SAND2015-7122C

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Sandia National Laboratories

BAM-SNL Cooperation on Container Behavior/Influence on Prolonged Storage Periods

BAM

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Sandia National Laboratories

6th US/German Workshop on Salt Repository Research, Design, and Operation

Hotel Pullman Dresden Newa

September 7-9, 2015

Sandia National Laboratories

Verantwortung für Generationen
Responsibility for Generations
DBE TEC
DBE TECHNOLOGY GmbH

PTKA
Project Management Agency Karlsruhe
Karlsruhe Institute of Technology

Federal Ministry for Economic Affairs and Energy

NNSA
National Nuclear Security Administration

U.S. DEPARTMENT OF ENERGY

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- Stainless Steel Canister Corrosion

Program Objectives: Storage and Transportation R&D

- Prepare for extended storage and eventual large-scale transport of used nuclear fuel (UNF) and high-level waste
- Develop the technical basis for:
  - Extended storage of used nuclear fuel
  - Fuel retrievability and transportation after extended storage
  - Transportation of high-burnup used nuclear fuel

Storage and Transportation R&D Guided by the 2012 Gap Analysis

Work focused in the red areas.

Source: Gap Analysis to Support Extended Storage of Used Nuclear Fuel, January 2012

System Component	Issue	Importance of R&D
Cladding	Annealing of Radiation Effects	Medium
	Oxidation	Medium
	H_2 effects: Embrittlement	High
	H_2 effects: Delayed Hydride Cracking	High
	Creep	Medium
Assembly Hardware	Stress corrosion cracking	Medium
Neutron Poisons	Thermal aging effects	Medium
	Embrittlement and cracking	Medium
	Creep	Medium
	Corrosion (blistering)	Medium
Canister	Atmospheric corrosion (marine environment)	High
	Aqueous corrosion	High

Storage and Transportation R&D Guided by the 2012 Gap Analysis

Work focused in the red areas.

Source: Gap Analysis to Support Extended Storage of Used Nuclear Fuel, January 2012

System Component	Issue	Importance of R&D
Bolted Direct Load Casks	Thermo-mechanical fatigue of bolts/seals	Medium
	Atmospheric corrosion (marine environment)	High
	Aqueous corrosion	High
Overpack and Pad (Concrete)	Freeze/Thaw	Medium
	Corrosion of steel rebar	Medium

Cross-cutting or General Gaps

- ***Temperature profiles for fuel*** — ***High***
- ***Drying issues*** — ***High***
- ***Monitoring*** — ***High***
- ***Subcriticality*** — ***High***
- ***Fuel transfer options*** — ***High***
- ***Re-examine INL dry cask storage*** — ***High***

Identification of these data gaps are used to inform new initiatives for FY15

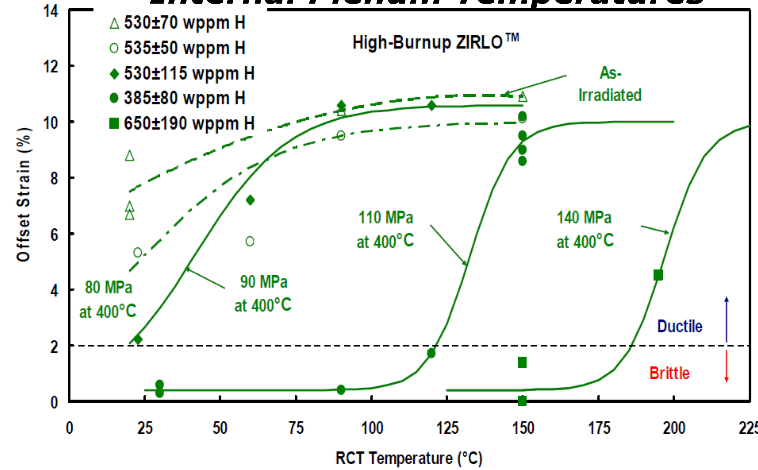
High Burnup Spent Fuel Cladding Material Properties

- Separate effects test to determine effects of hydrides, hydride reorientation, radiation damage, thermal annealing, and clad thinning on materials properties and performance.

- Hydrides and reorientation
  - Ring Compression Tests and determination of Ductile-Brittle Transition Temperature (ANL)
  - Cladding bend test and effects of fuel/clad bonding and pellet/pellet interfaces (ORNL)

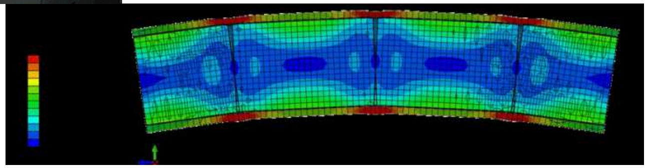
- Radiation damage and thermal annealing
  - Irradiate cladding in HFIR reactor at ORNL without all other effects.

DBTT data for Zirlo clad with Varying Internal Plenum Temperatures



Billone, Argonne National Laboratory, EPRI ESCP Meeting, Dec. 2013

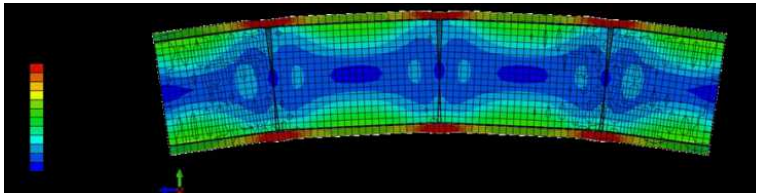
Used fuel rod stiffness experiments (in hot cell and out) and analyses of stress distribution



Jy-An, Wang; Oak Ridge National Laboratory, WM2014 Conference, March 2014

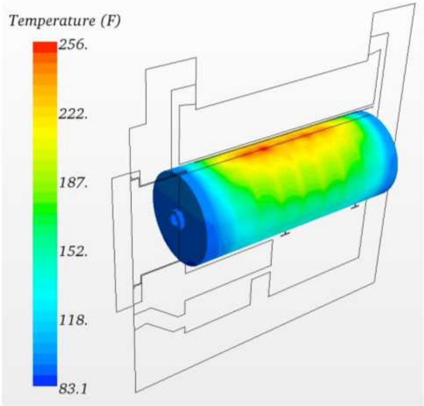
Analysis

- Predictive modeling
  - Thermal Analysis (PNNL) to predict cool down, Ductile-to-Brittle Transition, deliquescence, etc.
    - HBU Demonstration fuel selection and cool down
    - Modern, high heat load, high capacity systems
    - In-service inspections validation data
  - Hybrid hydride reorientation model (SNL)
  - Structural uncertainty analysis at assembly and canister level (PNNL)
  - Finite element analysis validation and application to out-of-cell testing (ORNL)
- Thermal profile analyses
  - Detailed thermal analyses for 2-3 licensed dry storage systems (PNNL FY15)

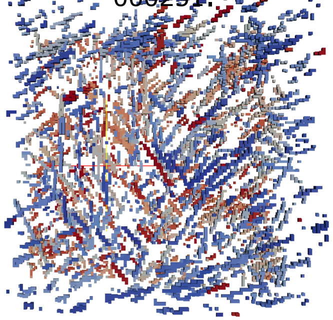


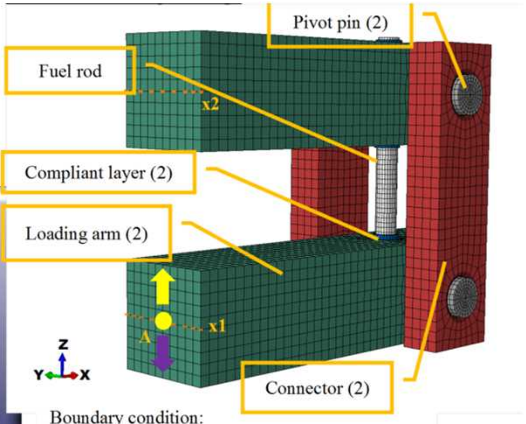
Jy-An, Wang; Oak Ridge National Laboratory, WM2014 Conference, March 2014

CFD Thermal Analysis of Dry Storage Casks
Suffield, et al, PNNL-21788

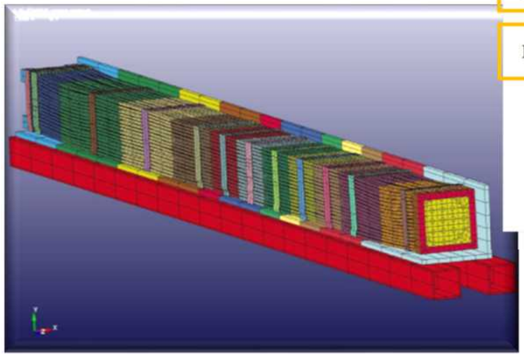


Model for Simulation of Hydride Precipitation,
Tikare et al, FCRD-UFD-2013-000251





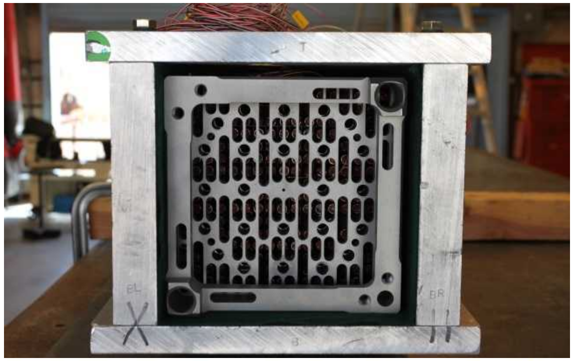
FE Model of Rod Bend Tests
Jy-An Wang et al, ORNL

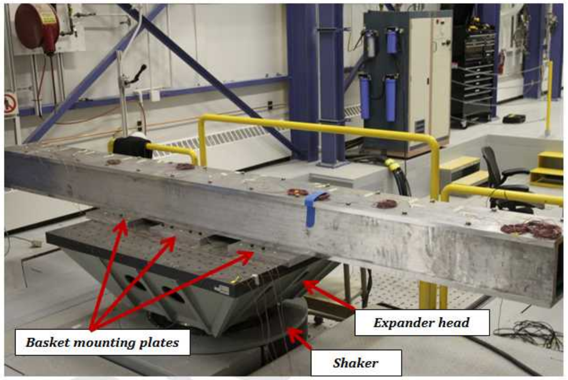


FE Models of Assembly
Klymyshyn, et al,
PNNL, FCRD-UFD-2013-000168

Normal Conditions of Transport – Loading on Fuel Assemblies

- A surrogate assembly was subjected to a 50-mile over-the-road test on a real truck with representative weight
  - Data results were >10 times below yield strength
  - The strains measured in both were an order of magnitude lower than the elastic Zircaloy rod yield strength and well below the fracture toughness value for brittle behavior
  - Strains were commensurate with strains obtained from the FY13 shaker table test
- If high burnup fuel can maintain its integrity during transport, pressure will be taken off experimental R&D efforts associated with hydride effects on cladding strength and ductility.





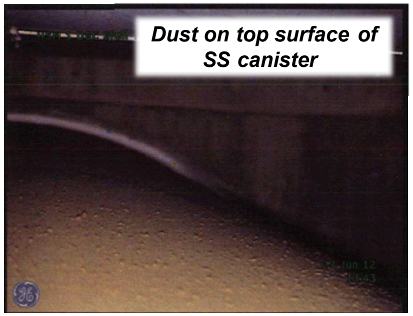
Data collection and analysis for NCT loads on a surrogate fuel assembly

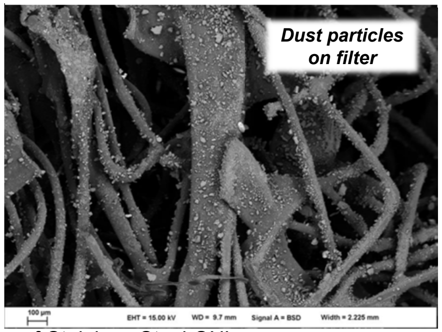
Sorenson, K., <u>Determination of Loadings on Spent Fuel Assemblies During Normal Conditions of Transport</u>, SAND2014-2043P.

Stainless Steel Canister Corrosion

Purpose: Better understand canister degradation, support Aging Management Plans, and license extensions.

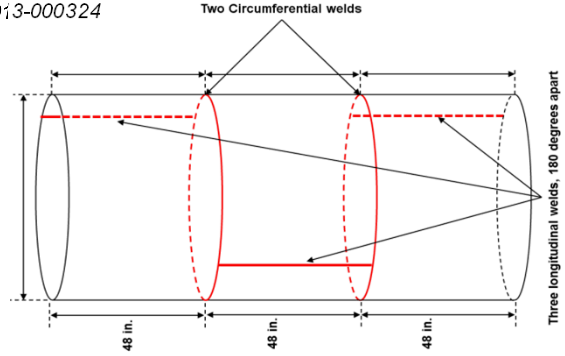
- Develop data to understand initiating conditions for corrosion conditions and progression of SCC-induced crack growth
- Obtain site data to assess atmospheric conditions and compare with initiating conditions.
- Procure a full scale (diameter) welded SS canister to investigate residual stresses due to plate rolling and welding.





Enos, et al., Data Report on Corrosion Testing of Stainless Steel SNL Storage Canisters, FCRD-UFD-2013-000324

Conceptual design for full-scale (diameter) SS welded canister



2. Overview of BAM activities associated with the BAM/SNL collaboration

- Spent Fuel and HLW Storage in Germany
- Extended Dry Interim Storage Issues
- Metal Seal Investigations
- Polymer Degradation Effects
- Elastomer Seal Investigations

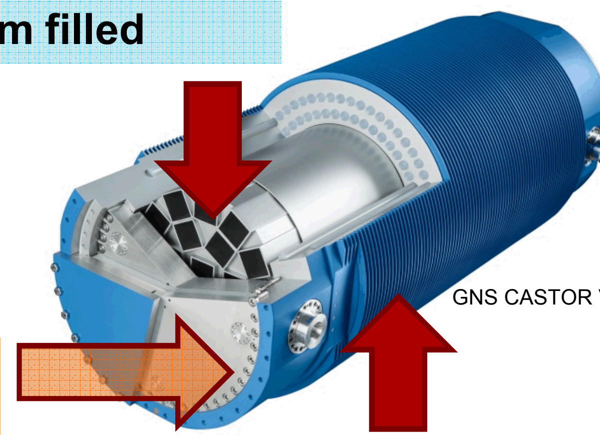
Spent Fuel and HLW Storage in Germany

BAM

- Site specific safety evaluation of casks and specific inventories performed for 40 years
- Accident safe dual purpose casks for storage and transportation
- Valid Type B(U) package design approval required before loading and during storage to guarantee permanent transportability

Photos: GNS

Inert cask interior: vacuum dried and helium filled



Permanently monitored bolted double barrier lid system equipped with metal seals

Corrosion protection of outer surfaces

Extended Dry Interim Storage Issues

BAM

Extended Interim Storage beyond 40 years

Ageing effects on DPCs (identification – evaluation)

Consideration of relevant stress factors of specific operation conditions and cask inventories

Examples

Metal Seals:

- Corrosion effects by remaining humidity
- Reduction of seal and bolt pressure force
- Reduction of useable seal resilience
- Resulting leakage rates (temp./time)
- Seal function under accident conditions

Polymer components for neutron shielding:

- Degradation by gamma-irradiation
- Thermal degradation
- Hydrogen release

Elastomer auxiliary seals:

- Degradation by gamma-irradiation
- Thermal degradation
- Loss of elasticity and seal function to provide test spaces for checking metal seal leak-tightness

Outer corrosion protection

- Paints
- Silicone sealings
- Trunnions

Internals:

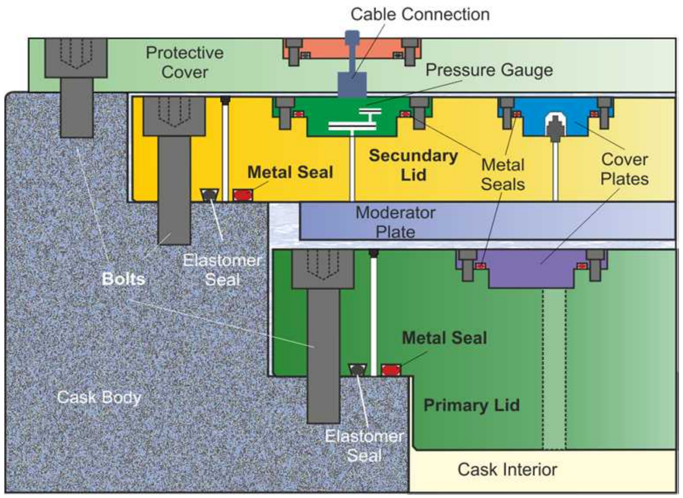
- Baskets
- Cladding integrity
- Encapsulation of defect fuel assemblies
- Moisture absorbers

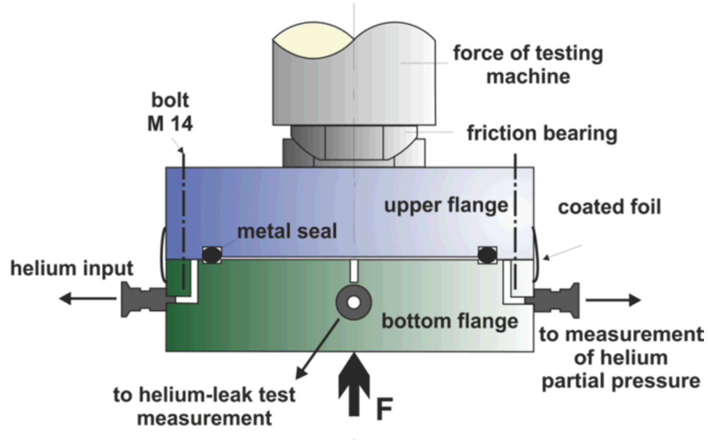
Pressure monitoring devices

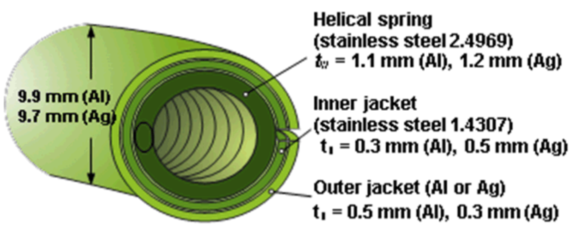
- Reliability, failure rate

Metal Seal Investigations

Long-term performance of Helicoflex® metal seals







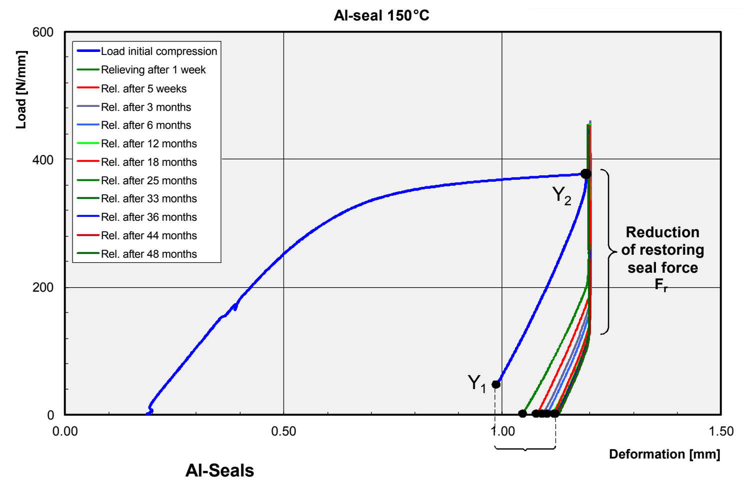
BAM laboratory tests with continuous leakage rate measurement during seal loading and unloading

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

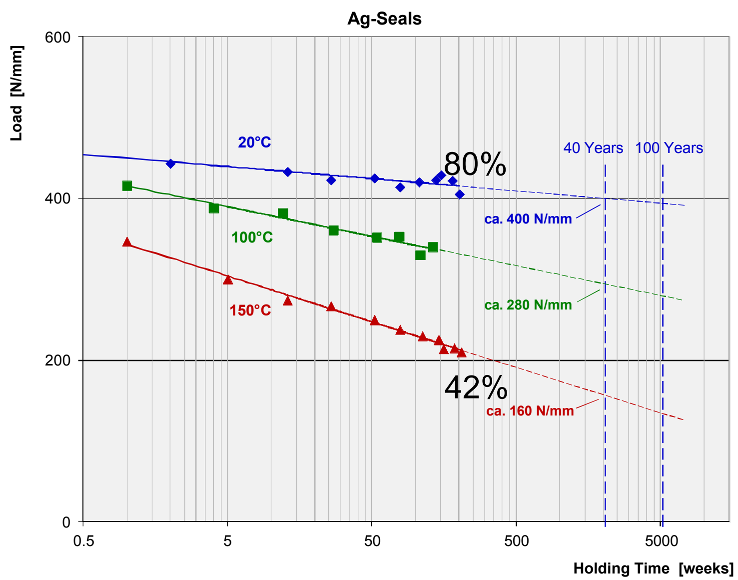
Metal Seal Investigations

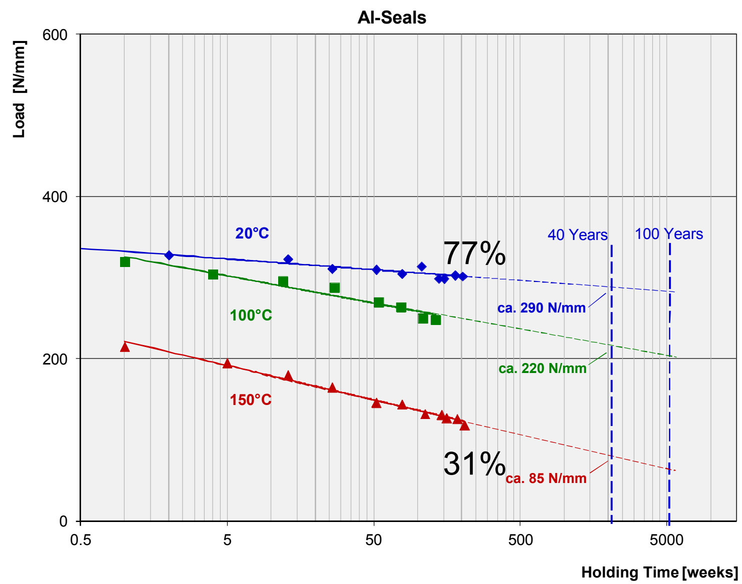
Exemplary test results:



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)

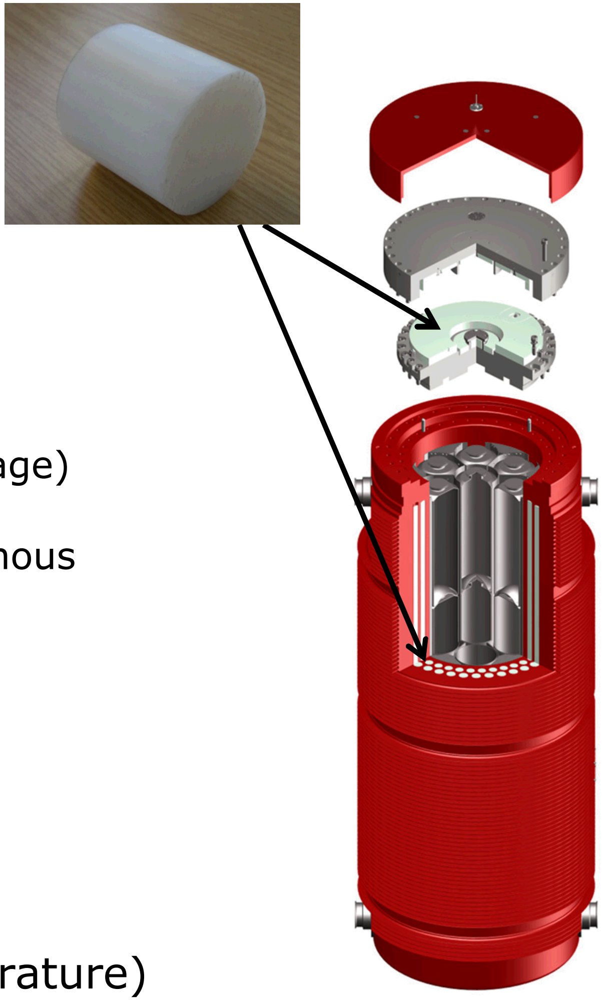




*Ref.: **Holger Völzke et al., Paper #104**, Proceedings of the 17th International Symposium on the Packaging and Transportation of Radioactive Materials PATRAM 2013, August 18-23, 2013, San Francisco, CA, USA*

Polymer Degradation Effects

Ultra-High Molecular Weight Polyethylene **(U)HMW-PE** for neutron radiation shielding



CASTOR® HAW28M
cask design by GNS

Basic 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

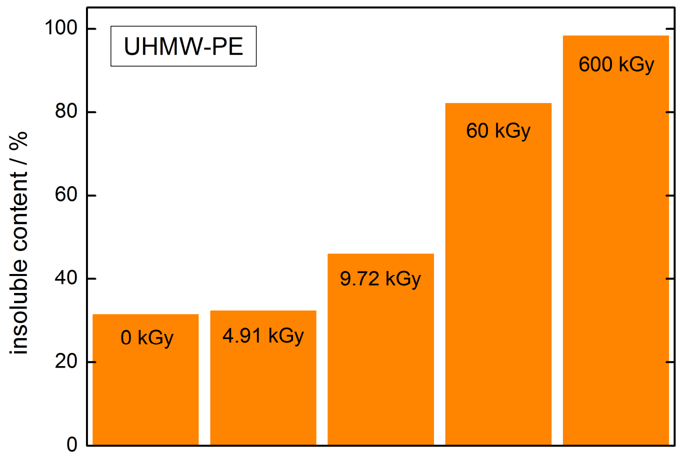
Gamma irradiation tests by BAM (at room temperature)

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

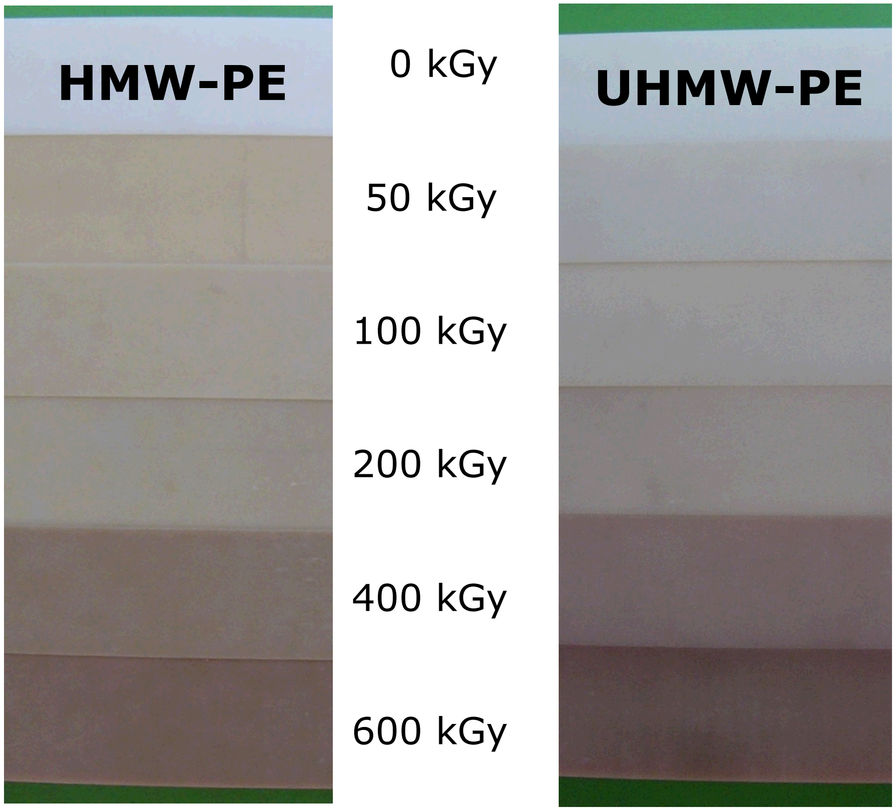
Polymer Degradation Effects

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

Elastomer Seal Investigations

Relevance:

- Auxiliary seals in spent fuel and HLW casks
- Primary seals in LLW/ILW casks

Major topics:

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.

Elastomer Seal Investigations

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 since May 2014.

The O-rings are oven-aged at four different temperatures (75 , 100 , 125 , 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).

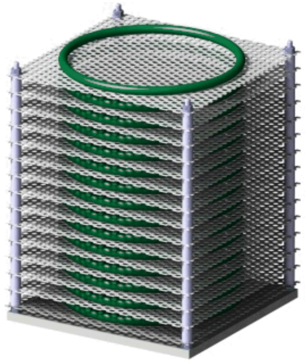


Fig. 1 Undeformed O-rings

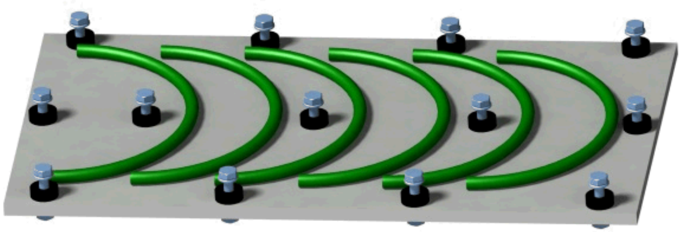


Fig. 2 Half O-rings compressed between plates

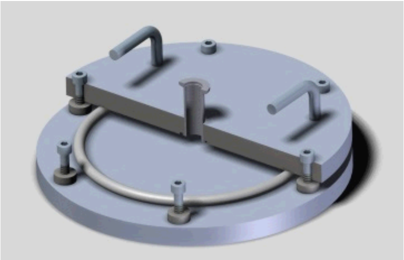


Fig. 3 O-ring in flange for leakage measurements

3. Summary and Outlook

- SNL and BAM collaborate in the areas associated with the backend of the commercial nuclear fuel cycle. Specifically, the focus is on packaging, transportation, and storage of commercial spent nuclear fuel.
- A Memorandum of Understanding (MOU) between SNL and BAM was established by 2012. Bilateral meetings/workshops take place twice a year.
- Extended interim storage of spent fuel and HLW needs to be addressed as a major issue in both countries due to delays disposal siting procedures.
- Various technical issues concerning degradation effects of casks and inventories during extended periods of interim storage have been identified and specific investigations are performed.
- Interim storage, subsequent transportation, and final disposal are closely linked and integrated approaches concerning waste package designs and operations are supposed to be beneficial for efficient long-term spent fuel and HLW waste management strategies
- Both, SNL and BAM perform specific test programs, share and discuss relevant outcomes, and address potential areas of technical and scientific collaboration