BAM
Bundesanstalt für Materialforschung und -prüfung

Sicherheit in Technik und Chemie

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ENHANCING REQUIREMENTS FOR HLW DISPOSAL CONTAINERS AND DEVELOPING TRANSPARENT SAFETY EVALUATION CONCEPTS IN COLLABORATION BETWEEN BAM AND BASE (RESEARCH PROJECT KANNE)

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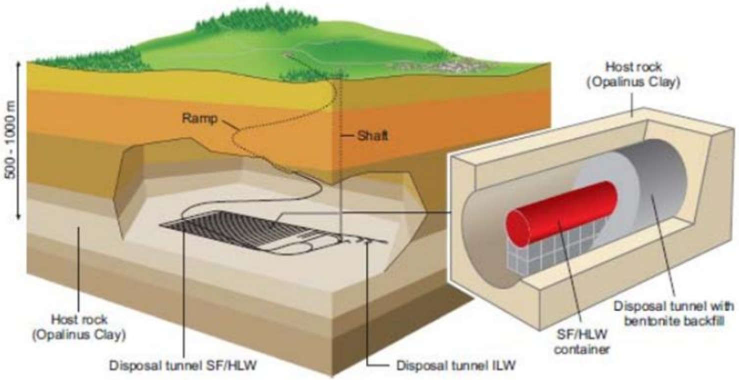
Disposal Container

Final disposal containers safely contain radioactive waste in deep geological repositories, allowing handling, emplacement, and possible retrieval or recovery.

Key Functions of Disposal Containers

- Safe enclosure of the radioactive waste
- Radiation shielding
- Ensuring subcriticality of fissile material
- Transfer of decay heat
- Manageability

NTB-20-01, Development of Copper Coated Canisters for the Disposal of SF and HLW in Switzerland. 2022, Nagra.



NAB 14-90, Feasibility evaluation study of candidate canister solutions for the disposal of spent nuclear fuel and high level waste - A status review, 2014, Nagra

Crucial Boundary Conditions for Disposal Containers

- Radiation & heat load of the radioactive inventory
- Mechanical stresses from handling and geology
- Environmental conditions (temperature, geo-chemistry, microbes, water)
- Transport properties of the container near-field (nuclide migration, water, corrosion agents, temperature)
- Gradients & transients affecting container and near-field
- Quality assurance in container manufacturing and operation

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The KAnnE Project

A collaborative research project between BAM and BASE from 2023 to 2026

Objectives of the KAnnE Project

- Monitor international disposal container designs and materials
- Identify and collect international requirements based on repository concepts
- Derive and quantify disposal container requirements for different host rocks for Germany
- Compile and structure a comprehensive list of container requirements

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International Container Concepts

Disposal container concepts depend on host rocks: crystalline rock, claystone and rock salt

International Container Concepts

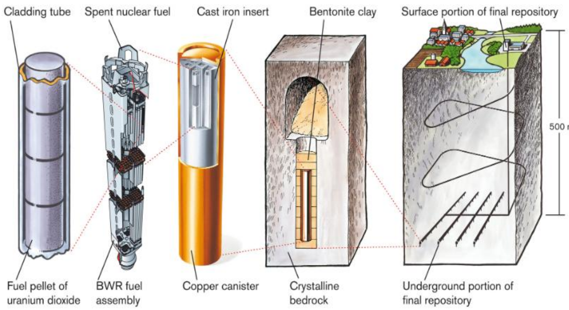
Several countries have developed repository and container concepts for their respective available geology and/or selected site

Crystalline rock	Claystone	Rock Salt
• **Finland** • **Sweden** • **Canada** • Czech Republic • Japan • South Korea	• **France** • **Switzerland** • Belgium • Netherlands	• Netherlands

International Container Concepts

Host Rock: Crystalline

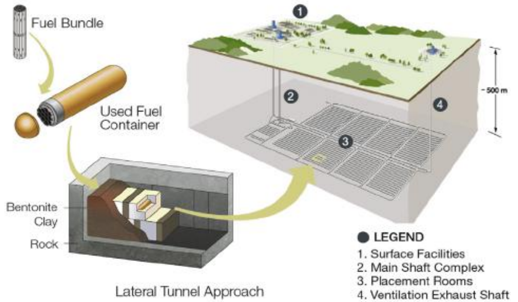
Sweden/Finland



Ronneteg, U., et al., *Reliability in NDT of canister for the Swedish spent nuclear fuel.* Proc. 4th European-American Workshop on Reliability of NDE, 2009

- Materials: Cast iron insert + copper shell ~50 mm
- Container lifetime: >100,000 years
- Buffer: Bentonite clay
- Retrievability: 40 years
- Emplacement: Vertical

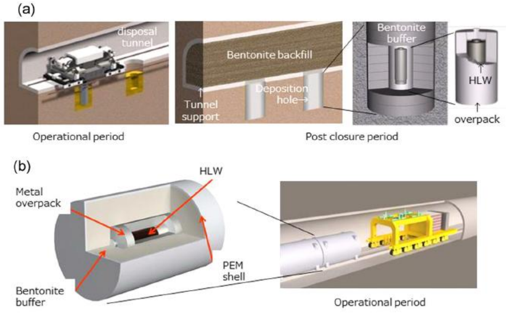
Canada



NWMO-TR-2023-01 - Technical Program for Long-Term Management of Canada's Used Nuclear Fuel – Annual Report 2022.

- Materials: Carbon steel + 3 mm copper coating (cold-spray technology)
- Container lifetime: >1,000,000 years
- Buffer: Bentonite clay box Retrievability: Required
- Emplacement: Horizontal

Japan



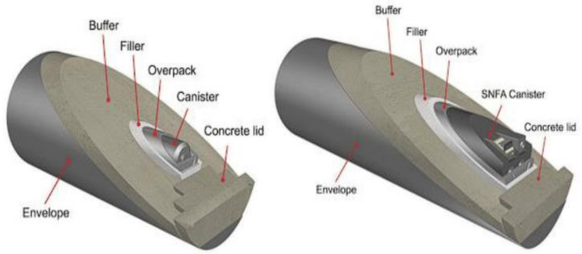
Suzuki, S., et al., The design of copper-coating overpack for the high-level radioactive waste disposal concept in Japan. Materials and Corrosion, 2021

- Materials: Carbon steel
- Container lifetime: >1000 years
- Buffer: Bentonite/sand mixture Retrievability: Required
- Emplacement: Horizontal or vertical

International Container Concepts

Host Rock: Claystone

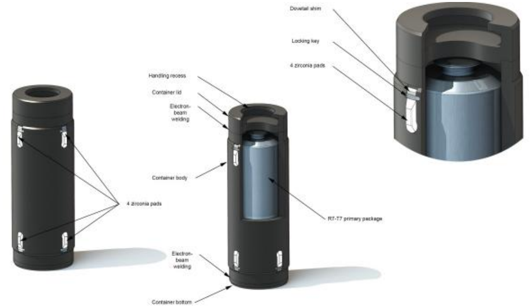
Belgium



Kursten, B., et al., Overview of anaerobic corrosion of carbon steel radioactive waste packages in alkaline media in support of the Belgian supercontainer concept. Materials and Corrosion, 2021

- Supercontainer:
  - Overpack (carbon steel)
  - Concrete buffer
  - Envelope (stainless steel)
- Container lifetime: >5000 years
- Retrievability: Required
- Emplacement: Horizontal

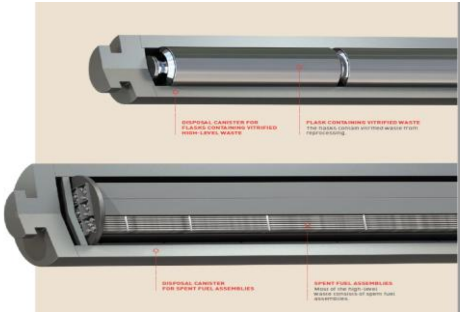
France



Dossier d'autorisation de création de l'installation nucléaire de base (INB) Cigéo - Pièce 7, PARTIE II, Volume 3 - Les colis de déchets. 2022, ANDRA.

- Material: Carbon steel
- Container lifetime: >500 years
- No buffer material around the container
- Retrievability: Required
- Emplacement: Horizontally in steel tunnels

Switzerland



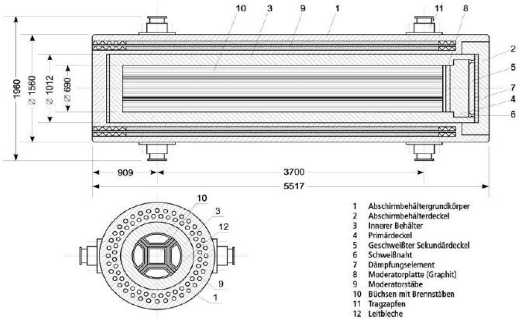
Brochure: The site for the deep geological repository, Nagra, 2022

- Material: Carbon steel, copper coating under consideration
- Container lifetime: >10,000 years
- Buffer: Bentonite clay
- Retrievability: Required
- Emplacement: Horizontal

International Container Concepts

Host Rock: Rock Salt

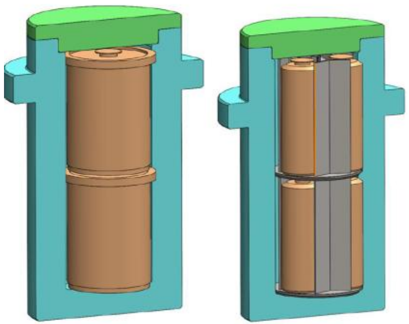
Germany



Planungsvorgaben zum POLLUX-Behälter. 1986, Deutsche Gesellschaft für Wiederaufarbeitung von Kernbrennstoffen mbH.

- POLLUX® (multi-purpose container)
  - Outer shell: ductile cast iron
  - Inner shell: steel 15 MnNi 63
  - Neutron moderation (polyethylene rods)
- Container lifetime: >500 years
- Buffer: crushed salt
- Retrievability: required
- Emplacement: horizontal

Netherlands



Ansgar Wunderlich, et al., Waste Package for Disposal of High-Level Waste (HLW) in Rock Salt. 2023, BGE-TEC

- Material: carbon steel
- Container lifetime: >1000 years
- Buffer: crushed salt
- Retrievability: under consideration
- Emplacement: vertical in shallow boreholes

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Requirements for Final Disposal Containers – at a glance

Safety requirements drive the design and implementation of final disposal containers

International **Regulatory** Requirements for Final Disposal

Country	Assessment period	Annual dose limit (for population)	Retrievability	
Sweden	100,000 years	Increase of cancer risk below 10^{-6} /a; about 0.014 mSv	Required	Crystalline Rock
Finland	10,000 years	0.01 mSv during operational phase and 0.1 mSv after disposal	Required	
Canada	Not specified	1 mSv, but the design target should be 0.3 mSv	Required	
Czech Republic	Not specified	0.25 mSv	No requirement yet	
Switzerland	1,000,000 years	0.1 mSv during assessment period	Required	Claystone
Belgium	Not specified	1 mSv (not specific for final repository)	Required	
France	10,000 years	0.25 mSv for probable scenarios For less probable evolutions: below levels likely to induce deterministic effects; as low as reasonably achievable	Required	

International Requirements for Final Disposal Containers - Derived by Implementors

Country	Max. isostatic Stress (MPa)	Max. container surface radiation dose	Max. Container Surface Temp. (°C)	Min. Container Lifetime (yrs)	
Sweden/ Finland	50	1 Gy/h	100	100,000	Crystalline Rock
Canada	45	15 Gy/h	100	1,000,000	Crystalline Rock
Czech Republic	20	Not fixed yet	95	1,000,000	Crystalline Rock
Japan	15	3 Gy/h	100	1,000	Crystalline Rock
Switzerland	σV = 22 σHMAX = 29	1 Gy/h	150	10,000	Claystone
Belgium	σV = 4–12 σHMAX = 3.5–10.4	25 µSv/h at 1 m distance	100	5,000	Claystone
France	8	10 Gy/h	90	~500	Claystone
Netherlands	20	10 Gy/h	100	1,000	Rock salt

Basic Container Requirements

- Container lifetime depends on host rock and repository safety concept
- Container integrity and gas tightness must be ensured during its lifetime
- Inventory must remain subcritical
- Containers must be compatible with their surroundings
- Containers must be manageable
- Containers must provide adequate radiation shielding
- Containers must maintain safety under credible accident scenarios (drop, fire)
- Containers must allow retrieval or recovery after their emplacement

Key Container Design Considerations

- Iron-based materials provide strength; copper offers corrosion resistance.
- For managing corrosion two approaches exist: largely preventing it (e.g., with a copper layer) or allowing it within tolerable limits (e. g. uniform corrosion of steel).
- Wall thickness is set by shielding needs, mechanical loads, and corrosion margin.
- Containers must exhibit sufficient thermal transfer properties to dissipate decay heat.
- Implementors may exceed regulatory requirements to improve robustness (e.g. extended lifetime).
- Both self-shielding containers and concepts requiring a shielding overpack and/or remote operations during handling and emplacement are developed.
- Shielding is also relevant for mitigating hydrolysis-induced corrosion.

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Requirements for German HLW Disposal Containers

Requirements are derived from German laws, regulations, and ordinances, considering also international standards

Relevant German Regulations

Laws

- Atomic Act (AtG)
- Radiation Protection Act (StrlSchG)
- Site Selection Act (StandAG)
- Federal Mining Act (BBergG)

Ordinances

- Radiation Protection Ordinance (StrlSchV)
- Disposal Safety Requirements Ordinance (EndlSiAnfV)
- Disposal Exploration Ordinance (EndlSiUntV)
- Climate Mine Regulation Ordinance(KlimaBergV)
- Nuclear Waste Disposal Ordinance (AtEV)

Other

- Calculation basis for dose estimation for the final disposal of high-level radioactive waste (binding)
- ESK recommendation:
  - (2017) Requirements for disposal packages for the final disposal of heat-generating radioactive waste
  - (2019) Safety conceptual requirements of the barrier system of a final repository high-level radioactive waste and their feasibility

Preliminary Quantified Container Loads and Requirements for the Respective Host Rocks

Host rock	Max. Isostatic Stress (MPa) in 1000 m depth	Max. Container Surface Radiation Dose	Max. Container Surface Temp. (°C)	Container Lifetime (years)
Crystalline rock (without ewG)	σ_V= 26 MPa σ_{HMAX}= 30 MPa 10 MPa swelling pressure 10 MPa glacial load	1-15 Gy/h	100	1,000,000
Claystone	σ_V = 25 MPa σ_{HMAX} = 32 MPa 10 MPa swelling pressure	1-10 Gy/h	100	1,000 – 10,000
Rock salt	σ_V = 24 MPa σ_{HMAX} = 29 MPa	10^4 Gy/h[1]	150	1,000
	Derived in the KAnnE project	Derived from international analysis; value for salt from literature	Taken from GRS/BGE reports[2]	From ESK recommendation[3]

[1] *ISIBEL - Überprüfung und Bewertung des Instrumentariums für eine sicherheitliche Bewertung von Endlagern für HAW, AP 1.2 – Konzeptionelle Endlagerplanung und Zusammenstellung des endzulagernden Inventars, TEC-20-2008-AP*. 2008, DBE TECHNOLOGY GmbH.
[2] *BGE-2024-GB-1, Auslegungstemperaturen in Schritt 2 Phase I des Standortauswahlverfahrens - Einordnung zum Umgang mit der Grenztemperatur. 2024, Bundesgesellschaft für Endlagerung, Peine.*
[3] *Anforderungen an Endlagergebinde zur Endlagerung Wärme entwickelnder radioaktiver Abfälle - Empfehlung der Entsorgungskommission (Requirements for HLW final disposal containers - Recommendations of the disposal commission), 2017, ESK Entsorgungskommission.*

Basic Container Lifetime Phases in Relation to Repository Phases

Container lifetime phases are merged to **three main phases**

1. Design & Manufacturing → design, materials, fabrication, quality assurance
2. Handling & Manageability → loading, transport, emplacement, retrieval/recovery
3. Post-Emplacement → after backfilling, container under disposal conditions

Container lifetime phases	Design	Manu-facturing	Loading	Emplacement	Potential Retrieval	Potential Recovery	Long-term phase
Design & Manufacturing							
Handling & Manageability							
Post-Emplace-ment							

Repository phases → Design & Construction | Operational phase | Post-closure phase

Conclusions

- The German container recoverability requirement of 500 years after final repository closure and the siting process for selecting the “safest” disposal site are globally unique.
- A minimum container lifetime can be either set by regulation (e.g. Switzerland) or by the implementer to meet the specific safety goals depending on the repository safety concept, and also to increase robustness.
- Mechanical loads depend on container handling procedures, accidental scenarios to be considered, repository depth, rock stresses, bentonite swelling pressure, and possible glacial loads.
- Adequate material selection, fabrication technologies, and quality assurance measures are crucial to provide long-term integrity of the disposal containers under corrosive disposal conditions.

➡ **Project outcomes will support the establishment of regulatory disposal container requirements and assessment criteria for a German repository.**