EPRI

Deterioration and Evaluation of Steel Liners and Vessels: Operating Experience

Technical Brief — *Nondestructive Evaluation, P41.04.01*

1 Introduction and Background

Preserving the integrity of containment liners is important to their ability to perform their main function—to maintain leak-tightness in the event of a loss-of-coolant accident. Over the years, numerous cases of containment liner deterioration have been documented in different publicly available sources. This report presents a compilation of the cases in which liner deterioration has been documented as well as recent operating experience that has not been documented in the literature. The report also presents insights regarding the inspections performed by utilities to verify the condition of the liners in the structure.

The report is divided into sections. Section 2 presents common examples of liner deterioration and the mechanisms behind it. Section 3 presents operating experience and instances of liner deterioration in the United States, France, Sweden, South Africa, and South Korea. The report ends with a summary and conclusions in Section 4.

As plants age, the inspection of liners and understanding liner deterioration become increasingly important. The operating experience presented in this report provides essential background information for utilities that might face this issue.

2 Examples of Liner Deterioration

This section presents a summary of the typical cases or scenarios of liner deterioration that have been noted in the industry. The typical cases include deterioration of the liner on the concrete side, deterioration of the liner at the concrete-liner interface at the transition where the liner becomes embedded, and deterioration of a liner embedded in concrete. In service, visual inspections of the accessible area of the liner have provided the first indications of deterioration. Once the results from visual inspection are assessed, in many cases, a more detailed inspection (ultrasonic, sounding, or destructive) is performed. This report does not include details about specific containment design or the mechanics of the corrosion process. Information related to these topics can be found in publicly available references [1–3].

2.1 Corrosion of Liners with One Side in Contact with Concrete

Corrosion initiating from the part of the liner that is in contact with concrete has been documented in multiple nuclear power plants around the world and is the most common occurrence of documented cases of liner corrosion [3, 4]. Corrosion initiating from the concrete side of the liner has been associated with objects embedded in the concrete that are in direct contact with the liner, lack of consolidation or large voids behind the liner that were created during initial construction, and construction joints that were left open and exposed during construction for extended periods in coastal plants [4, 5].

For items embedded in concrete, the most common item found has been wood or wood items left behind the liner during construction. The high-alkaline environment generated by the concrete provides protection to the liner plate by generating a passivating layer on the steel. The presence of wood in contact with the liner prevents the plate from becoming passivated. Further, the wood will likely absorb moisture from the concrete surrounding it and will serve as a localized point where corrosion can initiate.

From the corrosion standpoint, voids or honeycombs left behind during construction generate a similar environment to the piece of wood where the void is an area that is not passivated by the high-alkaline environment of the concrete and is therefore more susceptible to corrosion. Trapped moisture from the concrete and oxygen in the void further assist the corrosion process that can create loss of thickness on the steel liner or through-wall corrosion.

In the case of a construction joint exposed to the elements for extended periods in a plant near the ocean, the chlorides deposited on the construction joint are concerning. However, chlorides deposited between the liner and the concrete at a gap between the concrete and liner are of greater concern. When this occurs, the chlorides deposited adjacent to the steel liner will disrupt the passivating layer and promote and accelerate the corrosion process. The chlorides and air gap between the liner plate and concrete will generate corrosion activity on the plate [6].

In the instances where corrosion on the concrete side of the liner has been encountered, deterioration has been found on the surface of the liner in routine visual inspection followed by ultrasonic inspection of the thickness of the liner or by performing ultrasonic inspections in suspect areas. Reports of blistering on the surface were typically the first indicator that triggered a more detailed ultrasonic inspection of the thickness of the plate. In some instances where suspect areas were inspected with ultrasonic thickness measurements and found to have loss of cross-section in the liner, there were no signs of visual deterioration on the exposed surface of the liner.

2.2 Corrosion at the Intersection of Concrete Interfaces with Exposed Liner

Several occurrences of corrosion at the location where the steel liner or containment intersects the concrete have been documented in several plants around the world [4]. This type of corrosion can be divided into two scenarios: 1) corrosion at the concrete liner interface of the inside-diameter surface of the liner and 2) corrosion on the outside diameter (OD) of a freestanding containment liner.

In the first case, corrosion may be caused by a gap or separation between the liner and concrete at the intersection of the concrete and liner (see Figure 2-1). The vertical portion of the liner becomes embedded in concrete on the interior of the containment to allow the concrete to be a walking surface or support for equipment. As the liner becomes embedded in concrete, it gradually transitions with some curvature to the plate from a vertical to a horizontal position. If water accumulates at the region between the concrete and the steel liner, the environment becomes favorable to promote corrosion of the liner. In some containment structures, the transition region consists of a cavity with a liner in contact with each surface of the cavity. In some cases, the cavity is filled with alkaline water to prevent deterioration and corrosion of the steel plate.

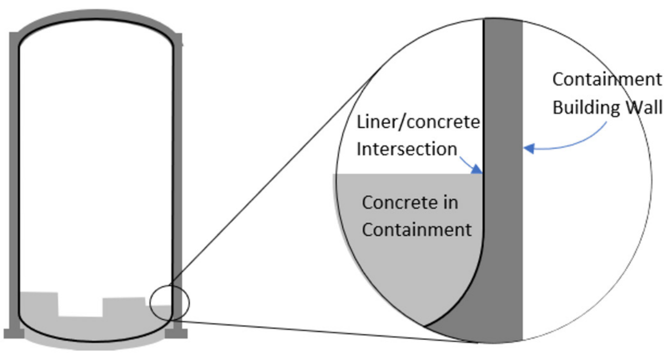

Figure 2-1. Containment liner at the intersection of an interior horizontal concrete surface

The scenario of corrosion on the exterior of the steel vessel plate is common for freestanding steel containments with a shield or enclosure building that protects the containment vessel from the elements (see Figure 2-2). In this type of structure, is it common to find a cavity between the steel plate and shield building. Within the cavity, the concrete might intersect the exterior of the steel plate. Similar to the case of corrosion on the interior of containment, a gap between the steel plate and concrete plus the presence of moisture could generate an environment that promotes corrosion.

In both scenarios of corrosion—interior or exterior—deterioration has been detected through visual inspection followed by ultrasonic thickness measurement of the steel plate. If the steel plate thickness is within the allowable limit, the steel is cleaned and coated, and the concrete is restored. If the thickness of the plate has been compromised, a plan to restore the thickness of the plate is put in place. This typically consists of welding an additional thickness of plate or performing a weld overlay.

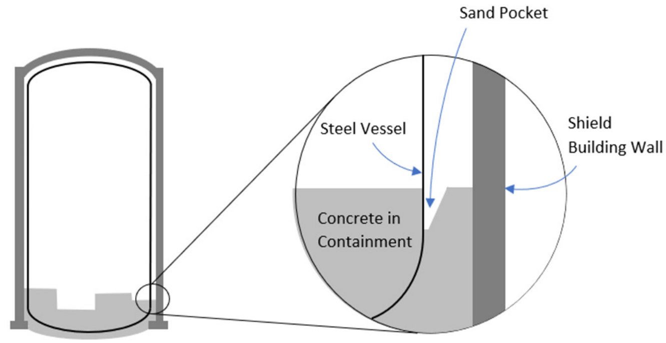

Figure 2-2. Steel vessel, shield building, and general detail of the sand pocket region

2.3 Corrosion of Liners Embedded in Concrete

This type of corrosion can be found in regions beyond the intersection of the concrete-liner interface (see Figure 2-3) and in containment buildings that have a steel liner embedded in concrete (see Figure 2-4). The main concern with this type of deterioration is that it cannot be detected through visual inspection because the liner is fully embedded in concrete. Some indications of deterioration of liners embedded in concrete have been realized by analyzing the results from leak rate testing and through-wall gas leakage detection. However, the gas leakage detection method provides only an approximate location of the deterioration. Concrete removal from inside the diameter of containment has been performed during these scenarios to find and repair the defects. Once the concrete is removed, visual and ultrasonic thickness measurements of the steel plate are performed to detect the extent of the condition. When defects have been found, these were caused by embedded wood objects, voids, or honeycombing resting against the surface of the plate.

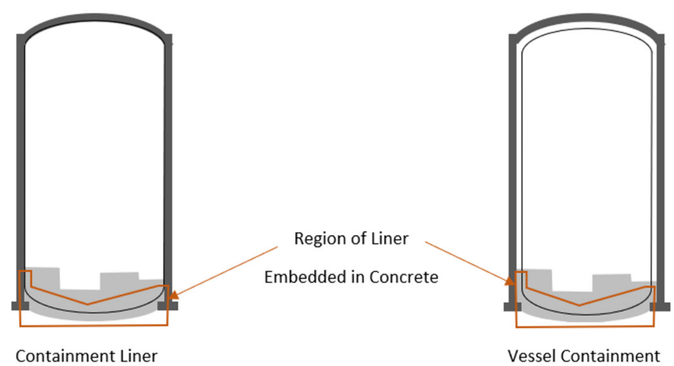

Figure 2-3. Examples of liner and vessel embedded in concrete

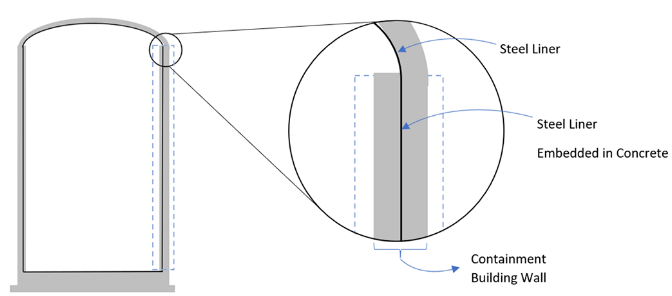

Figure 2-4. Example of containment with liner embedded in the containment wall

Once the defects are detected, the concrete behind the plate is restored, a new section of plate is welded, and the concrete cavity on the interior diameter of the containment is filled. A follow-up leak rate test is performed to verify the effectiveness of the repair.

3 Operating Experience

This section presents operating experience on liner deterioration and inspection. The following summarizes the operating experience with liner deterioration in nuclear power plants around the world as recorded in publicly available documents. Also included is a recent case in which an embedded liner was inspected as part of a licensing commitment. Note that information about deterioration of liners from countries not included in this report was not found.

3.1 Operating Experience from the United States from Publicly Available References

Numerous cases of liner deterioration have been documented through the years by plants in the United States. The occurrences have been recorded in publicly available documents published by the U.S. Nuclear Regulatory Commission (NRC) and the national laboratories. Due to the large number of cases documented, a summary of the type of deterioration and the respective references is given in Table 3-1. Most of the cases fall in the scenario of corrosion from the concrete side of the liner and corrosion at the intersection of the concrete-liner interface. Cases of embedded liner deterioration have not been documented.

Table 3-1. Summary of cases of liner deterioration in U.S. plants

Plant Name	Occurrence(s)	Reference(s)	Summary Description
Beaver Valley 1	1992, 2009, 2006	3, 7, 8	Corrosion of steel liner. The incident in 2009 was associated with a piece of wood embedded in concrete behind the liner. The incident in 2006 involved pitting found on the concrete side of the liner during the execution of a steam generator replacement.
Braidwood 1	1994	7	Liner leakage detected but not located
Brunswick 1	1987, 1993	7, 9	Corrosion of steel liner, corrosion of the toride plate
Brunswick 2	1988, 1993,1999	3, 7, 8	Corrosion of steel liner—1999 clusters of corrosion pitting and 2-mm-diameter holes
Catawba 1	1989	7	Corrosion on the outside of the steel cylinder in the annular region
Catawba 2	1989	7	Corrosion on the outside of the steel cylinder in the annular region
DC Cook	2001	3	Corrosion of steel liner caused by a wood-handled brush embedded in concrete and in contact with the liner
Fitzpatrick	N/A	9	Containment torus corrosion
Grand Gulf 1	2004	3	Weld overlay repair of containment liner
Limerick Unit 1	2006	3	Damage on the suppression pool liner
McGuire 1	1989, 1990	7	Corrosion on the OD of the steel cylinder in the annular region at the intersection with the concrete floor
McGuire 2	1989	7	Corrosion on the OD of the steel cylinder in the annular region at the intersection with the concrete floor
Nine Mile point	1988	9	Torus shell corrosion
North Anna 2	1999	3, 7	6-mm-diameter hole in liner due to corrosion caused by a piece of wood embedded in concrete and in contact with the liner
Oyster Creek	1986, 1989	9	Drywell plate corrosion
Robinson 2	1992	8	Containment liner loss of material
Salem 1	N/A, 2017	3, 10	Liner corrosion inside containment
Salem 2	1993	7, 8	Corrosion of steel liner
Seabrook	2020	11	Liner corrosion
Three Mile Island 1	1993	8	Loss of material
Turkey Point 3	1992	9	Liner corrosion and bulging
Turkey Point 4	1992	8, 9	Liner corrosion and bulging

3.1.1 *Liner Inspection at the Davis-Besse Nuclear Power Station*

This section summarizes the activities executed by the Davis-Besse Nuclear Power Station as part one of their license renewal commitments. The station made two commitments to inspect several portions of the freestanding vessel plate during the outage scheduled in February 2014. One commitment consisted of inspecting the OD of the freestanding vessel plate in a region where concrete and vessel plate intersected. The second commitment consisted of performing a steel plate thickness measurement as close as possible to the lowest region of the containment vessel plate embedded in concrete [12].

3.1.1.1 Procedure Preparation and Staff Qualification

In both commitments, the utility prepared a procedure and qualified the procedure and personnel using mockups to go through the different steps in the evolution of concrete removal. A more specific description of the process is given in the sections relevant to each part of the structure.

Regarding personnel and qualification of tooling, the mockups allowed individuals to have first-hand practice in conditions that resembled what would be expected in the field. The tools and techniques for removing concrete were also tried, and the best combination of tools was selected to execute the commitments during the outage.

3.1.1.2 Sand Pocket Inspection

The structure housing the reactor at the Davis-Besse Nuclear Power Station consists of a freestanding steel vessel with a concrete shield building. The region identified as the sand pocket is in the cavity between the shield building and the containment vessel plate. At the sand pocket, the steel vessel intersects with concrete, and the objective of the investigation was to ensure that the vessel plate had sufficient thickness in that region and to investigate if any corrosion was present below the elevation of the concrete at the concrete-steel vessel intersection.

The commitment required concrete to be removed below the intersection between the concrete and vessel plate intersection. A series of overlapping cores was drilled a few centimeters away from the vessel using a wet coring method. The remaining thickness of concrete was removed with hand tools to avoid damaging the vessel plate.

After exposing the plate, plant personnel performed ultrasonic thickness testing on the surface of the exposed plate. The tests indicated that the locations exposed below the intersection between the concrete and steel vessel did not have significant corrosion and that the steel vessel plate thickness was within the design tolerances.

3.1.1.3 Inspection of the Bottom of the Vessel Embedded in Concrete

The second commitment required the vessel plate to be inspected in the lowest region possible near the center of the vessel. To achieve this objective, plant personnel identified a hallway near a sump as the best location to remove concrete and to gain access to the bottom of the vessel plate. According to the drawings, the thickness of the concrete before reaching the plate at the inspection location was approximately 1.4 m (4.5 ft). This same thickness was incorporated in the concrete mockups used during the procedure development effort to practice concrete removal with the tools required for doing the work.

The engineering team responsible for the inspection restricted the amount of concrete and reinforcement that could be removed to reach the concrete plate. The team recommended removing an area no larger than 30 cm x 30 cm (12 in. x 12 in.), and only one piece or reinforcing could be removed for each layer. For removing the concrete, four 15-cm-diameter (6-in.-diameter) cores were marked in the 30 cm x 30 cm (12 in. x 12 in.) area. The cores in the first set were drilled to a depth of 15 cm (6 in.) from the top horizontal surface using a wet coring method. Once the depth was reached, the cores were extracted, and a new layer of cores would be removed. The remaining depth of coring was completed using a dry coring bit that is typically used for drilling through masonry. The reason for performing dry coring was to avoid including any water in the process and to see if a source of water was present along the depth or near the plate. At each layer of concrete removal, ground-penetrating radar was performed to identify any potential interferences not documented in the drawings. Figure 3-1 presents a plan and cross-section of the concrete removal sequence. Figure 3-2 presents the wet coring of the top surface of the concrete and the concrete cavity near the bottom layer of reinforcement.

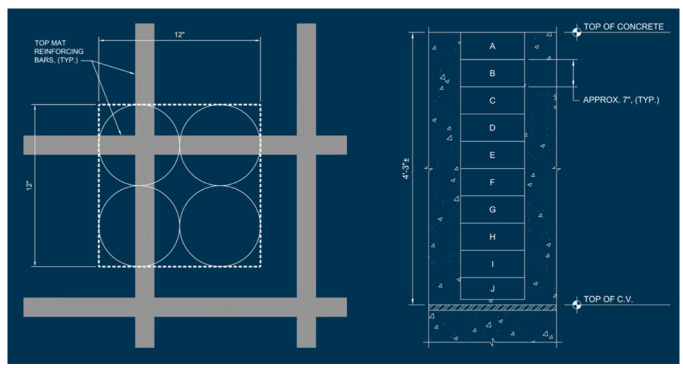

Figure 3-1. Plan and elevation of the concrete removal sequence (Used with permission from Energy Harbor.)

Once the bottom layer of reinforcement was reached, a long-handled needle scaler was used to reach the vessel plate. During the procedure preparation, 23 different tools were placed against a metal plate of similar thickness as the vessel to document the amount of damage that the tools could impose if they contacted the plate. During the trials, it was documented that the needle scaler was the tool that caused the least damage to the plate and was capable of removing concrete.

Once the plate was reached and exposed, an ultrasonic thickness measurement of the plate was collected. The thickness of the plate was within the acceptable range noted in the design drawings, and no water was observed during the concrete removal process. After performing the thickness measurement of the vessel plate, the cavity was filled with bagged repair mortar. The samples removed during the demolition process were subjected to petrographic examination and compressive strength. The petrographic examination did not indicate deterioration of the concrete, and the

Figure 3-2. Top surface of the concrete after wet coring (left) and bottom of the cavity a few centimeters away from the plate (right) (Used with permission from Energy Harbor.)

compressive strength was documented to be in the range of 75.8 MPa (11,000 psi), which is more than twice the design compressive strength of 34.5 MPa (5000 psi).

3.2 Operating Experience from France

3.2.1 Background, Containment Design, and Findings

The 900-MW French fleet containment is based on a prestressed wall and liner anchored at the inner face of the concrete. At the bottom of the building, the steel liner is embedded in concrete between the containment raft and internal concrete surface. Channels are positioned below the steel liner plate welds to monitor potential leaks.

The wall near the bottom of the containment building is angled toward the interior diameter of the structure until the bottom of the liner is reached, and adjoining liner plates are connected to conform the containment liner. A space between the internal concrete and liner was incorporated in the design to accommodate displacements caused by temperature effects. For means of constructability, the space was filled with a joint material called *Flexcell*.[1]

In the early nineties, during a plant inspection, Électricité de France (EDF) found widespread corrosion in the region of the seal [13]. The corrosion ranged from isolated spots to areas where the liner thickness was consumed by the effects of corrosion. The Flexcell material was noted to contain some chlorides. The presence of chlorides in the flex seal and occasional presence of moisture at the intersection of the liner and interior concrete surface created an environment that promotes corrosion.

All the other plants with similar configurations were also checked, and a similar type of generalized corrosion was found; however, only six plants were reported to have through-liner corrosion. Note that the containment leak-rate air test did not show any leakage, perhaps because through-wall corrosion did not exist at the time of the test or because the concrete behind the liner provided an additional barrier of protection from air leakage.

1 Flexcell is a registered trademark of Flexcell International Corporation.

3.2.2 Repair and Remediation

The general repair process consisted of the following steps:

1. Remove all Flexcell with high-pressure water injection.
2. Repair the holes in the liner with steel plates.
3. Apply anticorrosion paint to the liner.
4. Fill the channels with concrete to provide passivity to the steel.
5. Add a petroleum wax seal in the joint and a metallic protection plate.

All the containment buildings with this detail were found to be in the same condition. In the specific case of Bugey, some of the concrete was not removed at the joint between the slab and the bottom of the liner due to limited accessibility.

Since the repairs were performed, EDF has not detected indications related to corrosion of the steel liner. The air tests have been successful, and visual inspections of the new seal at the top of the joint are in good condition.

The results of the 2011 integrated leak rate tests (ILRTs) at the Bugey 5 nuclear power plant indicated an increase in leakage. However, the leak rates were within the expected margins for operation, and a leak rate test was scheduled for 2015. During the 2015 ILRT, the margin for leakage was exceeded. To narrow down the potential location of the leakage, the ILRT was tested in two stages. The first stage consisted of flooding the central area of the floor with water and excluded filling the seal area. The second stage consisted of filling with water the concrete floor, including the area of the seal. From these tests, it was noted that when the concrete and seal were filled with water, no leakage was detected.

The conclusion was that the seal continued to leak after the repairs or that degradation had continued, promoting further corrosion and leakage. Consequently, EDF decided to remove the seal (petroleum wax) and to check the entire length of the joint (approximately 70 cm deep) along the space between the liner and interior concrete. During this inspection, the liner was found to be in good condition with no deterioration or defects. To remediate the issue of leak-tightness, EDF took an alternative approach that consisted of filling the space between the liner and concrete with a saturated lime solution (lime water).

As discovered during testing, filling the gap with water would saturate the concrete and make it leak-tight to the effects of air. The inner concrete would block the air trying to reach the joint, and containment concrete near the liner would be saturated, providing additional leak-tightness. Further, the high pH (>12) of the water would prevent corrosion of the steel liner.

This solution has been successfully applied. A mastic seal and polymer coating cover the water seal to protect it from pollution. It is expected that the lime-saturated solution will fill all the cavities between the liner and interior concrete, providing additional air leak-tightness to the structure.

3.3 Operating Experience from Sweden

Multiple instances of liner corrosion have been discovered and repaired over the years in Sweden. This section presents a summary of cases in which liner deterioration was discovered.

3.3.1 Ringhals 2, 1988: Water in the Liner Plate [14, 15]

During the operation period in 1988, water was detected on the interior of the containment building. At Ringhals 2, the connection between the basemat liner plate and vertical liner consists of a cavity filled with high-pH water. The purpose of the water is to maintain the passivity of the metal and prevent corrosion in this region. During the investigation into the source of the leakage, it was concluded that the water found was of high pH and that the possible source was water from the cavity at the connection between the base plate and vertical liner plate.

3.3.2 Barsebäck 2, 1993: Corrosion Damage of the Steel Liner Due to Voids (BWR) [14, 16]

Corrosion of the liner plate was discovered during the execution of a leak rate test 15 years after construction of the plant. Note that the vertical portion of the steel liner is embedded within the concrete wall approximately 30 cm in depth from the interior surface of the containment building wall. Corrosion was caused by honeycombed grout around the penetration and poor drainage of water during the grouting operation. The combination of water and small pockets of air generated a corrosion cell. This was noted to be a safety issue that resulted in repair of all grouted areas around the penetrations.

3.3.3 Forsmark 1, 1997: Corrosion of Internal and External Toroid (BWR) [15, 16]

During a leak rate test with leakage above the acceptable values, corrosion of a toroid in the upper part of the containment was detected. The outer liner of the toroid was placed against insulation, and the insulation rests directly on concrete. During the investigation, it was discovered that a film of plastic had been placed between the insulation and concrete. Further, the epoxy protecting the liner resting against the insulation was noted to be defective. The reactor pool liner welds, located directly above the toroid, were noted to be cracked. Moisture from the pool traveled through the cracked welds to the insulation and collected at the location where the plastic film was located. The liner in the toroid was replaced, the pool liner welds were inspected and repaired, and a ventilation system was installed in the toroid to prevent accumulation of moisture. As a result of this finding, additional investigations were conducted at Forsmark Units 2 and 3. No issues were found at Forsmark Unit 2.

3.3.4 Forsmark 3, 1998: Water Between Toroid and Concrete [15]

During the inspection at Forsmark Unit 3, it was discovered that the cavity within the double-walled toroid was filled with water. The water was noted to have high pH, and no corrosion was found. As a result, the cavity was filled with alkaline water (~ pH 11.9) to maintain the integrity of the plate.

3.3.5 Oskarshamn 1, 2002: Hole in the Liner on the Ceiling [14]

A hole in the ceiling of the containment building was discovered in 2002. The hole was 70 mm in diameter, and it was concluded that the hole had been there since construction. In the same area of the hole, a 15-mm-long crack was discovered on the weld. The hole and crack were repaired, and the integrity of the liner was restored.

3.3.6 Ringhals Unit 1, 2017: Holes in Liner at the Concrete Liner Intersection [17]

The holes were discovered during a leak rate test performed in 2017. The results from the tests were satisfactory, but during the inspection of the containment building, three small pinholes were found in an area in the upper part of the containment where the liner is visible. Leaking water from a structure above collected at a location where insulation was placed between the liner and concrete wall. The presence of the insulation in addition to intermittent leakage promoted corrosion of the liner. The remedial action was to remove the insulation and repair the damaged portion of the liner.

3.3.7 Ringhals Unit 3, 2016–2020: Hole Near a Penetration [18]

During the 2016 containment integrity test, a detailed inspection that consisted of using a microphone in areas around multiple penetrations was carried out. The results from the acoustic tests and additional gas leakage testing indicated a leakage in an area close to a purge air penetration. Note that the overall pressure test of the structure was found to be within the allowable limits. A safety assessment was performed, and the unit was deemed safe to continue operating in the as-found condition.

In Swedish containments, the steel liner is embedded in the concrete of the containment building. In 2017 and 2018, concrete was removed, and the liner was exposed from the inside wall of the containment building in multiple areas near the penetration that was noted to have some leakage in 2016. During this inspection cycle, no damage to the liner was found. In 2020, a new area of the liner was exposed, and through-wall corrosion was found in one location. The area of corrosion, with an approximate size of 15 cm x 40 cm (6 in. x 16 in.) was caused by a wood wedge located against the liner; the hole in the liner was noted to be approximately 7 cm (2.8 in.) in diameter. Figure 3-3 is a general sketch of the areas of the liner exposed during the three investigation phases that required concrete removal. When isolated areas of the liner away from the penetration were exposed to investigate suspected deterioration, no deterioration was found. The damaged area of the liner was replaced, and concrete was restored. A containment integrity test was performed and deemed acceptable. No leakage through the concrete was detected.

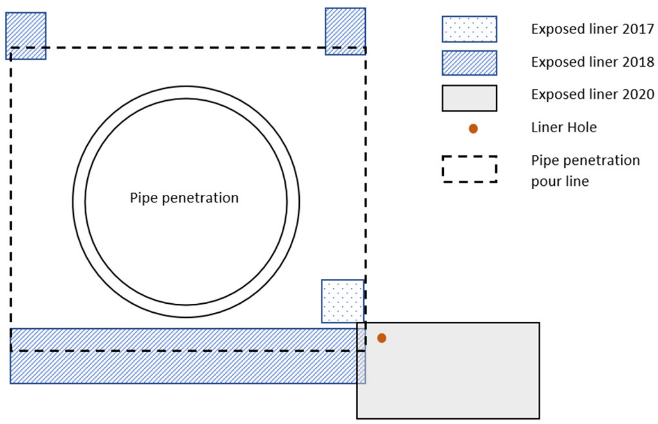

Figure 3-3. Pipe penetration and investigation openings performed between 2017 and 2020 to inspect the liner (not to scale)

3.4 Operating Experience from South Africa

3.4.1 Background

In 2009, during a refueling outage, a failed coating was discovered on the interior portion of a steel liner. The area of the liner was cleaned and tested ultrasonically, and the coating was restored. At the end of the outage, it was noted that some blistering was present on the surface of the recently applied coating, and ultrasonic testing was performed. The ultrasonic test results indicated some wall loss. The blistered coating was repaired and subsequently inspected a few months later. After the subsequent inspection, the coating was noted to be in good condition.

A follow-up examination was performed in September 2010 during the next refueling outage. During this inspection, the same areas were noted to have some blistering. After removal of the coating and inspection of the liner, it was noted that a 90 mm x 300 mm (3.5 in. x 11.8 in.) rectangular section of the liner was corroded, with the blister locations having some through-wall-thickness holes [19].

After removing a section of the steel plate, it was discovered that a piece of wood was resting behind the liner. The presence of the wood reduced the pH on the concrete-liner interface, generating corrosion of the liner.

3.4.2 Remediation Strategy

After an investigation and extent-of-condition assessment were performed, a repair strategy was put in place to restore the condition of the plate. A mockup with a steel liner was constructed to test the procedures and materials prior to performing the repair on the containment structure. The mockup included a concrete cavity and a portion of the liner removed that represented the conditions in the containment structure. The portion of the liner that was purposely removed was welded back to the liner. The welded plate included an injection port at the bottom region of the plate and a vent hole at the top region of the plate. Flowable non-shrink grout was pressure-injected through the bottom port until the grout overflowed out of the top port, and the grout pressure was maintained. The mockup implementation was successful. And the same process was implemented on the containment structure.

The final repair also included removing and plug-welding the injection and vent ports. After finalizing the welds, a local pressure test was performed to ensure the leak-tightness of the repair.

3.5 Operating Experience from South Korea

Between 2016 and 2017, deterioration of liner plates in PWR containment buildings was documented in six different units in South Korea [5]. Note that after the initial findings, the utility inspected all the containment buildings in their fleet. Visual inspection was the initial way of identifying the condition on the surface of the liner. After corrosion was noted, additional inspections were performed using ultrasonic thickness measurements.

Reduction in thickness of 10% or higher was noted, and the condition was remediated by removing the deteriorated plate, inspecting the condition of the concrete, restoring the concrete surface with new concrete or grout, and welding a new plate in place. After the new plate was installed, magnetic particle nondestructive evaluation was performed on the weld, and a localized pressure test was performed on an area covered by the new plate. A protective coating was placed on the surface of the new plate, and a general pressure test was performed on the structure [5].

The root cause of deterioration varied from site to site. Typically, however, the deterioration could be explained by corrosion at a construction joint exposed to the environment for extended periods during construction, an embedded foreign object (wood), iron debris in contact with the liner, or voids in the concrete behind the liner.

4 Summary and Conclusions

Numerous cases of liner corrosion have been documented around the world, with the primary deterioration mechanism being corrosion. Corrosion can be caused by foreign objects embedded in the concrete that are in direct contact with the liner, voids and honeycombs in the concrete behind the steel liner, chlorides at a construction joint that was exposed to a saline environment for an extended period during construction, and corrosion of the liner at the intersection where the liner is embedded in the concrete.

In the United States, recent operating experience includes the inspection of a liner embedded in concrete. Concrete was cored and removed to access the steel plate. The process required special tooling, and the procedures and results of the inspection indicated that the liner thickness was within the specifications for the specific containment structure.

This report presented operating experience from France and the remediation procedure used to prevent corrosion. Deterioration was caused primarily by chloride in a seal material used in containment. The remediation process included removing the chloride-contaminated material, restoring the integrity of the liner plate, and adding non-chloride-laden material at the seal region. In Sweden, an investigation was performed related to the suspect condition of liner deterioration. Multiple inspection openings were performed over several years; the liner corrosion was found and remediated.

In South Africa, a piece of wood embedded in the concrete and in contact with the liner was the cause of through-wall corrosion of the liner. The extent of the damage was identified, and the concrete and liner were restored to allow the structure to continue its function.

In South Korea, six containment buildings were noted to have deterioration on the liner caused by voids in the concrete behind the liner, foreign material in contact with the liner on the concrete side, and chlorides at a construction joint exposed to the elements for extended periods during construction. In all cases, the integrity of the concrete and liner was restored to allow the liner to perform its intended function.

The integrity of the liner in nuclear power plants is extremely important. For this reason, it is necessary to continue investigating methods to assess and characterize the condition of liners embedded or in contact with concrete to ensure that the liners perform their intended function.

5 References

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