

PII Pipeline Solutions

a GE Oil & Gas and Al Shaheen joint venture



ADVANCEMENTS IN THE DETECTION AND SIZING OF "PINHOLE" METAL LOSS IN ON & OFFSHORE PIPELINES

Martin Bluck, Senior Product Manager

19th November, 2014

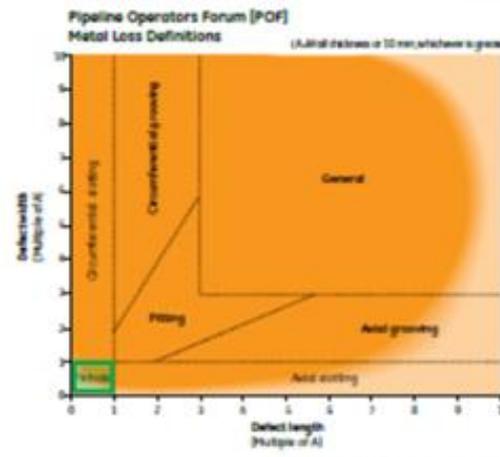
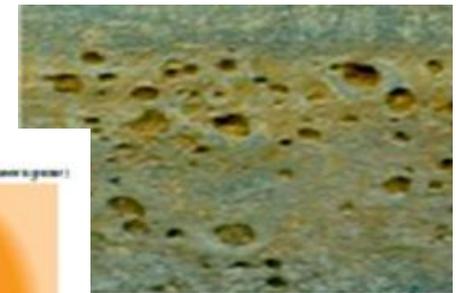
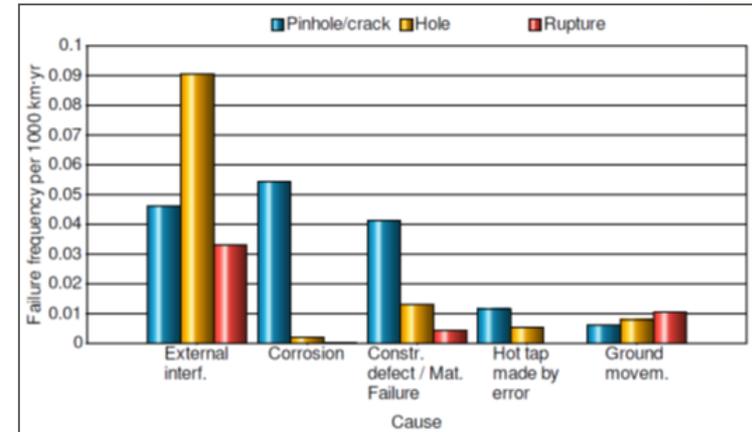


Outline

- Background
- MagneScan™ (MFL4) system
- Finite Element modelling
- “Pinhole” blind test program
- In-line inspection, analysis report, and dig verification
- Conclusions

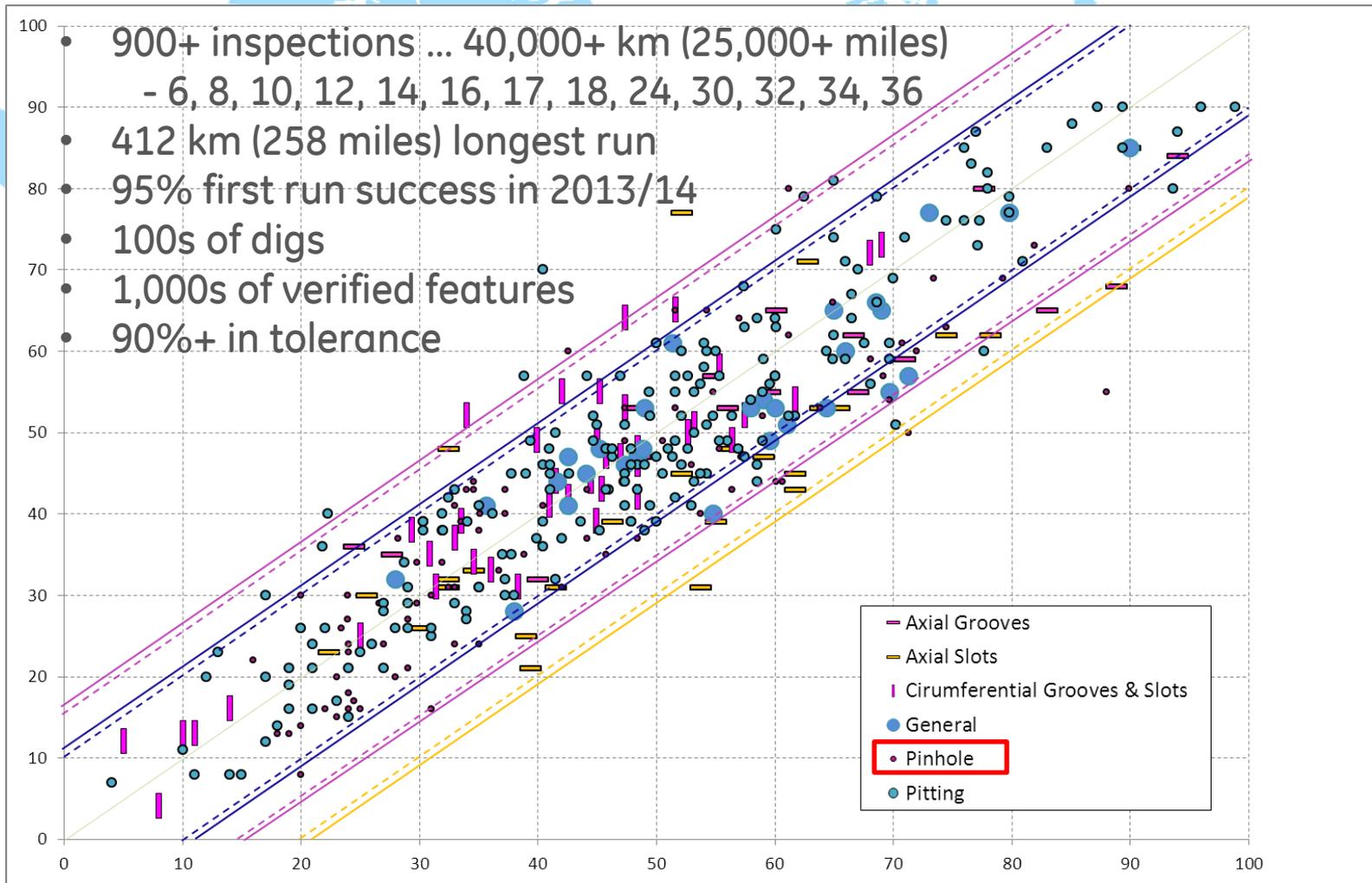
Background ... 'Pinhole' corrosion

- 'Pinhole Corrosion' & 'Hot Taps made by error' significant causes of pipeline failure – EGIG report, Dec '11
- Result of typical corrosion mechanisms e.g. MIC or 3rd party activity e.g. illegal tapping
- 'Pinholes' problematic for gas & liquid operators as a primary threat for leaks
- POF definition:- Length < 1A & Width < 1A. If wall thickness (t) < 10mm then A = 10mm, if ≥ 10 mm then A = t
- Typically beyond the capability of MFL systems



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MagneScan™ (MFL4) ... dig verification



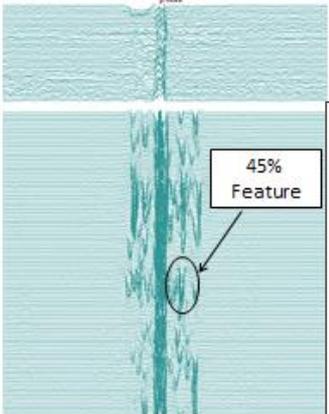
1,000s of features categorized & verified by dimension class
... including "Pinholes"

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MagneScan™ (MFL4) ... dig verification

Dig Verification ... digging down-under

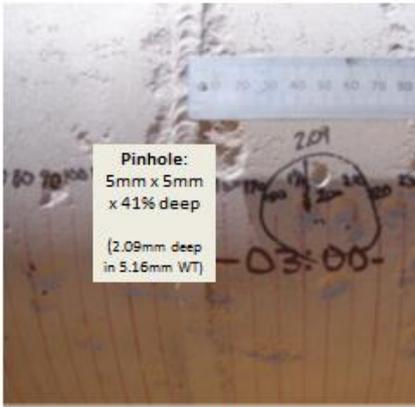


45% Feature

Analysis image



Dig Verification ... digging down-under



Pinhole:
5mm x 5mm
x 41% deep

(2.09mm deep
in 5.16mm WT)

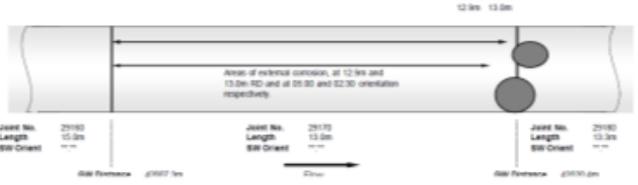
Photo of corrosion in field wrap zone showing ta



Dig Verification ... digging down-under

NDT Details
Manual Ultrasonics - Sonogage WT meter, 5-degree 5MHz twin compression wave probe, 10mm diameter.
Depth Micrometer and bridging bar, PE Gauge.

Results
The two features were shown to be areas of external corrosion in the downstream field wrap zone, with peak depths of 30% and 41% respectively.



12.9m 13.0m

Area of external corrosion, at 12.9m and 13.0m RD and at 00:30 and 02:30 orientation respectively.

Joint No.	25152	Joint No.	25170	Joint No.	25162
Length	15.0m	Length	13.0m	Length	13.0m
SW Orient	---	SW Orient	---	SW Orient	---

Weld Parameter: 20007.0m

GE reported 45% feature measured at 41% in ditch

Non Destructive Test Investigation sheet from final Dig Verification Report for target feature

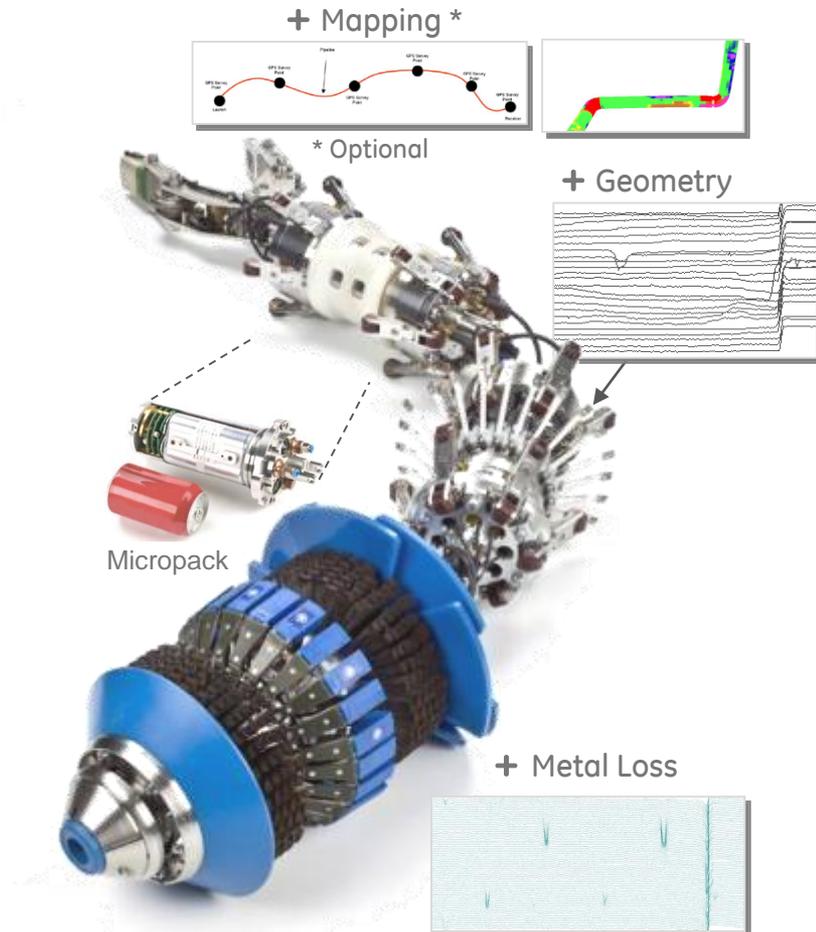


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Pinole 5mm x 5mm x 41% in 5.16mm wt 14" pipe from 2011

MagneScan™ (MFL4) ...attributes

- Hall Effect sensors for metal loss in 3 axes ... 216 on 6" system
- 5.4mm circumferential separation ... 2mm axial sampling
- Integrated High Resolution Caliper ... 24 sensors (1 per 20mm/0.8"circ.)
- Fiber Optic Gyroscope IMU ... 3D mapping & curvature/strain
- High field "Speed-stable" Magnetizer 0 to 5m/s (11 mph)
- ATEX Certified



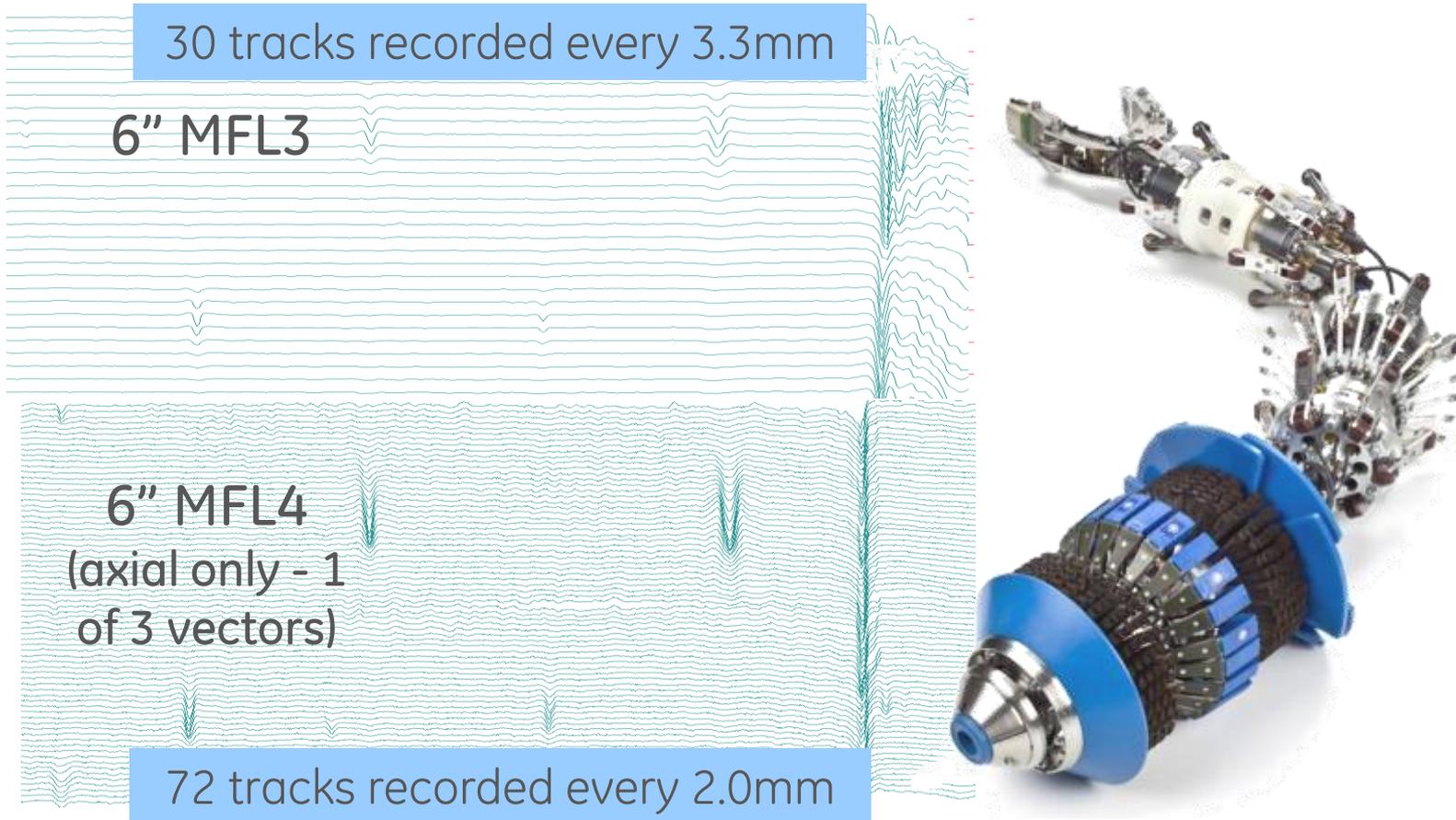
High Resolution ... Multi-mission



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Note: detail relates to 6 inch system

MagneScan™ (MFL4) ...high resolution

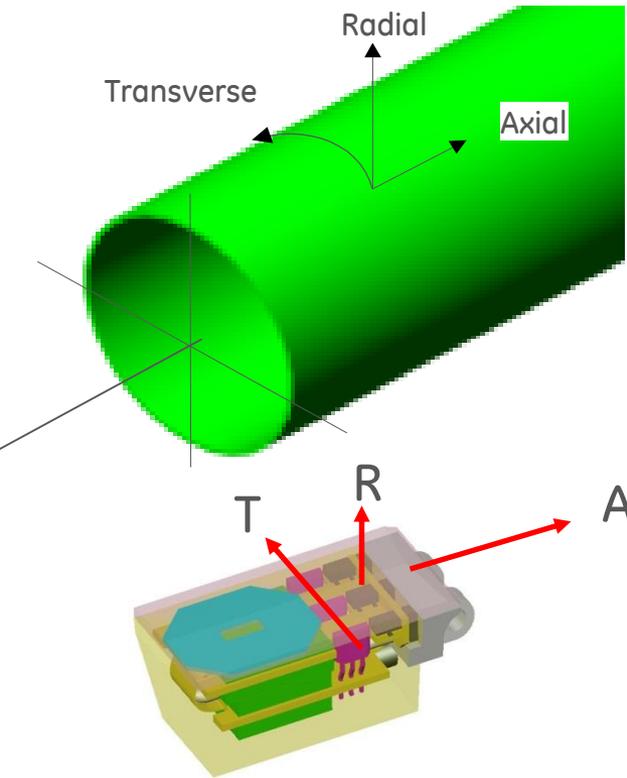


Enhanced axial & circumferential resolution ... effectively a 3 x zoom

MagneScan™ (MFL4) ... Hall Effects in 3 axes

“Leakage” is a Vector quantity

Each MFL4 sensor track measures the 3 orthogonal components of this vector



Axial

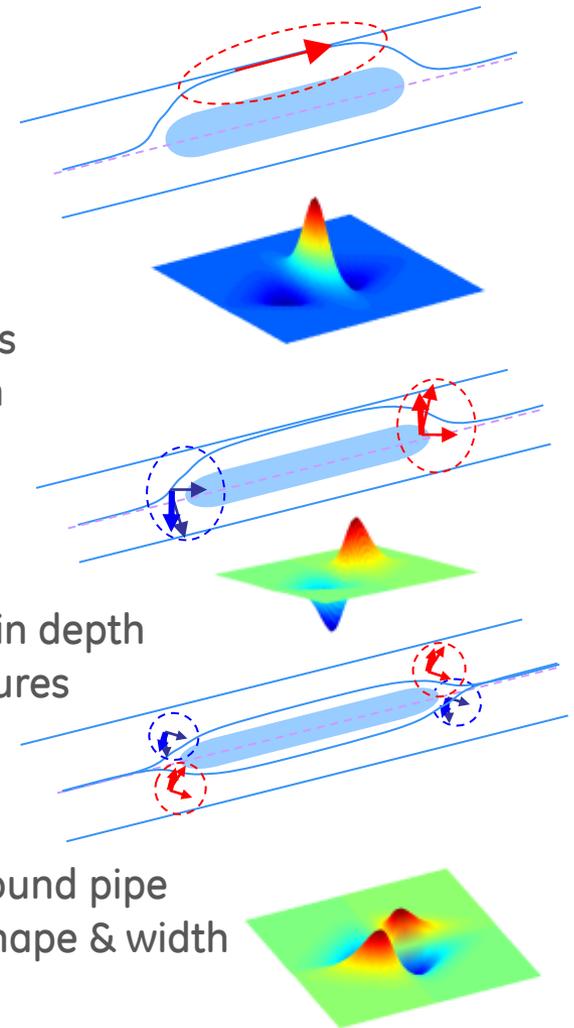
- Measured down pipe
- Sensitive to “ Volumetric” losses
- Measure nominal field strength

Radial

- Measured out/in from center
- Highest sensitivity to changes in depth
- Identifies start and end of features

Transverse

- Measured circumferentially around pipe
- Added sensitivity to in-plane shape & width

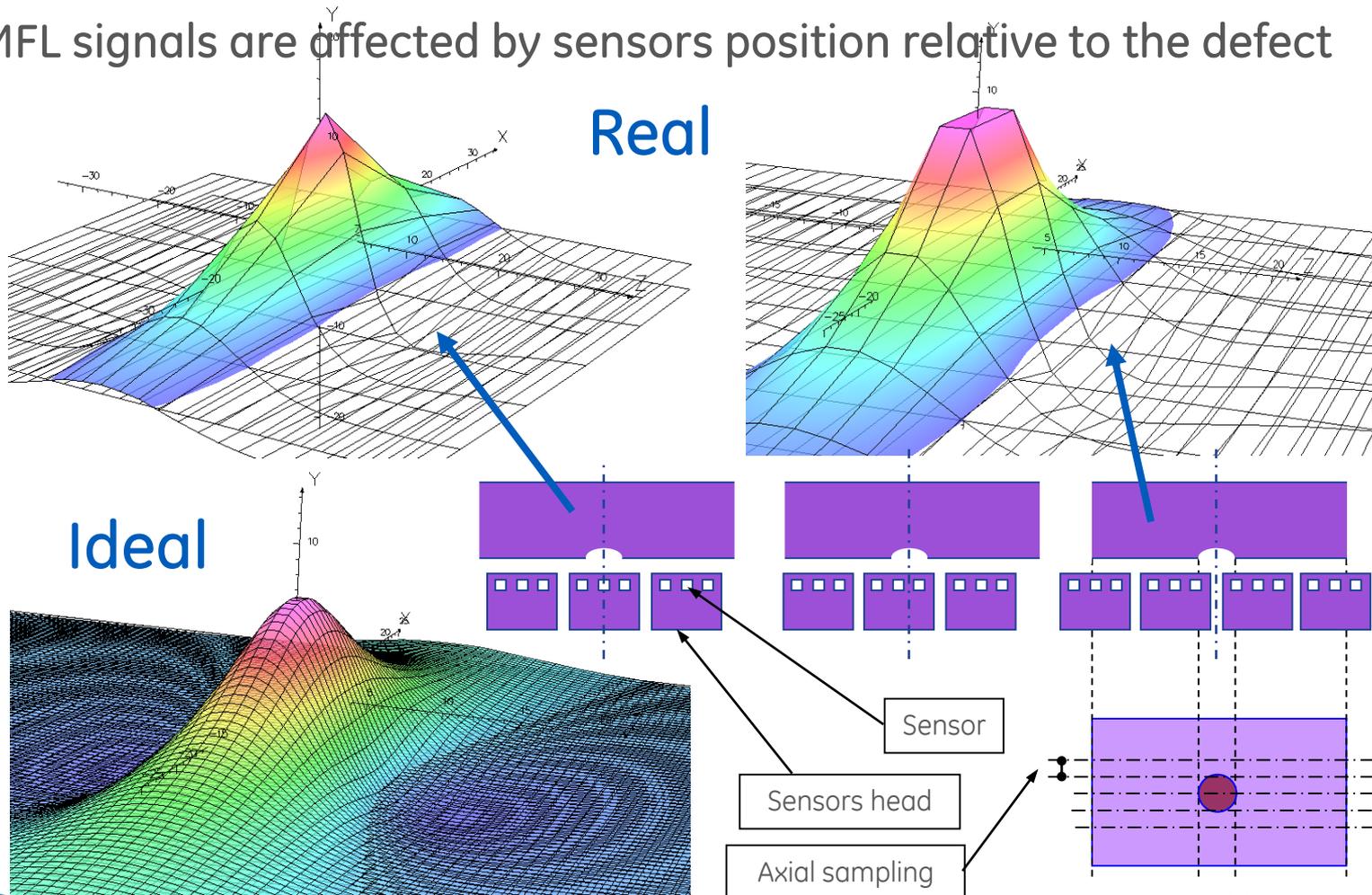


Enhanced detection (PoD), classification (PoI), & sizing

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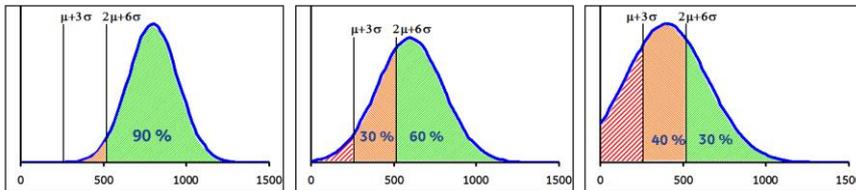
Finite Element Modelling ... sensor spacing & scan interval

MFL signals are affected by sensors position relative to the defect



Finite Element Modelling ... conclusions

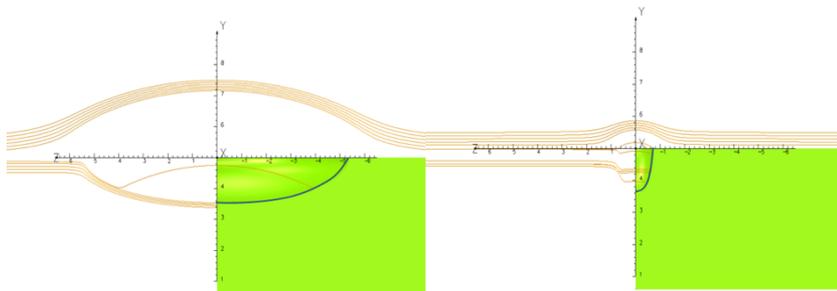
1. Increasing # of sensors & frequency of scans does not improve detection



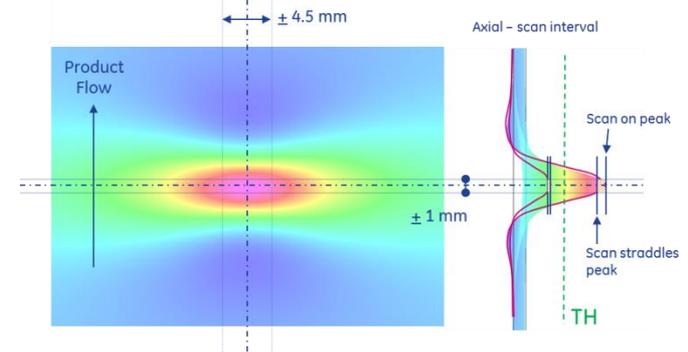
Detectable and measurable Detectable, not measurable Not detectable* (@90%PoD)

Rose Criterion: $SNR > 5$

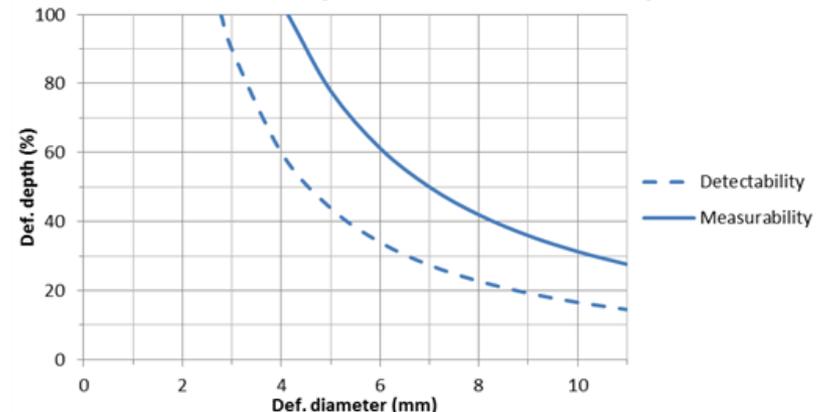
2. Dimensions of smallest Pinhole detectable with MFL were calculated



3. Below a minimum defect size signal amplitude falls below the noise threshold



4. MFL signal amplitude is lower for "Pinholes" leading to under-sizing



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MagneScan (MFL4) ... Pinhole” specification

Parameter		General Metal Loss		Pitting		Axial Grooving		Circumf. Grooving		Pinhole ***		Axial Slot **		Circumf. Slott **	
Depth @ POD = 90%	nwt	5% @4A		8% @2A		8% @4A*2A		5% @2A*4A		15% @0.5A		15% @0.5A*2A		5% @2A*0.5A	
	Certainty	80%	90%	80%	90%	80%	90%	80%	90%	80%	90%	80%	90%	80%	90%
Depth Sizing Accuracy	nwt (+/-)	8%	10%	8%	10%	-13%/+8%	-15%/+10%	-8%/+13%	-10%/+15%	-13%/+8%	-15%/+10%	-17%/+8%	-20%/+10%	-8%/+13%	-10%/+15%
Width Sizing Accuracy	mm (+/-)	12	15	12	15	12	15	12	15	12	15	12	15	12	15
Length Sizing Accuracy	mm (+/-)	7	10	4	5	7	10	7	10	4	5	7	10	7	10

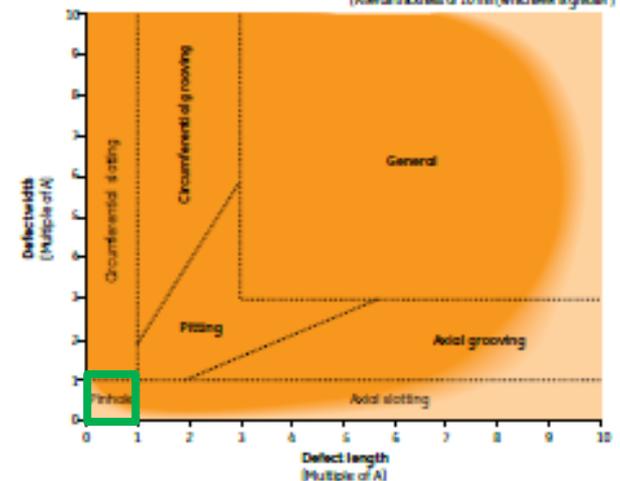
POD @ 90% 5mm PH > 15% in ERW

- Pinhole detection only: 4mm > 30% deep; 3mm > 40% deep; 2mm > 90% deep

Depth Sizing @ 90% Certainty

- PH > 5mm diameter ≤ 50%, -15%/+10%
- PH > 5mm diameter > 50%, -20%/+10%

Pipeline Operators Forum (POF)
Metal Loss Definitions (All wall thickness or 10 mm, whichever is greater)



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ExxonMobil

- World's largest publicly traded international oil & gas co.
- Industry leading inventory of global oil & gas resources
- World's largest refiner of & marketer of petroleum products
- Applying science & innovation to find better, safer, & cleaner ways to deliver the energy the world needs

AVONMOUTH PIPELINE

- Fawley Refinery to Avonmouth Terminal



- 6" x 133km refined product
- Previously inspected with MFL 22/03/05; 21/02/98; 23/08/93
- Concerns over 'Pinholes' & 'illegal tapping'

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ExxonMobil test program ... set-up

- 12 pulls with 06" MFL4
 - pulls from 0.5 to 4.5 m/s
 - included one conditioning run
- 77 features in 5.6mm wt test spool
 - 57 external & 20 internal
 - 41 drill hole & 36 conical
 - 64 covered by detection specification, 13 below
 - 44 covered by sizing specification, 33 below
- Note: assumed diameter of conical features = average of top & bottom e.g. 5/3 = 4mm

Defect Number	External / Internal	Defect position from start of spool (feet)	Defect Azimuth (Deg) *	Defect Depth %	Defect Diameter (mm)	Defect Profile **	Defect Number	External / Internal	Defect position from start of spool (feet)	Defect Azimuth (Deg) *	Defect Depth %	Defect Diameter (mm)	Defect Profile **
1	External	200	11	100	3		36	Internal	8200	2	100	3	9/5
2	External	400	6	25	6		38	Internal	8300	1	80	6	9/5
3	External	500	6	80	9		40	Internal	8400	9	80	7/5	9/5
4	External	600	6	50	5/2		42	Internal	8500	3	100	6/5	9/5
5	External	700	11	80	7		44	Internal	8600	11	25	7/5	9/5
6	External	800	11	25	1		46	Internal	8700	6	100	7/5	9/5
7	External	900	1	50	1		48	Internal	8800	2	80	5/5	9/5
8	External	1000	4	100	1		50	Internal	8900	1	80	6/5	9/5
9	External	1100	9	25	10		52	Internal	9000	1	25	6/5	9/5
10	External	1200	12	80	6		54	Internal	9100	9	50	10/5	9/5
11	External	1300	10	100	5/2		56	Internal	9200	7	25	10/5	9/5
12	External	1400	7	100	7		58	Internal	9300	5	100	6/5	9/5
13	External	1500	12	25	3		60	Internal	9400	11	25	9/5	9/5
14	External	1600	9	80	5/2		62	Internal	9500	9	80	10/5	9/5
15	External	1700	12	25	2		64	Internal	9600	1	100	10/5	9/5
16	External	1800	10	100	1		66	Internal	9700	1	80	6/5	9/5
17	External	1900	12	80	10		68	Internal	9800	9	80	10/5	9/5
18	External	2000	12	80	2		70	Internal	9900	7	100	10/5	9/5
19	External	2100	10	100	1		72	Internal	10000	1	80	6/5	9/5
20	External	2200	5	50	5/2		74	Internal	10100	9	80	10/5	9/5
21	External	2300	7	80	4		76	Internal	10200	7	100	7/5	9/5
22	External	2400	9	80	5		78	Internal	10300	9	100	9/5	9/5
23	External	2500	12	80	2		80	Internal	10400	11	80	6/5	9/5
24	External	2600	10	50	10		82	Internal	10500	9	100	6/5	9/5
25	External	2700	1	80	1		84	Internal	10600	1	80	6/5	9/5
26	External	2800	1	50	4		86	Internal	10700	1	100	6/5	9/5
27	External	2900	7	50	5/4		88	Internal	10800	7	100	10/5	9/5
28	External	3000	7	100	5/4		90	Internal	10900	7	100	10/5	9/5
29	External	3100	7	50	5/2		92	Internal	11000	7	100	10/5	9/5
30	External	3200	10	80	5		94	Internal	11100	10	100	10/5	9/5
31	External	3300	12	25	6		96	Internal	11200	12	25	6/5	9/5
32	External	3400	1	50	6		98	Internal	11300	1	50	6/5	9/5
33	External	3500	4	25	9		100	Internal	11400	4	25	9/5	9/5
34	External	3600	11	100	7		102	Internal	11500	11	100	7/5	9/5
35	External	3700	9	100	6		104	Internal	11600	9	100	6/5	9/5
36	External	3800	6	25	5/2		106	Internal	11700	6	25	5/2	9/5
37	External	3900	6	25	7		108	Internal	11800	6	25	7/5	9/5
38	External	4000	11	25	5/2		110	Internal	11900	11	25	5/2	9/5
39	External	4100	9	25	7		112	Internal	12000	9	25	7/5	9/5
40	External	4200	12	25	1		114	Internal	12100	12	25	1/5	9/5
41	External	4300	9	100	5/2		116	Internal	12200	9	100	5/2	9/5
42	External	4400	12	100	5		118	Internal	12300	12	100	5/5	9/5
43	External	4500	1	50	7		120	Internal	12400	1	50	7/5	9/5
44	External	4600	12	80	5/2		122	Internal	12500	12	80	5/2	9/5
45	External	4700	12	100	9		124	Internal	12600	12	100	9/5	9/5
46	External	4800	2	50	6		126	Internal	12700	2	50	6/5	9/5
47	External	4900	4	80	5/2		128	Internal	12800	4	80	5/2	9/5
48	External	5000	9	100	6		130	Internal	12900	9	100	6/5	9/5
49	External	5100	12	100	8		132	Internal	13000	12	100	8/5	9/5
50	External	5200	10	100	10		134	Internal	13100	10	100	10/5	9/5
51	External	5300	1	100	5/4		136	Internal	13200	1	100	5/4	9/5
52	External	5400	9	25	5/4		138	Internal	13300	9	25	5/4	9/5
53	External	5500	12	100	7		140	Internal	13400	12	100	7/5	9/5
54	External	5600	12	25	4		142	Internal	13500	12	25	4/5	9/5
55	External	5700	6	50	9		144	Internal	13600	6	50	9/5	9/5
56	External	5800	12	100	10		146	Internal	13700	12	100	10/5	9/5
57	External	5900	5	80	5/2		148	Internal	13800	5	80	5/2	9/5

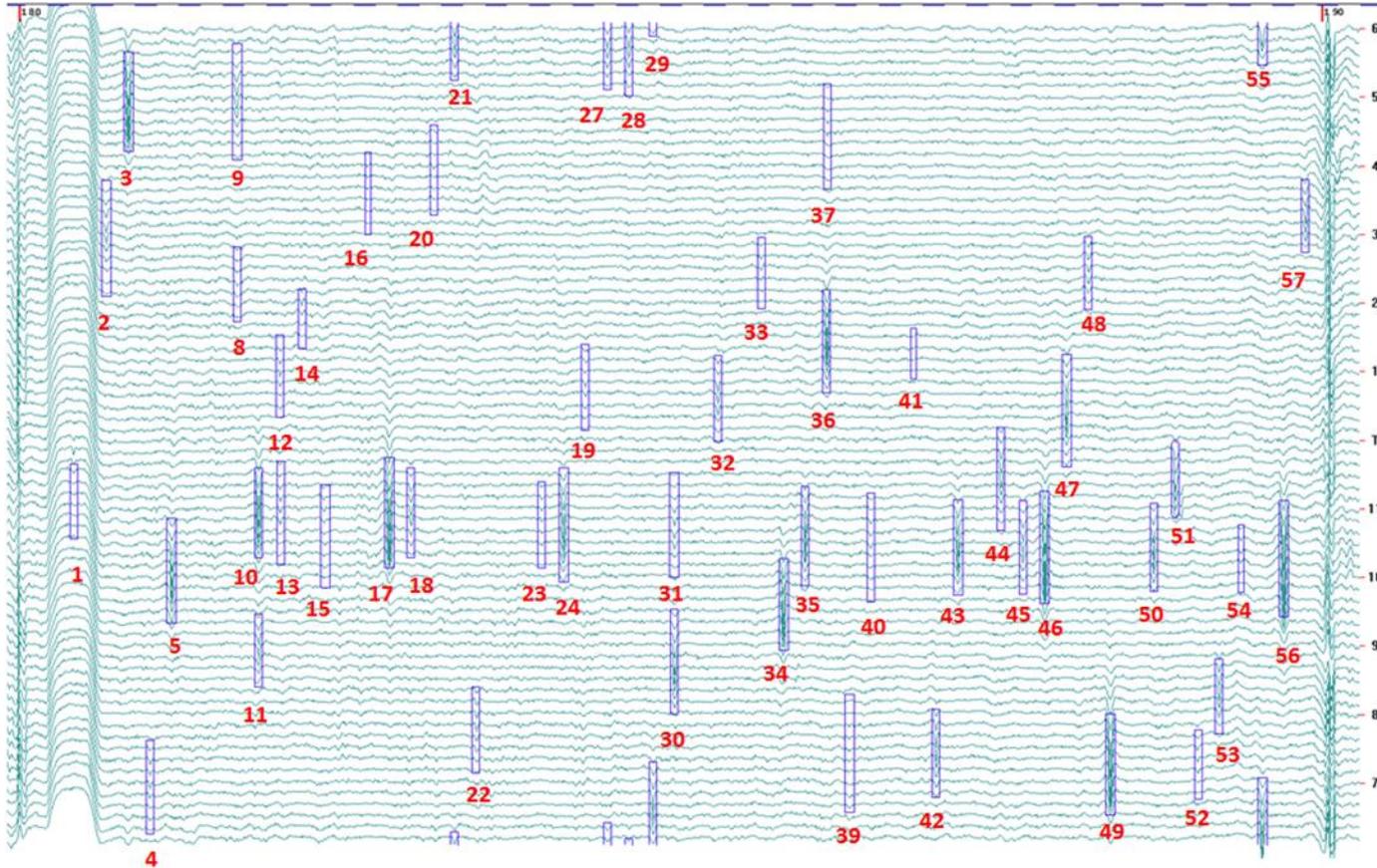
Run	Min (m/s)	Max (m/s)
1	1.0	1.2
2	1.0	1.2
3	1.0	1.2
4	1.0	1.2
5	0.5	0.6
6	0.6	0.6
7	2.0	2.4
8	2.0	2.5
9	2.6	3.2
10	2.6	3.2
11	3.2	4.4
12	3.2	4.5

Blind-test ... 12 pulls in spool provided by ExxonMobil



- POD @ 90% 5mm PH > 20% NWT in SLS
Pinhole Detection only: 4mm > 30% deep; 3mm > 40% deep; 2mm > 90% deep

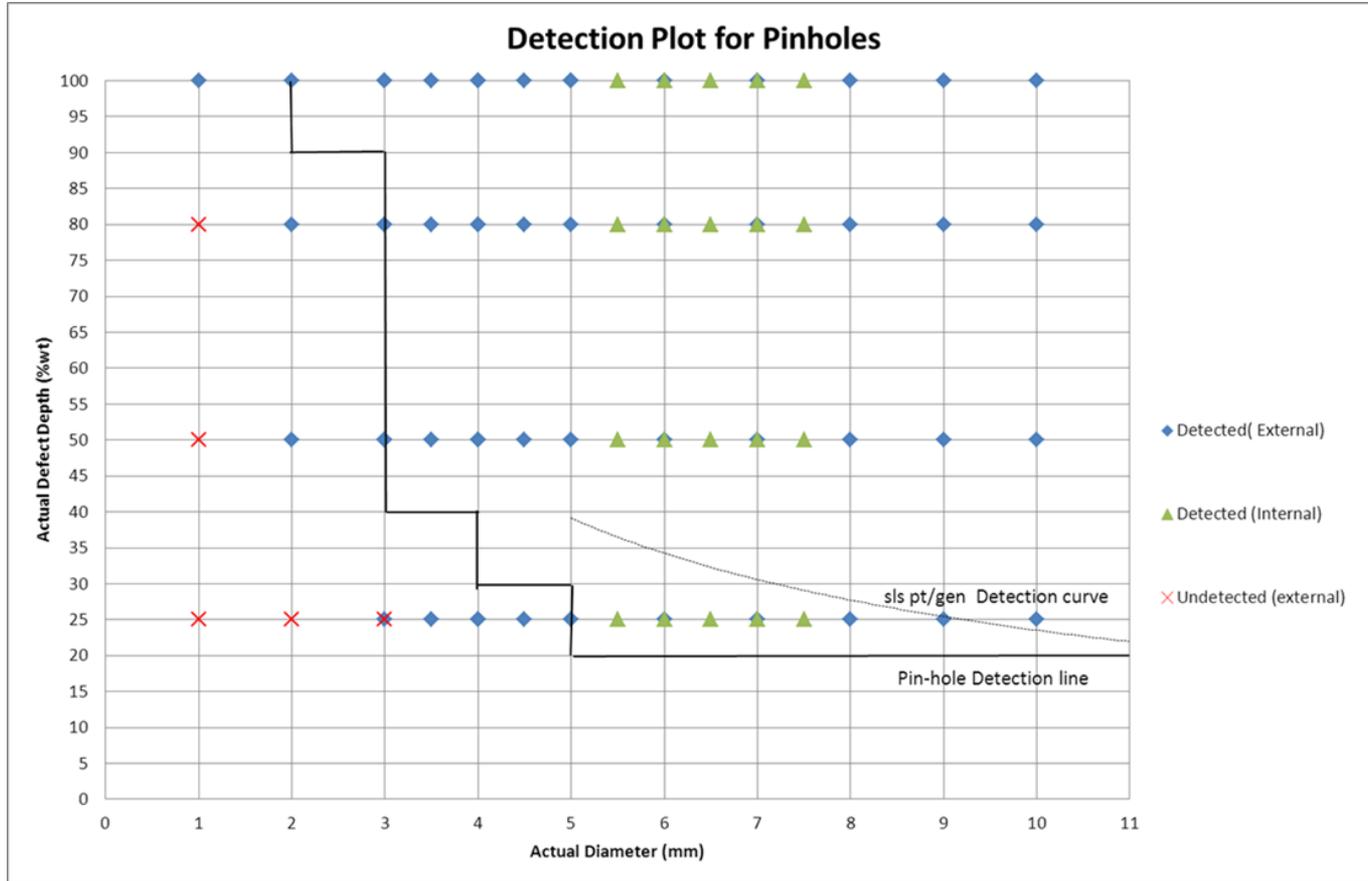
ExxonMobil test program ... detection



Note: Exxon defects boxed & referenced

- POD @ 90% 5mm PH > 20% NWT in SLS
Pinhole Detection only: 4mm > 30% deep; 3mm > 40% deep; 2mm > 90% deep

ExxonMobil test program ... detection



100% detection of 64 in-spec features across all runs
94% detection of all 77 features across all runs



ExxonMobil test program ... depth sizing

- Depth Sizing @ **90% Certainty**
PH > 5mm diameter ≤ 50%, -15%/+10%
PH > 5mm diameter > 50%, -20%/+10%

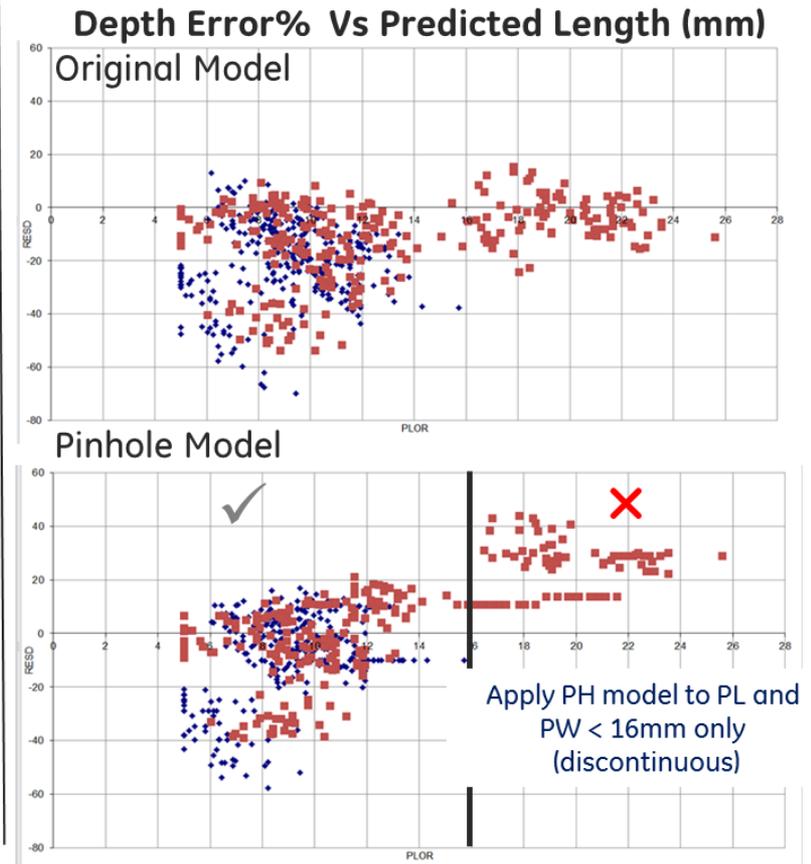
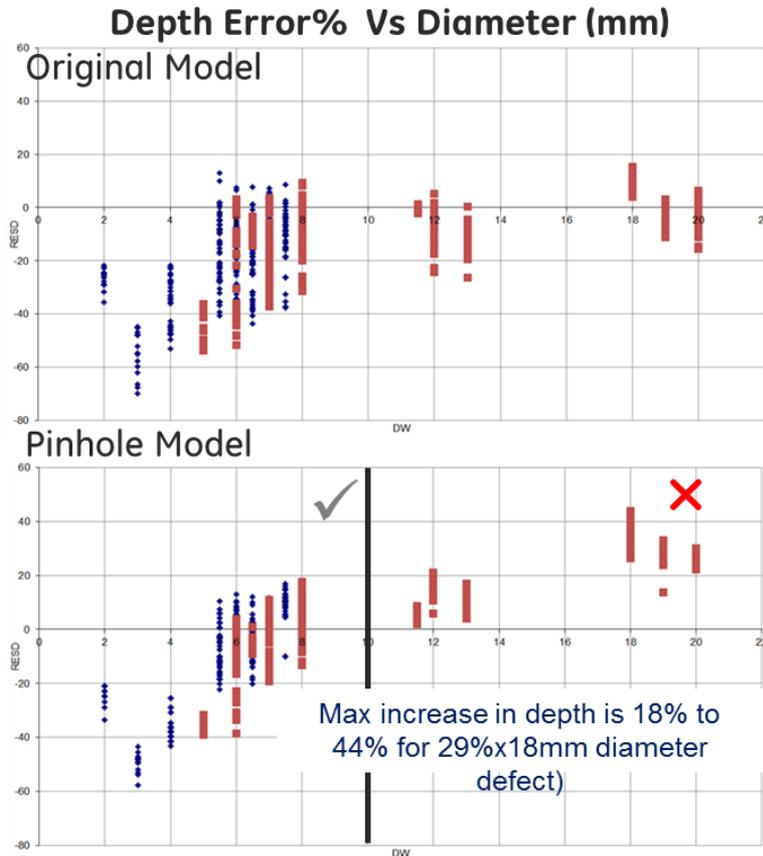
In-Spec Features

Depth	In	Out	In%	Min%	Max%	Rge%	- %	+ %
25%	49	6	89%	20	41	21	-5	16
50%	54	1	98%	38	65	27	-12	15
80%	55	0	100%	60	90	30	-20	10
100%	49	6	89%	76	90	14	-24	-10
Int	207	13	94%					
Depth	In	Out	In%	Min%	Max%	Rge%	- %	+ %
25%	54	12	82%	15	45	30	-10	20
50%	55	11	83%	31	68	37	-19	18
80%	55	11	83%	52	90	38	-28	10
100%	62	4	94%	75	90	15	-25	-10
Ext	226	38	86%					
Depth	In	Out	In%	Min%	Max%	Rge%	- %	+ %
25%	103	18	85%	15	45	30	-10	20
50%	109	12	90%	31	68	37	-19	18
80%	110	11	91%	52	90	38	-28	10
100%	111	10	92%	75	90	15	-25	-10
TOTAL	433	51	89%					

- Sizing performed with optimized pinhole algorithms
- 44 in-spec features (≥5mm) sized within specification
- Defect under metal casing was undersized as expected
- 43 non-spec features (<5mm) undersized as predicted by FEA

89% of in-spec features within depth sizing tolerance

ExxonMobil test program ... historical data



Sizing improved significantly if correctly classified as a pinhole ... if incorrect potential to overcall by up to 30%



Shaheen

Note: Predicted Length = Predicted Diameter

ExxonMobil ... inspection & report

- Completed full survey of Fawley Refinery to Avonmouth Terminal pipeline on 9th/10th July 2013
- Inspection confirmed 133.141km length & predominance of seamless pipe of 5.6mm wall thickness
- “Pinhole” listing included 49 entries (25 categorized as pinholes, and 5 features in 9.27mm wt pipe)
- 15 inspection/dig sheets provided based on Feature Selection Rules including 2 for Pinhole features

Pinhole Model Listing

The pinhole sizing model has been applied to the following features:

Fawley Refinery to Avonmouth Refinery

Upstream Girth Weld	Absolute Distance (metres)	Relative Distance (metres)	Spool Length (metres)	Anomaly Dimension Class	Orientation (hrs:mins)	Nominal Wall Thickness (mm)	Length (mm)	Width (mm)	Depth %WT	INT/ EXT	Estimated Tolerance %WT	Depth + Estimated Tolerance %WT
2400	2222.649	2.601	4.217	PINH	12:24	5.60	2	6	50%	EXT	25%	75%
71390	75931.002	7.611	12.059	PINH	01:03	5.60	7	8	68%	EXT	5%	73%
72410	77097.594	0.132	12.594	PINH	06:44	5.60	8	8	65%	EXT	5%	70%
73470	78325.881	11.810	13.140	PINH	06:13	5.60	2	5	44%	EXT	25%	69%
124500	132164.748	0.953	5.908	CISL	04:16	5.60	8	24	63%	EXT	5%	68%
73820	78707.050	9.734	11.525	PINH	04:48	5.60	5	9	55%	EXT	10%	65%
77980	83308.355	2.899	4.791	PINH	06:06	5.60	5	9	50%	EXT	10%	60%
72420	77121.839	11.783	13.025	PINH	07:11	5.60	7	8	51%	EXT	5%	56%
120940	129208.237	6.154	8.473	PINH	06:14	5.60	3	6	34%	EXT	20%	54%

Inspection Sheet Number 6 **437040_06A Issue 1**

Feature Description

Type:	External Metal Loss (Corrosion Cluster)
Orientation:	12:25 (o'clock)
Axial length:	162 mm
Circumferential width:	62 mm
Depth - Peak:	54% WT
Pressure Ratio (ERF):	1.251
Feature Selection Rule:	1
Nominal Pipe wall thickness for spool:	5.60 mm
Absolute Distance from Launch:	2222.598 metres

Comments:
 This isolated metal loss feature has the appearance of corrosion.
 This feature is in close proximity to an attachment.
 There is a pinhole within this feature.

Feature Location
 Strip Map Number: FAPIAL02

Reference/s:

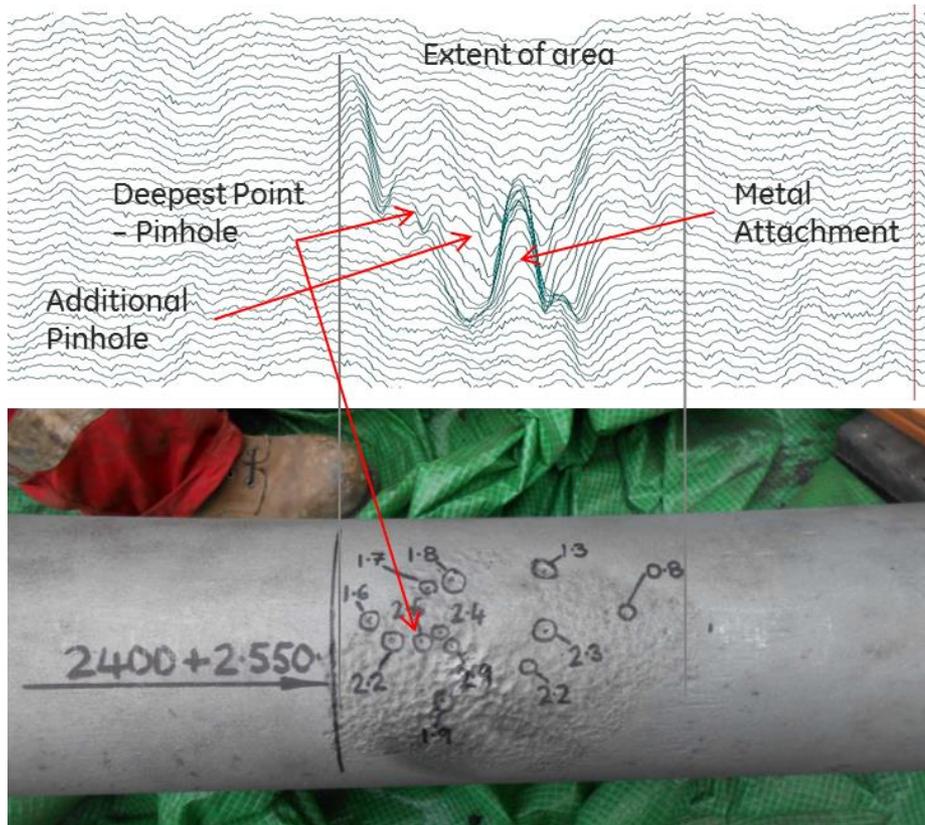
Upstream References	Downstream References
1. GATE VALVE (Girth Weld 110 + 0.439 m) Distance from Launch: 27.142 m Distance from Ref. Girth Weld: 2192.906 m	2. GATE VALVE (Girth Weld 3500 + 0.456 m) Distance from Launch: 3341.142 m Distance from Ref. Girth Weld: 1121.094 m
3. OFFTAKE SPHERE-TEE (Girth Weld 20 + 0.395 m) Distance from Launch: 1.680 m Distance from Ref. Girth Weld: 2218.368 m	4. MAGLOGGER GM 5 (Girth Weld 8600 + 3.505 m) Distance from Launch: 8777.118 m Distance from Ref. Girth Weld: 6557.070 m
5. GATE VALVE (Girth Weld 10 + 0.286 m) Distance from Launch: 1.005 m Distance from Ref. Girth Weld: 2219.043 m	6. MAGLOGGER GM 6 (Girth Weld 10160 + 9.167 m) Distance from Launch: 10505.874 m Distance from Ref. Girth Weld: 8285.826 m

Reference Girth Weld:
 The reference girth weld at the Fawley Refinery (upstream) end of the feature spool is number 2400.
 The location of this weld is 2192.906 metres downstream from reference 1 and 1121.094 metres upstream from reference 2.

Feature:
 The feature is located 2.550 metres downstream from the reference girth weld.
 The feature is located 1.667 metres upstream from the downstream girth weld (girth weld 2410).



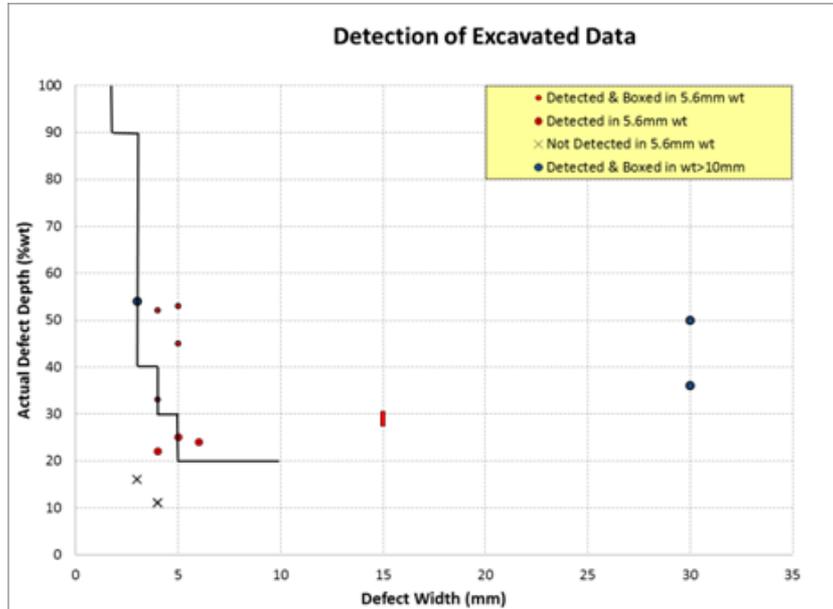
ExxonMobil ... dig verification



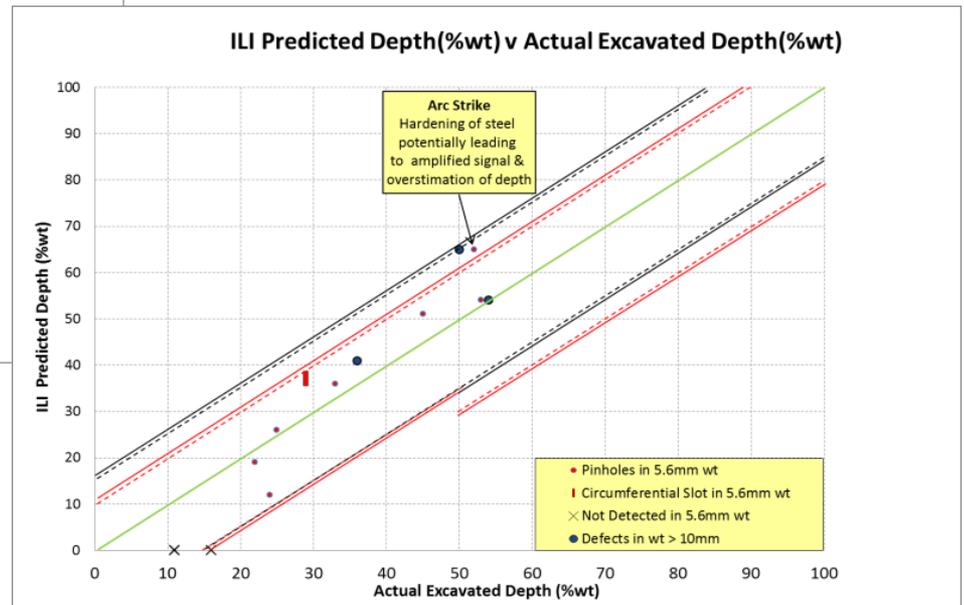
- **General area of corrosion:** Overall length reported slightly shorter due to low level corrosion around the periphery
- **Pin Hole:** Two reported and found. Deepest actual below PII's published specification
- Capability to detect & size pinholes validated on multiple features from 7+ dig sites

	PII Inspection Report			In-Field Measurement		
	Depth	Length	Width	Depth	Length	Width
Overall Area - (Cluster)	54%	162mm	62mm	53%	202mm	144mm
Deepest individual Pin-Hole	50%	3mm	6mm	53%	4mm	5mm

ExxonMobil ... dig verification



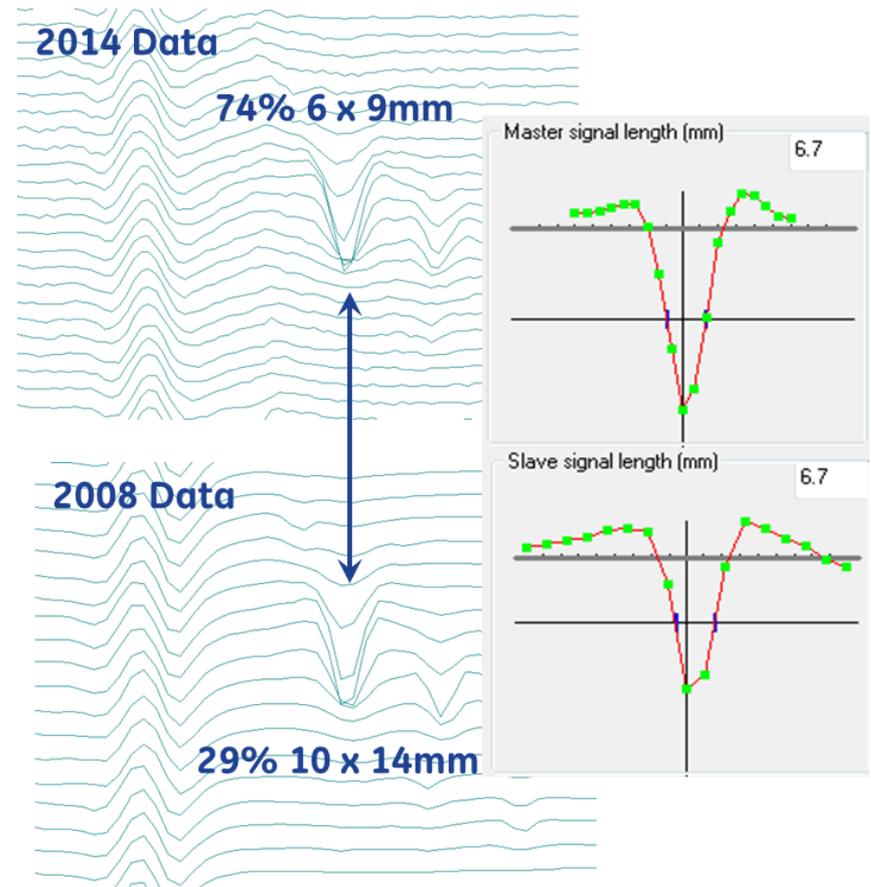
- 11 of 13 features found were detected
- 2 pinhole features not detected were below the detection threshold.



All features detected were sized within depth sizing tolerances, including 3 features in 9.27mm wall thickness pipe

Off-shore example ... North Sea

- Metal loss feature reported in 2008 as 29% x 10mm x 14mm (Pinhole)
- Same feature reported in 2014 as 74% x 6mm x 9mm (Pinhole)
- Improved axial & circumf. resolution better captures signal profile
- Higher resolution triax array & new algorithms for more accurate sizing
- Repeatability of MFL enables assessment of corrosion growth rate



More accurate sizing of “Pinhole” feature ...
Signal to signal repeatability for Corrosion Growth Assessment



Conclusions

- capability of MagneScan (MFL4) to detect & size “Pinhole” features validated in field
- enhanced performance through latest generation hardware, software, algorithms, & analysis processes
- modelling & testing suggests hardware configuration is optimal for this application
- further work required on discrimination of “ Pinholes” in heavily patterned seamless pipe
- success through Pipeline Owner/Operator & ILI Vendor working together

ADVANCEMENTS IN THE DETECTION AND SIZING OF "PINHOLE" METAL LOSS IN ON & OFFSHORE PIPELINES

Q & A

ADVANCEMENTS IN THE DETECTION AND SIZING OF "PINHOLE" METAL LOSS IN ON & OFFSHORE PIPELINES

In the last 4 years more than 800 inspections have been completed on & off-shore with the latest generation MFL ILI technology, capturing information on tens of thousands of kilometres of pipe, and generating a significant volume of dig verification data.

In collaboration with Oil & Gas pipeline operators around the world this growing dig verification database has been utilized to improve software models, algorithms, & analysis processes to validate and further enhance system detection, sizing, & reporting capabilities.

This paper focuses on the recent collaboration between ExxonMobil and PII, to investigate system capabilities with respect to "Pinholes", to address a known threat to a specific pipeline in the United Kingdom.

This paper will describe the:

- Evolution of the "Pinhole" specification that captured the interest of ExxonMobil.
- Use of Finite Element models to predict entitlement for characterization of "Pinhole" type defects
- Detail of and results from the ExxonMobil sponsored test program that was conducted in early 2013
- The in-line inspection, analysis report, and dig verification that followed for the pipeline in question.

This joint paper prepared by PII in collaboration with ExxonMobil will reflect the perspective and synergy of ILI vendor & and Pipeline Owner/Operator



At PII, we are dedicated to predicting our customers' potential problems, before they become real problems. Our heritage of providing reliable and accurate data sets sets us apart from our competitors, and helps promote environmental and public safety. Together with our customers, our goal is zero pipeline failures.

