TPA Training Course

Corrosion Management
in the Oil & Gas Industry

Marcel ROCHE

Part 4

Arkhangelsk State Technical University
April, 6 – 10, 2009

Cathodic protection and associated coatings

Cathodic Protection

Design and implementation

Selection criteria for CP systems

	Galvanic anodes	Impressed current
Installation	simple	complex
Power source	no	yes
Current distribution on protected structure	Homogeneous	May be heterogeneous
Size of the structure to protect	May be important but possibility of weight excess Not easy for elongated structures	OK for large and elongated structures
Influence of environment resistivity	Not possible if too high resistivity	No problem
Anode current output	low	high
Number of anodes	important	low
Operating flexibility	Self-regulation only	High flexibility
Risks of overprotection	Practically nil except with magnesium anodes	possible
Interferences with other structures	Low risk	High risk
Safety hazards	negligible	possible
Monitoring / maintenance	low	Mandatory, necessitating Specialised technicians

Total Prof

CP design

- **Design of CP system has to specify the number, weight, size, dimensions and location of anodes and to define all electrical equipment for impressed current systems**
- **It should be carried out in order to ensure the observation of the retained protection criterion at each point of the structure to be protected all along the design CP lifetime**
- **Design is most often carried out using simplified methods easy to apply**

CP design: Offshore structures

- evaluation of ”maintenance current demand" I_m for each individual structure area S to be protected from the maintenance current density j_m and, in case of coating, the mean coating breakdown factor x_m , after achievement of steady state of protection (effect of calcareous deposits):

$$I_m = j_m.S.x_m$$

- evaluation of "initial current demand" I_0 for each individual structure area S to be protected from the initial current density j_0 and (eventual) initial coating breakdown factor x_0:

$$I_0 = j_0.S.x_0$$

- same thing for the “final current demand” I_f, which is generally the dimensioning step in case of coating:

$$I_f = j_f.S.x_f$$

Selection of sacrificial alloys

- **Magnesium**
  - most “active” i.e. negative potential (rapid polarisation, long span)
  - short lifetime (temporary protection)
  - the most expensive
- **Zinc**
  - reliable in all conditions up to 60°C (very safe when buried, with low initial current output, e.g. on well coated structures)
  - not reliable at higher temperature
- **Aluminium**
  - the less expensive
  - light
  - remains active at high temperature (but low efficiency)
  - modern alloys qualified for use on buried and/or coated structures (e.g. Sea-lines)

Galvanic systems

Typical characteristics of galvanic anodes in seawater at ambient temperature

Type of alloy	Potential mV vs Ag/AgCl/seawater	Electro-chemical efficiency (%)	Anodic capacity Ah/kg	Practical consumption rate kg/A.yr
Al-Zn-In	-1100	88	2660	3,3
Zn	-1050	95	760	11,2
Mg	-1500	50	1230	7,1

Comparative costs of anodes (supply)

Material	Al	Zn	Mg
Cost of alloy (€/kg)	3	2.3	7.6
Consumption rate (Kg /A.yr)	3.5	11.2	7.7
Cost of protection (€/A.yr)	10.5	25.8	58.5
Costs ratio	1	2.5	5.6

CP design: Offshore galvanic systems

- Calculation of the total weight of anodes M_t to be installed from the "maintenance" current need, design lifetime D, practical consumption rate of sacrificial anode alloy m and utilisation factor of anodes u:

$$M_t = D.\ I_m\ .\ m\ /u$$

- Calculation of the number n, the individual weight M ($M_t = nM$) and the dimensions of anodes from determining conditions (generally initial for bare structures and final for coated structures), using the notion of "anode resistance" and Ohm's Law

CP design: Offshore galvanic systems

- It is assumed that electrolyte resistance between an anode and the structure (cathode) only depends on anode dimensions, the cathode being considered at the infinite which means that anodic current density is predominant.

- Semi-empirical formulae , comprising electrolyte resistivity ρ, are used to calculate the "anode resistance"; For slender anodes (length L, equivalent radius r) used on tubular structures (jackets), one of the Dwight formulae are used:

$$R = \rho / 2\pi L \, [\ln(4L/r) - 1]$$

CP design: Offshore galvanic systems

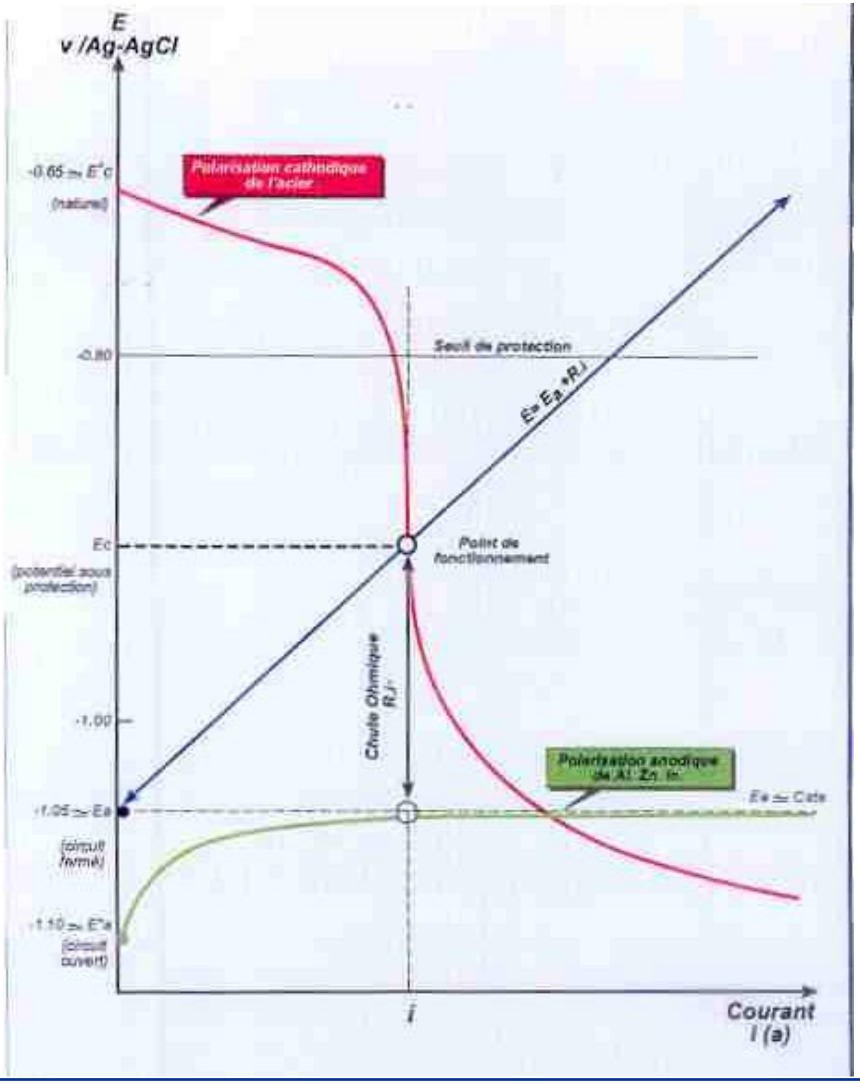
- The structure potential E_c should be checked to be always more negative than the retained protection threshold, for instance for initial conditions (determining for bare structures):

$$E_c = E_a + Ri$$

with $i = I / n$ and E_a closed-circuit potential of anodes.

- Optimisation of design is a permanent aim in order to reduce costs but without taking risks of retrofitting
- It is essentially based on the experience feed-back and the lessons from failures

CP design: Offshore galvanic systems



Total Prof

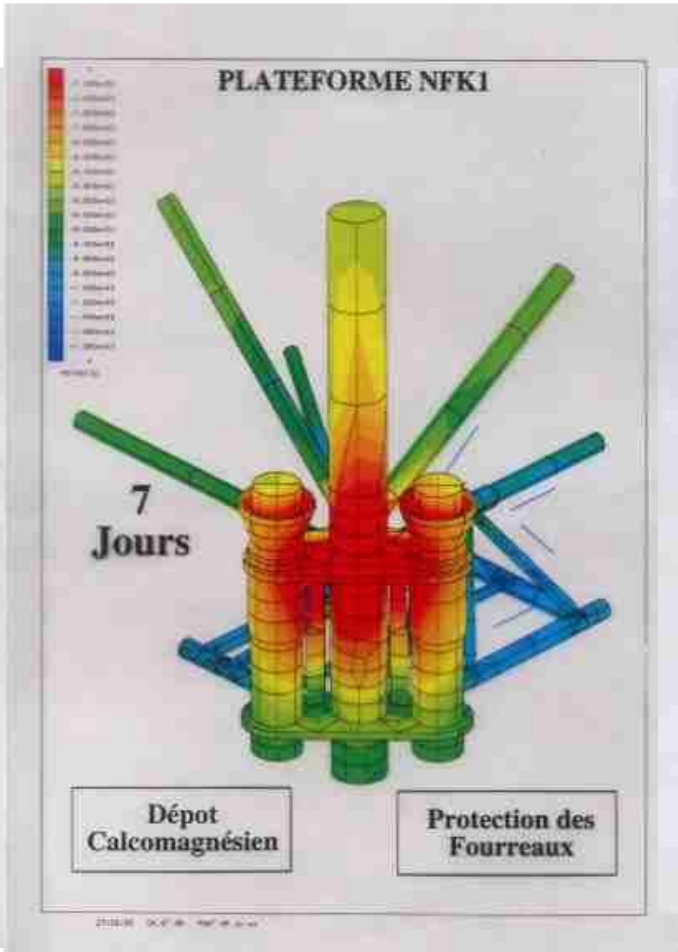
CP design: modelling

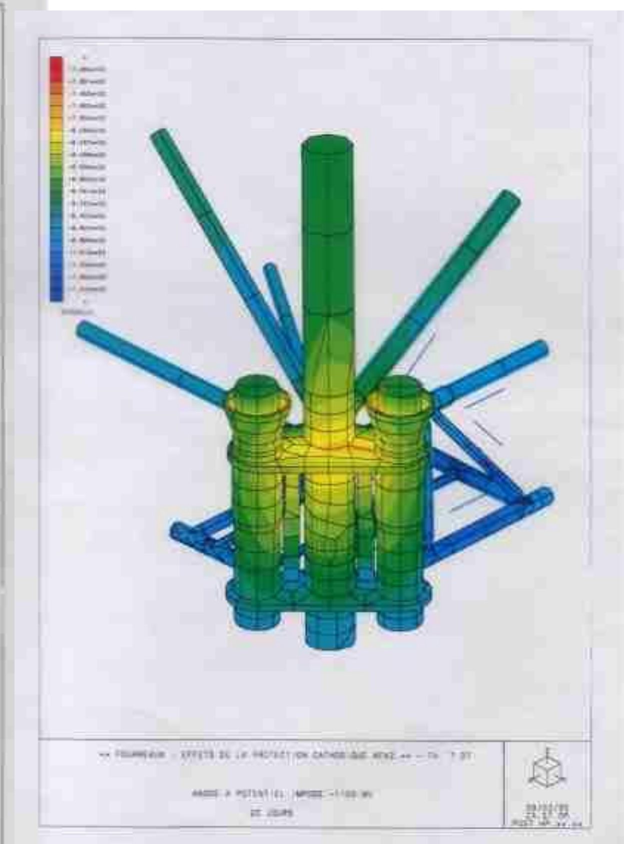
- However, it appeared useful to try to better approach the actual situation for the most complex cases, using Laplace equation which rules the electric field in the electrolyte:

$$\nabla\varphi(x) = \sum[\partial^2\varphi / \partial x^2] (x) = 0$$

- 3D modelling softwares based on finite elements or surface integral equations have been developed from the 80's on this principle

CP design: modelling





Cathodic Protection

Measurements

Aims of monitoring efficiency of cathodic protection

- **The ideal: to know the true metal - electrolyte potential at all locations of the protected structure and at each time**

  ===> impossible to achieve. Doubt to be kept within acceptable limits

- **Periodicity of routine measurements and of special surveys should be adapted to the probabilities of evolution of CP efficiency and to the risks of lack of protection and of over-protection**

- **Utmost importance of quality in the realisation of monitoring and surveys: CP personnel to be qualified and as much as possible certified**

General principles of measurements, problematic of the measurement error

- IR (ohmic) drop between the metal surface and the reference electrode: systematic error, practically always optimistic, except if external dc currents

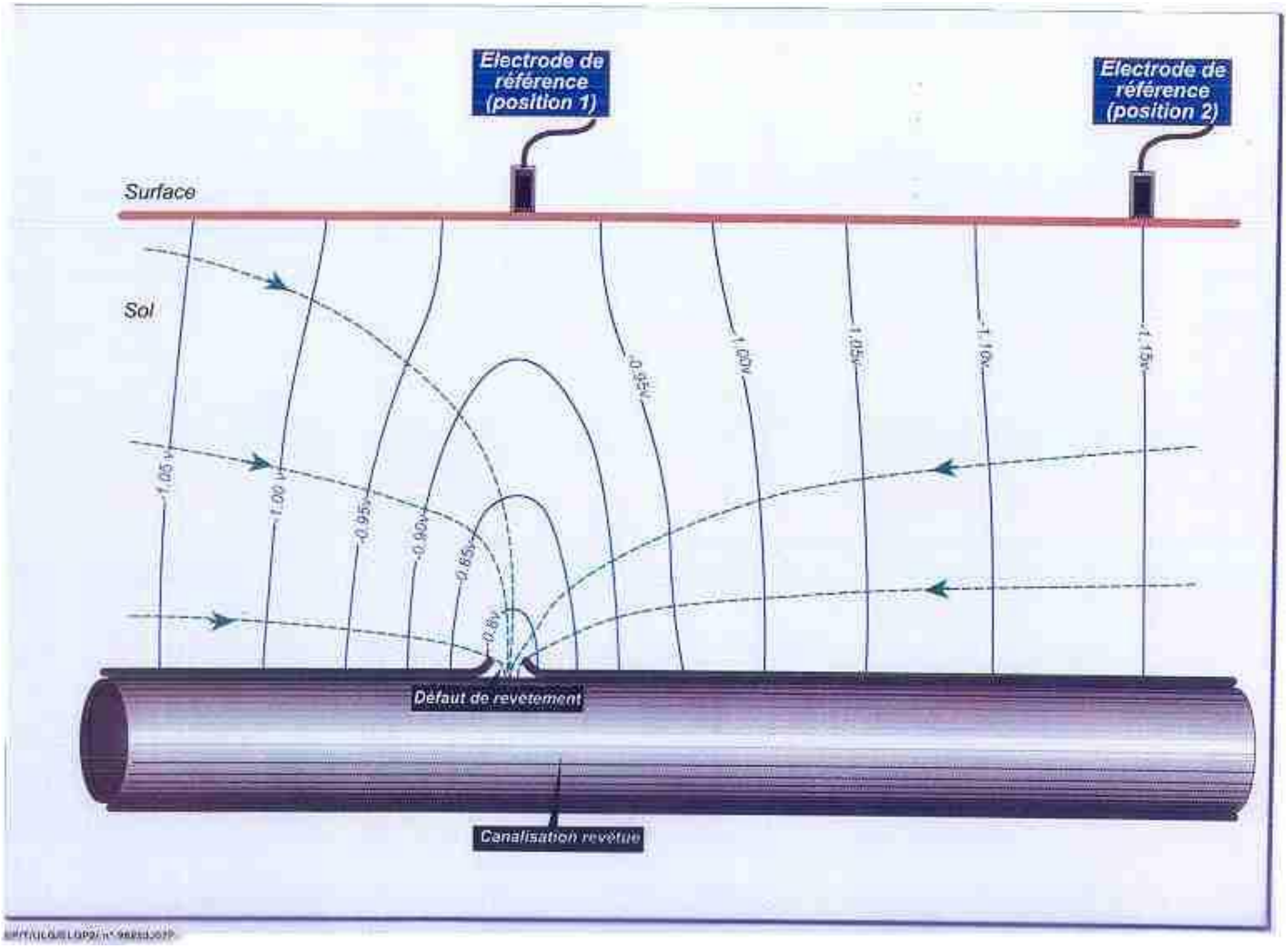
  ===> increases when resistivity increases and metal - electrolyte distance increases

  ===> concerns essentially buried pipelines

- variation of potential at the surface of structure for elongated structures such as pipelines

  ===> specific intensive methods to be used for better knowledge of potential all along the pipeline (CIPS)

Problematic of the measurement error

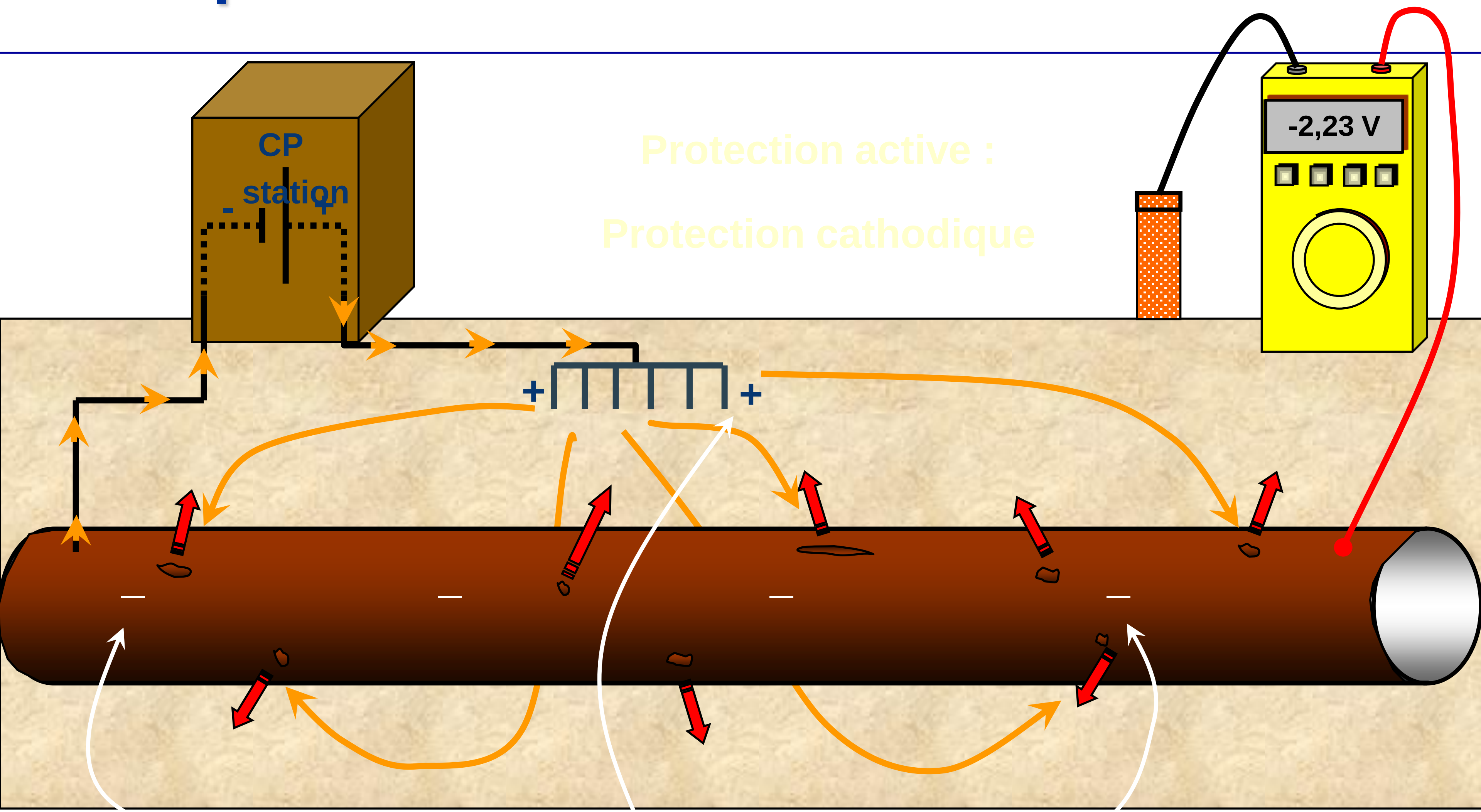


Total Prof

« ON potential » measurements

- This method is used **without switching off the CP current.**
- This is the basic method still the most often used
- It is simple to use, but the results are **not accurate** because they are containing the IR drop close to pipeline.

« ON potential » measurements



How to correct IR drop

1. Cancel I during measurement:

Switch-off all the acting CP stations in a synchronised way (breakers)
===> "OFF potential"

But: errors remain due to "compensation currents", stray currents, telluric currents

Possibility of rapid depolarisation in some soils.

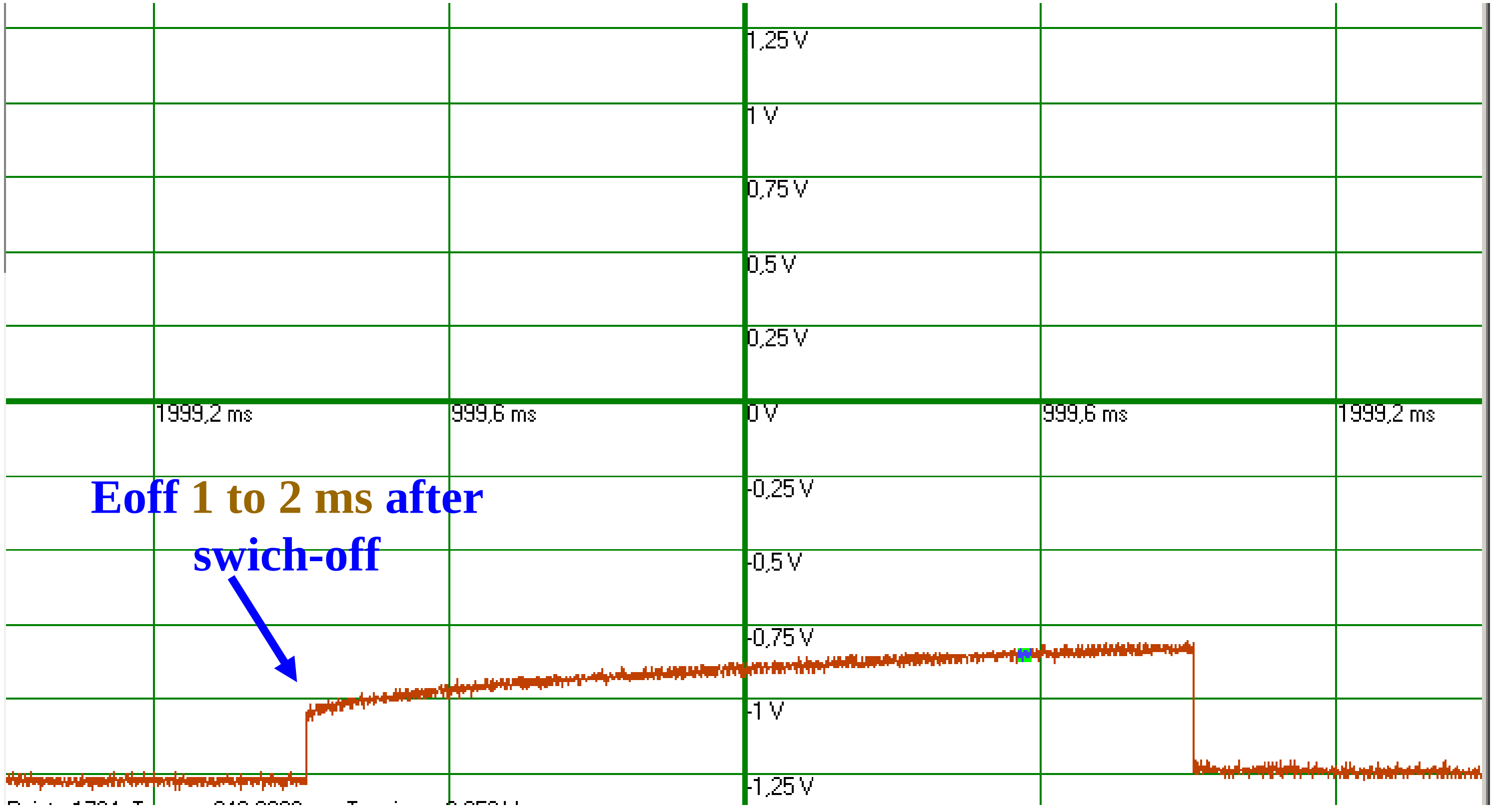
2. Cancel R

Installation of reference electrode close to the structure surface
===> Buried permanent reference electrode

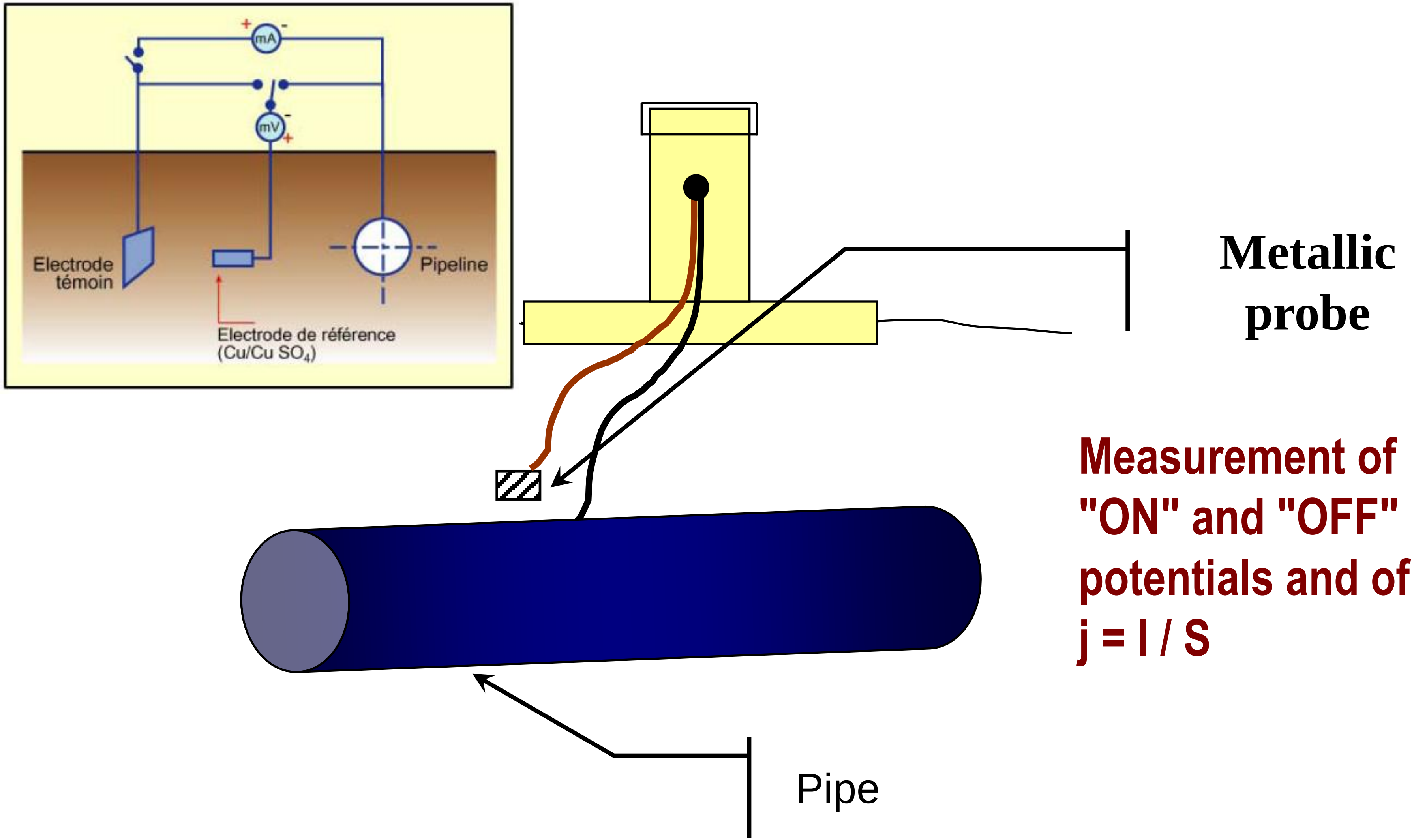
3. Combine both

Coupons with direct OFF measurement

ON/OFF measurements



Measurements with probes (coupons)



Measurement of "ON" and "OFF" potentials and of $j = I / S$

Measurements with probes (coupons)

AMPEROMETER

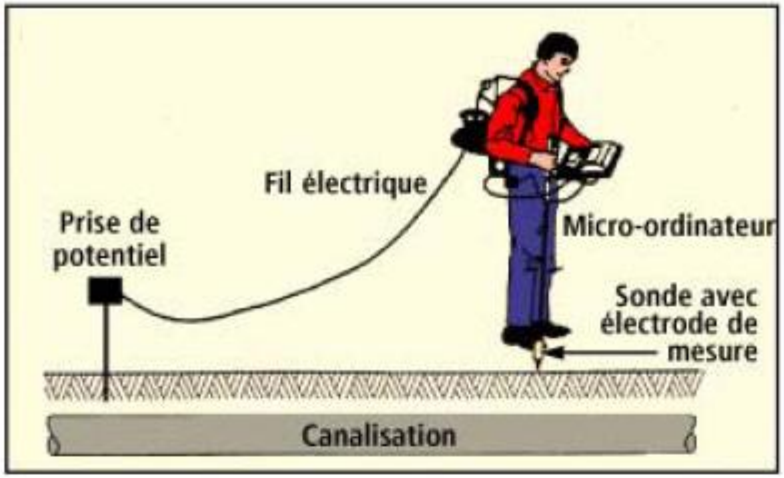
VOLMETER

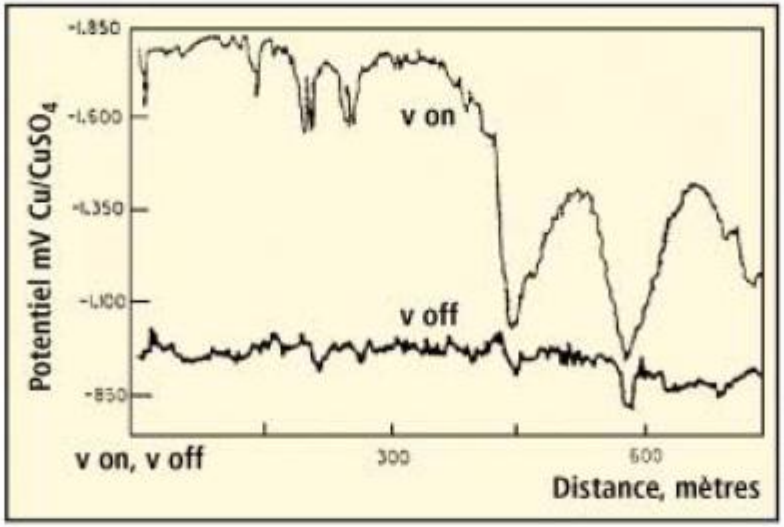
Measurement is carried out typically 1 second after switch-off

Total Prof

ON/OFF CIPS (Close Interval Potential Survey)

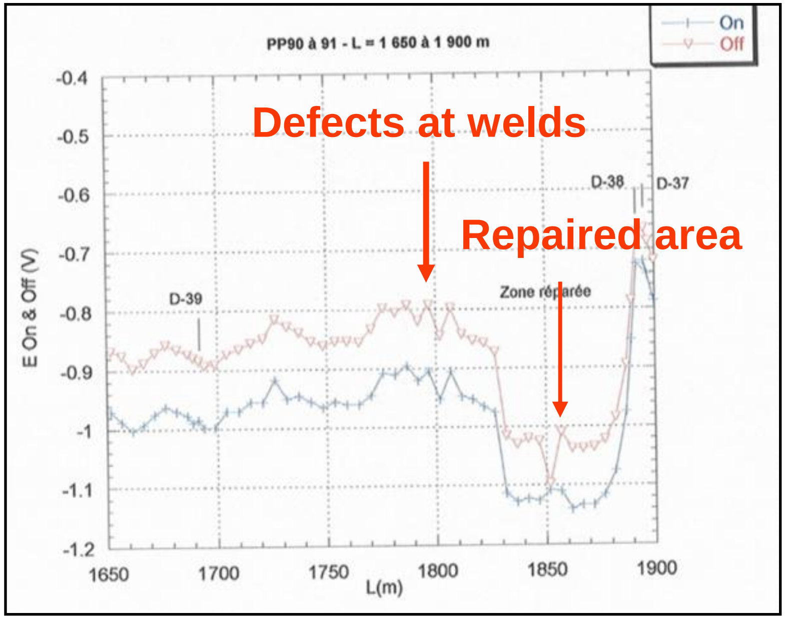
- **"CIPS" (Close Interval Potential Survey) carried out with an electrical wire unreeled (lost or not)**
- **Used when OFF measurement possible (without stray currents)**
- **May be concentrated on sections where coating defects have been detected or when especially critical (external corrosions detected by internal inspection, possible coating disbondments,…)**



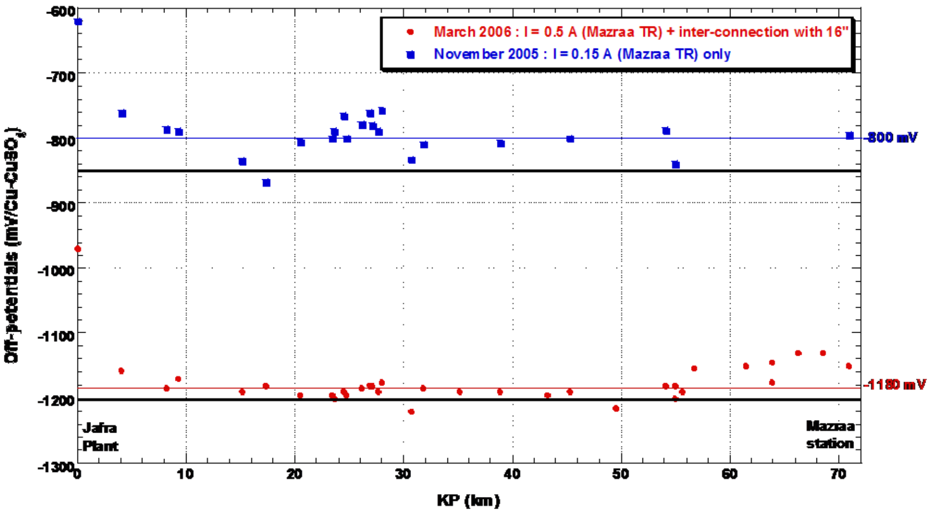


Total Prof

CIPS may work to detect corrosion under disbonded coatings



18" oil pipeline (Gabon)



16" oil export (Syria), before and after CP improvement

Detection of coating defects in the field

- Aims
  - detect and locate most of coating defects
  - assess their importance (surface)
  - try to assess their nocivity (anodic and cathodic defects)
- Methods

use of a dc current (measurement of potential gradient)

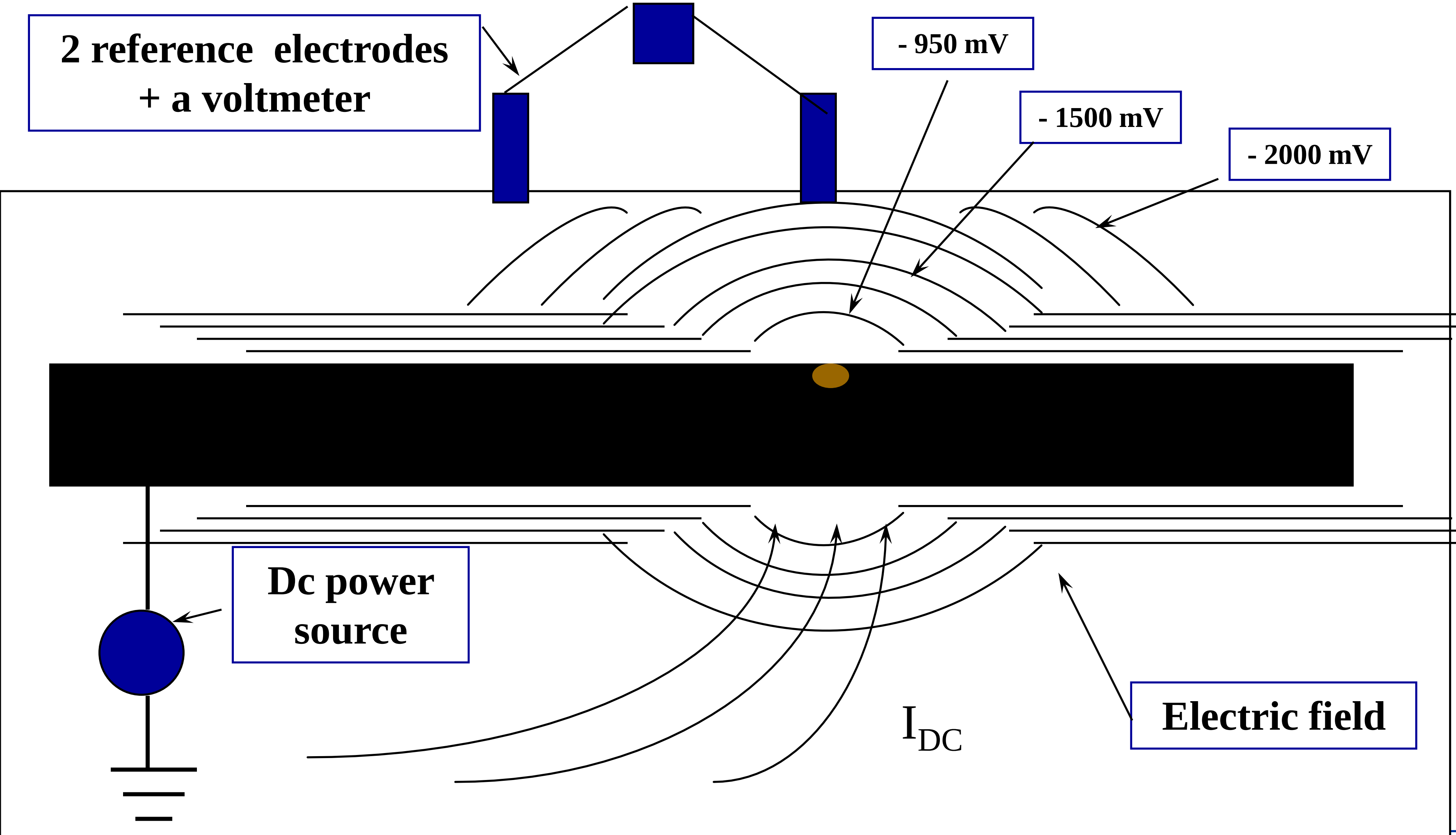
----> Direct Current Voltage Gradient (DCVG)

use of ac currents

----> Pearson (electrical field)

----> Electromagnetic field attenuation

Detection of coating defects:
DCVG (Direct Voltage Current Gradient)



Measurements on offshore structures

- **IR drop error not significant thanks to the low resistivity of seawater**
- **ON potential measurements are OK**
- **periodicity of detailed surveys may be long for galvanic anodes (e.g. every 5 years for jackets, together with general underwater inspection surveys, in addition to annual routine monitoring measurements)**

Measurements on offshore structures

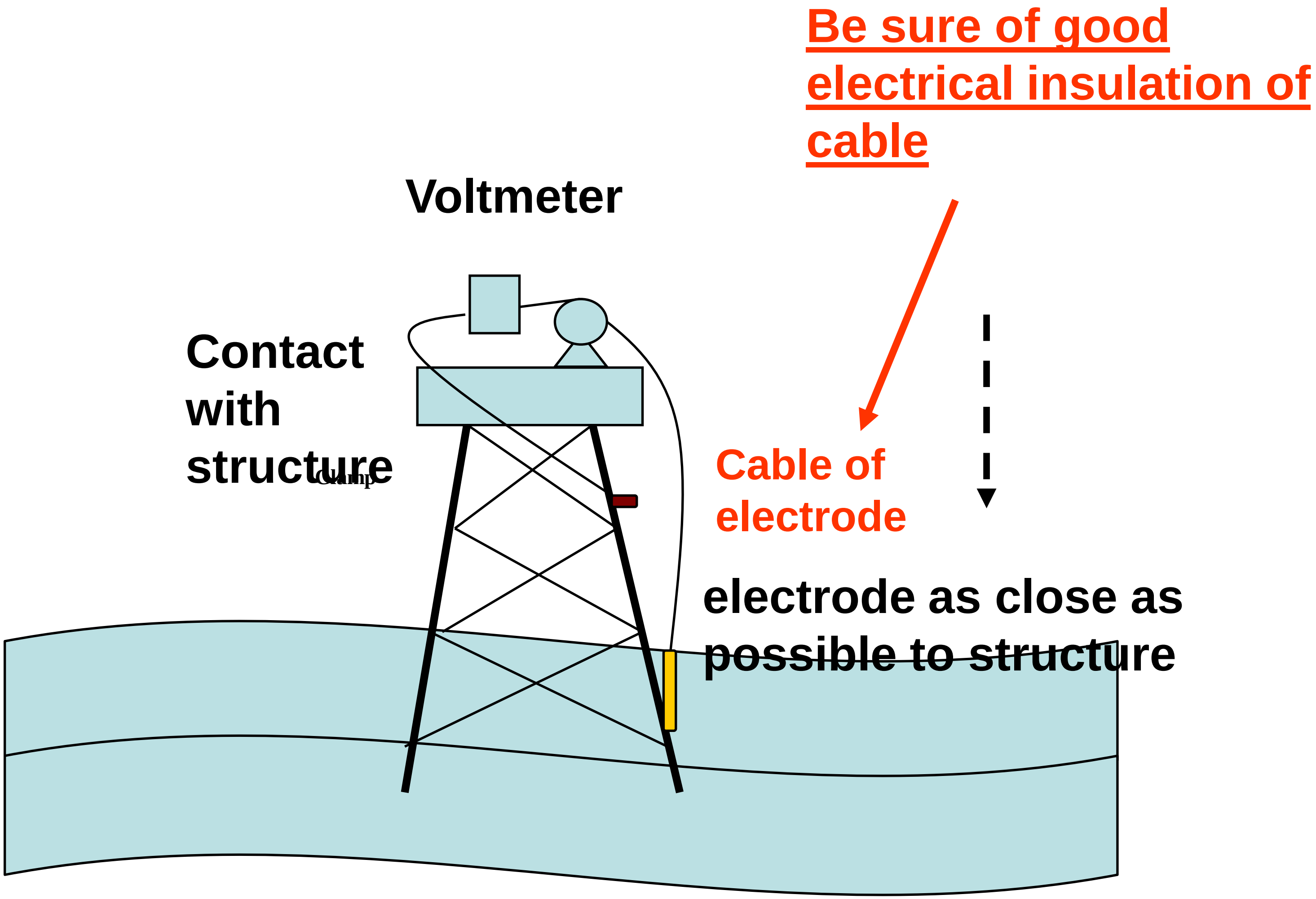
◆ Potential

- measurement electrode (Ag/AgCl/seawater) freely immersed, or moved along a fix support, or moved by diver or ROV.
- Permanent measurement electrode (Zn or Ag/AgCl/seawater), using cable or acoustic transmission.
- Autonomous integrated system operated by diver (”gun")

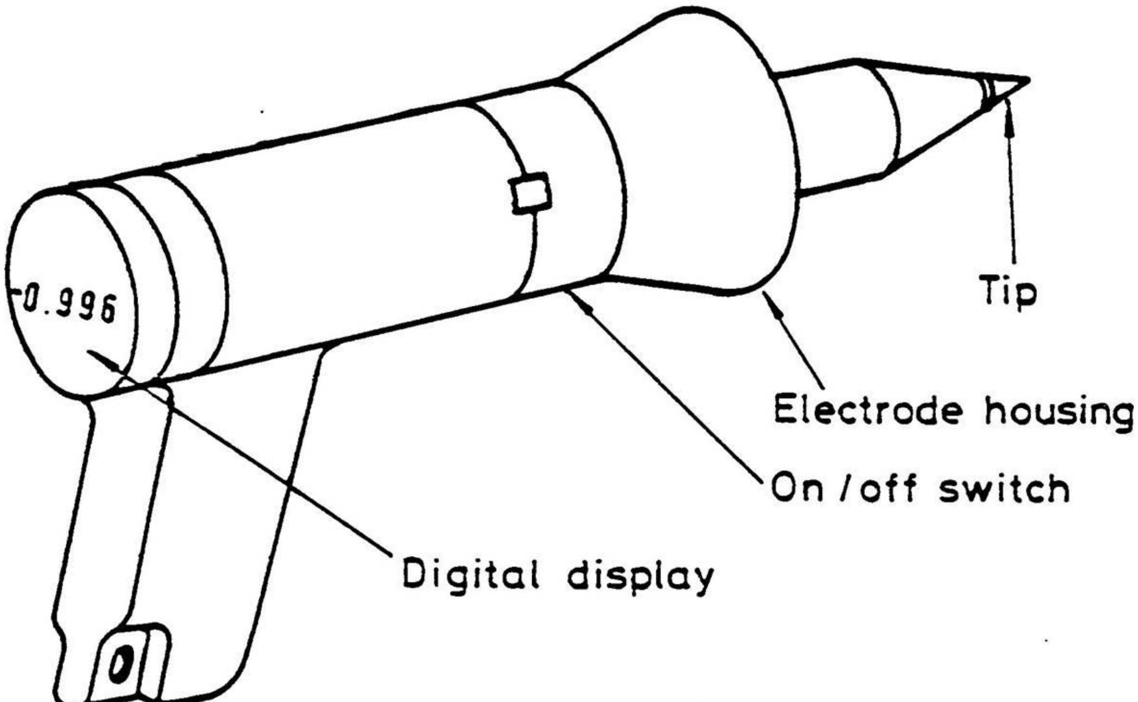
◆ Anode current output

- Instrumented anodes (isolating joints + shunt), using cable or acoustic transmission.
- Underwater amperometric clamp

Potential measurement with a mobile electrode

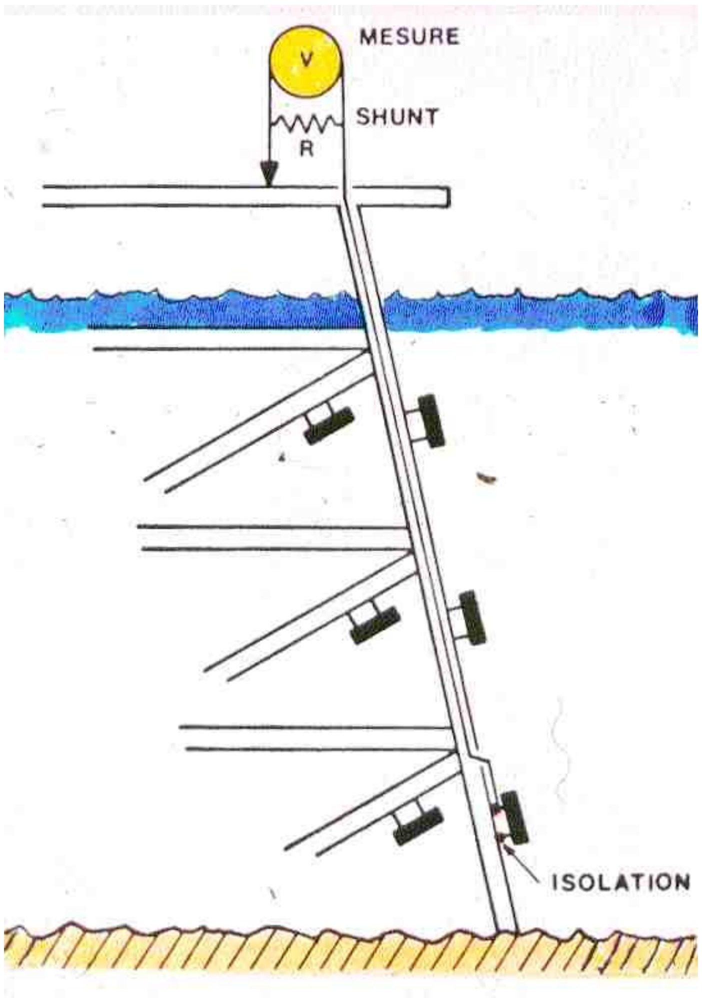


Potential measurement with an autonomous device ("gun")



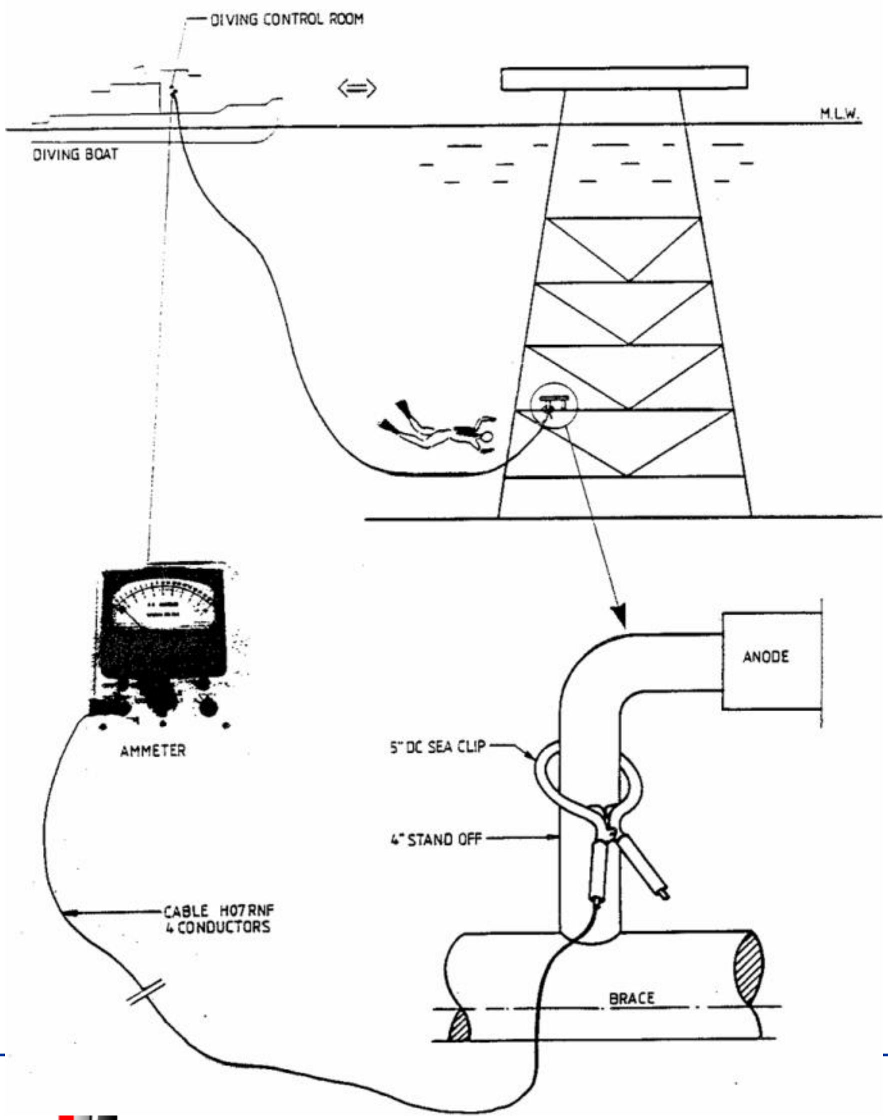
Interesting when metallic contact difficult at the sea surface or even impossible (sub-sea structures) and/or lack of electrical continuity de in structure (e.g.. chains)

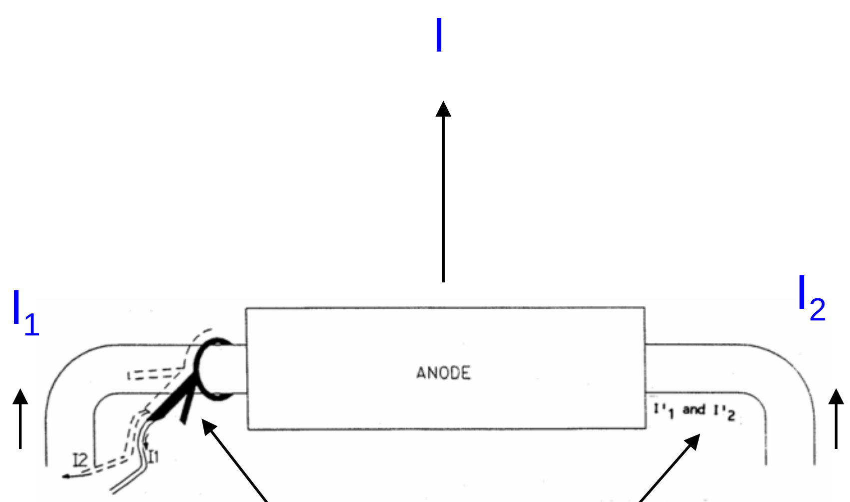
Measurements on offshore structures: current output of anodes



Total Prof

Measurements on offshore structures: Amperometric device



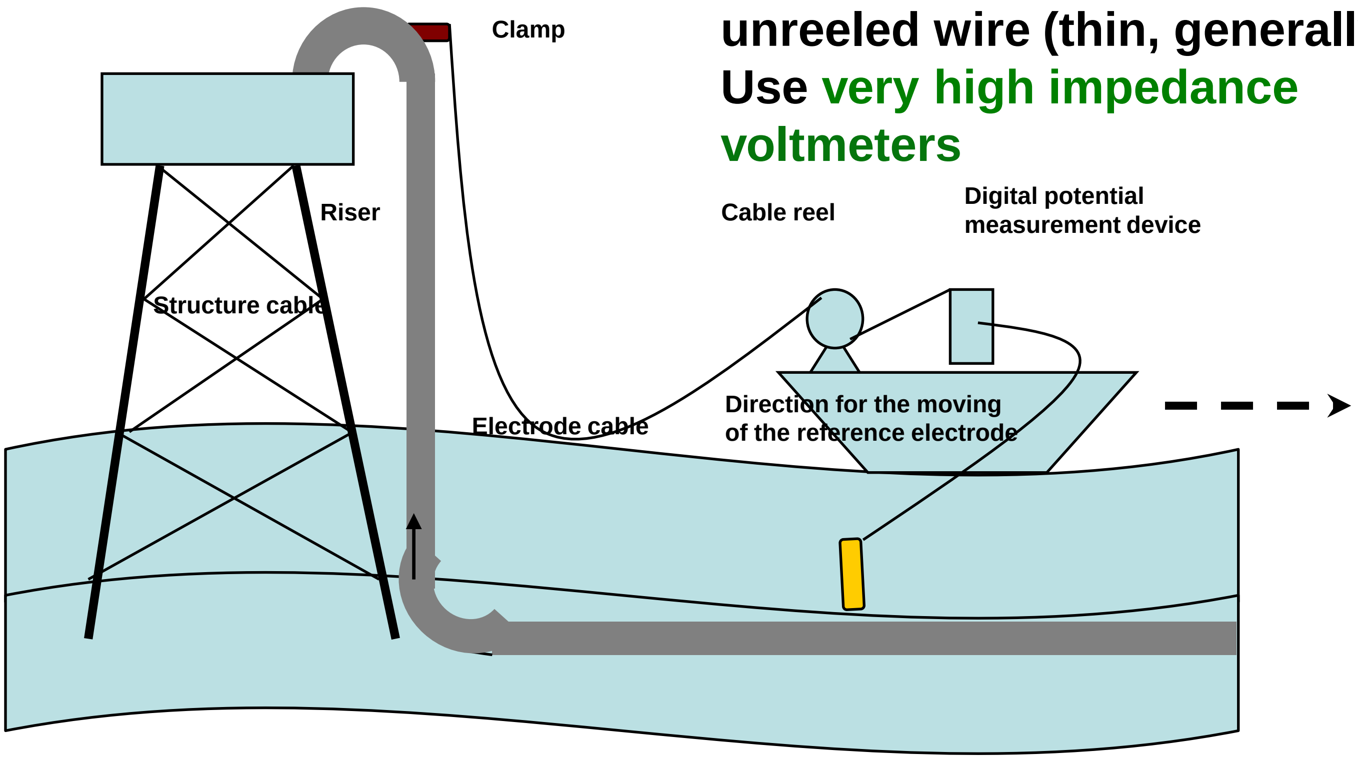


Do not forget to add currents measured in the 2 stand-offs!

$I = I_1 + I_2$

Measurement of potential on offshore pipelines with a moving electrode

Error due to ohmic drop in the unreeled wire (thin, generally lost). Use very high impedance voltmeters

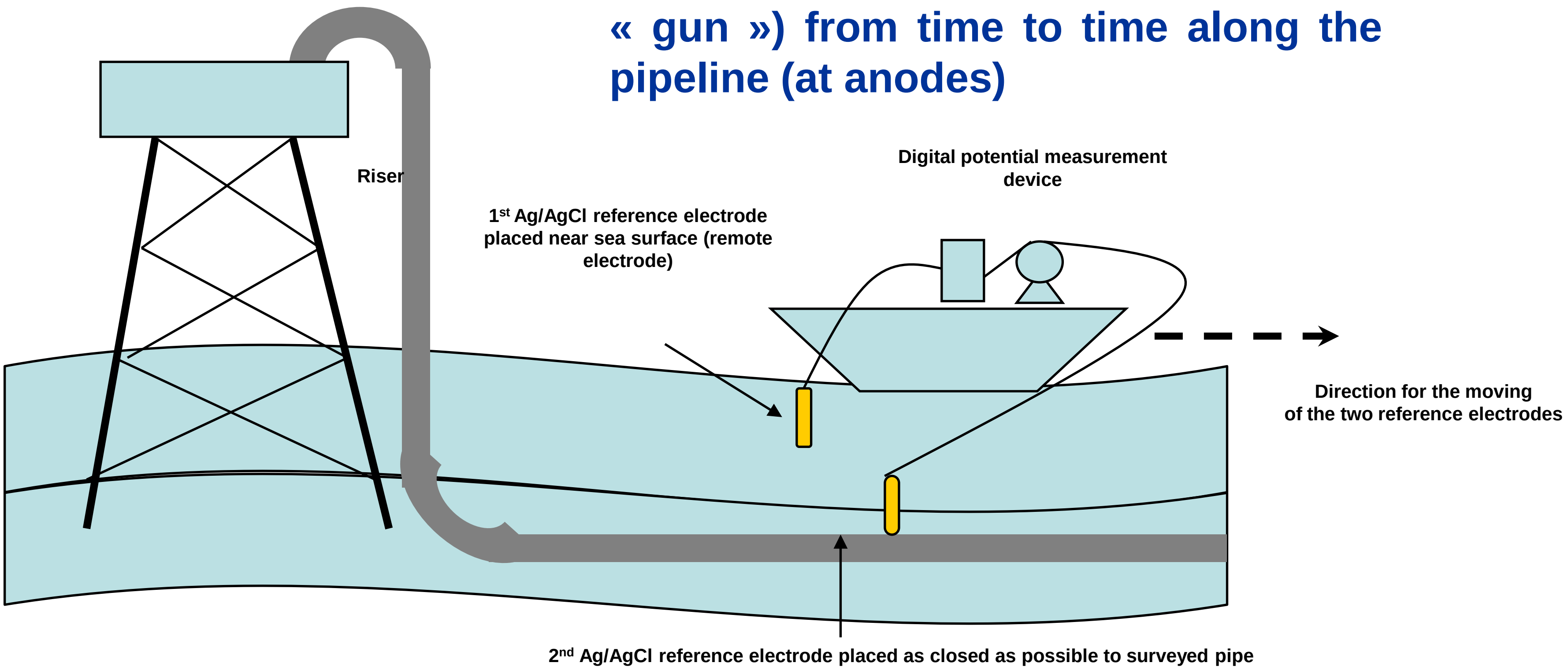


Ag/AgCl reference electrode placed as closed as possible to surveyed pipe

- **Peaks of negative potentials close to active anodes**
- **Peaks of positive potentials near important coating defects**

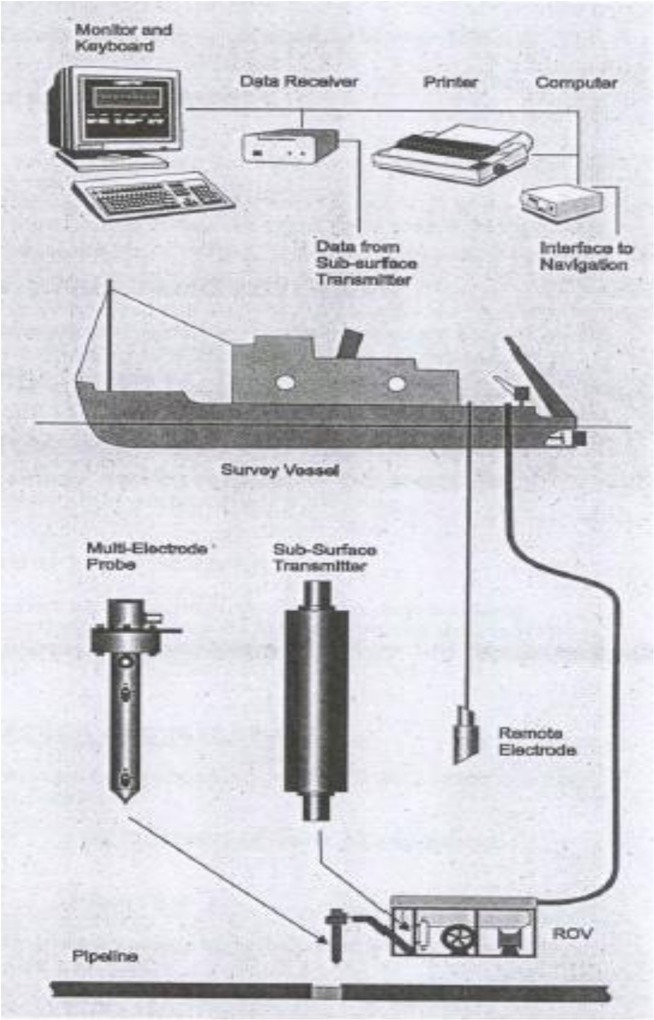
Evaluation of potential on offshore pipelines (remote electrode)

It is necessary to realise potential measurements by direct contact (by « gun ») from time to time along the pipeline (at anodes)



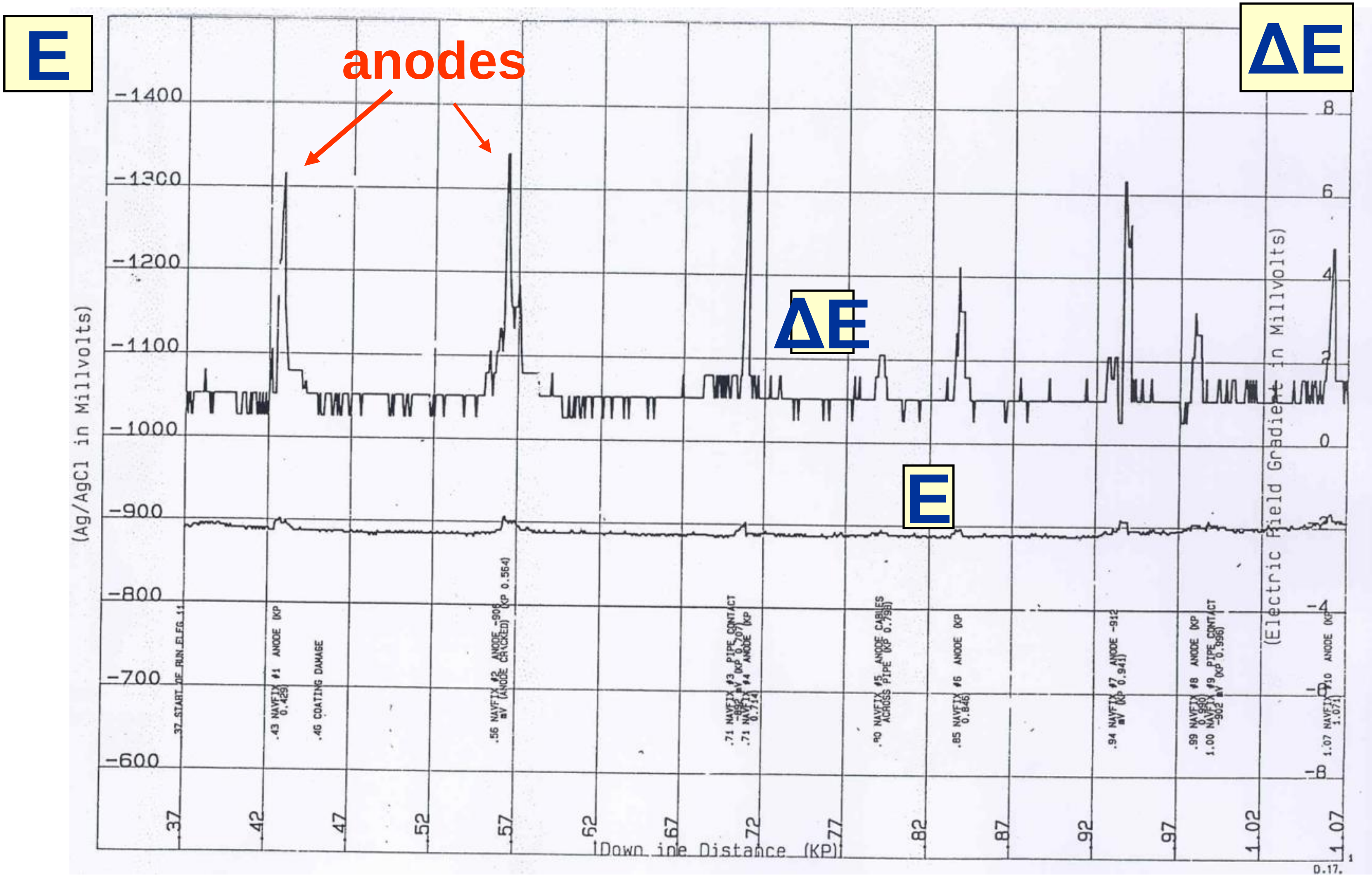
Measurements of potential gradients close to offshore pipelines (multi- electrode probe)

- Close potential gradiant is measured to get better information on electrical field near the pipeline
- Electrodes have to be checked to be at a few mV between them
- Anodic and cathodic peaks appera more clearly
- Possibility of rough evaluation of anode current output



Total Prof

Combined measurements on offshore pipelines



Total Prof

Measurements inside capacities and equipment

- Measurement of CP inside capacities is difficult to perform and often considered as not practicable and even not necessary
- Verification of protection efficiency is often made through the corrosion status during periodical internal inspection visits
- The measure of consumption of galvanic anodes during internal visits is also a way to determine the current need of structure
- There is a need of experience feed-back for improving design calculations

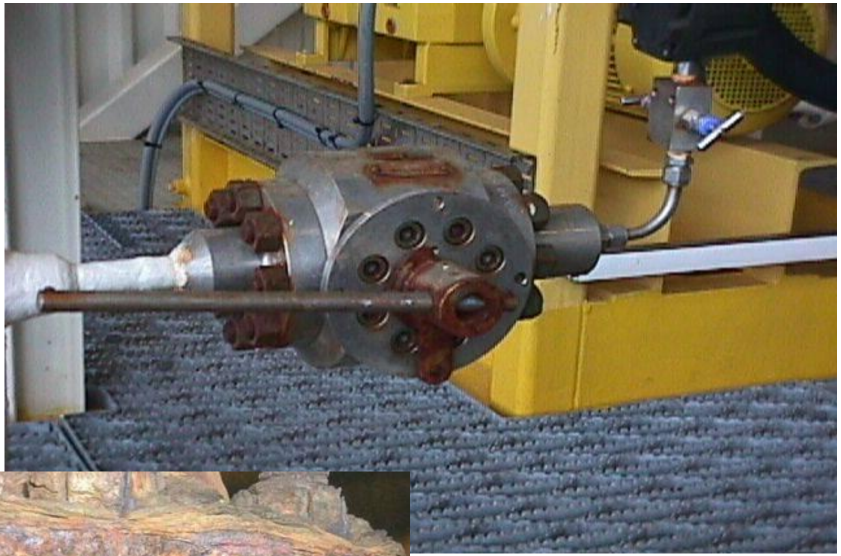
Measurements inside capacities and equipment

In above-ground oil storage tanks, it is possible to measure potential:

- by introducing from a hole in the roof a Ag-AgCl electrode dipped in a non metallic bottle filled with salt water and not tightly closed
- in installing permanent zinc measurement electrodes on the bottom and connected to a connection box fitted outside the tank

Corrosion prevention by paint systems and metallic coatings

Examples of external corrosion

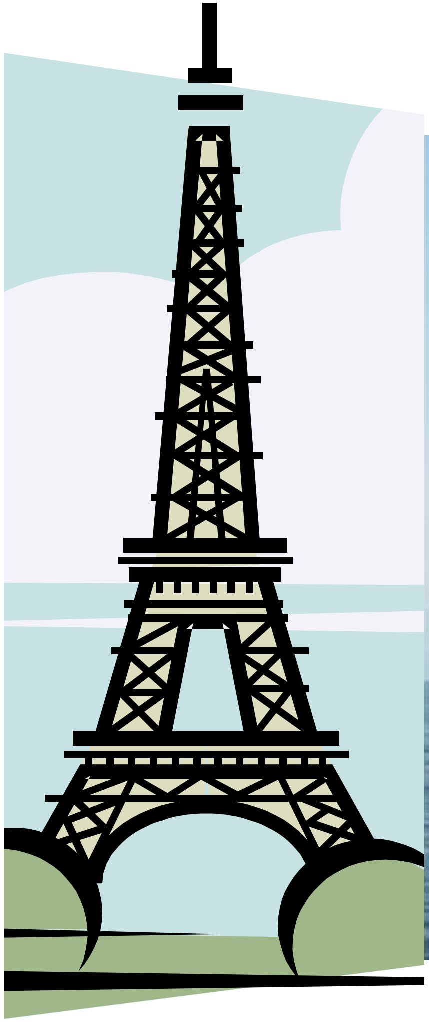


The scale of paint application in E&P: example for a FPSO (deep offshore)

- **For hull:**
  - **56 000 tons of steel, 5,5 x the weight of Eiffel Tower**
  - **140 tons of paints**
  - **1800 inspections of « blocks » before assembling, 3 per day**
  - **Cost of paints: 10% of total cost**
- **For topsides:**
  - **27 000 tons of steel, 2,5 x the weight of Eiffel Tower**
    - **6900 tons of equipement**
    - **5000 tons of pipings**
    - **13 500 tons of structures**
- **Duration for construction: 24 months, the same as for Eiffel Tower**

Total Prof

6 Eiffel Towers…..but more compact!



The challenges of paint systems in EP

- **Expected lifetime:**
  - **Design: 20 to 30 years**
  - **In practice: sometimes > 40 years**
- **Environment:**
  - **Most often, marine C5M atmosphere as per ISO 12944-2 (offshore, coastal areas)**
  - **IM2: for submarine facilities (with cathodic protection)**
  - **Thermal insulation, fire protection, test of deluge systems, important thermal cycles, mechanical impacts…**
  - **Offshore, desert areas, …**
- **Safety and Health: painting works may be dangerous and require a lot of precautions**

General policy for paint systems in EP

- **Use of high durability systems, if possible certified (ACQPA)**
- **Qualified suppliers with worldwide production and logistics**
- **Use of ISO referential and coating contractors and inspectors certified (ACQPA, FROSIO, NACE, …)**
- **Objective of minimum maintenance on facilities in operation, especially for offshore and geographically remote areas:**
  - **New offshore structures:**
    - ✓ *15 years without major maintenance*
    - ✓ *5 years of contractual guaranty co-ensured between supplier and contractor*
  - **Mean periodicity of major maintenance for existing structures: 10 years**

External paints

- A "paint system" is defined including the surface preparation method, which is a highly critical issue: at a minimum Sa2 ½ as per ISO 8501-1
- The system is generally made of several layers:
  - A primer (mainly zinc rich: zinc ethylsilicate for the best durability, zinc epoxy)
  - A sealer
  - One or several tightness layer(s) (mainly epoxy)
  - A finition for UV resistance (PU or acrylic), antifouling, etc.
- Alternative systems are proposed for better applicability and/or durability, generally with less layers
  - End users have to keep in mind that the final objective is proven durability
  - Use accelerated testing for qualification (ISO, NORSOK, NACE)

Examples of coating failures

Examples of coating failures

Good support

Bad support

Corrosion under insulation (CUI)

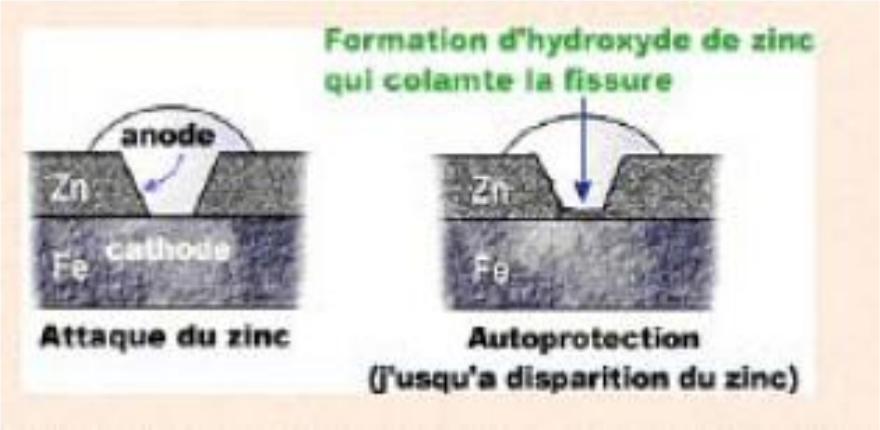
- The major cause of external corrosion in process plants
- Ingress of aerated water under thermal insulation when tightness not achieved or damaged
- Corrosion possible up to 140°C when no coating or a non efficient or damaged coating, increasing with temperature
- Very difficult and expensive to detect and size during inspection campaigns
- USE THERMAL INSULATION ONLY WHEN CLEARLY NECESSARY FOR PROCESS REASONS
- Use other systems (mechanical protection) for personnel protection

Internal flow improvement coating of gas lines

- Flow improvement with "anti-friction" may be useful for long gas transportation pipelines, reducing the consumed energy
- Thin (50 to 150 microns) epoxy internal paint coatings are used
- Girth weld areas are not painted because the cost increase is too high for the foreseen savings
- Deposit problems in valves were encountered on some major pipelines in North Sea due to a bad selection of the paint. Qualification tests should be carried out to prevent this risk

Metallic coatings

- Only anodic materials in aggressive environments. Risk of localised corrosions if cathodic coating damaged
- Zn, Cd and Al are the most frequently used anodic metals for protecting C steels
- Possibility of cathodic protection for cathodic coatings when immersed



Anodic coating

Cathodic coating

Metallic coatings

- **Zinc coatings (galvanizing or electrolytic coating) the most used for atmospheric protection: , stairs, handrails, ladders, gratings, bolts and nuts, etc.**
- **Good general behaviour, including on offshore structures, except in the most exposed areas to chlorides where lifetime may be reduced down to a few years (lower level of platforms, areas with leaks of seawater or heavy condensations)**
- **Short life in seawater especially when flowing**

Metallic coatings

- **TSA (Thermal Spray Aluminium) used in atmospheric zone of offshore structures in areas with difficult access to reduce maintenance works with paint systems**
- **Used also in seawater when cathodic protection is difficult to apply**

Cadmium (bichromated) coatings currently used for temporary protection of bolts and nuts (a few months in marine atmosphere)

Quality, Standardization, Certification, R & D

Quality in corrosion control

- Efficiency of corrosion control depends on quality of design, implementation and monitoring of systems.
- Quality is a result of competence of personnel and service companies.
- Standardisation in CP and coatings, qualification and certification of CP and coating personnel is a way contributing to Quality. It is very active at countries, regions (EN) and international (ISO) levels.
- Standardisation in cathodic protection has been very active since the end of the 1970's at the level of countries (NACE, BSI, DIN, NEN, GOST, DNV, AFNOR, UNI), Regional areas (CEN for Europe, AS) and at the international level (ISO).

EN CP standards (CEN TC 219)

- EN 12473 (2000): General principles of cathodic protection in sea water
- EN 12474 (2001): Cathodic protection for submarine pipelines
- EN 12495 (2000): Cathodic protection for fixed steel offshore structures
- EN 12499 (2003): Internal cathodic protection of metallic structures
- EN 12696 (2000): Cathodic protection of steel in concrete
- EN 12954 (2001): Cathodic protection of buried or immersed metallic structures - General principles and application of pipelines
- EN 13174 (2001): Cathodic protection for harbour installations
- EN 13173 (2001): Cathodic protection for steel offshore floating structures

EN CP standards (CEN TC 219)

- EN 13509 (2003): Cathodic protection measurement techniques
- EN 13636 (2004): Cathodic protection of buried metallic tanks and related piping
- EN 14505 (2005): Cathodic protection of complex structures
- TS 14038-1 (2004): Electrochemical realkalization and chloride extraction treatments for re-enforced concrete – Part 1: Realkalization
- EN 15112 (2006): Cathodic protection of well casing
- TS 15280 (2006): Evaluation of a.c. corrosion likelihood of buried pipelines – Application to cathodically protected pipeline
- EN 15257 (2006): Cathodic protection - Competence levels and certification of cathodic protection personnel

EN CP standards (CEN TC 219)

◆Standards are presently revised:

- EN 12473 (2000): General principles of cathodic protection in sea water
- EN 12696 (2000): Cathodic protection of steel in concrete
- EN 12954 (2001): Cathodic protection of buried or immersed metallic structures - General principles and application of pipelines
- EN 13174 (2001): Cathodic protection for harbour installations

◆Other documents are prepared:

- internal CP in oil & gas equipment
- CP of ships hulls
- sacrificial anodes
- CP of seawater ballasts and other equipment

NACE Standards for CP

- In the USA, NACE issued the first Recommended Practice dealing with CP in 1969 (first NACE RP): RP 01-69, "Control of external corrosion on underground or submerged metallic piping systems". Then a series of RP devoted to CP was issued and updated by NACE

- NACE main standards:
  - RP 0169-96 (onshore), RP 0675 (offshore), RP 0286 (electrical insulation), TM 0497 (measurement techniques), Pipeline ECDA (External Corrosion Direct Assessment) Methodology (RP0502-2002), Use of coupons for CP monitoring applications (RP0104-2004), DCVG (Direct Current Voltage Gradient) surveys, CIPS (Close-Interval Potential Surveys) including "Hybrid" methods, Report on 100 mV CP criterion

ISO Standards for CP

- For International Standardisation, ISO TC 156 devoted to Corrosion created WG 10 for CP a long time ago but no standard has been issued yet. Possible fast track votes for adoption of some EN standards as basis for future ISO standards

- ISO TC67 (Oil & Gas) published ISO 13623 in 2000, devoted to pipelines and addressing CP (now on revision process), followed by a specific standard for CP of pipelines in 2004: ISO 15589- Part 1 (onshore) and Part 2 (offshore)

International Standardisation in Pipeline Coatings

- **Most used existing National Standards**
  - for 3LPE: NF A49-710, DIN 30670, CAN/CSA - Z245 20-M92, AS/NZS 1518: 2002
  - for 3LPP: NF A49-711 and DIN 30676
  - for FBE: CAN/CSA - Z245 20-M92, AS/NZS 3862: 2002
  - for FJC: NF A49-716
- **European Standards**
  - for 2LPE: EN 10288
  - for FJC: EN 10329 to be published soon
- **NACE Recommended Practices**
  - RP 0394-94 (plant-applied FBE), RP 0402 (field joint FBE)
- **DNV Recommended Practices**
  - for plant coatings: RP- F106
  - for FJC: RP- F109

ISO TC 67 standards for pipelines coatings

- **ISO 21809 Petroleum and natural gas industries – External coatings for buried or submerged pipelines used in pipeline transportation systems**

- **Documents published:**
  - **Part 2: Fusion Bonded Epoxy Coatings**
  - **Part 3: Field Joint Coatings**

- **Document to be published later:**
  - **Part 1: Polyolefin coatings (3-layer PE and 3-layer PP)**
  - **Part 4: Polyolefin Coatings (2 Layer Polyethylene)**
  - **Part 5: Concrete weight coatings**

Progress in Certification

- It became progressively obvious that **third-party verification of competence of CP personnel or companies** was necessary for contributing to ensure quality of design, implementation and control of CP systems

- In the **USA, NACE** introduced a general "Accreditation Program" for 4 levels in Corrosion in **1971**. "Corrosion Professional Recognition Program" devoted to **CP in 1987**. The system **"NACE CP Training and Certification Program"** was put in operation in **2000**. Since 2004, **4-levels** (1=CP Tester, 2=CP Technician, 3= CP Technologist, 4=CP Specialist), no specific sectors

Progress in Certification

- The oldest (1976) European Certification system for CP companies for buried gas or water pipes and tanks, based on evaluation by a Committee of experts, is being operated in Germany by DVGW and specified by Merkblatt GW11. 50 companies are certified today
- In France, CFPC was launched by CEFRACOR in 1996 and mandated by AFNOR for attribution of "AFNOR Competence" certificates in 1998 for CP personnel in application of NF A05-690 and 691 (3 levels, 4 application sectors). 260 certificates attributed today. In addition, NF A05-800 on services in CP has be published in 2006
- Other certification schemes exist in Italy, UK, Netherlands

Total Prof

Progress in Certification

- EN 15257 "Competence levels and certification of cathodic protection personnel", issued in Dec. 2006, defines a "framework" allowing national Certification Bodies to operate with equivalence of levels
- 3 levels of competence and 4 possible Application Sectors (Land applications, Marine, Concrete and Internal of apparatuses) are defined
- Common acceptance criteria for candidates based on initial education and practical experience
- Training mandatory but defined by Certification Bodies
- Agreement of Examination and Training Centres
- Validity period of certificate: 5 years

Certification in coatings

- NACE system active since a long time (3 levels)
- ICor system working in UK
- FROSIO system working for Coating Inspectors in Norway
- ACQPA system in France for certification of paint coating systems, certification of coating operatives and Certification of Coating Inspectors in application of equivalence FROSIO

Main concerns requiring R&D activities

- Increasing requirement for integrity and availability ➔ How to limit the use of Corrosion Resistant Materials, which are expensive:
  - Clarify / extend limits of use of CRAs ➔ Avoid over-design
  - Extend limits of use of inhibitors (temperature, multi-functional)
- Inhibition of multiphase sour gas pipelines
  - Managing corrosion in HP acid gas re-injection networks
- Increasing inhibitor performance and areas of application
  - High temperatures
  - Environmental impact of inhibitors (ecotoxicity, water de-oiling…)
  - Understanding / using both negative and positive effects of oil wetting

Main concerns requiring R&D activities

- **Degradation by sand (mature fields, deep sea…)**
  - Erosion prediction. Sand and erosion monitoring.
  - Typically a transverse topic. Efforts to be increased in 2006.
- **Increasing production from "sour" fields (with H_2S)**
- **Fields with traces of H_2S (initial or during service life)**
  - Extend limit of use of "non sour materials"
  - Predict and control "reservoir souring"
- **Long term failures of pipeline coatings**
  - Identify the main involved phenomena,
  - Improve performance of present coatings or select others.
  - Qualify new coatings, particularly for HT applications.
- **Steam Activation:** Corrosion impact on the production side

Corrosion Management in the Oil & Gas Industry

End of Part 4