

Severe Accident Testing of a Personnel Airlock

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INTRODUCTION

Sandia National Laboratories (Sandia) is investigating the leakage potential of mechanical penetrations as part of a research program on containment integrity under severe accident loads for the U.S. Nuclear Regulatory Commission (NRC). Barnes et al. (1984) and Shackelford et al. (1985) identified leakage from personnel airlocks as an important failure mode of containments subject to severe accident loads. However, these studies were based on relatively simple analysis methods. The complex structural interaction between the door, gasket, and bulkhead in personnel airlocks makes analytical evaluation of leakage difficult. In order to provide data to validate methods for evaluating the leakage potential, a full-size personnel airlock was subject to simulated severe accident loads consisting of pressure and temperature up to 300 psig and 800°F. The test was conducted at Chicago Bridge and Iron under contract to Sandia. Julien and Peters (1989) provide a detailed report on the test program.

TEST PREPARATIONS

The airlock tested in this program was partially fabricated for the Callaway Unit 2 nuclear power plant, which was subsequently cancelled. Construction of the airlock was completed for this test program. The test configuration is shown schematically in Figure 1. The personnel airlock consists of a cylindrical sleeve with a door/bulkhead assembly at each end. It was designed for 60 psig and 340°F 'inside containment' or 60 psig and 340°F simultaneously in the airlock (between the doors) and 'inside containment'. The airlock was fabricated entirely from A516 Gr 70 steel. The cylindrical sleeve has an inside diameter of 118 inches and is about 228 inches in length. The bulkheads are 1-1/2 inch thick flat plates that are reinforced with structural stiffeners. A 40 inch by 80 inch rectangular doorway is centered in each bulkhead and is framed by the primary bulkhead stiffeners. The doors are 1 inch thick plate and measure 84.5 inches by 46.5 inches, thereby overlapping the bulkhead doorway. The doors are pressure-seating and are held shut under ambient conditions with a latch mechanism that compresses the gasket approximately 1/16 to 1/8 inch.

Double dog-ear gaskets made of Presray EPDM E603 were used to maintain a seal between the door and bulkhead. Details of the sealing surfaces are shown in Figure 2. Before the severe accident test, the gaskets were subjected to an accelerated thermal aging process that was intended to simulate in-service radiation and thermal aging over a 40 year service life plus a loss-of-coolant-accident. The accelerated aging conditions were derived from calculations based on the Arrhenius model and involved heating the gaskets in place to a temperature of approximately 370°F for 172 hours. The aging process resulted in a significant change in the gasket cross section, to the point that the original double dog-ear cross section was not recognizable. At several points, the gasket material had flowed into the space between the door and bulkhead; this material prevented full compression of the

gasket into the gland (the gasket is designed to do this) and thereby precluded metal-to-metal contact between the door and bulkhead under pressurization.

Instrumentation included 123 strain gages, 115 thermocouples, 88 displacement transducers, 5 pressure transducers, and flow meters. Chamber V-1 was constructed to form a pressure chamber with the inner door and a leak tight bottom chamber was added to collect leakage past the outer door. Access manholes, nozzles for instrumentation feed-throughs, and pipe fittings were also installed. Additional information on the instrumentation, data acquisition, and heating and pressurization systems can be found in the report by Julien and Peters (1989).

The following simplifications were made for the purposes of this test:

- Based on analytical investigations, structural interaction between the containment wall and the airlock was considered to have a negligible effect on the deformation of the sealing surfaces and thus no effect on the leakage potential. No attempt was made to model the effects of the containment wall in this test.
- Heated air was used rather than steam to simplify structural and leakage measurements and, for safety reasons, the airlock was oriented vertically instead of horizontally. These differences affect primarily the heat transfer. On the inner door, forced convection was used to more closely approximate the heat transfer in a steam environment for a horizontal orientation. However, no correction was made for the heat transfer to the outer door. As a result, the temperature profiles from the inner door outward may not be representative.

Detailed finite element structural analyses were performed prior to the severe accident test as described by Clauss (1987). This analysis was used to help plan the location and measurement range of the instrumentation and the conduct of the test. The pretest analysis did not take into account the effects of (1) aging on the gasket, (2) temperature gradients in the door/bulkhead assemblies, or (3) thermal expansion of the gasket. Therefore, comparisons between the pretest analysis and experimental results must be interpreted carefully.

CONDUCT OF SEVERE ACCIDENT TEST

The loads used in this test were designed to simulate conditions under which different leakage mechanisms occur within the range of loads that could plausibly be obtained inside a containment during a severe accident. Models being developed at Sandia consider two basic factors in evaluating leakage potential of penetrations: 1) relative deformation of the sealing surfaces in response to pressure and temperature and 2) the performance of the gasket material, which depends strongly on temperature and aging effects. Organic gasket materials exhibit a threshold temperature at which their performance changes dramatically. Above the threshold temperature the gasket material becomes unstable; there are changes in the composition and integrity of the material, which may be due to actual combustion of the material. The threshold temperature for the EPDM material used to fabricate the 'double dog-ear' seals reported by Brinson and Graves (1988) is approximately 650°F (time is also recognized as an important parameter, but its effect is not quantified). In many severe accident sequences, the maximum temperature is less than this threshold temperature, but there are some sequences that may result in higher temperatures. Three cycles of loading were conducted to investigate the leakage potential of the airlock for two different regimes of gasket performance.

- Cycle 1: Temperature was held at approximately 400°F with stepwise pressurization to 300 psig in order to determine the leakage potential when the performance of the gasket is characterized principally by loss of resiliency (compression set retention) and other effects of aging.
- Cycles 2 and 3: Temperature was raised to approximately 800°F followed by stepwise pressurization to 300 psig in order to investigate the leakage potential

when the gasket material is heated beyond its stability limit. Cycle 2 was an unsuccessful attempt to heat the gasket on the inner door beyond its threshold temperature, thereby necessitating Cycle 3.

Pressure was limited to 300 psig since other components of the containment pressure boundary would certainly fail at or below this pressure.

4. TEST RESULTS AND ANALYTICAL COMPARISONS

Leakage

During the first two load cycles of the severe accident test, no leakage past the inner door was measured. As expected, the relative deformation of the sealing surfaces was small and the gasket material had enough resiliency to maintain a seal. The gasket temperature in these first two cycles did not exceed its stability limit.

Before the third load cycle, temperature above the inner door was maintained (at low pressure) at 800°F for over two hours to ensure that the gasket material was heated beyond its threshold temperature. During this cycle, a large portion of the gasket on the inner door was ejected from its groove at 150 psig and from this point on the inner door was effectively bypassed. Pressurization continued to 300 psig (because of the inner door seal failure, the air space between the doors was also pressurized to 300 psig), but no leakage past the outer door was detected. The gasket on the outer door was subject to much lower temperature (the maximum temperature of the outer door was approximately 100°F) due to the isolation of the outer door from the loads inside containment provided by the airlock space. As a result, the leak integrity of the outer door and thus, of the airlock as a whole, was maintained.

The condition of the gasket after the test is shown in Figure 3. Along the bottom of the door, the gasket material was gone altogether. In other areas, the gasket was charred and badly cracked. Also, an oily, sooty coating was found on the fixtures and piping that was in the path of leakage from the inner door. These observations suggest that the instability of the EPDM gasket can be characterized as ignition and combustion of the material.

The accelerated aging of the gaskets may have affected the performance of the inner door seal. Because the gasket flowed into the space between the door and bulkhead during aging, it was not possible to obtain metal-to-metal contact between the sealing surfaces during pressurization. The gasket is designed to allow metal-to-metal contact when it is fully compressed; the tests described by Brinson and Graves (1988) indicate that metal-to-metal contact can prevent significant leakage even when the gasket material is heated beyond its stability limit. Conversely, thermal expansion of the gasket could prevent full compression and metal-to-metal contact even if the gasket is not aged.

Structural Response

The structural integrity of this airlock was exceptional; as predicted by analyses, the maximum strains at 300 psig were only about 0.3% and there was no significant risk of structural failure. As indicated by Figure 4, analytical predictions were reasonably accurate for the response of the bulkheads. The response was essentially linear and the effect of elevated temperature on the bulkhead deformation was small. Unfortunately, comparisons for the sealing surface deformations are not very meaningful because the changes in the gasket properties resulting from thermal aging were not modeled in the pretest predictions. Also, thermal expansion of the gasket material, which was neglected in the analysis, apparently had a significant effect on the deformations of the inner door. Nevertheless, the pressure-induced deformations of the sealing surfaces were small, as predicted by analysis. Additional study of the door and sealing surface deformations is required to validate analysis methods. Future evaluations of leakage from penetrations should take the thermal expansion of the gasket into account.