Performance estimation of a remote field eddy current method for the inspection of water distribution pipes

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Degradation and renewal of water distribution pipes

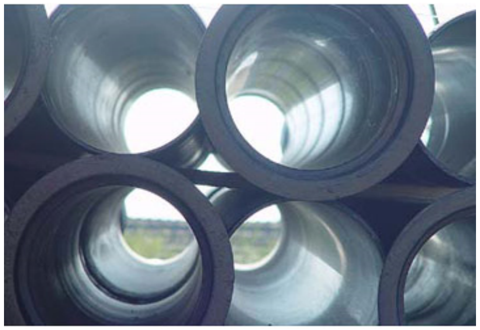
- Replacement of water pipes: important expenditures
  - e.g. Burn et al. (2007): annual worldwide expenditure for water distribution pipes > US$ 33,000 million/year
  - should rise significantly in the future as existing assets increasingly come to the end of their useful lives
- Most of small diameter pipes installed < 1990 = metallic (ductile or gray cast iron)

Source : http://video.monteregie.hebdosregionaux.ca

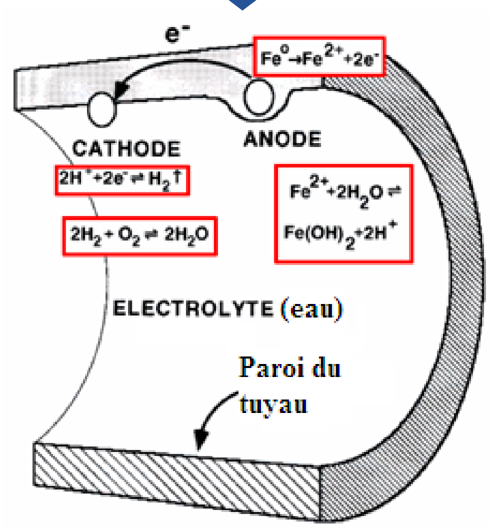
Source : http://www.cfgservices.fr

Corrosion of water distribution pipes

Cast iron pipes (installation)



Corrosion over time



Tubercles
(corrosion product)

External corrosion
(here graphitic)

Hole in the pipe

Consequences of corrosion

- Increased frequency / probability of pipe breaks and leaks
- Increased costs + interruptions in water supply
- <u>Solutions :</u>
  - replace?
  - repair?
  - which pipes?
  - when?

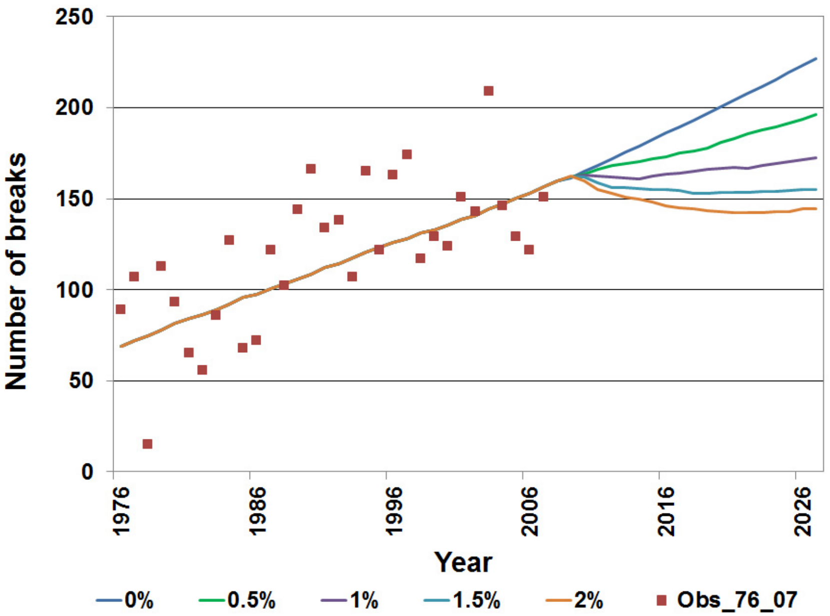
Source : http://www.cfgservices.fr

Source : http://video.monteregie.hebdosregionaux.ca

Existing tools to plan the renewal

- Prediction models and planning tools:
  - assess the required financial resources
  - prioritizing pipes that should be replaced and/or rehabilitated

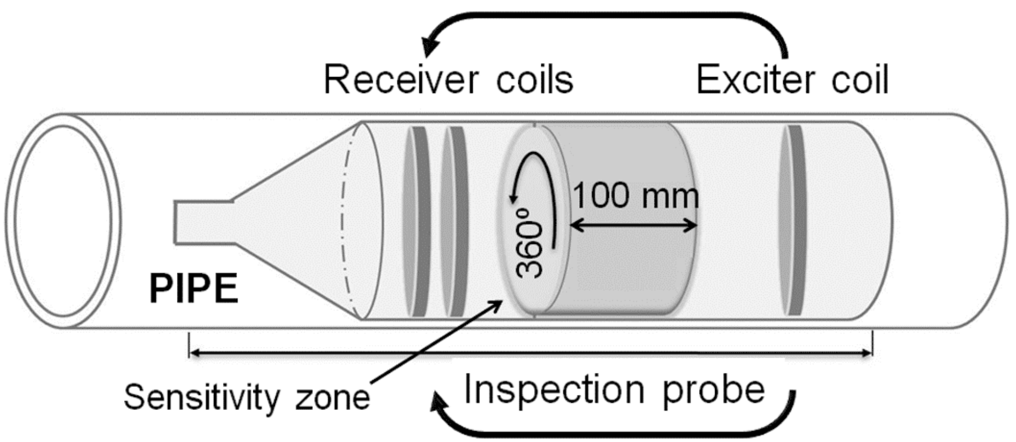
- Decision to replace / repair a specific pipe:
  - requires assessment of its conditions
    - ➢ observed breaks and leaks (indicators)
    - ➢ observations from inspection

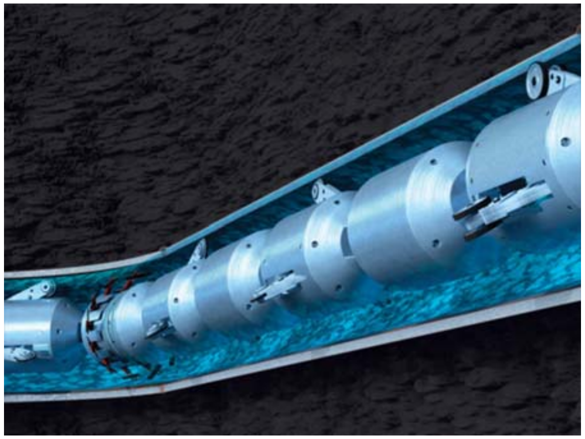


Source : Duchesne et al. (2016)

RFEC technique for the inspection of water distribution pipes

- Remote Field Eddy Current:
  - application well known for the identification and sizing of defects in metallic gas distribution pipes
  - can be applied to water distribution pipes



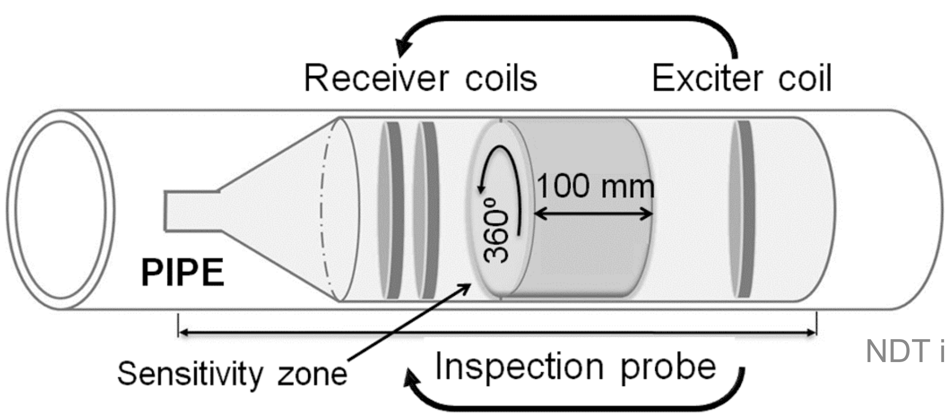


Source : http://www.popsci.com/technology/article/2011-01/pig-robots-keep-gas-lines-blowing

RFEC technique for the inspection of water distribution pipes

- Exciter transmits a low frequency magnetic field that can reach receivers by two paths:
  1. inside the pipe through the water (direct path)
  2. through the outside of the pipe (indirect path)

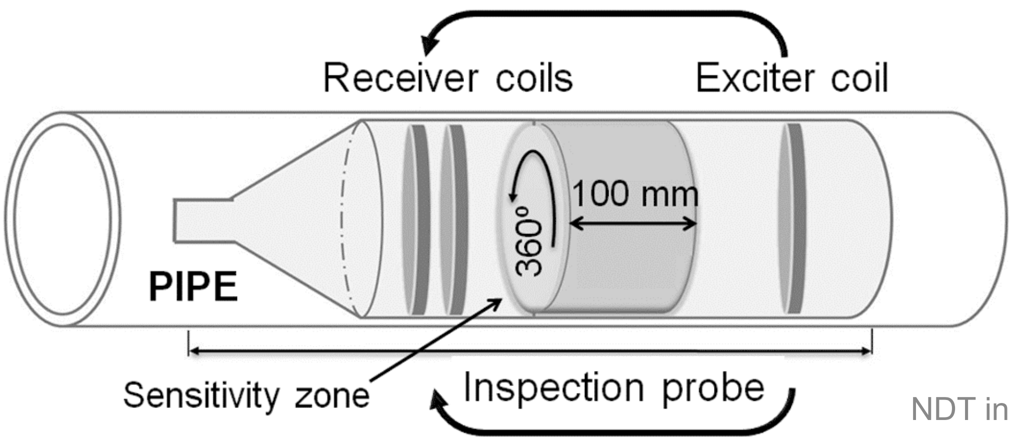
- Strength of magnetic field attenuated rapidly in direct path
  - ➢ at ≈ two pipe diameters from exciter, indirect field dominates the direct field: the remote field zone begins



RFEC technique for the inspection of water distribution pipes

- Variations of wall thickness at the locations where the magnetic field goes through the pipe modify phase and/or amplitude of the signal
  - ➢ can be translated into wall thickness reduction and spatial extent of the detected flaw

- Does not measure the actual pipe-wall thickness: evaluation of the material loss percentage



Objective and general methodology

Objective : Assess the performance of an existing RFEC probe for the inspection of cast iron water pipes

1. Inspect 6 pipes with the probe

2. Compare size and location of corrosion defects estimations with values resulting from the processing of computed tomography (CT) images of the same pipes

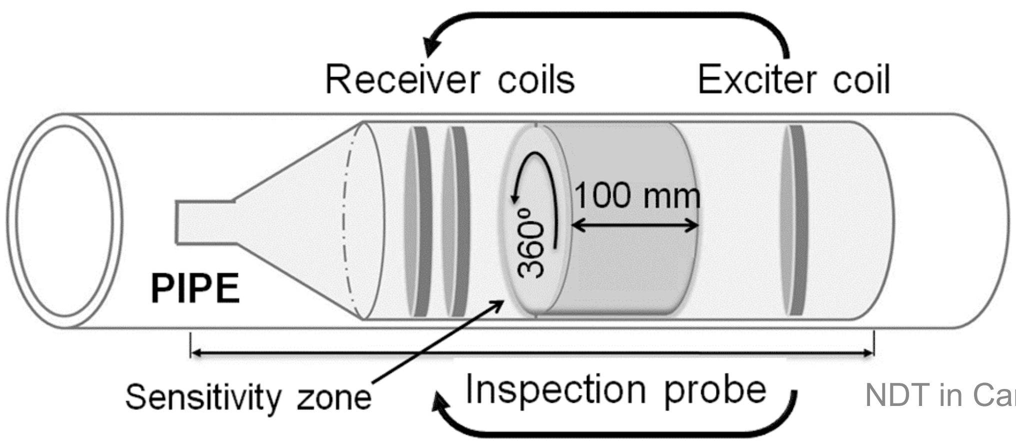
Analyzed pipes (excavated)

	Estimated date of installation	Estimated age at inspection	Diameter	Length	Average wall thickness
		(years)	(mm)	(m)	(mm)
NEW-PIPE	-	-	150	1.1	7
SILL-MAG-1A	1948	61	200	1.6	14
B-MAN-1A	1909	100	150	2.6	10
B-MAN-1B	1909	100	150	2.5	10
B-MAN-2A	1909	100	150	1.7	12
B-MAN-2B	1909	100	150	1.7	9
LHSTCH-MC	1945	64	150	1.3	7
LHSTCH-HOP	1957	52	150	3.2	8

- RFEC probe passed once in each pipe (laboratory = air)
- Comparison with *in situ* inspection for one pipe

Inspection results

	Defect	Location (m)	Thickness loss (%)	Sensitivity zone coverage (%)
B-MAN-1A	#1	1.2	22	22
B-MAN-1B	#1 #2	0.8 1.6	17 28	13 17
B-MAN-2A	#1	1.8	15	63
B-MAN-2B	#1 #2	0.4 1.3	23 26	< 13 13
LHSTCH-MC	#1	0.7	38	24
LHSTCH-HOP	#1	1.4	20	< 13



Condition evaluation with the CT scan

- Based on Lambert-Beer law:

$$N = N_0 e^{-\mu x}$$

N = measured intensity after layer of thickness x;

N_0 = incident radiation intensity (usually in keV);

μ = linear attenuation coefficient $\rightarrow$ depends linearly on the density of the material

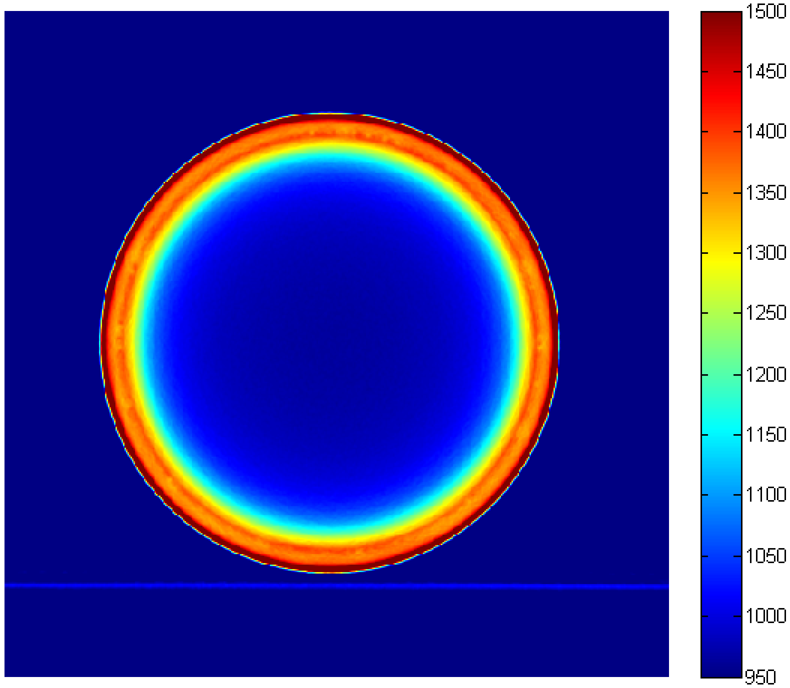
- Output from CT scan computer:

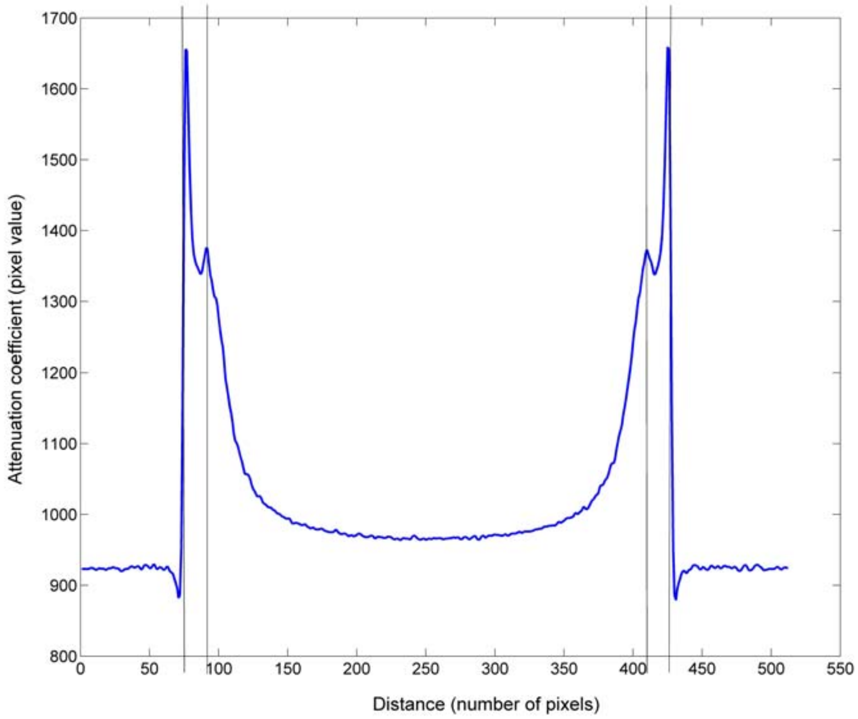
$$HU = \frac{\mu - \mu_{water}}{\mu_{water}} \times 1000$$

- When viewed in Matlab:

$$pixel\_value = \frac{HU + 10240}{10}$$

Condition evaluation with the CT scan

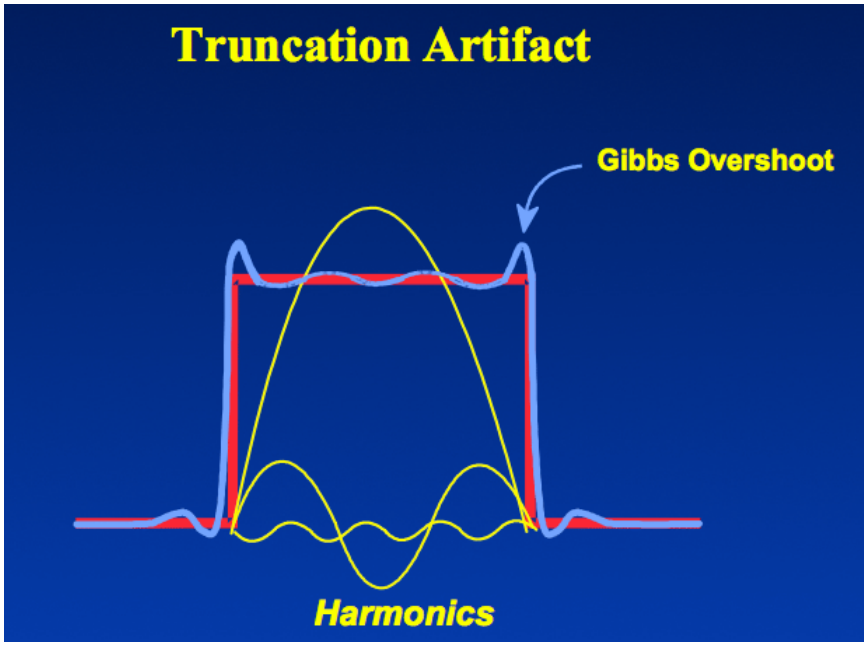




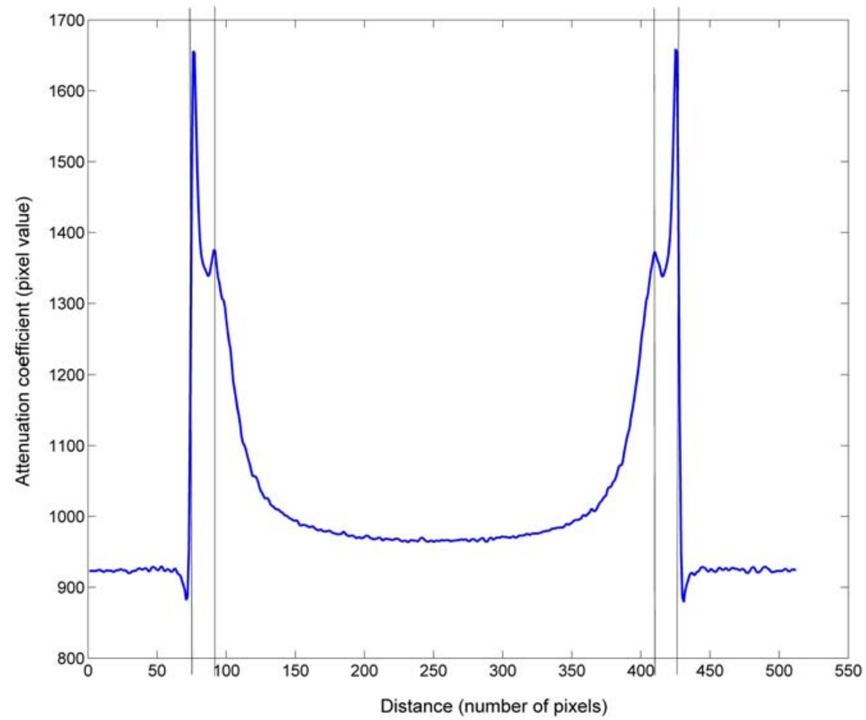
- When viewed in Matlab:

$$pixel\_value = \frac{HU + 10240}{10}$$

Condition evaluation with the CT scan



Source: http://mriquestions.com/gibbs-artifact.html

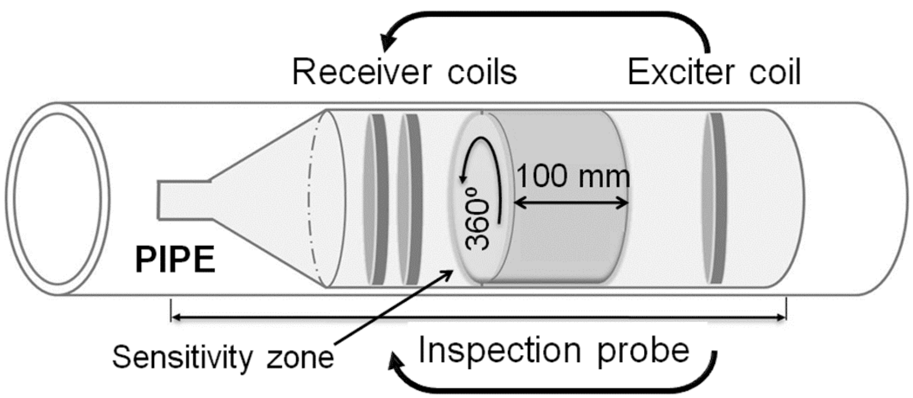


- When viewed in Matlab :

$$pixel\_value = \frac{HU + 10240}{10}$$

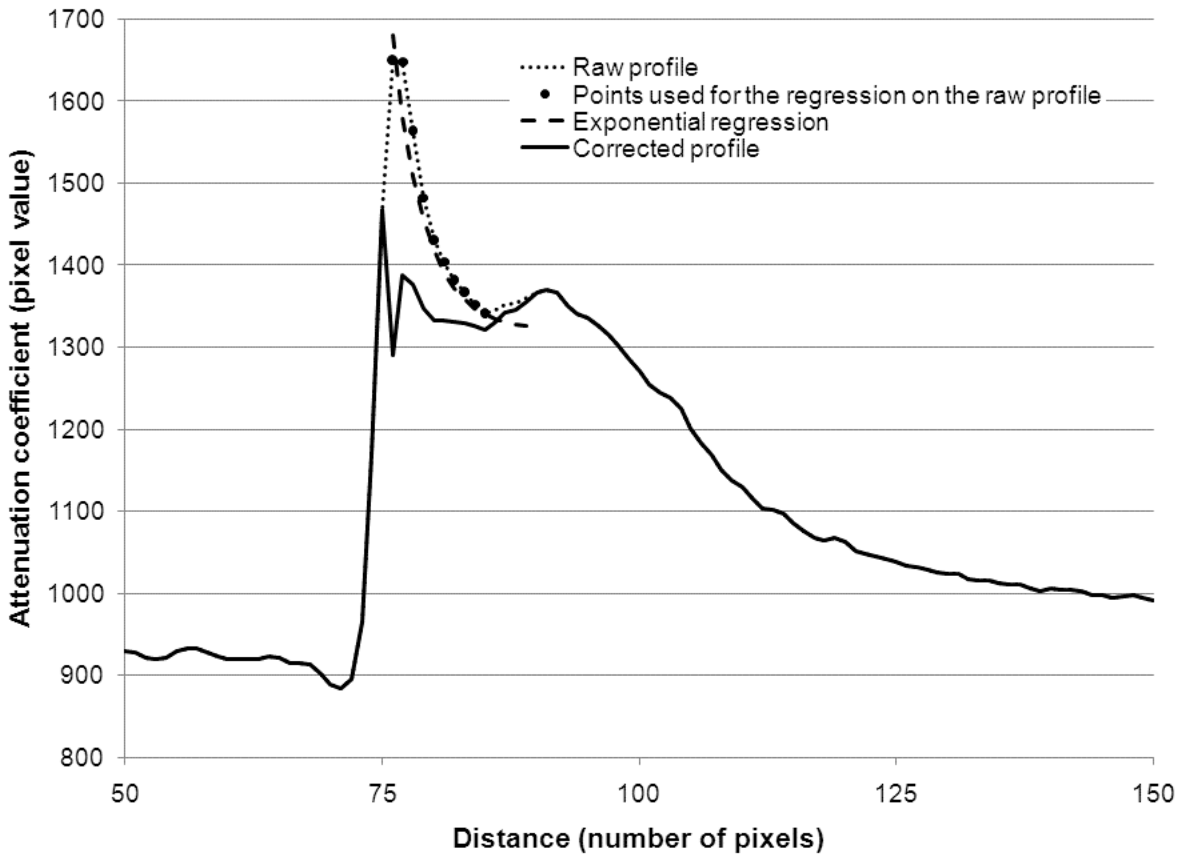
Condition evaluation with the CT scan

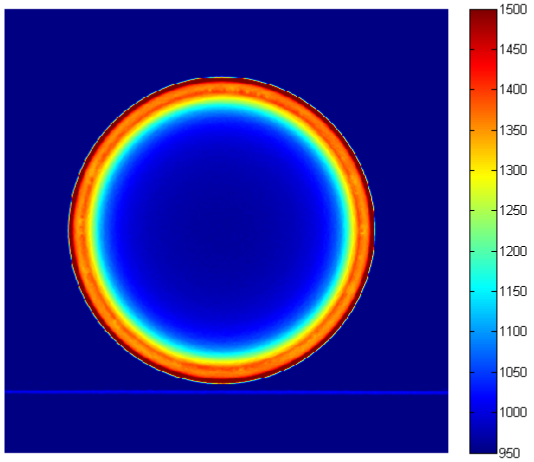
- <u>Objective, to compare with the RFEC tool:</u>
  1. pipe thickness loss = percentage of lost material on 100 mm sensitivity zones, all along the pipes
  2. spatial extent of this loss



- <u>Steps :</u>
  1. Correction of artifacts
  2. Estimation of the mean percentage of material loss for 100 mm by 360º zones
  3. Estimation of the worst percentage of material loss on specific proportions of these 100 mm by 360º sensitivity zones

Correction of artifacts





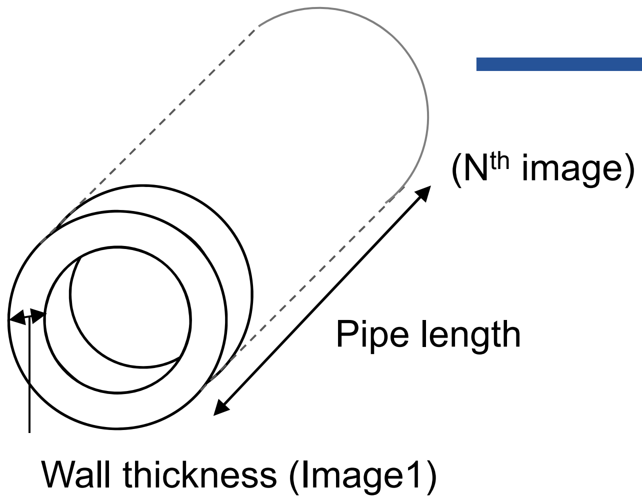
$$pv_{reg} = A + B \ \exp(\text{-}Cx)$$

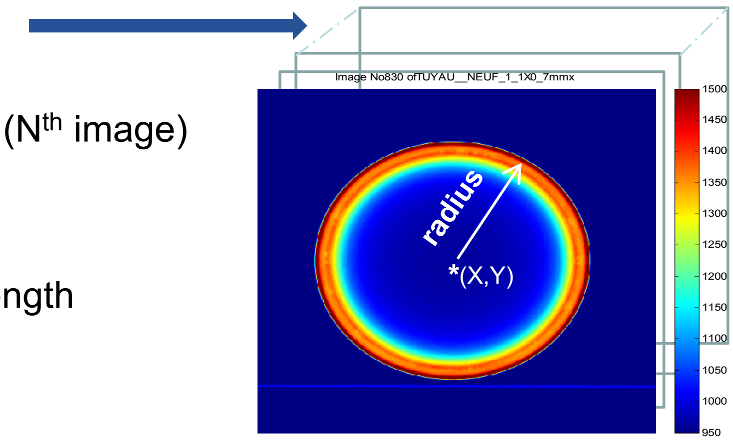
$$\Delta pv = B \ \exp(\text{-}Cx)$$

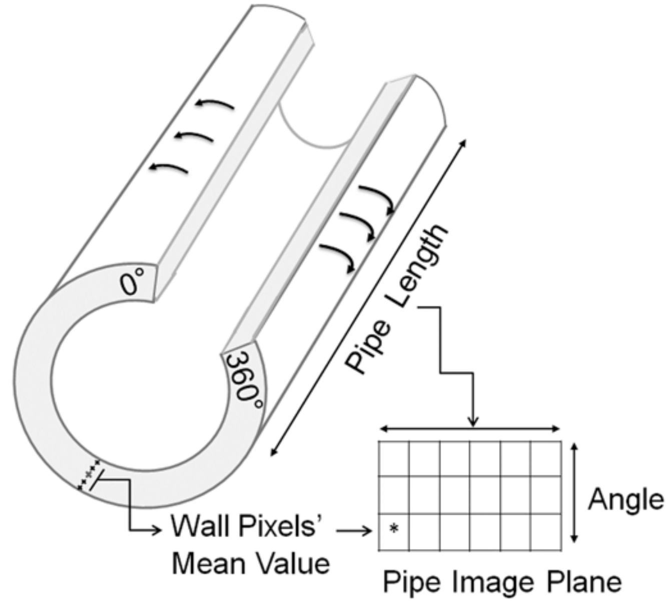
$$pv_{corr} = pv - \Delta pv$$

Estimation of mean percentage of material loss

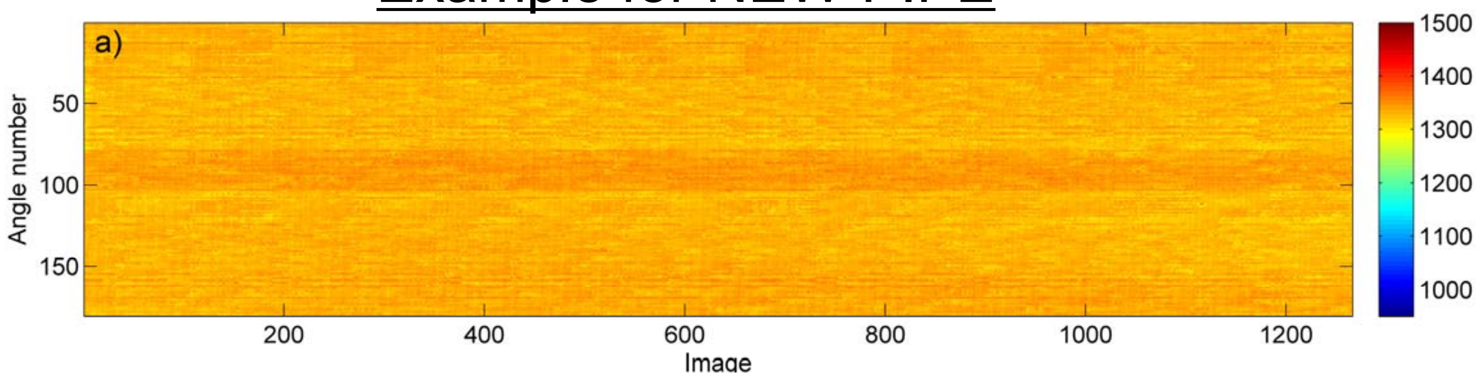
i. Compute mean corrected pixel value across the pipe wall for 180 different angles (2º apart)







<u>Example for NEW-PIPE</u>



Estimation of mean percentage of material loss

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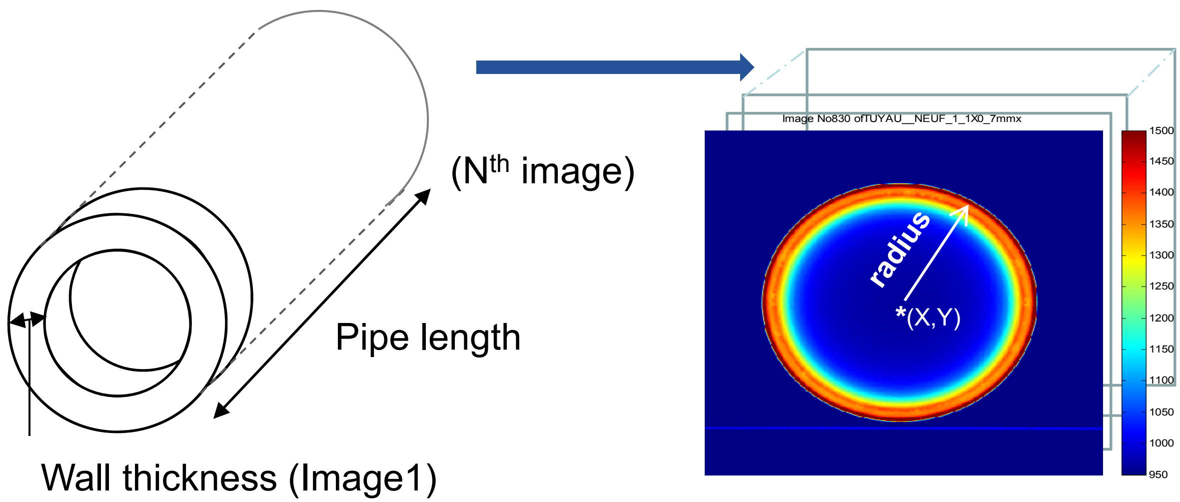

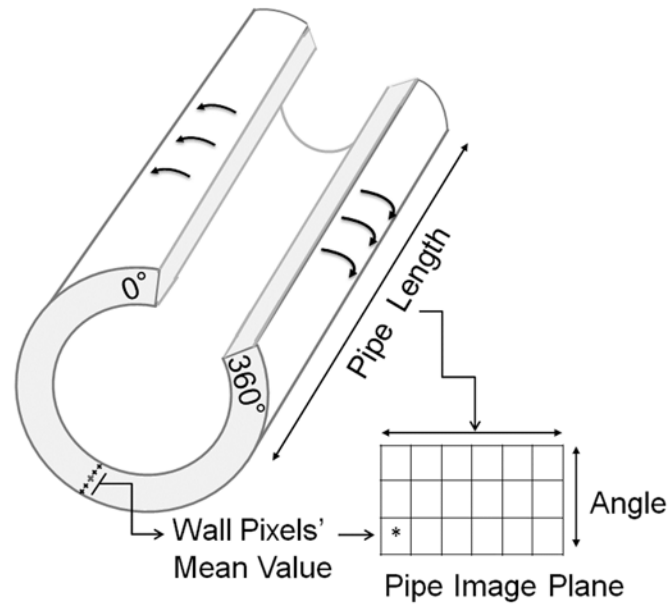

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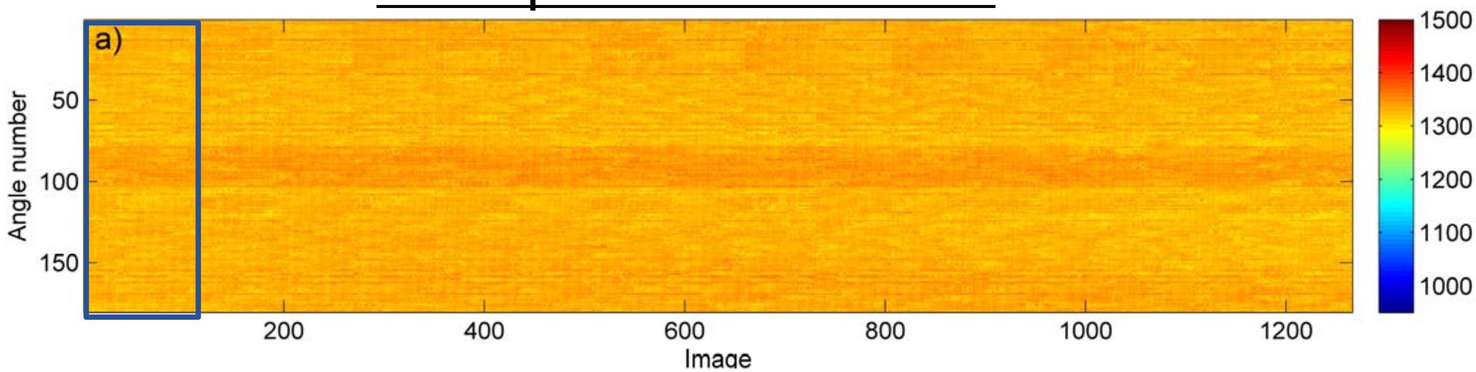
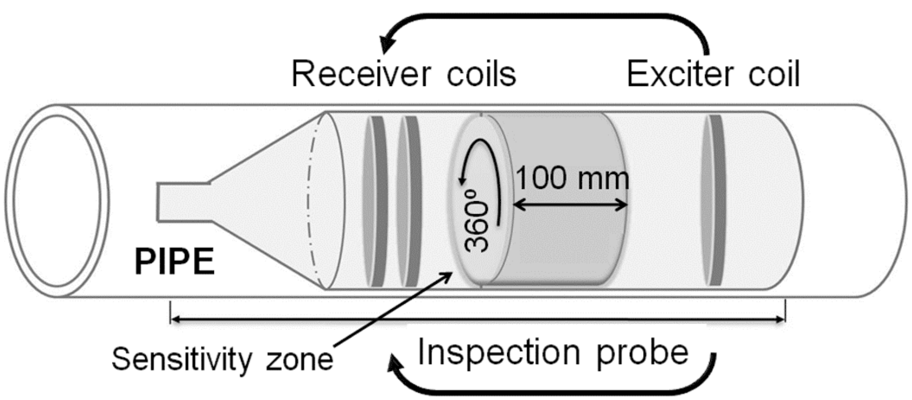


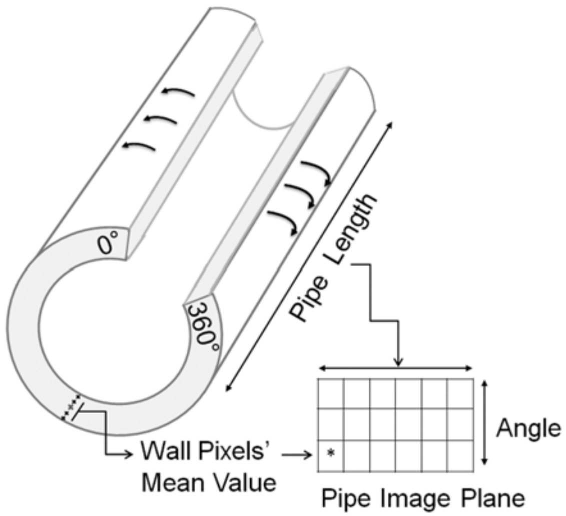
Estimation of mean percentage of material loss

ii. Compute percentage of pipe-wall loss for each pixel

$$\%loss = \left[1 - \left(\frac{pv - pv_{min}}{pv_{max} - pv_{min}}\right)\right] \times 100$$

iii. Average the percentage of material loss (for 100-mm strips) over all 180 - 2º angles (360º)





Estimation of mean percentage of material loss

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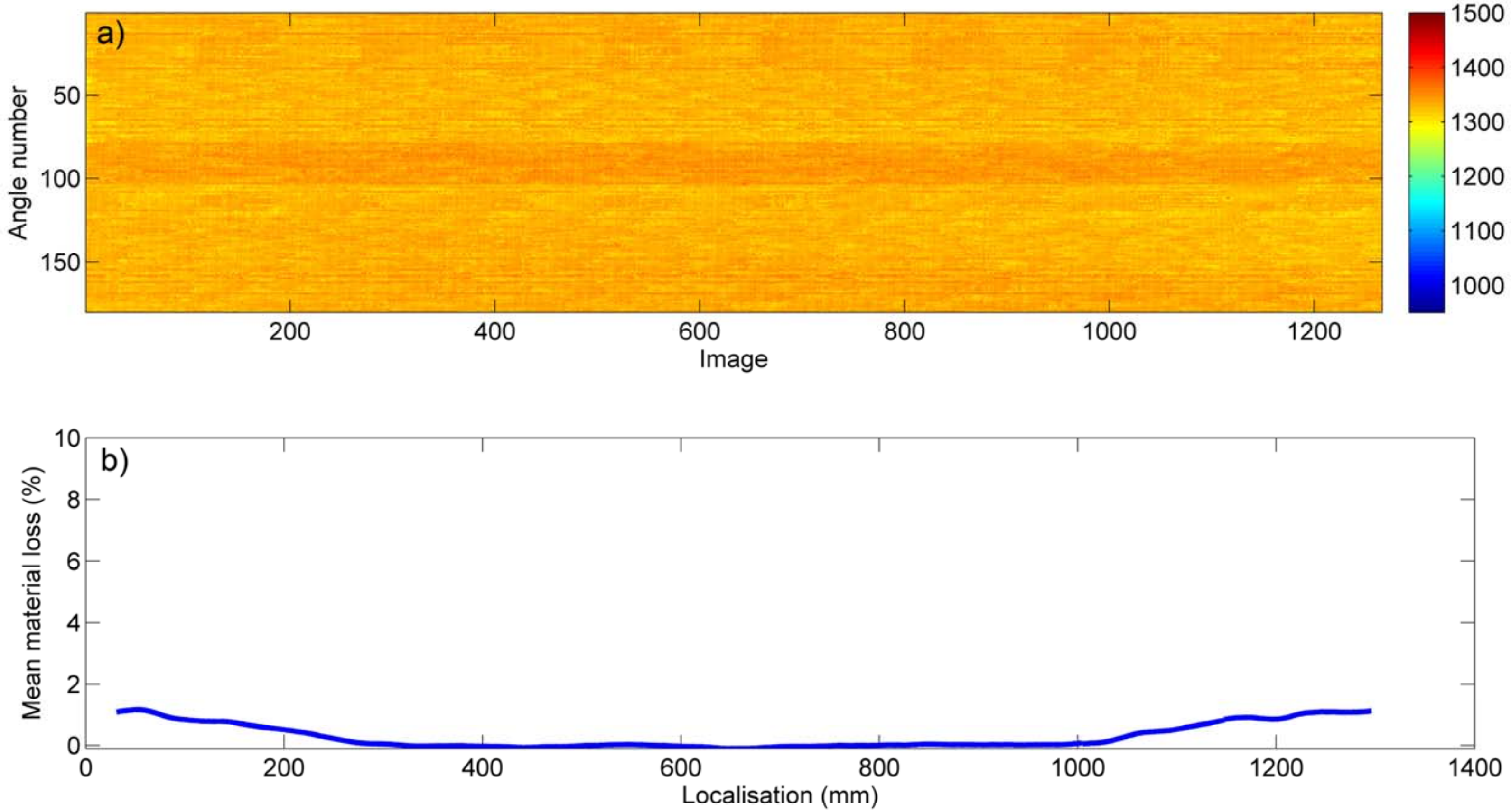

Estimation of mean percentage of material loss

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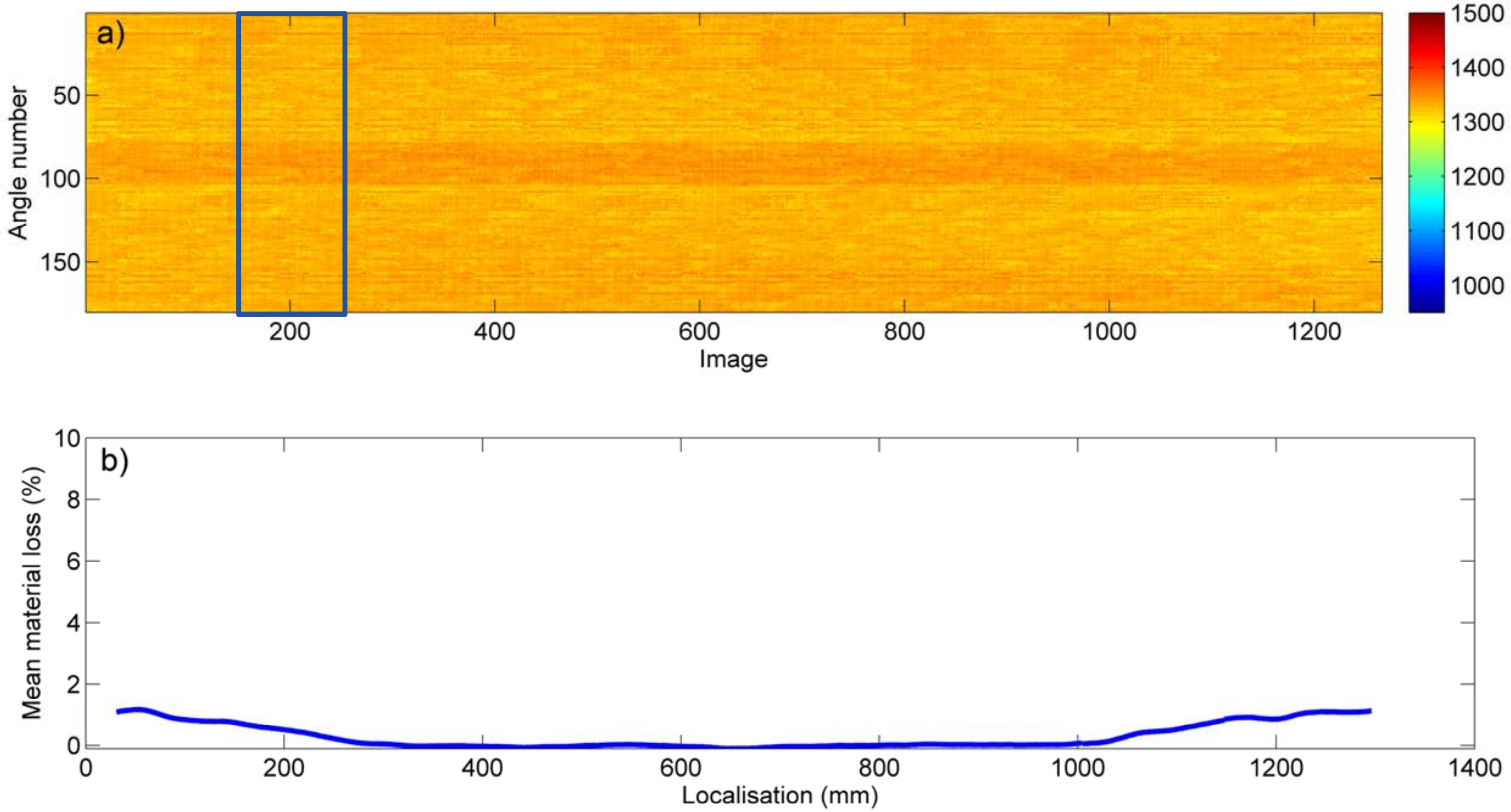
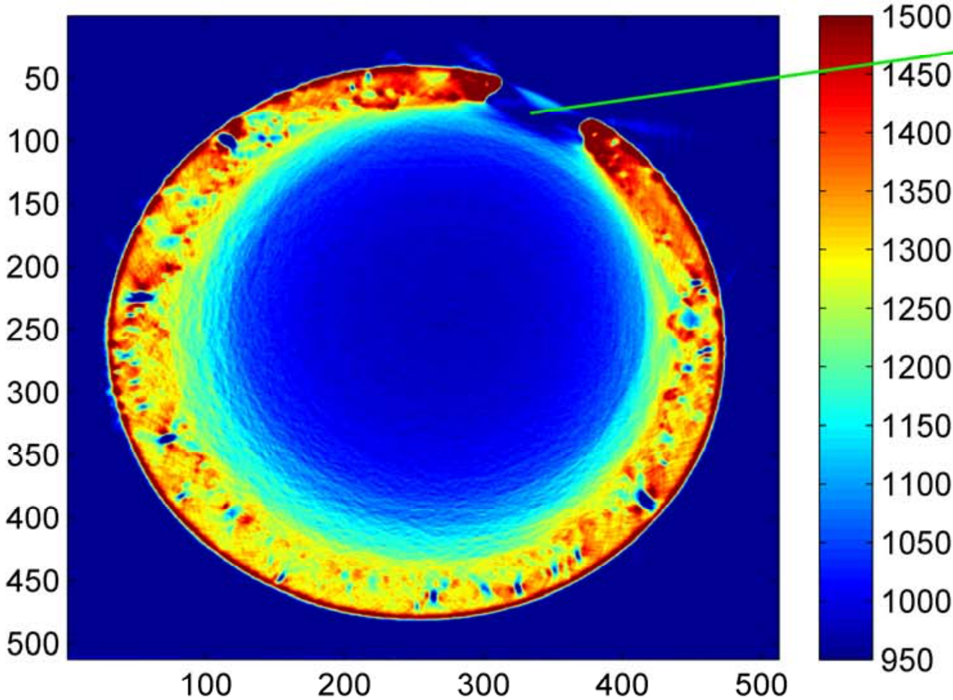
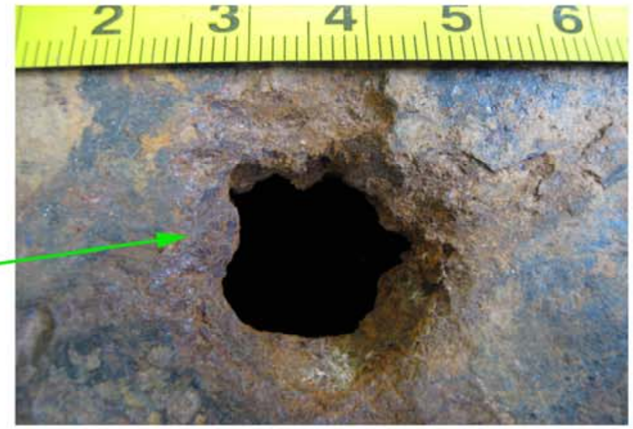
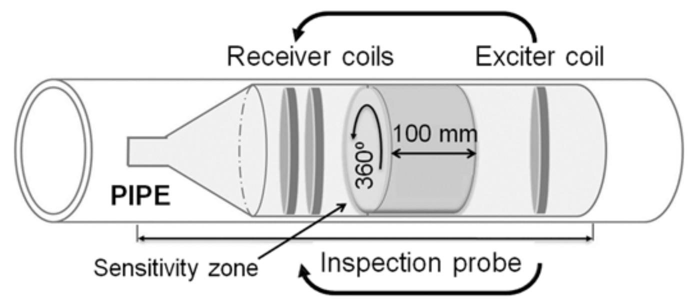


Estimation of worst thickness loss

Example for SILL-MAG-1A

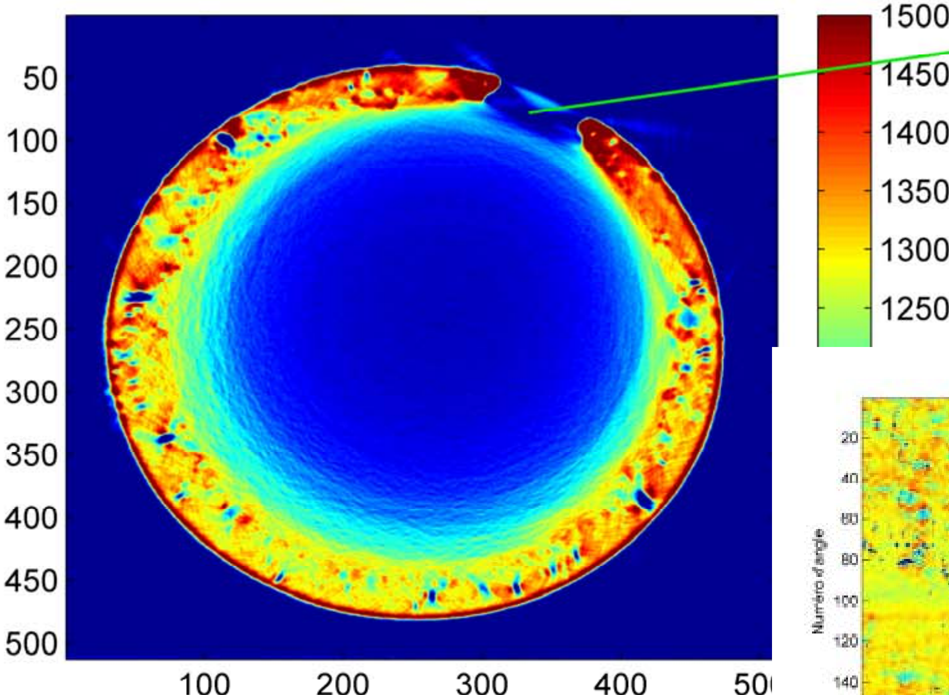


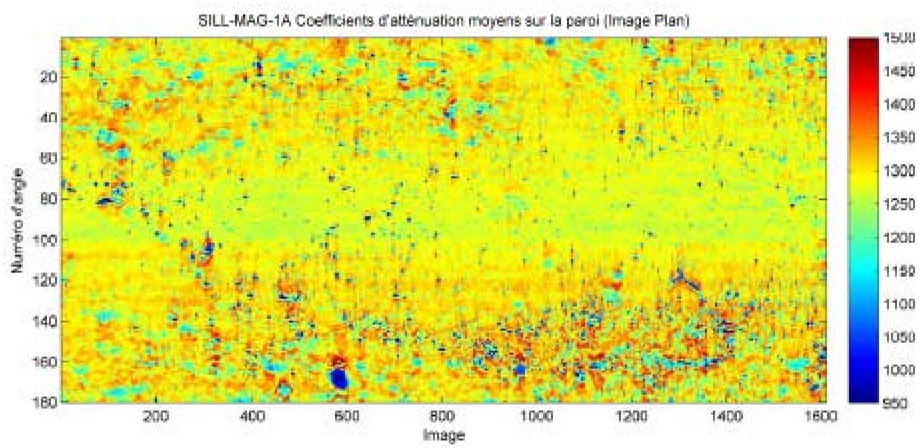




Estimation of worst thickness loss

<u>Example for SILL-MAG-1A</u>





Estimation of worst thickness loss

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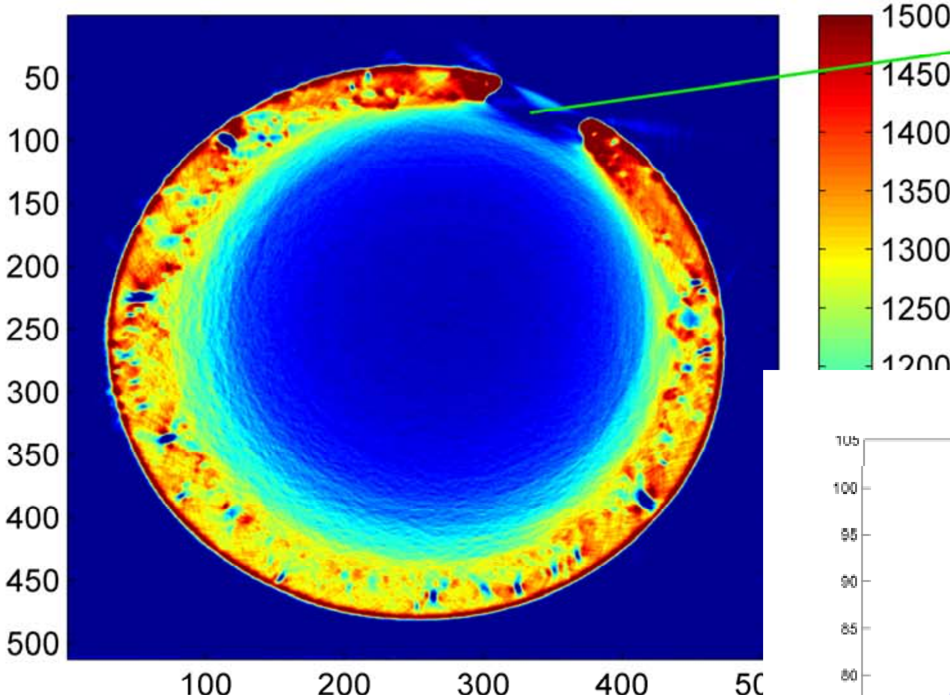
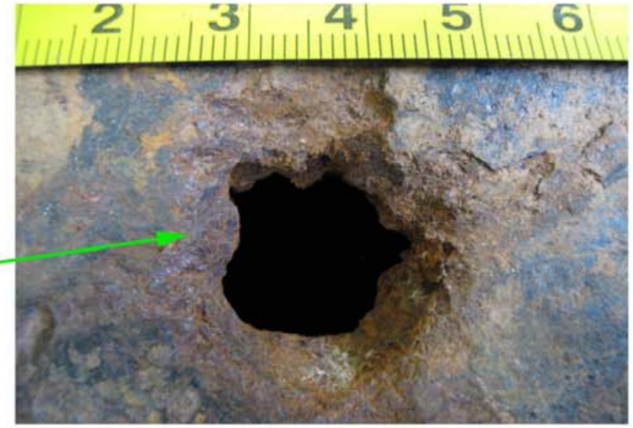
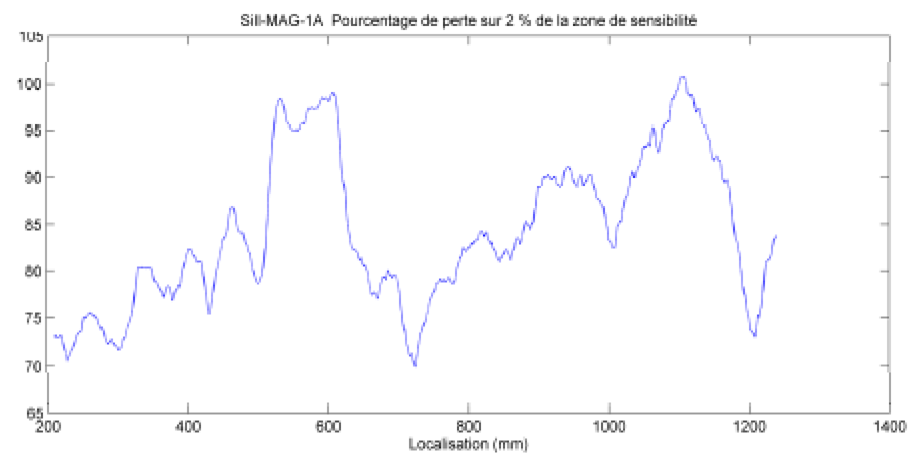






Summary of results

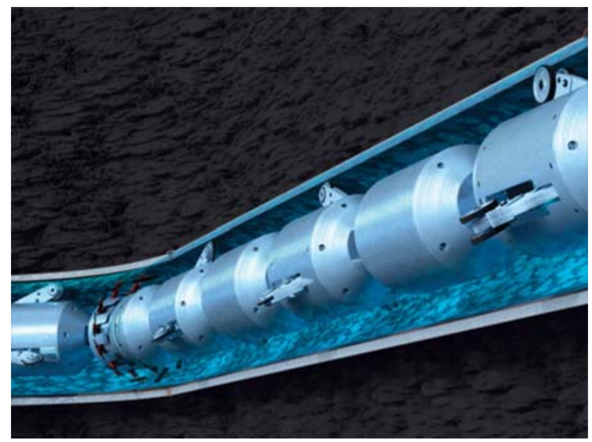
Pipe	Defect	CT scan image analysis			RFEC Tool		
		Location (m)	Thickness loss (%)	Sensitivity zone coverage (%)	Location (m)	Thickness loss (%)	Sensitivity zone coverage (%)
B-MAN-1A	#1	0.7	18	13	n.i.	n.i.	n.i.
	#2	1.3	22	22	1.2	22	22
B-MAN-1B	#1	0.7 - 0.9	16	13	0.8	17	13
	#2	1.6	15	17	1.6	28	17
B-MAN-2A	#1	0.8	34	13	n.i.	n.i.	n.i.
	#2	1.2 - 1.5	14	63	1.8	15	63
B-MAN-2B	#1	0.4	20	13	0.4	23	< 13
	#2	1	25	13	n.i.	n.i.	n.i.
	#3	1.4	48	13	1.3	26	13
LHSTCH-MC	#1	0.1	27	13	n.i.	n.i.	n.i.
	#2	0.7	20	24	0.7	38	24
LHSTCH-HOP	#1	0.2	17	13	n.i.	n.i.	n.i.
	#2	1.4	12	13	1.4	20	< 13

n.i.: not identified

Conclusions

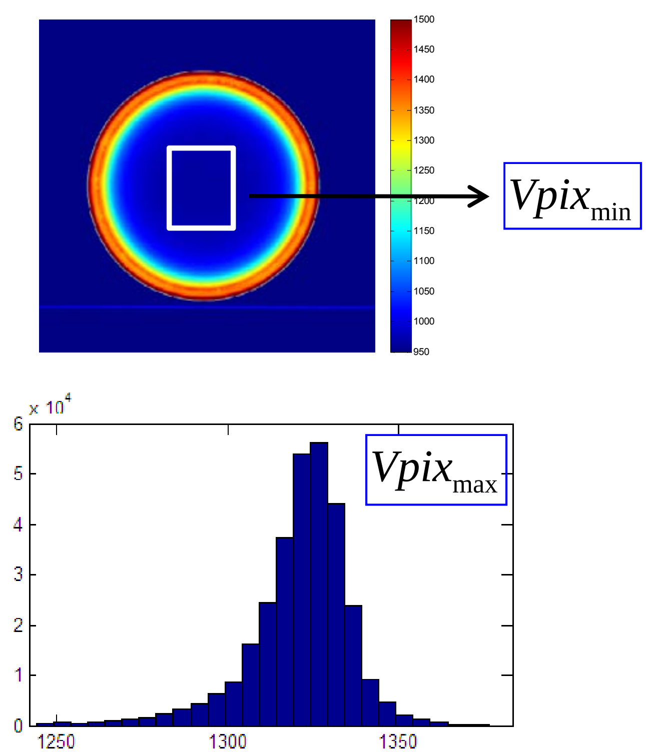
- Similar results for both techniques:
  - but RFEC tool: thickness loss $\geq$15% when averaged on the 13% most corroded area of the tool's sensitivity zone
- RFEC tool provides reliable information on the main corrosion defects and thus on the general structural state of water pipes
- RFEC tool cannot identify small corrosion pits:
  - could cause leaks and even initiate larger corrosion areas
  - better detected by leak detection methods (e.g. acoustic)
- Further tests required (more pipes, lined or coated pipes, ductile iron pipes)

Questions ?



Source : http://www.popsci.com/technology/article/2011-01/pig-robots-keep-gas-lines-blowing

Name	Pixel size (mm)	Slice thickness (mm)	Spacing between slices (mm)
NEW-PIPE	0.492	1	0.7
SILL-MAG-1A	0.517	1	0.7
B-MAN-1A	0.492	1	0.7
B-MAN-1B	0.492	1	0.7
B-MAN-2A	0.492	1	0.7
B-MAN-2B	0.492	1	0.7
LHSTCH-MC	0.449	1	0.7
LHSTCH-HOP	0.431	1	1.0


1500
1450
1400
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1200
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1100
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1000
950
$Vpix_{min}$
x 10^4
6
5
4
3
2
1
0
1250
1300
1350
$Vpix_{max}$