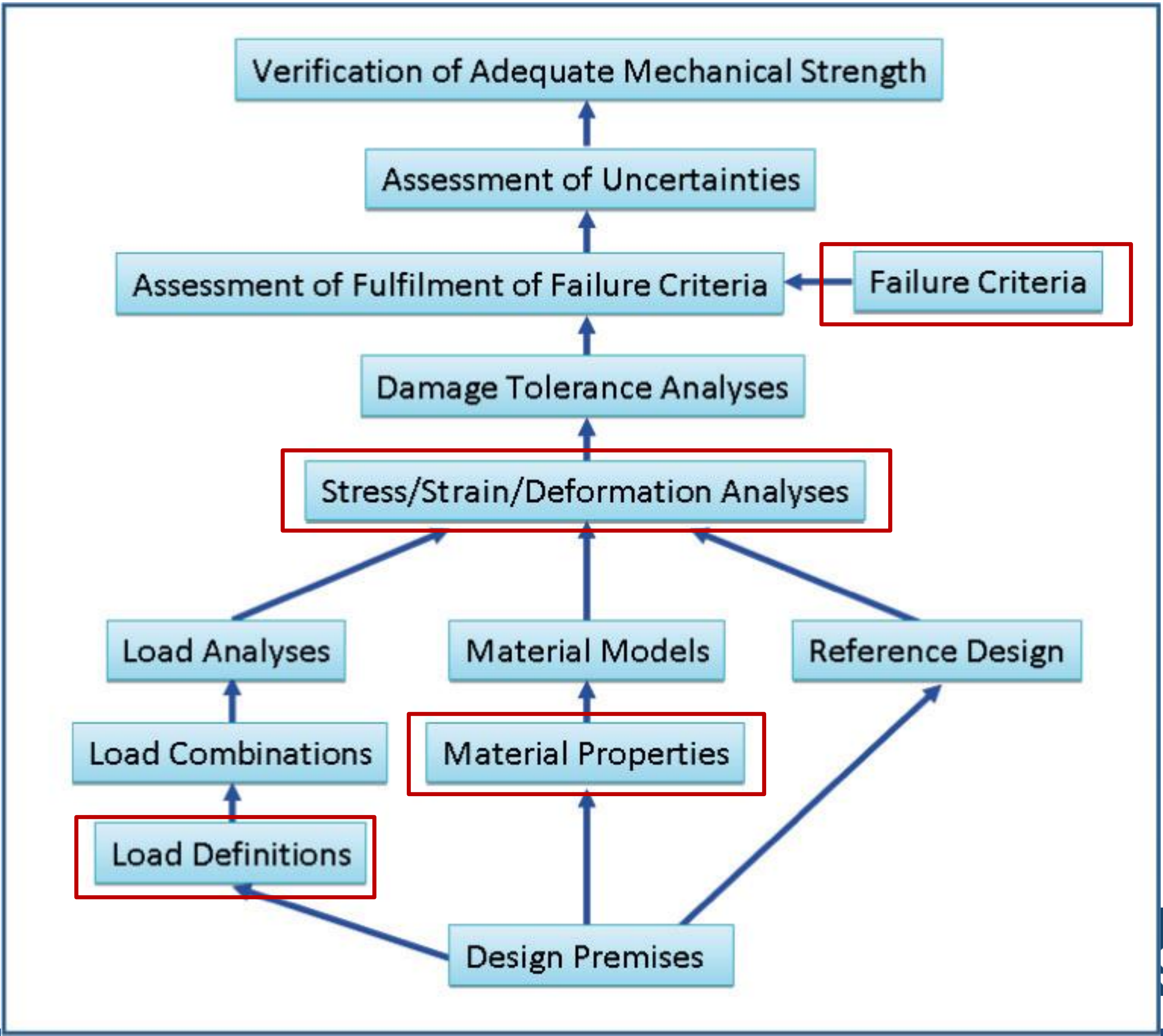
The canister



PWR



BWR



Verification of Adequate Mechanical Strength

Assessment of Uncertainties

Assessment of Fulfilment of Failure Criteria

Failure Criteria

Damage Tolerance Analyses

Stress/Strain/Deformation Analyses

Load Analyses

Material Models

Reference Design

Load Combinations

Material Properties

Load Definitions

Design Premises

Load definitions and extent of analysis

1. Bentonite buffer swelling effects during wetting and saturation, as well as after saturation. Assessed by stress analysis.
2. Isostatic loads associated with hydrostatic pressures under temperate climate conditions and increased pressures under glacial conditions.
   - BWR: deterministic stress and damage tolerance analysis and probabilistic analysis
   - PWR: deterministic stress and damage tolerance analysis, however with BWR material data
3. Shear loads associated with rock displacements in fractures intersecting deposition holes.
   - BWR: Deterministic stress and damage tolerance analysis
   - PWR: stress analysis
4. Relevant combinations of the load cases have also been considered in the design analysis of the canister.

Material properties used in TR-10-14

- BWR
  - Sampling of data from five consecutive castings to mimic serial production conditions.
  - The casting process was qualified in advance according to SKB routines.
- PWR
  - Process still under development. Aim to develop a process that can be qualified and demonstrate ability in a limited serial production. Sampling of data will follow the procedures described for BWR.
- Material properties of importance: K_{1C}, J_{2mm}, $A_{5\%}$, σ_B, σ_S

Failure criteria, insert

- Plastic collapse (buckling).Used for outside pressure.
- Crack initiation. Used for isostatic load case (allowable defect sizes to avoid initiation determined)
- Maximum 2 mm crack growth. Used for bending/shearing load case that is displacement controlled. (Allowable defect sizes to avoid unlimited stable growth.)
- Ultimate tensile strength is exceeded.(Overload situation)
- Details in evaluation and safety factors adapted to Swedish nuclear regulations

Results

- TR-10-28
- BWR inserts: The design meets all criteria. The requirements on manufacturing and QC are realistic.
- PWR inserts: The design is not completely analysed but is judged to be robust.
- Discussion
  - Isostatic loads
    - Compressive properties of the material are of importance.
      The compressive properties are insensitive to defects and structural deviations. A small area shows tensile stresses but any crack growth will stop when it propagates into compressive stress areas. The stress/strain analysis for PWR isostatic loads are therefore relevant, which is also shown in a later updated analysis using PWR data.
  - Shearing case
    - Materials properties are more crucial. A renewed PWR analysis (using PWR data) shows that for surface or subsurface defects the acceptance criteria are close to those in the BWR case.
    - For internal defects (the thicker sections) the new analysis is more uncertain. For the safety case also the copper shell needs to be considered as loss of containment relates to this.

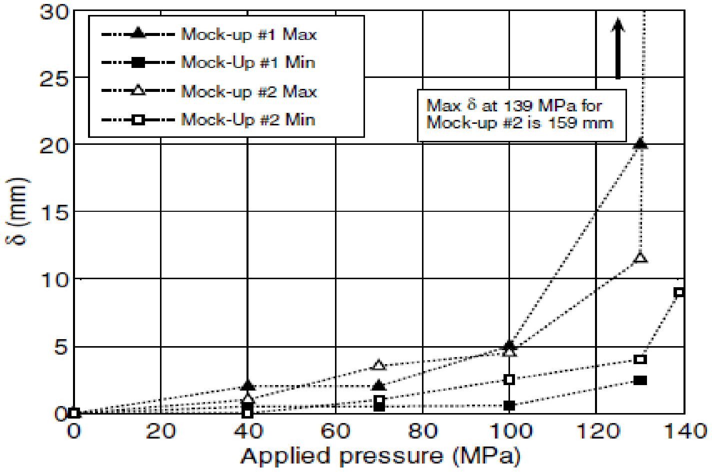
Example question #9

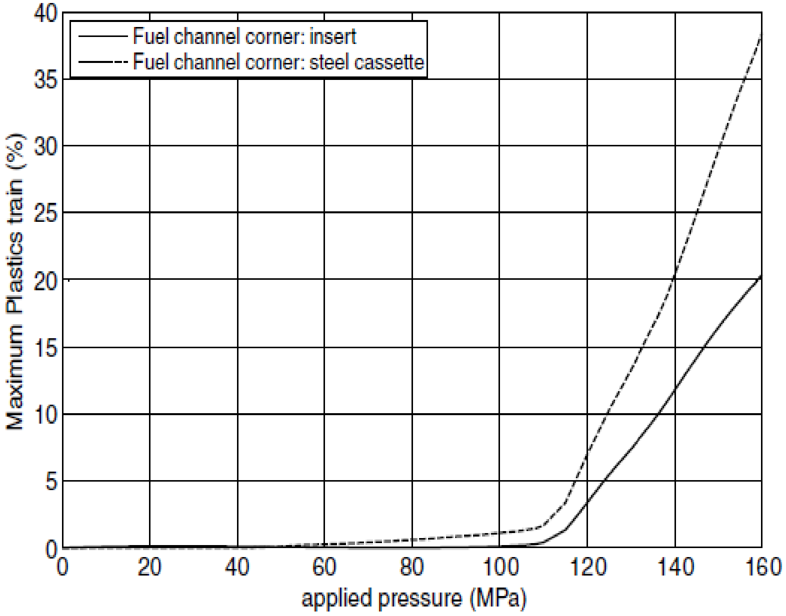
The canister seems to be capable to bear more than twice the original design load (100 MPa collapse load vs. 45 MPa design load), and the safety margin between design load and possible isostatic loads is considered to be small. Can SKB assess whether a stronger commitment towards the capability of the canister to withstand a much higher load could contribute to confidence in the safety case, especially if combined with a demonstration that a higher design load (for example 75 MPa) can be guaranteed by means of adequate QA procedures?

Increasing the isostatic design load?

- Design load
  - The expected future loads in the repository form the basis for determining the design load.
  - Based on the loads identified in SR-Site, it was concluded that a moderate increase in design load would be appropriate (section 15.5 SR-Site main report)
  - The new design load remains to be determined; 60 MPa was seen as an extreme upper bound in SR-Site
- Failure criteria in evaluating the canister isostatic design load
  - There are currently several failure criteria against which the insert’s response to an isostatic load is evaluated (local plastic collapse, crack initiation and exceeding of ultimate tensile strength)
  - It has been verified that the current BWR design does not fail according to any of the criteria for the current design load (45 MPa).
  - It needs to be further evaluated which of the failure criteria really relate to the loss of canister integrity, i.e. the crucial event for the safety assessment.
  - The failure criteria will determine (through a renewed design analysis) the design and QA measures required for an updated design load

Pressure test of two canister mock-ups at high pressures (130-140 MPa) mesured and computed strains



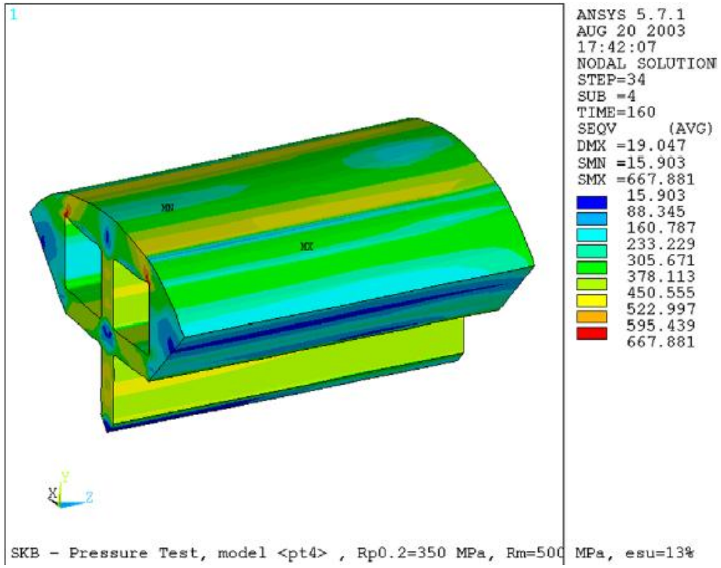


Engineering Failure Analysis 14 (2007) 47–62

Failure of spent nuclear fuel canister mock-ups at isostatic pressure

European Commission, DG-JRC, Institute for Energy,

Illustrating example collapse modes

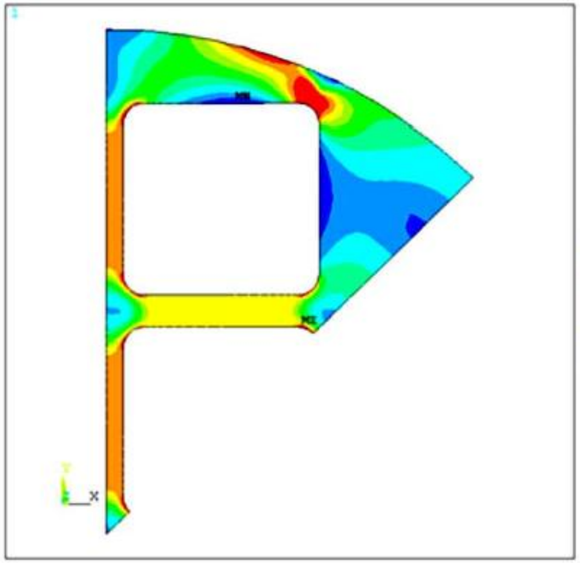


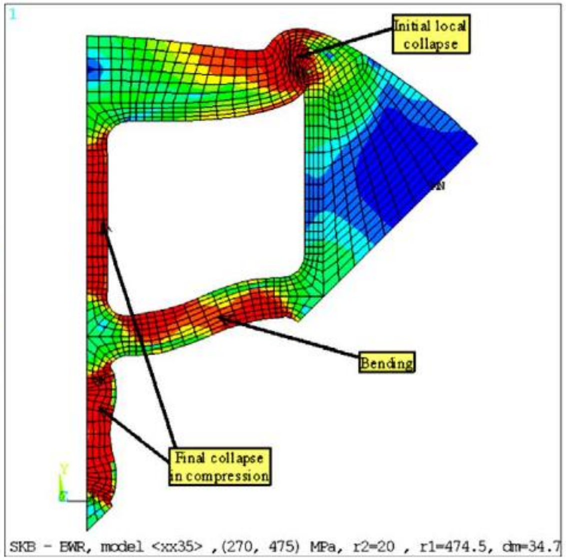
SKB - Pressure Test, model <pt4> , Rp0.2=350 MPa, Rm=500 MPa, esu=13%

- Stress concentrations in a BWR insert under isostatic pressure

- Elastic stress/strain at 44 MPa (left)

  Total plasticization at 130 MPa (right)





Initial local collapse

Bending

Final collapse in compression

SKB - BWR, model <xx35> ,(270, 475) MPa, r2=20 , r1=474.5, dm=34.7

Increasing the isostatic design load?

- Conclusions
  - The confidence in the safety case could indeed be increased by a higher isostatic design load as long as the risk for failure remains insignificant.
  - An updated design load should be determined based on identified loads in the repository.
  - The current interpretation of the “buckling criterion” needs to be revised.
  - Based on the current design analysis it is not possible to state that the current canister design will be resilient to an isostatic load of 75 MPa.

Example question #10

According to the information provided so far it seems that currently there is no valid safety assessment for the disposal of PWR spent fuel in the planned repository. Are complementary analyses for the PWR insert planned to fill this gap in the licensing information?

PWR status

- The PWR canister has been verified with respect to corrosion load (TR-10-14).
- For the verification of the isostatic load case SKB has used BWR data (TR-10-28).
  - The renewed analysis shows that this is relevant. Also spread in PWR data is comparable to what was used in the first version of the probabilistic analysis for BWR (TR-05-17), meaning that the expected outcome for PWR will show low probability for local collapse at the design load and that global collapse will only occur above 100 MPa
- The PWR insert's resilience to shear load has been shown but better data are needed for the inner sections, which are less critical
- Situation today
  - SKB and our suppliers are working on establishing an industrial PWR casting process.
- Criteria to be met
  - Micro-structural requirements
  - Requirements on defects
  - Geometrical requirements
  - Reproducibility in process

Plan PWR verification

- Finalize process development 2012-06
- Prequalify process 2012-08
- Demonstration (mimic serial production) 2012-12
- Sample data period 2012-08 – 2013-02
- Verify already performed deterministic analysis and damage tolerance analysis isostatic load 2013
- Deterministic analysis and probabilistic analysis for shear load case 2013

Notes

The verification procedures developed for BWR inserts will simplify the PWR verification.

Probabilistic analysis for the shear load case (BWR) is ongoing.

Example question #11

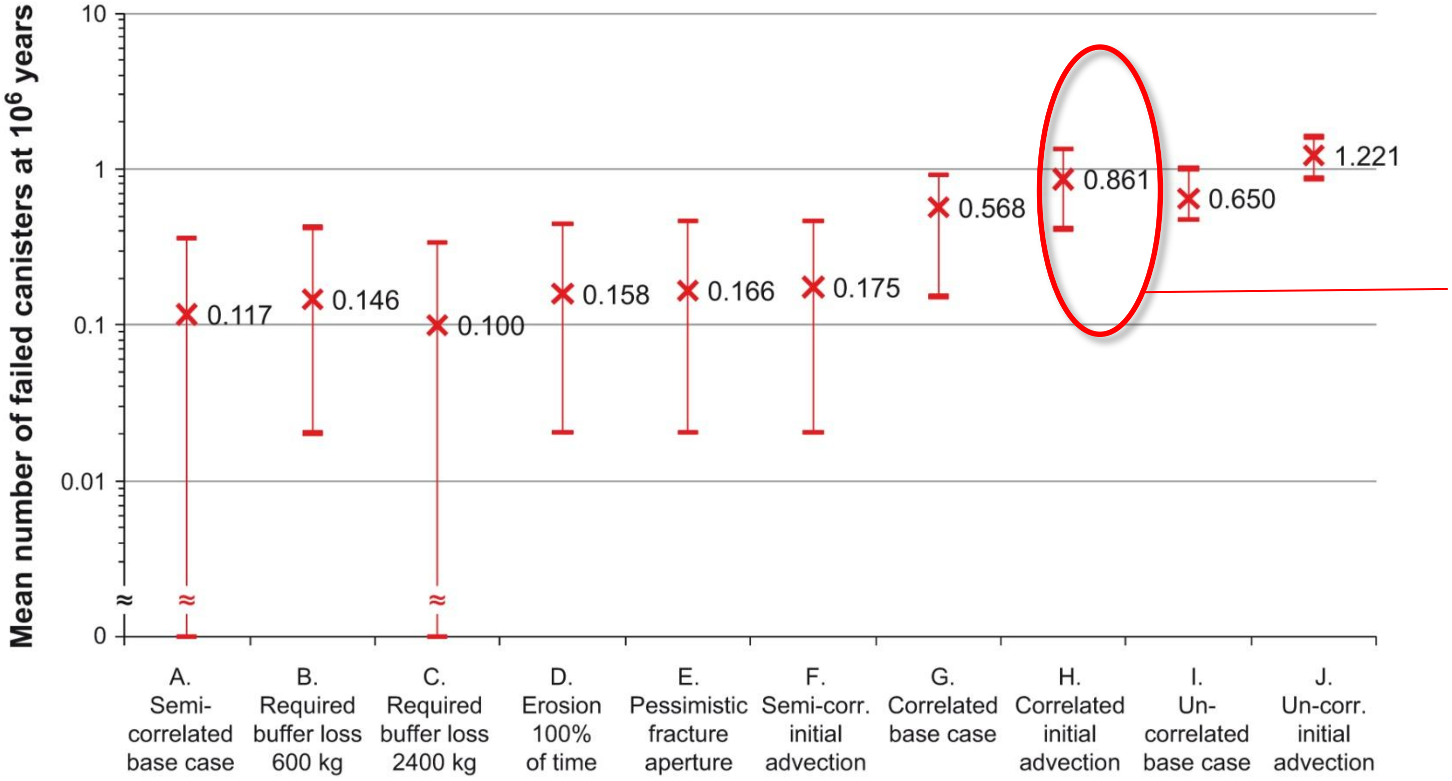
The answer to Questionnaire 2 question 2.5.23 states it takes on the order of ten canisters to fail for the regulatory risk criterion to be violated.

While ten canisters is about an order of magnitude above SKB’s assessment of the mean number of canister failures (0.86), from a perspective of the total number of canisters to be used (~6000) ten canisters is a small fraction. Thus, SKB has to be very confident they have characterized the number of copper canister failures well – or conservatively. Are there any plausible conditions for which the mean number of canisters that would fail could exceed ten?

Are there any plausible conditions for which the mean number of canisters that would fail could exceed ten?

- We do not see any such plausible conditions.
- The SR-Site methodology addresses exactly this issue, i e
  - the scenario analysis evaluates all relevant uncertainties, for each failure mode, often by formal sensitivity analyses (example for corrosion scenario next slide)
  - a defensible approach with regard to compliance demonstration is then adopted when making assumptions and selecting data within the uncertainty range
- Details for the corrosion scenario in section 12.6.2 of the SR-Site main report
- Several pessimistic assumptions for corrosion scenario in compliance demonstration
  - Advective conditions initially in all deposition holes
  - Used most pessimistic variant of hydrogeological model (full correlation between fracture transmissivity and length)
  - Assumed no variation in sulphide concentrations over time whereas e.g. assuming that present spatial variability reflects long-term temporal variability would result in no canister failures

Sensitivity analyses corrosion scenario



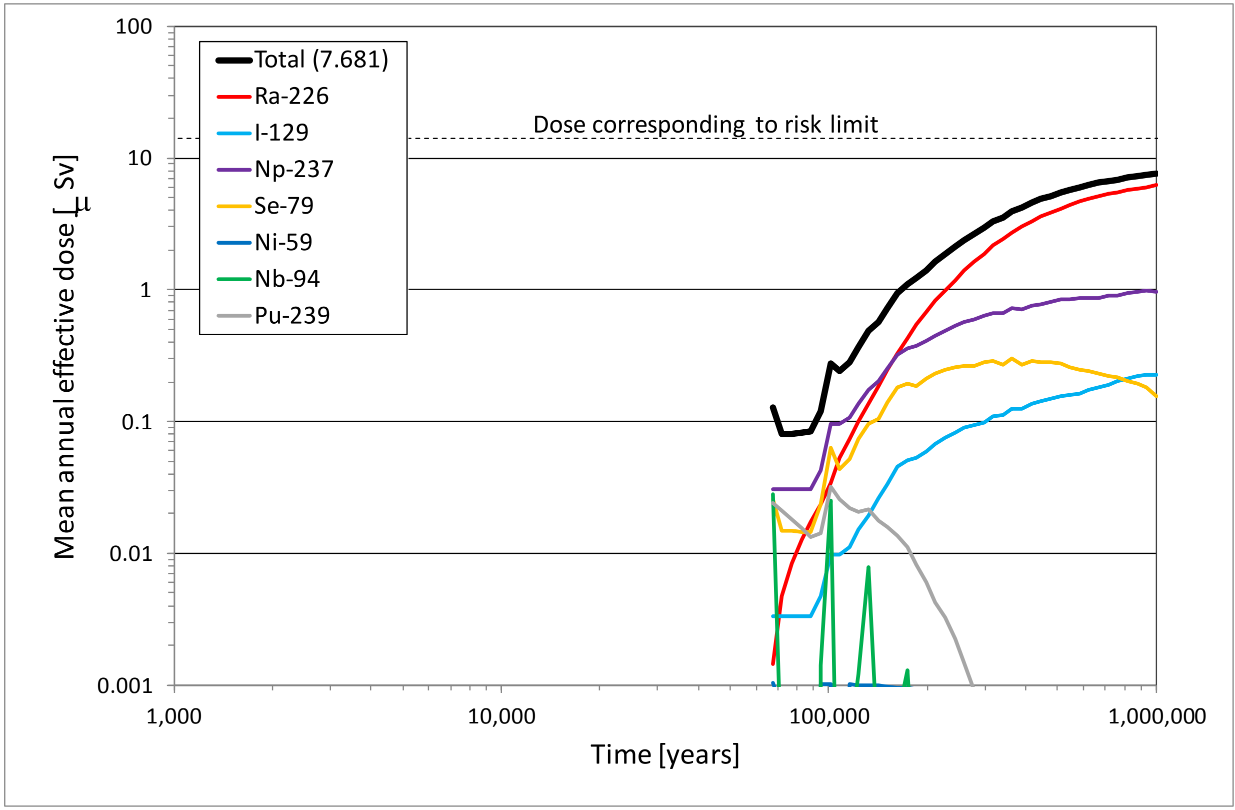
Used this case in compliance demonstration since it yields the highest dose/risk

- Also: The answer given to Q 2.5.23 (10 canisters to exceed risk limit in corrosion scenario) disregards that the consequences increase slower than linearly with the number of failed canisters.
  - If several canisters fail, their releases will be more spread over the landscape;
    - Taking this into account reduces risk by about a factor of 3
  - Canister failures occur in deposition holes with the highest flow rates, correlated to poor rock retention properties. If several canisters fail, then also “better” deposition positions would be affected and the consequences would increase slower than linearly with the number of positions.

What would it take to fail ~10 canisters in the corrosion scenario?

What if

- highest sulphide concentration ($1.2 \cdot 10^{-4}$ M) everywhere all the time
- “worst” hydro model
- advective conditions in every deposition hole initially
- releases distributed in landscape



Then

- 31 failed canisters at 10^6 yrs
- Calculated risk: about $5 \cdot 10^{-7}$
  - – I.e. still a factor of about 2 below risk limit
- Case calculated after SR-Site, in response to the IRT question

Example questions #12, #13, #14 and #15

#12: SKB recognizes an incomplete conceptual understanding of the buffer erosion process. As a consequence, and taking a conservative approach, SKB is using pessimistic hypothesis to deal with this long term process. Can SKB explain the future R&D plans on the issue of colloid formation and erosion?

 # 13: Can SKB give a comparison of the advantages and disadvantages of buffer materials available, with respect to their hydraulic, mechanical, thermal and geochemical performance?

#14: The argument that the estimated eroded mass (1640kg) is small compared to the total mass of bentonite in the backfill (>10 tonnes) may not be strong if the eroded mass leads to a water pathway. If erosion occurs, then a pathway is likely.

#15: Advantages and disadvantages of increasing the buffer thickness

The buffer erosion process

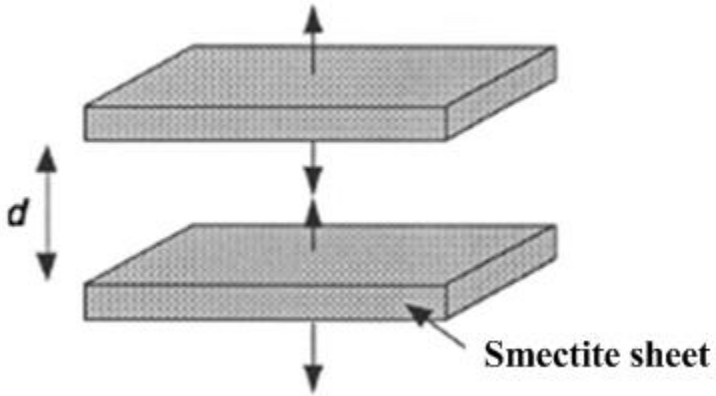
- RD&D 2010
- BELBaR

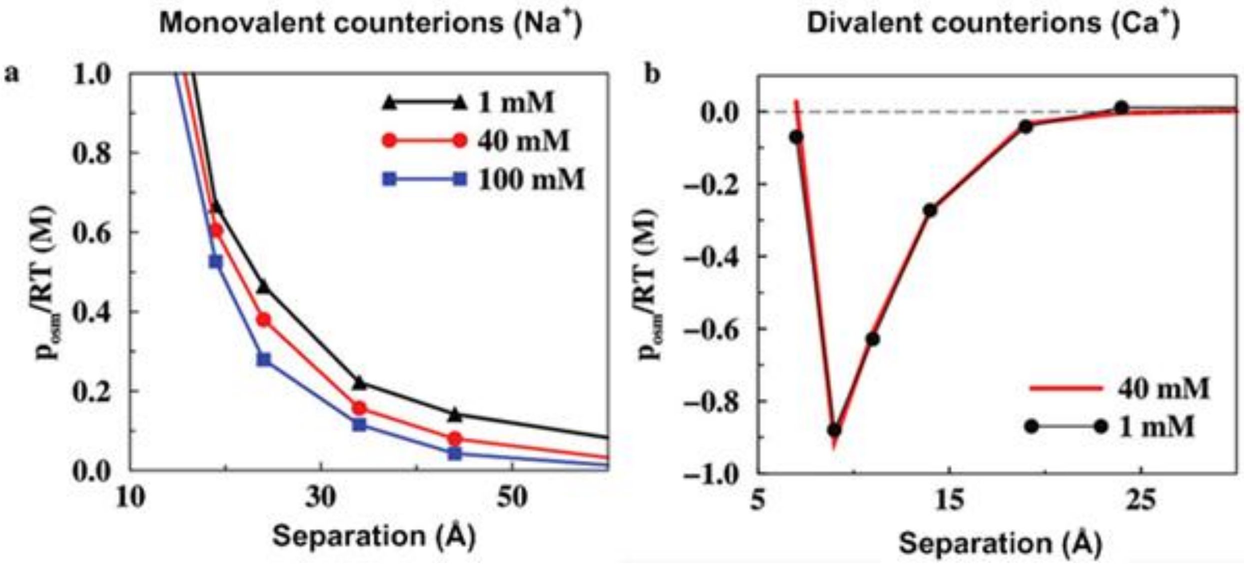
RD&D 2010

- Despite great efforts, the results from the “Bentonite Erosion” project do not give a clear picture of how the process can be quantified
- Uncertainties still exist regarding how calcium affects the process, especially in mixed Na/Ca systems
- The actual erosion takes place in a fracture, while most experiments have been done in open pipes or through filters

Interactions between Smectite Sheets

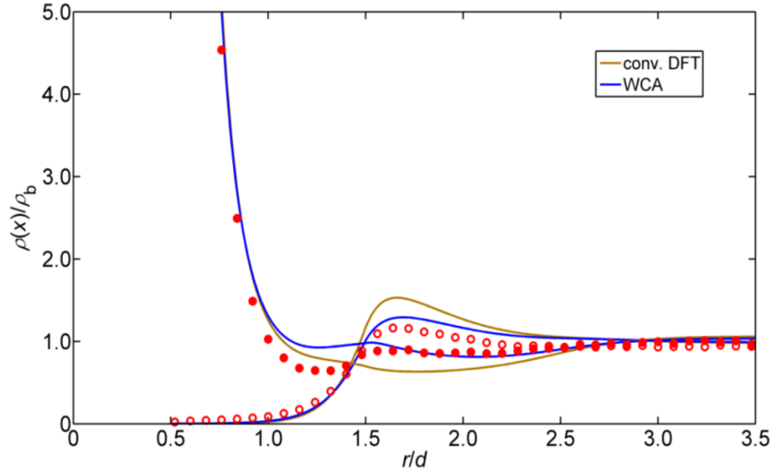
- Interaction between parallel plates
  - Van der Waals force
  - Diffuse double layer force
- **Poisson-Boltzmann equation (points charges) fails in divalent case (Ca-bentonite)**





Modelling smectite forces by density functional theory

- Density profiles near charged surface



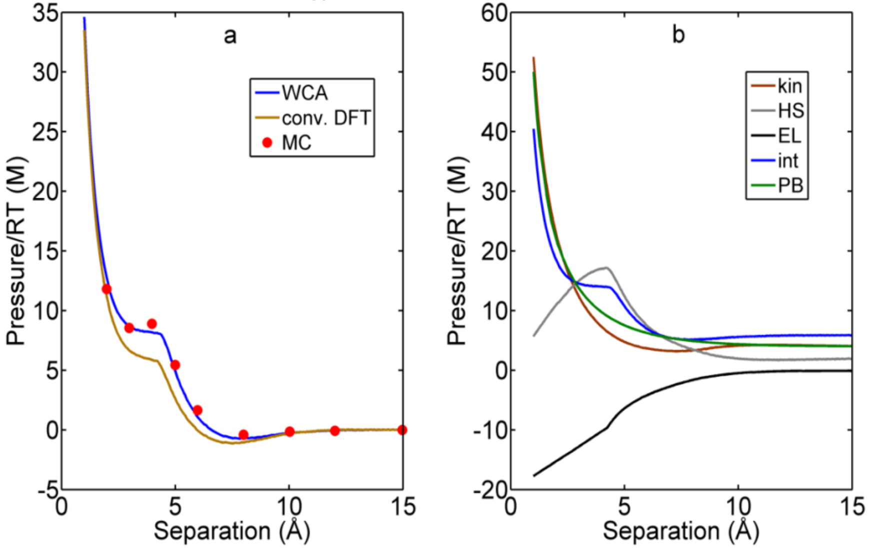
0.2 M, 2:1 electrolyte solution. σ = 0.24C/m^2

WCA incorporated into the force balance model

- Pressure between charged surfaces

$$P^{\text{int}} = P^{\text{kin}} + P^{\text{HS}} + P^{\text{EL}}$$

2.0 M, 1:1 electrolyte solution. σ = 0.267 C/m2

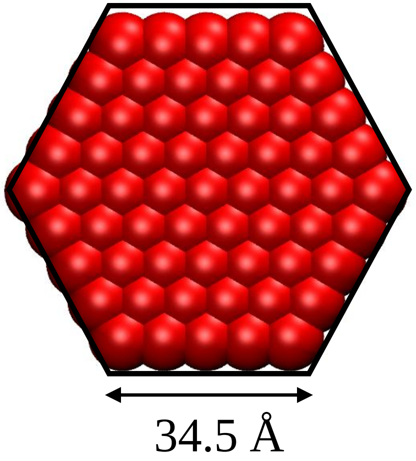


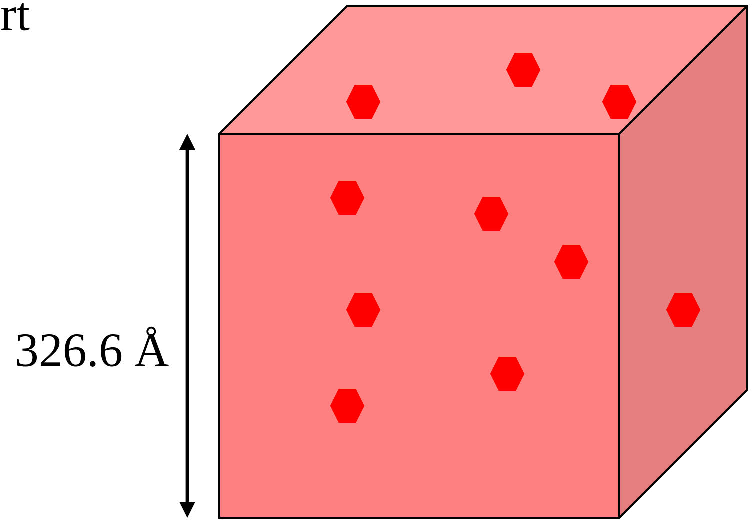
Refined model of montmorillonite

Slightly higher charge -100 Å²/e
$(Si_8)(Al_3Mg)O_{20}(OH)_4$

Each O_{20} unit cell represented by a sphere of diameter ~9 Å

Hexagonal clay platelet 61 spheres 7.5 Å apart





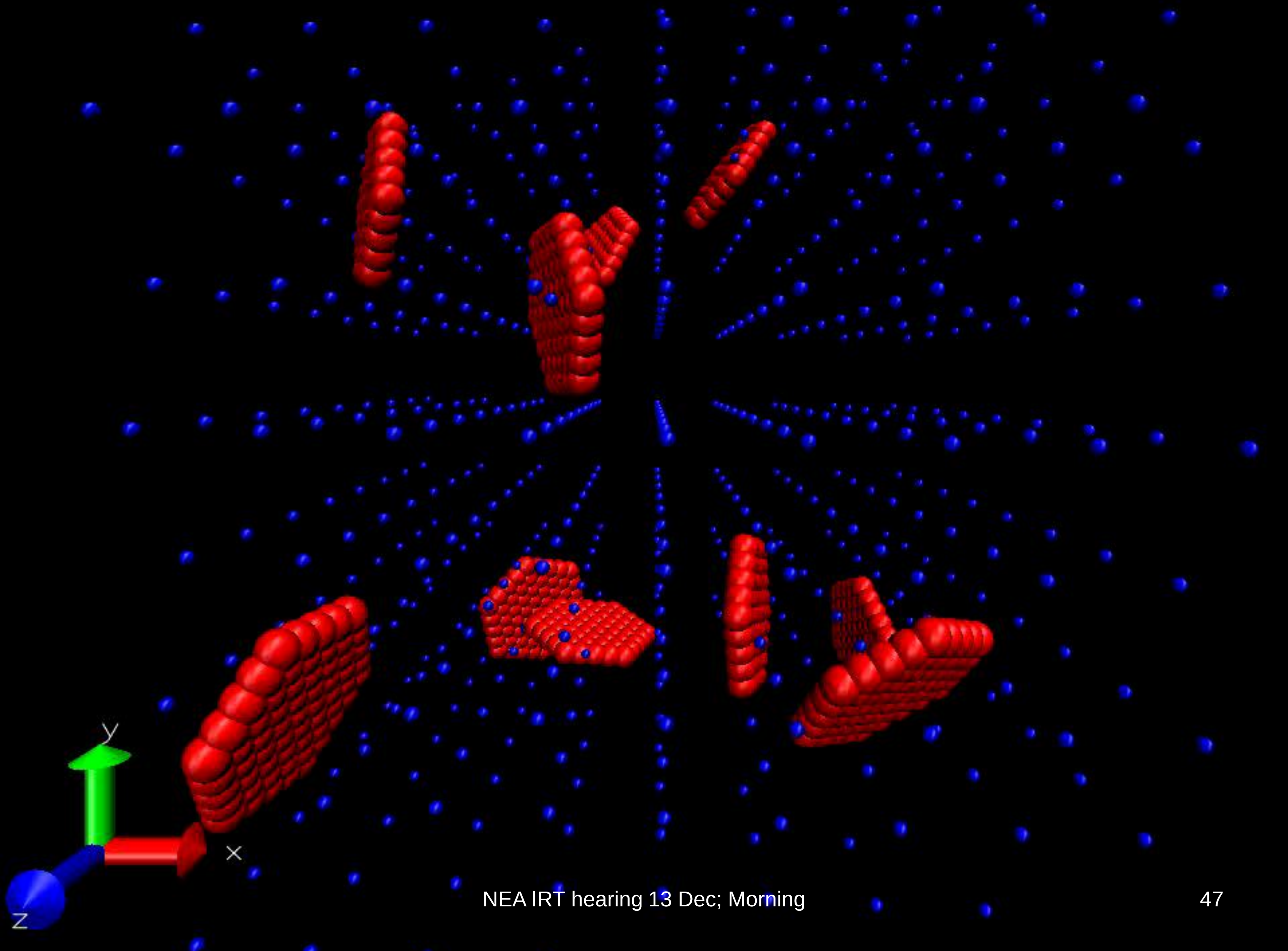
Area about 15-20 times smaller than laponite
and 800 times smaller than montmorillonite

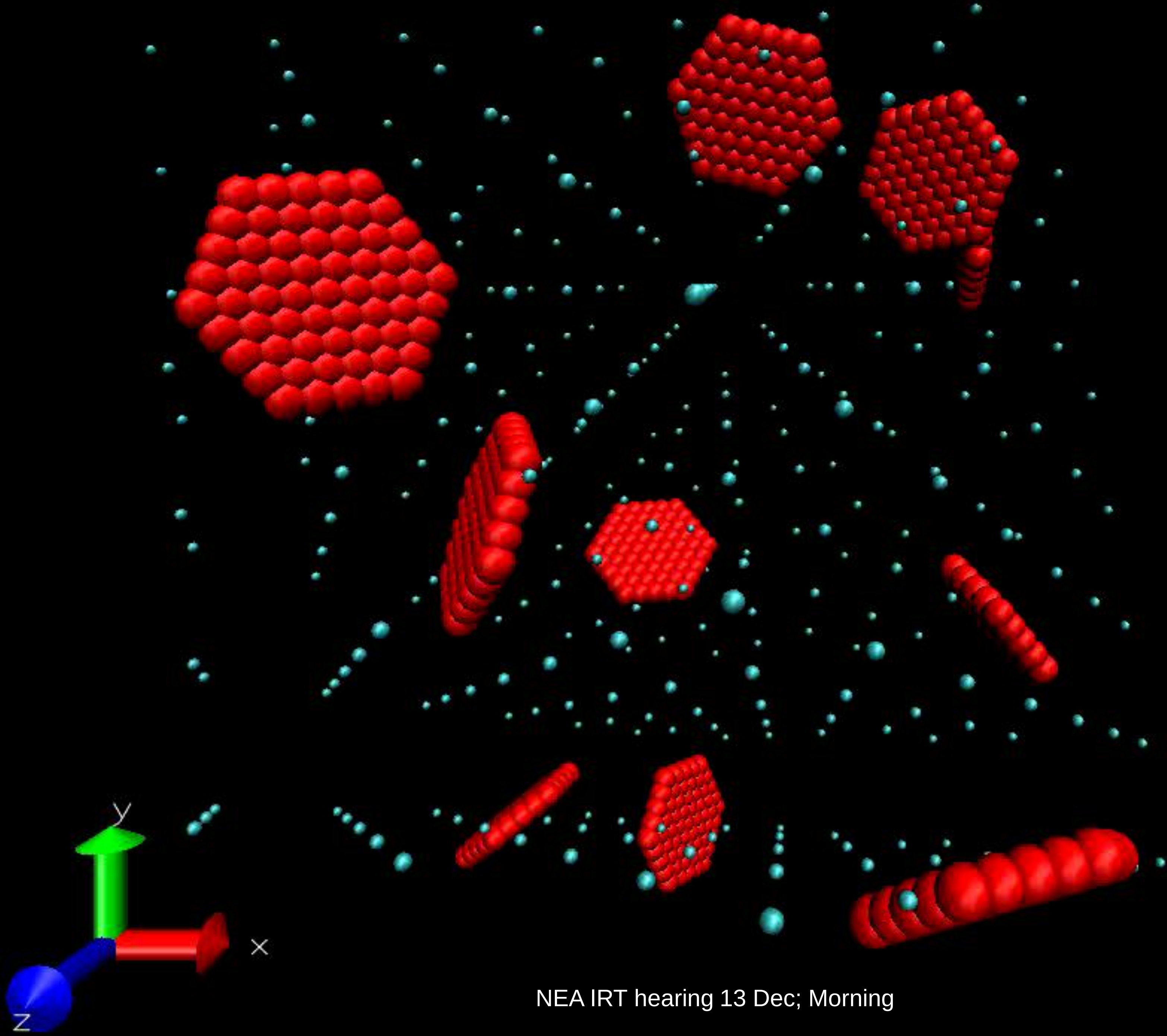
10 clay particles
10*61/Z counterions
Z=1 or 2
Volume fraction $\phi = 0.008$

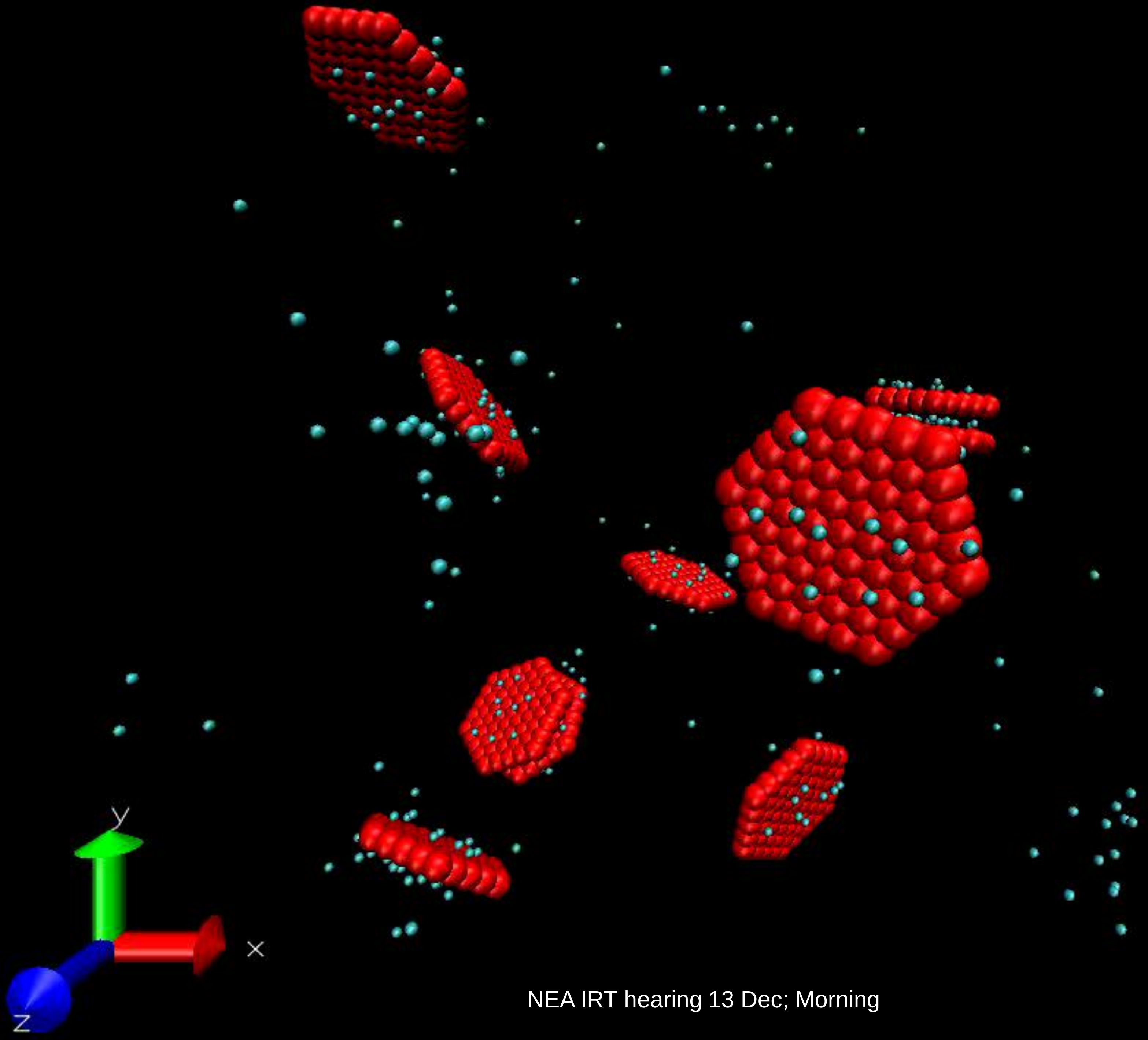
Three movies of MD simulation

- 1 Sodium as counter ion –no aggregation
- 2 Calcium as counter ion –aggregation
- 3 Calcium the final stages –Formation of a particle with three clay layers

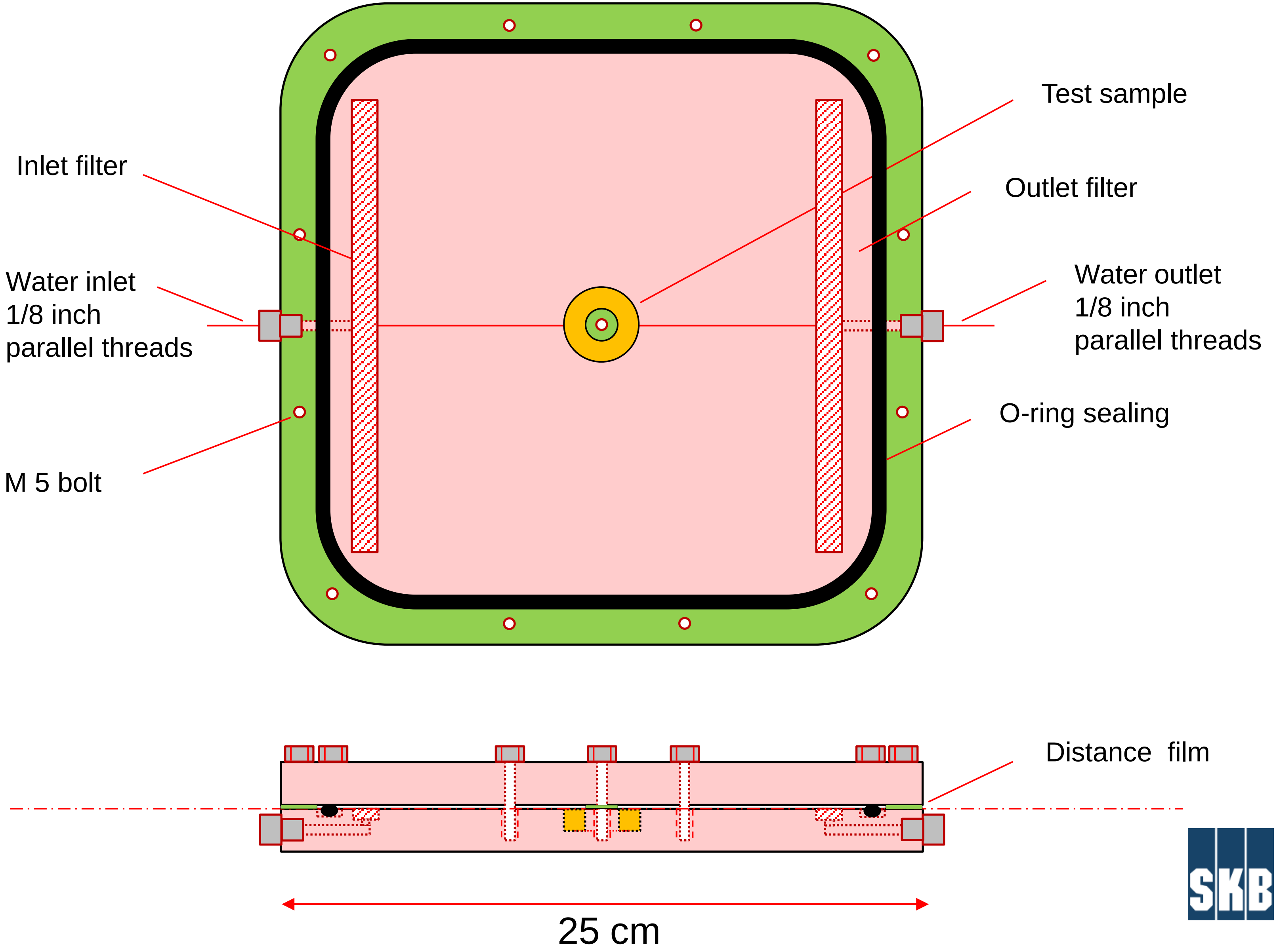
- Initially all particles are placed on a grid but ions find their positions around the clay layers quickly due to Coulomb attraction.

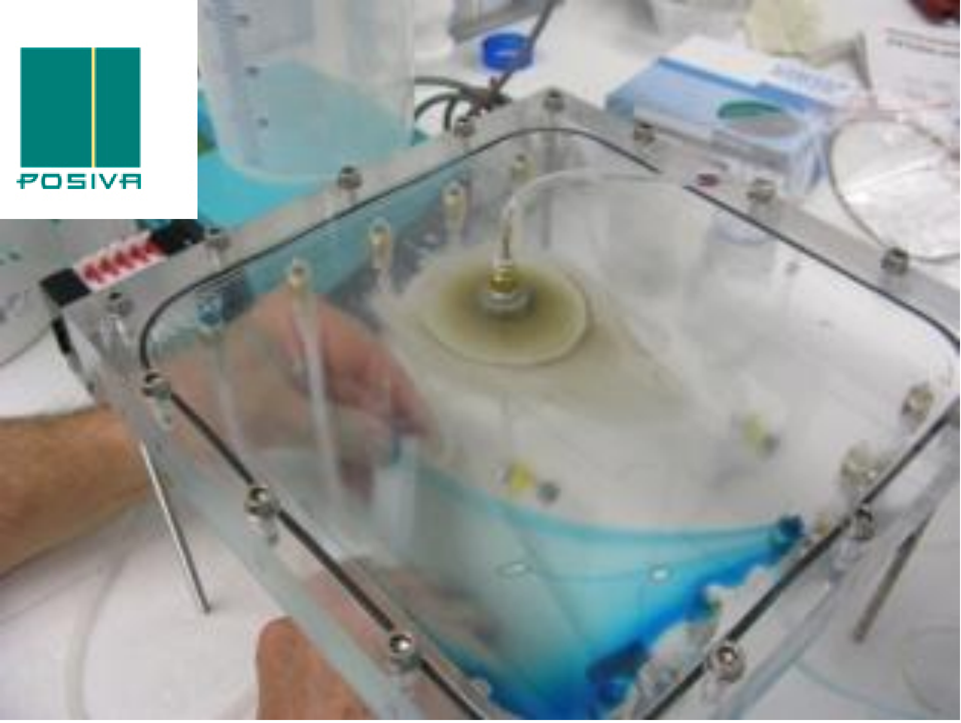

y
x
z

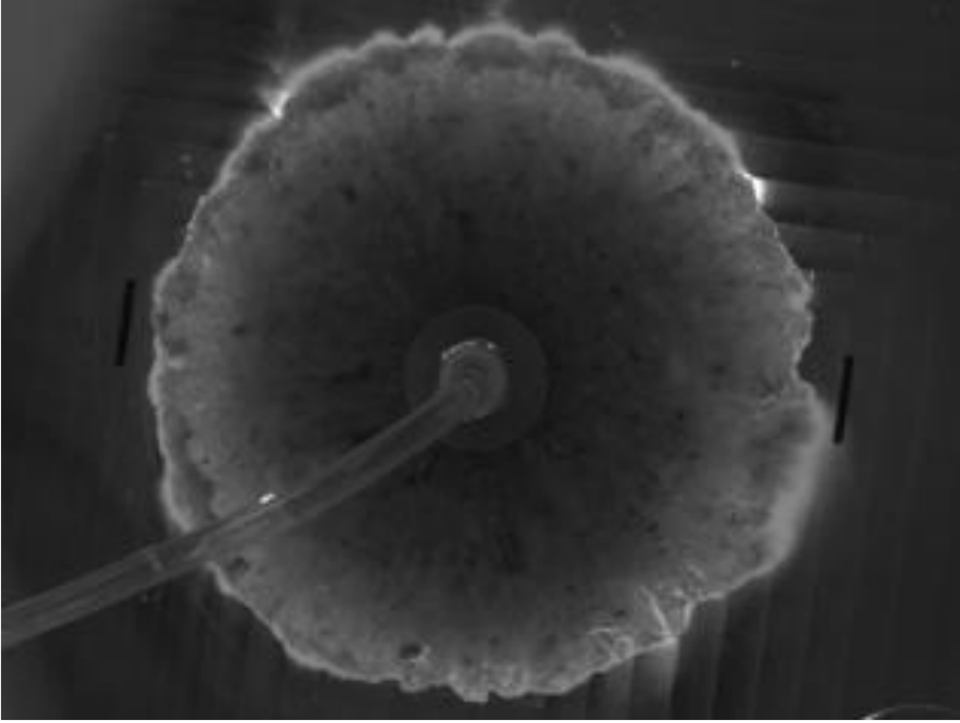

y
x
z

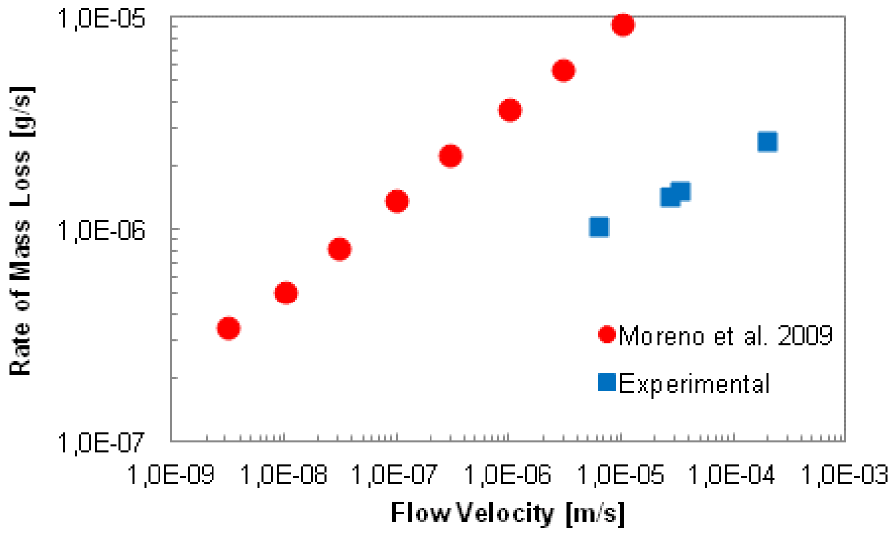

y
x
z

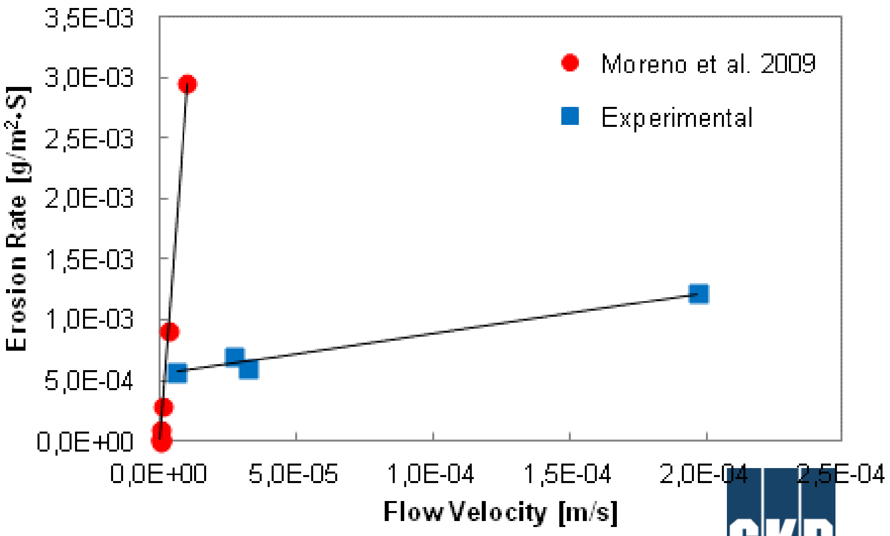
Test cell for quantification of colloidal particle release








1,0E-05
1,0E-06
1,0E-07
Rate of Mass Loss [g/s]
1,0E-09
1,0E-08
1,0E-07
1,0E-06
1,0E-05
1,0E-04
1,0E-03
Flow Velocity [m/s]
● Moreno et al. 2009
■ Experimental

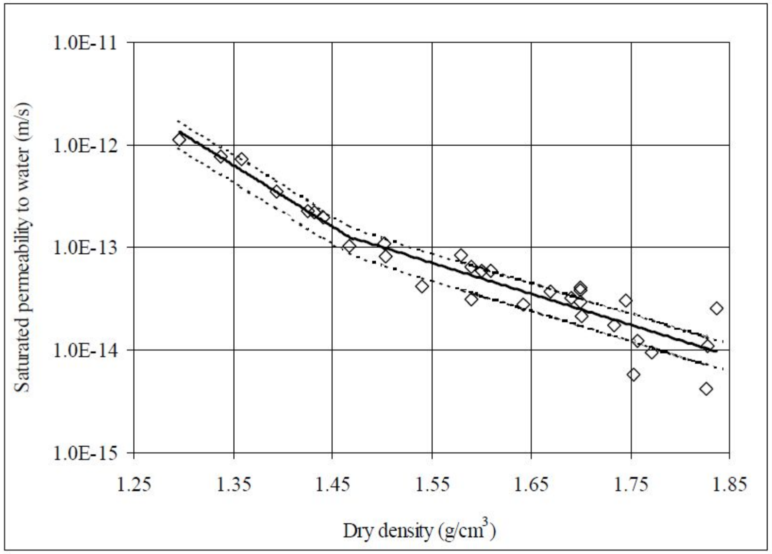

3,5E-03
3,0E-03
2,5E-03
2,0E-03
1,5E-03
1,0E-03
5,0E-04
0,0E+00
Erosion Rate [g/m^2·s]
0,0E+00
5,0E-05
1,0E-04
1,5E-04
2,0E-04
2,5E-04
Flow Velocity [m/s]
● Moreno et al. 2009
■ Experimental

BELBaR

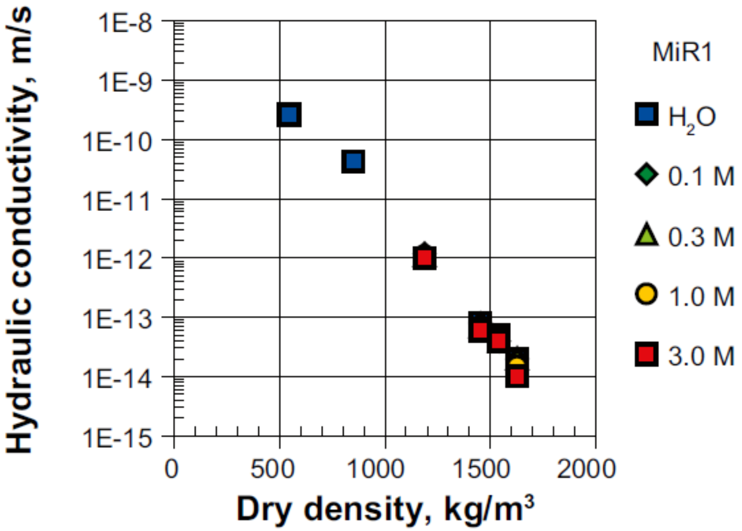
- Improving the understanding on when bentonite colloids are unstable. For a given site/site evolution, this is critical information, since it determines whether or not clay colloids need to be included in the long-term assessment.
- Improving the quantitative models for erosion of the bentonite barrier for the cases when the colloids are stable
- Improving the understanding of how radionuclides attach to clay colloids. This information will be used to formulate improved transport models for the assessment of radionuclide transport in the Geosphere
- 14 partners, 7 European countries,
  - Total budget: € 5 087 574 (*EC contribution: EUR 2 581 476*)
  - Duration: 48 months
  - Starts: 2012-03-01
  - Coordinator: SKB

Advantages and disadvantages of buffer materials available

Hydraulic performance

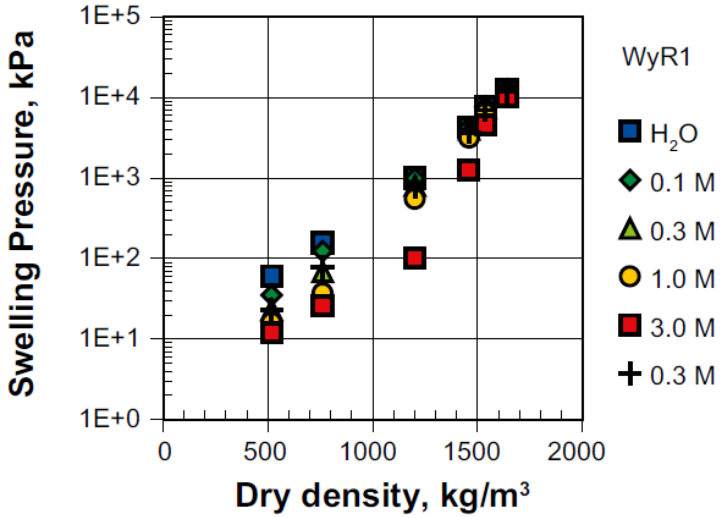


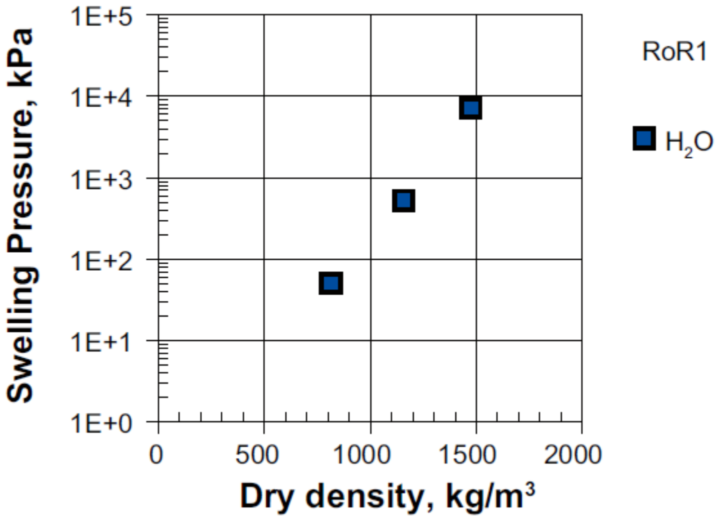
Febex



Ibeco RWC

Swelling pressure

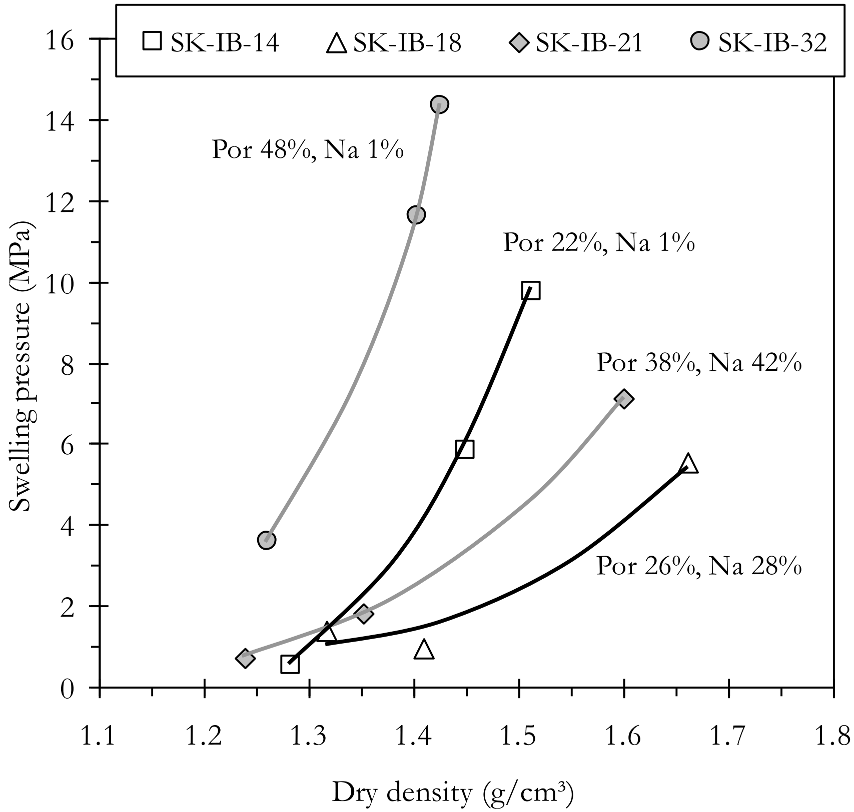




Mx-80

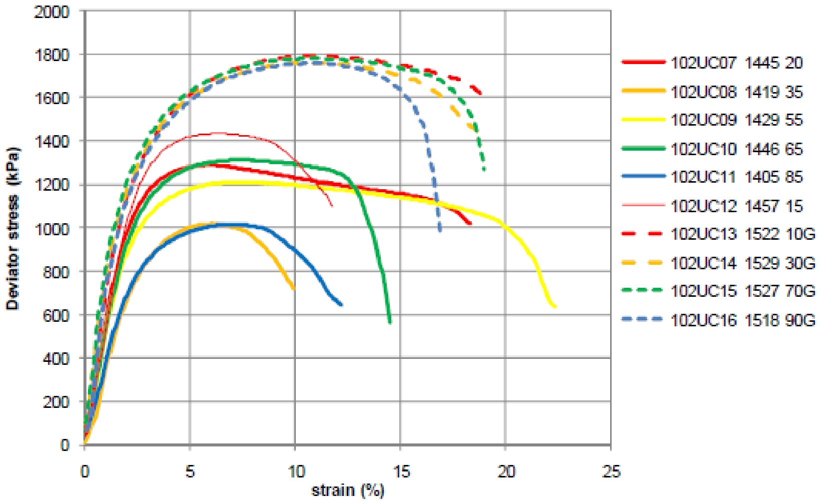
Rokle

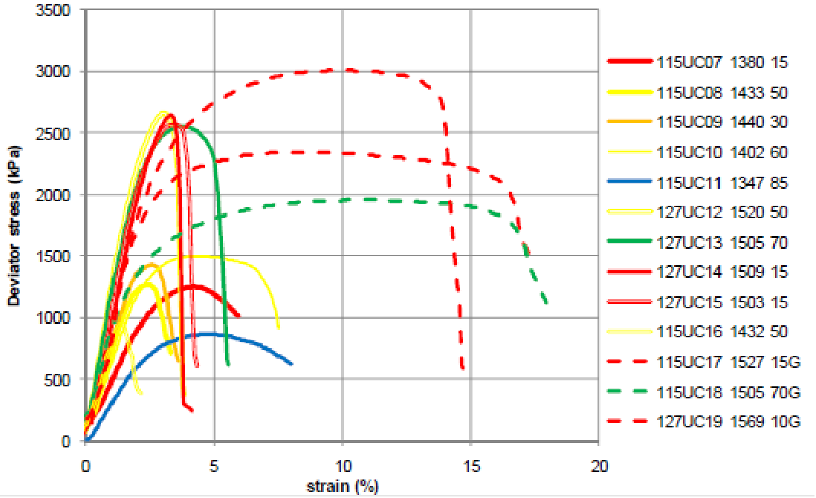
But…



□ SK-IB-14
△ SK-IB-18
◆ SK-IB-21
● SK-IB-32
Por 48%, Na 1%
Por 22%, Na 1%
Por 38%, Na 42%
Por 26%, Na 28%
Swelling pressure (MPa)
0
2
4
6
8
10
12
14
16
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
Dry density (g/cm³)

Mechanical performance





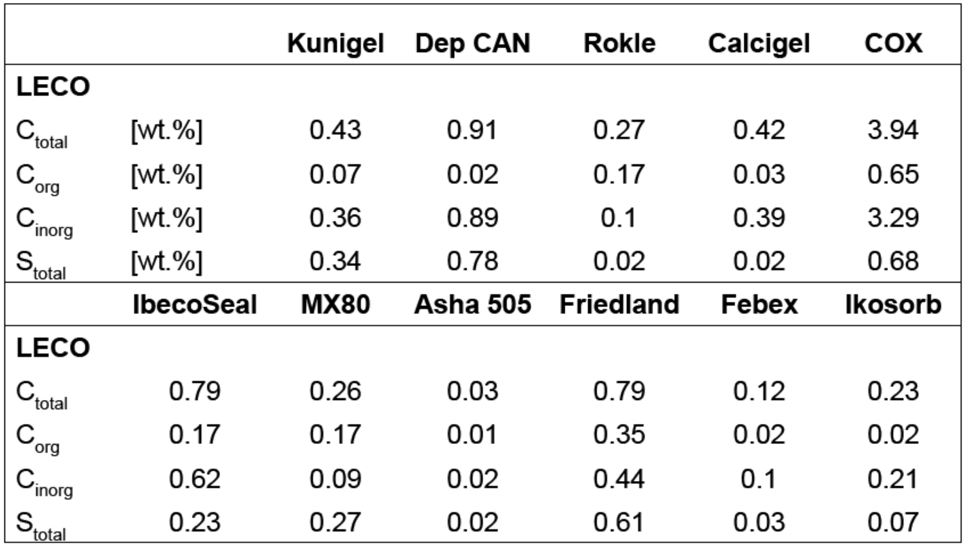
Mx-80

Ibeco RWC

Thermal and geochemical performance

- Long term thermal stability is generally not an issue:
  - Could be affected by layer charge
  - However, no clear evidence
- Limits on organic C and S
  - Lower is better
  - Still, limited contribution to corrosion
- Erosion stability
  - Ca-bentonite more stable
  - But the composition will be affected by the groundwater

LECO (BGR)



		Kunigel	**Dep CAN**	**Rokle**	**Calcigel**	**COX**
LECO						
C_{total}	[wt.%]	0.43	0.91	0.27	0.42	3.94
C_{org}	[wt.%]	0.07	0.02	0.17	0.03	0.65
C_{inorg}	[wt.%]	0.36	0.89	0.1	0.39	3.29
S_{total}	[wt.%]	0.34	0.78	0.02	0.02	0.68
	IbecoSeal	**MX80**	**Asha 505**	**Friedland**	**Febex**	**Ikosorb**
LECO						
C_{total}	0.79	0.26	0.03	0.79	0.12	0.23
C_{org}	0.17	0.17	0.01	0.35	0.02	0.02
C_{inorg}	0.62	0.09	0.02	0.44	0.1	0.21
S_{total}	0.23	0.27	0.02	0.61	0.03	0.07

Summary

- There are differences in performance between different bentonites, however:
  - All studied materials would meet the requirements
  - In general, the differences are small
  - Interaction with the groundwater will alter the composition
- Any selected material needs to be well characterized

Loss of backfill and buffer mass during the early evolution of the repository

Piping/erosion

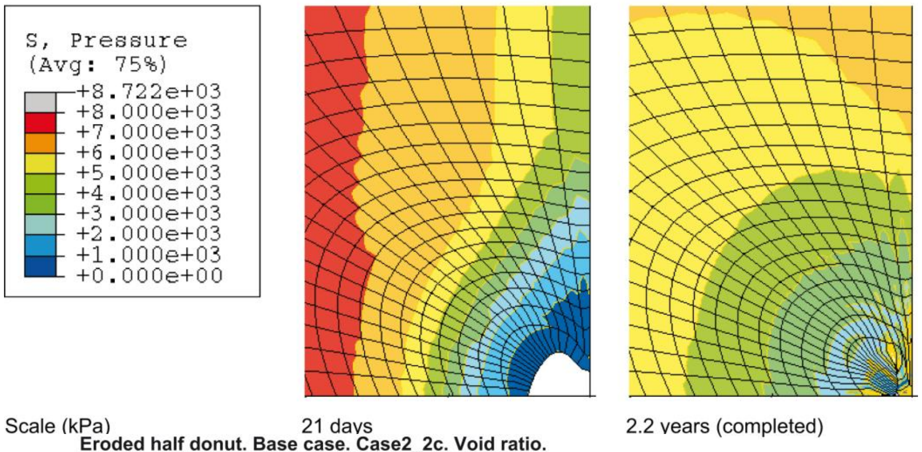
Mass loss in backfill in the early evolution

- In the backfill, the largest possible loss due to piping/erosion is 1,640 kg (re-distributed) if there is one single point inflow in a tunnel:
  - Small compared to 10,000 tonnes
  - Pathways will **always** form in the backfill (independent of magnitude of erosion)
  - Will re-seal when gradients are restored

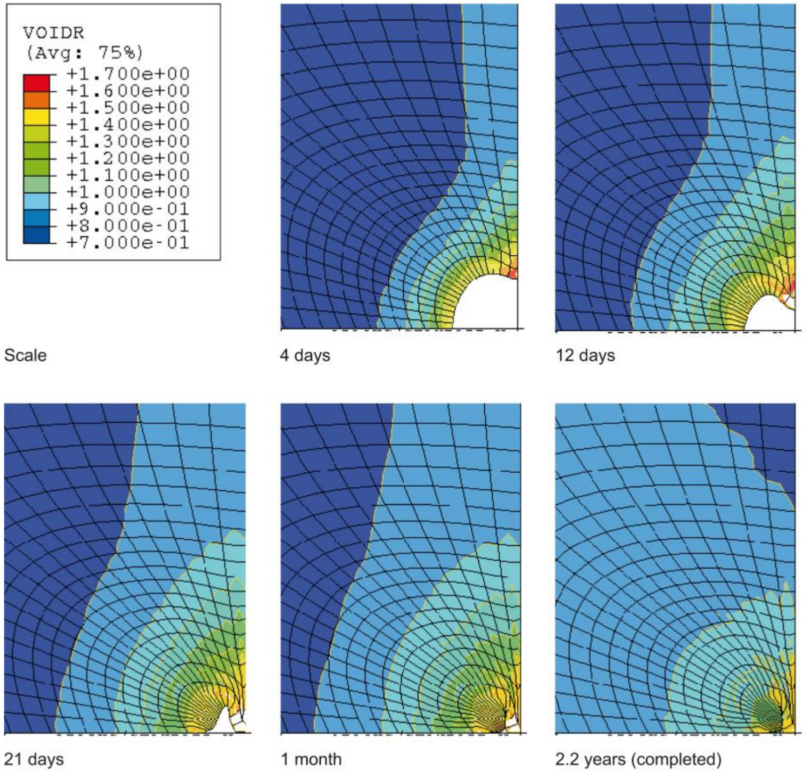
Sealing after piping

- The erosion will stop when the plug is built and sealed and the voids in backfill pellets are filled with water.
- Calculations only done for erosion in the buffer
  - More severe since total mass is smaller
- Strong decrease in density and swelling pressure due to the friction in the bentonite
- Still, the swelling pressure after completed homogenisation is in none of the cases studied below 1 MPa

Eroded half donut. Base case. Case2_2c. Pressure.



Eroded half donut. Base case. Case2_2c. Void ratio.



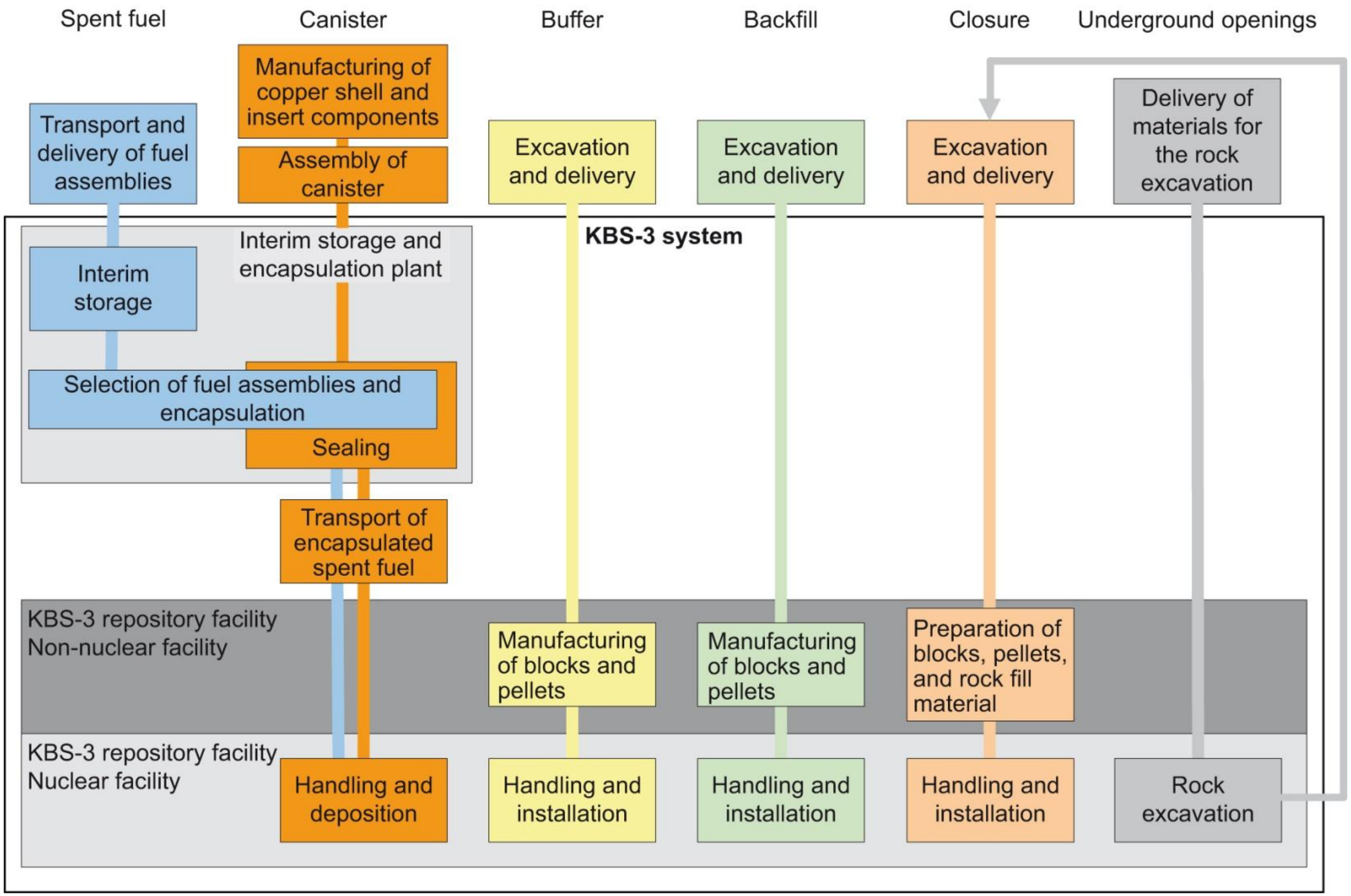
Advantages and disadvantages of increasing the buffer thickness

- A larger buffer mass is not seen as a practical means of mitigating the effects of buffer erosion
  - A larger buffer mass may offer a slightly longer time before advective conditions occur in the deposition hole, but it is not seen as a solution to the issue
- *An increased buffer thickness will reduce the damage on the canister at a rock shear*
- *An increased buffer thickness will also increase the overall buffer mass, which would make the buffer more resistant to alteration and mass-loss processes*
  - *Still, it is not an unambiguous advantage since an increased thickness also would decrease the heat transfer capacity*
- *An increased diameter would also increase the distance for diffusion between the canister and the rock*
  - *However, this would also lead to a bigger deposition hole, which would increase the probability of intersection of a water conductive fracture*

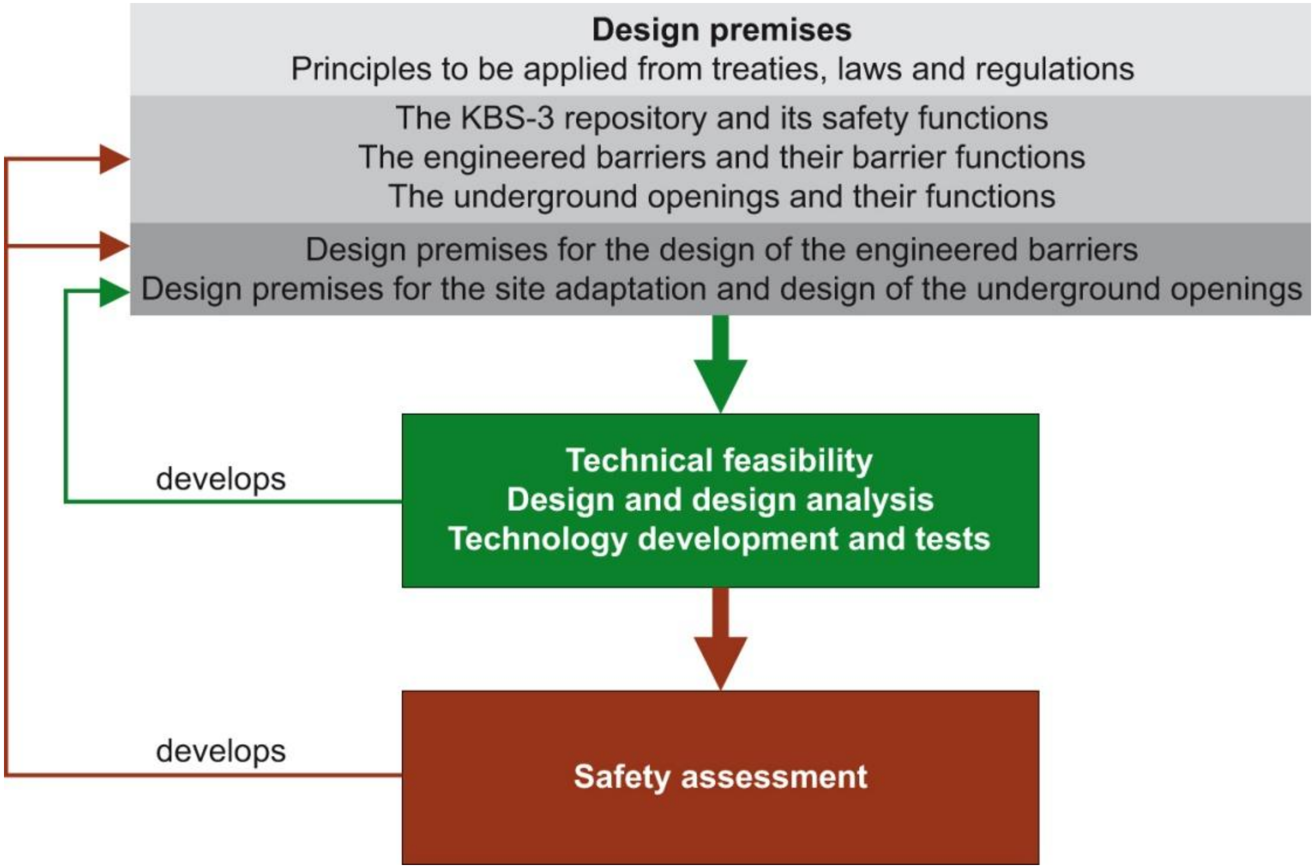
Example question # 16 “Industrial feasibility”

While SKB recognizes the importance of QA for the main engineered barriers (canister, buffer), SKB also states that QC of the manufacturing process is not part of the license process, but would be a separate supervised process. However, international recommendations (e.g., IAEA, OECD/NEA) emphasize that the manufacturing process of canister and buffer (the main engineered barriers) and its QA are, in principle, to be included in the safety case/safety assessment to strengthen confidence in the safety case and its completeness. When and by whom will the QA approach reviewed? Can SKB provide an overview of the QA plan?

The production lines – A structured process for constructing and operating the KBS-3-system



Iterative process for substantiation of design premises



Design premises
Principles to be applied from treaties, laws and regulations

The KBS-3 repository and its safety functions
The engineered barriers and their barrier functions
The underground openings and their functions

Design premises for the design of the engineered barriers
Design premises for the site adaptation and design of the underground openings

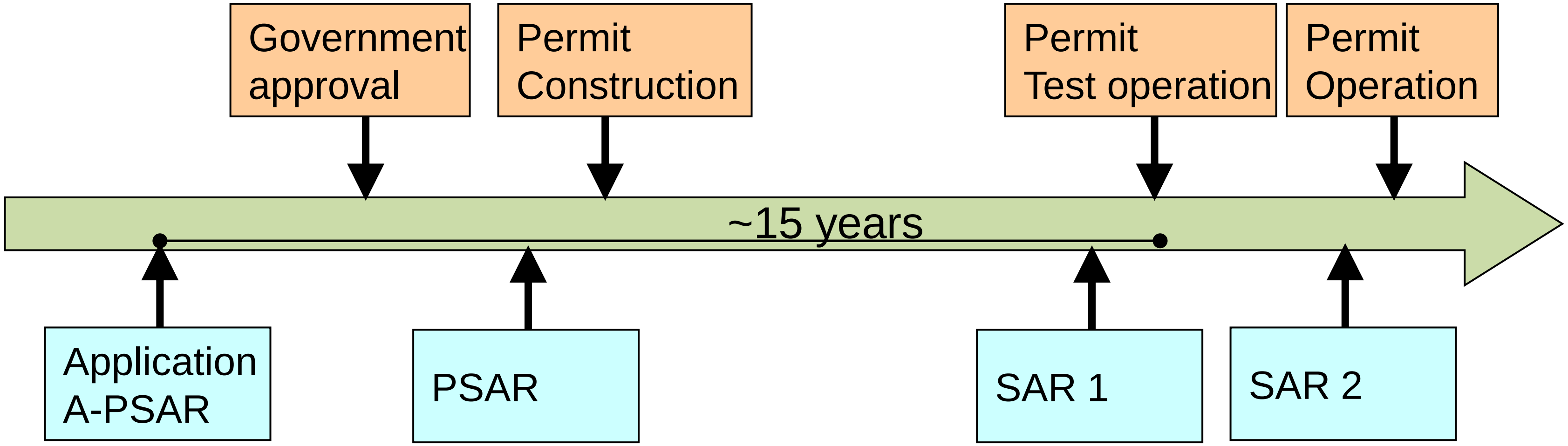
Technical feasibility
Design and design analysis
Technology development and tests

develops

Safety assessment

develops

From License application to deposition of canisters



Government approval

Permit Construction

Permit Test operation

Permit Operation

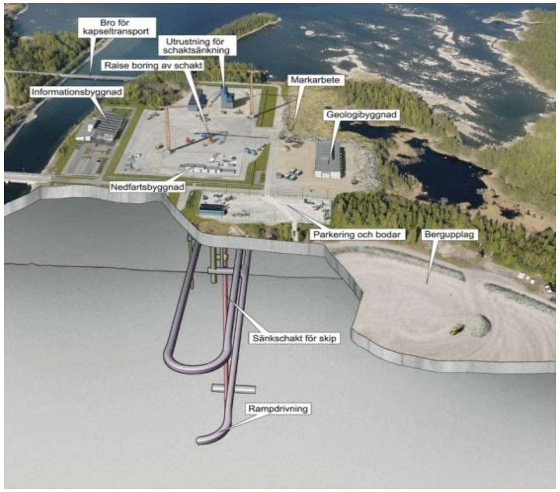
~15 years

Application A-PSAR

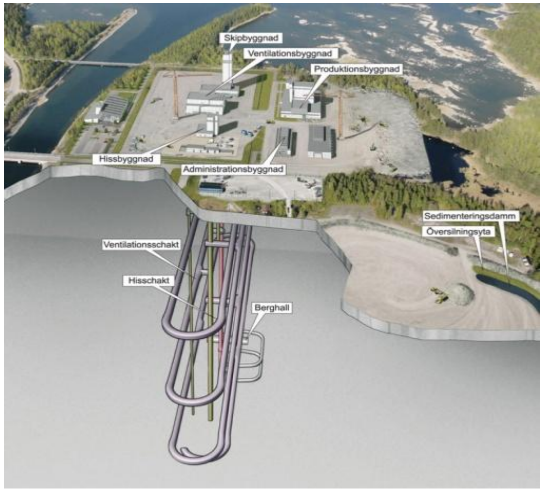
PSAR

SAR 1

SAR 2



2 y after construction initiation



4 years …

6 years…

Quality management system

Design premises

Reference design

Design analysis
Meeting requirements?

Production Control and inspection

Development and assessment of
Production methods
Inspection methods

Approved product
Initial state

- Documented procedures for design, analyses, computer codes, data management, testing, etc.
- Review and approval
  - Primary and independent safety reviews and 3rd party reviews as required by safety and quality classification
  - Licensed procedures, components and staff where appropriate
- Review and approval of safety relevant parts of quality management system by SSM
- More comprehensive plans to be presented in PSAR
- Final system to be implemented in SAR
- To be reviewed and approved by SSM

Quality assurance and control

Manufacturing of canister components and assembly of canisters Chapter 5

- Manufacturing of insert Section 5.2
- Manufacturing of copper tubes Section 5.3
- Manufacturing of copper lids and copper bases Section 5.4
- Welding of bases Section 5.5
- Assembly of canisters Section 5.6
- Transport of canister to encapsulation plant Section 5.7

Encapsulation in Clink Chapter 6

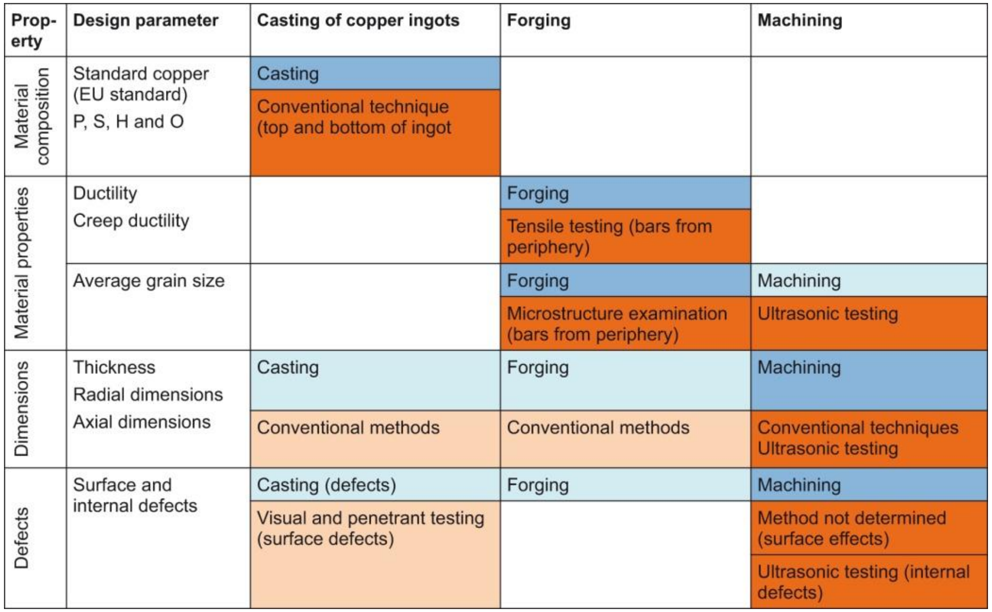
- Canister to encapsulation plant Section 6.2
- Selection and handling of fuel assemblies Spent fuel report, Chapter 4
- Copper lid welded to canister by friction stir welding Section 6.3
- Placement of canister in a transport cask (KTB) Section 6.4

Transportation of encapsulated spent fuel Chapter 6

- Road transport to harbour Section 6.5.1
- Sea transport Section 6.5.2
- Road transport to final repository facility Section 6.5.3

Handling and deposition of canisters in final repository Chapter 6

- Transportation to repository depth Section 6.6
- Reloading of canister from KTB to deposition machine Section 6.7
- Deposition of canister Section 6.8



Property	Design parameter	Casting of copper ingots	Forging	Machining
Material composition	Standard copper (EU standard) P, S, H and O	Casting Conventional technique (top and bottom of ingot)		
Material properties	Ductility Creep ductility		Forging Tensile testing (bars from periphery)	
	Average grain size		Forging Microstructure examination (bars from periphery)	Machining Ultrasonic testing
Dimensions	Thickness Radial dimensions Axial dimensions	Casting Conventional methods	Forging Conventional methods	Machining Conventional techniques Ultrasonic testing
Defects	Surface and internal defects	Casting (defects) Visual and penetrant testing (surface defects)	Forging	Machining Method not determined (surface effects) Ultrasonic testing (internal defects)