Safety Functions and Safety Function Indicators – Key Elements in SKB's Methodology for Assessing Long-Term Safety of a KBS-3 Repository

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Outline

- Safety assessments during SKB's current program stage
- Function indicators
  - Definitions
  - Properties
  - Use in the safety assessment SR-Can
  - Summary

Safety assessments during SKB:s site investigation stage

- SKB is currently pursuing site investigations for a final repository for spent nuclear fuel in the municipalities of Forsmark and Oskarshamn.
  - Application to build encapsulation plant made in November 2006
  - Application to build final repository planned December 2009
- The safety assessment SR-Can
  - Based on initial site data from Forsmark and Laxemar
  - Published in October 2006, SKB TR-06-09 (available at www.skb.se)
  - Reviewed by SKI and SSI aided by int'l team of experts during 2007
  - Not a basis for any formal licence application
- The safety assessment SR-Site
  - Supports license application to build final repository to be made in 2009

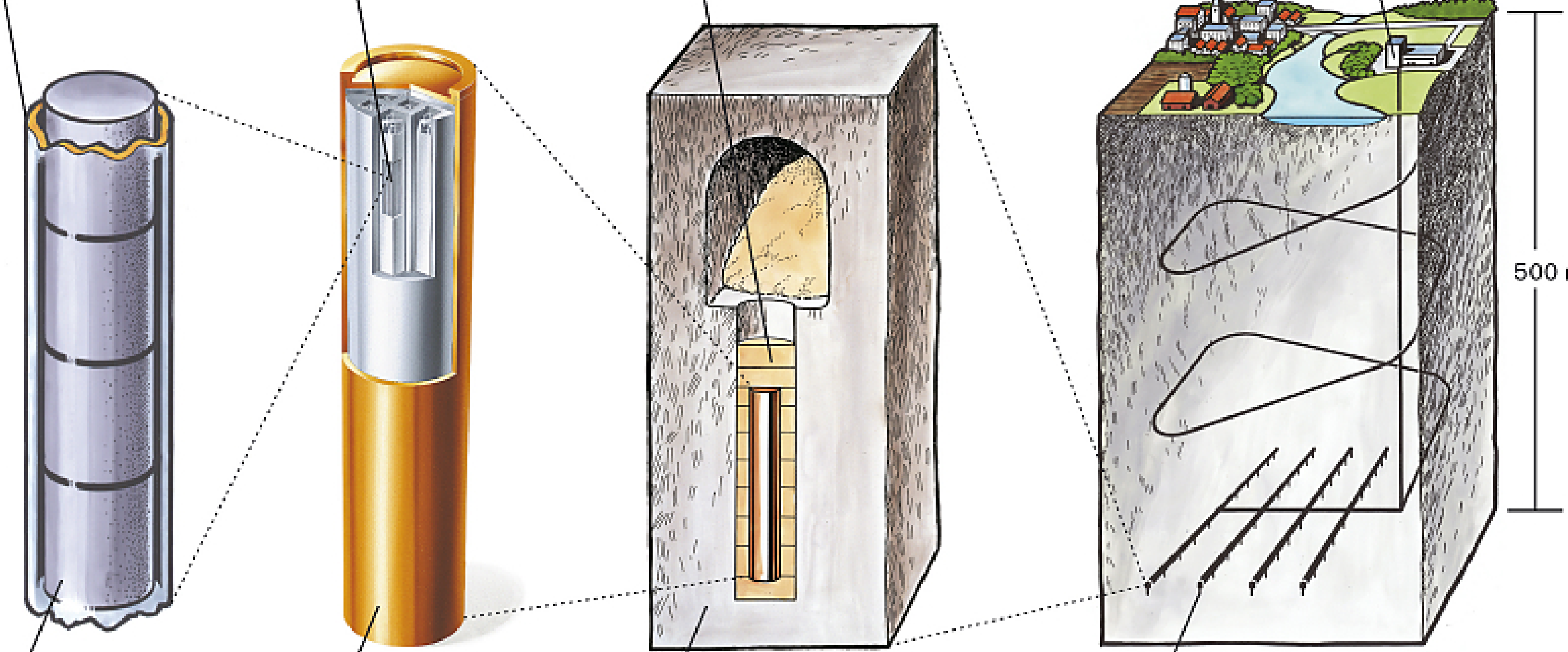
Purposes of the safety assessment SR-Can

- To preliminarily assess the safety of potential KBS-3 repositories at Forsmark and Laxemar to dispose of canisters as specified in SKB's application to build an encapsulation plant.
- To provide feedback to design development, to SKB's R&D programme, to further site investigations and to future safety assessment projects.
- To obtain feedback from SKI and SSI for safety assessment supporting license application for a deep repository, SR-Site

The SR-Can team

- Kastriot Spahiu, fuel
- Lars Werme, canister
- Patrik Sellin, buffer and backfill
- Ignasi Puigdomenech, geochemistry
- Raymond Munier, geology
- Jan-Olof Selroos, flow and transport geosphere
- Ulrik Kautsky, biosphere
- Lena Morén, FHA issues
- Jens-Ove Näslund, future climate
- Fredrik Vahlund, radionuclide transport and dose calculations, input data
- Karin Pers (Kemakta), Initial state engineered barriers
- Kristina Skagius (Kemakta), FEP database, methodology, link to SDM Forsmark
- Johan Andersson (JA Streamflow AB), methodology, coordination with site investigations and design, coordination of mechanics issues, input data
- Lisa Wedin, project administration
- Allan Hedin, project leader, editor main report, methodology

The KBS-3 repository



- Primary safety function: isolation
- Secondary safety function: retardation

Safety function indicators

- Dose and risk compliance criteria are the ultimate measures of safety, but…
  - …need also intermediate measures in order to evaluate system in a more detailed and disaggregate fashion
- Therefore, a number of (safety) function indicators have been defined and criteria yielding ”good” performance of the system have been determined
- Measurable or calculable properties of the system, primarily related to the near-field and that should preferably be <u>fulfilled throughout the one million year assessment period</u>
- Example:
  - Function indicator: Groundwater concentration of divalent cations
  - Criterion: Above 1 mM to prevent loss of buffer material to groundwater

Definitions

- A safety function is a role through which a repository component contributes to safety
  - Example: The canister should withstand isostatic load
- A safety function indicator is a measurable or calculable property of a repository component that indicates the extent to which a safety function is fulfilled
  - Example: Isostatic stress in canister
- A safety function indicator criterion is a quantitative limit such that if the safety function indicator to which it relates fulfils the criterion, the corresponding safety function is maintained
  - Example: Isostatic stress < isostatic collapse load

Relation between global safety and individual safety functions

- Breaching of a safety function indicator criterion does not mean that the repository is unsafe, but rather that more elaborate analyses and data are needed in order to evaluate safety.
- Example: Groundwater concentration of divalent cations should exceed 1 mM in order for buffer erosion to be excluded.
- If breached, buffer erosion must be quantitatively evaluated and consequences in terms of reduced buffer density assessed.
- Thus fulfillment of all safety function indicator criteria is not necessary to argue safety

Relation between function indicator criteria and design criteria

- Safety function indicator criteria are not the same as design criteria.
- Function indicator criteria should be fulfilled throughout the assessment period - design criteria relate to the initial state of the repository.
- Design criteria need to be defined with sufficient margin to allow deterioration of the system components over the assessment period, i.e. so that, ideally, all the function indicator criteria are fulfilled also at the end of the assessment period.
- Example: Copper canister thickness
  - Design: 5 cm thick
  - Function indicator criterion: > 0!

Safety functions, canister and buffer

Canister

C1. Provide corrosion barrier
Copper thickness > 0

C2. Withstand isostatic load
Strength > isostatic load

C3. Withstand shear load
Rupture limit > shear stress

Buffer

Bu1. Limit advective transport
a) Hydraulic conductivity < 10^{-12} m/s
b) Swelling pressure > 1 MPa

Bu2. Filter colloids
Density > 1,650 kg/m^3

Bu3. Eliminate microbes
Swelling pressure > 2 MPa

Bu4. Damp rock shear
Density < 2,050 kg/m^3

Bu5. Resist transformation
Temperature < 100 °C

Bu6. Prevent canister sinking
Swelling pressure > 0.2 MPa

Bu 7. Limit pressure on canister and rock
Temperature > −5 °C

Safety functions, deposition tunnel backfill and geosphere

Deposition tunnel backfill

BF1. Limit advective transport
a) Hydraulic conductivity < 10^{-10} m/s
b) Swelling pressure > 0.1 MPa
c) Temperature > 0 °C

Geosphere

R1. Provide chemically favourable conditions
a) Reducing conditions; Eh limited
b) Salinity; TDS limited
c) Ionic strength; $[M^{2+}]$ > 1 mM
d) Concentrations of K, HS^-, Fe; limited
e) pH; pH < 11
f) Avoid chloride corrosion; pH > 4 or $[Cl^-]$ < 3M

R2. Provide favourable hydrologic and transport conditions
a) Transport resistance; high
b) Fracture transmissivity; limited
c) Hydraulic gradients; limited
d) Kd, De; high
e) Colloid concentration; low

R3. Provide mechanically stable conditions
a) Shear movements at deposition holes < 0.1 m
b) GW pressure; limited

R4. Provide thermally favourable conditions
Temperature > Buffer freezing temperature

Use of safety functions in SR-Can

- The function indicators are used in the safety assessment SR-Can
  - for focussing, at an early stage, on critical issues to be studied in the safety assessment,
  - for structuring the evaluation of safety in a comprehensive main scenario, and,
  - for the derivation of additional scenarios in the assessment.

Use of safety functions in the main scenario

- A main scenario describing a reasonable evolution of the repository system, is the basis for the analysis of repository safety
- Repetition of latest glacial 120,000 year cycle, the Weichselian
- Function indicators provide a structure for evaluating safety in the main scenario.
- Repository evolution analysed in a number of timeframes
  - Excavation/operation phase
  - First temperate period after closure with particular emphasis on initial 1,000 years
  - First 120,000 year glacial cycle
  - Subsequent seven cycles up to one million years
- For each timeframe, safety is systematically evaluated through an account of the status of the function indicators during and at the end of that timeframe.

Use of safety functions when selecting and analysing additional scenarios (1/2)

- Consider every safety function: How can it be lost?
- Example: The canister should withstand isostatic load
- Define scenario “Canister failure due to isostatic load”
- Look for all possible ways this could occur
  - Evaluate uncertainties not considered in the reference evolution/main scenario
  - Higher than reference buffer density leading to high buffer swelling pressures on canister?
  - Severe design flaws in canister insert, weakening the structure?
  - More massive ice sheets in future glaciations than assumed in reference evolution?
  - I.e. evaluate uncertainties related to all FEPs of relevance for this safety function

Use of safety functions when selecting and analysing additional scenarios (2/2)

- Bottom line: Could it happen?
- If yes:
  - estimate probability or assume pessimistically p=1
  - calculate consequences and include in risk summation
- If no:
  - consider as residual scenario not to be included in risk summation
  - In some cases: calculate consequences for illustrational purposes
- Not all safety functions used to generate a scenario
  - Lumping necessary since functions are connected and not fully independent

Selected scenarios

- Main scenario
  - Base variant
  - Greenhouse variant
- Buffer advection
- Buffer freezing
- Buffer transformation

Results of buffer scenarios propagated to analyses of

- Canister failure due to corrosion
- Canister failure due to isostatic load
- Canister failure due to shear load

In addition:

- Scenarios related to future human actions

Summary and conclusions (1/2)

- Definitions
  - A safety function is a role through which a repository component contributes to safety.
  - A safety function indicator is a measurable or calculable property of a repository component through which a safety function can be quantitatively evaluated.
  - A safety function indicator criterion is a quantitative limit such that if the function indicator to which it relates fulfils the criterion, the corresponding safety function is upheld.
- Safety functions indicators aid in evaluation safety
  - but fulfilment of all safety function indicator criteria is not necessary to argue safety.
- Safety function criteria are related to, but not the same as, design criteria.
  - Design criteria relate to initial state and primarily to its engineered components,
  - Safety function indicator criteria should be fulfilled throughout the assessment period and relate, in addition to the engineered components, to the natural system.

Summary and conclusions (2/2)

- The function indicators have proven useful in SR-Can
  - by aiding in the focussing, at an early stage, on critical issues to be studied in the safety assessment
  - by providing a structure for evaluating safety in a comprehensive main scenario, and
  - by providing key information in the selection of additional scenarios in the assessment.
- Several aspects of the repository evolution and barrier performance can however not be readily captured by a simple comparison to a criterion.