Dry Spent Fuel Storage in Dual Purpose Casks - Aging Management Issues -

BAM

Bundesanstalt für Materialforschung und –prüfung

(Federal Institute for Materials Research and Testing)

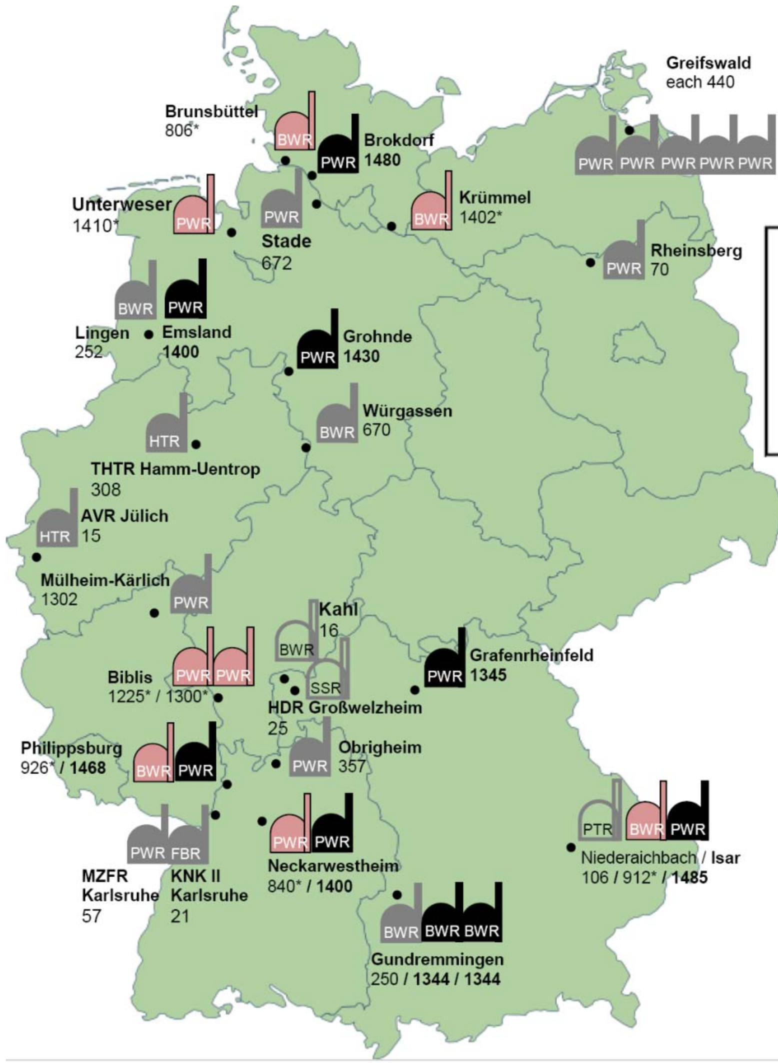
Berlin, Germany

Holger Völzke

Outline:

1. Spent Fuel Management in Germany
2. Aging Management Provisions for Interim Storage Facilities
3. R&D in View of Extended Interim Storage
4. Conclusions

Nuclear Power Plants in Germany



08/2011

Legend

PWR	Pressurised Water Reactor
BWR	Boiling Water Reactor
FBR	Fast Breeder Reactor
HTR	High Temperature Reactor
PTR	Pressure Tube Reactor
SSR	Superheated Steam-Cooled Reactor

in operation — shut down

*License terminated according to the 13th Act on the Revision of the Atomic Energy Act — completely dismantled

Numbers indicate gross capacity [MWe]

Aerial view of NPP Emsland
Source: http://www.industcards.com/nuclear-germany.htm

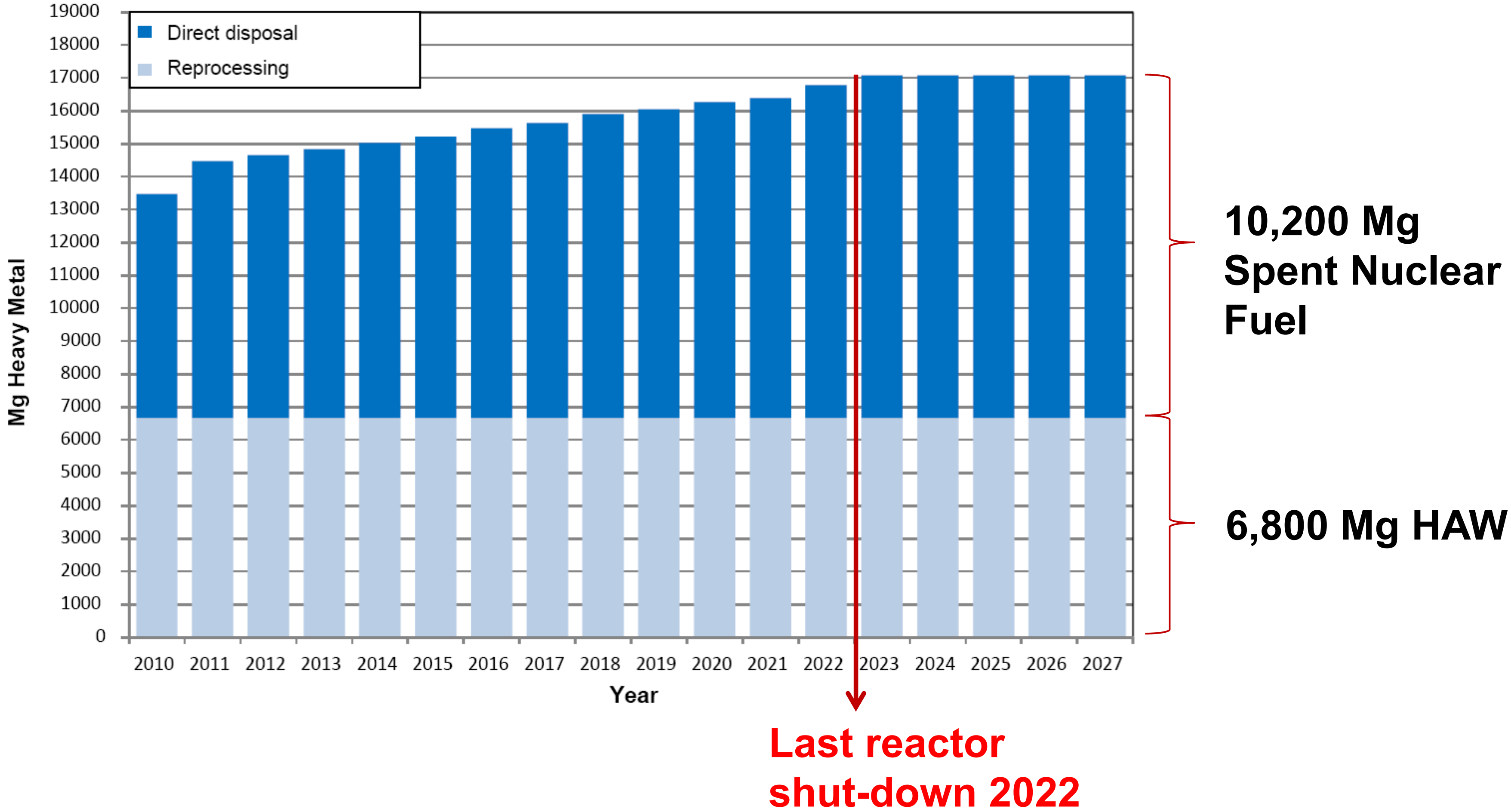
Spent Fuel Storage Facilities

Source: BMU Report of Germany to the Joint Convention in May 2012

Site	Storage capacity		Status		Emplaced
	(Number of storage positions)	[Mg HM]	Applied for	Licenced	[Mg HM]
Fuel pools in reactor buildings					
Nuclear power plants total	19 523 positions[1)]	Approx. 6 040[1)]		X	3 348
Onsite interim storage buildings					
Biblis	135 cask positions	1 400		X	468
Brokdorf	100 cask positions	1 000		X	134
Brunsbüttel	80 cask positions	450		X	51
Grafenrheinfeld	88 cask positions	800		X	133
Grohnde	100 cask positions	1 000		X	135
Gundremmingen	192 cask positions	1 850		X	280
Isar	152 cask positions	1 500		X	214
Krümmel	80 cask positions	775		X	175
Lingen/Emsland	130 cask positions[2)]	1 250		X	327
Neckarwestheim	151 cask positions	1 600		X	333
Obrigheim	980 positions[3)]	286		X	100
	15 cask positions		X		
Philippsburg	152 cask positions	1 600		X	357
Unterweser	80 cask positions	800		X	72
Centralised interim storage facilities					
Gorleben	420 cask positions[4)]	3 800		X	37[6)]
Ahaus	420 cask positions[5)]	3 960		X	55[7)]
Local storage facilities outside the reactor sites					
Greifswald	80 cask positions	585		X	583
Jülich	158 casks	0.225 nuclear fuel[8)]		X	0.075

Cumulated Generated Spent Fuel

Source: BMU Report of Germany to the Joint Convention in May 2012



1. Spent Fuel Management in Germany

Main Design Features of Storage Casks

- **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
- **Double lid system with metal seals** and **permanently monitored pressure** between **bolted lids**
- Vacuum dried and helium filled (≈800 hPa) cask interior
- **Polyethylene for neutron radiation shielding**:
  - rods in cylindrical boreholes in cask side wall
  - plates between primary and secondary lid
  - plate below bottom of cask body

CASTOR® HAW28M and CASTOR® V cask design by GNS, source: GNS

Dry Storage in Dual Purpose Casks

- Cask inventory
- Cask structure and components
- Storage facility with buildings and technical equipment

Driving aging 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, various steel types, basket materials)
- Polymers (neutron shielding, auxiliary seals, cavity sealing)

Aging effects

- Degradation by radiation
- Mechanical degradation (relaxation, creeping)
- Corrosion

Materials performance and aging management

- **Degradation of SF storage structures, systems and components (SSCs) is inevitable and increases with time. Safety-related SSCs must be evaluated to ensure that aging effects do not result in loss of safety function(s).**
- **Knowledge gaps on materials aging behavior for dry interim storage can be identified and addressed.**
- **Aging effects resulting in loss of safety function(s) can be prevented, mitigated, and monitored by an Aging Management Program.**
- **For dry cask storage systems interior and spent fuel (i.e. cannot readily be inspected), indirect methods such as monitoring, analysis, surrogate tests, and records with accumulated knowledge can be relied upon to demonstrate safe dry interim storage and transportability after storage.**
- **SSCs of the facility (including cask components) shall be replaced or renewed before the end of their service life.**

German approach for dry interim storage aging management

Interim Storage North at Greifswald with CASTOR 440/84 casks containing VVER fuel (photo: EWN)

German Atomic Law

Safety Guidelines
for Dry Interim Storage of Spent Fuel in Casks

Storage license

Periodic Safety Review Guidelines
for Interim Storage Facilities for Spent Fuel and Heat-Generating Radioactive Waste in Casks

Storage operation

Aging Management
for Dry Interim Storage of Spent Fuel and Heat-Generating Radioactive Waste in Casks

Transportation after storage

Periodic Safety Review Guidelines for Interim Storage Facilities for Spent Fuel and Heat-Generating Radioactive Waste in Casks

Draft agreed in Nov. 2010

Test phase with two selected storage facilities was started in 2011 and is expected to be finished by the end of 2013.

by

ESK (Nuclear Waste Management Commission)

on behalf of

BMU (Federal Ministry for the Environment, Nature Conservation and Nuclear Safety)

Goals:

- **To be performed every 10 years at each storage facility**
- **Documentation and evaluation of operational experience and changes with respect to the level of safety, integrity of operation and dose minimisation.**
- **Updated safety evaluation under consideration of the state-of-the-art of science and technology and with respect to:**
  - Safe and reliable continuation of operation.
  - Consequences of aging mechanisms on all relevant storage components like building structures, handling equipment, casks and cask inventories.
  - Adherence of safety requirements with respect to cask handling and transportation after storage.
- **Conclusions and provisions for further operation**

Aging Management for Dry Interim Storage of Spent Fuel and Heat-Generating Radioactive Waste in Casks

by ESK on behalf of BMU

Final Draft agreed in Jan. 2012

Outline:

- Basics, Goals
- Approach to the technical aging management
  - Planning
  - Implementation
  - Documentation
  - Assessment
- Requirements for the monitoring concept
  - Casks (accessible regions; not accessible regions)
  - Storage building
  - Other technical equipment (fire protection, crane, cask monitoring installations)
- Non-technical aging
  - Long-term personnel management
  - Long-term documentation and knowledge management
  - Long-term operation management (safety management, electronic data processing systems)

3. R&D in View of Extended Interim Storage

❖ **Outcomes from periodic safety inspections, operation experience and improvement**

❖ **Development of the technical and scientific state-of-the-art with regard to safety assessment**

❖ **Changes of regulatory requirements**

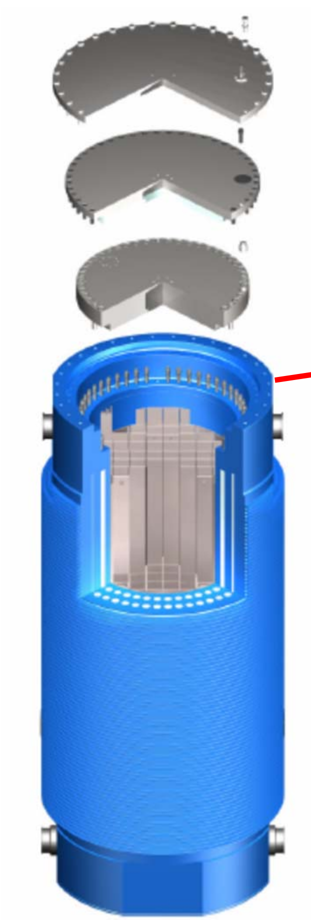
Data gaps concering storage periods beyond 40 years:

➢ Long-term performance of bolted lid systems
- Bolt relaxation
- Metal seal relaxation and creep
- Material degradation by temperature, time, ambient conditions
- Leakage rate measurements after long storage periods concerning elastomer auxialiary seal degradation and helium contamination
- Safety margins in case of severe accident scenarios

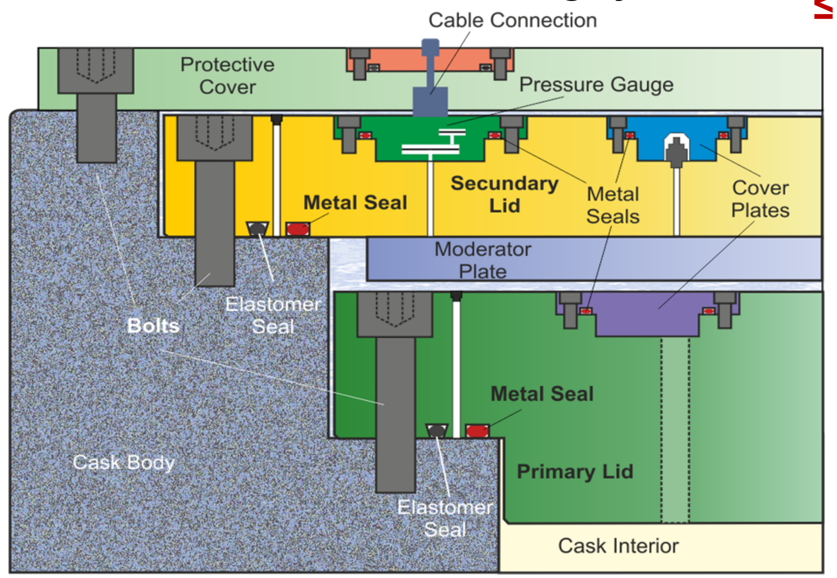
➢ Degradation of polymer components for neutron shielding

➢ Reliability of pressure monitoring devices

Dual Purpose Casks (DPC) with bolted lid systems sealed with metal seals



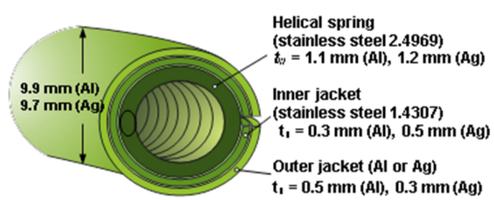
DPC lid area and sealing system



Required helium leakage rate ≤ 10^{-8} Pa m^3/s

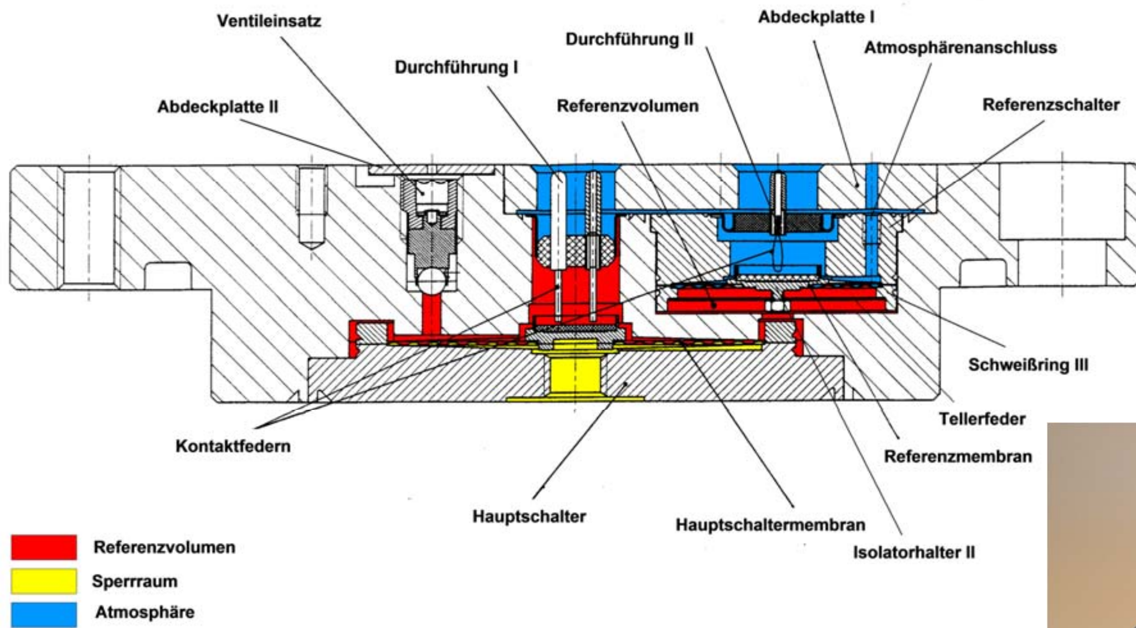
Secondary lid: 3 metal seals

Primary lid: 2 metal seals

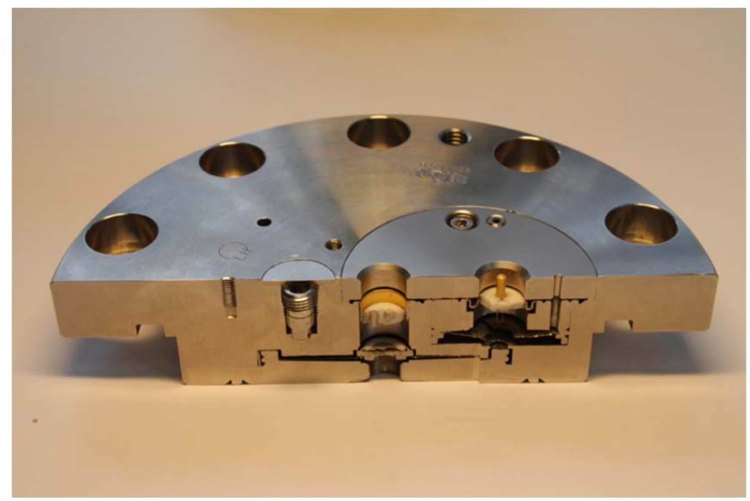


Helicoflex® metal seal

Pressure switch DPS 220 – a part of the lid system

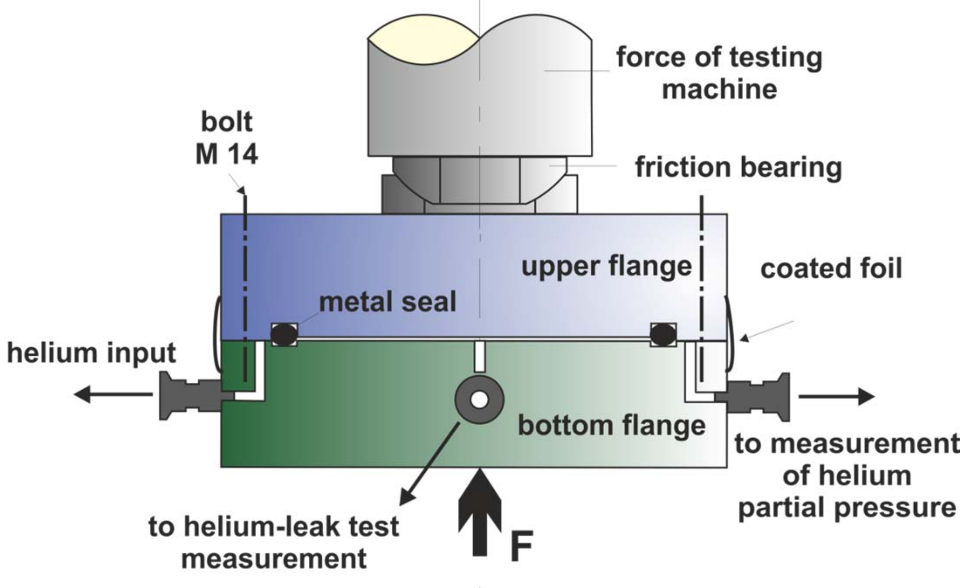


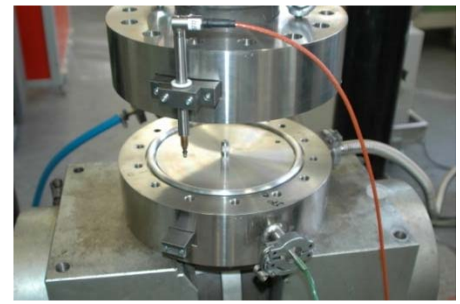
Function:
Detection of pressure decrease > 3 bar between the two barrier lids (initial over pressure ≈ 6 bar)



Issues:
- **Long-term leak-tightness**
- **Long-term reliable system function**

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



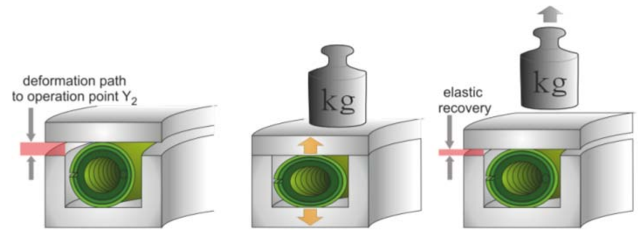


Test Parameters

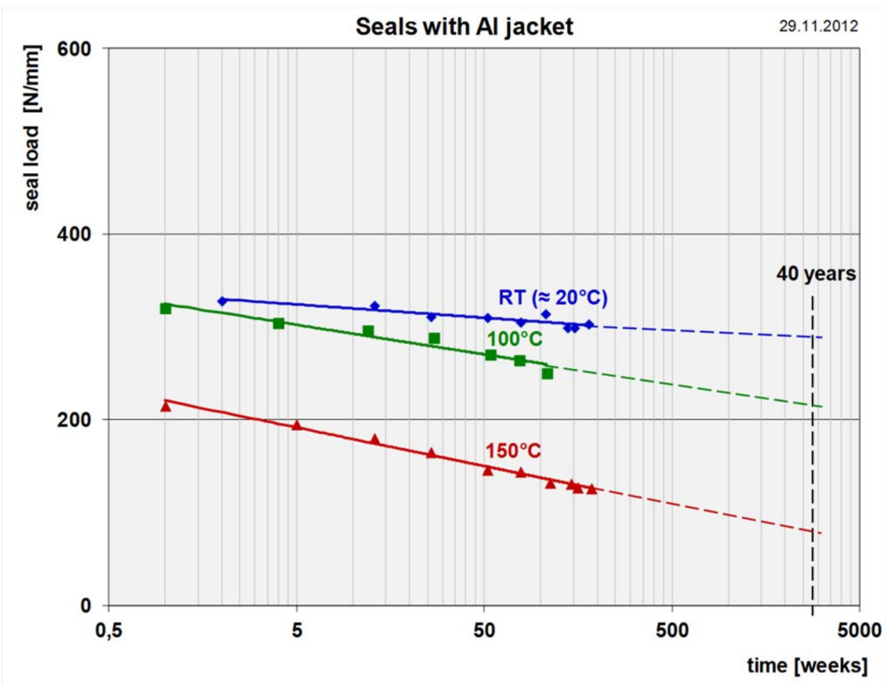
Temperatures:	+20°C	+100°C	+150°C
Holding times since:	Febr. 2009	Nov. 2010	Febr. 2009
Seal type	Al + Ag	Al + Ag	Al + Ag

Metal seal test results under static long-term conditions

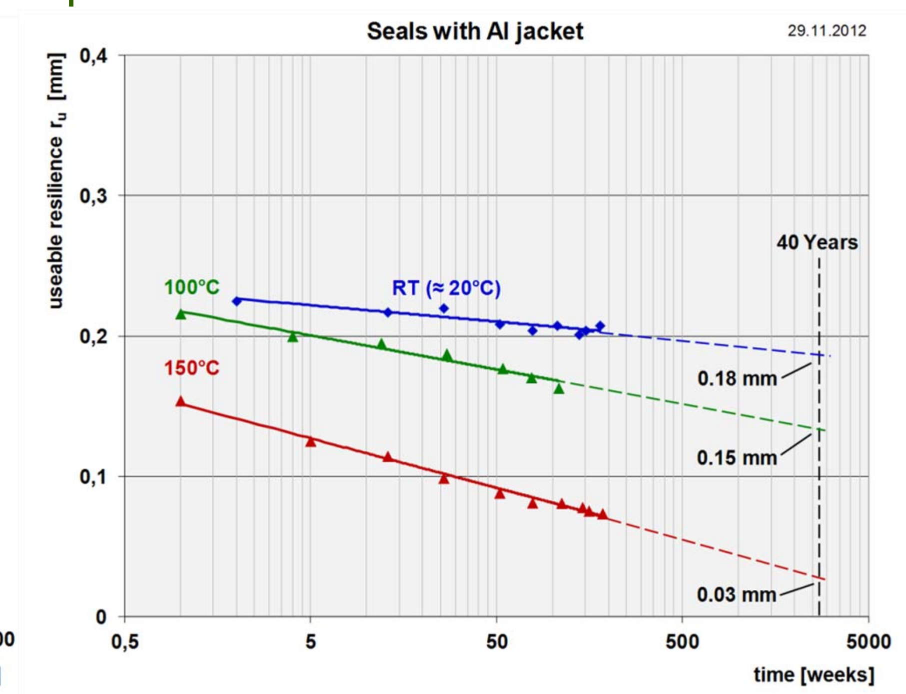
Restoring seal force F_r (Load) and useable resilience (u_r) depending on holding time and temperature



F_r



u_r

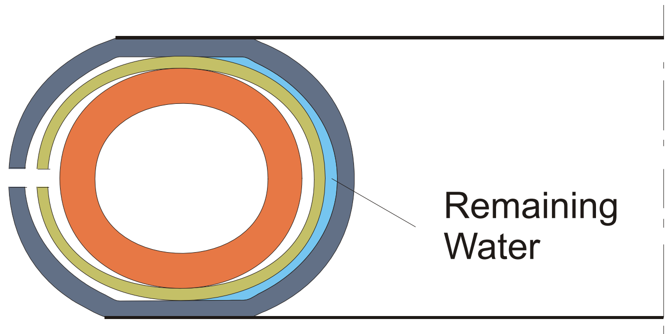


BAM test series on metal seals with enclosed water between inner and outer jacket

Corrosion tests with water in the gap between inner and outer 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!

(U)HMW-PE for neutron radiation shielding

Requirement:

Sufficient long-term neutron radiation shielding over a period of 40 years (or longer) without any degradation affecting safety relevant aspects

Aging effects:

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

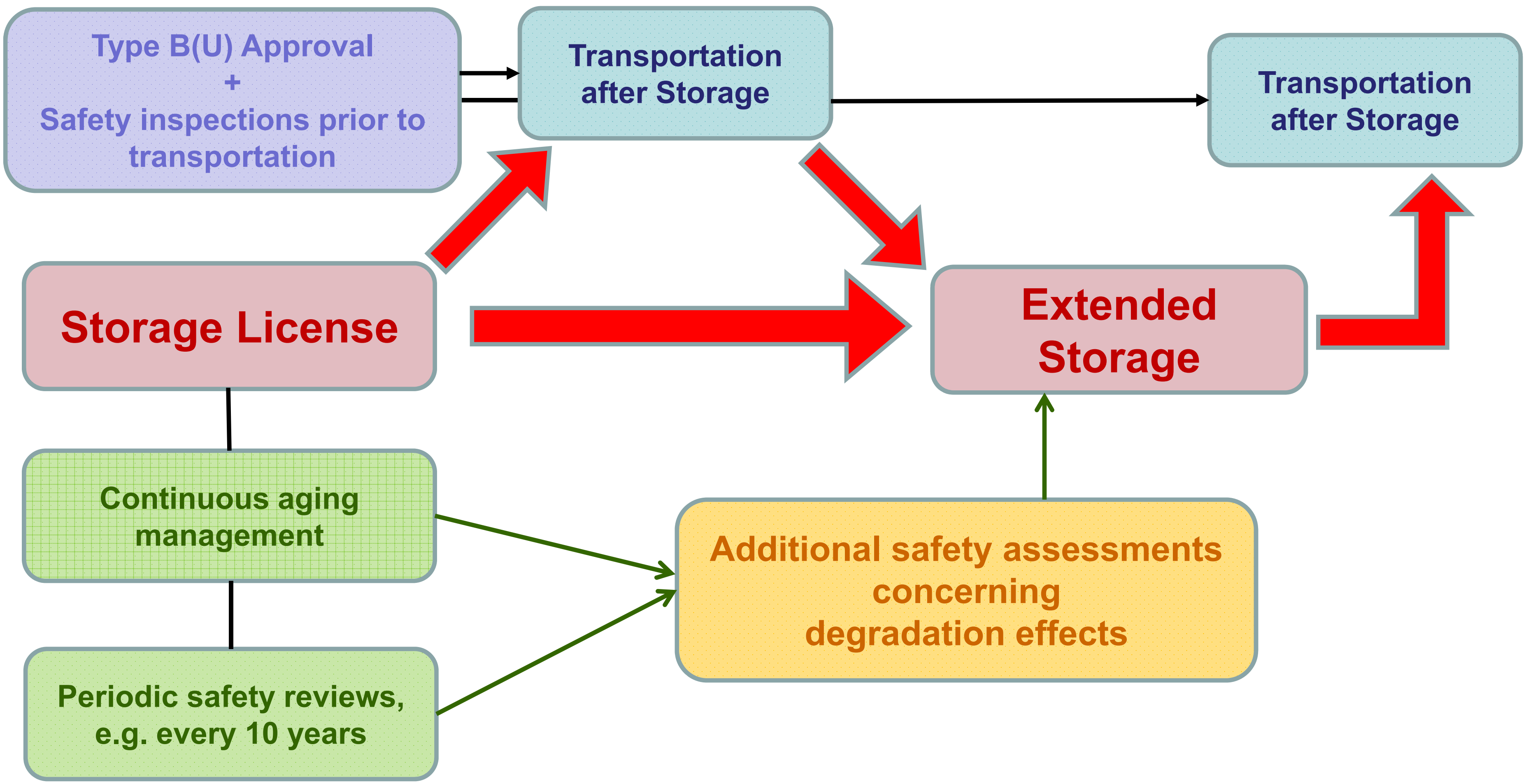
Gamma irradiation conditions for investigated samples:

Low dose irradiation: 0.5 – 60 kGy, ^{60}Co source, RT,

High dose irradiation (realistic circumstances): 600 kGy , RT

Ultra-high molecular weight polyethylene (UHMW-PE)

Path Forward to Extended Storage



BAM R&D Perspectives

- **Investigation of metal seals (outer liner aluminium and silver)**
  - Long term behavior at different temperatures (+20 …+150°C)
  - Determination of restoring seal force (F_r) and useable resilience (r_u) reductions; First outcome:
    → Linear logarithmic correlation and extrapolation of F_r and r_u up to 40 years
  - Further plans:
    → Test program since 2009 and will be continued as long as needed
    → Investigation of additional temperature levels (e. g. +75°C, +125°C)
    → Evaluation of the *"Larson-Miller Approach"*
    → Development of numerical simulation models for the short-term and the long-term seal behavior

- **Investigation of polymers**
- **Investigation of elastomer seals**
- **Extended R&D-programs with a new BAM test facility starting 2013**