Spent Nuclear Fuel Transportation Package Seals in Beyond Design Basis Temperature Excursions

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Background

- Spent Nuclear Fuel Cask Transportation Regulation Design Requirements:
  - Impact (free drop and puncture),
  - Fire,
  - Water-immersion

- Fire performance is evaluated with computer models

- Limited experimental data is available for performance of seal materials at high temperatures (fires)
Background

• Studies sponsored by the NRC

• These studies evaluate historical transportation industry fires and the effects of the fire conditions in a nuclear transportation cask.
Purpose

Obtain experimental data on the performance of seals during extreme temperature exposures, beyond the seal manufacturer specified rated/design temperatures.
Test Vessel and Seals

- SS 304 Vessel
  - Cylindrical shell
  - Flange in conformity to ASME Standard B16.5-(2009)
  - Internal cavity of 100mL
  - Four SS304 bolts (torque to seal vendor specifications)

- Metallic O-ring seal
  - Inconel 718 with silver coating (rated at 427°C [800°F] maximum operating temperature by manufacturer)

- Polymeric O-ring seals:
  - Ethylene-propylene seal (rated at 149°C [300°F] maximum operating temperature by manufacturer)
  - TFE seal (rated at 260°C [500°F] maximum operating temperature by manufacturer)
Test Furnace and Data Acquisition System (DAQ)

• Programmable temperature-controlled electrical furnace (internal capacity of 25.4 cm x 25.4 cm x 40.64 cm)

• Lab VIEW-based 16-bit DAQ

• Four Type K thermocouples (TCs) used to monitor transient temperature distribution
  – inside vessel cavity
  – inside of furnace
  – 2 TCs close to seal location
Test Apparatus
## Test Conditions and Parameters

<table>
<thead>
<tr>
<th>Test #</th>
<th>Vessel #</th>
<th>Nominal initial vessel conditions</th>
<th>Exposure duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1*</td>
<td>1</td>
<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Heat-up + 30 min at 800 °C (1427°F) + cool-down</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Heat-up + 9 h at 800 °C (1427°F) + cool-down</td>
</tr>
<tr>
<td>3</td>
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<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Heat-up + 9 h at 800 °C (1427°F) + cool-down</td>
</tr>
<tr>
<td>4</td>
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<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Heat-up + 9 h at 800 °C (1427°F) + cool-down</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Heat-up + 9 h at 427 °C (800°F) + cool-down</td>
</tr>
<tr>
<td>6</td>
<td>2**</td>
<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Heat-up + 9 h at 427 °C (800°F) + cool-down</td>
</tr>
<tr>
<td>7</td>
<td>1**</td>
<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Heat-up + 9 h at 427 °C (800°F) + cool-down</td>
</tr>
<tr>
<td>8</td>
<td>6</td>
<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Heat-up + 9 h at 800 °C (1427°F) + cool-down</td>
</tr>
<tr>
<td>9</td>
<td>1***</td>
<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Heat-up to 427 °C (800°F) and then to 800°C (1427°F) for about 4 h + cool-down</td>
</tr>
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<tr>
<td>10</td>
<td>7</td>
<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Incremental heating from 427°C (800°F) to 627°C (1160°F) with 100°C increment§ + cool-down</td>
</tr>
<tr>
<td>11</td>
<td>3**</td>
<td>24°C (75°F) at 2 bar (72.5 psi) (Ethylene-propylene Seal)</td>
<td>Incremental heating from 150°C (302°F) to 300°C (572°F) with 50°C increment§§ + cool-down</td>
</tr>
<tr>
<td>12</td>
<td>3**</td>
<td>24°C (75°F) at 2 bar (72.5 psi) (TFE Seal)</td>
<td>Incremental heating from 150°C (302°F) to 300°C (572°F) with 50°C increment§§ + cool-down</td>
</tr>
<tr>
<td>13</td>
<td>8</td>
<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Incremental heating from 427°C (800°F) to 727°C (1341°F) with 100°C increment§ + cool-down</td>
</tr>
<tr>
<td>14</td>
<td>9</td>
<td>24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)</td>
<td>Heat-up + 9 h at 800 °C (1427°F) + cool-down</td>
</tr>
<tr>
<td>15</td>
<td>3**</td>
<td>24°C (75°F) at 2 bar (72.5 psi) (Ethylene-propylene Seal)</td>
<td>Heat-up + more than 24 h at 450 °C (842°F) + cool-down</td>
</tr>
</tbody>
</table>

*Shakedown test; during this test DAQ malfunctioned and no temporal data was collected.

**Flange and groove surfaces refurbished

***Flange and groove surfaces refurbished again

§Vessel was heated at each set temperature for 9 hours or more

§§Vessel was heated 150°C (302°F) for 1 hour, 200°C (392°F) for 1 hour, 250°C (482°F) for 1 hour and 300°C (572°F) for more than 20 hours
Test Procedure

• With seal in place the flange was torque to Manufacturer’s specifications

• Vessel was evacuated and filled with Helium at room temperature to nominal pressure of 5 bar

• Tested for leaks
  – Soap water
  – 48 hrs to monitor leaks

• Vessel placed in electrical furnace and heated to seal manufacturer design temperatures (300°C, 427°C, 800°C), or step increases

• The vessel was allowed to cool down inside after ending the test
Test Descriptions and Results

• Test #2:
  – Metallic seal
  – Heat-up + 9 hrs at 800°C + cool-down

• Results:
  – Very Small leak shortly after reaching 800°C
Test Descriptions and Results

- **Test #3:**
  - Metallic seal
  - Heat-up + 9 hrs at 800°C + cool-down

- **Results:**
  - Slow leak initially
  - Significant leak at around 7 hrs at 800°C
Test Descriptions and Results

• Test #4:
  – Metallic seal
  – Heat-up + 9 hrs at 800°C + cool-down

• Results:
  – Significant leak at around 5.5hrs at 800°C
Test Descriptions and Results

• Test #6:
  – Metallic seal
  – Heat-up + 9 hrs at 427°C + cool-down
  – Refurbished vessel

• Results:
  – Very small leak shortly after reaching 427°C
Test Descriptions and Results

- **Test #8:**
  - Metallic Seal
  - Heat-up + 9 h at 800 C (1427 F) + cool-down

- **Results:**
  - Rapid pressure decrease at about 6 hrs
  - Gradual pressure decrease after 7 hrs
Test Descriptions and Results

• Test #12:
  – TFE Seal
  – Incremental heating from 150°C (302°F) to 300°C (572°F) with 50°C increment + cool-down

• Results:
  – Slight drop in vessel pressure at the end of heating increase
Test Descriptions and Results

• Test #15:
  – Ethylene-propylene seal
  – Heat-up + 24+ h at 450° C (848° F) + cool-down

• Results:
  – Leak occurred soon after the vessel had attained the nominal target temperature
Test Descriptions and Results

The following tests recovered the original pressure:

- Test #5: Metallic Seal
  • Maximum test temperature: 427°C (800°F)

- Test #7: Metallic Seal
  • Maximum test temperature: 427°C (800°F)

- Test #9: Verification of the pressure transducer performance (picture in slide)

- Test #10: Metallic Seal
  • Maximum test temperature: 627°C (1160°F)

- Test #11: Ethylene-propylene Seal
  • Maximum test temperature: 300°C (572°F)

- Test #13: Metallic Seal
  • Maximum test temperature: 727°C (1341°F)

- Test #14: Metallic Seal
  • Maximum test temperature: 800°C (1427°F)
Summary and Conclusions

- 15 tests of metallic and polymeric seals were performed to determine its performance in beyond-design-basis fire exposures.

- In general, the seals tested exhibit little to no leakage for multiple hours (5 or more hours) at temperatures approaching twice their rated temperatures.

- No catastrophic failure (e.g. lose all pressure) were detected.

- The data obtained in tests was used to estimate the leakage rate of the system when a seal failure was detected.

- NUREG/CR – 7115 Published April 2012

- Next Steps:
  - Further characterization of Polymeric Seals
  - Perform Tests on Double O-Ring Seal configuration
Questions?