Experiments to Determine the Leakage Behavior of Pressure-Unseating Equipment Hatches

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1 INTRODUCTION

Under the sponsorship of the United States Nuclear Regulatory Commission, Sandia National Laboratories is conducting several research programs to develop methods for estimating the ultimate pressure capacity, at elevated temperatures, of light water reactor containment buildings. These programs are collectively known as the Containment Integrity Programs. The developed methods will be used to assess the performance of containments in the highly unlikely event of a severe accident. A recent summary of these programs is provided by Parks et al. (1990a).

As a part of the Containment Integrity Programs, a series of tests were recently conducted to investigate the leakage potential of pressure-unseating equipment hatches. By unseating it is meant that the containment pressure pushes the hatch cover away from the containment wall thus 'unseating' or separating the sealing surfaces such that metal-to-metal contact no longer exists.

2 BACKGROUND INFORMATION

Based on the information provided by Shackelford et al. (1985), pressure-unseating equipment hatches are used in approximately 20% of all LWR containment buildings in the United States. The most common seal designs are tongue-and-groove and O-rings. Ethylene propylene diene terpolymer (EPDM) or silicone (Si) materials are normally used to construct the gaskets. The hatch covers are fastened to the containment shell by eye-bolts (sometimes referred to as 'swing' bolts) or by hexagonal-head bolts. The bolt preload varies from plant-to-plant such that unseating of the sealing surfaces will usually occur at pressure levels between 1.1 to 1.5 times the containment design pressure, P_d.

3 DESCRIPTION OF TEST PROGRAM

3.1 Test Specimen and Instrumentation

A pressure-unseating equipment hatch on a 1:6-scale reinforced concrete containment model (Horschel 1988) served as the test specimen. A sketch of the hatch design is shown in Figure 1. This hatch was virtually undamaged by a previous overpressurization test of the containment model (in July 1987); thus, it was an ideal specimen for further investigation of pressure-unseating hatch covers. As shown in Figure 1, the hatch includes a tongue-and-groove sealing configuration with rectangular gaskets. A total of

SMiRT 11 Transactions Vol. F (August 1991) Tokyo, Japan, © 1991

twenty eye-bolts are used to connect the hatch cover to the sleeve. It should be noted for future reference that the design pressure for the reinforced concrete containment model, including the unseating equipment hatch, was 46 psig.

In preparation for these tests, the inner, pressure-seating cover was welded shut to prevent leakage into the containment model. During the tests, the volume between the hatch covers was pressurized using nitrogen gas. Radiant heaters were used for the elevated temperature tests. Separation of the sealing surfaces was measured by displacement transducers at ten equally spaced locations around the circumference of the hatch cover. Strain gages were attached to the bolts to measure the total bolt preload and the total bolt load during the tests. The bolt temperature was monitored by thermocouples (TCs) that were welded to the bolts. Other sensors were used to monitor the applied test pressure and temperature as well as the amount of leakage.

3.2 Test Matrix

Several parameters that affect the leakage behavior of pressure-unseating equipment hatches were identified and incorporated into the test matrix. Bolt parameters such as preload and stiffness have a direct effect on leakage. The bolt load may also be affected by the temperature differential between the bolts and sleeve. The gasket parameters of primary importance are the type of material (EPDM or silicone), the condition of the gasket (aging effects), and the effect of temperature on the gaskets.

As shown in the test matrix in Table 1, the effect of these parameters has been investigated through a series of thirteen tests. Both EPDM and silicone gaskets were tested; however, the majority of the tests were of EPDM gaskets, because they are more commonly used in U.S. penetrations. In order to determine the effect of gasket condition on leakage, some of the gaskets were thermally aged in an air environment at 300°F for six or seven days. This amount of aging is intended to approximate the condition of the gaskets at the end of a 40 year life (Orwick 1986).

The total bolt preload varied such that unseating occurred at 0.9 to 1.4P_d. To investigate the effect of bolt stiffness, every other bolt was left out in tests HT1 and HT2. This reduced the total bolt stiffness by one-half for these tests.

The hatch was subjected to several different temperature conditions. As shown in Table 1, the first four tests (HT1-HT4) were conducted at ambient temperature. For the second group of four tests (HT5-HT8), the pressure and temperature were increased simultaneously according to the saturated steam pressure versus temperature relationship. (As mentioned earlier, nitrogen gas was used as the pressurizing medium.) Tests HT9 through HT13 were conducted at the constant temperature level that is shown. Before beginning pressurization, the temperature was held at these levels for a minimum of two hours.

3.3 Test Results

Results of the test program are summarized in Table 2. Leakage onset pressure is arbitrarily defined as the pressure at which leakage past the unseating equipment hatch first reached 1 standard cubic foot per minute (scfm). This amount of leakage corresponds to about 14% mass/day for the containment model. Leakage onset occurred in all tests before general yielding of the bolts.

3.3.1 Effect of Bolt Preload and Bolt Stiffness on Leakage. As expected, increasing bolt preload and stiffness was effective in increasing the containment pressure required to produce leakage. The effect of bolt preload may be seen by comparing the results of HT5 and HT6. The bolt preload was such that unseating would occur at 1.2P_d (57 psig) for HT5 and 1.0P_d (46 psig) for HT6. As shown in Table 2, leakage onset was 175 psig for HT5 and 155 psig for HT6.

HT2 and HT3 may be compared to examine the effect of total bolt stiffness on leakage. As indicated by the leakage/unseating pressure ratios in Table 2, the larger bolt stiffness in HT3 was effective in delaying leakage to a higher relative pressure level than for HT2.

3.3.2 Effect of Gasket Material on Leakage. A comparison of the observed leakage behaviors of EPDM and silicone gaskets is provided in Figure 2. For the compared tests the gaskets were thermally aged and had a bolt preload such that unseating would occur at the design pressure of 46 psig. As shown, the leakage behavior of the EPDM and silicone gaskets was similar at 370°F; however, silicone performed much better than EPDM at 700°F. The latter results agree very well with the results of previous seal and gasket test programs (Brinson and Graves 1988).

Previous testing of seals and gaskets revealed that the degradation temperature of EPDM is normally in the range of 600-650°F and that it is independent of the test environment. However, the degradation temperature of silicone gaskets is highly dependent on the test environment. In a steam environment, the tested silicone gaskets normally failed around 500°F whereas in nitrogen or air, they did not fail until the temperature approached 700°F. Because the equipment hatch tests were conducted in a nitrogen environment, it was expected that the silicone gaskets would perform much better than EPDM at 700°F. However, it should be recognized that, if steam had been used instead of nitrogen, the silicone gaskets would have likely performed worse than EPDM in the temperature range of about 500-650°F.

3.3.3 Effect of Aging on Leakage. Thermal aging did not have a significant effect on the observed leakage behavior. In fact, the unaged gaskets in HT6 actually leaked more for a given pressure level than the aged gaskets in HT7. Again, this result agrees with the information gained from past seal and gasket test programs (Brinson and Graves 1988).

3.3.4 Effect of Temperature on Leakage. Surprisingly, elevated test temperatures, up to the gasket degradation temperature, did not have an appreciable effect on leakage. Figure 3 provides a comparison of four tests in which the only difference was in the applied test temperature. As shown, at 370, 500, and 600°F the leakage behavior was quite similar. However, at 700°F the EPDM gasket material was degraded to the point that it was not effective at preventing leakage for pressures much beyond the unseating pressure of 46 psig. As previously mentioned, it was expected that the leakage behavior of EPDM gaskets at 700°F would be poor; however, before conducting this series of tests, the effect of temperatures up to the degradation temperature was not known.

3.3.5 Comparison of Leakage Onset to Unseating Pressures. A summary of the leakage onset pressure levels is provided in Table 2. As shown, there was considerable margin between the leakage onset pressure and the unseating pressure. In fact, there was a factor of three between the leakage onset and unseating pressures for all tests except HT1, HT2, HT9, and HT10. For HT1 and HT2, only half of the intended number of bolts were used. Therefore, it was expected that there would be less margin for these tests. For HT9 and HT10, the gaskets were completely degraded before beginning the pressure tests. Thus, the margin between leakage onset and unseating for these tests was much lower than for the tests conducted below the gasket degradation temperature.

4 SUMMARY

A series of thirteen tests has been conducted to determine the leakage behavior of pressure-unseating equipment hatches. The tested unseating equipment hatch is a part of the 1/6-scale reinforced concrete containment model at Sandia. During the test series, the effect of the following parameters on leakage was observed: bolt preload and stiffness, gasket material, aging, and temperature. A summary of the findings of this test program is provided below:

1) increasing bolt preload and/or stiffness effectively delayed leakage to higher pressure levels,
2) leakage was not significantly affected by gasket material, aging, or test temperature up to the gasket material degradation temperature, and
3) there is considerable margin between the leakage onset and unseating pressures up to the gasket material degradation temperature.

Additional information on this test program is provided by Parks et al. (1990b). This reference presents a semi-empirical method, based on the results of this test program, to estimate the leakage onset pressure for unseating equipment hatches.

5 ACKNOWLEDGEMENT

This work was supported by the U.S. Nuclear Regulatory Commission and performed at Sandia National Laboratories, which is operated by the U.S. Department of Energy under contract number DE-AC04-76DP00789.

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Table 1
Test Matrix

Test Designation	Gasket Material	Aging Duration (hours)	(Bolt Preload)[1] Unseating Pressure (xP_d)	Number of Bolts	Test Temperature (°F)
HT1	Si	144	0.9	10	AT[2]
HT2	EPDM	Unaged	1.0	10	AT
HT3	EPDM	Unaged	1.4	20	AT
HT4	EPDM	168	1.3	20	AT
HT5	EPDM	Unaged	1.2	20	SS[3]
HT6	EPDM	Unaged	1.0	20	SS
HT7	EPDM	168	1.0	20	SS
HT8	Si	168	1.0	20	SS
HT9	EPDM	Unaged	0.9	20	700°F
HT10	EPDM	168	1.0	20	700°F
HT11	Si	168	1.0	20	700°F
HT12	EPDM	Unaged	1.0	20	500°F
HT13	EPDM	Unaged	1.0	20	600°F

1. Bolt preload is expressed as a multiple of the hatch design pressure.
2. AT - indicates that the test was conducted at ambient temperature, normally around 70°F.
3. SS - indicates that the pressure versus temperature relationship was equivalent to saturated steam throughout the test.

Table 2
Results of Pressure-Unseating
Equipment Hatch Tests

Test Designation	Unseating Pressure (psig)	Leakage Onset Pressure (psig)	Leakage Onset Temperature (°F)	Leakage/ Unseating Pressure
HT1	40	90	AT	2.2
HT2	48	110	AT	2.3
HT3	63	195	AT	3.1
HT4	61	>180	AT	>3.0
HT5	57	175	375	3.1
HT6	46	155	365	3.4
HT7	46	155	365	3.4
HT8	46	170	375	3.7
HT9	42	60	700	1.4
HT10	47	70	700	1.5
HT11	45	140	700	3.1
HT12	48	145	500	3.0
HT13	47	145	600	3.1

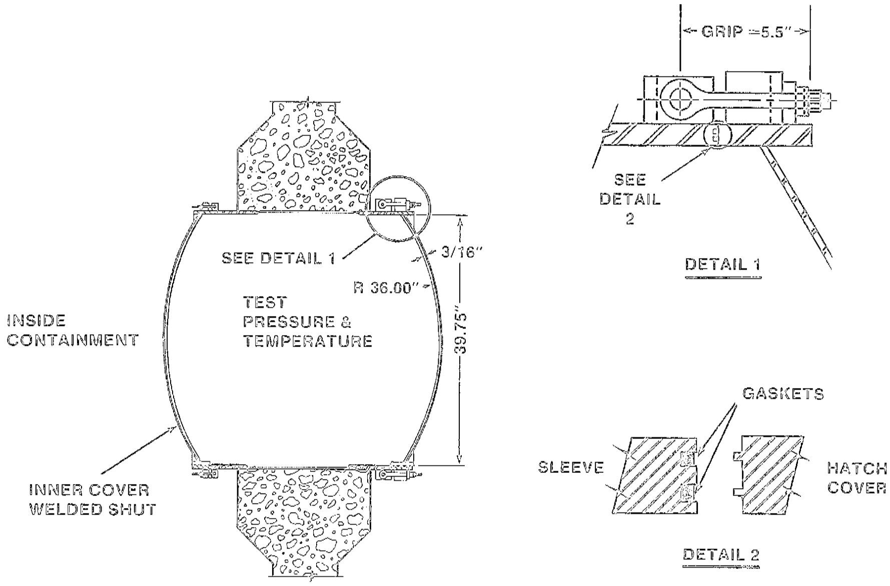

Figure 1. Sketch of the Tested Pressure-Unseating Equipment Hatch

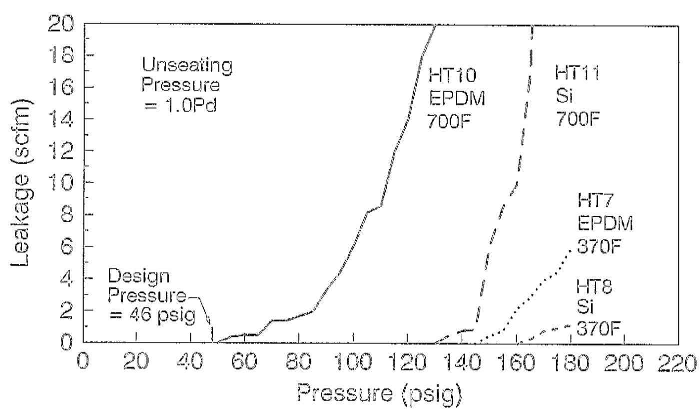

Figure 2. Effect of Aged Gasket Material on Leakage

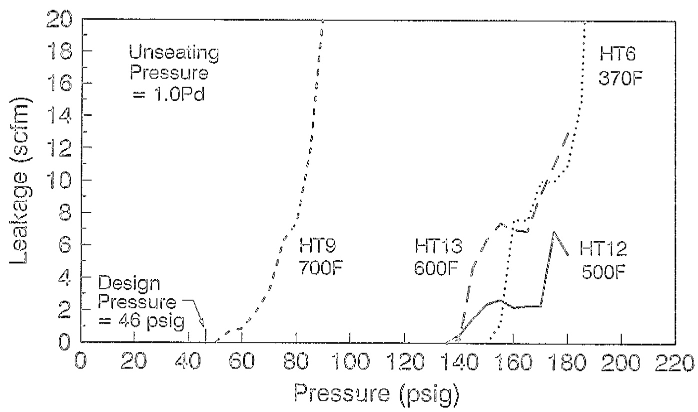

Figure 3. Effect of Temperature on Leakage of Unaged EPDM Gaskets