Extended Interim Storage Issues and Long-Term Investigations at BAM

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Outline:

1. Present Status of SNF and HLW Management in Germany
2. Operation Experience and Regulatory Framework in DPC Storage
3. Perspectives and Challenges Concerning Extended Interim Storage
4. Current Long-term Investigations at BAM
5. Conclusions

Until 2011:

➔ **17 NPPs with 21,5 GWe**

Since Aug. 2011 (After phase out decision and Atomic Energy Act revision):

➔ **9 NPPs with 12,7 GWe remaining**

NPP Grafenrheinfeld

Further reactor shut downs until 31.12.2022 !

Accumulated spent fuel until 31.12.2013:
≈ 14,900 Mg HM (≈ 53,600 fuel assemblies)

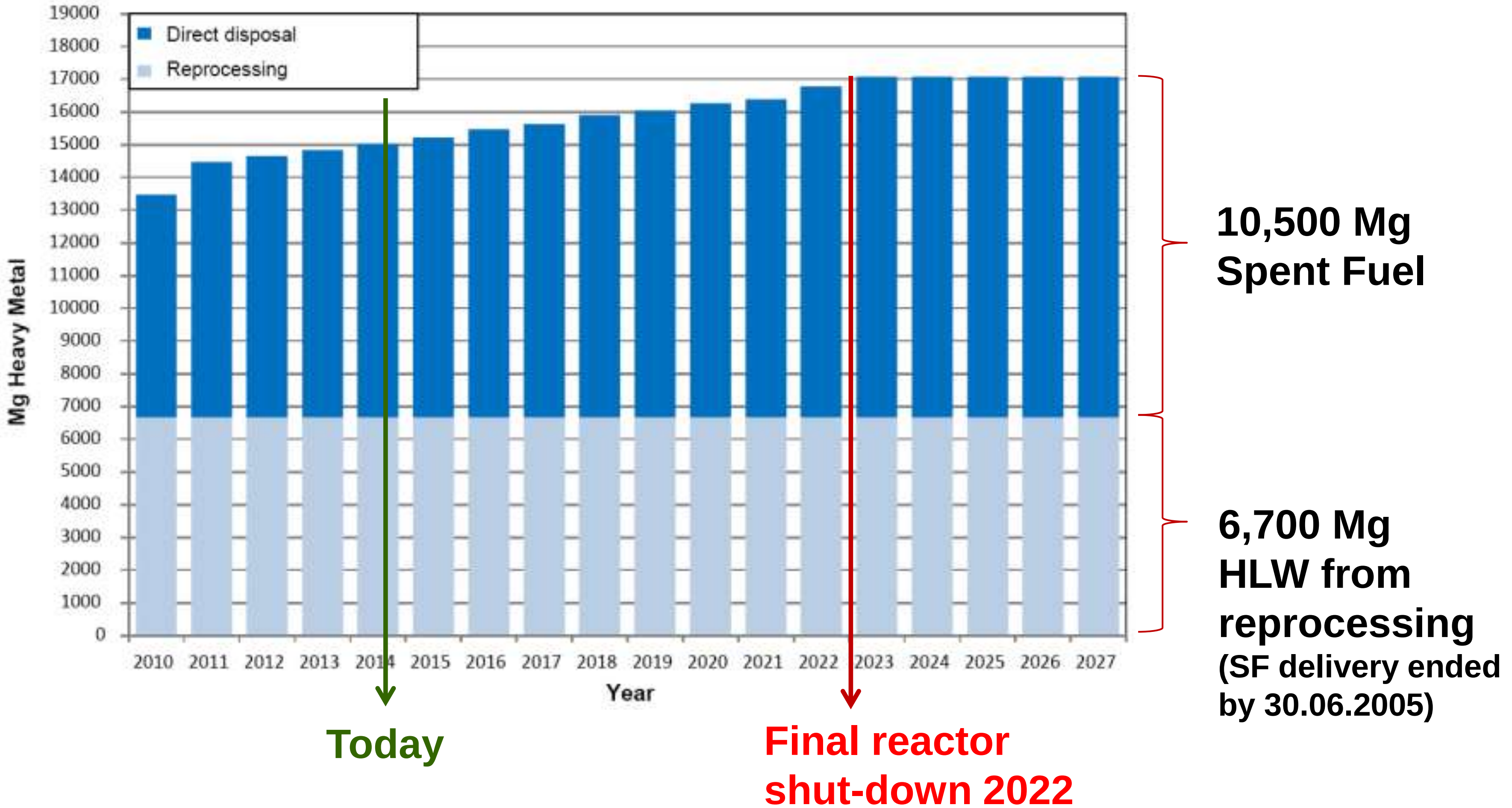
Estimated amounts until final reactor shut-down (incl. cores):
≈ 2,300 Mg HM (≈ 6,400 fuel assemblies)

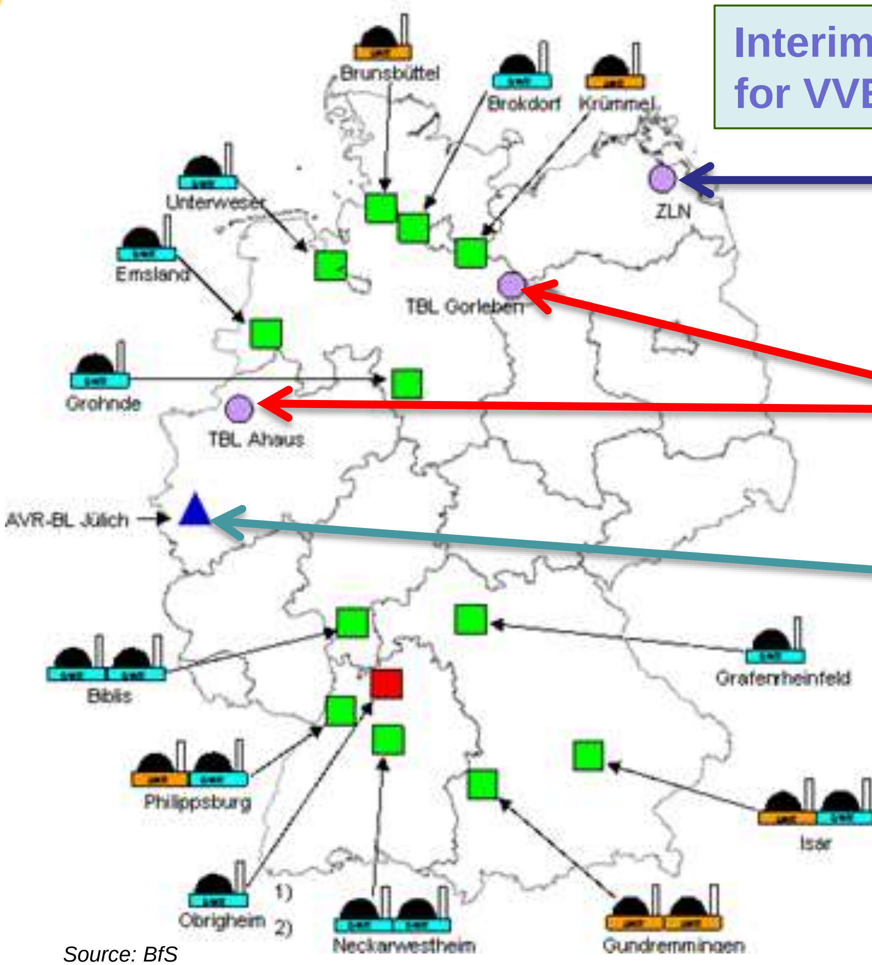
Total amount until 31.12.2022:
≈ 60,000 fuel assemblies
≈ 17,200 Mg HM

At present ≈ 1,000 dual purpose casks of various types are in use for dry storage of SNF and HAW - at 16 storage sites (12 on-site)

- **About 500 …600 additional casks needed during the next decade.**
- **About 50 … 80 casks every year to be manufactured, loaded and stored**
- **Additional transport and storage licenses needed for various fuel data (e.g. burn-up) and also defect fuel assemblies**

Cumulated Generated Spent Fuel





Source: BfS

Interim Storage North for VVER Fuel

Interim Storage North near Greifswald with CASTOR 440/84 casks containing VVER fuel
(Photo: EWN GmbH)

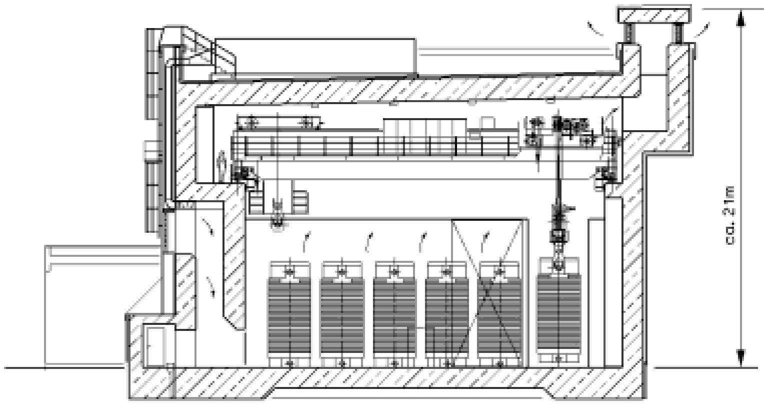
Central SF Storage Facilities
(since 1982)

Jülich Research Center:
20 year storage license for AVR fuel expired June 30, 2013 !

12 On-site SF Storage Facilities
(since 2002-2005)

12 On-Site Storage Facilities – 3 Designs

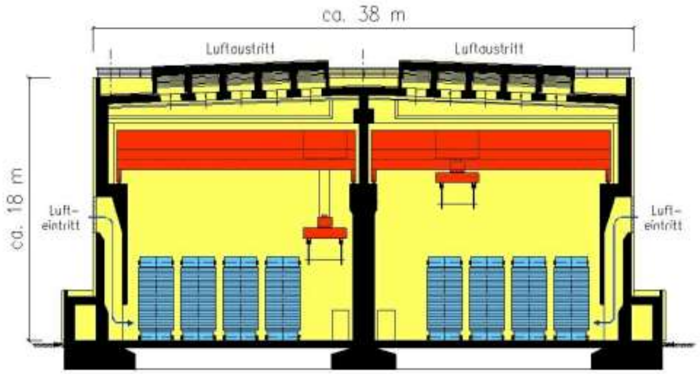
Steag Design



Interim Storage Facility at Isar NPP

Tunnel Design
(NPP Neckarwestheim)

WTI Design



German Dry Spent Fuel and HLW Storage Concept

- Accident safe dual purpose transport and storage casks
- Valid Type B(U) approval required before loading and during storage to guarantee permanent transportability
- Monolithic thick walled metal cask body
- Vacuum dried and helium filled (≈ 800 hPa) cask interior
  ➔ inert conditions
- Permanently monitored double barrier lid system equipped with metal seals
- Qualified repair concept in case of hypothetical lid failure
- Casks stored inside buildings
- Current storage licenses limited to 40 years

Photos: GNS

Licensing Procedure | Operational Regime

Storage License
issued by **BfS**
(Federal Office for Radiation Protection)

Licensee/Operator

Supervising State Authority

Contracted Experts | **Contracted Experts**

Storage operation since:

- **1992 ➔ CASTOR® THTR/AVR (TBL Ahaus)**
- **1993 ➔ CASTOR® THTR/AVR (Jülich)**
- **1997 ➔ CASTOR® Ic, V/19, HAW 20/28CG (TBL Gorleben)**
- **….**

> 20 years of safe storage operation without safety relevant issues (e.g. no seal failure)

§6 of Atomic Energy Act (AtG) - Act on the Peaceful Utilization of Atomic Energy and the Protection against its Hazards

E S K

Nuclear Waste Management Commission

"Guidelines for Dry Cask Storage of Spent Fuel and Heat-generating Waste"
German Waste management Commission (ESK), Revised version of 10.06.2013,
http://www.entsorgungskommission.de/englisch/downloads/eskempfehlungesk30llberevfassung10062013en.pdf

"ESK-Guidelines for Periodic Safety Inspections and Technical Ageing Management for Interim Storage Facilities for Spent Nuclear Fuel and Heat-generating Radioactive Waste"
German Waste management Commission (ESK), Version of 13.03.2014,
http://www.entsorgungskommission.de/downloads/empfehlungpsuzl13032014homepage.pdf

The **Storage License** contains all relevant safety evaluations to satisfy the protection goals (safe enclosure, shielding, subcriticality, heat dissipation) under operational and accidental conditions of the specific storage facility and defines conditions and requirements for its safe and secure operation.

Ruled by the German Atomic Energy Act

Ruled by the Transport Regulations for Dangerous Goods under consideration of IAEA Regulations for the Transportation of Radioactive Materials

Storage License

incl. specific cask types and inventory

Type B(U) package design approval + Safety inspections prior to transportation

Permanent transportability of all stored casks

Continuous aging management

Periodic safety reviews every 10 years

Timeframe for aging considerations: 40 years? Longer periods?

Holistic approach merging requirements from storage licenses and type B(U) approvals

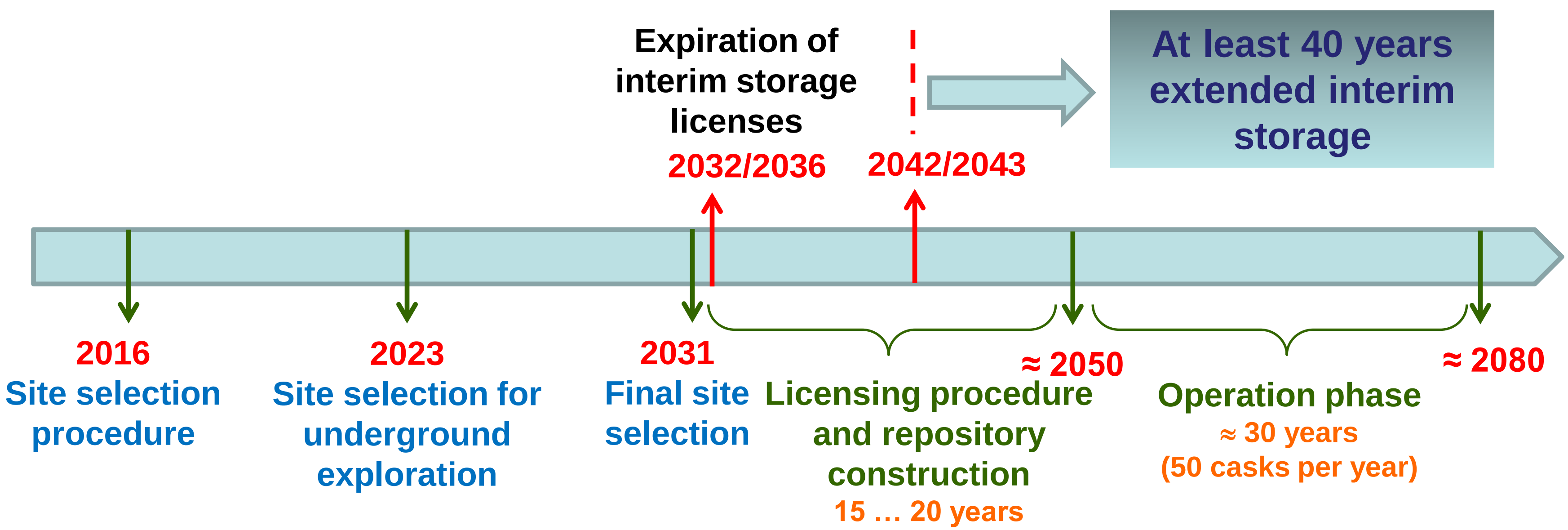
Aging management has to consider transport and storage needs and has to be inserted in the operational storage regime

3. Perspectives and Challenges Concerning Extended Interim Storage

Expiration of present interim storage licenses:

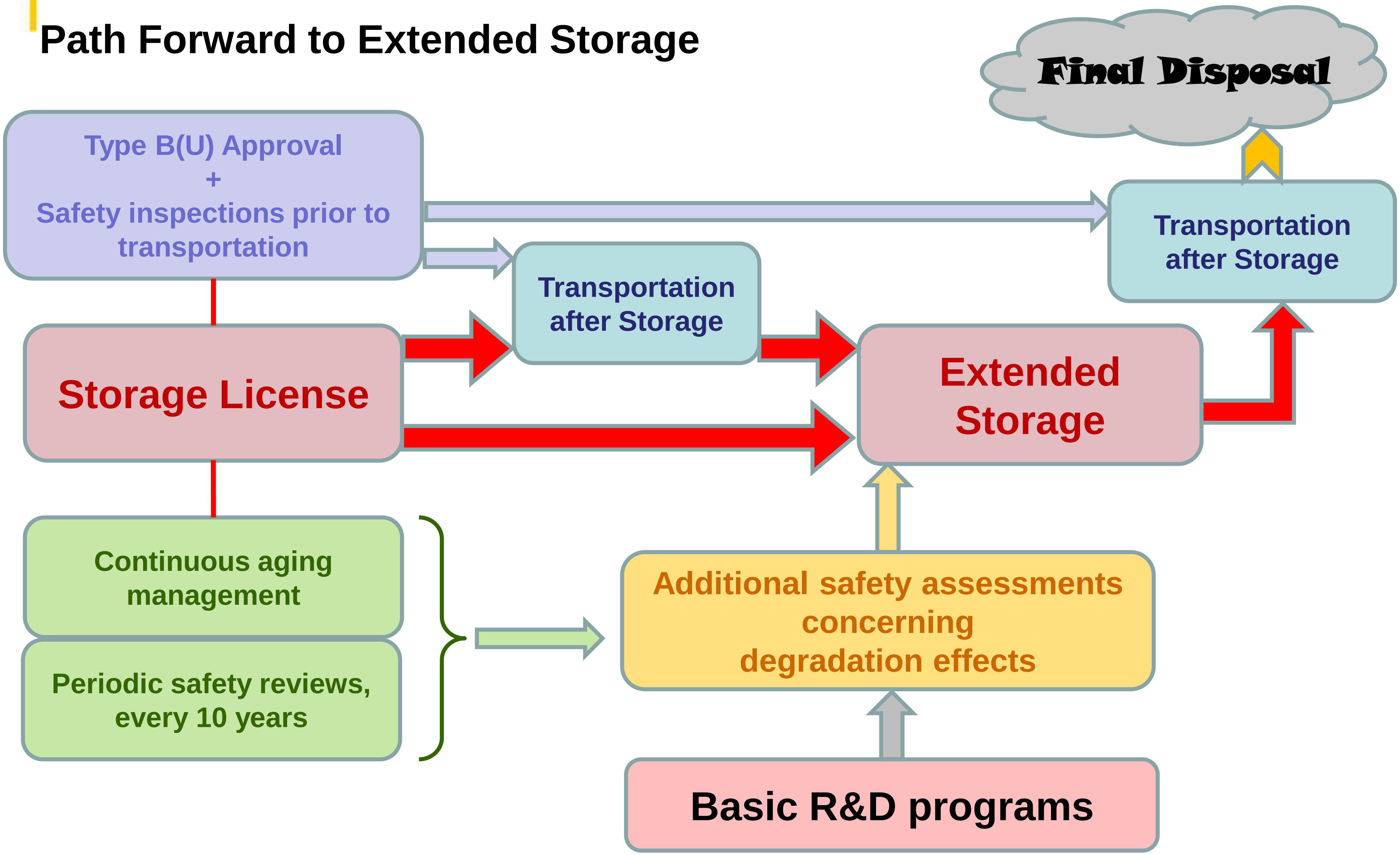
On-site Storages	→	2042/43
Interim Storage North	→	31.10.2039
Gorleben	→	31.12.2034
Ahaus	→	31.12.2036 (first CASTOR® THTR/AVR cask already 2032 !)
Jülich	→	30.06.2013 ! (After only 20 years !)

Timeline derived from the current Site Selection Law for Disposal:



Timeline without any delays caused by lawsuits !!!

Path Forward to Extended Storage



Dual Purpose Casks During Interim Storage

Initial package design approval for transportation

Validity up to 10 years

Design approval prolongation

Cask operation:
- Storage
- Handling
- Maintenance
- Aging Management

Requirements / Outcomes

Initial cask loading and storage

Periodic safety inspections every 10 years

Initial storage period: 40 years

Extended storage period(s): 20, 40, 60, … (?) years

BAM

Additional safety assessments concerning degradation effects for extended storage periods and transportation after storage

- **Outcomes from operation experience, ageing management programs, and periodic safety inspections**
- **Development of the technical and scientific state-of-the-art with regard to necessary precautions against damages by the storage of nuclear fuel**
- **Changes of regulatory requirements**
- **Consideration of existing casks and their inventories**

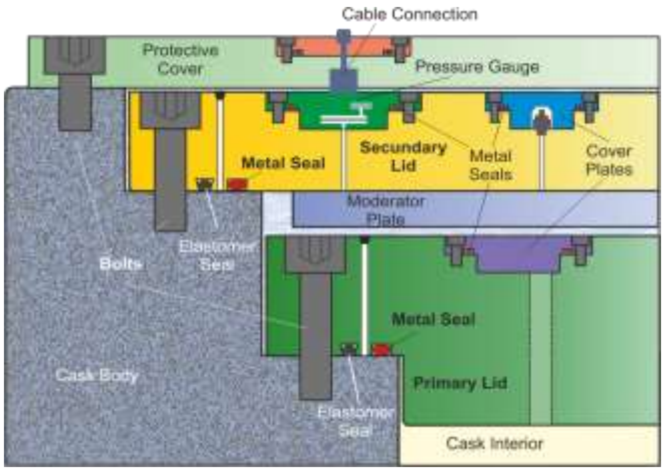

Photo: GNS

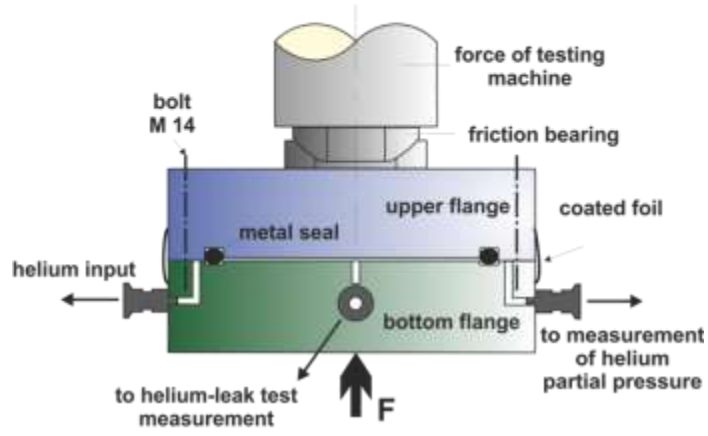
Data needs concerning storage periods beyond 40 years:

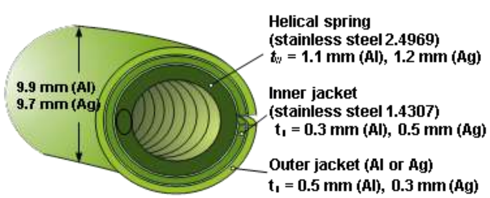
- **Long-term performance of bolted lid systems**
  - Bolt relaxation
  - **Metal seal relaxation and creep**

  } **Resulting leak-tightness**
  - Other material degradation by temperature, time, ambient conditions
  - Leakage rate measurements after long storage periods concerning elastomer auxiliary seal degradation and helium contamination
  - Reliability of pressure monitoring devices
- **Degradation of polymer components for neutron shielding**
- **Safety margins of aged casks in severe accident scenarios**
- **Long-term performance of cask inventories (fuel assemblies, canisters, baskets)**

Long-term performance of Helicoflex® metal seals







Helicoflex® metal seals

BAM laboratory tests with continuous leakage rate measurement during seal loading and unloading

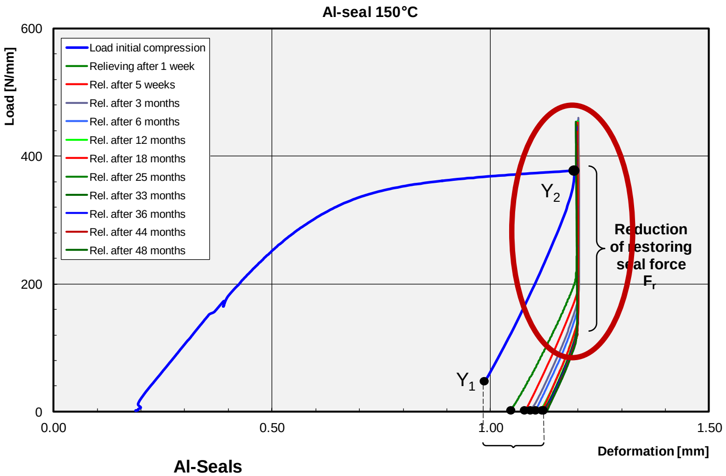
Test Parameters

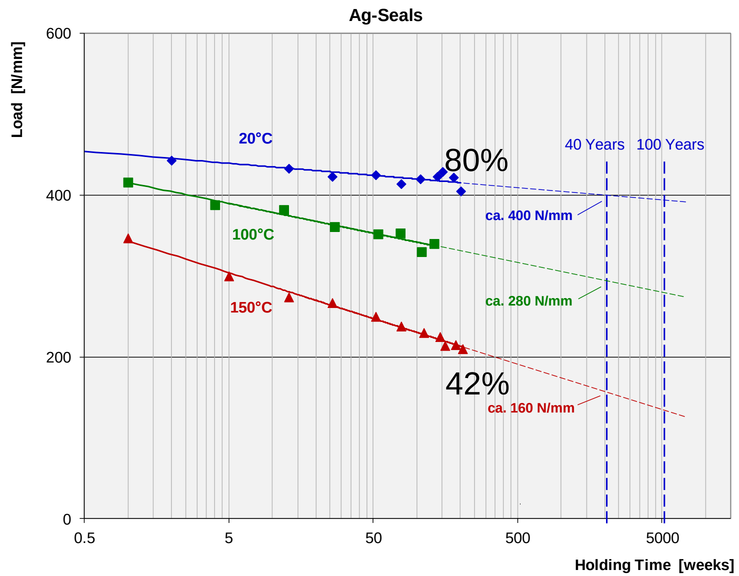
Temperatures:	+20°C	+75°C	+100°C	+125°C	+150°C
Holding times since:	02/2009	01/2014	11/2010	01/2014	02/2009
Seal type	Al + Ag	Al + Ag	Al + Ag	Al + Ag	Al + Ag

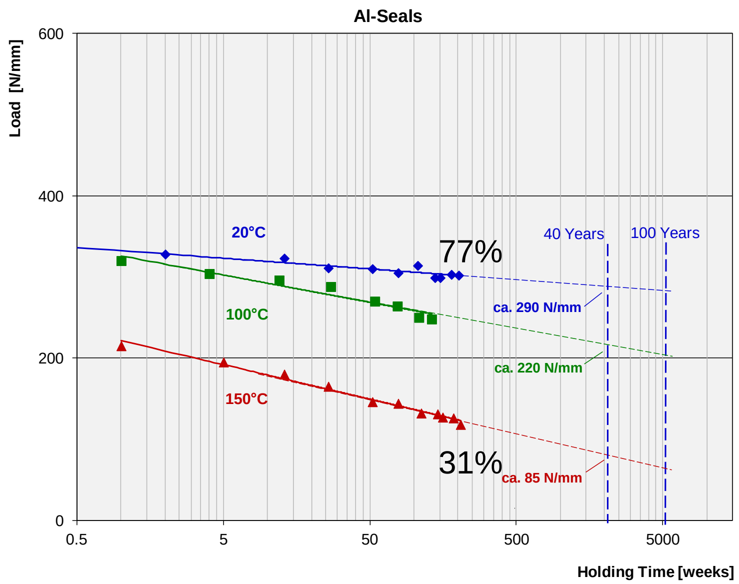
Metal seal test results (1):

Restoring seal force F_r (Load) reduction
depending on holding time and temperature

- for test periods up to 48 months and
- extrapolation up to 100 years (dashed lines)







*Ref.: **Holger Völzke et al., Paper #104**, Proceedings of the 17th International Symposium on the Packaging and Transportation of Radioactive Materials PATRAM 2013, August 18-23, 2013, San Francisco, CA, USA*

(U)HMW-PE for neutron radiation shielding

Requirement:

Sufficient long-term neutron radiation shielding without safety relevant degradation

Degradation effects:

- **Temperatures** (max. 160°C; decreasing during storage)
  - → **Thermal expansion**
  - → **Structural changes from semi-crystalline to amorphous**
- **Gamma radiation** (decreasing during storage)
  - → Structural damages and/or crosslinking
  - → hydrogen separation
- **Mechanical assembling stresses**
  - → Stress relaxation

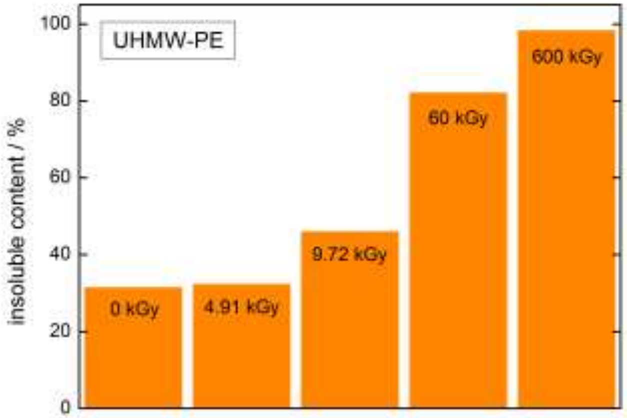
Gamma irradiation tests by BAM (at room temperature)

- Low dose irradiation (^{60}Co source): 0.5 – 60 kGy
- High dose irradiation (conservative max. storage dose): 600 kGy

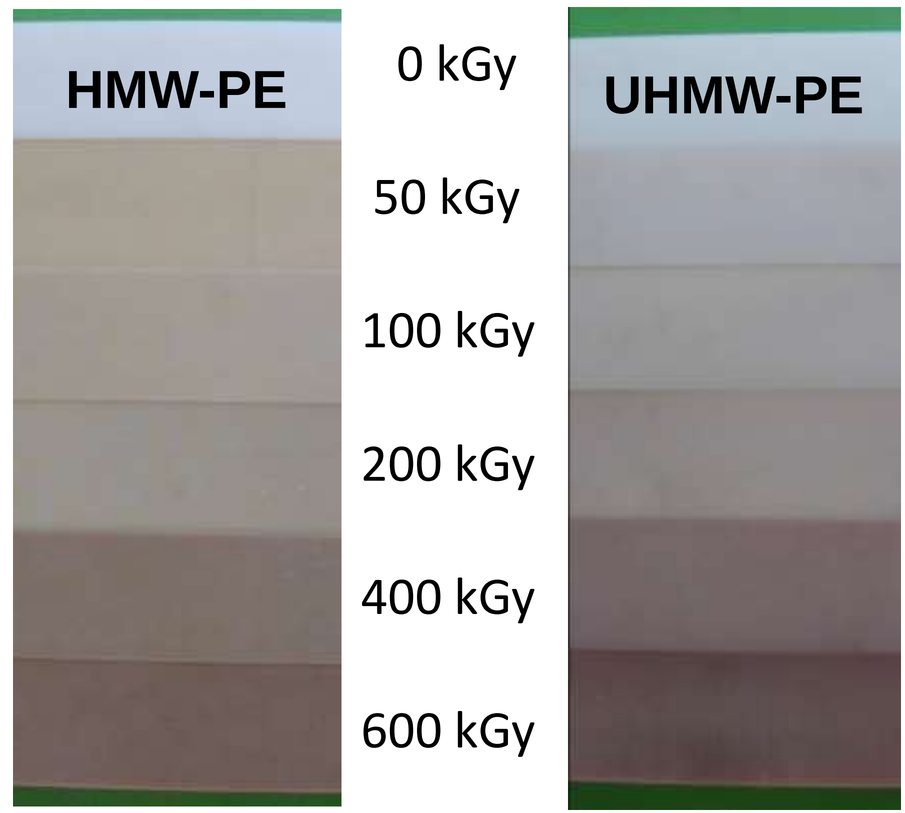
CASTOR® HAW28M cask design by GNS

Outcomes for UHMW-PE from various analyses (exemplary):

→ **Increase of insoluble, crosslinked fraction after high dose gamma irradiation**



Further gamma irradiation tests with material blocks of 10*10*50 cm³



Future investigations planned:

- **Thermal aging of(U)HMW-PE at elevated temperatures**
- **Combination of radiation and thermal aging**
- **Development of adequate prognostic methods to allow extrapolation of long-term material performance**

Investigation of Elastomer Seals

- Used as auxiliary seals in spent fuel and HLW casks
- Used as primary seals in LLW/ILW casks

Points of interest:

1. Low temperature behavior down to -40°C

Recent Publications by Matthias Jaunich, Wolfgang Stark, and Dietmar Wolff:

Low Temperature Properties of Rubber Seals
Kgk-Kautschuk Gummi Kunststoffe, 2011. **64**(3): p. 52-55.

A new method to evaluate the low temperature function of rubber sealing materials
Polymer Testing, 2010. **29**(7): p. 815-823.

Comparison of low temperature properties of different elastomer materials investigated by a new method for compression set measurement.
Polymer Testing, 2012. **31**(8): p. 987-992.

2. Aging under themo-mechanical loads (and by irradiation)

Investigation program with selected rubbers (HNBR, EPDM and FKM) tested as O-rings with an inner diameter of 190 mm and an cross sectional diameter of 10 mm has been started in May 2014.

The O-rings are oven-aged at four different temperatures (75 °C, 100 °C, 125 °C, 150 °C). They are examined after various times (1 d, 3 d, 10 d, 30 d, 100 d, 0.5 a, 1 a, 1.5 a, 2 a, 2.5 a, 3 a, 3.67 a, 4.33 a and 5 a).

In order to be able to compare between compressed and relaxed rubber, the samples are aged in their initial O-ring state (Fig. 1) as well as compressed between plates (Fig. 2) with a deformation of 25 % corresponding to the actual compression during service. Furthermore, we are aging samples in flanges that allow leakage rate measurements (Fig. 3).

Fig. 1 Undeformed O-rings

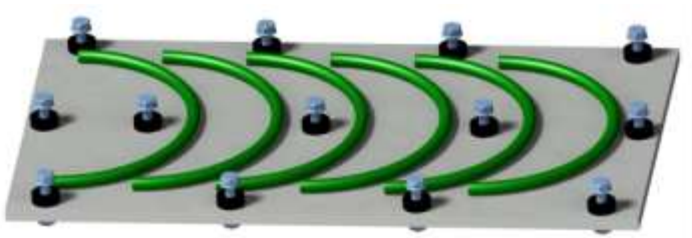


Fig. 2 Half O-rings compressed between plates

Fig. 3 O-ring in flange for leakage measurements

Present BAM R&D Perspectives

- **Investigation of Helicoflex® metal seals (Ag- and Al-seals) concerning the long-term behavior at various temperatures between 20°C and 150°C**
  - **Main objectives:** Determination of
    - Restoring seal force (F_r) reduction
    - Useable resilience (r_u) reduction
  - **Outcomes from 48 months test period**
    - Plasticization of the outer seal jacket
    - Reduction of F_r and r_u during long-term loading
    - Increased seal function due to improving material contact
    - Linear logarithmic correlation and extrapolation of F_r and r_u up to 100 years
  - **Further plans**
    - Continuation of running seal tests towards longer periods of time
    - Investigation of additional temperature levels
    - Evaluation of the Larson-Miller approach

- **Investigation of polymers for neutron shielding**
  - Material property changes due to mechanical and thermal aging and irradiation
- **Investigation of elastomer seals**
  - Low temperature behavior
  - Aging by mechanical and thermal loads and irradiation

5. Conclusions

- For more than 20 years dry interim storage of spent fuel and HLW in approved dual purpose casks has demonstrated safe, secure, reliable, and flexible operation without any failures.
- Germany's final phase-out decision 2011 and the complete restart of the repository siting procedure in 2013 result in new challenges for near-term cask availability and provoke the need for extended interim storage periods
  - ➔ Extended storage periods of 80 years or even more are most likely
- Storage and transportation (after storage) are closely linked
  - ➔ Further improvement of the regulatory framework gives valuable support
  - ➔ Ageing management issues should be addressed in a holistic approach
- Additional safety demonstrations and material data for the long-term <u>concerning casks and inventory</u> will be required in the future and should consider both storage and transportation needs
- First R&D initiatives have already been started by BAM concentrating on metal seals, polymers for neutron shielding, and elastomer seals