Package Design: Aging Management – Long-term Storage and Containment

LONG-TERM PERFORMANCE OF METAL SEALS FOR TRANSPORT AND STORAGE CASKS

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LONG-TERM PERFORMANCE OF METAL SEALS FOR TRANSPORT AND STORAGE CASKS

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Outline:

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2. Seal Test Configuration
3. Test Results Concerning Seal Force
4. Test Results Concerning Useable Resilience
5. Analytical Approaches
6. Conclusions
1. INTRODUCTION

The German interim storage approach for spent nuclear fuel

- Storage License
  - Type B(U) Cask Design Approval
  - Dual purpose casks

Storage Period
- 40 years
- Permanent supervision by competent state authorities
- Continuous aging management
- Periodic safety reviews, e.g. every 10 years

Extended Storage due to availability of a repository
- + 30 .... ? years
- Additional safety assessments concerning degradation effects
- Transportation after Storage
- Type B(U) Cask Design Approval + Safety inspections prior to transportation
Transport and Storage Casks with double lid system and Helicoflex® metal seals (type HN 200)

Key points:
- required Helium leakage rate ≤ 10^{-8} Pa m^3/s
- evaluation period 40 years so far
- ca. 1,000 casks in storage so far
1. INTRODUCTION

Lid Area and Sealing System of a Transport and Storage Cask

Primary lid: 2 metal seals

Secondary lid: 3 metal seals
2. SEAL TEST CONFIGURATION

Typical Load – Deformation Relationship for Helicoflex® seals

- $Q_{He/St} \leq 10^{-8}$ Pa m³/s
- $Y_0 =$ Initial achievement of $Q_{He/St}$ during compression
- $Y_1 =$ Exceeding $Q_{He/St}$ during load relieving
- $Y_2 =$ Operation point. Deformation path according to manufacturer specification
- $r_u =$ useable resilience up to exceeding $Q_{He/St}$
2. SEAL TEST CONFIGURATION

BAM Test Setup for continuous leakage rate measurement during loading and unloading
## 2. SEAL TEST CONFIGURATION

Metal seal test configurations (Helicoflex® HN 200)

![Diagram of metal seal test configurations](image)

<table>
<thead>
<tr>
<th>Seal temperature</th>
<th>20°C (ambient temp.)</th>
<th>100°C</th>
<th>150°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seal types</td>
<td>Al + Ag</td>
<td>Al + Ag</td>
<td>Al + Ag</td>
</tr>
</tbody>
</table>
2. SEAL TEST CONFIGURATION

Restoring seal force \( (F_r) \) and \( r_u \) reduction depending on time and temperature due to creeping effects (Al-seal at 150°C)

![Graph showing load and deformation over time for an Al-seal at 150°C]

Useable resilience \( r_u = \) elastic seal recovery until \( Q_{He/St} \) is exceeded

Computer tomography scan of an Al-seal after 3 months at 150°C
Restoring seal force ($F_r$) and $r_u$ reduction depending on time and temperature due to creeping effects (Ag-seal at 150°C)
3. TEST RESULTS CONCERNING SEAL FORCE

Restoring seal force $F_r$ (Load) reduction depending on holding time (logarithmic scaling) and temperature
- for current test periods (up to 48 months) and
- extrapolation up to 100 years (dashed lines)
Useable resilience ($r_u$) reduction depending on holding time (logarithmic scaling) and temperature
- for current test periods (up to 48 months) and
- extrapolation up to 100 years (dashed lines)
5. ANALYTICAL APPROACHES

Larson-Miller approach for the restoring seal force $F_r$:

$$LMP(T, t) = T \cdot (C + \log_{10}(t))$$

time $t$ in hours, temperature $T$ in Kelvin, material constant $C$

Parameter $C$ can be derived from experimental data of several iso-static test series at variable temperatures with an equal constant load.

Theory: linear correlation

Tests: non-linear correlation

C-values from literature vary, e.g. 11 or 14 for Ag-Seals
5. ANALYTICAL APPROACHES

\[
LMP = T_1 \cdot (C + \log_{10}(t_1)) = T_2 \cdot (C + \log_{10}(t_2))
\]

Calculation of time \(t_2\) for temperature \(T_2\) from measurement data at \(T_1/t_1\) and \(C=11\)

<table>
<thead>
<tr>
<th>LMP</th>
<th>(F_r) [N/mm]</th>
<th>(T_1) [°C]</th>
<th>(t_1) [h]</th>
<th>(T_2) [°C]</th>
<th>(t_2) [h]</th>
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<tr>
<td>5724</td>
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<td>22176</td>
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<td>495</td>
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<td></td>
<td>150</td>
<td>0</td>
</tr>
</tbody>
</table>

Significant differences in resulting times \(t_2\)!

\[C \neq \text{const.}\]
6. CONCLUSIONS

- Metal seals are a major component for the long-term safe enclosure of radioactive inventories in dual purpose casks
- Delays in finding and establishing a final repository will require significant extensions of interim storage periods beyond 40 years in Germany
- Investigation of Helicoflex® metal seals (Ag- and Al-seals)
  - Long-term behavior (temperatures: 20°C, 100°C, 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
  - Larson-Miller approach used to calculate data for various times and temperatures
  - Test results indicate that parameter C is not an independent material constant
- Further plans
  - Continuation of running seal test towards longer periods of time
  - Investigation of additional temperature (75°C, 125°C)
  - Evaluation of the Larson-Miller approach