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

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Background

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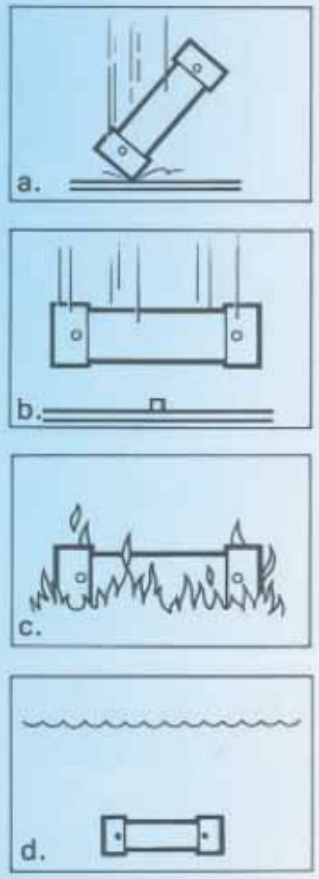
- Spent Nuclear Fuel Cask Transportation Regulation Design Requirements:
  - Impact (free drop and puncture),
  - Fire,
  - Water-immersion
- Fire performance is evaluated with computer models
- Limited experimental data is available for performance of seal materials at high temperatures (fires)



The impact (free drop and puncture), fire, and water-immersion tests are considered in sequence to determine their cumulative effects on a given package.

Background

- Studies sponsored by the NRC
  - NUREG/CR-6886, “Spent Fuel Transportation Package Response to the Baltimore Tunnel Fire Scenario”
  - NUREG/CR-6894, “Spent Fuel Transportation Package Response to the Caldecott Tunnel Fire Scenario”
- 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)

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- 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

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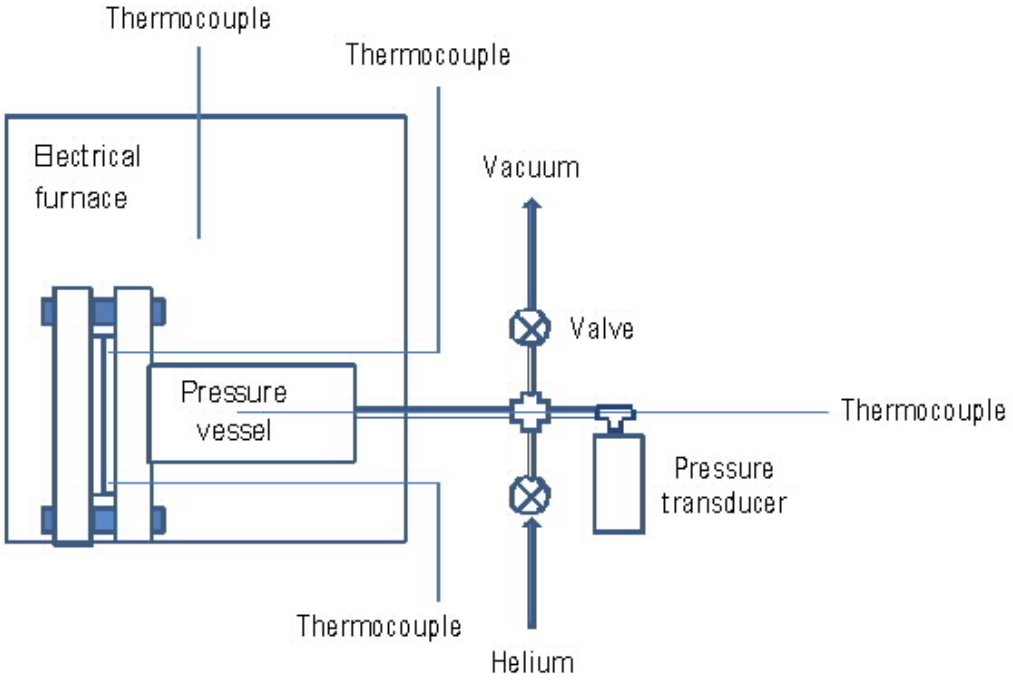

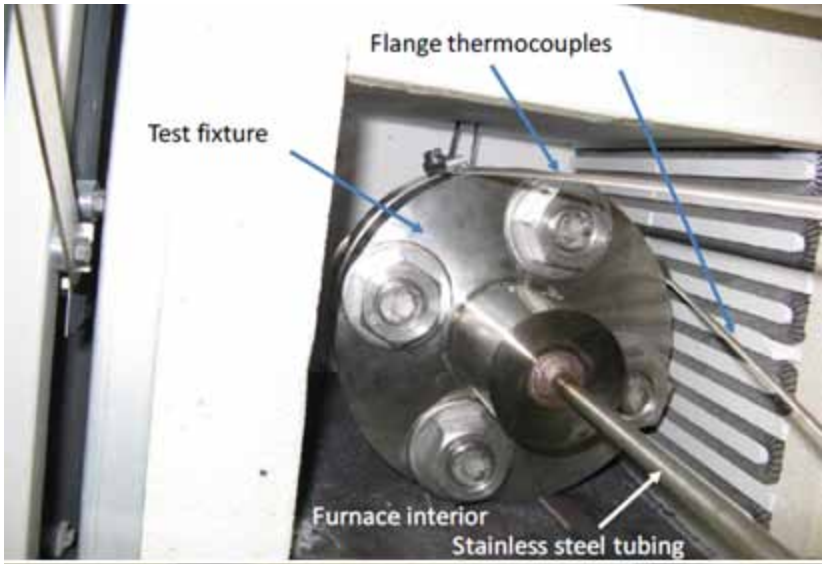

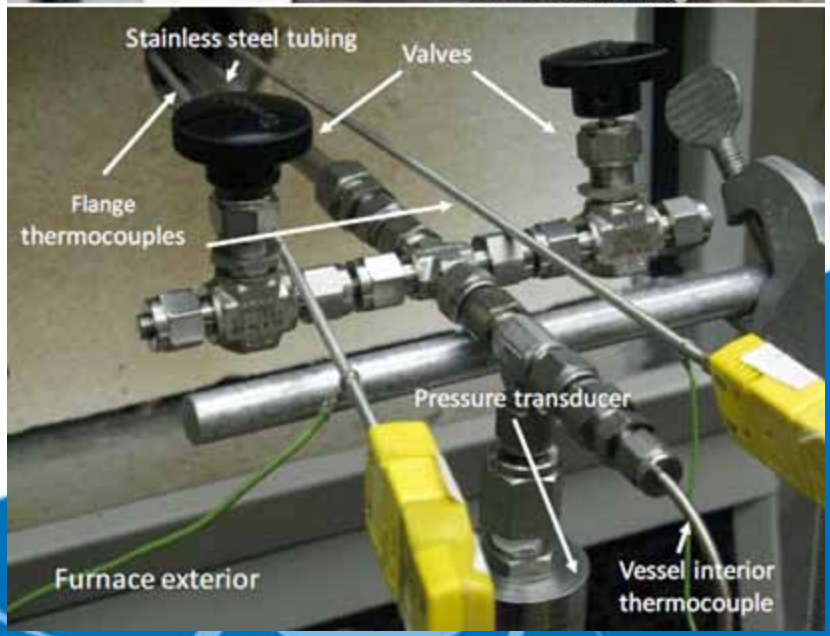

Test Conditions and Parameters

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Test #	Vessel #	Nominal initial vessel conditions	Exposure duration
1*	1	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Heat-up + 30 min at 800 °C (1427°F) + cool-down
2	2	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Heat-up + 9 h at 800 °C (1427°F) + cool-down
3	3	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Heat-up + 9 h at 800 °C (1427°F) + cool-down
4	4	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Heat-up + 9 h at 800 °C (1427°F) + cool-down
5	5	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Heat-up + 9 h at 427 °C (800°F) + cool-down
6	2**	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Heat-up + 9 h at 427 °C (800°F) + cool-down
7	1**	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Heat-up + 9 h at 427 °C (800°F) + cool-down
8	6	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Heat-up + 9 h at 800 °C (1427°F) + cool-down
9	1***	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Heat-up to 427 °C (800°F) and then to 800°C (1427°F) for about 4 h + cool-down

Test Conditions and Parameters

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Test #	Vessel #	Nominal initial vessel conditions	Exposure duration
10	7	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Incremental heating from 427°C (800°F) to 627°C (1160°F) with 100°C increment§ + cool-down
11	3**	24°C (75°F) at 2 bar (72.5 psi) (Ethylene-propylene Seal)	Incremental heating from 150°C (302°F) to 300°C (572°F) with 50°C increment§§ + cool-down
12	3**	24°C (75°F) at 2 bar (72.5 psi) (TFE Seal)	Incremental heating from 150°C (302°F) to 300°C (572°F) with 50°C increment§§ + cool-down
13	8	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Incremental heating from 427°C (800°F) to 727°C (1341°F) with 100°C increment§ + cool-down
14	9	24°C (75°F) at 5 bar (72.5 psi) (Metallic Seal)	Heat-up + 9 h at 800 °C (1427°F) + cool-down
15	3**	24°C (75°F) at 2 bar (72.5 psi) (Ethylene-propylene Seal)	Heat-up + more than 24 h at 450 °C (842°F) + cool-down

*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 1hour, 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

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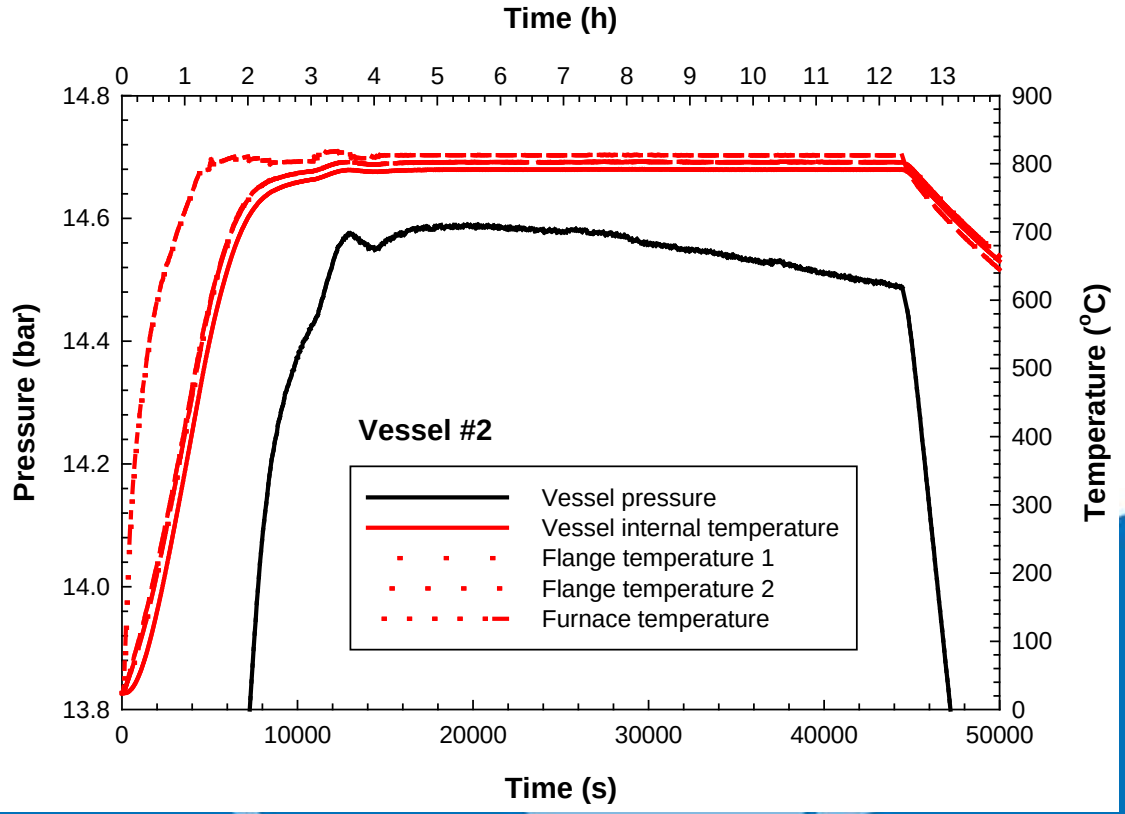
- Test #2:
  - Metallic seal
  - Heat-up + 9 hrs at 800°C + cool-down

- Results:
  - Very Small leak shortly after reaching 800°C



Test Descriptions and Results

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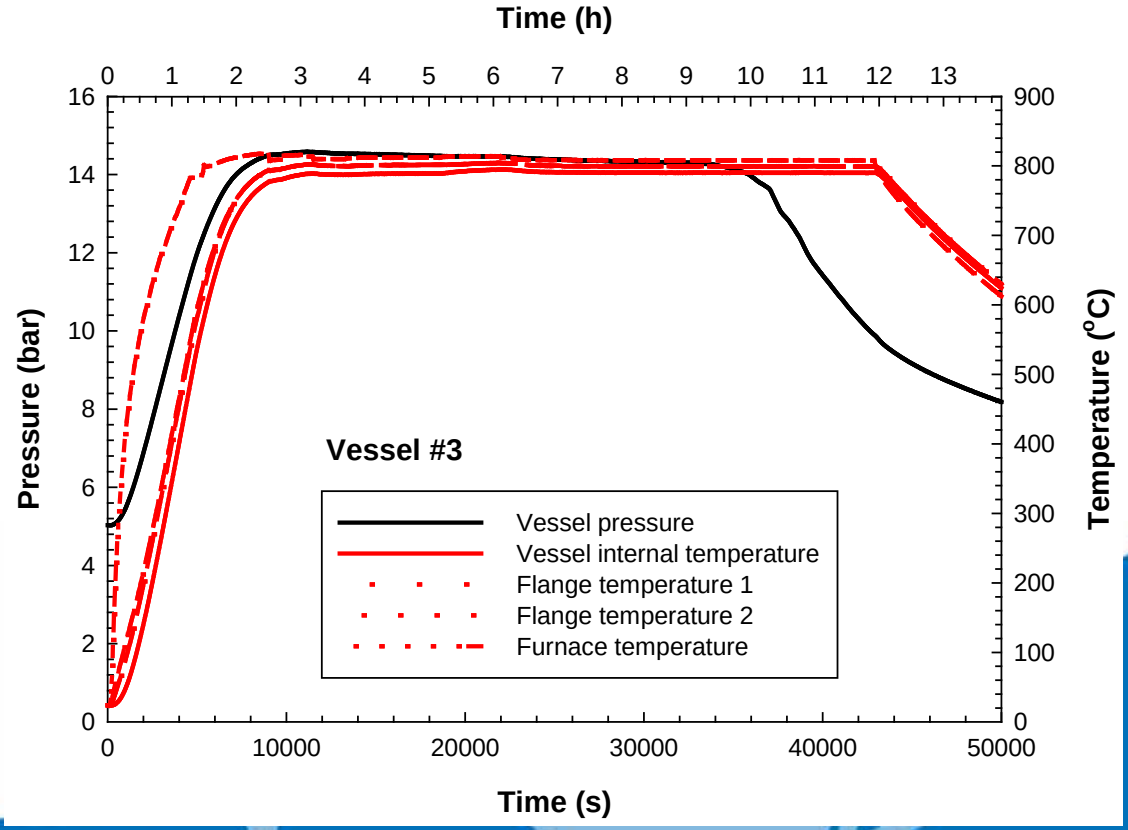
- Test #3 :
  - Metallic seal
  - Heat-up + 9 hrs at 800°C + cool-down

- Results:
  - Slow leak initially
  - Significant leak

  at around **7 hrs**
  at 800°C



Test Descriptions and Results

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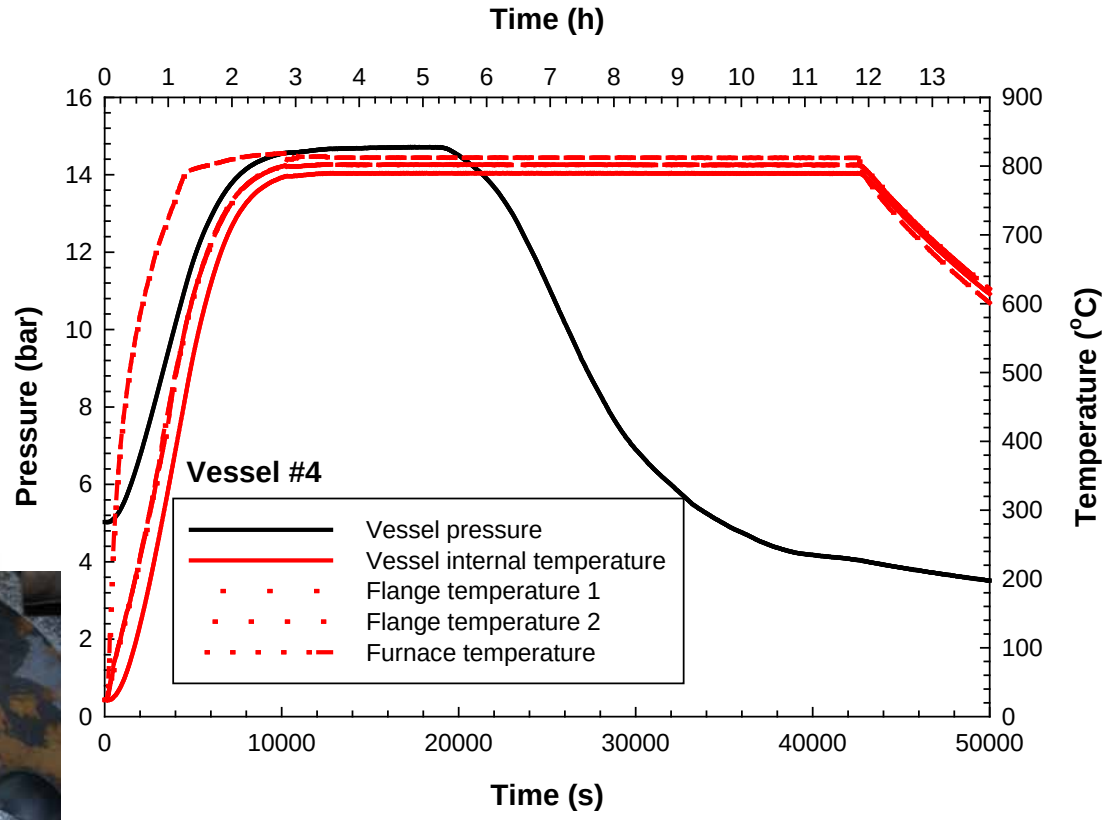
- Test #4 :
  - Metallic seal
  - Heat-up + 9 hrs at 800°C + cool-down

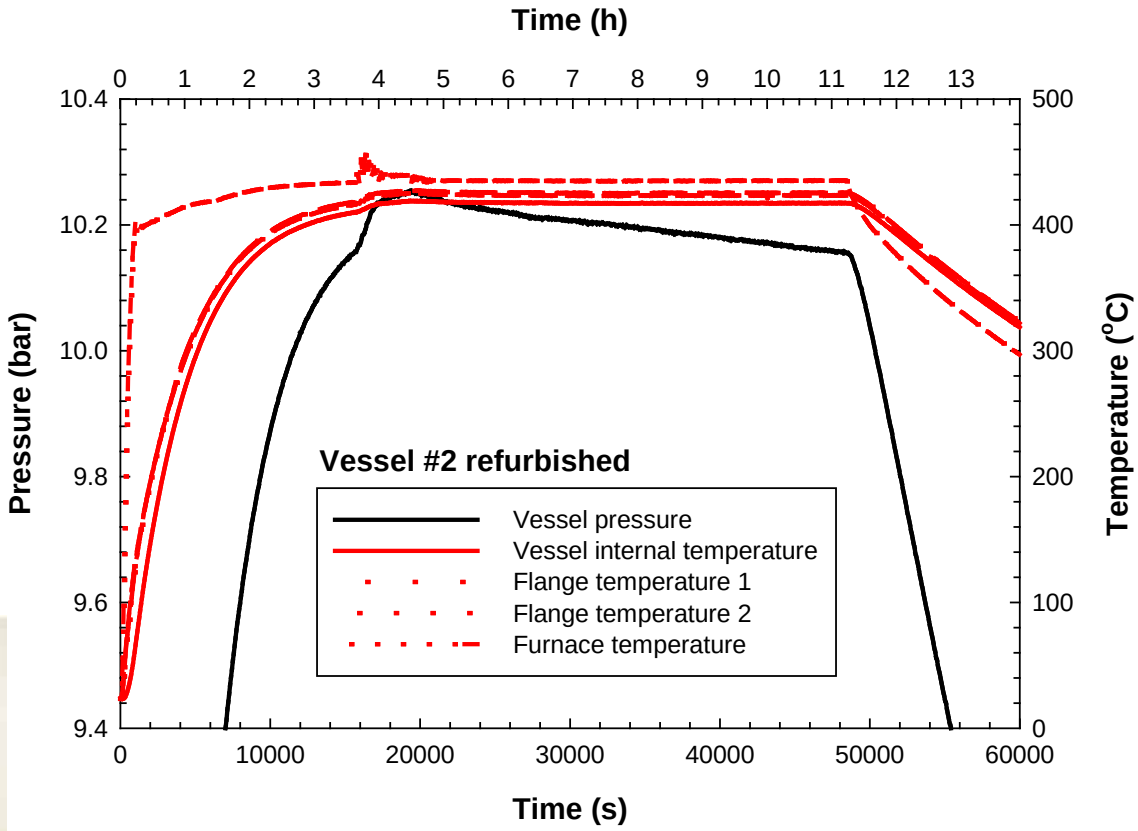
- Results:
  - Significant leak at around **5.5hrs** at 800°C



Test Descriptions and Results

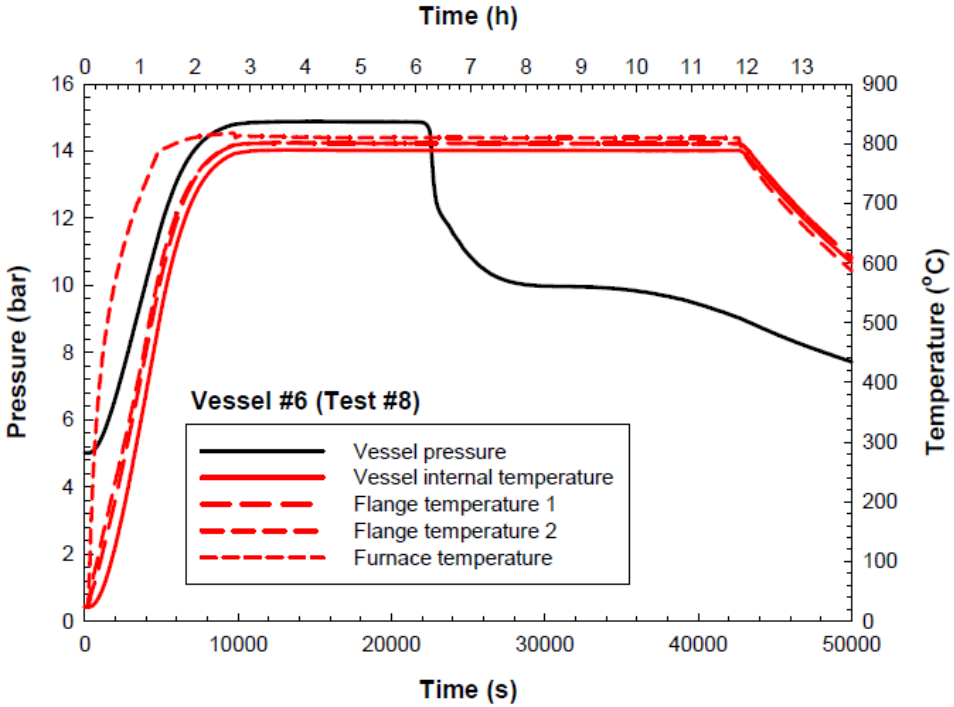
- Test #6:
  - Metallic seal
  - Heat-up + 9 hrs at 427°C + cool-down
  - Refurbished vessel

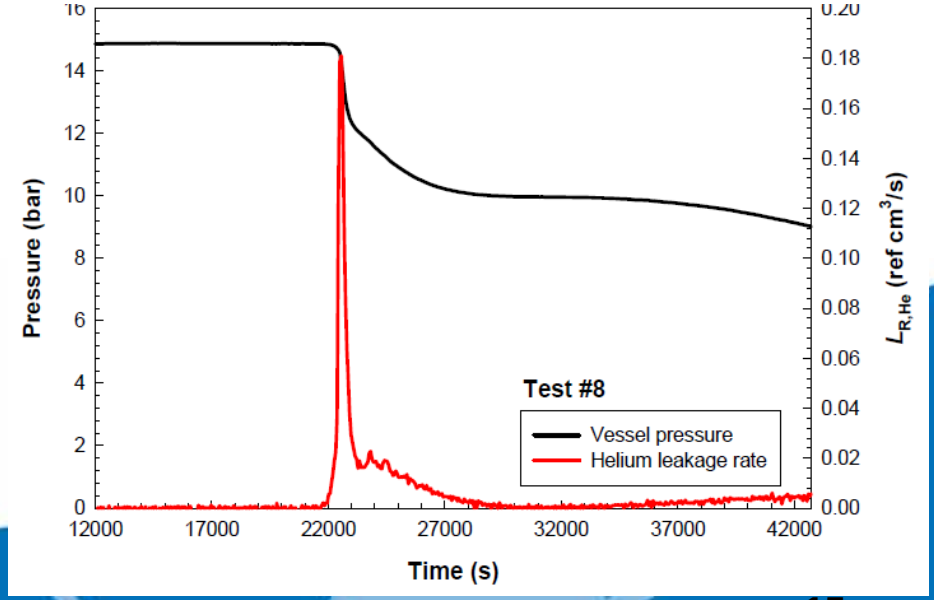
- Results:
  - Very small leak shortly after reaching 427°C



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

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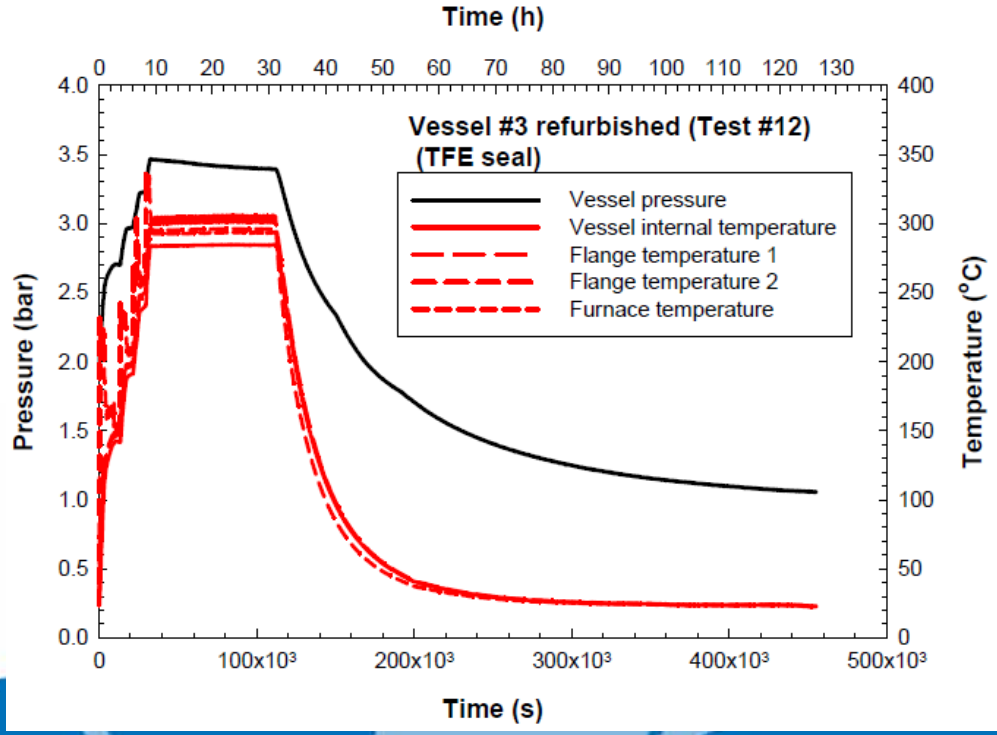
- Test #12:
  - TFE Seal
  - Incremental heating from 150°C (302°F) to 300°C (572°F) with 50°C increment + cool-down

- Results:
  - Slight drop in vessel pressure at the end of heating increase



Test Descriptions and Results

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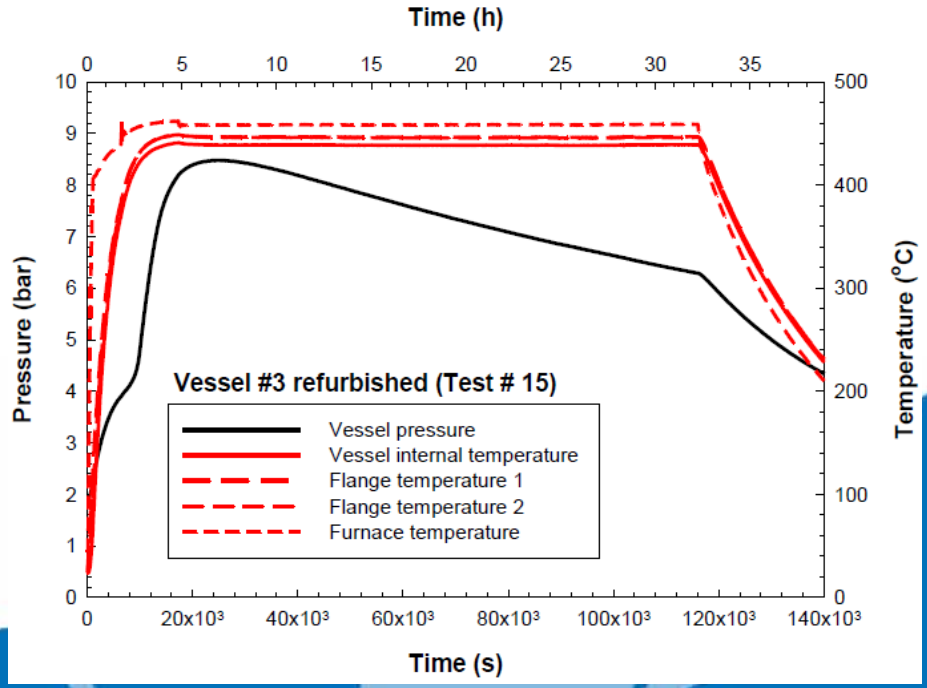
- Test #15:
  - Ethylene-propylene seal
  - Heat-up + 24+ h at 450º C (848ºF) + cool-down

- Results:
  - Leak occurred soon after the vessel had attained the nominal target temperature



Test Descriptions and Results

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- 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

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- 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
  - http://pbadupws.nrc.gov/docs/ML1211/ML12110A066.pdf
- Next Steps:
  - Further characterization of Polymeric Seals
  - Perform Tests on Double O-Ring Seal configuration

Questions?

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