Aberdeen Branch

Key Sponsor

ICORR ABERDEEN BRANCH WELCOMES ABERDEEN FOUNDRIES

INSTITUTE OF CORROSION

Aberdeen Branch

SHERWIN-WILLIAMS.
Protective & Marine Coatings

Key Sponsor

ABERDEEN FOUNDRIES

1976 - 1998- 2017

SACRIFICIAL ANODES AND NON FERROUS CASTINGS

SCOTLAND -> THE WORLD

Aberdeen Branch

Key Sponsor

Nigel Owen

Aberdeen Foundries

Aberdeen Branch

Key Sponsor

Dr. Nigel Owen. B.Sc., D.I.C, Ph.D, MIMMM.

B.Sc. Metallurgical Engineering and Ph.D Materials.
Professional Member of Institute Metals: MIMMM & Member Inst. Corrosion.

After completing Degrees worked in the Aluminium Industry for over 35 years:
RTZ Australia & USA - R & D of Cast and Rolled Aluminium products and Smelter waste recycling in New Zealand.

Worked as a Materials Consultant and in the Galvanising industry before joining Aberdeen Foundries as Sales, Technical and Plant Manager.

At the Aberdeen Foundry he is in charge of manufacturing, testing and technical specification of Subsea and marine sacrificial anode systems.

Aberdeen Branch

Key Sponsor

Corrosion Mitigation by Cathodic Protection

Scope

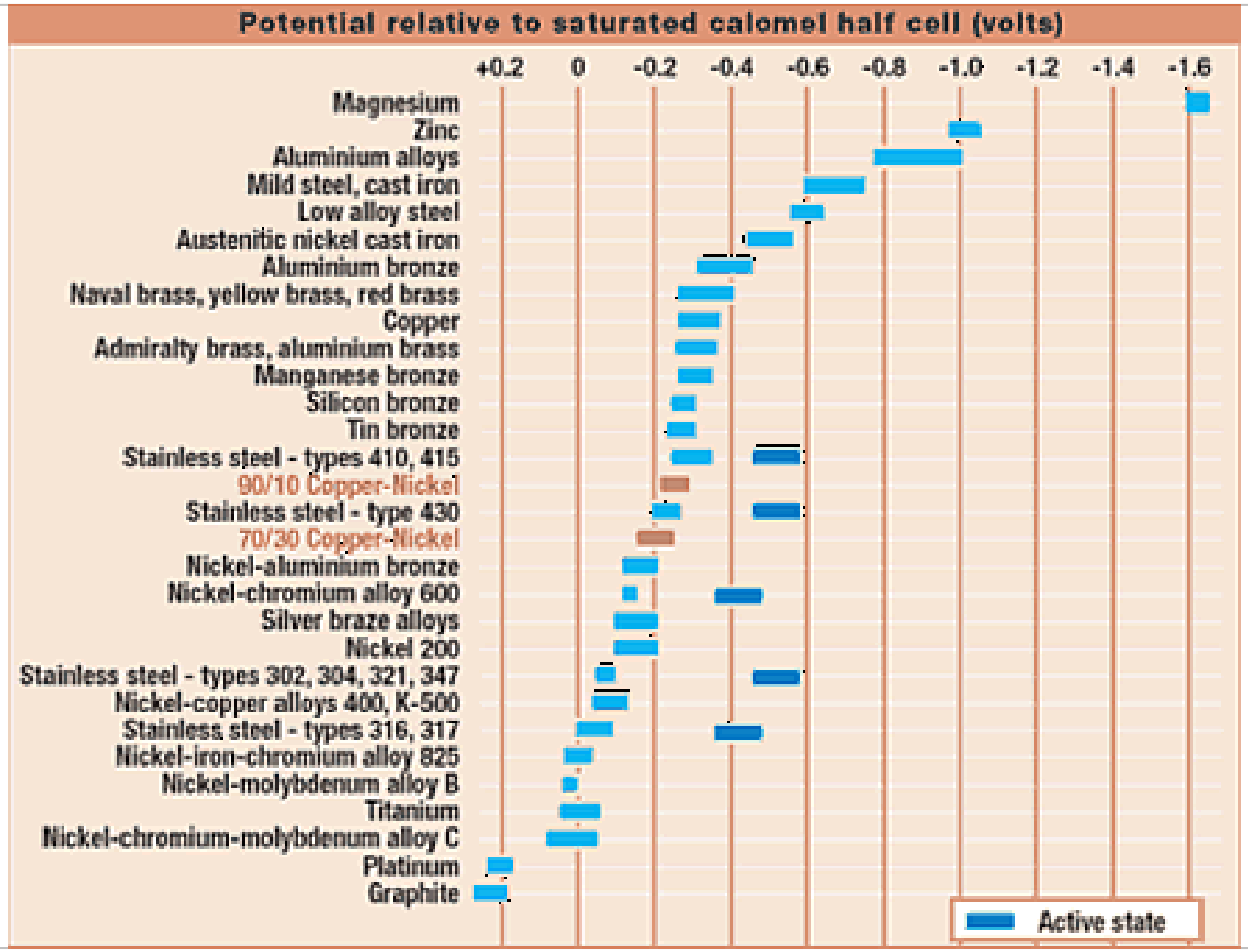
CORROSION MITIGATION BY CATHODIC PROTECTION

- Galvanic System
- Materials for Sacrificial Anode Systems
- Manufacture and & Testing of sacrificial anodes
- Designing of a CP system to protect a structure
- Applications of Sacrificial Anodes
- The selection of the CP system: pros and cons of sacrificial and Impressed current
- Impressed current applications

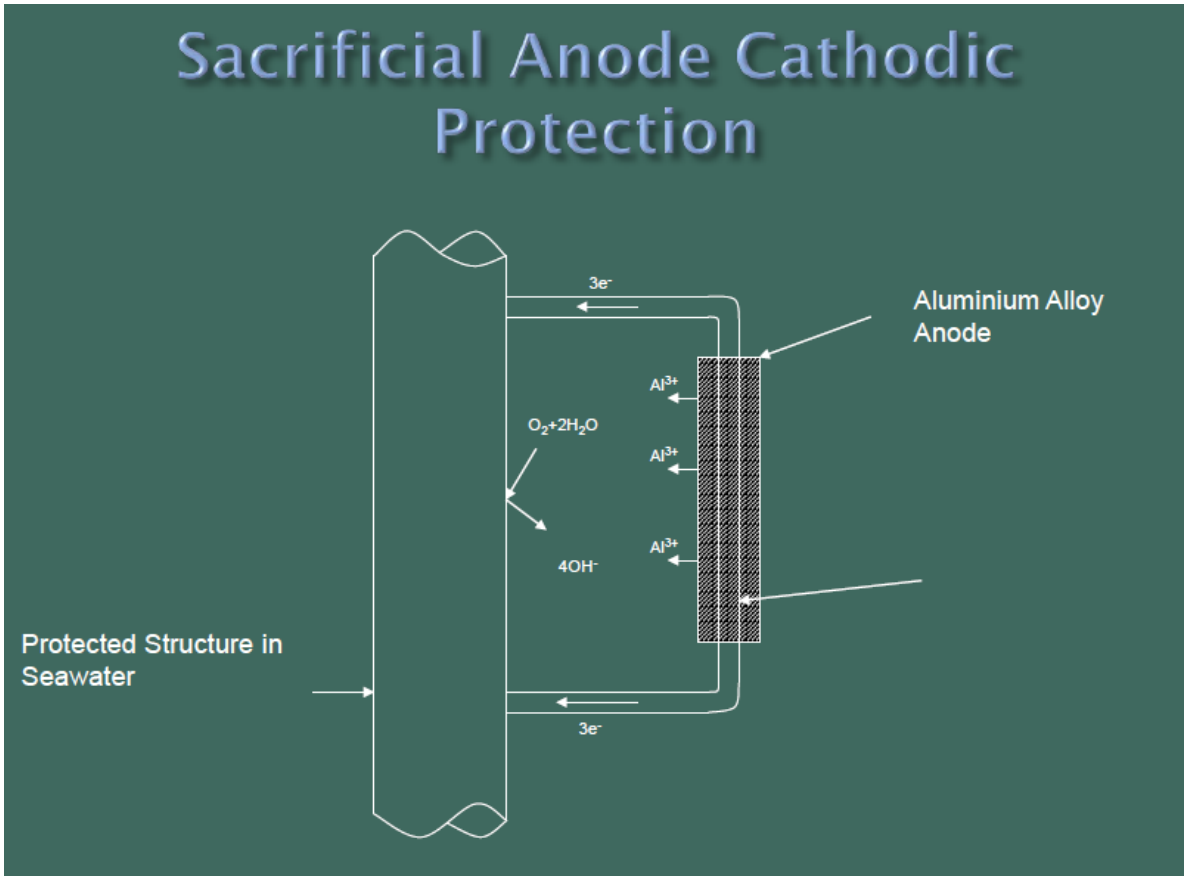
To Mitigate Corrosion by Cathodic Protection

•Means by imposing a current on the item of interest which will halt or reduce the corrosion level to one which is insignificant
•How?

•Either by:
• utilising the galvanic properties of 2 dis-similar metals when joined together in a conductive medium (Anode/Cathode)
or
•Imposing a current using an electrical system (Impressed Current) to achieve similar


Potential relative to saturated calomel half cell (volts)
+0.2
0
-0.2
-0.4
-0.6
-0.8
-1.0
-1.2
-1.4
-1.6
Magnesium
Zinc
Aluminium alloys
Mild steel, cast iron
Low alloy steel
Austenitic nickel cast iron
Aluminium bronze
Naval brass, yellow brass, red brass
Copper
Admiralty brass, aluminium brass
Manganese bronze
Silicon bronze
Tin bronze
Stainless steel - types 410, 415
90/10 Copper-Nickel
Stainless steel - type 430
70/30 Copper-Nickel
Nickel-aluminium bronze
Nickel-chromium alloy 600
Silver braze alloys
Nickel 200
Stainless steel - types 302, 304, 321, 347
Nickel-copper alloys 400, K-500
Stainless steel - types 316, 317
Nickel-iron-chromium alloy 825
Nickel-molybdenum alloy B
Titanium
Nickel-chromium-molybdenum alloy C
Platinum
Graphite
Active state

Sacrificial Anode System



Primary Requirements for Sacrificial Anode - Reasons for Selection

What makes the best anode material?

- Potential sufficiently electronegative – Galvanic Table vs you coupled material (driving potential)
- Temperature and Conductivity (salinity)
- High current output per Kg consumed
- Low Metal Cost (Amps per Kg)

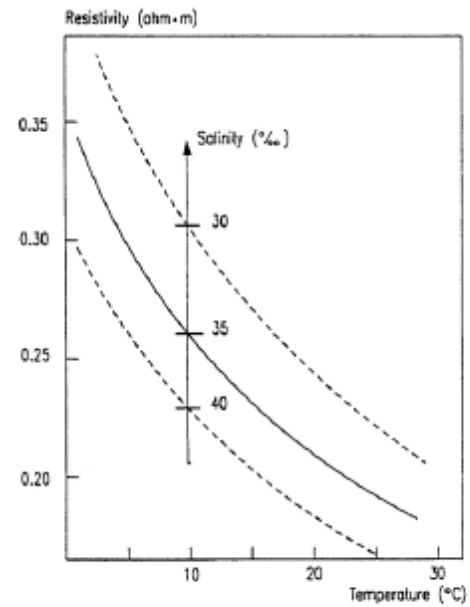


Figure 10-1
Seawater resistivity as a function of temperature for salinity 30 to 40 ‰.

Sacrificial Anode Material Types

- Magnesium
  - High Potential, low life, Fresh water (5-150 ohm. m) , High cost/Kg
- Zinc
  - Low capacity/ Kg (800), Limited Temp (50 ° C), water to 30 ohm. m
- Aluminium
  - High Capacity/Kg (2500), High Temp (80-100 ° C), water to 10 ohm. m

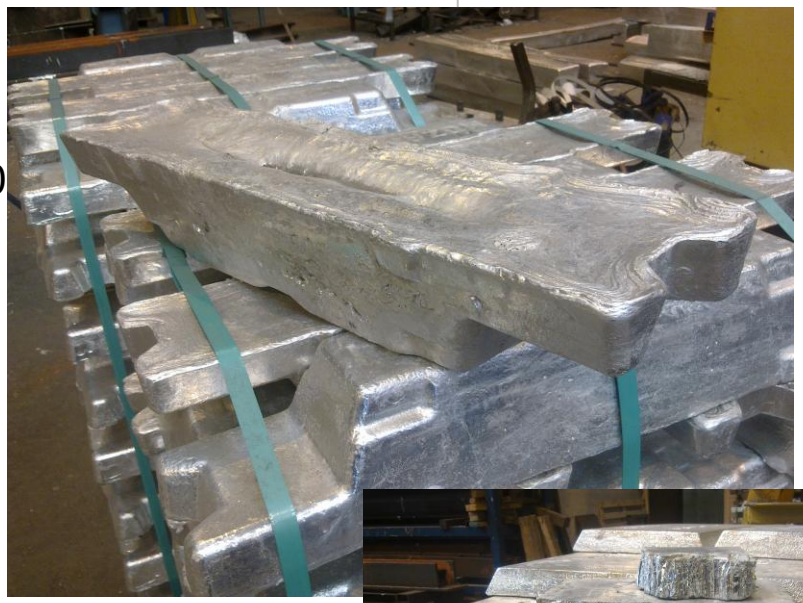
Primary Requirements for Sacrificial Anode - Reasons for Selection

– Al-Zn-In Alloy Galvallum III Composition

Al-Zn-In Anode Alloy								
	Element	**Al**	**Zn**	**Si**	**In**	**Cu**	**Fe**	**Others**
Wt%	**Min**	**Bal**	**2.8**	**0.08**	**0.010**	**0.000**	**0.00**	
Wt%	**Max**	**Bal**	**6.5**	**0.21**	**0.020**	**0.006**	**0.12**	**<0.02**
Wt%	Nom	Bal	**5.0**	**0.09**	**0.018**	**0.001**	**0.06**	<0.02

Typical Performance:
Nominal closed circuit anode potential -1050 (mV relative to. Ag/AgCl/seawater),
Short term test Capacity Ampere hours <2500 Amp. Hr/ Kg
Density Nominally 2750kg/m^3

- Al-Zn-In Alloying -Base metals
  - Al (99.85%min)
    - Fe, Cu, Ga, Sn
    - Ingot Spec PO610
  - Zn (99.99%)
    - Fe, Cu, Pb, Sn
    - Ingot SHG
  - Indium
    - 99.99%
  - Si (Al-Si) -hardener

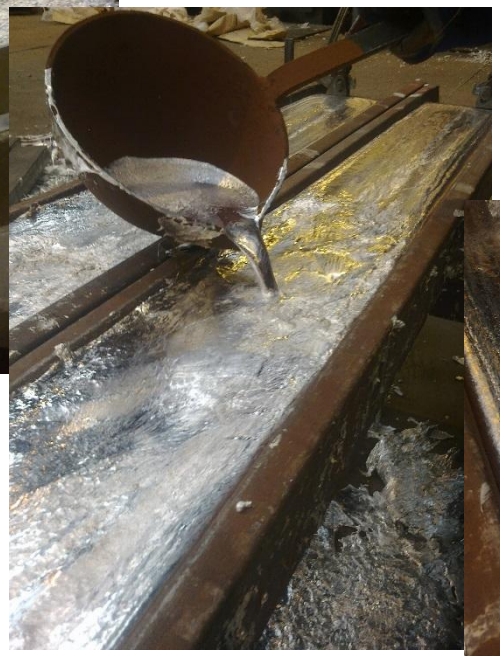


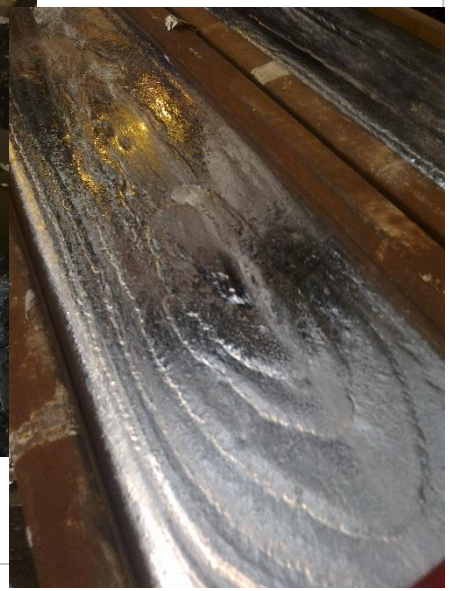
Manufacturing

- Heat melt – Alloy constituents
- Prepare and manufacture steel inser
- Select & Assemble mould
- Test melt and approve*
- Cast into mould and top up
- Fettle /tidy
- Mark identification on anode

*Melt sample Test piece OES

Melting, Pouring & Finishing

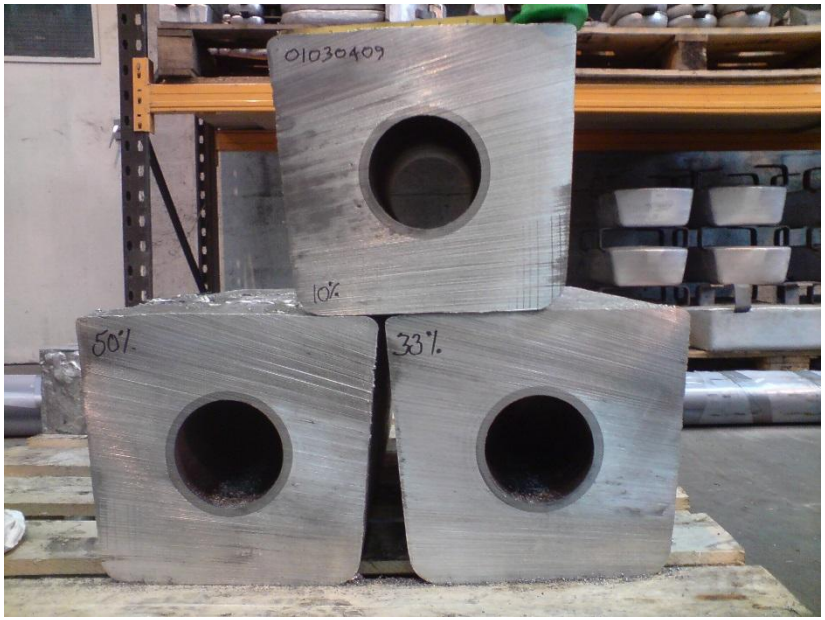


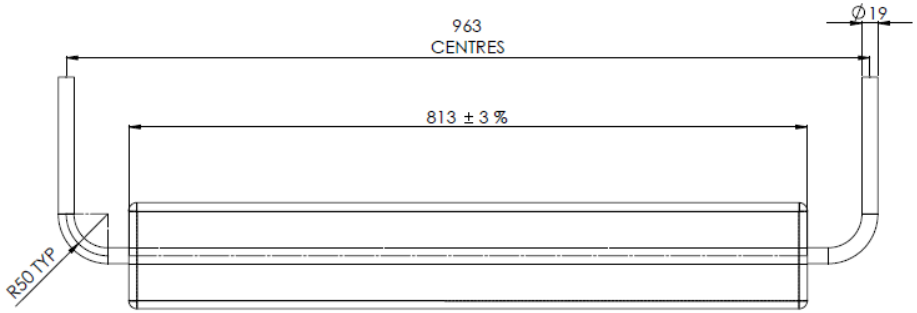


- Melt Base Metal
- Zinc Additions
- Indium Additions
- Add balance of Silicon
- Heat to Molten, stir, prepare
- Sample and Test
  - Spectrometry OES
- Pour

Testing of Anodes

- Composition
- Dimensions (body/insert)
- Cracks / sinks/ finish
- Integrity (porosity/Holes)*
- Insert position
- Shape (straightness/Fit)
- Electrical Continuity
- Electrochemical test





Electrochemical Testing

Secondary test

DNV

–1 test per 15 Tonnes production

importance?

Comparative Test

Set temp

Accelerated (x 20 current density)

cannot be used as test of field condition performance

Reliability

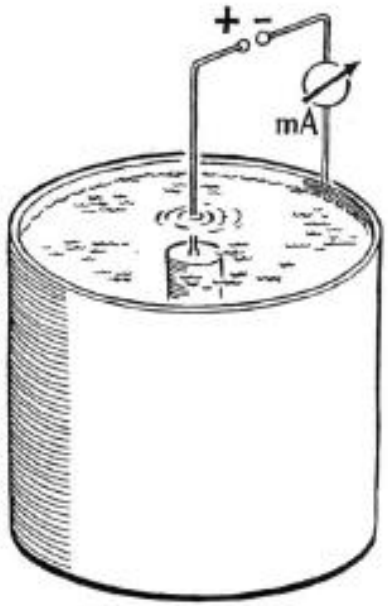
Subject to debate – sampling

Multiple test methods

Redundant

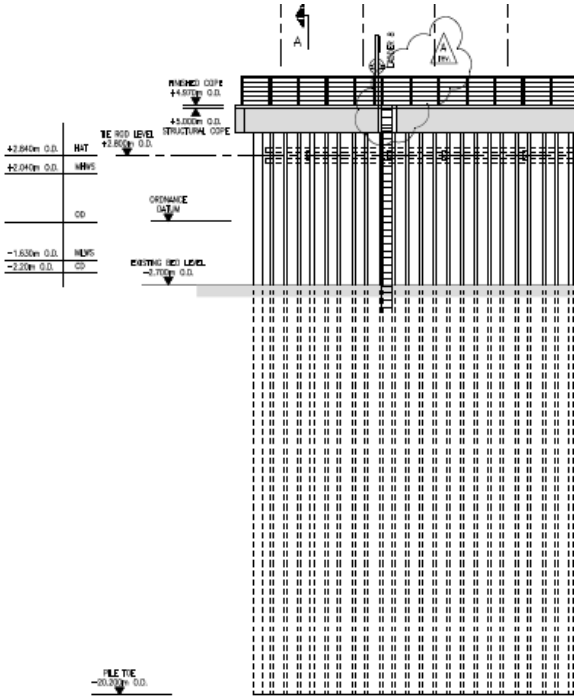
Totally Composition dependant

Unrealistic sampling and accelerated paramete



Example of a project to Design install a Sacrificial CP system

- Harbour wall CP protection system



System Parameters

- Design Life : Years or months
- Areas of the materials
  - Bare, Painted & immersed in mud
  - Type of materials.
  - All those conductive and have continuity to the main unit
- Design Current Densities
  - Initial mean and final (for bare surfaces)
    affected by Geographic region and depth
  - Coating Breakdown factors (discounts for coating integrity)
- Resistivity of Medium in which they are immersed: Seawater,
  Estuarine/River waters soils & muds/ sediment

Design Solution

- Select sacrificial anode material (Al, Zn or Mg base)
  Material has properties of Amp Hr/ Kg and Potential

- Multiply areas of materials and Current density required with coating factors –
  Calculate mean current Demand
  Then calculate the Mean mass requirement for system design life

7.7 Anode Mass Calculations

7.7.1 The total net anode mass, M_a (kg), required to maintain cathodic protection throughout the design life, t_f (yrs), is to be calculated from I_{cm} (A) for each unit of the protection object (including any current drain):

$$M_a = \frac{I_{cm} \cdot t_f \cdot 8760}{u \cdot \varepsilon} \qquad (2)$$

In (2), 8760 refers to hours per year. u and ε (Ah /kg) are to be selected based on (6.8) and (6.5), respectively.

ANODE MATERIAL DESIGN PROPERTIES

Anode type	Anode surface temperature[a]	Immersed in seawater		Buried in seawater sediments[d]	
		Potential	Electrochemical capacity	Potential	Electrochemical capacity
		Ag/AgCl/ seawater	ε	Ag/AgCl/ seawater	ε
	°C	mV	A·h/kg	mV	A·h/kg
Aluminium	< 30	− 1 050	2 000	− 1 000	1 500
	60	− 1 050	1 500	− 1 000	800
	80[b]	− 1 000	900	− 1 000	400
Zinc	< 30	− 1 030	780	− 980	750
	> 30 to 50[c]			− 980	580

Electrochemical capacity for a given alloy is a function of temperature and anode current density. Reference is made to Annex A for guidance on CP design for variations in anode current densities.

For non-buried pipelines, the anode surface temperature should be taken as the external pipeline temperature and not the internal fluid temperature. For buried pipelines, the anode surface temperature shall be taken as the internal fluid temperature.

[a] For anode surface temperatures between the limits stated, the electrochemical capacity shall be interpolated.

[b] For aluminium anodes, the anode surface temperature shall not exceed 80 °C unless the performance has been demonstrated in tests and has been documented.

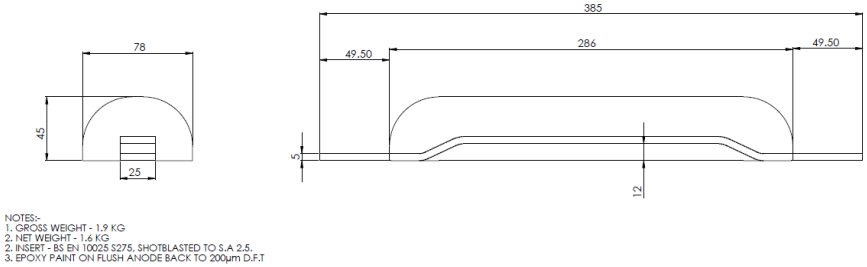
[c] For zinc anodes, the anode surface temperature shall not exceed 50 °C unless satisfactory performance has been demonstrated in tests and has been documented.

[d] Pipelines which are rock-dumped shall be considered as buried in seawater sediments.

Anode Type solution

•Decide Type of anodes that can be fitted or will be most practical to fit (Flush fit, Standoff Type , Long or Short, Bracelet?)
•Estimate number, distribution of anodes (spacing/coverage) and anode mount type (position/utilisation factor)
•Proceed with Design

•Calculate anode resistance from shape & mount type
•Check the initial and final current output of the anode types meets the given required current for polarisation and final life



$$C_{a\,tot} = N \cdot C_a \geq I_{cm} \cdot t_f \cdot 8760$$
$$I_{a\,tot\,i} = N \cdot I_{ai} \geq I_{ci}$$
$$I_{a\,tot\,f} = N \cdot I_{af} \geq I_{cf}$$

Design Parameters – Anode Resistance for Shape Utilisation Factor

- Recommended Practice DNV-RP-B401, October 2010
  Page 24

Table 10-7 Recommended Anode Resistance Formulae for CP Design Calculations.

Anode Type	*Resistance Formula*
Long slender stand-off [1) 2)] $L \geq 4r$	$R_a = \frac{\rho}{2 \cdot \pi \cdot L}\left(\ln\frac{4 \cdot L}{r} - 1\right)$
Short slender stand-off [1) 2)] $L < 4r$	$R_a = \frac{\rho}{2 \cdot \pi \cdot L}\left[\ln\left\{\frac{2L}{r}\left(1+\sqrt{1+\left(\frac{r}{2L}\right)^2}\right)\right\} + \frac{r}{2L} - \sqrt{1+\left(\frac{r}{2L}\right)^2}\right]$
Long flush mounted [2)] $L \geq 4 \cdot$ width and $L \geq 4 \cdot$ thickness	$R_a = \frac{\rho}{2 \cdot S}$
Short flush-mounted, bracelet and other types	$R_a = \frac{0.315 \cdot \rho}{\sqrt{A}}$

1) The equation is valid for anodes with minimum distance 0.30 m from protection object. For anode-to-object distance less than 0.30 m but minimum 0.15 m the same equation may be applied with a correction factor of 1.3

2) For non-cylindrical anodes: $r = c / 2\pi$ where c (m) is the anode cross sectional periphery

Table 10-8 Recommended Anode Utilisation Factors for CP Design Calculations.

Anode Type	*Anode Utilisation Factor*
Long slender stand-off $L \geq 4r$	0.90
Short slender stand-off $L < 4r$	0.85
Long flush mounted $L \geq 4$ width and $L \geq 4$ thickness	0.85
Short flush-mounted, bracelet and other types	0.80

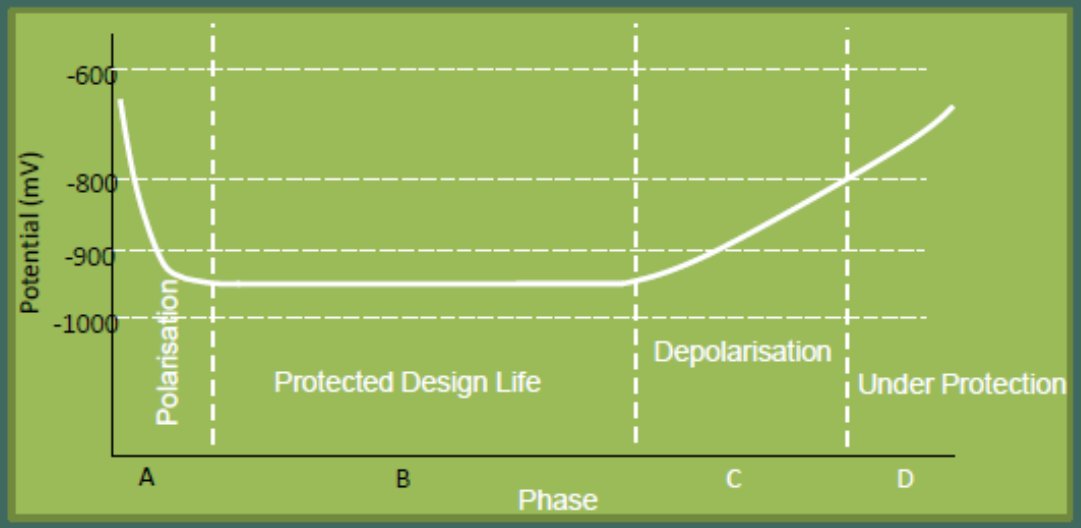
Design Parameters – Anode Resistance for given Shape & Utilisation

- Flush Fit
  - Hull Long flush (UT=0.85)
  - curved segments, Bracelets Short Flush (UT= 0.8)
- Standoff
  - Long & Slender (UT=0.9)
  - Massive

Design of Cathodic Protection system

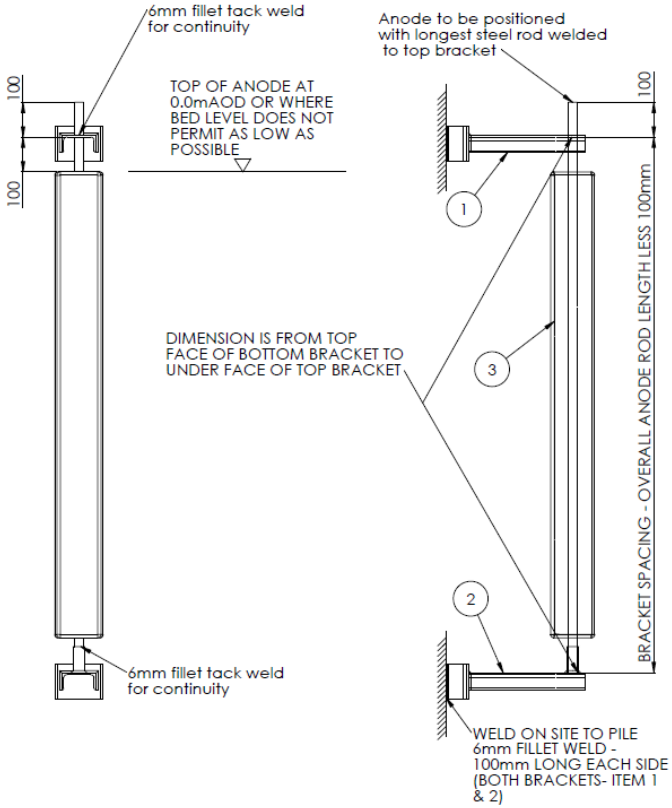
The aim of the CP design is to polarise the structure (period A) as quickly as possible and maintain the protection (period B) for the design life.

When depolarisation (period C) starts the CP system has reached its design life and leads to under protection (period D).

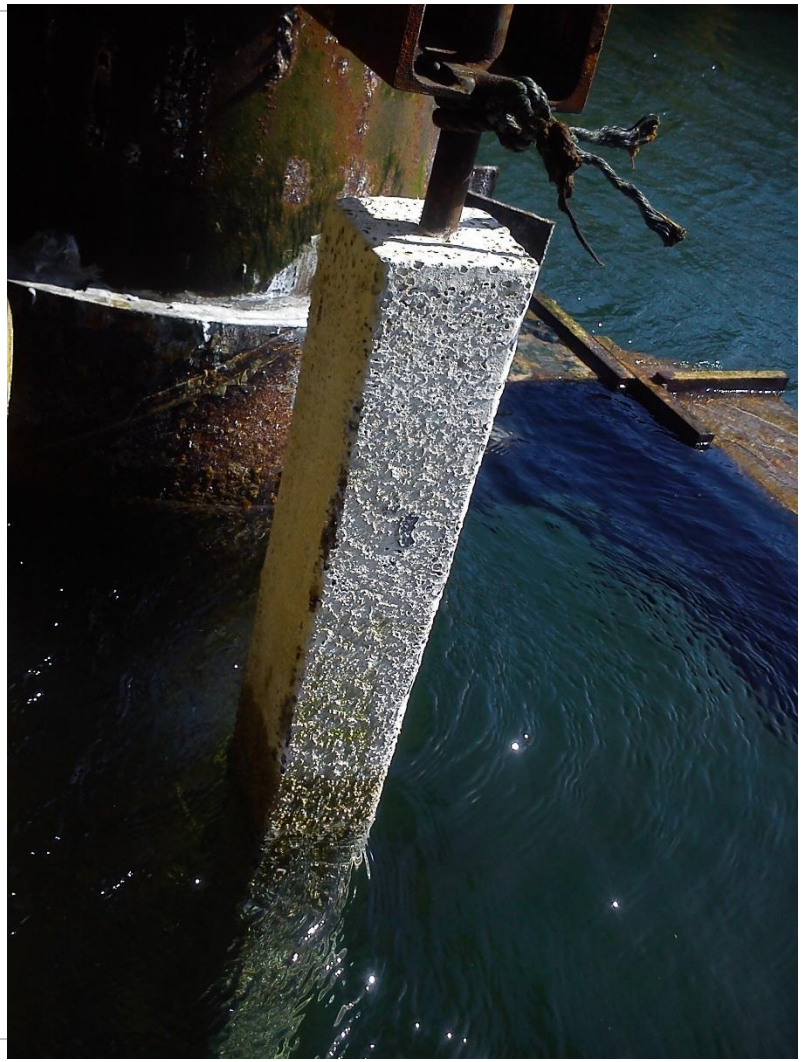


Long stand-off anodes for Harbour wall installation

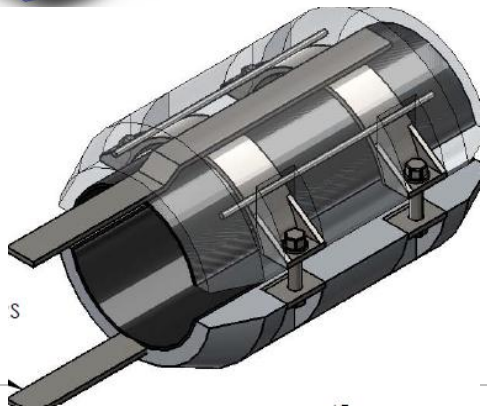
- Design & Install Anodes

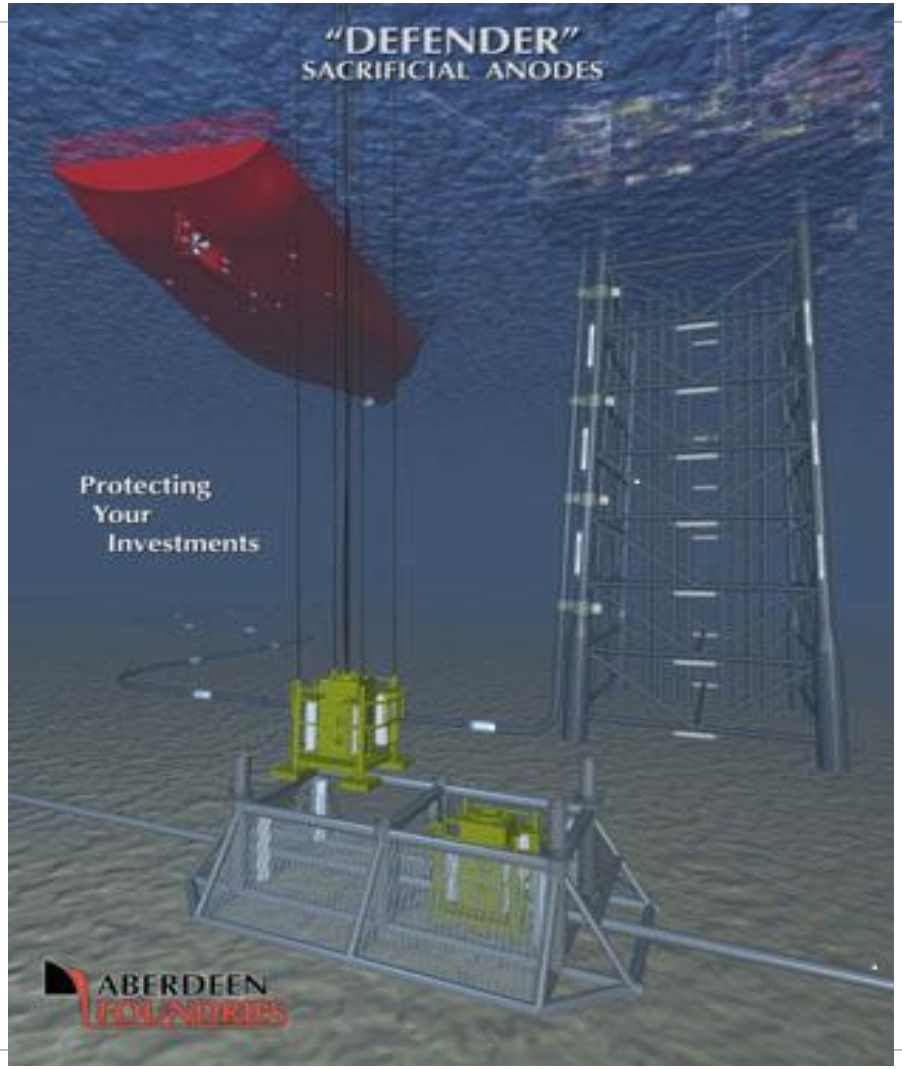


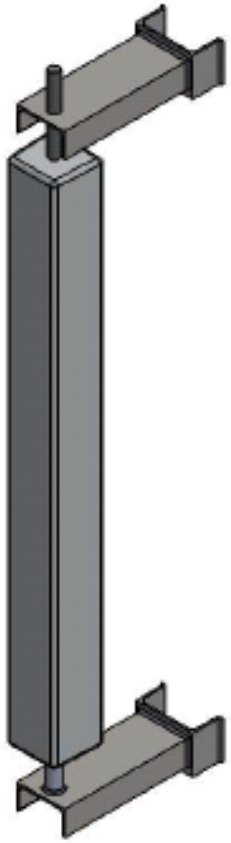
Jetty Anodes installed



Sacrificial Anode Applications

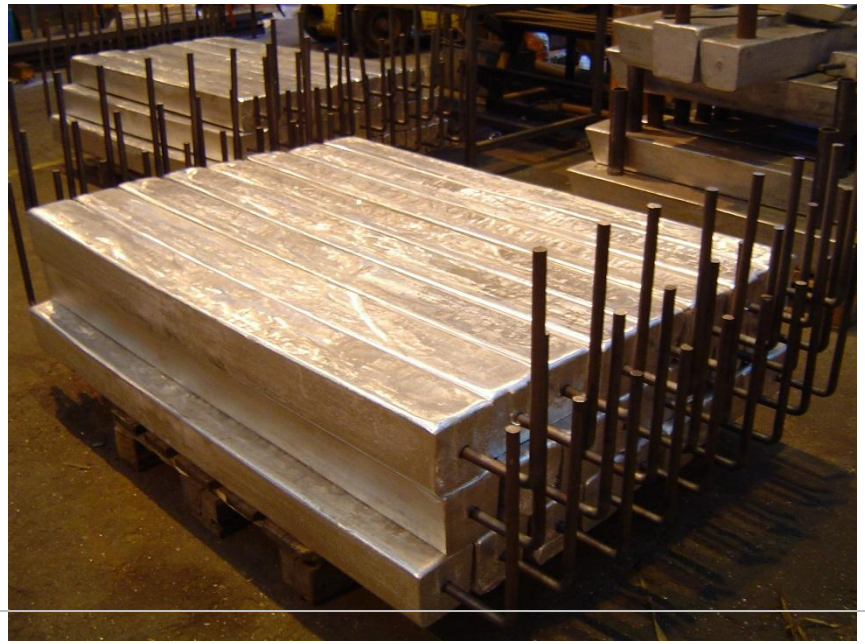






Sacrificial anodes in Zinc for flush fit (Hulls & steelwork)

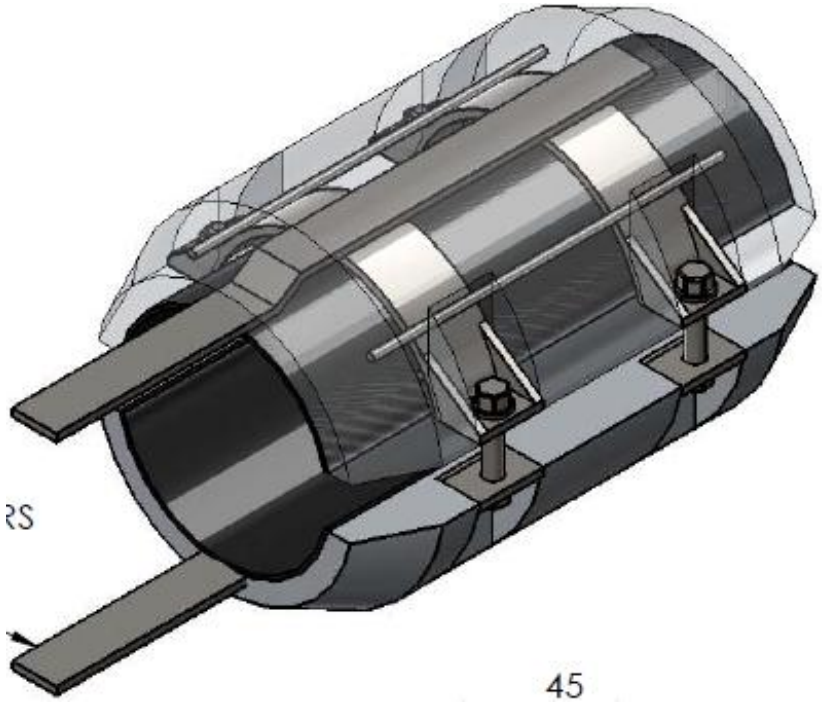
Slender Anodes for Subsea Manifold Frame



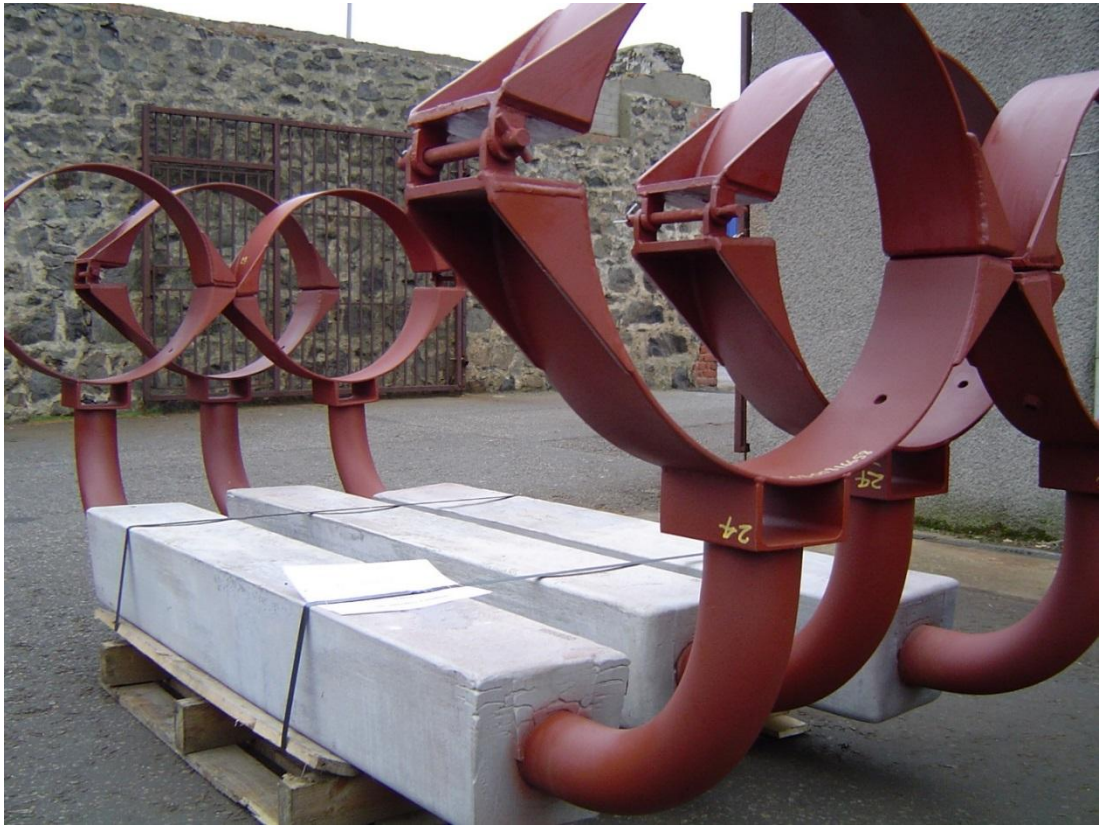
Manifold Anodes


SEA FASTENING
ONLY.
P21U400-REV3.
100783-082D2-U-04.

Bracelet Anodes for Pipelines & Spools



Retrofit Anodes



Anode Skids for Remote Retrofit of Manifold

Design Parameters may limit the use of Sacrificial Anodes or make them impractical.

- Conductivity / Resistivity of the environment
- Size of the areas to be protected by the system
- Location and water depth
- Availability of Power sources or personnel (operation & monitoring)
- Ability to install
- Design Life of the system short term submersion or 60 year lifespan

- Impressed Current Cathodic protection can be utilised to cover most other fields of protection.

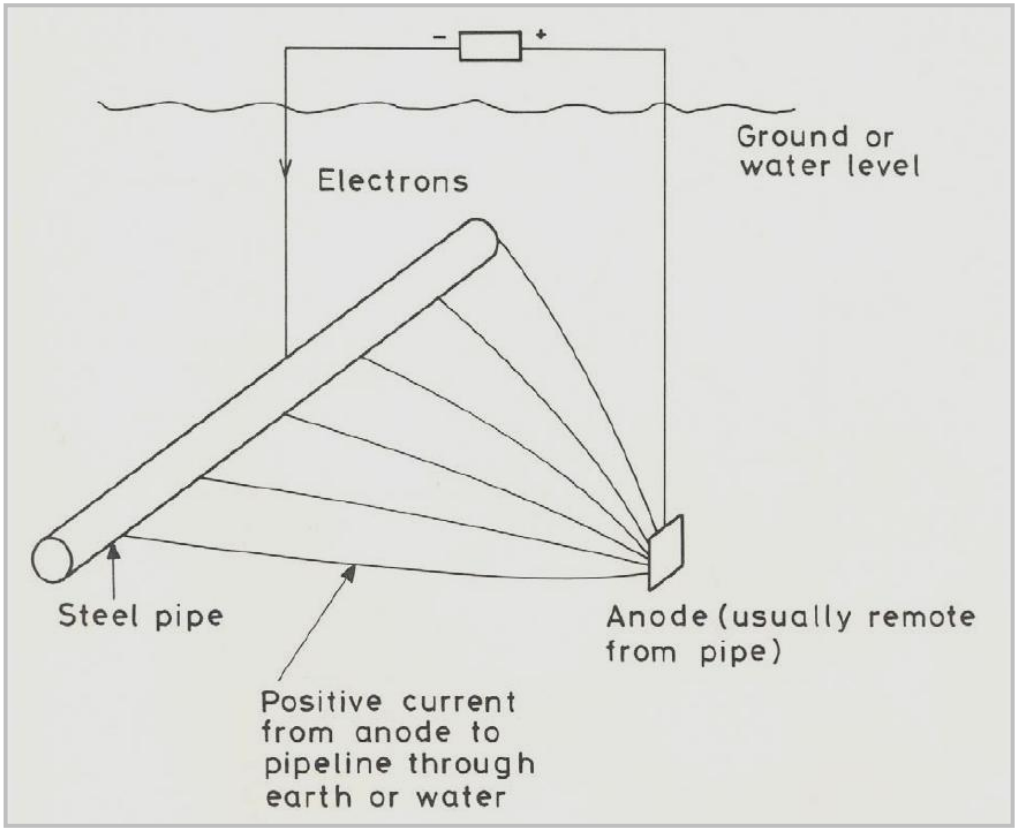
Sacrificial Protection vs Impressed Current

- Sacrificial Anode
- Simple
- Short term (Days to 30 years)
- Low/no maintenance
- Welded, secure installation
- Conductive environments (seawater)
- Restricted by anode material
- No adverse effects on structures, coatings etc
- Doesn't overprotect

Impressed Current

- Anodes are not consumed (inert)
- Use for long term systems (20-50 yr's)
- Requires regular maintenance
- Remote anodes & wiring
- Complex - has to be accurately set up
- Works in Low conductivity water areas (& onshore buried pipelines & Concrete)
- Can cause:
  - Coating de-bonding
  - Hydrogen embrittlement of steel piles
  - Cathodic corrosion of Al (hulls etc)
  - Stray current corrosion

Cathodic Protection - Impressed Current Systems



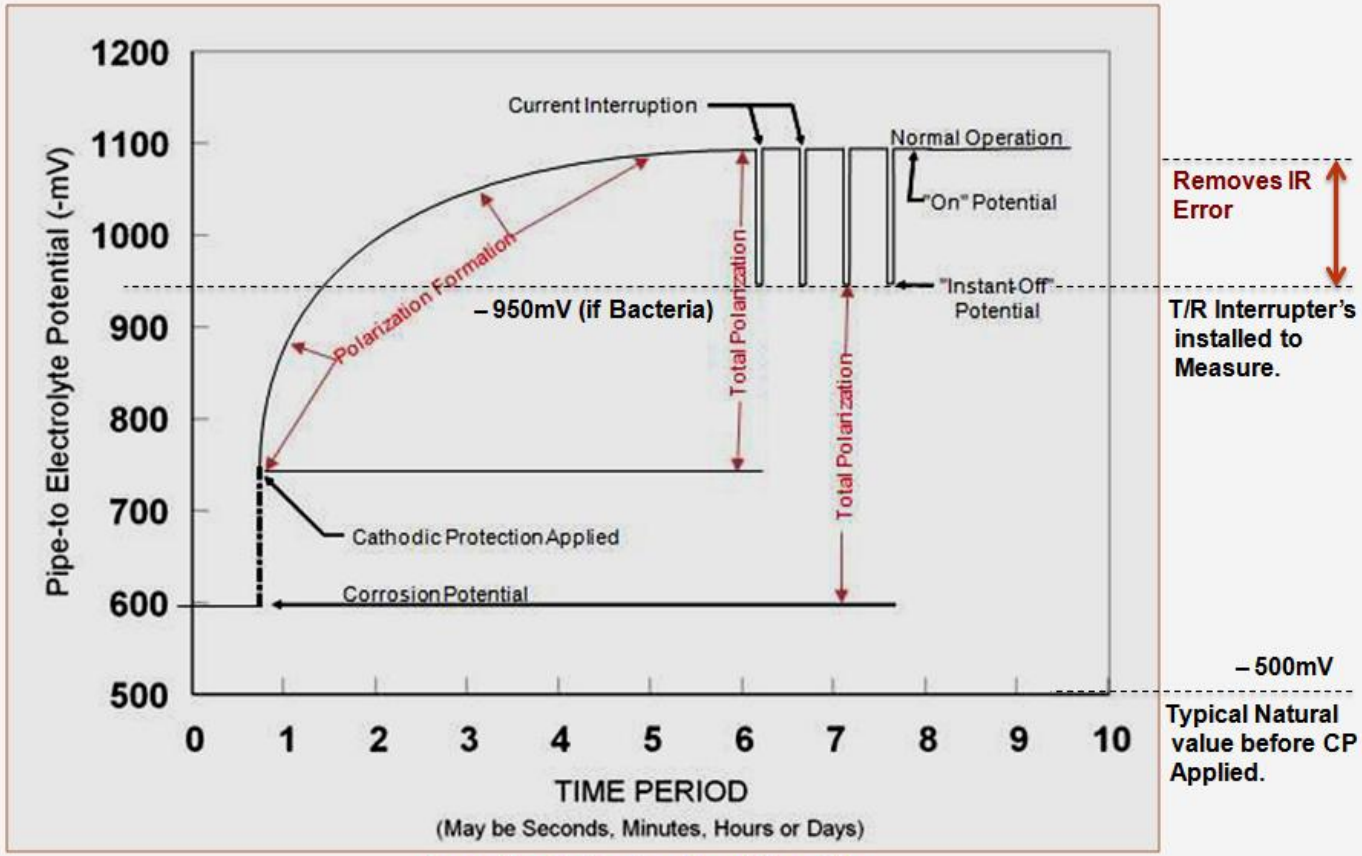
Mains and Solar Power Sources.

CATHODIC PROTECTION OVERVIEW / IMPRESSED CURRENT SYSTEMS

- MAIN DIFFERENCES BETWEEN SACRIFICIAL (IP) AND IMPRESSED CURRENT (SAC) SYSTEMS
- COMMON APPLICATIONS OF IP SYSTEMS
- COMMON DESIGN FAILINGS OF IP SYSTEMS
- COMMON OPERATIONAL FAILINGS OF IP SYSTEMS
- RECENT INNOVATIONS IN MONITORING IP SYSTEMS

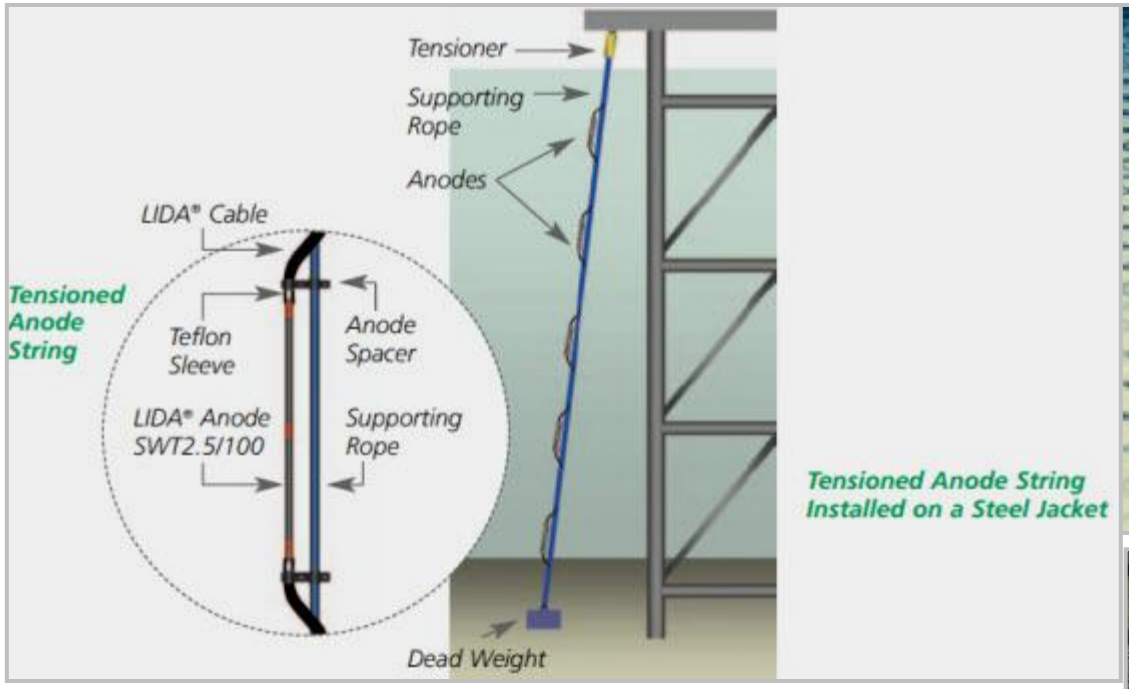
CATHODIC PROTECTION OVERVIEW / IMPRESSED CURRENT SYSTEMS

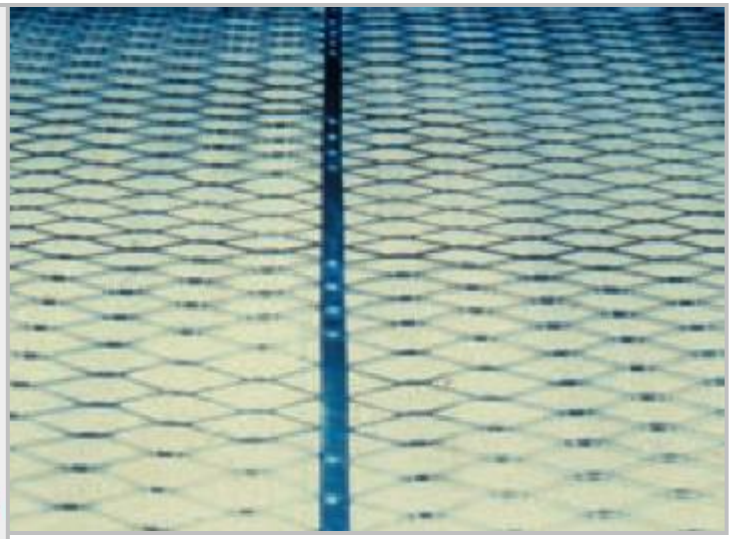
CATHODIC PROTECTION – POLARIZATION PRINCIPLE



According to Coating Type / Condition

Cathodic Protection Overview / Impressed Current Systems

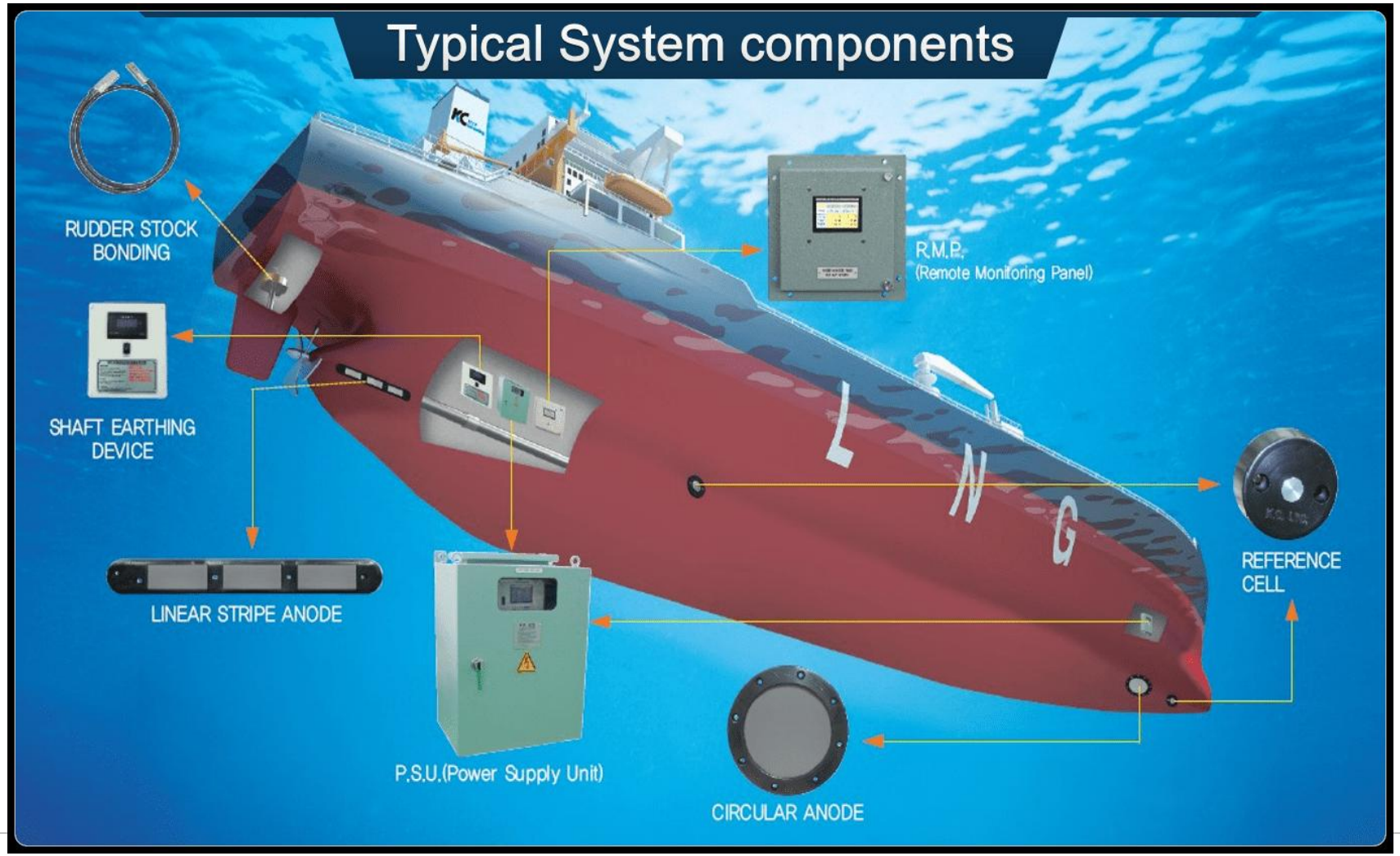




Mesh For RC Concrete and Linear Anodes For Jackets and Pipelines.

COMMON APPLICATIONS OF IP SYSTEMS

- LARGE SHIPS, CRUDE OIL TANKERS.
- LONG-DISTANCE PIPELINES.
- HIGHWAYS / BRIDGE FOUNDATIONS.
- LOADING JETTIES.
- BASES OF STORAGE TANKS.
- PROTECTION OF REINFORCED CONCRETE

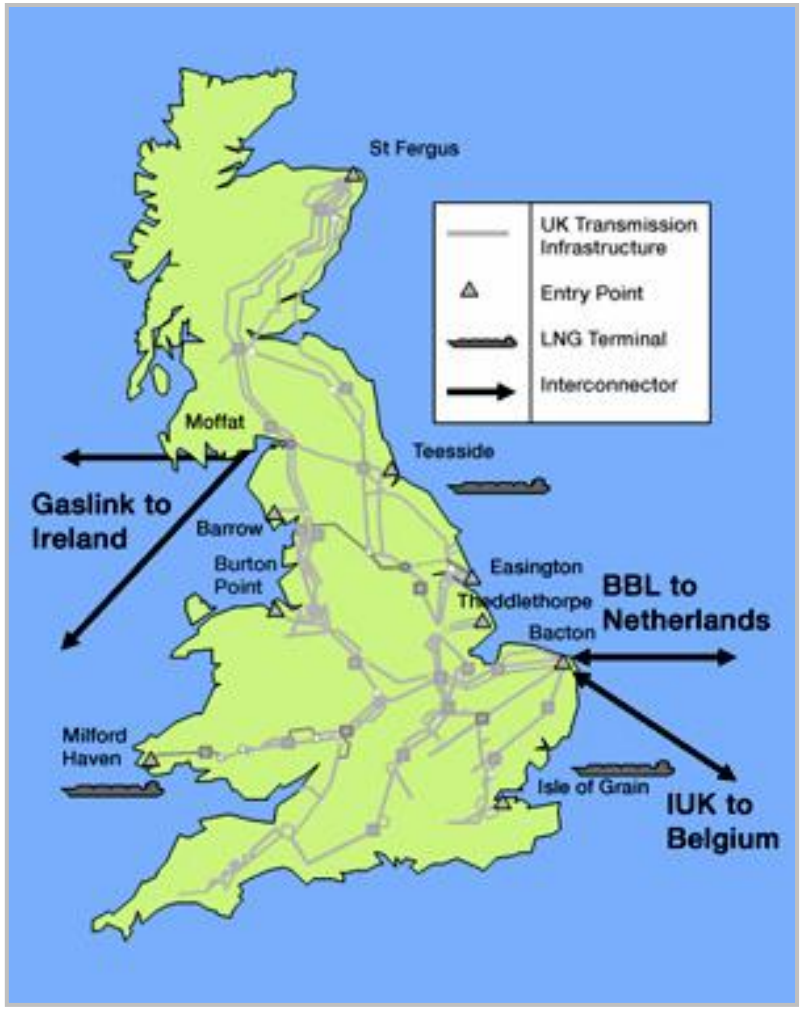

Typical System components
RUDDER STOCK BONDING
R.M.P.
(Remote Monitoring Panel)
SHAFT EARTHING DEVICE
L N G
REFERENCE CELL
LINEAR STRIPE ANODE
P.S.U.(Power Supply Unit)
CIRCULAR ANODE

Cathodic Protection Overview / Impressed Current Systems

Whitecart Viaduct Glasgow Airport and Tay Road Bridge Dundee Both Have CP – Foundations and RC Concrete Supports, as do M9 Bridges

Protection of reinforced Concrete

Cathodic Protection Overview / Impressed Current Systems



Tanks, Jetties, Tankers, Large Ships and Pipelines.

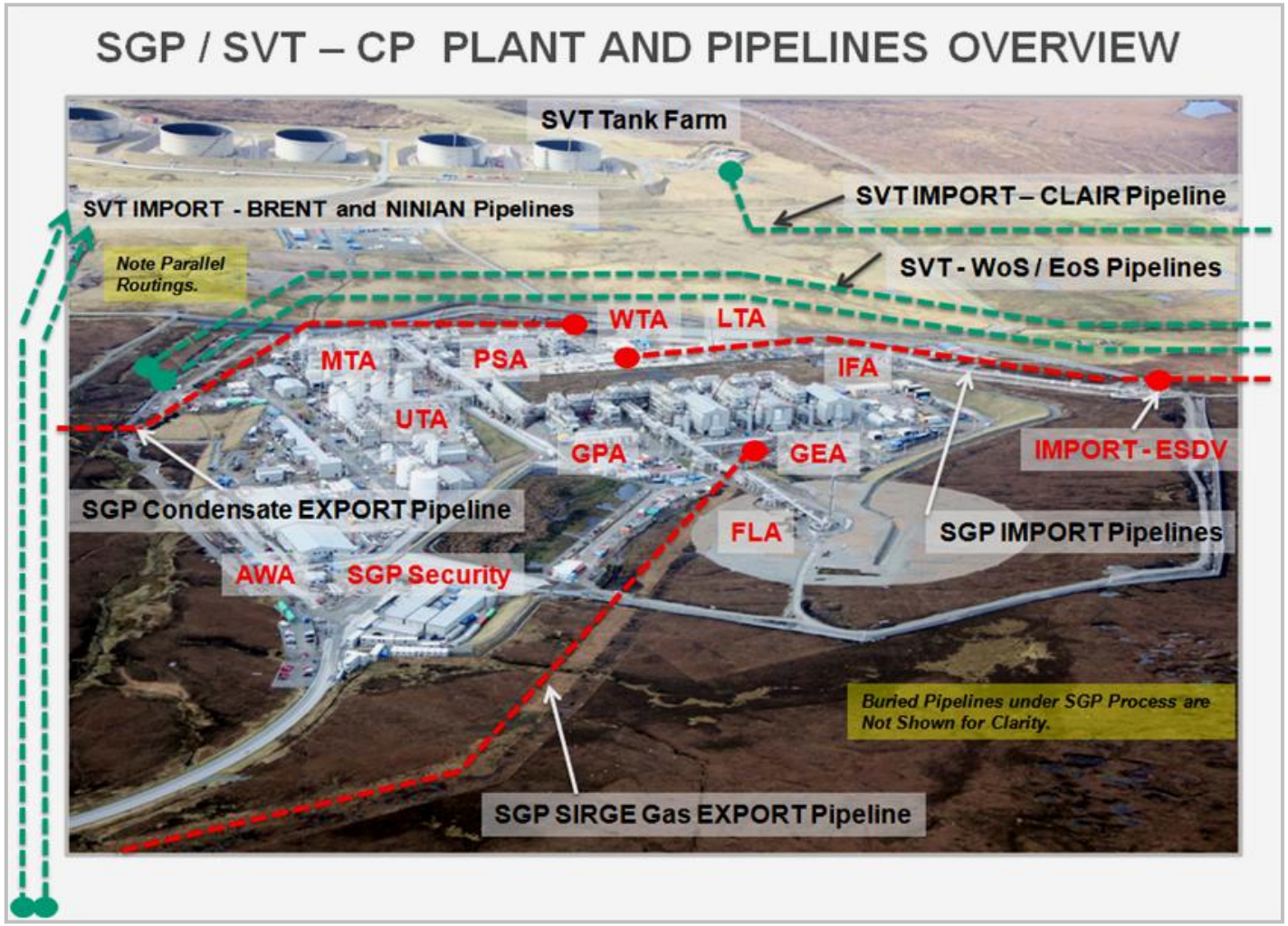
COMMON DESIGN FAILINGS OF IP SYSTEMS

- OVER ESTIMATION OF CP CURRENT REQUIREMENTS.
- OVER-SIZING OF POWER SOURCES AND CONTROL UNITS.
- LACK OF CONSIDERATION FOR NEIGHBOURING CP SCHEMES.
- CP INTERACTION ISSUES.
- OVER-PROTECTION OF CRA'S / NON CARBON STEEL ITEMS.

COMMON DESIGN FAILINGS OF IP SYSTEMS

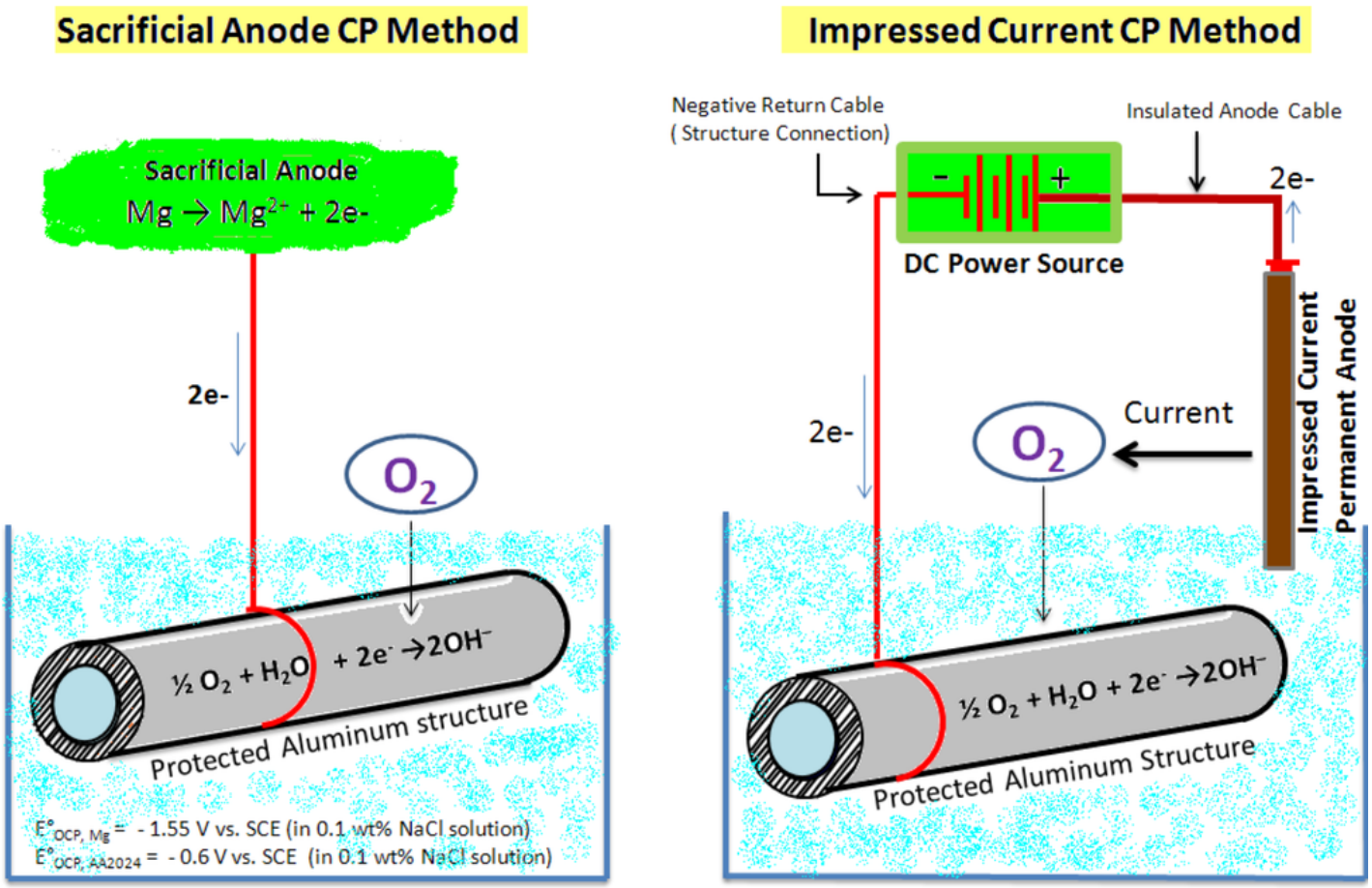
- **OVER ESTIMATION OF CP CURRENT REQUIREMENTS.**
- LACK OF UNDERSTANDING OF MODERN COATING PERFORMANCE, E.G. MULTI-LAYER POLYPROPYLENE AND FBE – FUSION BONDED EPOXY'S.
- CURRENT REQUIREMENT MAY BE 1 AMP MAX.
- DESIGN HOUSE THEN DOUBLES FOR CONTINGENCY.
- LATER CLIENT REP, DOUBLES FURTHER AMENDS SPEC.
- **END RESULT - TRANSFORMER UNIT IS TOO POWERFUL AND CP OUTPUT CANNOT BE FINELY TUNED / CONTROLLED TO ACTUAL CP REQUIREMENT AT SITE.**

CATHODIC PROTECTION OVERVIEW / IMPRESSED CURRENT SYSTEMS



LACK OF CONSIDERATION FOR NEIGHBOURING CP SCHEMES AT DESIGN STAGE.

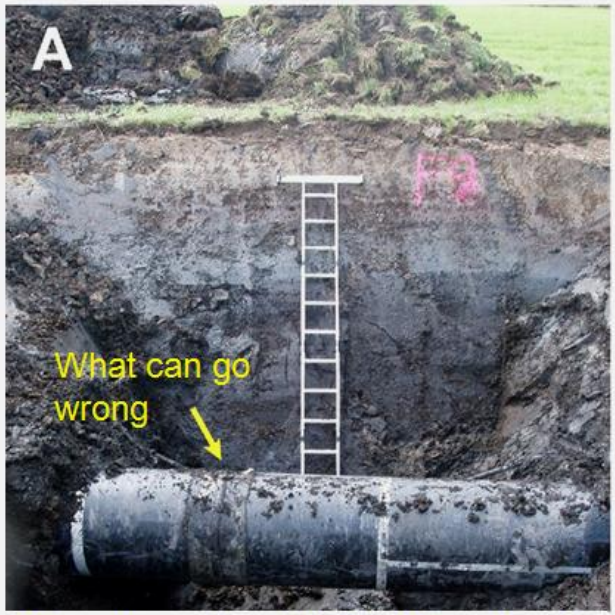
LAYING MODERN PIPELINES FOR CATHODIC PROECTION



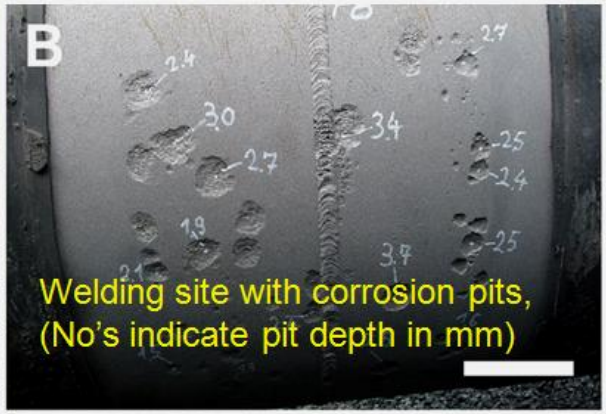
Cathodic Protection (CP) Methods

CATHODIC PROTECTION OVERVIEW / IMPRESSED CURRENT SYSTEMS

OLDER PIPELINES – COATING DIS-BONDMENT ISSUES



External corrosion at dis-bonded coating at Field Joint on buried gas transmission pipeline in bog soil of Germany. Trench with coated carbon steel gas pipeline in water-logged, anoxic soil. CP cannot not get to areas under Dis-bonded Coatings.



COMMON OPERATIONAL FAILINGS OF IP SYSTEMS

- LOSS OF CP ISOLATION AT PIPELINE ENDS / E.G. GAS TERMINALS.
- ISOLATION FLANGES BONDED OVER BY CLADDING.
- LIGHTENING STRIKES.
- FUSE FAILURES.
- STAFF SWITCHING OFF CP SYSTEM (INTERFERES WITH TELEVISION!).
- CABLE DAMAGE / CABLE THEFT.
- CONTRACTORS DIGGING NEAR PIPELINES.

Cathodic Protection Overview / Impressed Current Systems

CP Interference / Damage – Lightening and Tv.

Cathodic Protection Overview / Impressed Current Systems

Ensure Isolation Joints are not Bridged / Shorted by Insulation Cladding, or will get Loss of CP

RECENT INNOVATIONS IN MONITORING IP SYSTEMS

- REMOTE DATA COLLECTION (OPERATING CHARACTERISTICS AND PERFORMANCE).
- MORE ADVANCED / MORE DURABLE ANODE MATERIALS.
- WIDER RANGE OF ANODE TYPES TO SUIT MANY APPLICATIONS.
- USE OF DRONES AND HELICOPTERS TO ASSIST CP MONITORING (ESP. OF PIPELINES).

Cathodic Protection Overview / Impressed Current Systems

Use Of Drones For Equipment Monitoring – Transformer Rectifiers Etc.

- THE END

- More Anodes Please!

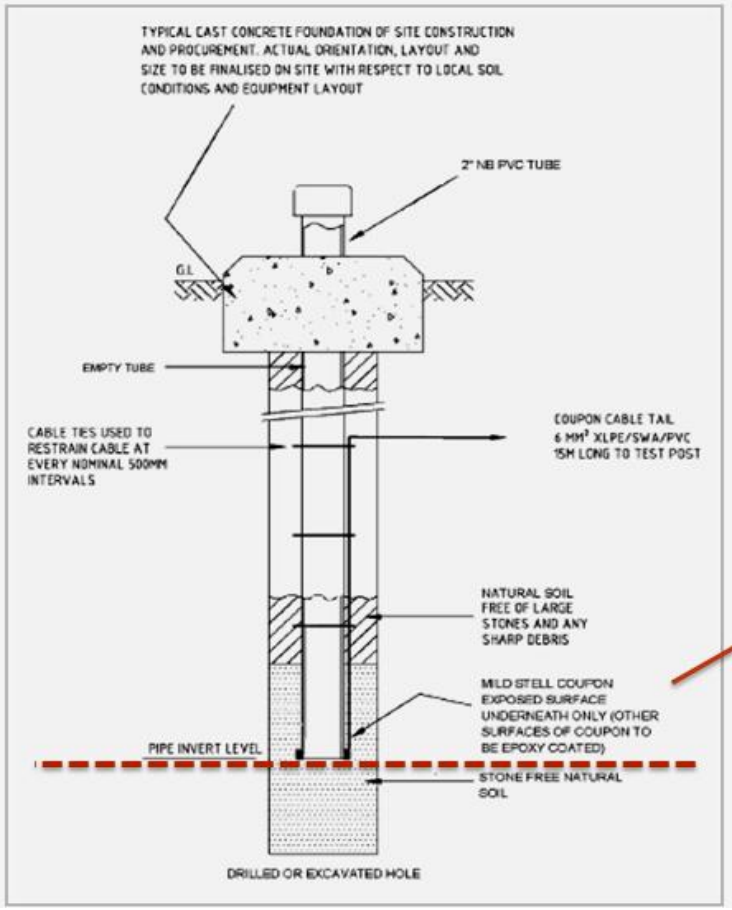
Aberdeen Branch

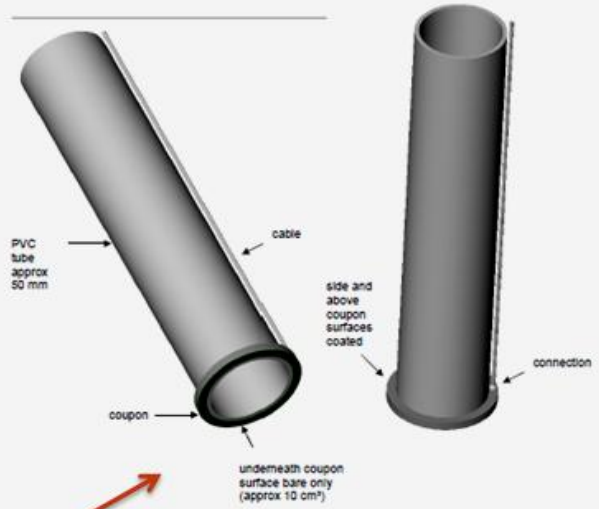
Key Sponsor

THANK YOU FOR YOUR ATTENTION
ANY QUESTIONS?

CATHODIC PROTECTION OVERVIEW / IMPRESSED CURRENT SYSTEMS

TEST COUPONS ON PIPELINES TO MEASURE CP VALUES

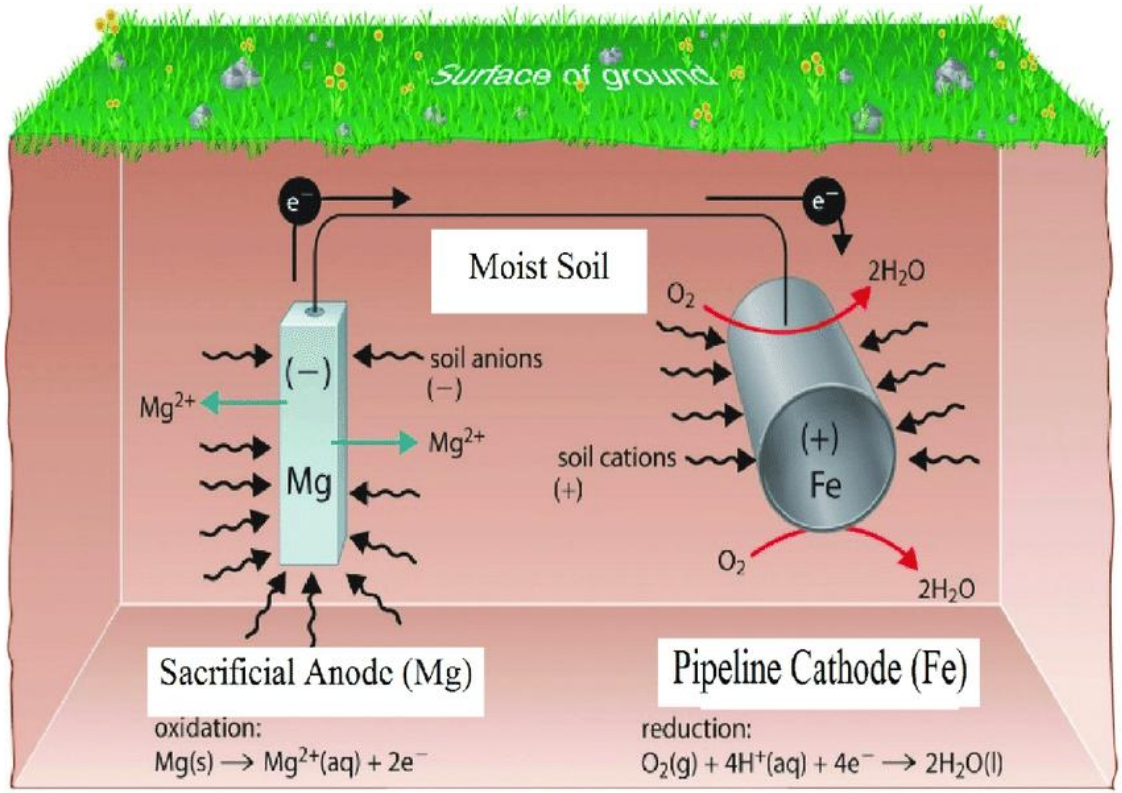




Required CP Monitoring Facilities at Pipe Invert Level to Record IR Error Free CP Values.

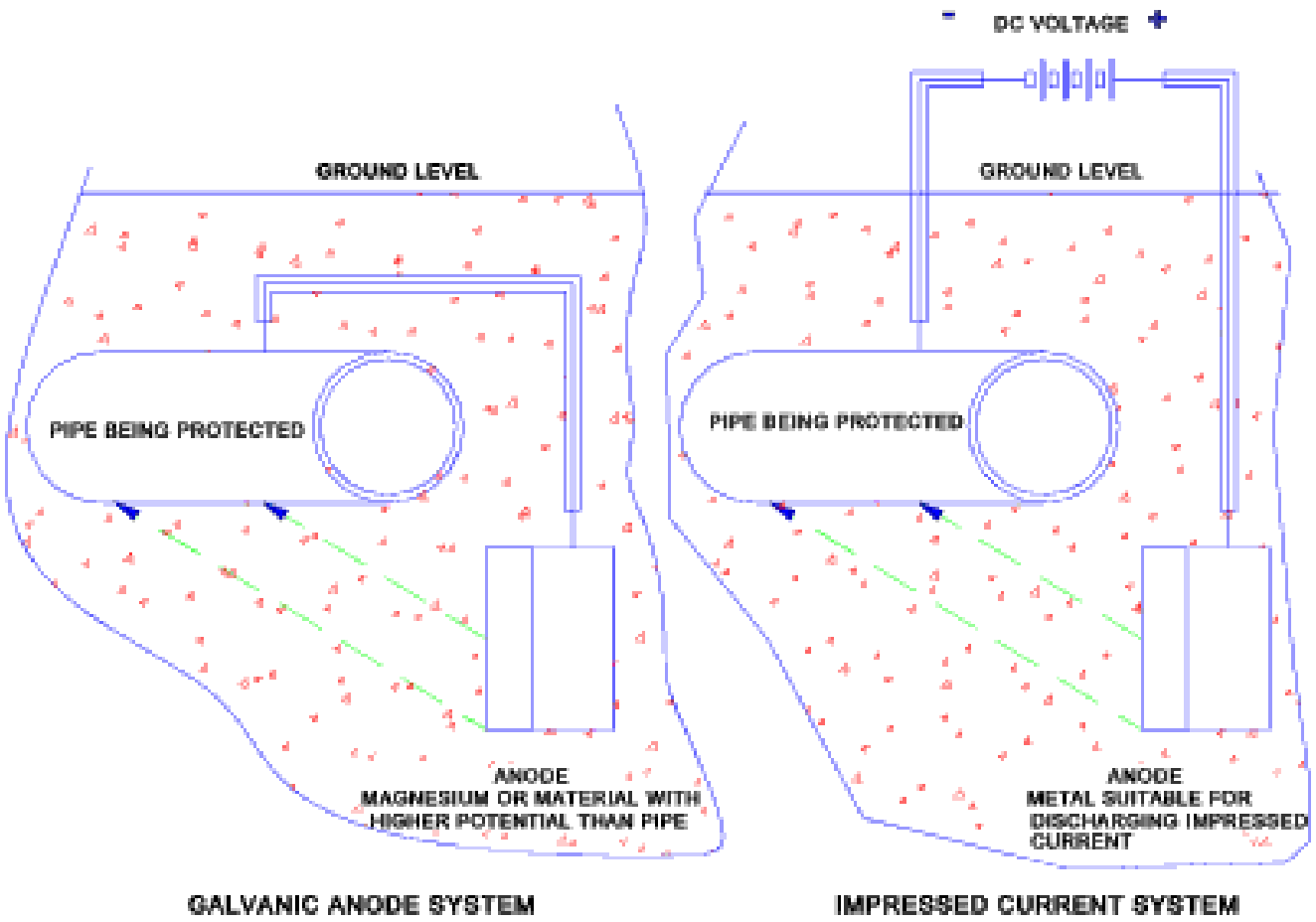
CATHODIC PROTECTION OVERVIEW / IMPRESSED CURRENT SYSTEMS

LAYING MODERN PIPELINES FOR CATHODIC PROECTION


Surface of ground
e⁻
e⁻
Moist Soil
O_2
$2H_2O$
(−)
soil anions
(−)
Mg^{2+}
Mg^{2+}
Mg
soil cations
(+)
(+)
Fe
O_2
$2H_2O$
Sacrificial Anode (Mg)
oxidation:
$Mg(s) \rightarrow Mg^{2+}(aq) + 2e^-$
Pipeline Cathode (Fe)
reduction:
$O_2(g) + 4H^+(aq) + 4e^- \rightarrow 2H_2O(l)$

- **THE END**

- More Anodes Please!


DC VOLTAGE
-
+
GROUND LEVEL
PIPE BEING PROTECTED
ANODE
MAGNESIUM OR MATERIAL WITH
HIGHER POTENTIAL THAN PIPE
GALVANIC ANODE SYSTEM
GROUND LEVEL
PIPE BEING PROTECTED
ANODE
METAL SUITABLE FOR
DISCHARGING IMPRESSED
CURRENT
IMPRESSED CURRENT SYSTEM