Pipeline Research Council International

Hard Spot ILI Risk Prioritization – Past and Present

Sean Moran and Kelly Thompson
Williams

Fall TC Meeting - Dallas, TX
Oct 15,2024

LEADING PIPELINE RESEARCH

Hard Spot ILI Prioritization

- Evolution of Williams Hard Spot Program
- Using Williams hard spot ILI findings for risk evaluation
- Quantitative Hard Spot Risk Modeling (with MAT 7-2)

Development of Williams Hard Spot Program

- **As a result of the Enbridge hard spot failure in August 2019, Williams undertook a study in early 2020**
  - Williams found sporadic failure history from 1960-1980s that did not align well with industry data.
    - Manufacturers: Consolidated Western, Bethlehem, and National Tube - **Not A.O. Smith**
  - 2016 hard spot leak –> hard spot ILI run –> no hard spots found

- **Williams begins Hard Spot ILI in 2020/2021 on targeted segments with failure history (7 segments)**
  - This effort was prior to hard spot risk model
  - By end of 2022, 46 digs completed and 1 hard spot found

- **Williams has 1 Station hard spot rupture in 2022 and 1 mainline hard spot leak in 2023**
  - Williams begins on a new path of understanding hard spot susceptibility and Hard Spot ILI capabilities and limitations

Enbridge near Danville, Kentucky on August 1, 2019
30” x 0.375”, X52
A.O. Smith, Flash Welded
1942 Installation
(amended CAO)

2022 Station Rupture (piggable pipe)

Incident:

- Hard Spot - 450+ BHN - 6.5"L X 3" W
- Recent increase in CP current
- Operating stress 46% SMYS
- Crack initiated in 2mm corrosion pit
- 1957 Bethlehem, 30", X52, from a specific PO

Response:

- Expedited hard spot ILI (more Bethlehem pipe)
- Review/mitigate CP levels
- Develop Station Piping Risk Model
  - Assess Station Piping by Risk Prioritization

Piece	Row	F1	F2	G1	G2	H1	H2	I1	I2	J1	J2	K1	K2	L1	L2	M1	M2	N1	N2	O1	O2	P1	P2	Q1	Q2	R1	R2
PIECE 1	8	180	190	172	176	176	185	185	200	165	195	200	195	180	190	185	205	195	190	185	185	190	176	190	185	190	185
	7	185	195	200	180	180	195	195	200	190	200	190	210	205	190	195	205	195	190	190	176	195	190	190	180	195	176
	6	180	185	195	185	195	200	205	222	195	200	195	228	234	205	210	210	222	222	210	210	200	195	195	190	190	180
	5	185	190	190	180	190	195	222	228	240	253	253	279	286	271	258	258	279	279	247	253	247	228	205	200	195	172
	4	185	180	190	200	200	240	253	258	301	294	327	319	271	286	311	286	279	301	311	247	234	228	247	216	195	185
	3	176	190	195	210	222	264	301	344	353	344	301	327	336	327	344	327	344	371	319	319	253	240	258	240	200	195
	2	190	185	216	210	286	327	353	362	362	371	371	362	362	294	311	286	336	344	319	311	311	205	271	271	200	200
	1	180	176	205	216	301	301	279	222	205	240	336	353	336	336	301	240	311	311	294	294	253	222	228	210	185	200
PIECE 2	1	176	185	205	216	311	432	353	432	421	451	353	371	264	294	311	271	271	253	271	253	228	216	200	180		
	2	195	195	216	222	294	371	400	432	400	336	327	336	319	294	301	301	234	258	222	200	210	185	190	190		
	3	190	180	185	200	200	205	222	264	253	247	240	222	228	247	222	228	210	205	195	195	190	190	195	185		
	4	180	180	169	185	190	195	190	210	210	210	205	210	205	200	200	210	195	195	185	185	176	176	180	180		
	5	180	180	176	195	195	180	185	185	205	185	200	190	190	185	185	190	185	190	185	185	180	190	180	185		
	6	172	180	180	172	190	180	176	190	200	180	205	210	185	185	190	180	190	185	185	180	176	176	185	190		

PRCI
LEADING PIPELINE RESEARCH

2023 Hard Spot Leak

Leak reported by Landowner in March 2023

- NDE evaluation discovered leaking hard spot with crack
- Same Bethlehem purchase order as Station hard spot failure

Hard Spot ILI had been Completed: October 2021

- Six (6) hard spot features reported by ILI Vendor in February 2022
    - Highest hardness reported by ILI was 285 BHN and 0 hard spots found in-ditch

Hard Spot ILI re-analysis effort

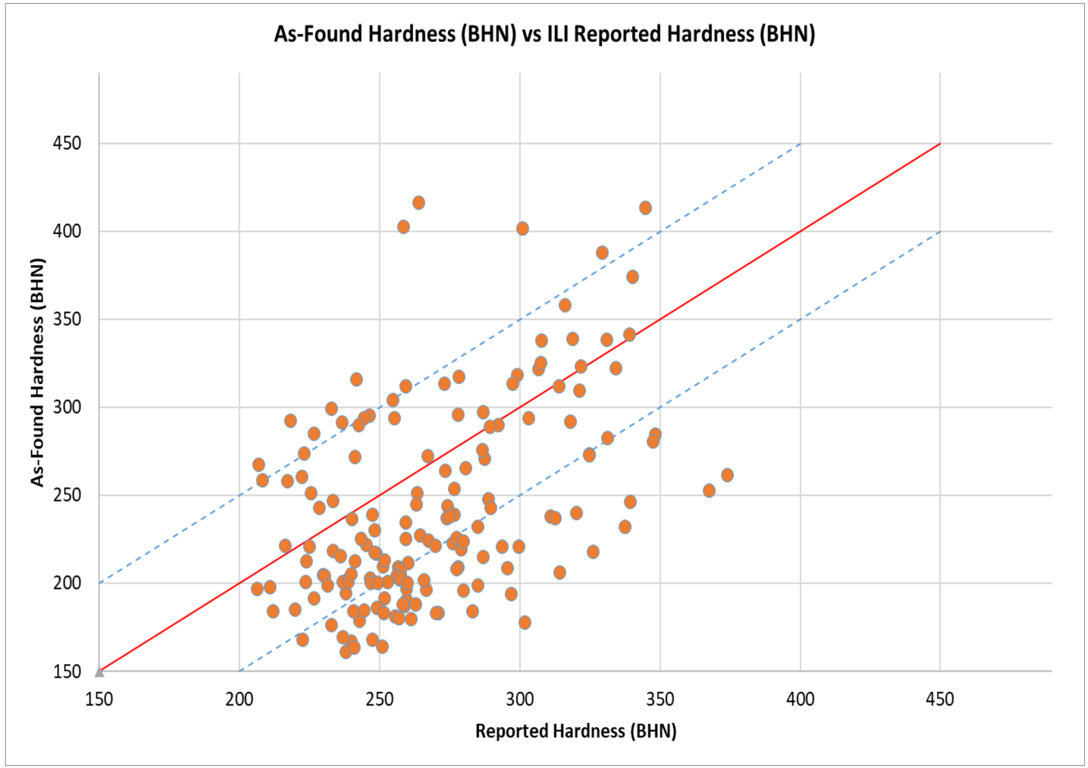
- We now understand hard spot signals can vary and identification can be a challenge for ILI vendors
- After hard spot leak incident, Williams worked with ILI vendor to re-analyze prior segments
    - Hard Spot ILI re-analyses and/or reassessments may be something for Operators to consider

171.3	175.2	180.9	196.1	228.5	248.5	263	210	202.5	199.4	184.2	177.6	174.5	165.9
168.2	174.3	206.5	233.3	241.4	259.8	256.9	279.2	287.6	290.8	247.4	181.2	178.5	175.2
173.3	195.1	239.5	258.1	248.1	316.9	298.2	288.5	294.1	311.4	310	212.7	180.8	177.3
185.9	242.6	253.2	268.4	307.6	350.5	346	337.7	332.6	288.6	268.7	268.7	188.1	180.1
208.1	239.4	231.8	318.1	315.5	352.8	343	353.1	353.4	291.3	235.5	224.4	231.6	187.3
229.5	254.2	235.9	330.3	335.2	332.2	353.8	356.2	350.6	340.3	275.6	238.3	223.5	186.3
205.6	241.6	225.7	257.2	352	334.6	347.1	353.5	363.7	355.7	282.9	234.2	200	188.1
186.7	250.3	220.4	245.4	318.7	340.2	356.7	364.3	323.5	340.6	310.4	234.2	188.9	191.3
177.1	210.6	237	235.8	217.9	292.4	314.1	327.2	269.9	322.6	287.9	213.3	182.5	171.2
168.9	188.7	220.2	222.5	195.3	231.4	318.6	281.6	192.2	214.4	205.2	209.9	176.3	169.8
175.7	175.9	193.7	191.4	214.9	217.2	207.3	195	203.5	207.2	207.3	185.6	166	168.7

1957 Bethlehem 30", 0.3125" NWT, X52

Williams Hard Spot ILI Program

- **51 Hard Spot ILIs (~2800 miles) completed to date (2020 to Present)**
  - Risk based prioritization (MAT 7-2 and Williams hard spot findings)
  - Thousands of hardness anomalies reported (not all are injurious hard spots)
    - Operators need criteria for screening hard spots
- **228 digs (1067 hardness anomalies) (2021 to Present)**
  - 93 hard spots requiring repair (Hardness ≥ 280 BHN)
    - ~40% of digs, ~8% of calls dug
    - 44 hard spot defects (Hardness ≥ 327 BHN)
      - ~19% of digs, ~4% of calls dug
- **All hard spot digs are integrated into a HS database which Risk model consumes**
  - Allows Williams to use data from hard spot findings each year
    - Spatially located with all necessary pipe attributes and details of hard spot finding (hard spot defect or not)



Hard Spot ILI Risk Prioritization

Practically impossible	Very unlikely to occur	Not likely to occur	Possibility of occurring sometime	Possibility of isolated incidents	Possibility of repeated incidents	(Annualized Probabilities)
$1x10^{-6}$	$1x10^{-5}$	$1x10^{-4}$	$1x10^{-3}$	$1x10^{-2}$	$1x10^{-1}$	
6P	**5P**	**4P**	**3P**	**2P**	**1P**	
4	**3**	**2**	**2**	**1**	**1**	**1S** $100M
4^5	**4**	**3**	**2**	**2**	**1**	**2S** $10M
4^6	**4^5**	**4**	**3**	**2**	**2**	**3S** $1M
4^7	**4^6**	**4^5**	**4**	**3**	**2**	**4S** $100k
4^8	**4^7**	**4^6**	**4^5**	**4**	**3**	**5S** $10k
4^9	**4^8**	**4^7**	**4^6**	**4^5**	**4**	**6S**

Severity Considerations

Public Health & Safety	Employee/Contractor Health & Safety	Environmental
Fatality; two or more injuries requiring in-patient hospitalization; officially declared community evacuation ≥ 48 hrs	Multiple fatalities	Widespread release, major emergency response, long-term cleanup, potential significant adverse effects to environmentally sensitive area (ESA), potential remedial concerns ≥ 5 yrs, negative health effects for members of the public due to chemical exposure; large-scale injury or death of aquatic or land-based wildlife; release resulting in acute cost ≥ $100M
Injury requiring in-patient hospitalization; officially declared community evacuation ≥ 24 hrs and < 48 hrs	Fatality	Widespread release, major emergency response, long-term cleanup, potential significant adverse effects to environmentally sensitive area (ESA), potential remedial concerns ≥ 2 and < 5 yrs, no negative public health effects; medium-scale injury or death of aquatic or land-based wildlife; release resulting in acute cost ≥ $10M and < $100M
Injuries requiring treatment beyond first aid (treatment by a medical professional); officially declared community evacuation ≥ 3 hrs and < 24 hrs; officially declared shelter in place or public road closure ≥ 3 hrs	Severe injury/illness resulting in life threatening or life altering impact to daily activity and extended recovery duration from months to forever	Localized release, intermediate emergency response, cleanup lasting weeks to months, potential adverse effects to environmentally sensitive area (ESA), potential remedial concerns ≥ 6 months and < 2 yrs; small-scale injury or death of aquatic or land-based wildlife; release resulting in acute cost ≥ $1M and < $10M
Injury requiring first aid; officially declared community evacuation < 3 hrs; officially declared shelter in place or public road closure < 3 hrs	Serious injury/illness resulting in significant impact to daily activity and recovery duration from weeks to months	Localized release, local emergency response, cleanup < 2 weeks, potential minor adverse effects to environmentally sensitive area (ESA), potential remedial concerns < 6 months; release resulting in acute cost ≥ $100k and < $1M
Numerous public complaints	Minor to moderate injury/illness resulting in minor impact to daily activity and recovery duration from hours to days	Release confined to site or close proximity, prompt cleanup, inconsequential or no adverse effects on environmentally sensitive area (ESA); release resulting in acute cost ≥ $2.5k and < $100k
Isolated public complaints	Minor event with little to no physical damage and no significant impact to daily activity	Any unplanned or unpermitted release that is not reportable to a regulatory or tribal agency; release resulting in acute cost < $2.5k

Approvals and Notifications*

	Reduce Risk (Continue operation until resolution/mitigation)		Accept Risk (Continue operation at residual risk level)
Risk Level	**Approval**	**Notification**	**Approval**
1	Senior Vice President	Chief Operating Officer	N/A -Outside Risk Capacity
2	Vice President/General Manager	Senior Vice President	Senior Vice President
3	Director	Vice President/General Manager	Vice President/General Manager
4	None Required	None Required	None Required

Risk Capacity

Risk Appetite

* Risk DOA rolls upward when a role/title does not exist in an organization.

LEADING PIPELINE RESEARCH

Critical Review of Prior Model MD Module: E-M-R Approach

Exposure

- Likelihood of manufacturing defect
- Based on observed defects and
- failure history
- HS observations and failures rolled into this general category

Mitigation

- Pressure testing
- Seam and crack tools

Resistance

- Based on MAOP percent of SMYS
- Stronger pipe, lower stress % → higher resistance

Critical Model Review
Issues with the old approach

Exposure Mismatch

- Other manufacturing defects susceptible to stress induced failure without additional environmental conditions

Mitigation Mismatch

- Pressure testing
  - Hard Spot defect absent further embrittlement or stress concentrators may survive qualifying test
- Seam and crack tools
  - Unlikely to detect hard spot with cracks
  - Crack failure occurs abruptly in embrittled hard spot with small stress concentrator (2mm corrosion pit)

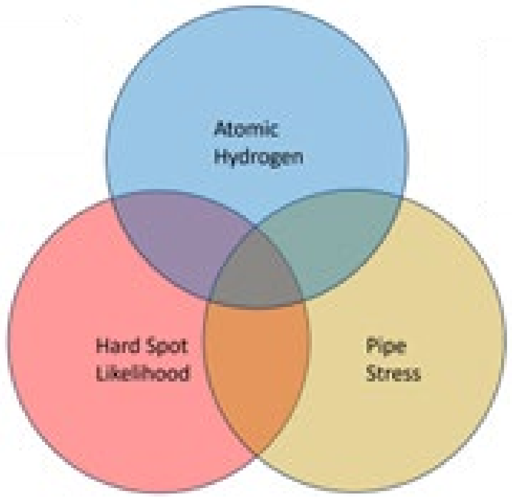
Resistance mismatch

- No embrittlement component interaction
- Vintage higher strength steel manufacturing processes contribute to exposure

Most Effective Fix – New Hard Spot Module

Table IV-1
Interacting Threat Matrix

			Time-Dependent			Stable									Time-Independent							
			EC	IC	SCC	MFR		CON			EQ				IO	TPD			WROF			
			EC	IC	SCC	DP	DPS	DFW	DGW	CD	MCRE	TSBPC	GF	SPPF	IO	TP	PDP	V	EM	HRF	LIGHT	CW
Time-Dependent	EC	EC			1	1	1		1	1[1]	1	1[3]	1		1	1	1		1	1		1
	IC	IC				1	1		1		1		1		1		1					
	SCC	SCC				1	1	1	1	1[4]	1				1		1		1	1		
Stable	MFR	DP					1	1	1	1	1[2]					1[7]	1[7]	1[7]				
		DPS								1[5]	1[2]				1[6]	1[7]	1[7]	1[7]	1			
	CON	DFW										1			1	1			1	1		1
		DGW								1	1					1	1		1	1		1[8]
		CD									1[2]	1							1	1		
	EQ	MCRE										1	1	1	1	1	1			1	1	1
		TSBPC													1	1			1	1		1
		GF													1	1		1	1	1	1	
		SPPF													1							
Time-Independent	IO	IO														1	1	1	1	1		1
	TPD	TP															1		1	1		
		PDP																	1	1		
		V																				
	WROF	EM																		1		1
		HRF																				1
		LIGHT																				
		CW																				

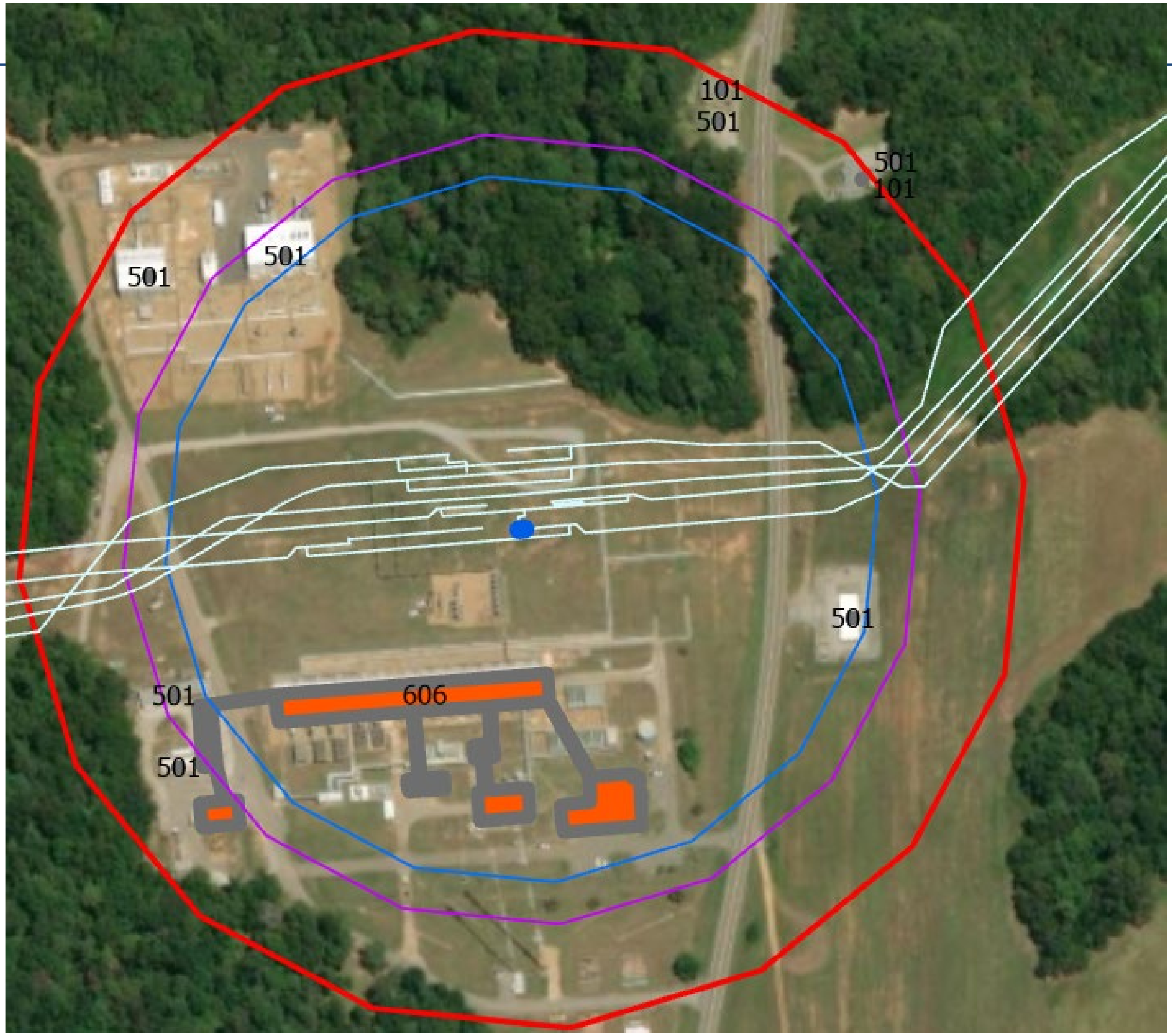


- **Hard Spot conditions not well captured in the Interacting Threat Matrix.**
- **Three legs of the stool: hard spot, atomic hydrogen, stress**

https://www.phmsa.dot.gov/sites/phmsa.dot.gov/files/2020-03/Pipeline-Risk-Modeling-Technical-Information-Document-02-01-2020-Final.pdf

Modeled Consequence

- **Consequence**
  - Safety receptors (occupancy)
  - Property estimates
  - Pipe Repair
  - Enforcement



First Pass Injurious HS Rate Estimation

Our Starting Point - Williams and Industry History

Pipe Populations

- Certain Manufacturers
- Particular batches of pipe / Purchase Orders
- Particular Vintages, OD/WT Combinations

Rates developed from failures and amount of pipe in inventory

Weighted toward Williams' history since understanding of the inventory not available for industry failures – limited accurate rate setting to those manufacturers we had experience with

Pipe Seam Type	Pipe Manufacturer	Pipe Production Year	No. of Incidents
Flash Weld	A.O. Smith	1951	1 (0)
		1952	21 (17)
		1954	2 (1)
		1955	1 (1)
		1957	1 (1)
DSAW	Consolidated Western	1947	1 (0)
		1957	2 (2)
	Bethlehem	1955	1 (1)
	Kaiser	1949	2 (2)
	Republic	1957	1 (1)
ERW	Youngstown	1947	2 (1)
		1950	1 (1)
		1959	1 (0)
		1960	1 (1)

Failure_MP	Failure_Da	Main_l	Diame	Wt	Grad	Install_date	Manufacturer	Caus	EST_FAIL_PRES	PO
719.96	6/18/1961	B	36	0.406	x52	1957	Bethlehem Steel	HS	N/A	90,000
918.71	7/5/1967	B	36	0.406	x52	1957	National Tube	HS	720	90,001
663	4/3/1969	A	30	0.325	x52	1949	Consolidated Western	HS	790-795	
517.73	4/4/1969	A	30	0.325	x52	1949	Consolidated Western	HS/SCC?	N/A	
1389.26	2/11/1970	B	30	0.312	x52	1958	Bethlehem Steel	HS	702	90,000
1562.46	6/9/1974	B	30	0.312	x52	1957	Bethlehem Steel	HS	718	90,000
628.94	10/3/1981	B	36	0.406	x52	1954	Consolidated Western	HS	N/A	75,101
626.02	7/17/1983	C	36	0.469	x52	1962	Bethlehem Steel	HS	1090	89782, WO 5222.04
577.74	4/10/2016	C	36	0.406	x52	1961	National Tube	HS	N/A	84395
811.17	4/12/2022	A	30	0.5	x52	1959	Bethlehem Steel	HS	779	90,000
1558.66	3/8/2023	B	30	0.312	x52	1957	Bethlehem Steel	HS		90,000

2024 Injurious HS Rate Estimation

- **Better Rate Setting**
  - **MAT 7-2A provided:**
    - **More comprehensive failure data**
    - **Large dataset of pipe populations**
- **ILI Finding incorporation**
  - **Evolving insights: 1,383 miles → 3,780 miles (2 years)**
  - *****Beware "the law of small numbers"**
  - **Using our in-house ILI figures tied to specific populations**

Pipe Seam Type	Pipe Manufacturer	Pipe Production Year	No. of Incidents
Flash Weld	A.O. Smith	1951	1 (0)
		1952	21 (17)
		1954	2 (1)
		1955	1 (1)
		1957	1 (1)
DSAW	Consolidated Western	1947	1 (0)
		1957	2 (2)
	Bethlehem	1955	1 (1)
	Kaiser	1949	2 (2)
	Republic	1957	1 (1)
ERW	Youngstown	1947	2 (1)
		1950	1 (1)
		1959	1 (0)
		1960	1 (1)

Table 18. Pipe mileage by manufacturer, 16-inch OD and Larger, 40% SMYS and Greater, Pre-1960 and 1960-1969

Pipe Manufacturer	Mileage (5 PRCI Operators)			ALL Incidents			Incidents/Mile x1e-3		
	< 1960	1960 -69	< 1970	< 1960	1960-69	< 1970	< 1960	1960-69	< 1970
AO Smith	16,404	5,029	21,434	58	0	58	3.536	0	2.706
Bethlehem	884	2,620	3,504	7	0	7	7.915	0	1.998
Claymont	35	0	35	0	0	0	0	0	0
Consolidated Western	4,709	402	5,111	2	0	2	0.425	0	0.391
Kaiser	2,399	3,593	5,991	2	2	4	0.834	0.557	0.668
National Tube	8,620	2,874	11,494	2	1	3	0.232	0.348	0.261
Republic	5,277	2,989	8,266	3	0	3	0.569	0	0.363
US Steel	391	3,385	3,776	0	1	1	0.000	0.295	0.265
Welland Tube	559	366	925	1	0	1	1.788	0	1.081
Youngstown S&T	3,669	804	4,473	5	0	5	1.363	0	1.118
Unknown, Other	2,332	1,401	3,733	3	1	4	1.287	0.714	1.072
Aggregate	*45,279*	*23,461*	*68,740*	*82*	*5*	*87*	*1.833*	*0.213*	*1.280*

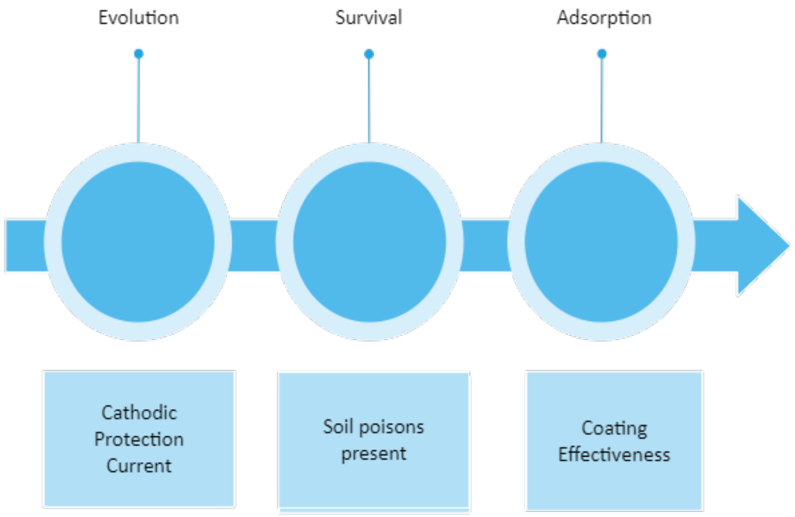
Seven other incident operator mileage	3627	3321	7066
Proportion of 5 PRCI operator aggregate	0.080	0.142	0.103

Table 16. Reported ILI hard spot indications

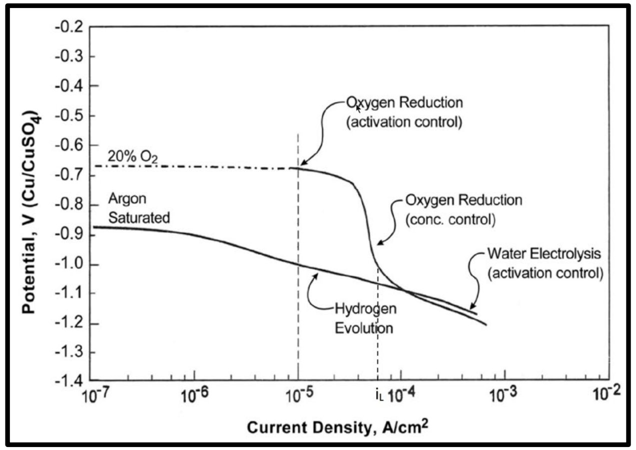
Manufacturer	2022 ILI hard spot count			2024 MAT-7-2 update		
	ILI Miles	Hard Spots	HS/Mile	ILI Miles	Hard Spots	HS/Mile
A.O. Smith	739	282	0.382	1440	587	0.408
Bethlehem	67	30	0.448	460	550	1.196
Claymont	33	5	0.152	68	20	0.294
ConWestern	46	10	0.217	306	87	0.284
Kaiser	96	27	0.281	229	133	0.581
Lonestar	--	--	--	10	4	0.400
National Tube	232	197	0.849	471	228	0.484
Republic	170	79	0.465	581	90	0.155
US Steel	--	--	--	148	46	0.311
Youngstown	--	--	--	57	6	0.105
Unknown	--	--	--	10	78	7.800
Aggregate	*1,383*	*630*	*0.456*	*3,780*	*1829*	*0.484*

Embrittlement Likelihood

- **Keying on CP Potentials**
  - Atomic Hydrogen needed for embrittlement
    - No great discriminator found for soil poisons
    - Coating quality -- future improvement to model
    - CP -- largest source of potential hydrogen generation



- **Two Embrittlement Components**
  - Latest CP levels
    - On protected steel, 100 mV of additional polarization requires 10x current (second activation control region)
      - Logarithmic multiplier for additional mV beyond -950mV CSE
      - Maxes out at -1350mV CSE with 10000x multiplier
  - Recent CP level changes
    - Polarization increase between last read and 3 years previous
      - Maxes out at 200mV --- 100x multiplier
      - 100mV, 10x multiplier



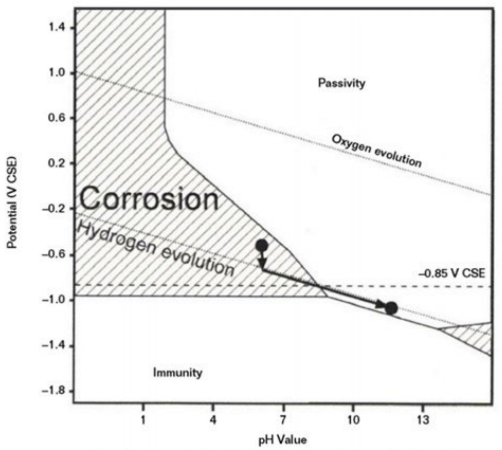
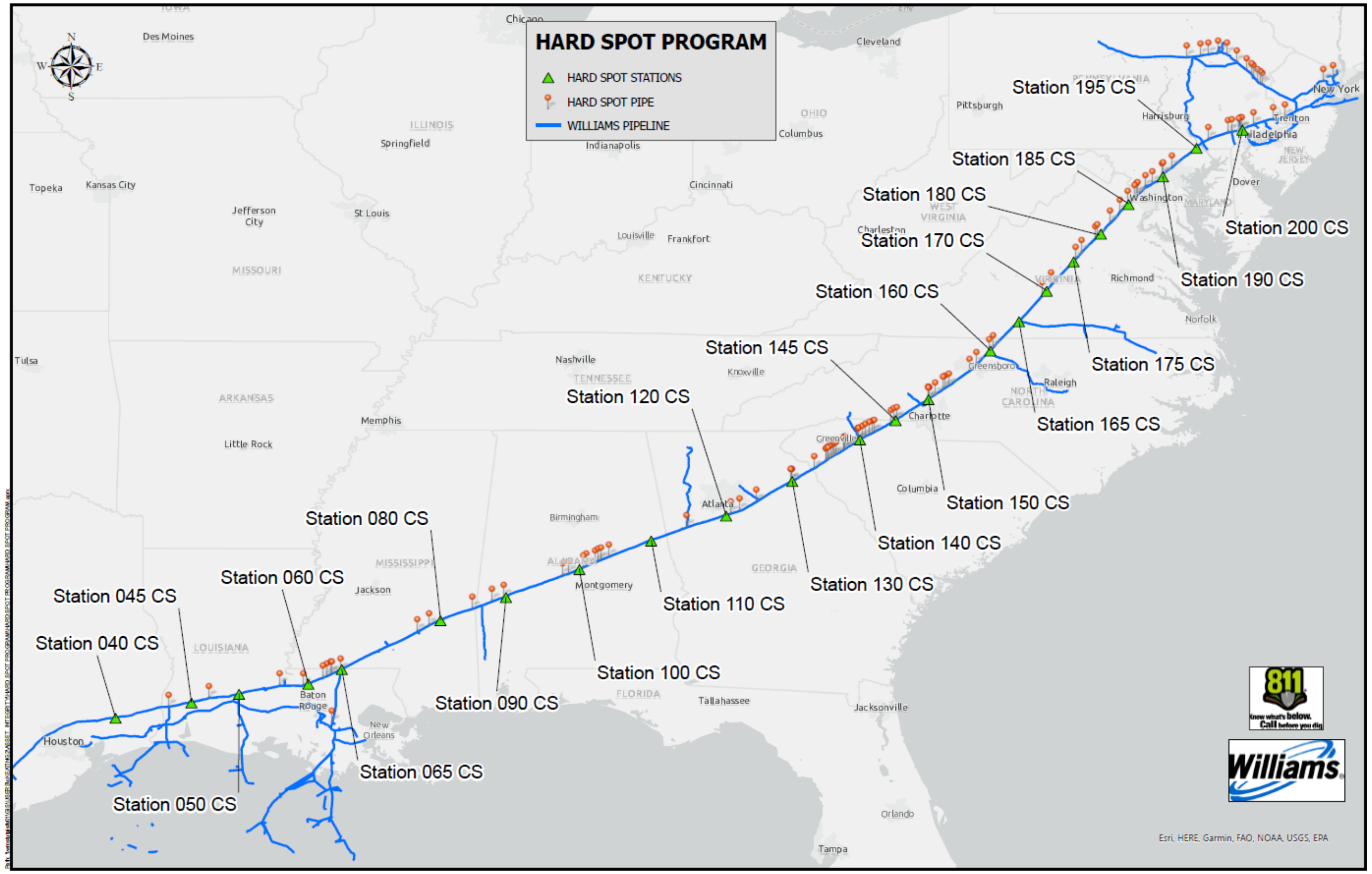


FIGURE 4 On a Pourbaix diagram, cathodically polarized potentials on steel are limited by the hydrogen line and increased CP current increases the steel/electrolyte interfacial pH.

LEADING PIPELINE RESEARCH

Mitigation driven by Risk Results

- **HS ILI Assessments**
  - **51 Segments Assessed**
    - **At least 93 hard spots (Hardness ≥ 280 BHN)**
- **Additional ROW CP Survey**
  - **104 segments**
  - **258 miles total**
- **Additional Station CP Survey**
  - **23 Stations Surveyed (test points, CIS)**
    - **CP reductions, CP coupon installation**
- **Station Piping Assessments**
  - **High risk pipe being excavated, assessed, recoated**

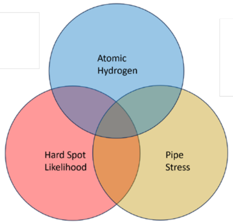


LEADING PIPELINE RESEARCH

Hard Spot ILI Risk Prioritization - Results

- **2023 Hard Spot Risk Model = 24 Risk 1-3 piggable segments identified (Williams risk exceedance)**
  - Resulted in 114 digs issued and 24 digs completed to date (more to come in 2025)
    - 14 hard spot defects repaired

Failure Probability



Consequence

Practically impossible	Very unlikely to occur	Not likely to occur	Possibility of occurring sometime	Possibility of isolated incidents	Possibility of repeated incidents	(Annualized Probabilities)
$1x10^{-6}$ 6P	$1x10^{-5}$ 5P	$1x10^{-4}$ 4P	$1x10^{-3}$ 3P	$1x10^{-2}$ 2P	$1x10^{-1}$ 1P	
4	3	2	2	1	1	1S $100M
4^5	4	3	2	2	1	2S $10M
4^6	4^5	4	3	2	2	3S $1M
4^7	4^6	4^5	4	3	2	4S $100k
4^8	4^7	4^6	4^5	4	3	5S $10k
4^9	4^8	4^7	4^6	4^5	4	6S

24 risk 1-3 segments assessed

Adjacent Occupancy

Adjacent Structure Cost

Repair Cost

Enforcement ($100MM)

LEADING PIPELINE RESEARCH

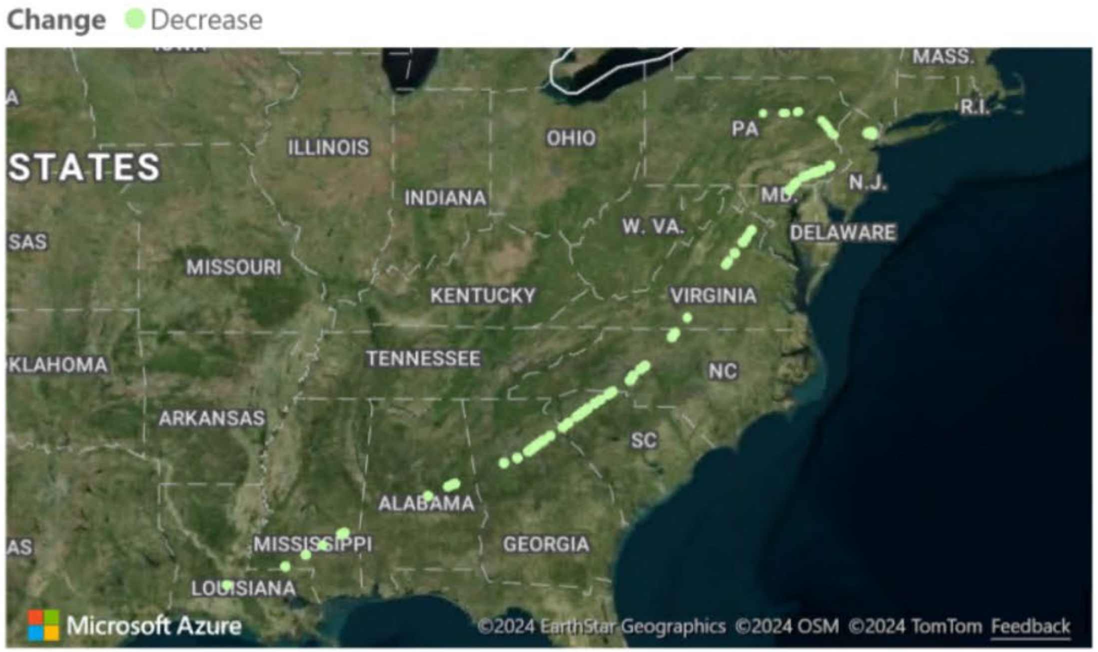
Realized Risk Reduction from ILI Assessment

- **HS ILI Assessments drove 90% probability reduction**

2023 Risk Reduced through ILI Assessment

2023 Risk Cat	Line	Segments	Miles
2	MAIN-B-...	7	2.79
2	MAIN-C-...	1	0.14
2	LEID-A-T...	1	0.05
3	MAIN-B-...	16	22.58
3	LEID-A-T...	2	6.79
3	MAIN-C-...	5	5.28
3	CFL-T-T-T	1	0.66
3	MLCWB-...	1	0.61
Total		**25**	**38.88**

2024 Risk Cat	Line	Segments	Miles
3	MAIN-B-...	3	0.35
Total		**3**	**0.35**



Hard Spot ILI 2025 +

- **Using most recent Hard Spot Susceptibility knowledge + Williams hard spot findings to update Risk Model (annually)**
  - Susceptibility is not binary so the challenge is drawing a line in the sand
- **Consideration based on MAT 7-2A outcomes**
  - What gaps are identified and how will that change our program
- **Consideration for re-analysis if technology hasn't changed**
- **Consideration for re-assessments to improve POD/POI or technology changes**
  - This could simply be trying out different vendors since not every ILI technology is the same

LEADING PIPELINE RESEARCH

Questions