



Shell Global Solutions

Presentation to SGS on Pulsed Eddy Current



January 2006

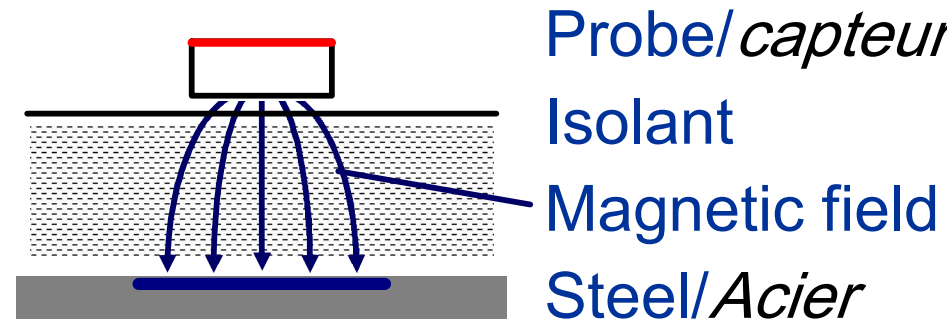
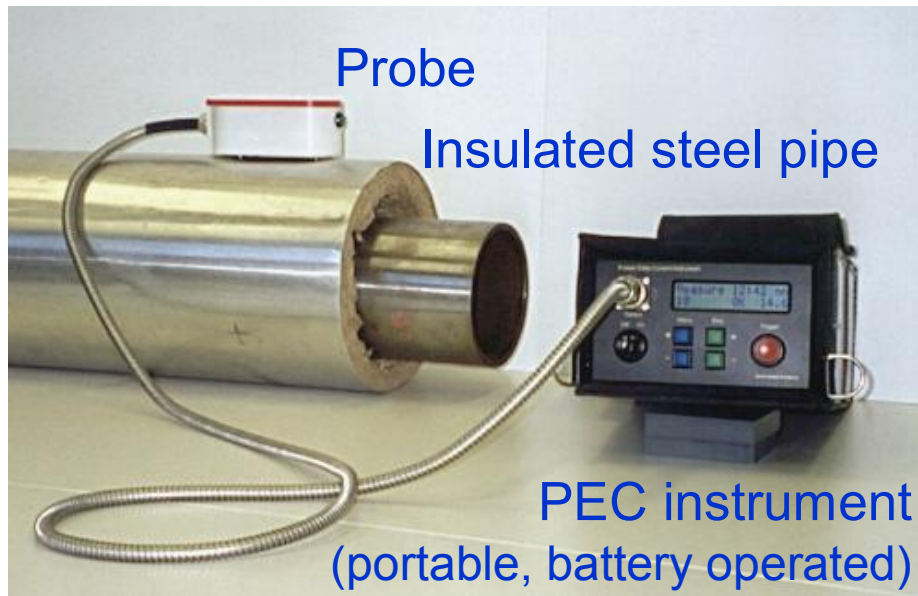
Paul Crouzen, Shell Global Solutions Int.

Agenda / *Ordre du Jour*

- What is Pulsed Eddy Current
- *Qu'est – ce que “les Courants de Foucault Pulsés”*
- Strength and weakness
- *Points forts et points faibles*
- When to apply PEC
- *Quand appliquer le PEC*
- Application examples: onshore and offshore
- *Exemples d'application: onshore et offshore*
- PEC corrosion monitoring
- *Surveillance de la corrosion par PEC*

PEC measures steel thickness through insulation

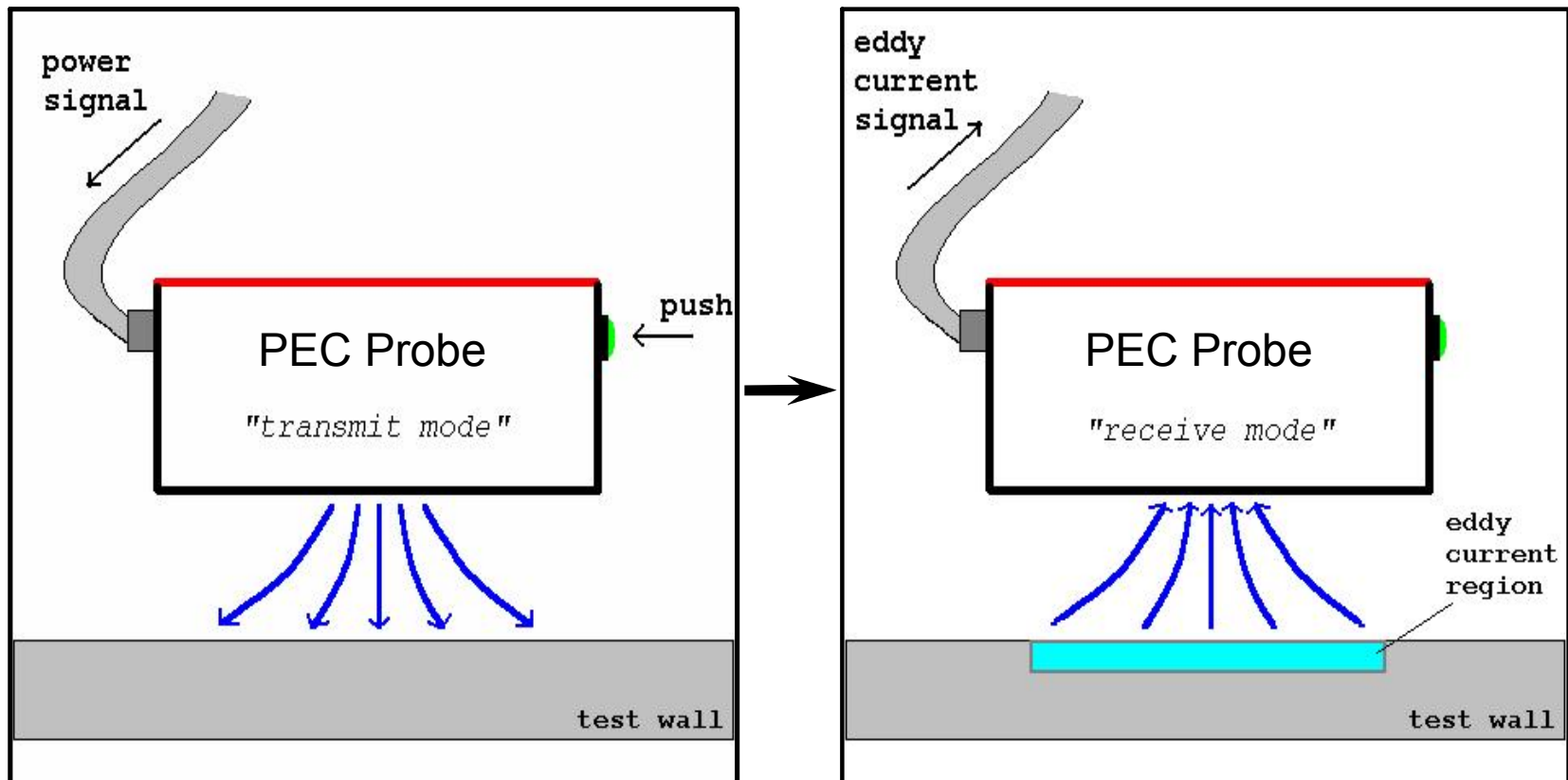
Mesure d'épaisseur à travers le calorifuge



- Pulsed magnetic field induces eddy currents in steel
Les champs magnétiques pulsés induisent des Courants de Foucault dans l'acier
- Wall thickness determined by sensing decay of eddy currents
L'épaisseur est déterminée par la variation des Courants de Foucault

Working Principle Pulsed Eddy Current (1)

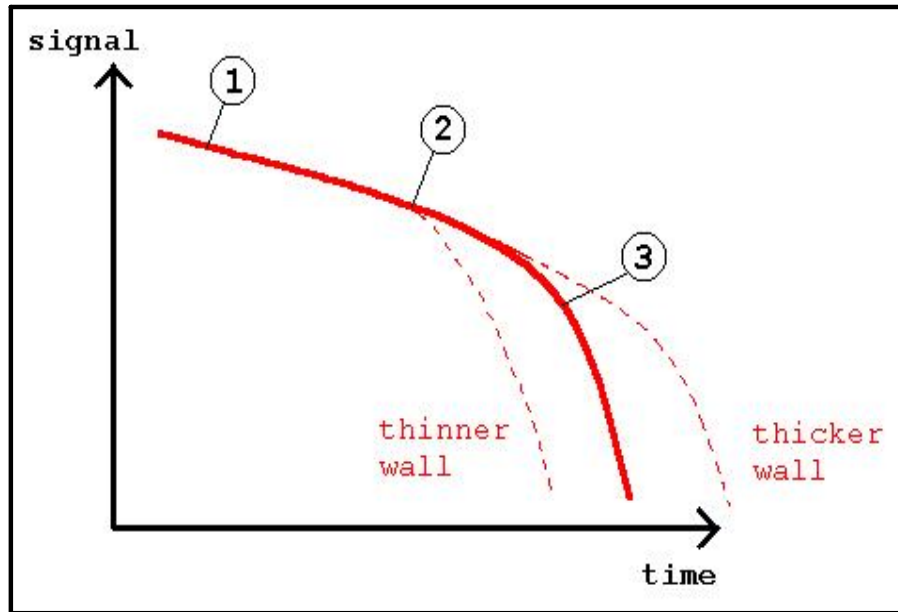
Principe de la Méthode PEC



Working Principle Pulsed Eddy Current (2)

Principe de la Méthode PEC

PEC signal



1: Eddy currents diffuse

2: Back wall is hit

3: Signal-decay increases sharply

Wall thickness determined
L'épaisseur est déterminée
by point where rapid signal
dès que la chute du signal
decay begins (point 3 on graph)
commence (point 3 sur la courbe)

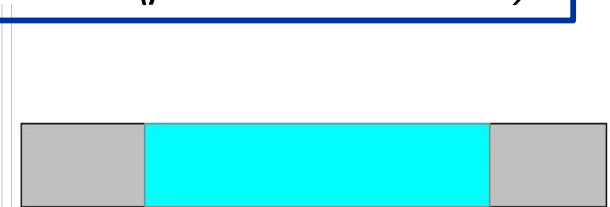
eddy
current
region



1



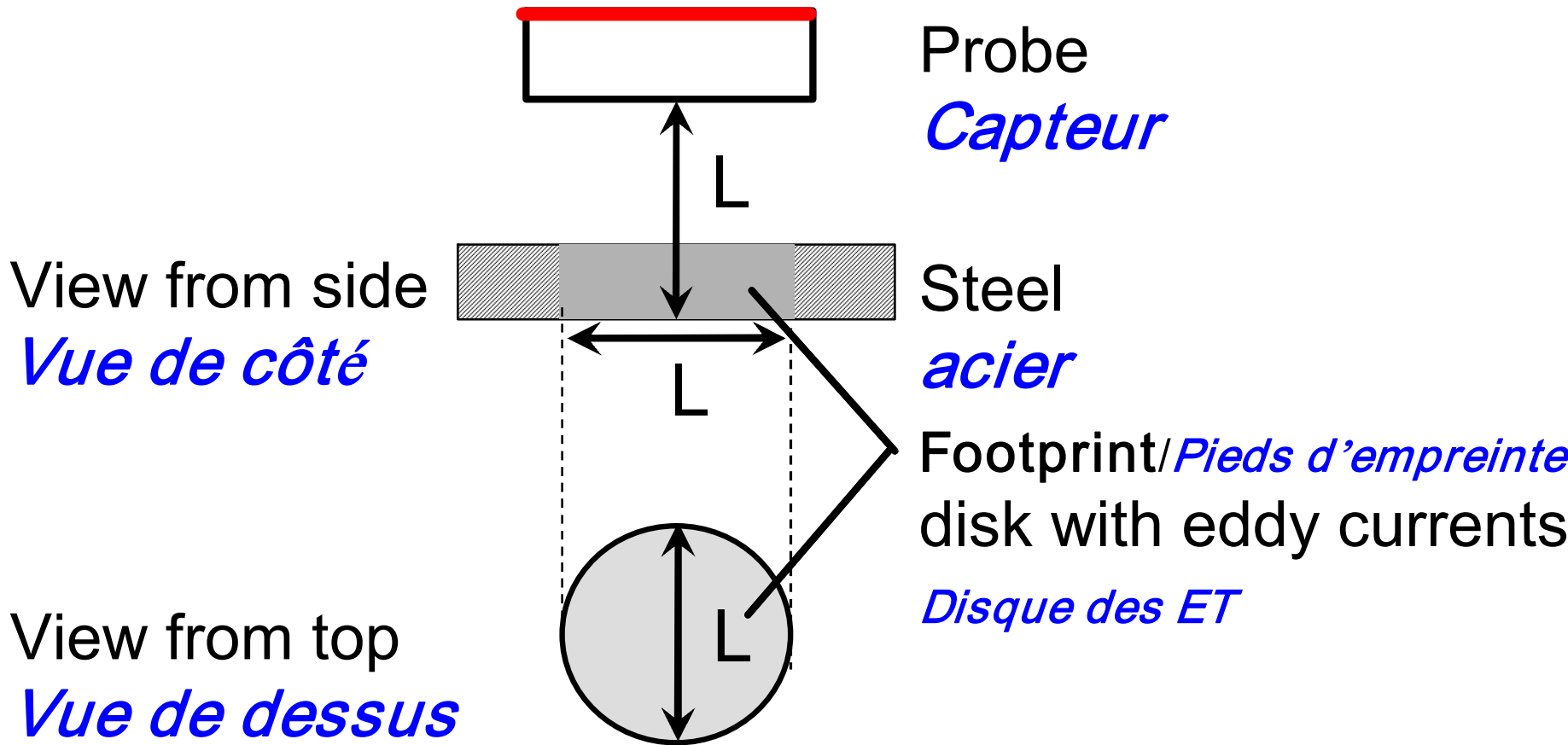
2



3

PEC averages over 'foot print area'

Moyenne de la zone d'empreinte des PEC



Characteristics of PEC versus Ultrasonics

Caractéristiques du PEC par rapport aux UT

Pulsed Eddy Current

Based on electromagnetism

Méthode électromagnétique

- Average measurement over probe footprint area

Mesure proportionnelle à la zone d'empreinte

- Measures relative wall thickness

Mesure d'épaisseur relative

- No contact or surface preparation required
shoots through any non-metal, including coatings, insulation, marine growth, corrosion products

Aucun contact ou préparation de surface n'est nécessaire

Ultrasonics

Based on high frequency sound

Méthode UT à haute Fréquence

- Point measurement over very small area

Point de mesure de petite dimension

- Measures absolute wall thickness

Mesure d'épaisseur absolue

- Contact and surface preparation required (needs couplant and clean surface)

Nécessité de préparer les surfaces et d'utiliser un couplant

PEC Strengths & Limitations

PEC Points forts et limites

Strengths/*Points forts*

- Non-contact, non-invasive/ *Pas de contact, non invasive*
- No removal of: coatings, insulation, marine growth,
Pas d'élimination de peinture, isolation, salissures marines
- No surface preparation/ *Pas de préparation de surface*
- No shut down needed/ *Aucun arrêt nécessaire*
- Surface temperature up to 550 °C (1000°F)
Opère sur surface en T° jusqu'à 550 °C
- Corrosion monitoring: unique same-spot reproducibility
Pour la surveillance de Corrosion, assure une parfaite reproductibilité

Limitations/*Limites*

- Wall thickness averaged over probe “footprint”
La moyenne des épaisseurs est limitée par l'empreinte du capteur
- PEC is a comparator: measures thickness *variations* on same object
La méthode de mesure de variation d'épaisseur est comparative
- Some geometries can make measurement difficult
Certaines géométries peuvent poser des difficultés de mesure

When to apply PEC
Quand appliquer PEC ?

General wall loss
*En général pour
des pertes
d'épaisseur*

No access to the surface
Pas d'accès à la surface

- Insulation, coating, fireproofing
- Corrosion product
- Narrow access

Under water, splash
zone, *Subaquatique,*
zone de marnage

Wall thickness monitoring

Surveillance des épaisseurs

- Remarkable same-spot
repeatability *Remarquable
répétitivité des mesures*

Application examples/*Exemples d'applications*

- Corrosion under Insulation
Corrosion sous calorifuge
- Corrosion under Fireproofing
Corrosion sous inifugeage
- Detection of Flow Accelerated Corrosion
Détection d'une accélération de Corrosion
- Corrosion of tank floors
Corrosion face opposée des fonds de réservoirs
- Offshore applications
Applications Offshore
- Corrosion monitoring
Surveillance de la corrosion

Corrosion Under Insulation/ *Corrosion* sous calorifuge

PEC can inspect in-service without removing insulation

PEC permet une Inspection en service sans retirer l'isolant

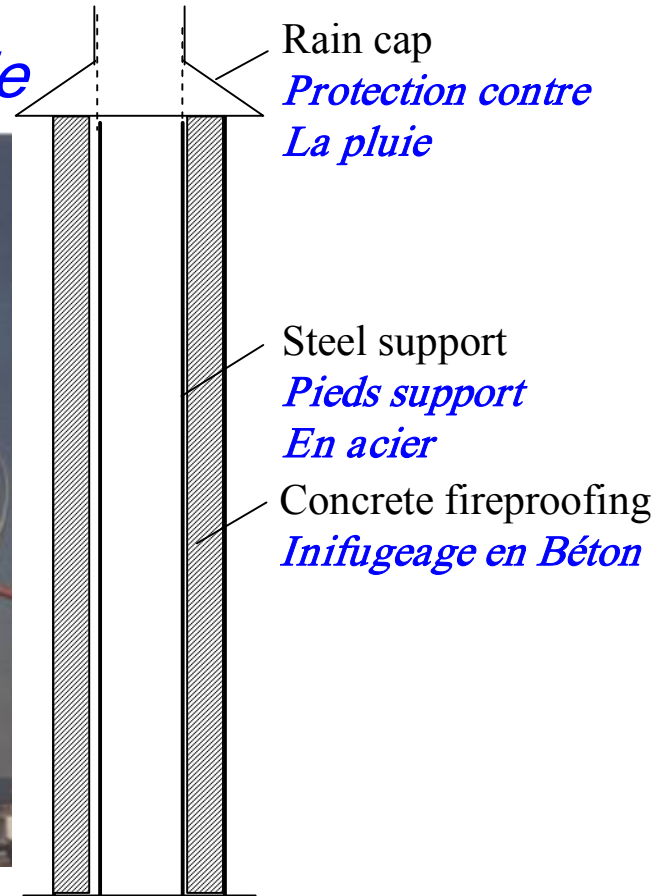


17.9	16.9	13.6	14.4	14.2	17.5	16.5	16.9
17.5	17.1	12.4	13.9	13.9	17.1	14.8	16.6
17.5	17.1	11.3	12.9	12.0	17.2	11.8	16.4
17.6	16.9	11.1	11.6	11.4	17.3	11.8	15.0
17.5	17.2	11.1	11.2	10.8	17.3	12.3	15.0
17.5	17.0	10.7	11.3	10.5	17.0	14.0	16.5
17.4	16.8	9.9	10.8	11.1	16.9	16.9	16.8
17.5	16.9	11.3	10.2	9.7	16.7	17.5	17.2
17.5	17.0	10.8	9.5	8.5	17.0	17.5	17.4
18.4	17.4	10.2	9.2	8.2	17.2	14.8	17.4
17.3	17.4	9.9	9.2	8.3	17.1	14.7	17.2
17.0	14.8	8.7	8.5	8.8	17.0	10.6	16.3
16.7	11.7	8.7	8.6	8.7	16.8	14.4	16.7
17.3	11.4	8.9	8.7	8.7	16.9	16.8	17.1
17.7	11.1	9.0	8.6	8.6	17.1	17.6	17.2
17.6	15.7	10.0	9.1	15.6	17.2	17.5	17.5
17.7	16.9	11.0	9.5	16.3	17.4	17.7	17.6
17.8	17.4	12.3	10.1	16.6	17.3	17.5	17.5
17.8	17.5	12.5	10.7	17.1	17.4	17.5	17.5
17.4	17.6	12.8	11.7	17.2	17.2	17.3	17.4
18.0	17.5	12.7	13.0	17.9	17.8	17.7	17.8
18.0	17.6	13.0	14.4	17.9	17.7	17.8	17.8
18.1	17.9	16.5	16.8	17.9	17.8	17.3	17.8
18.1	18.0	17.6	17.8	17.8	17.7	17.6	17.7
17.6	17.7	18.0	17.9	18.0	17.6	17.6	17.4
16.2	16.3	17.8	18.0	17.6	17.4	17.5	17.6
16.6	16.7	17.8	18.0	17.9	17.3	17.4	17.6
17.1	17.2	17.8	18.1	17.8	17.6	17.6	17.8
17.9	18.0	17.9	18.1	17.9	17.7	17.8	18.3

Wall thickness in mm (color-code) *L'épaisseur en mm est codifiée par la couleur*

Corrosion under Fireproofing (CUF) *Corrosion sous inifugeage*

Incident in Tunisia / *Incident de Tunisie*



Corrosion of the steel support, hidden underneath the fireproofing
Corrosion des pieds en acier, cachée par l'inifugeage

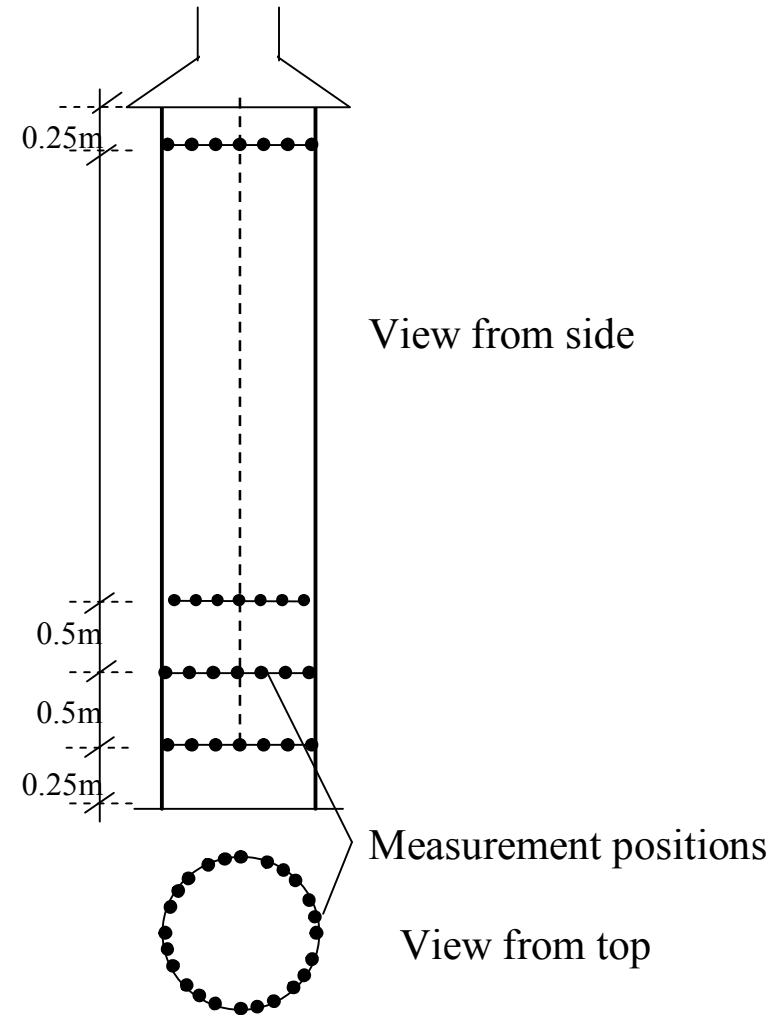
PEC inspection of sphere legs for CUF

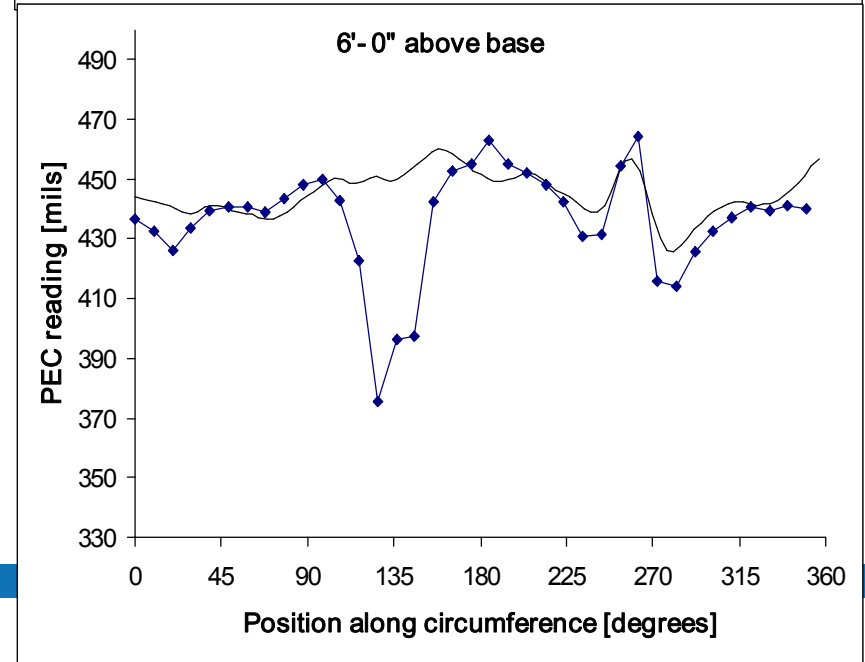
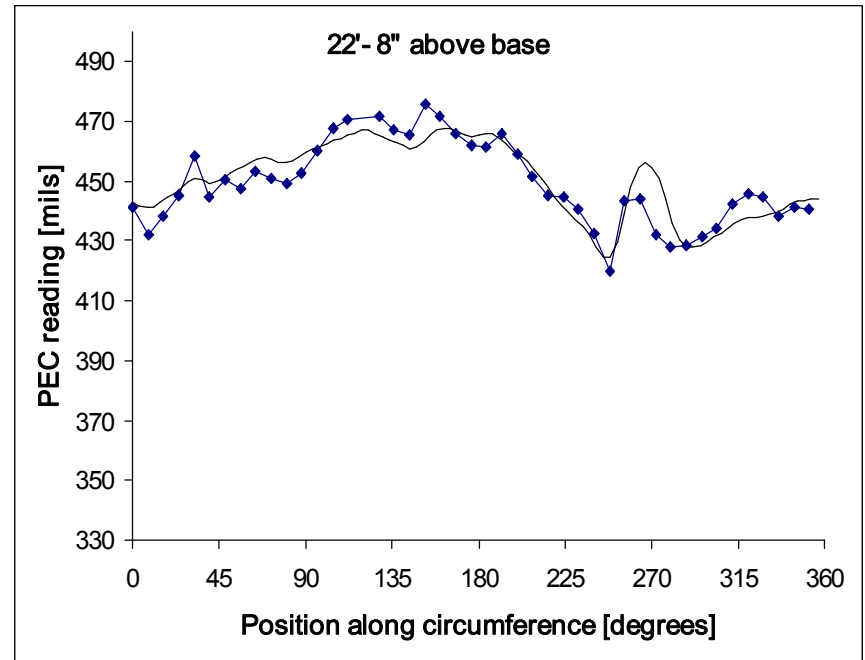
Inspection des jambes d'une sphère par PEC



PEC Probe

PEC probe in jig operated from cherry picker





PEC for corrosion under fireproofing



Sphere legs



Column skirts

Accident at Mihama nuclear power plant

Accident de la Centrale Nucléaire de Mihama

- 9 August 2004 / *9 Août 2004*
- Nine people killed/ *9 personnes tuées*
- Cause: 'Flow Accelerated Corrosion' (FAC)
Cause: Accélération d'une corrosion migrante



Flow accelerated corrosion (FAC)

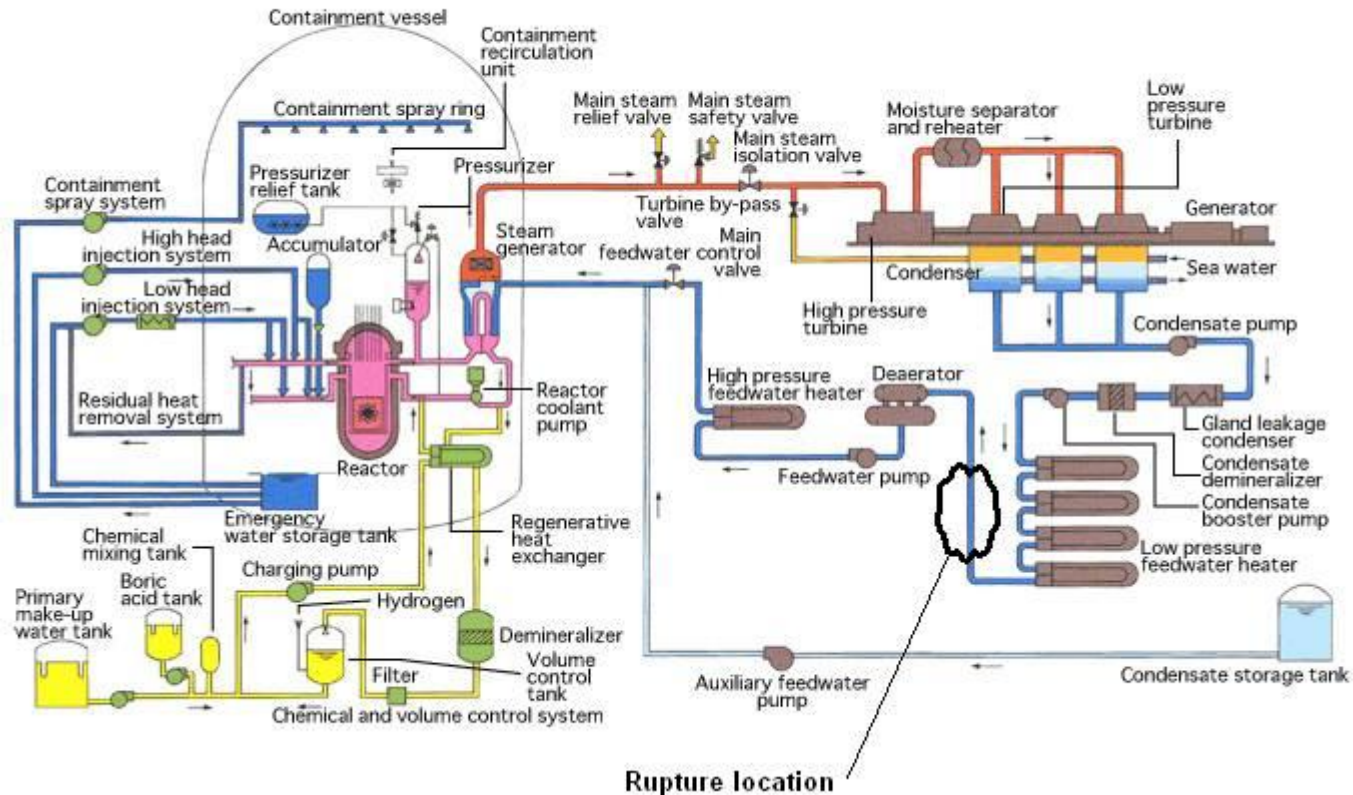
- Occurs on carbon steel in contact with water or wet steam at temperatures between 80 and 300°C
- Chemical process accelerated by flow rates
- Main wear mechanism in water supply circuits
- FAC is influenced by:
 - ✓ Flow rates and pipe geometry.
 - ✓ Chemical conditions.
 - ✓ Temperature.
 - ✓ Chromium contents of the steel.

FAC in primary and secondary cooling system

Accélération de la corrosion sur circuit de refroidissement Primaire et secondaire

Original diagram taken from http://www.mhi.co.jp/atom/hq/atome_e/03/01.html

BASIC SYSTEM CONFIGURATION



Ruptured pipe

Rupture d'une tubulure



Same problems elsewhere
Problème identique ailleurs



PEC is well suited to detect FAC

PEC est bien adapté à la détection d'une corrosion accélérée

- Conventional method to detect FAC:

Méthode conventionnelle:

remove insulation and inspect with ultrasound

démontage des isolants pour inspecter en UT

Can only be done when the plant is out of service, because of high temperature.

Peut nécessiter l'arrêt des installations à cause de la T°

- PEC can be used in-service, without removing the insulation

PEC peut être utilisé unité en service sans démontage de l'isolant

Wall loss over large surface area, so suited for PEC

Perte d'épaisseur sur de Larges surfaces est mieux pour le PEC

- Very large potential for PEC

PEC présente un bon potentiel

Inspection of test piece

Inspection d'une pièce d'essais



Insulated pipe with FAC damage
Tube isolé présentant de la FAC

Insulation, 100 mm thick
Épaisseur isolant 100 mm

Insulation sheeting, 1 mm Aluminum
Feuille calorifuge, 1 mm aluminium

Chicken wire inside insulation
Grillage intérieur à l'isolant

Validation program/ *Programme de validation*



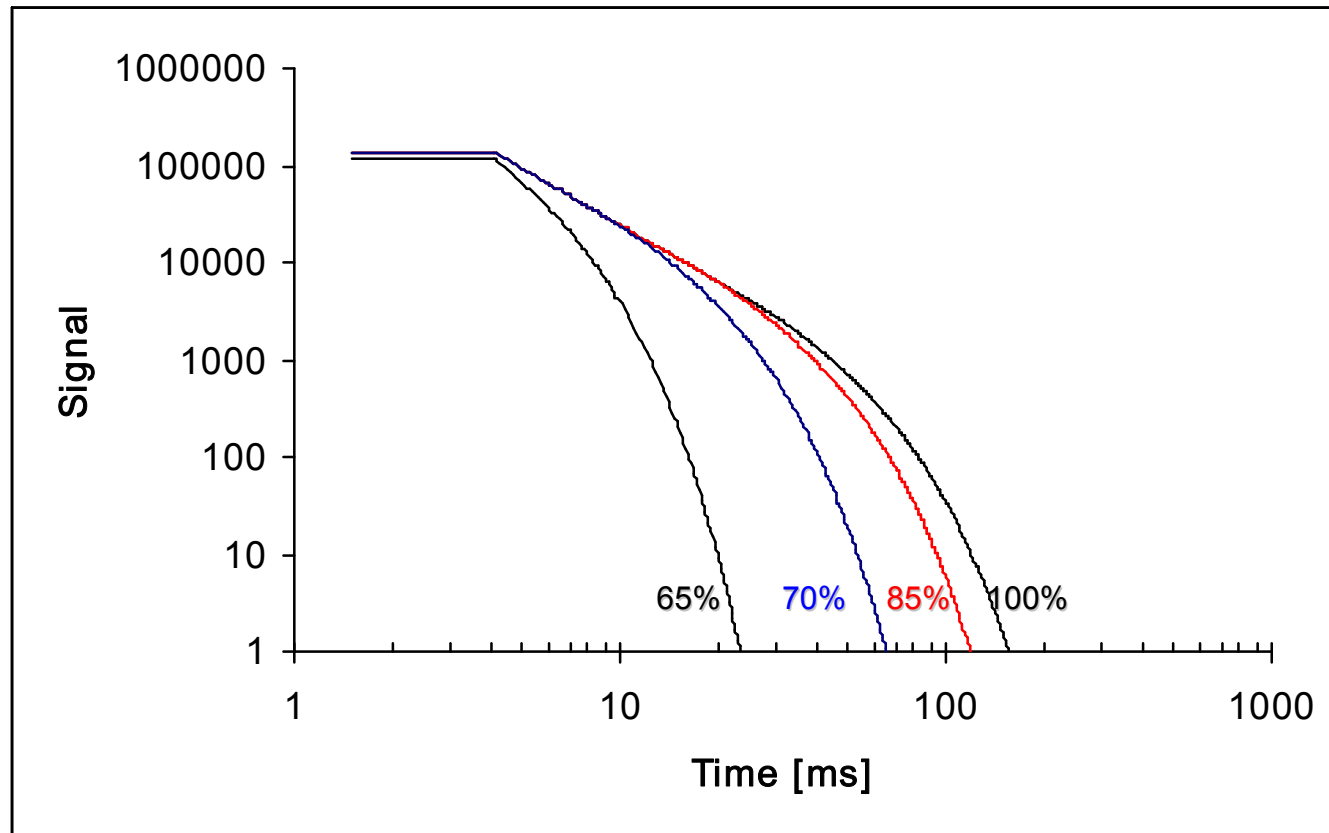
Insulated test sample with FAC
examined by PEC



Test sample without
insulation

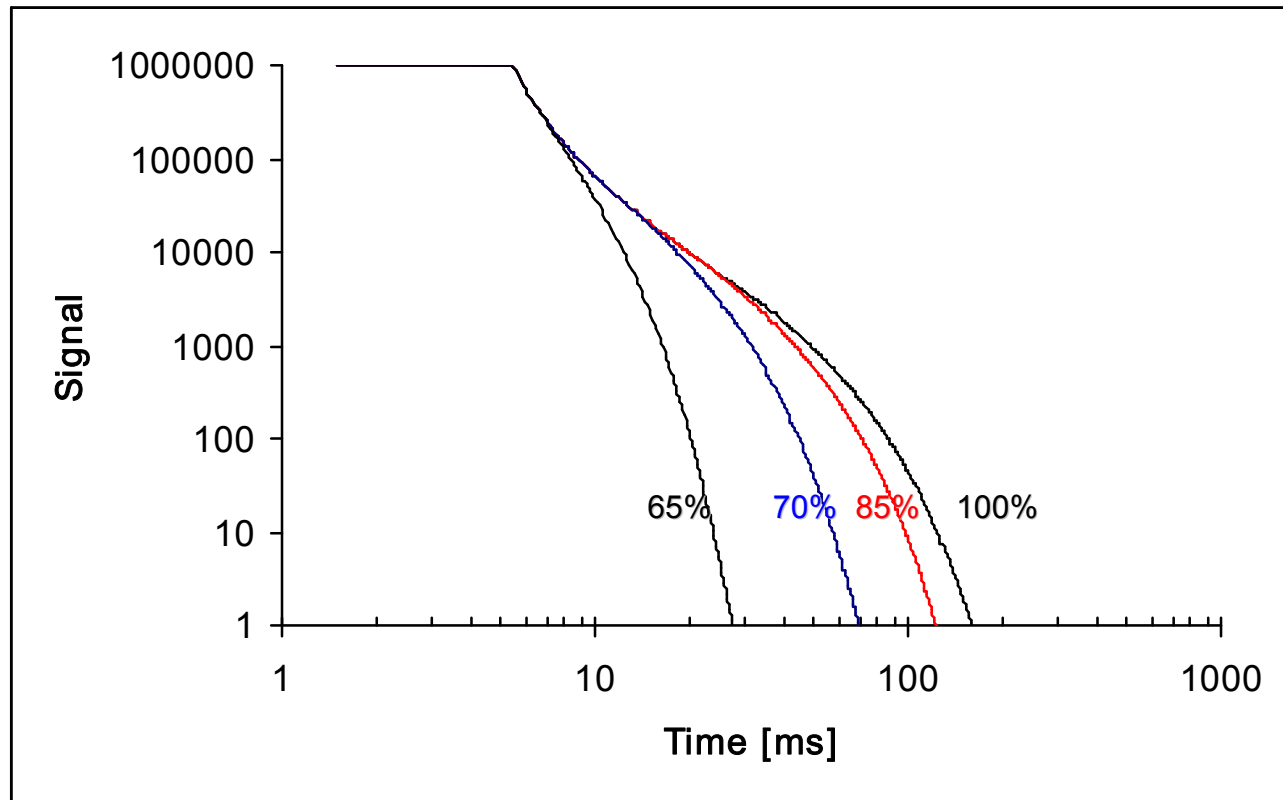
Calculated PEC signals versus steel thickness, stainless sheeting

Variation de Signaux PEC sur épaisseur d'acier et feuille en Inox



Calculated PEC signals versus steel thickness, Al sheeting

*Variation des signaux PEC sur épaisseur d'acier et tôle
Alu*



Results: PEC can detect FAC

		Position along circumference [mm]														
		0	100	200	300	400	500	600	700	800	900	1000	1100	1200	1300	1400
Axial Position [mm]	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	
	65	9.3	11.0	10.0	10.1	9.4	8.8	8.9	8.6	8.8	10.3	9.6	9.7	10.7	10.1	9.6
	135	9.6	10.5	9.8	9.6	9.5	9.1	8.2	8.6	8.5	8.8	8.9	9.4	10.2	10.6	10.9
	205	11.2	10.9	9.9	9.5	9.4	8.8	7.7	8.4	8.0	9.4	8.9	9.1	10.5	10.9	11.5
	275	10.4	10.4	9.6	9.3	9.2	8.4	7.5	8.4	7.5	8.6	8.7	9.4	10.4	10.7	10.9
	345	9.2	9.1	9.5	9.5	9.1	7.9	7.5	7.4	8.4	8.2	8.5	9.5	10.5	10.0	9.4
	415	9.1	8.7	9.4	9.4	8.9	7.6	7.4	7.5	7.8	7.9	8.3	10.3	10.4	9.4	9.1
	485	8.7	8.6	9.3	9.3	8.8	7.7	7.8	7.6	7.7	8.1	8.5	9.2	16.2	9.2	9.0
	555	8.5	8.6	9.0	9.7	9.6	7.9	7.7	7.6	7.9	8.2	8.6	11.7	10.1	9.4	9.1

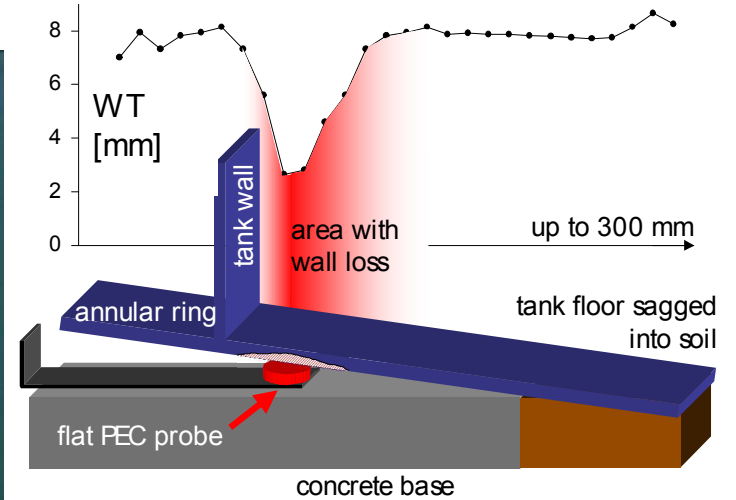
Wall thickness measured by PEC through insulation



Next step: tests at a nuclear power plant in France

In-service inspection of annular rings of storage tanks

Inspection en service des tôles marginales d'un réservoir de stockage



- Access
- No need to remove corrosion products

Detection of cracked welds of 'plate and frame' steel bridges (orthotropic bridges)

Détection de fissures dans soudures de structures en acier de Ponts



Problem with long span bridges, 40 years old, heavy loading

Problème de durée de vie des ponts de lourde charge et de 40 ans d'âge

Applications offshore platforms: splash zone

Applications Plateformes Offshore: Zone de marnage

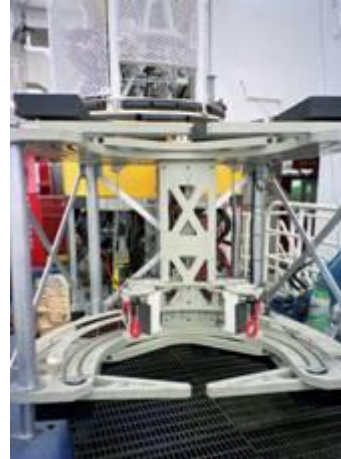


Jig with PEC probe

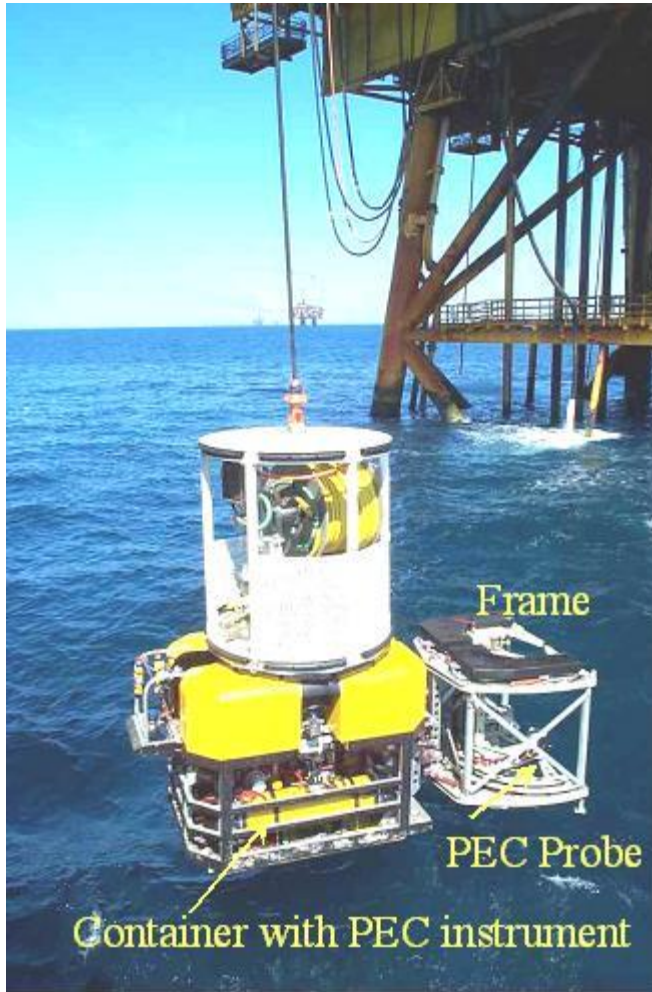
Vertical Position [mm]	Clock Position [hours]					
	2	4	6	8	10	12
0	16.5	12.5	17.2	16.9	15.1	16.5
-100	16.8	12.4	17.0	16.7	13.8	16.4
-200	16.7	10.4	16.4	16.7	11.3	16.1
-300	16.5	10.5	14.3	16.5	12.2	15.9
-400	17.1	9.6	13.3	16.4	11.1	16.4
-500	16.9	9.7	12.9	16.3	12.5	16.6
-600	16.5	10.2	13.9	16.3	15.3	16.7
-700	16.9	9.1	13.4	16.0	16.5	16.4
-800	16.6	8.6	11.9	16.1	16.4	16.7
-900	16.9	8.4	11.9	16.3	16.5	16.8
-1000	16.5	7.9	12.0	16.4	16.4	16.7
-1100	16.1	8.0	13.5	16.2	14.2	16.6
-1200	14.9	8.1	13.0	16.2	16.5	16.3
-1300	13.9	8.5	13.8	16.3	16.7	16.1
-1400	14.7	8.6	14.0	16.3	16.9	16.6
-1500	15.8	9.1	13.3	16.3	17.0	17.4
-1600	16.5	9.5	12.8	16.3	16.9	16.8
-1700	15.3	11.7	13.2	16.4	16.8	16.8
-1800	16.4	11.6	16.7	16.5	16.7	16.4
-1900	16.4	12.0	16.9	16.4	16.6	16.5
-2000	16.7	12.7	17.0	16.4	16.6	16.5
-2100	16.8	13.7	17.0	16.3	16.6	16.5
-2200	16.8	16.0	16.9	16.3	16.5	16.7
-2300	16.6	16.8	16.9	16.2	16.2	16.3
-2400	15.5	16.5	17.1	16.3	16.5	16.6
-2500	15.2	16.5	16.0	16.3	16.5	16.5
-2600	15.7	16.6	16.9	16.2	16.5	16.5
-2700	16.4	16.5	16.9	16.1	16.6	16.5
-2800	16.8	16.6	16.9	16.2	16.5	16.4
-2900	16.8	16.7	16.7	15.9	16.2	16.3
-3000	17.1	17.2	17.5	16.7	17.1	17.0

Color-coded wall thickness graph

PEC on a Remotely Operated Vehicle (ROV) system

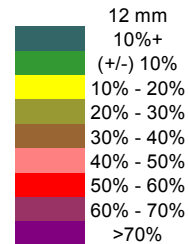


Underwater inspection of caissons by ROVs



Photograph: D. Mackay, Subsea7

Vertical Position [mm]	Position along circumference [hours]											
	12	11	10	9	8	7	6	5	4	3	2	1
1550	11.0			11.0			9.7			9.6		
1250	10.2			10.2			10.3			8.9		
1050	9.6	10.5	9.7	10.6	8.9	10.4	10.2	10.0	9.7	9.6	10.2	10.6
800	10.2	10.4	9.9	10.3	8.8	9.4	9.3	10.1	9.0	9.1	9.6	10.2
700	9.3	8.9	9.8	10.2	8.6	8.6	8.6	9.1	8.5	8.9	9.1	9.0
600	8.0	8.0	8.5	8.4	8.1	8.1	7.1	8.7	7.4	7.4	8.5	8.1
500	7.5	6.8	8.5	8.3	8.2	7.7	6.8	8.4	7.7	7.7	8.8	7.9
400	6.1	7.1	7.6	7.7	8.2	7.4	6.7	6.7	6.8	7.5	7.2	7.5
300	5.9	6.0	7.2	7.2	6.9	6.1	5.9	5.9	6.0	6.7	6.4	6.3
200	6.1	5.5	5.8	5.6	5.7	5.5	5.4	5.4	6.3	6.2	5.5	5.8
100	9.5		5.5	5.5	6.5	6.4	5.7		6.5	7.4	6.9	8.9
0	10.7	11.7	8.4	10.2	9.4	11.5	11.7	10.5	8.8	10.8	11.1	11.5
-100	10.8	11.4	10.4	10.3	11.5	10.9	11.5	10.3	10.1	11.0	11.0	10.4
-200	10.6	12.0	11.1	10.5	11.3	11.5	11.8	10.4	10.6	10.8	11.2	10.4
-300	10.6	12.1	12.3	11.9	11.4	12.0	12.2	10.3	10.3	10.8	11.0	11.1
-400	11.7	12.4	12.2	11.7	12.0	12.4	12.0	10.7	10.7	11.9	11.7	11.4
-500	11.1	11.4	11.9	10.8	10.5	12.0	11.7	11.1	11.6	12.2	10.6	10.6
-700	10.3	9.8	9.7	10.6	11.4	10.7	10.2	11.1	10.9	11.7	10.1	10.6
-800	10.1	10.6	9.9	9.9	10.5	11.0	11.0	10.8	10.3	10.1	9.9	10.1
-900	10.6	11.3	9.6	10.2	10.6	11.0	11.7	10.2	10.4	10.2	10.4	10.7
-1000	10.7	11.7	10.8	10.5	10.6	10.6	11.6	10.4	10.1	10.4	11.4	10.7
-1100	10.1			10.4	10.9		11.5			10.3	10.8	
-1300	10.5			11.4			12.0			11.1		
-1500	10.2			11.5			11.7			12.2		



Color-coded wall thickness graph

PEC wall thickness monitoring

Surveillance des épaisseurs par PEC

- Remarkable same-spot reproducibility: typical 0.2 % of the wall thickness

Reproductibilité remarquable: 0,2 % de l'épaisseur mesurée

- Operator independent / *Opération indépendante*
- Simple and robust / *Simple et robuste*
- Suited for high temperatures (applied till 800 F/420 C)

Conseillé pour les hautes T°(jusqu'à 420 °c)

Value / *Valeur*

Keep installation in operation despite corrosion problem

Laisser l'installation en service malgré les problèmes de corrosion

Operation outside design window

Permet l'exploitation hors limite de calcul

Example: Air cooler outlet pipes at a refinery

Exemple: Sorties d'aéroréfrigérants de Raffinerie



- Routine inspection revealed high corrosion rates at 48 elbows
Inspection de routine a révélé une forte corrosion sur 48 coudes
- Needed time to order replacement material
Temps nécessaire au réapprovisionnement
- Need technique that can be installed in-service
Besoin d'une technique pouvant être installée unité en service
- Conventional UT: tried, but not repeatable enough to determine short-term corrosion rates
UT conventionnels testés mais reproductibilité des mesures insuffisantes pour déterminer à court terme les valeurs de corrosion limite
- Pulsed Eddy Current was selected
PEC ont été retenus

Where? *Où*

- UT shows wall loss at first bend in outlet pipe

UT ont montré une perte d'épaisseur du premier cintre de la tubulure de sortie

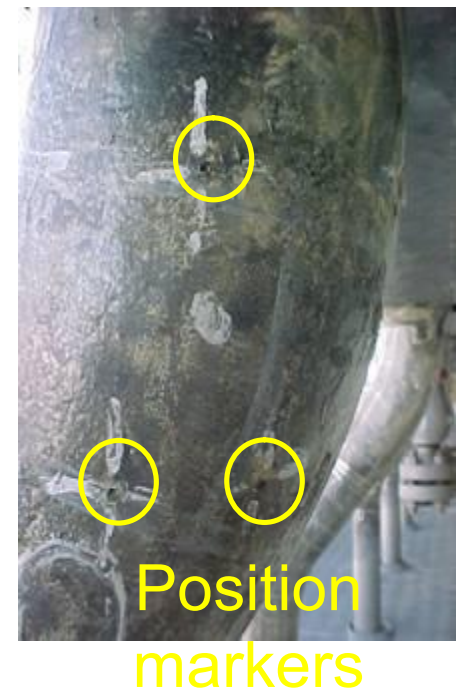
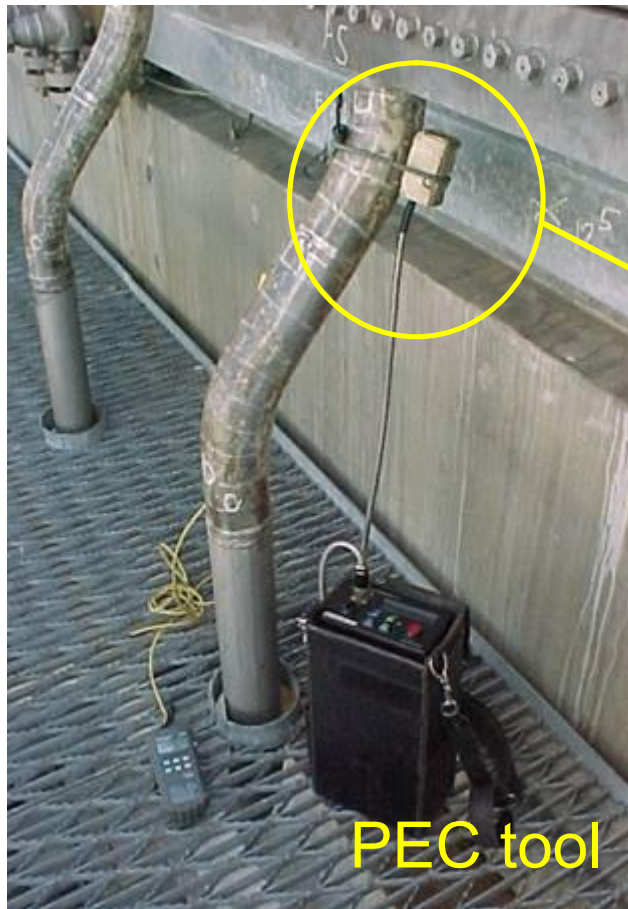
- Detailed UT measurements (grid over whole bend) used to identify thinnest position

Les mesures UT (quadrillage de l'ensemble du coude) utilisées pour identifier les plus faibles épaisseurs



PEC and UT wall thickness monitoring

PEC et UT surveillance des épaisseurs



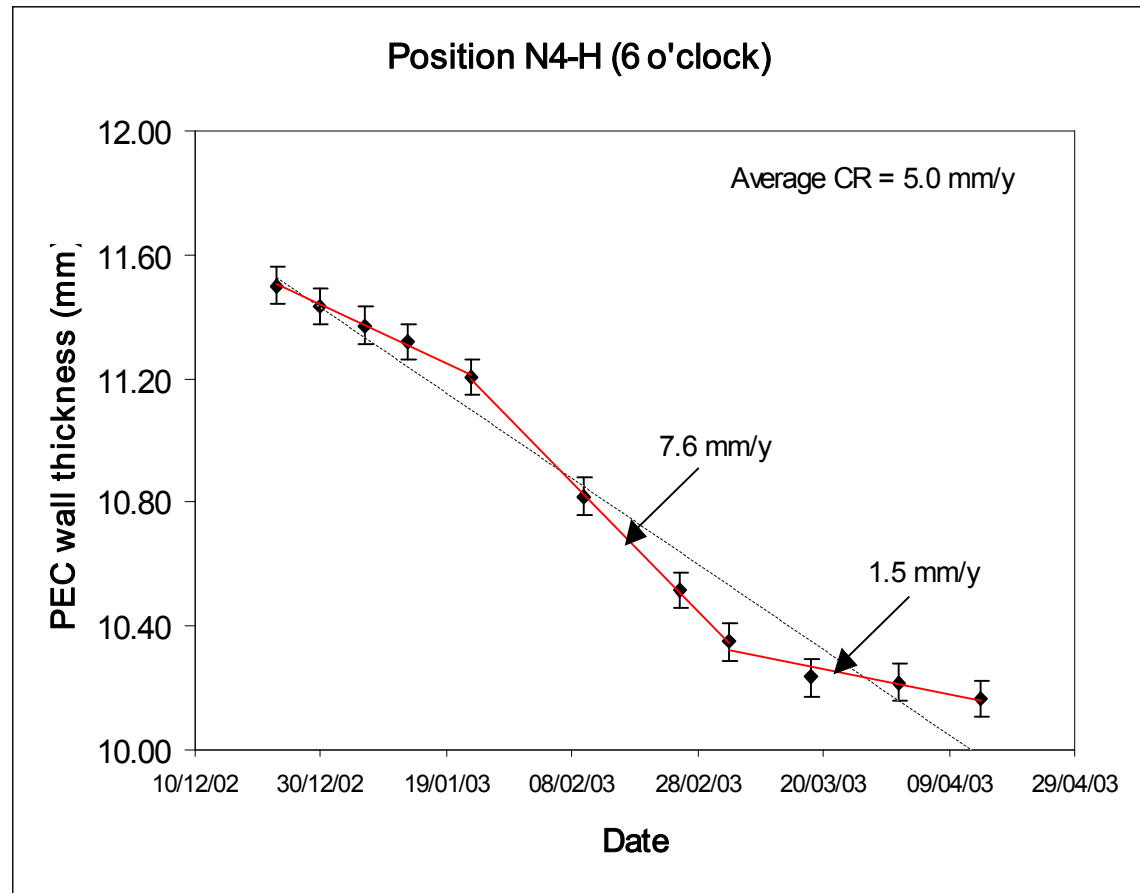
Mobile system: one sensor for all locations
Robustness & simplicity; DIY

Retro-fit capability: in-service installation

Examples of PEC results on air cooler outlet

Exemple de résultats obtenus sur sortie des Aéroréfrigérants

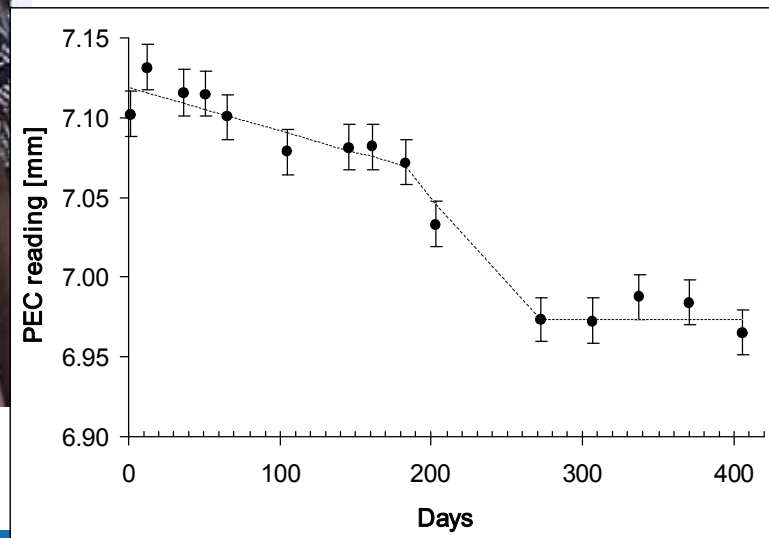
2mm



Role of PEC: help operations to get the corrosion under control
keep plant in operation till repairs can be made

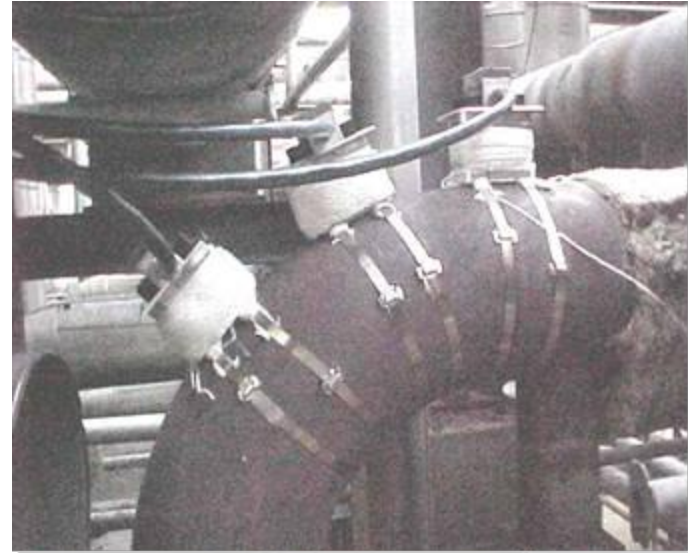
PEC corrosion monitoring

Surveillance par PEC de corrosion d'une tubulure sur colonne



Fixed PEC probes at positions with difficult access

Fixation des capteurs PEC en positions d'accès difficile



Features PEC / *Caractéristiques des PEC*

- **Mobile system:** one probe with positioning frame or markers
- *Système mobile: Un capteur avec châssis ajustable ou repère*
(also fixed sensors for inaccessible locations)
(avec fixation de capteurs pour zone inaccessibles)
Consequence: cost-effectiveness
Conséquence: réduction des coûts
- *Simplicity / Simplicité:*
 - easy to set up monitor points; in service, no welding
 - *Mise en oeuvre facile pour la surveillance de points, en service sans soudage*
 - easy to collect and analyze data (automated)
 - *Acquisition et analyse des données automatisées*
- **Robust, especially at high temperatures**
Robuste, notamment pour les hautes T°