Contract No:

This document was prepared in conjunction with work accomplished under Contract No. DE-AC09-08SR22470 with the U.S. Department of Energy (DOE) Office of Environmental Management (EM).

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Analyses Methodologies for In-Situ Corrosion Monitoring of Tank Bottom Plate Corrosion Using Electrical Resistance Probes

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CORROSION 2021

Virtual

April 19-30, 2021

Outline

- Background
- Objective and approach
- Experimental
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- Results and Discussion
- Conclusions
- Acknowledgements

Background

- Electrical resistance (ER) probes are used for corrosion monitoring
- ER probe data could fluctuate between readings, analyses methodologies are required to correctly interpret the data
- Monitoring of aboveground storage tank bottoms
- A nuclear-system application was used to demonstrate applicability of the methodologies
  - Corrosion mitigation method of double-shell storage tanks' bottoms is being developed
  - Vapor Corrosion Inhibitors are being investigated
  - ER probes were used in corrosion monitoring

Objective and Technical Approach

- Objective: develop analyses methodologies for ER probe data

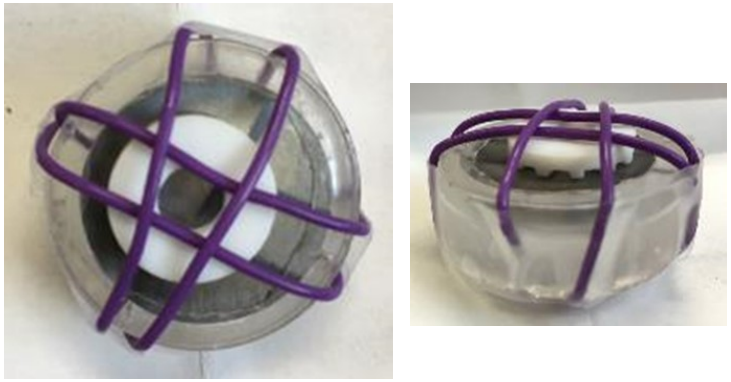
- Technical Approach
  - Disk coupons were exposed to ground water electrolyte for weathering
  - Exposure time: two months
  - Two commercially available VCIs were tested: VCIs added after initial 2 months of weathering
  - 50% of coupons taken out before VCIs' addition and reaming after additional 4 months of exposure
  - Surface average and pitting corrosion rates from coupons
  - ER probe data derived corrosion rates
  - Cross consistency between the coupons and ER-probe derived corrosion rates

Experimental: Materials

- Carbon steel coupons from AART 128 Rail Car Steel which has approximate chemistry, microstructure and age as the steel of which the tanks were fabricated (ASTM A515 Grade 60)

Compositions (wt.%) of the Carbon Steel

Elements	C	Mn	P	S	Si	Fe
Specification (wt%)	0.24 (max.)	0.9 (max.)	0.035 (max.)	0.04 (max.)	0.13 to 0.33	Balance
Measured (wt%)	0.212	1.029	0.012	0.013	0.061	Balance



Mounted disk coupons with polished surfaces

- Circular coupons 1” dia. from plate, 1/8” thick, crevice former
- Mount in two-part clear epoxy mixture
- Electrical Resistance (ER) probes for in-situ monitoring
  - Cylindrical element probes
  - Wire element probes

Experimental: Electrolytes

- Simulant were prepared based on analytical studies of water samples taken at leak detection pit and above zone groundwater.

Chemical species, Temperature and pH range of maximum and minimum values

Composition of the Leak Detection and Ground Water Simulants		
Source chemical	**Concentration (M)**	
	Leak Detection Pit (LDP)	**Ground Water (GW)**
Sodium bicarbonate	1.120E-03	1.750E-03
Calcium hydroxide	1.210E-04	1.500E-03
Potassium nitrate	6.750E-05	2.400E-04
Magnesium Nitrate	1.520E-05	–
Strontium Nitrate	4.040E-06	2.874E-06
Sodium sulfate	1.830E-06	–
Ferric sulfate	–	6.250E-04
Sodium Metasilicate	4.570E-05	6.000E-04
Ferric chloride	2.670E-06	7.667E-05
Manganese Chloride	–	3.100E-04
Acetic Acid	3.000E-04	3.000E-04
pH adjusted using sodium carbonate and acetic acid	7.6	7.6

Experimental: Vapor Space Corrosion Testing

Simulant

Level 3: Top level.
- Not dipped in simulant
- Representative of region only exposed to vapor and any volatile species from the solution.

Level 2: Intermediate level.
- Dipped in the simulant for five minutes prior to testing.
- No direct contact with solution after initial 5-minute exposure.

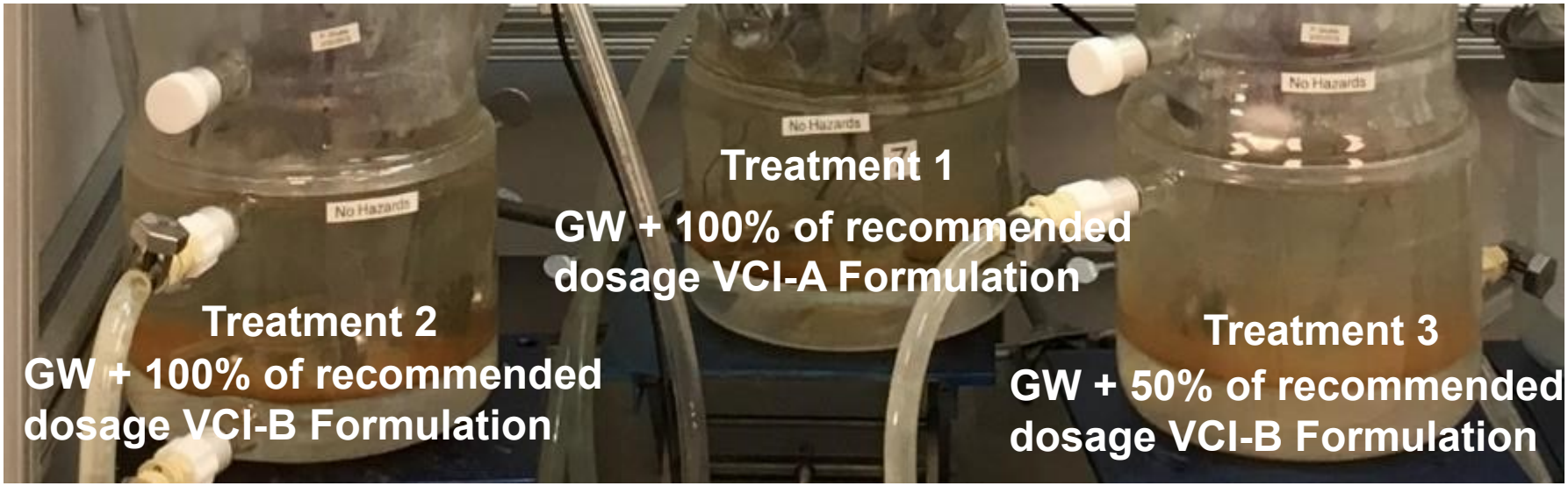
Level 1: Low level.
- Dipped in the simulant prior to testing and every two weeks
- Representative of the situation when secondary liner bottom plate experienced periodic wetting/drying.

Temperature: 45 ºC
Duration of testing: 6 months

Setup Image

Experimental: Vapor Corrosion Inhibitors (VCI) Corrosion Strategy

- Initial two-month exposure with GW, and then GW+VCI thereafter
  - **VCI-A**
    - VpCI-337® mixed at 10% v/v in GW simulant
  - **VCI-B**
    - VpCI-609® (10 wt.%) and VpCI-649MF® (0.75% v/v) in GW simulant



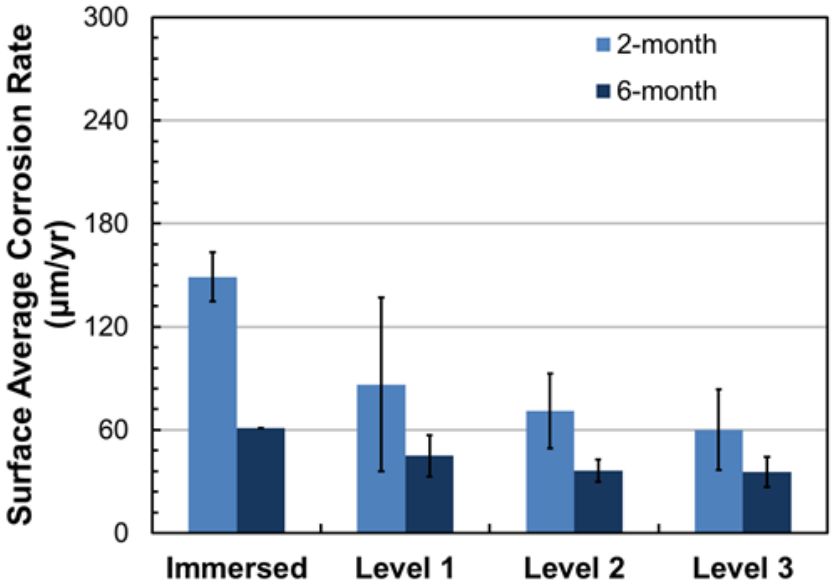
- Half of the coupons were taken out before VCIs' addition

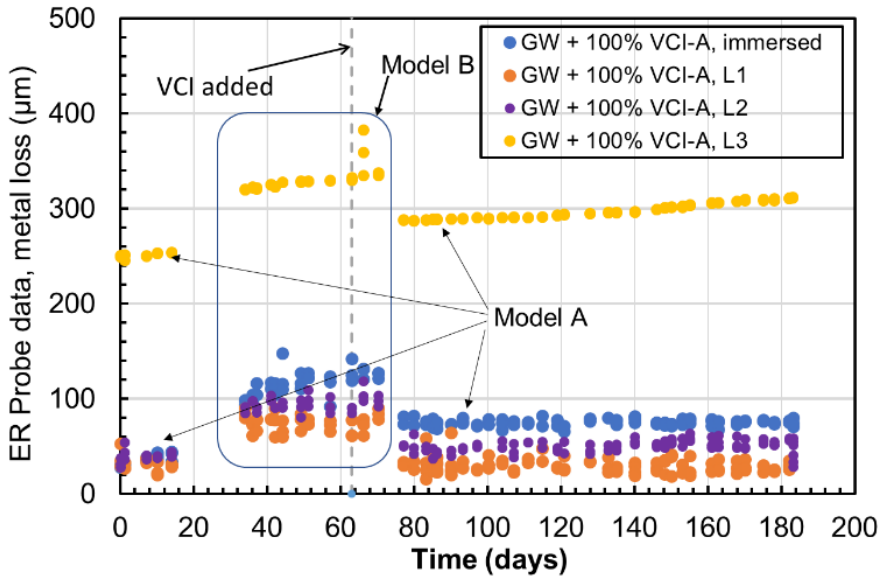
Results: VCI Treatment Summary

Solution	Treatment Vessel	Notes
Initially GW simulant, and then 100% of the recommended dosage of VCI-A after 2 months	Vessel 1	• 6 coupons each in immersed, Level 1, Level 2, and Level 3 positions, total 24 coupons. • ER probes at each level. Cylindrical element probes at immersed, Levels 1 and 2, and wire element probe at Level 3.
Initially GW simulant, and then 100% of the recommended dosage of VCI-B after 2 months	Vessel 2	• 6 coupons each in immersed, Level 1, Level 2, and Level 3 positions, total 24 coupons. • ER probes at each level. Cylindrical element probes at immersed, Levels 1 and 2, and wire element probe at Level 3
Initially GW simulant, and then 50% of the recommended dosage of VCI-B after 2 months	Vessel 3	• 6 coupons each in immersed, Level 1, Level 2, and Level 3 positions, total 24 coupons. • Cylindrical element probe at Level 2 and wire element probe at Level 3

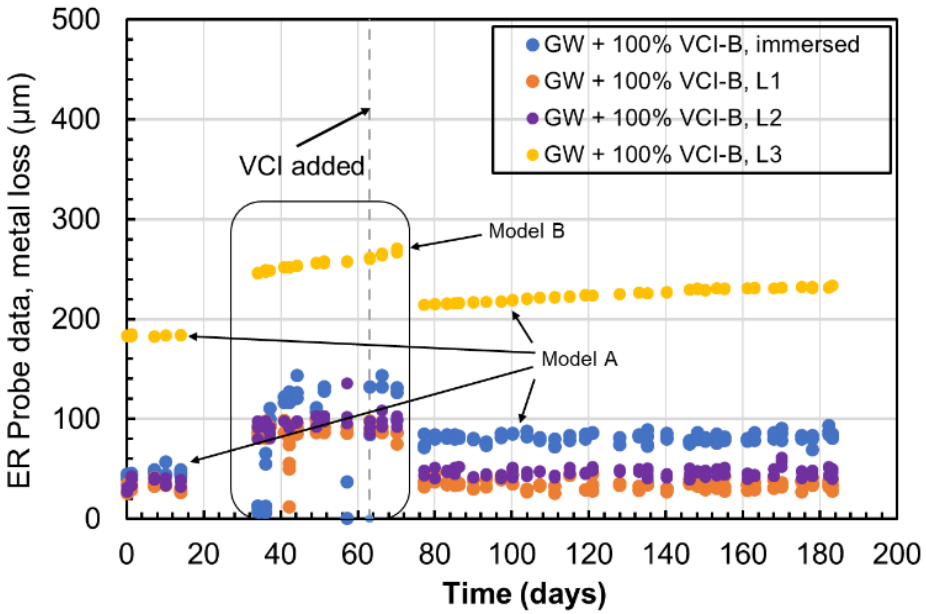
Results: GW and GW + 100% VCI-A, ER Probe Data

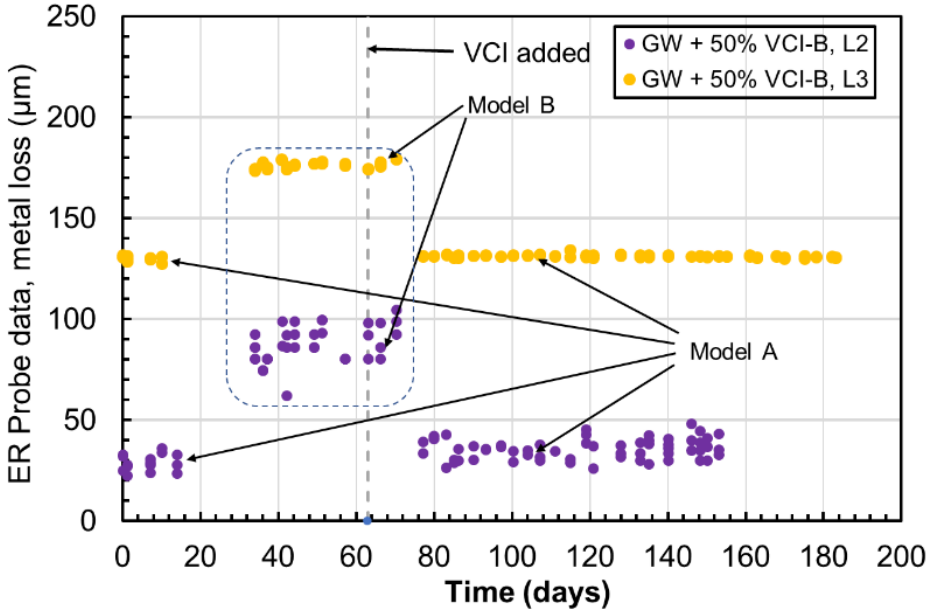
- Each data point is average of 3 coupons
  - 2 months: GW only exposure
  - 6 months: Each data point is average of 3 coupons
- ER probe data was collected using two dataloggers
  - Model A and Model B
  - Model A malfunctions after two weeks
  - Model B was used in the interim, during Model A repair
  - Model A data was analyzed after VCIs' introduction
  - 3- and 5-period rolling averages of ER probe data were used



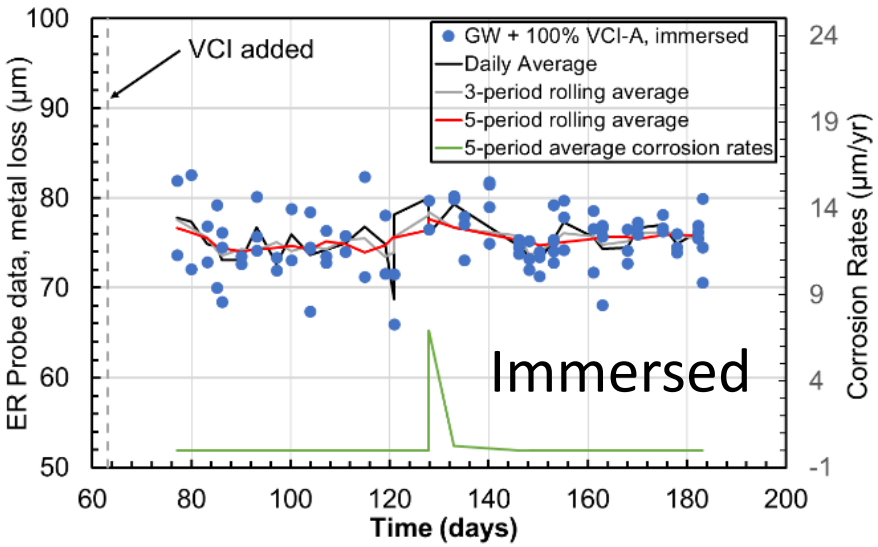


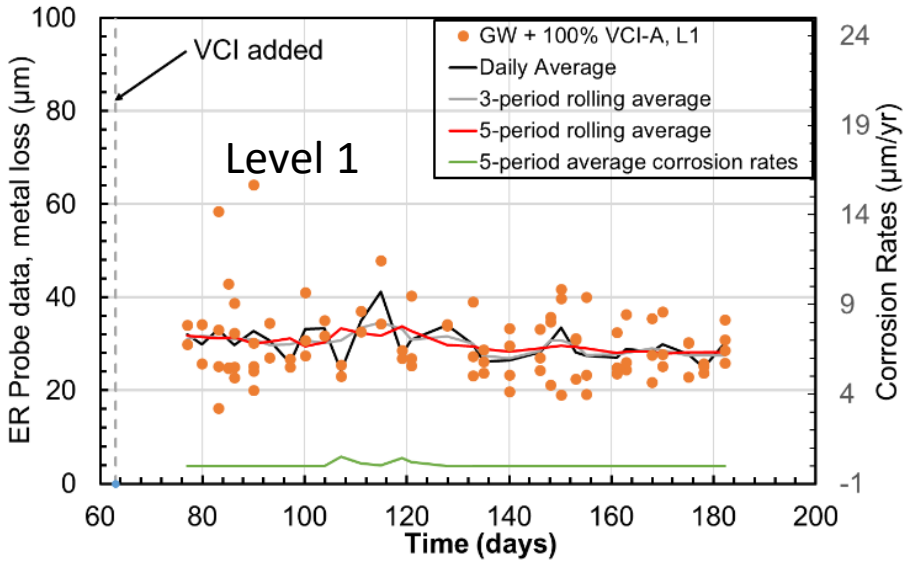
Results: GW and GW + 100% VCI-B, and GW and GW + 50% VCI-B ER Probe Data

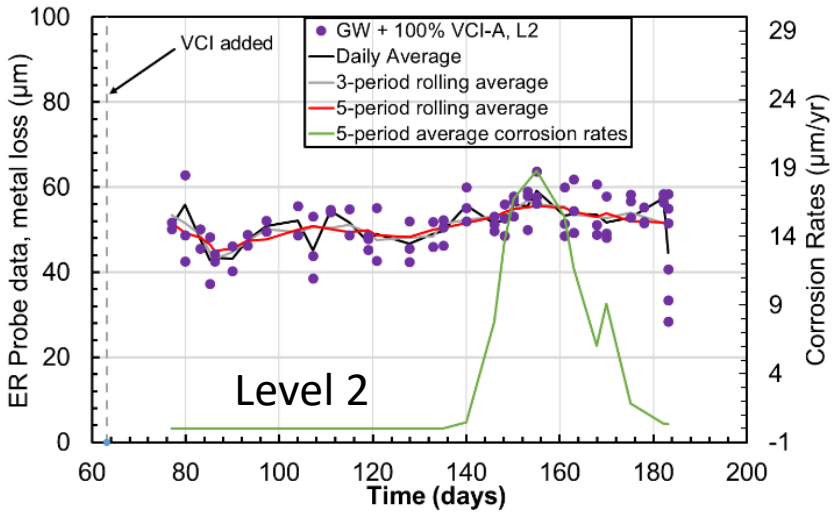


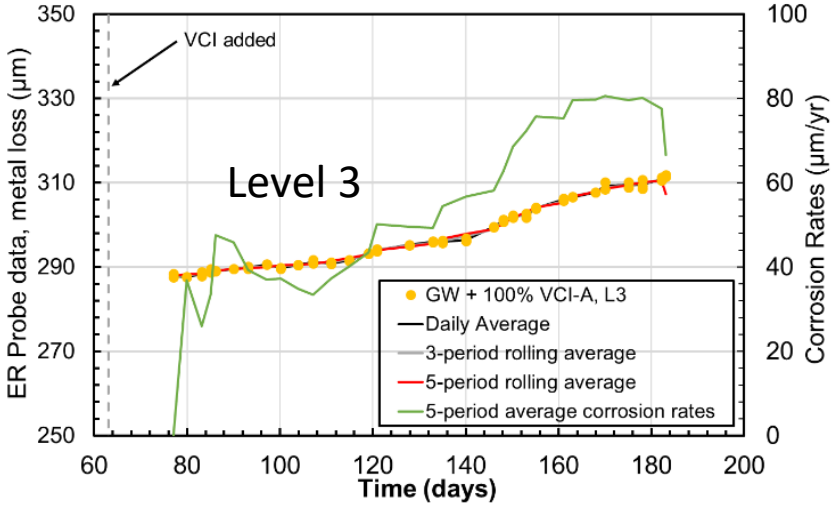


Results: GW and GW + 100% VCI-A, ER Probe Data

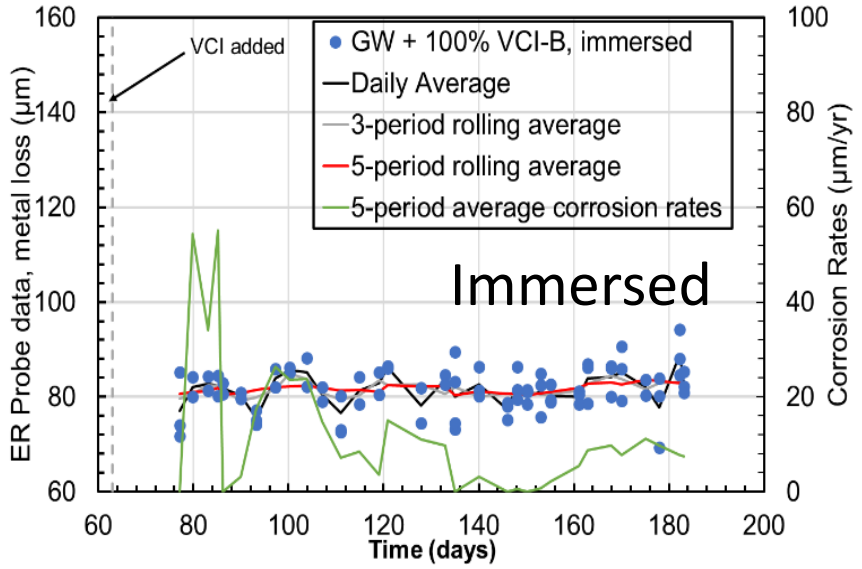


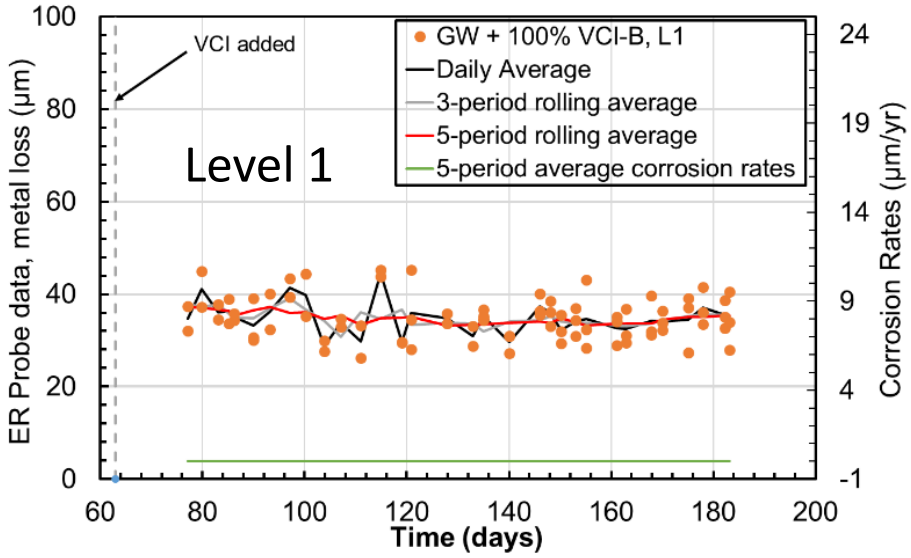


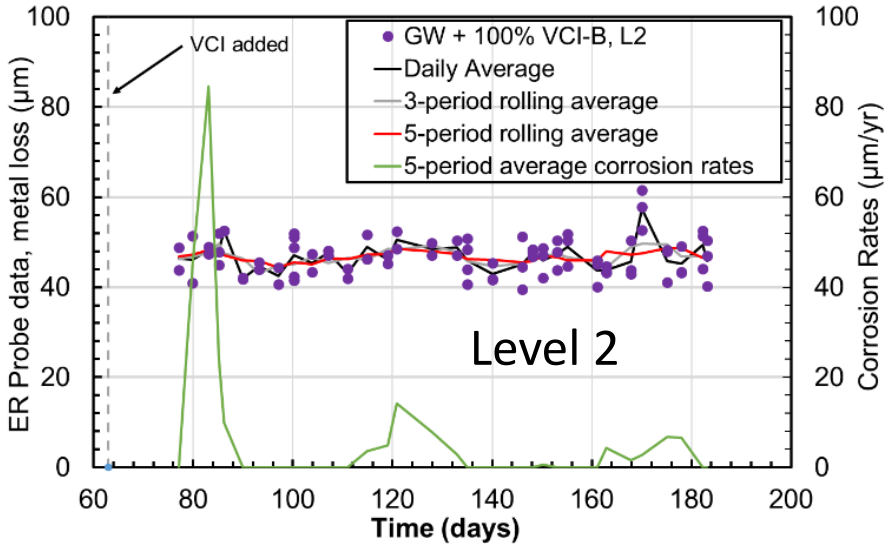


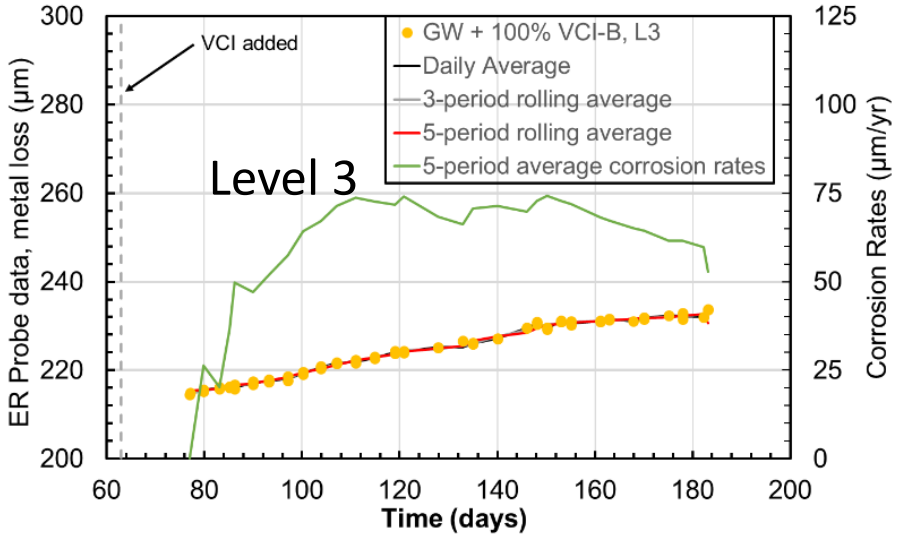


Results: GW and GW + 100% VCI-B, ER Probe Data

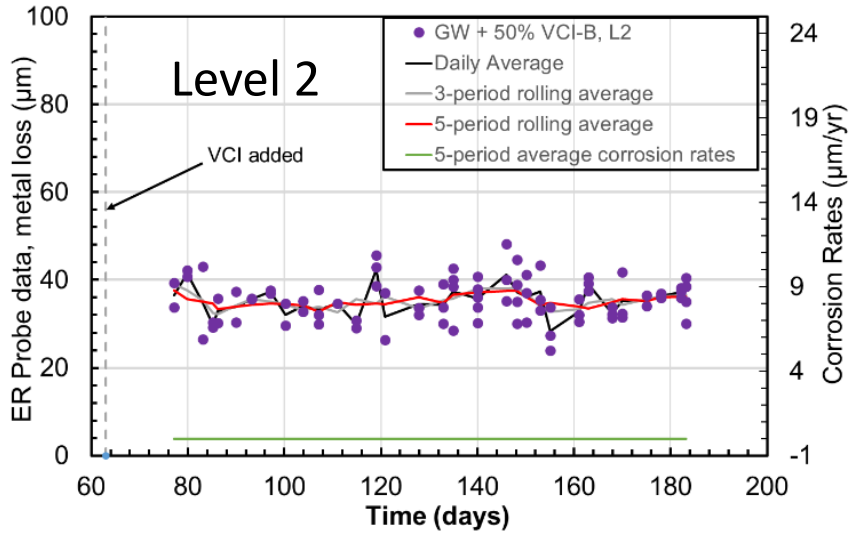


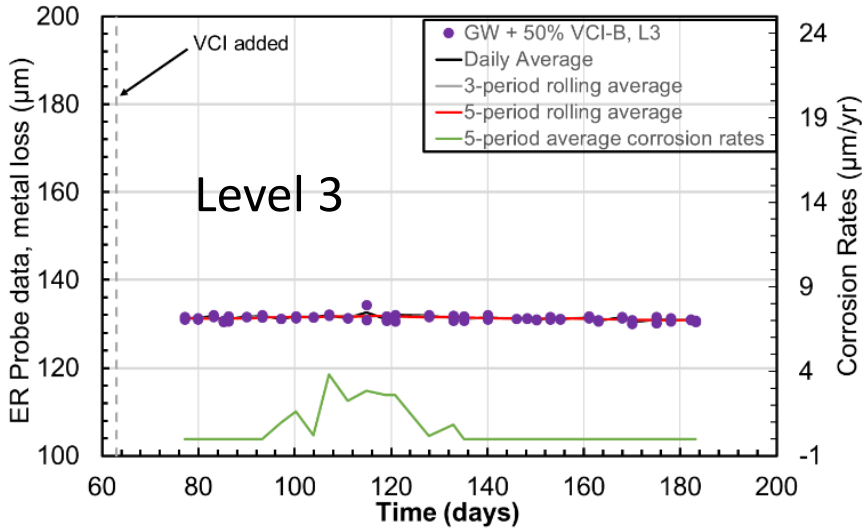






Results: GW and GW + 50% VCI-B, ER Probe Data





Results: Comparison of Coupon and ER Probe Data

Coupon and Electrical Resistance Probe Corrosion Rates

Vessel	Level	Coupon Corrosion Rates (µm/yr)***		ER Probe Corrosion Rates (µm/yr)			
				3-period rolling average		5-period rolling average	
		2-month*	6-month**	2-month*	6-month♣	2-month*	6-month♣
1	Immersed	149 ± 14	61 ± 0	224	0	224	0
	Level 1	86 ± 51	45 ± 12	–	2.4	–	1.4
	Level 2	71 ± 22	36 ± 6	66	2.5	66	0.3
	Level 3	60 ± 24	36 ± 9	197	81	197	67
2	Immersed	125 ± 9	82 ± 5	207	0.5	207	7.5
	Level 1	94 ± 13	42 ± 8	15	0	15	1.7
	Level 2	97 ± 18	49 ± 8	60	2.4	60	0
	Level 3	59 ± 24	36 ± 2	147	61	147	53
3	Immersed	116 ± 15	51 ± 5	–	–	–	–
	Level 1	58 ± 15	22 ± 4	–	–	–	–
	Level 2	60 ± 8	47 ± 26	37	1.8	37	0
	Level 3	36 ± 12	47 ± 36	7	0	7	0

*2-month coupons were exposed to GW only
**6-month coupons were exposed to GW for the first two months and then to GW plus VCI for additional four months
***Corrosion rate data is estimated using three coupons per exposure level, 25 µm/yr = 1 mil/yr = 1 mpy
♣Corrosion rates are for the duration of the VCI treatment

Analysis: Cross Consistency Check

- Coupon data for GW for 2-months plus GW+VCI treatment for additional 4 months
- ER probe data after VCIs' addition
- Two ratios were calculated using 6-month coupons' corrosion rate data
  - Statistically, if ratio range included 3, ER-probe derived corrosion rates with fully effective VCIs were cross consistent
  - If ratio range did not include 3, ER probe corrosion rate must be correspondingly adjusted

$$Ratio\ 1 = \frac{(Corrosion\ Rate - Std)_{2-month}}{(Corrosion\ Rate + Std)_{6-month}}$$

$$Ratio\ 2 = \frac{(Corrosion\ Rate + Std)_{2-month}}{(Corrosion\ Rate - Std)_{6-month}}$$

Analysis: Cross Consistency Check

Vessel	Level	Ratio Range	6-month ER probe corrosion rates during VCI treatment* (µm/yr)	Notes
Vessel 1 (GW for first two months, and GW+100% VCI-A for additional four months)	Immersed	2.2 to 2.7	0	Ratio range upper limit is close to 3
	Level 1	0.6 to 4.2	1.4	Ratio range includes 3
	Level 2	1.1 to 3	0.3	Ibid
	Level 3	0.8 to 3	67	Ratio range include 3, but ER probe corrosion rates were high
Vessel 2 (GW for first two months, and GW+100% VCI-B for additional four months)	Immersed	1.3 to 1.8	7.5	Ratio range does not include 3
	Level 1	1.6 to 3.1	1.7	Ratio range includes 3
	Level 2	1.4 to 2.8	0	Ratio range upper limit is close to 3
	Level 3	0.9 to 2.5	53	Ratio range upper limit is close to 3
Vessel 3 (GW for first two months, and GW+50% VCI-B for additional four months)	Level 2	0.7 to 3.2	0	Ratio range includes 3
	Level 3	0.3 to 4.4	0	Ibid
*VCI treatment only corrosion rates based on 5-period rolling average				

Conclusions

- ER probe data fluctuated from measurement to measurement. A rolling average method was used to estimate the probes' corrosion rates. 5-period rolling average corrosion rates were closest to the coupons' corrosion rates.

- 100% VCI-A treatment: coupon corrosion rates were consistent with ER-probe corrosion rates in immersed, Level 1 and Level 2. Level 3 were not.

- 100% VCI-B treatment: coupon corrosion rates were consistent with ER-probe derived corrosion rates at Level 1 and Level 2. Immersed and Level 3 were not.

- 50% VCI-B: coupons corrosion rates were consistent with ER-probe derived corrosion rates at Level 2 and Level 3.

Conclusions

- Six cylindrical-element ER probes were used between the three vessels. Of those, the corrosion rates of the five were found to be consistent with the corresponding coupons' corrosion rates.

- Three wire-element ER probes were used between the three vessels. Of those, only one element's corrosion rate was found to be consistent with the corresponding coupons' corrosion rates.

- The study indicated that the cylindrical element ER probes with larger surface area compared to the wire-element ER probes provide more accurate representation of the bottom plate corrosion rates.

Acknowledgements

- United States Department of Energy
- Hanford Tank Integrity Expert Panel - Corrosion Subgroup