Aspects on Long Term Storage of Used Nuclear Fuel and High Active Waste in Germany

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Todays Nuclear Facilities in Germany

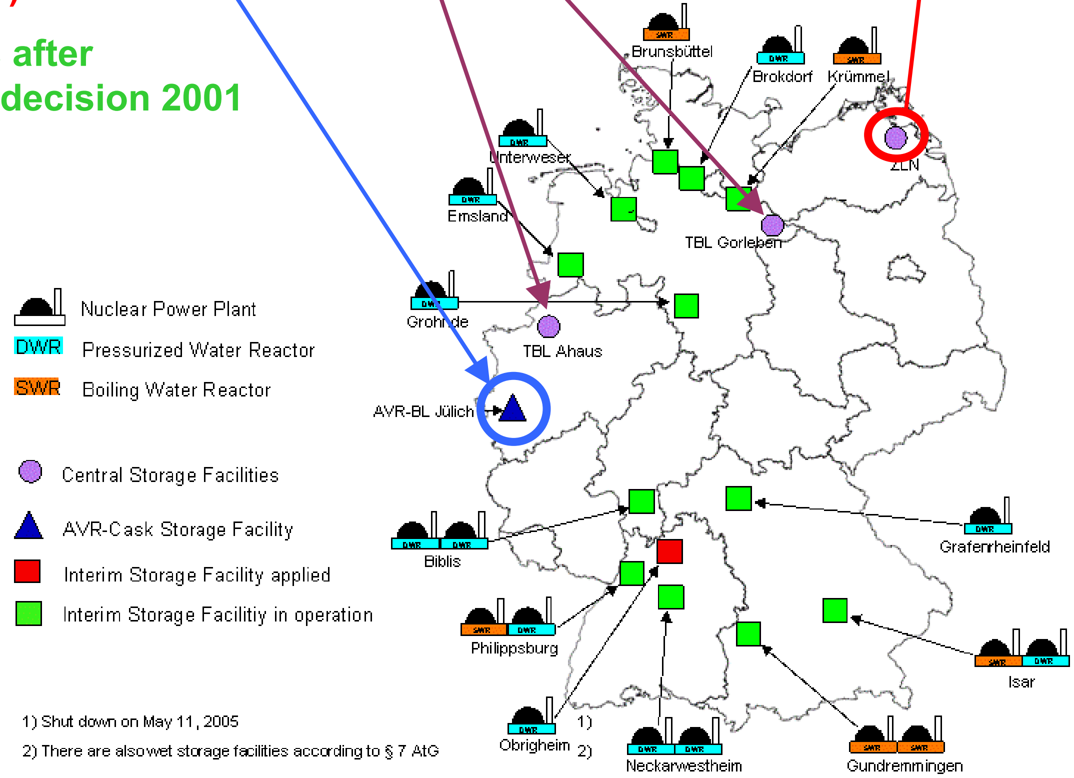
First central storage facilities: Ahaus and Gorleben (1983)

First on-site storage facilities:

Jülich research center (1993)

Interim Storage North (1999)

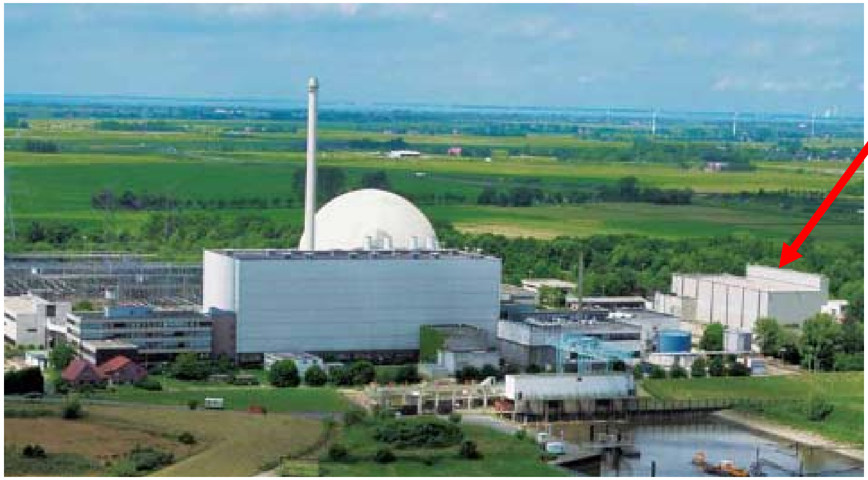
At-reactor storage facilities after German nuclear phase out decision 2001



1) Shut down on May 11, 2005

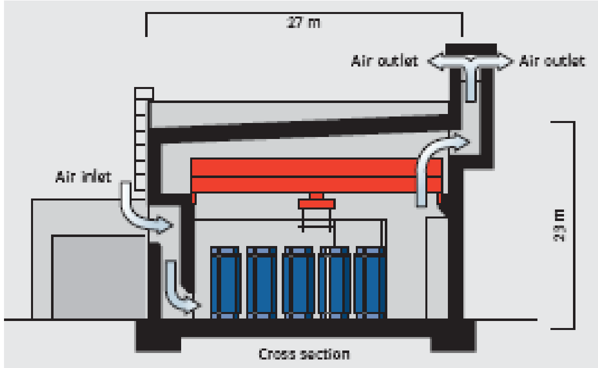
2) There are also wet storage facilities according to § 7 AtG

Interim Storage Facilities



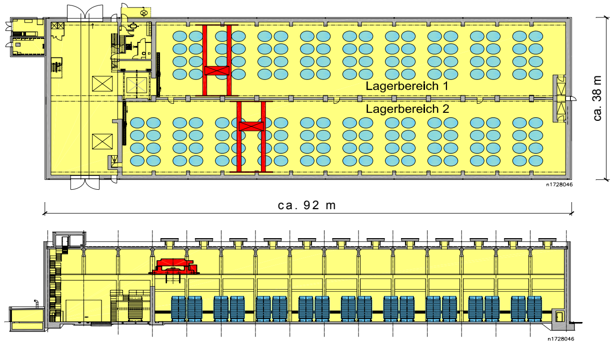
NPP Unterweser with cask storage facility (E.ON)

STEAG-design with massive concrete structures

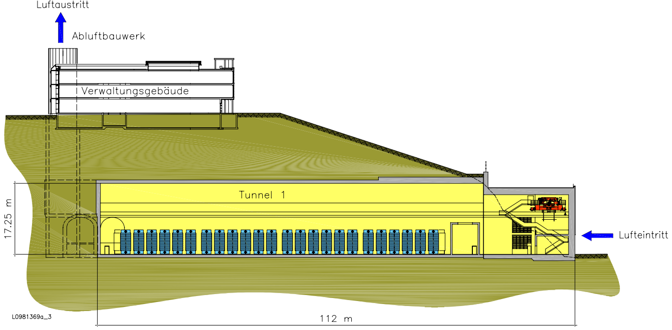


WTI-design

NPP Emsland cask storage facility (RWE)



Tunnel cask storage facility at NPP Neckarwestheim



Dry Spent Fuel and HAW Storage Casks

The Storage Concept (based on German Reactor Safety Commission (RSK) guidelines from April 2001)

- Accident safe dual purpose metal casks with
  - Type B qualification and certification
  - Two independent sealed barriere lids
  - Permanent monitoring of cask tightness
- Storage period 40 years
- Casks in a storage building for weather protection and additional shielding

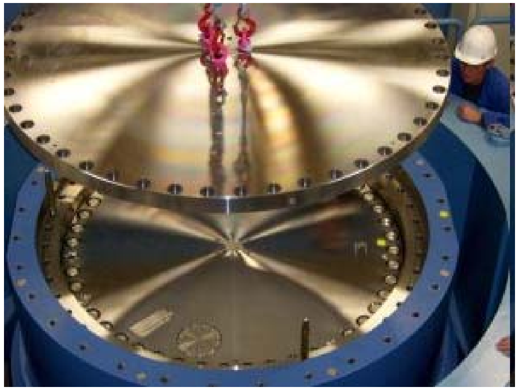
Main Cask Design Criteria

- Nuclear safety (subcriticality)
- Radiation protection (shielding)
- Decay heat removal
- Site specific accident safe cask design (integrity, leak-tightness)
- 40 years cask durability

Main Storage Cask Design Features

- Dual purpose for transport and storage operation
- Monolithic cask body made of ductile cast iron (alternate cask designs made of forged steel cylinder with welded bottom plate)
- Dimensions
  - Length : 4.0 to 6.0 m
  - Diameter : 1.5 to 2.5 m
  - Wall thickness: 0.25 to 0.45 m
- Cylindrical holes filled with polyethylene neutron moderator in cask side wall
- Double lid system with metal seals and permanently monitored pressure between bolted lids
- Vacuum dried and helium filled (≈800 hPa) cask interior

Example: CASTOR® V cask design by GNS



Cask Storage History

First stored casks:

- CASTOR® Ic-Diorit (ZWILAG, CH) since 1983
- CASTOR® V/21 (Surry, USA) since 1985 →
- CASTOR® THTR/AVR (TBL Ahaus) since 1992
- CASTOR® THTR/AVR (Jülich) since 1993
- CASTOR® V/19, CASTOR® Ic, CASTOR® HAW 20/28CG (TBL Gorleben, D) since 1997

→ **Cask storage periods up to 27 years (18 years in Germany)**

Current storage licenses ending:

TBL Gorleben → 31.12.2034

TBL Ahaus → 31.12.2036 (first CASTOR® THTR/AVR casks → 2032)

On-site facilities → 2042/43

Availability of a repository is open so far

→ Gorleben salt dome vs. new site selection procedure

→ Investigation and construction work needs at least 15 years from now

→ Availability beyond 2025

→ Interim storage periods may need to be extended in the future

Driving ageing forces on storage casks

Gamma radiation

Neutron radiation

Decay heat

Environmental effects from outside: moisture, air pollution

Mechanical stresses: fuel rods, bolted lids and trunnions, metal seals

Materials

Metals (ductile cast iron, different steel types, basket materials)

Polymers (neutron shielding, auxiliary seals, cavity sealing)

Ageing effects

Degradation by radiation

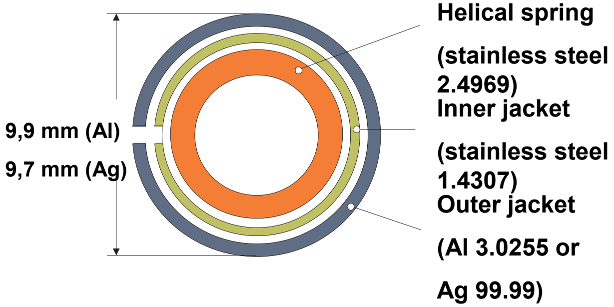
Mechanical degradation (relaxation, creeping)

Corrosion

Investigation of Metal Seal Resistance

Typical cask seal of the Helicoflex® type

Required standard helium leakage rate
$Q_{He} < 10^{-8}$ Pa·m³/s



Test series to demonstrate long-term resistance

(1) CEA Atomic Energy Commision (France):

- 1973 – 1984 six test seals (1,9 m and 3.6 m outer Ø) with > 650 thermal cycles between ambient temperature (+20°C) and +130/150°C to increase ageing mechanisms
- since 1984 (25 years) continuation of test series at ambient temperature (+20°C) with helium leakage rate measurements twice a year

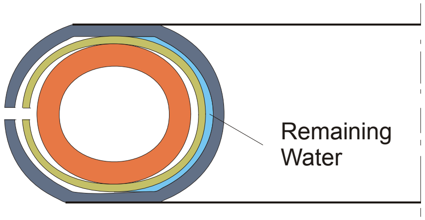
(2) CRIEPI Central Research Institute of Electric Power Industry (Japan):

- since 1990 two full-scale test seals (outer jacket of Al and Ag) at 160°C

→ Results so far: no significant changes in leakage rates

BAM corrosion tests with water in the gap between inner and outer seal jacket since 2001

→ boronated pool water (2400 ppm)
→ 10^{-3} mol sodium chloride dissolution

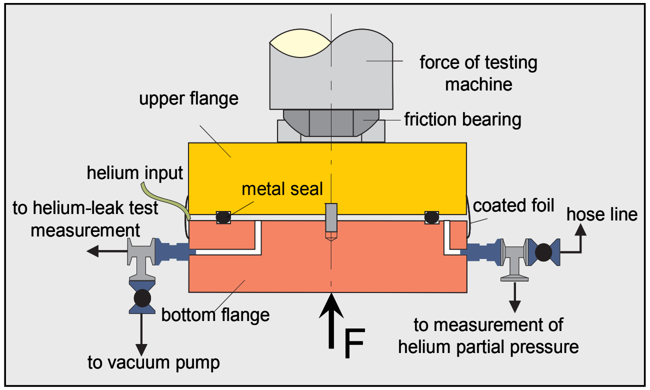


Result: no leakage rate increase so far!

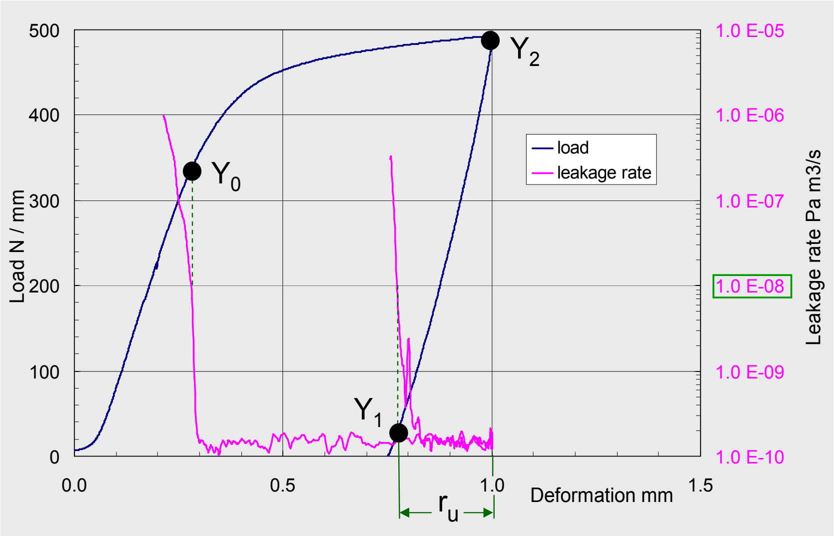
Leakage rate measurements with seals prepared with defects in the outer jacket

Result: no leakage rate increase!

BAM test setup for metal seal investigations with continous leakage rate measurements



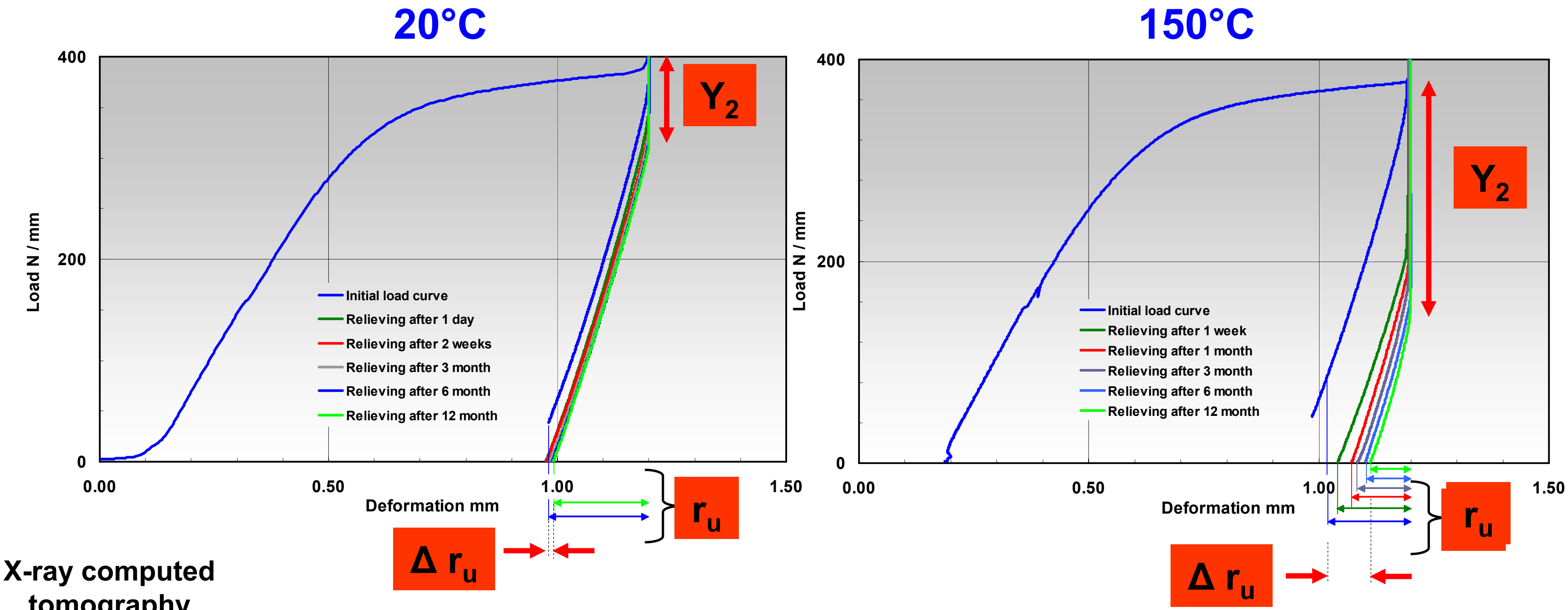
Characteristic load – deflection curve of a Helicoflex® metal seal (Ag) and correlation with the helium leakage rate



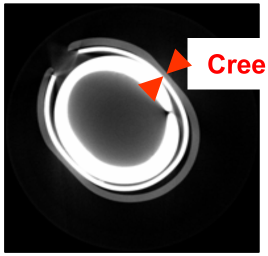
$Q_{He/St}$ = $\leq 10^{-8}$ $Pa \cdot m^3 \cdot s^{-1}$

- Y_0 = Achievement of $Q_{He/St}$ during pressing process
- Y_1 = Exceeding $Q_{He/St}$ during load relieving
- Y_2 = Optimal operation point according to manufacturers specification
- r_u = usable resilience

Reduction of seal pressure force and useable resilience as a function of time and temperature Helicoflex® metal seal with outer aluminum jacket



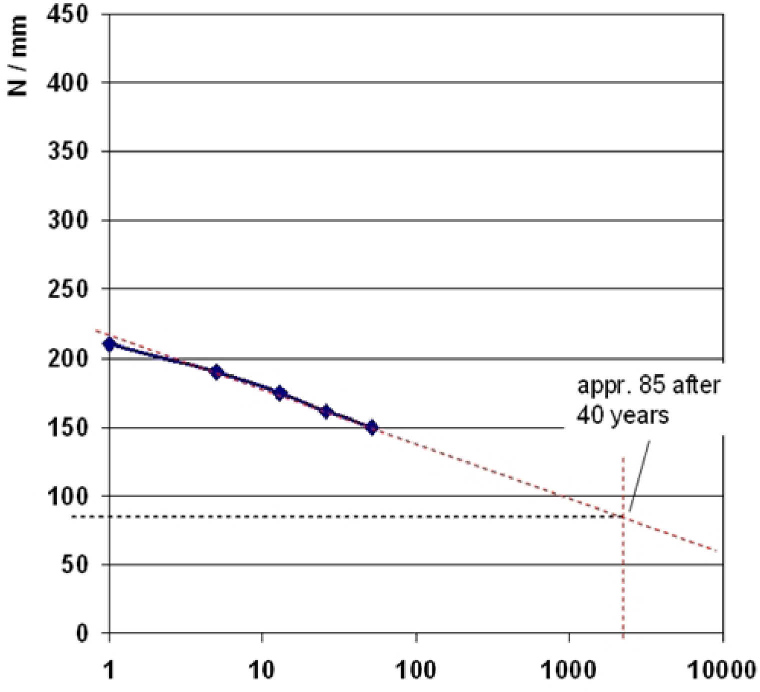
X-ray computed tomography



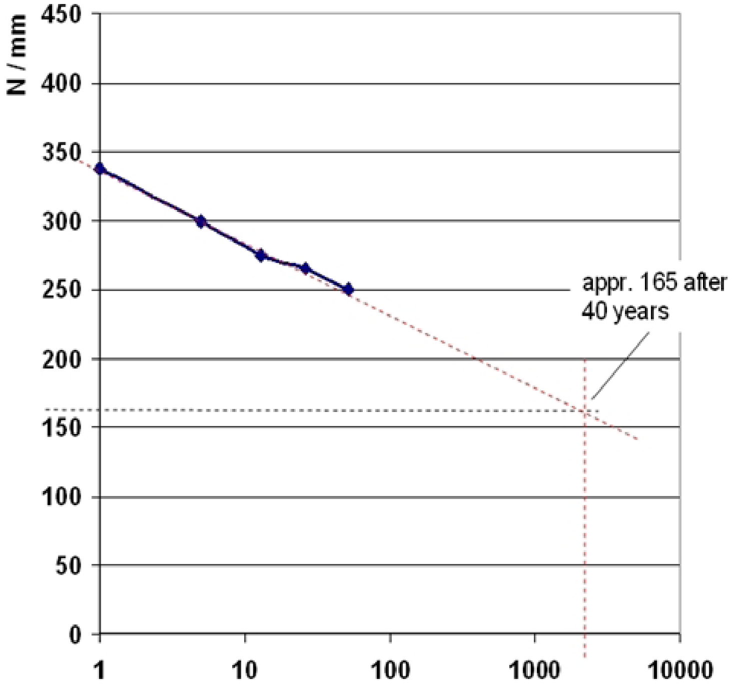
Creeping of outer seal jacket

	Reduction of Y_2 after 1 year [% of initial value]	
Seal jacket material	**150°C**	**20°C**
Al	**61 %**	**22 %**
Ag	**49 %**	**19 %**

Extrapolation of seal force decrease over 40 years under constant conditions



Seal with aluminium jacket at 150°



Seal with silver jacket at 150 °C

Ageing Effects of Storage Cask Polymer Components

Neutron shielding components

Ultra-high molecular weight polyethylene (UHMW-PE)

- Temperatures up to 160 °C (→ decrease during storage)
  - Thermal expansion
  - Structural changes from semi-crystalline to amorphous
- Radiation (→ decrease during storage)
  - → hydrogen separation by gamma radiation causes structural damages and/or crosslinking
- Mechanical assembling stresses
  - → Stress relaxation
- Focus on neutron moderator material

Elastomeric auxiliary seals

- Materials:
  - Viton
  - EPDM (ethylene propylene diene monomer (M-class) rubber)
  - Silicone
- Low temperature and long-term behavior

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Matthias. Jaunich, et al.

Understanding the Low Temperature Properties of Rubber Seals

Oral Presentation 169 in Session T41
Friday, Oct. 08, 9:20 a.m.

Investigated Materials

- High molecular weight polyethylene (HMW-PE) Lupolen 5261Z
- Ultra-high molecular weight polyethylene (UHMW-PE) GUR 4120 →

- Gamma irradiation dose: 600 kGy at 20°C under inert conditions

Used methods for determining the structural differences

- **Thermoanalytical methods**
  - → Differential Scanning Calorimetry (DSC)
  - → Thermomechanical Analysis (TMA)
  - → Thermogravimetric Analysis (TGA)
- **Optical methods**
  - → Fourier-Transformation-Infrared-Spectroscopy (FT-IR)
- **Weighing methods**
  - → density gradient column
  - → degree of crosslinking

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Kerstin von der Ehe, et al.

Radiation Induced Structural Changes of (U)HMW Polyethylene with regard to its Application for Radiation Shielding

Oral Presentation 173 in Session T25
Wedenesday, Oct. 06, 11:20 a.m.

4. Summary and Outlook

- Dry cask storage of SF and HAW in Germany is well established for up to 40 years.
- Long-term performance of all safety relevant cask components was evaluated prior to licenses and no failure occurred during operation so far.
- Further long-term investigations of metal seals and polymer components are carried out (by BAM) to gain increased knowledge for better predictions, perhaps for necessary extended storage periods.
- Currently, the German Nuclear Waste Management Commission (ESK) - Committee on Waste Conditioning, Transport and Interim Storage (AZ) – develops new guidelines for periodic safety inspections of interim storage facilities including ageing mangement.
- Transport after storage is an important issue because …
  - Transportation after storage is essential due to the limited lifetime of any interim storage facility;
  - Transport regulations do not consider long-term dry storage as specific operation conditions for transport casks and required periodic inspections can‘t be performed in full extent due to loaded and sealed casks which are - on the other hand - under permanent surveillance;
  - Transport after long-term storage requires aged material and cask properties for complete Type B - safety demonstration;
  - Transportation issues can‘t be ruled by interim storage licenses due to different legal areas (in Germany: Regulations for the Transportation of Dangerous Goods vs. Atomic Law). Thus, transport regulations should be modified with respect to (dual purpose) casks for transport <u>and</u> (interim) storage.