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Product Performance

Performance of metal and polymeric O-ring seals during beyond-design-basis thermal conditions☆

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ABSTRACT

This paper summarizes the small scale thermal exposure test results of the performance of metallic and polymeric O-ring seals typically used in radioactive material transportation packages. Five different O-ring materials were evaluated: Inconel/silver, ethylene-propylene diene monomer (EPDM), polytetrafluoroethylene (PTFE), silicone, butyl, and Viton. The overall objective of this study is to provide test data and insights to the performance of these O-ring seals when exposed to beyond-design-basis temperature conditions due to a severe fire. Tests were conducted using a small-scale stainless steel pressure vessel pressurized with helium to 2 bar or 5 bar at room temperature. The vessel was then heated in an electric furnace to temperatures up to 900 °C for a pre-determined period (typically 8 h–9 h). The pressure drop technique was used to determine if leakage occurred during thermal exposure. Out of a total of 46 tests performed, leakage (loss of vessel pressure) was detected in 13 tests.

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1. Introduction

As described in 10 CFR Part 71.73 [1], the characterization of the performance envelop of seals used on radioactive material transportation packages are normally conducted under the hypothetical accident conditions (HAC) fire (800 °C for 30 min). However, historical non-nuclear transportation fire incidents suggest that potential thermal exposures could exceed HAC fire. Examples are the Caldecott Tunnel fire in 1982 [2], the Baltimore Tunnel fire that occurred in 2001 [3], and the MacArthur Maze fire in 2007 [4]. The performance of package seals is important for determining the potential for release of radioactive material from a package during a beyond-design-basis accident because the seals, in general, have lower temperature limits than other package components. The conservative approach for evaluating seal performance in any HAC or beyond-design-basis fire is to assume that seals fail completely if their normal operating temperature limits are exceeded at any point in the transient thermal evaluation of a given package. Such conservative and bounding approach yields the maximum possible estimates of potential for release of radioactive material from transportation packages in fire exposures.

An evaluation of the potential release of radioactive materials from three different transportation packages has been studied in detail by Adkins et al. [3]. The evaluation used predicted temperatures from a simulation of the Baltimore Tunnel fire using the NIST Fire Dynamics Simulator (FDS) [5] as boundary conditions for numerical models to determine the temperature of various components of the packages, including the seals. The model calculations predicted the seals exceeded their continuous-use rated service temperature in two of the packages evaluated, meaning a potential release of radioactive material if one assumed worst case performance (complete failure) of the seal. However, for both of those packages, the analysis determined, by a bounding calculation, that the maximum expected release was well below the regulatory

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limits for the release allowed during the HAC series of events in 10 CFR Part 71.

Previous work on O-ring seal performance reported in the literature has mainly focused on elastomeric seals and temperatures well below 800 °C. The test fixtures in previous work typically consisted of two flanges or two plates with two concentric O-ring grooves, one for the test seal and one for the secondary external seal, and a small cavity for helium tracer gas [6,7]. A similar experimental configuration was used to examine the performance of elastomer seals at temperatures below 0 °C [8]. Testing of package seals to determine their performance in beyond-design-basis fire scenarios can provide physical data needed to understand the seal performance and likelihood of a release of radioactive materials.

The objective of this work is to provide small scale experimental seal performance data for metallic and polymeric seals for thermal exposures beyond their rated temperatures. Both materials are used in the design of seals, with metallic seals having higher allowable temperatures due to their design and material properties. The data was obtained using a test fixture consisting of a vessel body and a flange cap. The scope of the testing does not evaluate the size of the test fixture as a test parameter with no attempts of scaling up the results. The testing was performed using new seals and did not evaluate the performance of aged seals under beyond-design-thermal exposure. An electric furnace was used to provide various controlled and repeatable thermal environments since it is difficult replicate a real fire environment for testing. This paper highlights and summarizes the test results. Detailed test descriptions and data analysis can be found in Yang et al. [9].

2. Experimental method

2.1. Test vessel and apparatus

The test fixture consists of a seamless vessel body with a flange machined from a stainless steel (SS 304) cylindrical stock and a removable SS 304 flange (vessel cap) with seal groove machined to O-ring manufacturer specifications. The flange dimensions were made in conformity with the ASME Standard B16.5–2009 [10], Flange Class 2500 with a design pressure rating up to 29.2 bar at 800 °C. The vessel body and the cap were joined together using four bolts. The vessel cavity had a nominal internal volume of 100 mL, and the whole apparatus had a nominal volume of 107 mL. Detailed engineering drawings of the test vessel, O-ring groove dimensions, and O-ring product information are provided in Yang et al. [9].

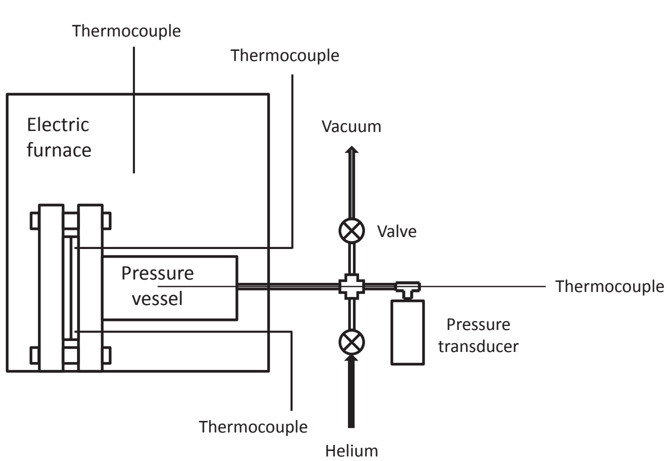

Fig. 1. A schematic illustration of the experimental apparatus.

Fig. 1 shows a schematic of the experimental apparatus. A pressure transducer and two needle valves (one for vacuum and one for helium supply) were connected to the test vessel. Four thermocouples (TC) were used to record temperatures, one placed in the interior of the vessel cavity, one inside the furnace and two located close to the O-Ring groove to monitor the temperatures experienced by the test seal. The exposure of the seal to a high temperature environment was achieved using a programmable temperature-controlled electric furnace with an internal capacity of 25.4 cm × 25.4 cm × 40.6 cm. The electric furnace has a maximum operating temperature of 1200 °C. Pressure and temperature data were recorded using a 16-bit data acquisition system at 100 Hz, with data recorded at 1 min intervals. Fig. 2 shows two photographs of the experimental apparatus.

2.2. Test procedure

The vessel was assembled and placed inside the furnace. The vessel was then evacuated for at least 60 s using a vacuum pump and was filled with helium (nominally to 5 bar for metallic seals and 2 bar for polymeric seals as specified by spent fuel shipping cask manufacturer's specifications) at room temperature. Helium is typically used for leak tests in spent fuel casks due to its propensity to leak and high sensitivity to detection compared to other gases.

Fig. 2. Photographs of the experimental apparatus.