Disposal canister requirements in context of the Swiss geological repository concept

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TFS 29: “Alternative canister materials”

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Nagra's canister development strategy

- The time to repository implementation is long (~2060): maximum advantage should be taken of developments elsewhere
  - Options should remain open until ~2035 (Application for repository construction license in ~2045).
- Main objectives for general license application (~2022):
  - Ensure that a **broad range of options** is adequately considered
  - Demonstrate **feasibility** of materials choices and concepts
  - Provide evidence that **operational** and **long-term safety** can be assured
- Close integration with safety assessment
- Ensure consideration of expert views
  - Canister Materials Review Board (NTB 09-02)
  - Networking and active collaboration with other WMOs
  - Discussion/consultation with (inter)national experts

Canister concepts

- Active contribution to the development of:

Forged carbon steel canister

Copper-coated carbon steel (or cast iron) canister

Ceramic canister

- Other canister concepts being evaluated:
  - Copper shell with cast iron insert (KBS-3)
  - Titanium or Nickel alloy shell with carbon steel support
  - Nickel-coated carbon steel or cast iron

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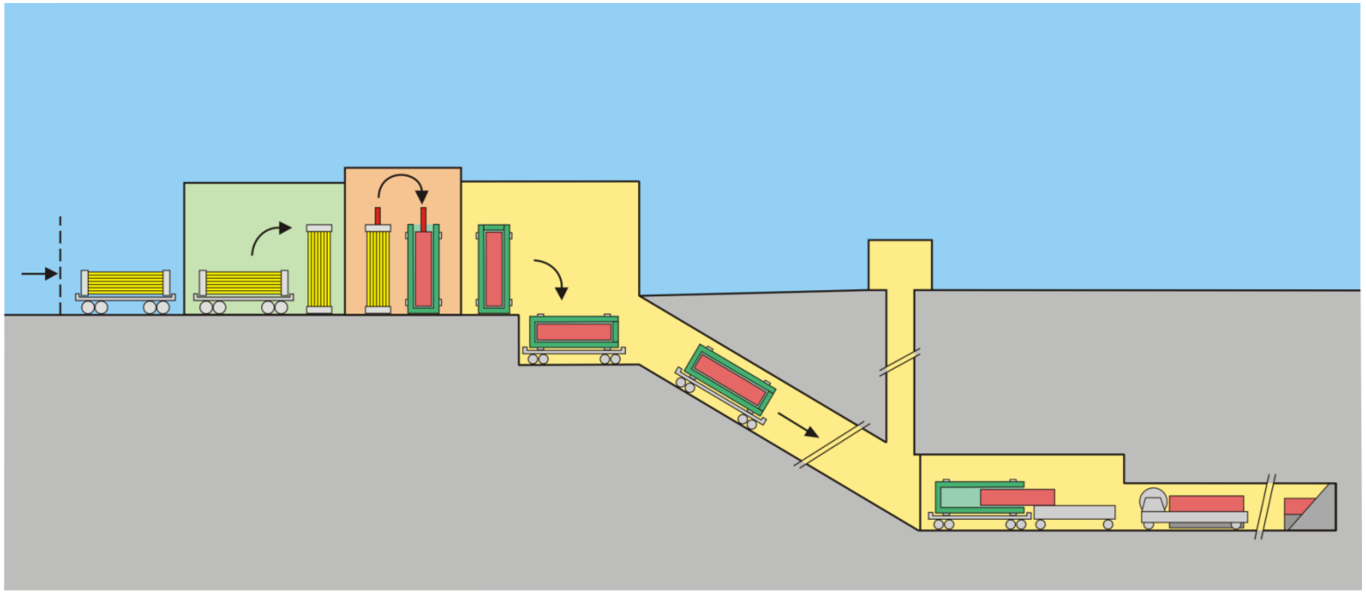
Main recent products of the canister program

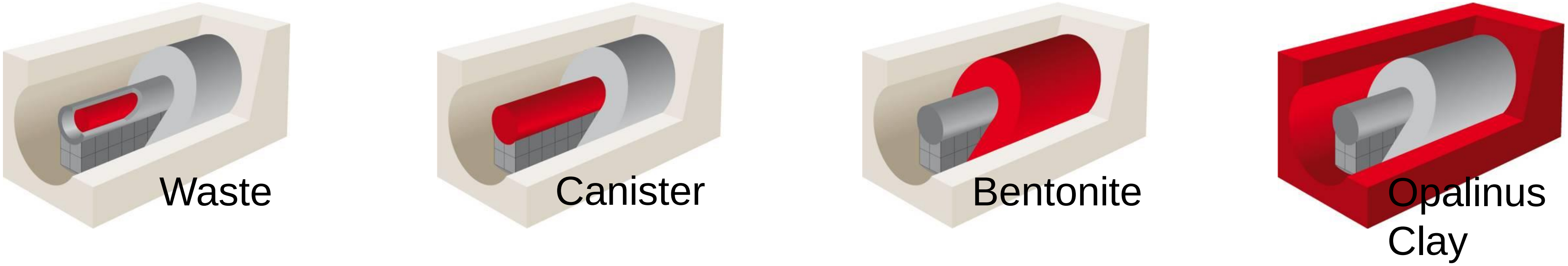
- Canister development strategy (NAB 13-38)
- Detailed design study of a carbon steel canister (NTB 12-06)
- Review of ceramic materials solutions (NAB 12-45)
- Feasibility evaluation study of disposal canisters options (NAB 14-90)
- Stress analyses of a copper coated canister (NAB 15-18)
- Lid and weld designs for a copper coated canister (*in preparation*)
- Copper coating development (*in preparation*)
- Review of Nickel coating feasibility (*in preparation*)
- *In-* and *ex-situ* corrosion studies of candidate canister materials in repository relevant conditions (*in preparation*)

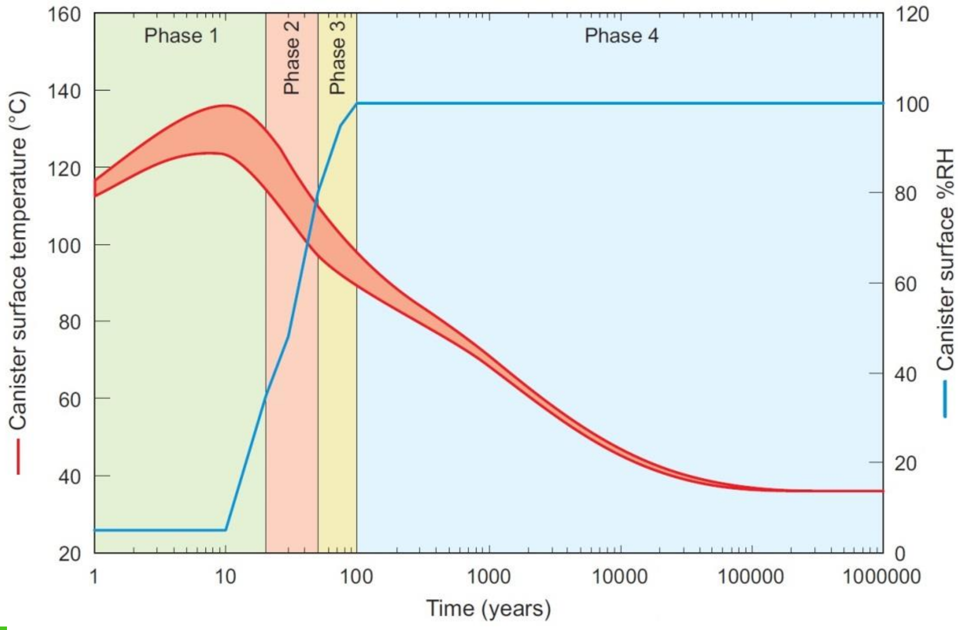
Operational safety: Canister handling scheme

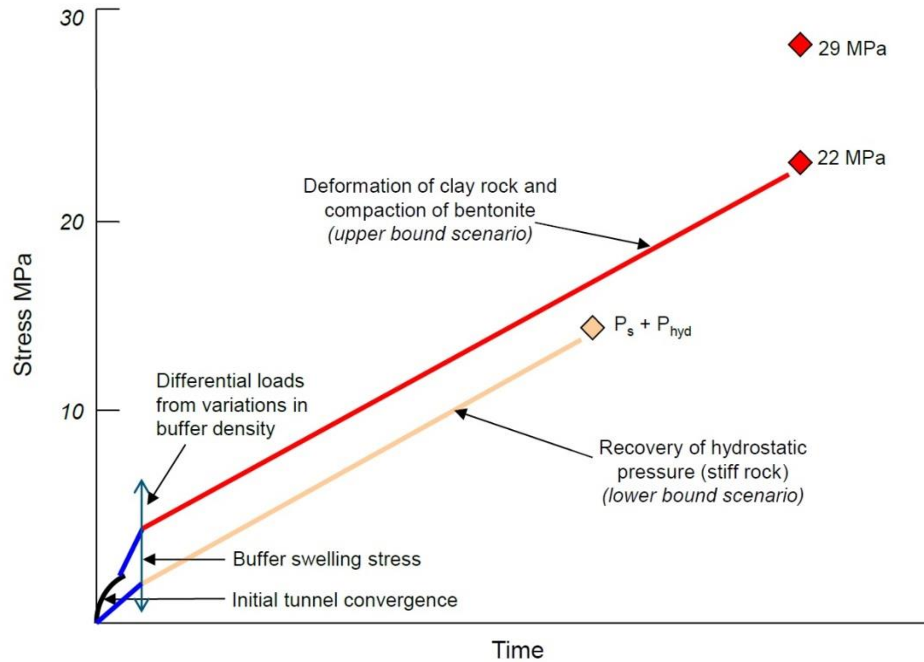
- Receipt of transport container, disposal canister and lid
- Inspection and docking
- Loading and sealing of disposal canister
- Non-destructive examination (coating of weld region)
- Transfer to underground transport wagon
- Transfer from wagon to emplacement wagon
- Emplacement of canister and backfilling



Long-term safety: Near field conditions







Broad requirement categories

- Waste producer and waste types requirements
- Regulatory requirements
- Nagra's long-term safety principles
- Containment requirements for the operation and the operational safety of the Encapsulation Facility
- Other requirements

Waste producer and waste type requirements

- Dimensions, number of canisters
  - The canister should be of adequate dimensions (and clearance) to accommodate SF and HLW according to the proposed SF and HLW waste loadings.
  - If multiple SF assemblies are put in one canister an internal structure (e.g. basket) is needed. Loading is limited by thermal constraints (currently: 9 BWR or 4 PWR or 2 HLW).
  - Manufacturing and sealing/welding feasibility at required size, wall thickness and throughput (~1 canister/day).
- Integrity of waste
  - Any operation should not damage the spent fuel or HLW (e.g. Post-Weld Heat Treatment: SF < 400°C; HLW < 450°C).
- Waste sub-criticality
  - The loaded SF canisters should be subcritical when the void spaces are water-filled.

Regulatory requirements

- Canister lifetime
  - The canister must provide complete containment of radionuclides for a period of 1’000 years after emplacement (ENSI G-03).

- Retrievability
  - The canister must satisfy the requirement for retrievability during the operational phase.
- Lifting/handling method
  - There should be a method to allow handling, including possible retrieval.
- Structural integrity - Retrieval
  - The stresses in the canister as a result of retrieval should be less than values that would indicate a possibility of breaching by an adequate margin.

Operational safety requirements

- Inner lid
  - An inner lid should be installed in the canister after loading of the SF. The lid should have an air-tight seal to prevent a leak of radioactive materials.
- Structural integrity
  - The canister must remain structurally sound during normal handling and incidents that might occur during handling.
- Re-packaging or repair
  - There should be a method for repackaging or repairing (e.g. the coating) in case of significant damage to a canister during a handling incident.

Long-term safety requirements (I)

- Long term integrity
  - Required canister integrity for 10’000 years. This represents a *design target* that exceeds the regulatory requirement by a large margin.

- No significant adverse effect on geological barrier
  - The corrosion rate of the selected material under anaerobic conditions should be less than 10 µm/a by an adequate margin (set by gas transport limit of rock).

Long-term safety requirements (II)

- Canister wall thickness
  - Should ensure that the radiation dose rate at the canister outer surface after loading and sealing is <1000 mSv/hr in order to preclude radiation-induced corrosion.
  - Should ensure that the stresses in the canister wall, lid, base, and weld region should be less than the failure limit (based on yielding and fracture criteria) for at least 10'000 years by an adequate margin for the reference structural loading in the repository.
  - A suitable basis for the safety margin for structural integrity should be defined.

Long-term safety requirements (III)

- Weld integrity and residual stress
  - The stresses in the weld region and Heat Affected Zone should be low enough to reduce the probability of stress-assisted failure processes (Stress Corrosion Cracking, Hydrogen Induced Cracking)
- Residual stress reduction
  - The weld stresses should be reduced to a depth exceeding the corrosion allowance by an adequate margin or the design of weld should avoid the need for stress reduction
- Critical flaw size
  - The fabrication and welding procedure should ensure any defects remaining in the canister are smaller than the critical flaw length by a suitable margin.
- Inspection and testing
  - The inspection process should be able to detect defects that are smaller than the critical flaw size by an adequate margin.

Other requirements (I)

- Surface finishing
  - The canister body and weld region should have a surface finish allowing inspection (e.g. machining residual weld material or scale resulting from heat treatment, or as preparation for coating).

- Marking & Identification
  - A method of physically marking canisters so that each one is uniquely identified should be proposed.

Other requirements (II)

- Material properties
  - The selected canister material should meet all higher level requirements.
- Costs
  - Issue of materials availability, raw material cost, canister development costs, prototype costs, unit production costs etc. should be documented.
- Manufacturing best practice
  - Best available present day technology should be adopted for the production, fabrication and welding concept.
- Codes and standards
  - Codes and standards relevant to design, construction, structural analysis etc. for the canister should be proposed.

Requirements in practice: assessment of canister options (I)

- Mechanical integrity
  - Handling & retrieval
  - Long-term disposal

- Environmental damage
  - General corrosion
  - Localized corrosion
  - Microbially induced corrosion
  - SCC and HIC
  - Influence of radiation on corrosion properties

- Impact on engineered and geological barriers
  - H_2
  - Corrosion products

Requirements in practice: assessment of canister options (II)

- Robustness of lifetime prediction
  - Mechanical integrity
  - Assessment boundary conditions
  - Material property input data
  - Environmental damage (Models, analogues, long-term tests, mechanistic understanding)

- Fabrication
  - Canister manufacturing
  - Sealing
  - Inspection

- Costs
  - Development
  - Unit costs

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Requirements in practice: assessment of Cu-coated steel canister (I) (see NAB 14-90)

Table 6c Feasibilty Evaluation Summary for Copper Coated Carbon Steel SF Canister Concept for a Repository in Opalinus Clay (4.6m long, 770mm ID, 100mm/5mm-Cu thick)

Assessment Category	Sub-Category	Condition(s)	Desirable Features	Indicator(s)	Criteria	Quantities	Sect. in report	Feasibility
Mechanical Integrity	Handling	*tbd*	Damage tolerance (deformation/fracture)	CO/CO^{FAE}(2mm)	≤ 1.00			
	Disposal (short time)	P ≤ 6/1MPa (TWI-5 load case)	Acceptable structural integrity during aerobic phases	$\sigma_{VM,max}/R_{p0.2,min}$ *100mm* $\sigma_{VM,max}/R_{p0.2,min}$ *80mm*	≤ 1.50	0.40 0.54	App. I	High High
				$CO/CO^{FAE}(2)_{max}$ *100mm* $CO/CO^{FAE}(2)_{max}$ *80mm*	≤ 1.00	0.14 0.14	App. J	High High
	Disposal (long time)	P ≤ 29/22MPa (TWI-2 load case)	Acceptable structural integrity during anaerobic phase	$\sigma_{VM,max}/R_{p0.2,min}$ *100mm* $\sigma_{VM,max}/R_{p0.2,min}$ *80mm*	≤ 1.50	1.20 1.69	App. I	High Medium/low
				$CO/CO^{FAE}(2)_{max}$ *100mm* $CO/CO^{FAE}(2)_{max}$ *80mm*	≤ 1.00	0.28 0.44	App. J	High High
	Creep	*n/a*		$\varepsilon_C/\varepsilon_R$	< 1.00		App. D	High
Environmental Damage	General corrosion	Active material	Low and/or predictable rate of general corrosion	Anaerobic *dx/dt*	≤ 0.02μm/a	≤ 0.002μm	App. D	High/medium
		Passive material		Anaerobic *dx/dt*	≤ 0.02μm/a	*n/a*		
	Local/crevice/IG corrosion		Low susceptibility to: - pitting - crevice corrosion - IGA	 Y/N Y/N Y/N	 Y Y Y	 Y Y Y	 App. D App. D App. D	 Medium High High
	MIC		Low susceptibility to MIC	Y/N	Y	Y	App. D	High
	SCC/HIC		Low susceptibility to: - SCC - HIC	 $\sigma_{1,max}/R_{SCC}$ $K_{1a,max}/K_{1HIC}$	 ≤ 0.80 ≤ 0.80	 <<0.6 ≤~0.01	 App. D App. D	 High High
Impact on geological barrier	Gas production		Low rate of H_2 production	Equivalent anaerobic CS corrosion rate	≤ 10μm/a	~0	App. D	High
	Effect on buffer,		Effect on Bentonite buffer	Y/N	N	N	App. D	High
	host rock		Effect on host rock	Y/N	N	N	App. D	High

Mechanical integrity data for 80mm thick carbon steel sub-structure also included for information

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Requirements in practice: assessment of Cu-coated steel canister (II) (see NAB 14-90)

Assessment Category	Sub-Category	Condition(s)	Desirable Features	Indicator(s)	Criteria	Quantities	Sect. in report	Feasibility
Fabrication	Manufacture of canister body	SF	Involves current proven technology	Y/N	Y	Y	App. D	High/medium
	Sealing		Involves current proven technology	Y/N	Y	Y	App. D	High/medium
			Procedure can be performed remotely	Y/N	Y	Y	App. D	High
			- in radiation field	Y/N	Y	Y	App. D	High
			Sealing and PSHT temperatures do not exceed SF limit	T/400°C	≤ 1	Y	App. D	High
	Inspectability		Procedures can be performed remotely	Y/N	Y	Y	App. D	High
			- in radiation field	Y/N	Y	Y	App. D	High
			Material amenable to inspection	Y/N	Y	Y	App. D	High
Costs	Development costs		Involves currently available technology	Y/N	Y	Y	App. D	High/medium
	Unit costs		Inexpensive raw materials	$(CHF/cc)^{mat}/(CHF/cc)^{cs}$	≤ 2	13	App. D	Medium
			Estimated unit cost	$kCHF/(kCHF)^{cs}$	≤ 1.3	~1.3	App. D	High/medium
			Multiple potential suppliers	N_{sup}	$\geq 2N_{sup}$	Y	App. D	Medium

Requirements in practice: assessment of weld techniques for a Cu-coated canister (work in progress)

- Technology readiness level
- Automatic and remote process operation
- Welding and monitoring equipment for hot operation
- Filler, gas and service requirements
- Welding position and rotation
- Joint cleanliness, interpass cleaning, joint fit-up, preheat
- Welding time
- Qualification standards
- Likelihood of weld defects (general or at start/stop)
- Joint zone strength, toughness and hardness
- Stress state after welding
- …

Summary

- Generic canister requirements have been defined according to the following categories:
  - Waste producer and waste types requirements
  - Regulatory requirements
  - Nagra's long-term safety principles
  - Containment requirements for the operation and the operational safety of the Encapsulation Facility
  - Other/general requirements

- The feasibility of candidate canister solutions can be evaluated by defining assessment criteria reflecting the canister requirements.

thank you
for your attention

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