Containment Liner Corrosion

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Background

- A few cases of through-wall liner corrosion initiating at the concrete/liner interface
- Concrete pH ≈ 12.5 to 13 should prevent corrosion by passivating the steel
- Visual exams only identify corrosion initiated at the concrete/liner interface after through-wall corrosion has occurred
- NDE techniques cannot identify foreign objects at the concrete/liner interface
- Full liner NDE inspection is not practical with currently available methods

Containment Construction

Containment Design	Number of Domestic Plants[1]		
	Free standing steel with a concrete enclosure	Post-tensioned concrete with a steel liner	Reinforced concrete with a steel liner
BWR MK I	21	0	2
BWR MK II	1	2[2]	5
BWR MK III	2	0	2
PWR Ice condenser	7	0	2
PWR Sub-atmospheric	0	0	7
PWR Large Dry	7	36	10
Totals	38	38	28

[1]Hessheimer and Dameron, 2006
[2]Reinforced drywell, post-tensioned wetwell

Operating Experience Review

- NRC reviewed operating experience with containment liner corrosion
  - Licensee inservice inspection (ISI) reports
  - Licensee event reports (LER)
  - NRC inspector reports during PWR RPVH and/or SG replacement
  - NRC inspections during license renewal
- Obtained foreign plants liner corrosion experience from colleagues in France, Japan and Sweden
- Reports produced
  - Operating experience summary report
  - Expert panel report

Operating Experience Summary

- 5 cases (4 U.S.) plants where corrosion penetration of the containment liner associated with embedded foreign material in the reinforced concrete containments
  - Brunswick-2 (1999) worker's glove
  - North Anna-2 (1999) wood
  - D.C. Cook-2 (2000) wire brush with a wood handle
  - Beaver Valley-1 (2009) wood
  - Koeberg-1 (South Africa, 2010) wood
- 1 case of liner corrosion associated with voids/poorly consolidated concrete
  - Barsebeck -2 (Sweden, 1999)
- 1 case where cause of external corrosion was not identified (concrete was removed for steam generator replacement)
  - Beaver Valley-1 (2006)

Liner Corrosion Summary

Plant /Location	Plant Information	Year of incident	Plant age, years	Corrosion penetration	Average corrosion rate
Barsebeck-2 Sweden	BWR ASEA-Atom	1993	16	7 mm 0.275”	0.44 mm/yr [17 mpy]
Brunswick-2 North Carolina	BWR GE 4 Mark 1	1999	24	8 mm 0.312”	0.33 mm/yr [13 mpy]
North Anna-2 Virginia	PWR West-3LP Sub-atmospheric	1999	19	9.5 mm 0.375”	0.5 mm/yr [20 mpy]
D.C. Cook-2 Michigan	PWR West-4LP Ice-condenser	2000	22	4.8 mm 0.188”	0.22 mm/yr [8.5 mpy]
Beaver Valley-1 Pennsylvania	PWR West-3LP Sub-atmospheric	2006	30	5.8 mm 0.227”	0.19 mm/yr [7.5 mpy]
		2009	33	9.5 mm 0.375”	0.29 mm/yr [11 mpy]
Koeberg-1 South Africa	PWR Framatome-3LP	2010	26	6 mm 0.236”	0.23 mm/yr [9.1 mpy]

Foreign Material

- 4 additional cases where embedded foreign material was found without liner corrosion
  - Arkansas Nuclear One – 1 (2000) wood near the exterior surface of the concrete
  - North Anna – 1 (2001) 6 pieces of wood visible from the exterior surface of the concrete; 1 piece contacted the steel liner
  - Point Beach – 1 (2001) wood near the exterior surface of the concrete
  - D.C. Cook – 1 (2001) 3 pieces of wood shallowly embedded in the concrete

Expert Panel Review

NRC sponsored a panel of experts to review the operating experience summary and address the following areas interest:

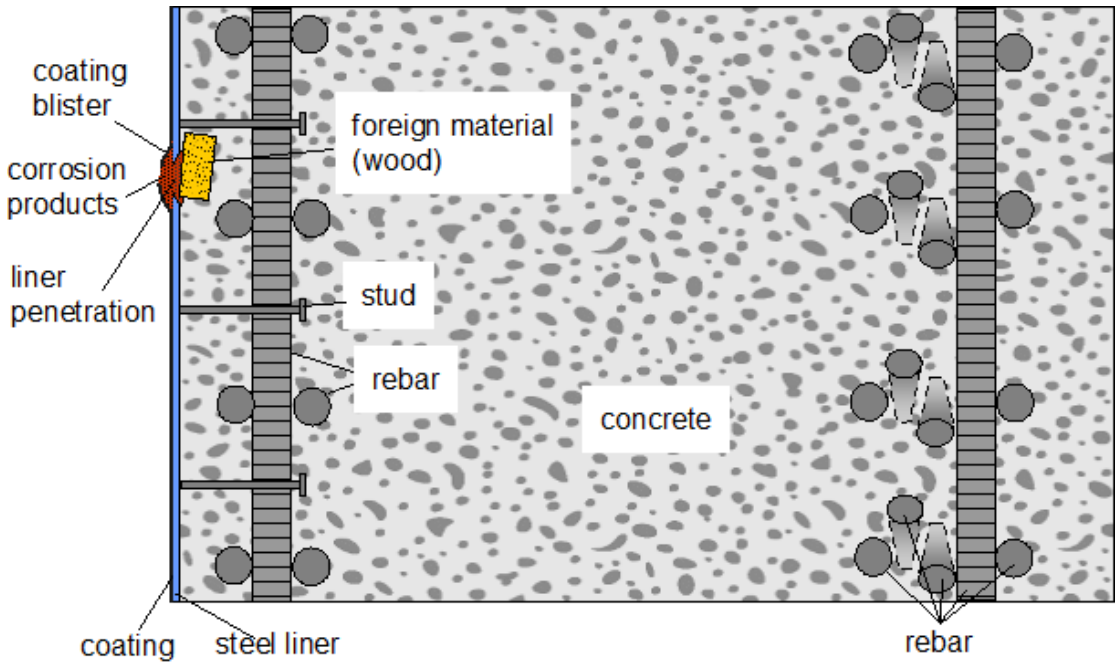
- Identification of the liner corrosion mechanisms
- Significant aging and environmental factors
- Concrete aging and degradation assessment methods
- NDE methods for construction defects and liner corrosion
- Evaluation of construction practices and concrete defects on concrete degradation and steel corrosion
- Methods to prevent or mitigate concrete degradation and corrosion of steel in concrete
- Recommended future research

Expert Panel

Member	Affiliation	Expertise
Dr. Jason Petti	Sandia National Laboratories	Containment structural integrity
Bryan Erler	ASME Board of Nuclear Codes and Standards	Containment design and construction
Professor Alberto Sagues	University of South Florida	Corrosion, concrete degradation
Dr. Dan Naus	Oak Ridge National Lab	Aging management, containment design and construction, NDE
Professor Richard Weyers	Virginia Tech	Corrosion, concrete degradation and repair
Dr. Neal Berke	W.R. Grace	Concrete aging and characterization
Henry Stephens *	EPRI	Containment design, NDE
Nathan Muthu *	EPRI	Containment liner NDE

* Non-panel member participant

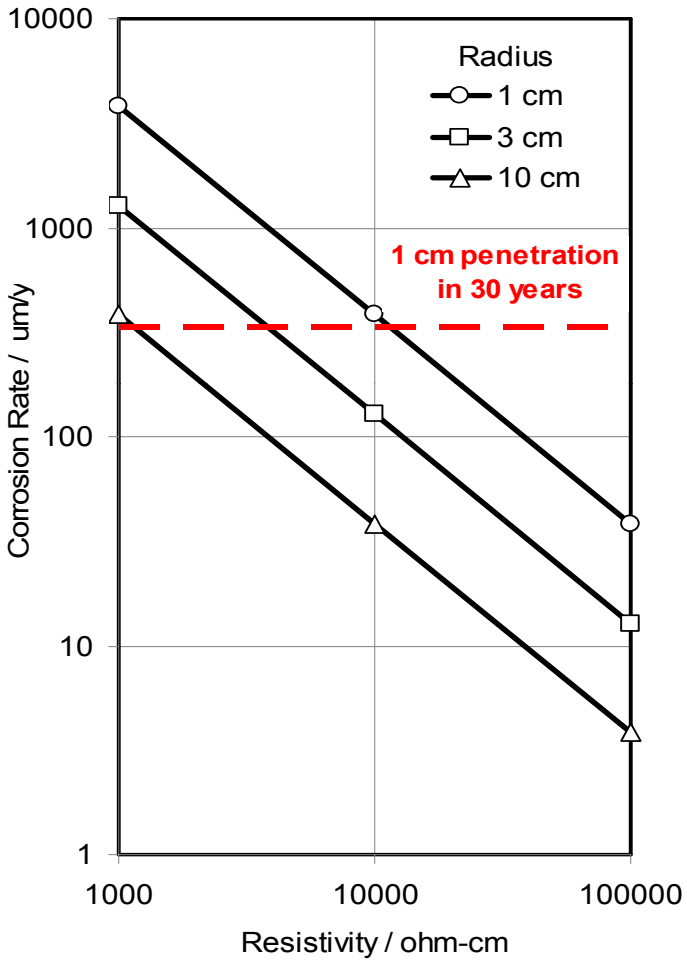
Liner Corrosion Mechanism



- Macrocell-Accelerated Localized Corrosion
- Foreign body could promote early corrosion initiation with even moderate pH decrease and minor chloride presence

- Concrete can provide moisture needed for macrocell
- Liner and rebar provides ample passive surface for cathodic reaction
- Even limited oxygen presence may provide enough cathodic action for corrosion to propagate

Liner Corrosion Calculation



- Calculations performed by Professor A. Sagues
- Concrete resistivity and radius of anodic area varied
- Calculated corrosion rates consistent with observed penetration of containment liners from corrosion initiated at the concrete/liner interface

Expert Panel Conclusions

- Macrocell-accelerated localized corrosion
- No evidence of other corrosion mechanisms
- Higher rebar density of reinforced concrete structures may be a factor in the inclusion of foreign materials
- The operation of subatmospheric containments was not believed to be a significant
- Large scale screening of containment liners not feasible with currently available NDE techniques
- No evidence that corrosion was influenced by materials, concrete additives or concrete contamination
- No condition found resulted in the containment failing to meet the 10CFR50 Appendix J integrated leak rate test

Expert Panel Conclusions

- Carbonation and chloride ingress were determined to be insignificant for known liner corrosion events
- Long term concrete degradation mechanisms, such as delayed ettringite formation and dissolution in combination with the presence of a foreign body, may be significant
- Current concrete and liner repair methods are well established and unlikely to have negative implications
- Temporary containment openings could affect liner corrosion if corrosive materials are introduced
- Mitigation methods such as cathodic protection may not be effective

Expert Panel Recommendations

- Detailed study embedded foreign material cases
  - Construction practices and procedures
  - Location of foreign material in relation to higher density rebar or at construction joints
- Liner corrosion modeling and supporting experiments
  - Capture the complexity of the system including polarization at anodic and cathodic regions and the effect of oxygen transport
  - Evaluate the effect of parameters such as concrete quality, water content, wall dimensions, rebar placement, temperature
  - Determine/confirm conditions under which corrosion can be sustained at the debris/liner interface

Expert Panel Recommendations

- Assessment of NDE Methods
  - Limited investigation of potential techniques
  - Use containment “mock-ups” with simulated flaws
  - Consider evaluation on decommissioned plants
- Concrete Aging and Degradation
  - Investigate the possibility of sulfate induced corrosion of the steel liner from delayed ettringite formation and dissolution and other concrete degradation mechanisms
- Concrete Repair and Corrosion Mitigation
  - Evaluate the durability and effectiveness of repairs that have been made to nuclear power plant concrete structures.

Current Status

- NRC is evaluating the Expert Panel recommendations
  - Follow on actions will be determined
  - Some recommendations may be addressed in existing NRC programs
- NRC continues to follow industry efforts on the development on NDE methods

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