Guidelines for Subsea Pipeline Cathodic Protection Survey

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1. Overview

1.1 Introduction

In order to safeguard the technical integrity of subsea pipelines a combination of cathodic protection and/ or coatings is used to protect the external steel surface from corrosion.

Regular inspection of the cathodic protection system provides information as to its condition and allows identification of any areas that may be susceptible to external corrosion due to inadequate cathodic protection.

Cathodic protection systems that are not performing satisfactorily can lead to under protection of the steel surface, resulting in corrosion on the pipeline & ancillary surfaces. If remedial action is not taken, continuing degradation processes can lead to thinning of the pipe wall resulting in failure & loss of containment.

Depending on the degree of failure & the pipe contents, serious consequences can ensue in terms of injury, loss of life, economic losses & environmental impact.

In order to ensure that pipeline CP systems are operating satisfactorily, there are a number of different methodologies that can be employed to provide information as to the condition of a subsea pipeline's cathodic protection system and thus provide a quantifiable indication of continuing integrity assurance.

There is no prescriptive timing for conducting CP surveys, however a common approach is to conduct an inspection shortly after installation, usually within one year, however it should be noted that a period of time should be allowed after installation for the system to reach equilibrium.

Future survey frequency would depend on the findings of the initial survey and the period for inspections would be based on the "as found" conditions.

If the condition of the CP system is found to be satisfactory, then general industry practice would suggest that a survey be conducted every 3-5 years and is this is usually done in conjunction with a planned ROV visual inspection.

As a pipeline ages and anode deterioration and coating breakdown becomes apparent then the frequency of inspection would increase.

Historic data of periodic inspections should be kept such that long-term trends become apparent and can be analysed to assist in future inspection planning or intervention.

1.2 Purpose

The purpose of this document is to provide the user with a clear understanding of the different types of ROV based CP inspection methodologies used during ROV based subsea pipeline CP surveys and provide information on how to construct a suitable work pack, and from this allow the CP contractor to develop a suitable set of procedures that will comply with the Client's required survey specifications & deliverables.

1.3 Scope

This CP inspection guide has been prepared in order to allow the user to identify the correct methodology for ROV pipeline CP surveys.

Further, the document aims to ensure that informed decisions can be made regarding the applicability of the different CP survey techniques used & the implications with regard to data acquisition, analysis & reporting.

Having this knowledge will assist the user in the preparation of focused work packs and procedures that will identify the most appropriate methods to match the Client's information requirements.

A number of methods can be used to obtain information on the condition of a pipeline's cathodic protection system during an ROV based pipeline inspection.

There are four different methods that are used for ROV based pipeline survey that are used and generally accepted in the industry.

Depending on the level & detail of information required detail any one or more of the four methods described below may be applicable.

- Proximity half cell
- Single point contact systems (Spot CP)
- Single point contact with continuous CP (Cell to Cell Method)
- Single point contact with Continuous CP & Field Gradient

Each of these methods has their uses & limitations and will be discussed in detail later in this document.

It should be noted that this document relates to the inspection of sacrificial cathodic protection of carbon steel pipelines and does not cover ICCP systems (Impressed Current Cathodic Protection), pipelines constructed from exotic materials e.g. stainless steels, flexible flow lines, nor structures utilizing high strength steels.

1.4 Industry Standards

Contractors carrying out CP Survey operations shall be an approved Company by hereafter called COMPANY.
Contractors shall comply with the following or equivalent appropriate regulations, legislations and standards which shall include but not be limited to:

- Government Regulations
- DNV-RP-B401 *CATHODIC PROTECTION DESIGN JANUARY 2005 latest amendment April 2008*
- NORSOK STANDARD M-503 Edition 3, May 2007 *Cathodic protection*
- ISO 15589-2:2004 *Petroleum and natural gas industries -Cathodic protection of pipeline transportation systems -- Part 2: Offshore pipelines**
- NAMAS ; *National Accreditation of Measurement and Sampling* (or Equivalent)

Subsequent updates of - or new issues of - Rules/ Regulations/ Standards as mentioned above.

2 CP Survey Requirements

2.1 Personnel Qualifications & Requirements

There are no specific industry requirements or qualifications required to undertake offshore subsea CP survey, however the following competencies should be seen as the minimum required*.

Lead CP Survey Technician (Offshore);

- Familiarity with all aspects of ROV based sub sea pipeline CP surveys
- Successful completion of training & competency in required CP system operation
- Ability to troubleshoot equipment and resolve interfacing issues
- System software operation, data analysis & PC based reporting
- Minimum 3 years in field experience conducting ROV based pipeline surveys
- Client Liaison
- Hold valid Offshore survival & medical certificates

CP Survey Technician (Offshore);

- Familiarity with all aspects of ROV based sub sea pipeline CP surveys
- Successful completion of training & competency in required CP system operation
- Ability, with assistance to troubleshooting equipment and resolving interfacing issues
- System software operation
- Minimum 1 year in field experience conducting ROV based pipeline surveys
- Client Liaison
- Hold valid Offshore survival & medical certificates

CP Technical Authority (Onshore);

- Graduate with a qualification in corrosion engineering, metallurgy, materials or other relevant subject
- At least 5 years direct experience in subsea pipeline CP inspection activities
- Detailed data analysis & report review skills
- Client Liaison

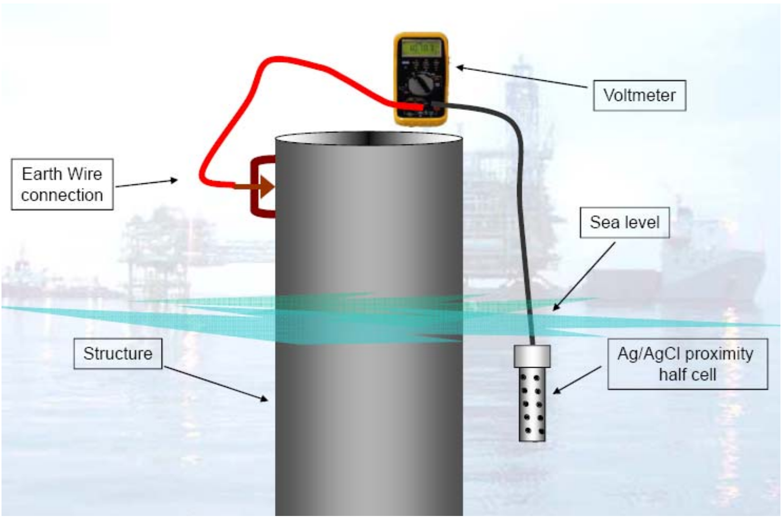
To undertake a high specification pipeline CP survey based on 24hr operations, it is normal that there are two CP survey technicians on board the vessel to cover each 12 hour period.

*Note, for simple contact measurements or proximity half CP measurements suitably trained ROV or inspection personnel can be used to take measurements.

2.2 Pipeline CP Survey Tools

2.2.1 Proximity Half Cell

This is the simplest tool used for obtaining potential measurements.
A hard wire connection is made to a structure (above water) and connected to the negative terminal on a voltmeter. The positive terminal is connected to a silver/silver chloride (Ag/AgCl) half cell through a voltmeter and is positioned close to the surface being measured. No direct contact is required.

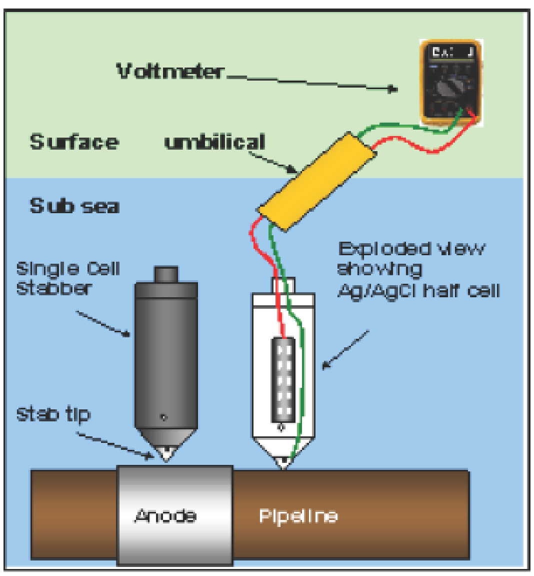


Advantages.
• Quick & easy to take measurements, as there is no need to make contact with the surface being measured.
• Can be used to provide continuous CP profiles.

Disadvantages
• As a hard earth wire connection is required, access to the structure would be required.
• Can be inaccurate if distance between probe and surface being measured is too great.
• Can only provide CP measurements.
• Can only be used on platforms, risers and sections of pipeline very close to structures.
• Cannot be used on fully submerged structures where no ground connection can be made.
• Cannot be used to provide detailed information on anode current output & remaining life.

2.2.2 CP Stab Probe

A probe containing a silver/silver chloride half cell and hard steel stab tip.
Stab Probes can be used by diver or mounted on an ROV. They are used to take contact measurements on steel and anodes.
The probe consists of a hard contact tip with a Silver/Silver Chloride half cell housed in a unit either connected via the ROV umbilical to a topside voltmeter or an incorporated voltmeter read out display.
When the probe tip makes contact with the surface of the steel or anode a potential reading is obtained.



Advantages.
• Does not need to have an earth wire contact to the structure being inspected.
• Can be used to provide CP contact readings on fully submerged structures and pipelines

Disadvantages
• Can only be used to take “spot” CP measurements”.
• Can be difficult to get readings where there is thick marine growth cover.
• Can only provide CP measurements.
• No continuous CP profile can be taken.
• Cannot be used to provide accurate information on anode current output & remaining life.

2.2.3 Contact & Remote Half Cell (Cell to Cell)

Using the same type of CP Stabber probe as above, a remote Silver/silver Chloride half-cell is also used to provide a stable “zero reference” instead of a hard wire connection commonly known as the “Cell to Cell” technique.

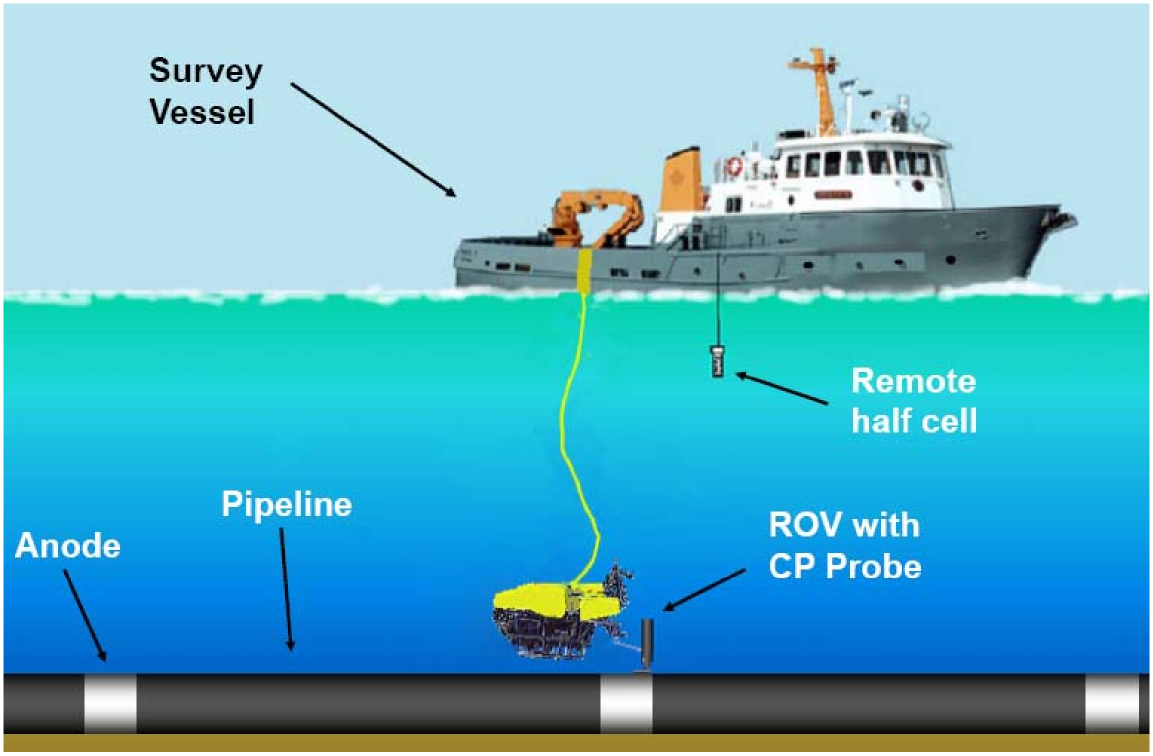
As the term implies the “remote” half-cell is positioned remotely from local potential influences and is typically deployed over the side of the survey vessel.

During the survey, regular contact measurements are obtained, to provide “absolute” potential measurements at a given location (equivalent at the time of contact to making a hard wire connection).

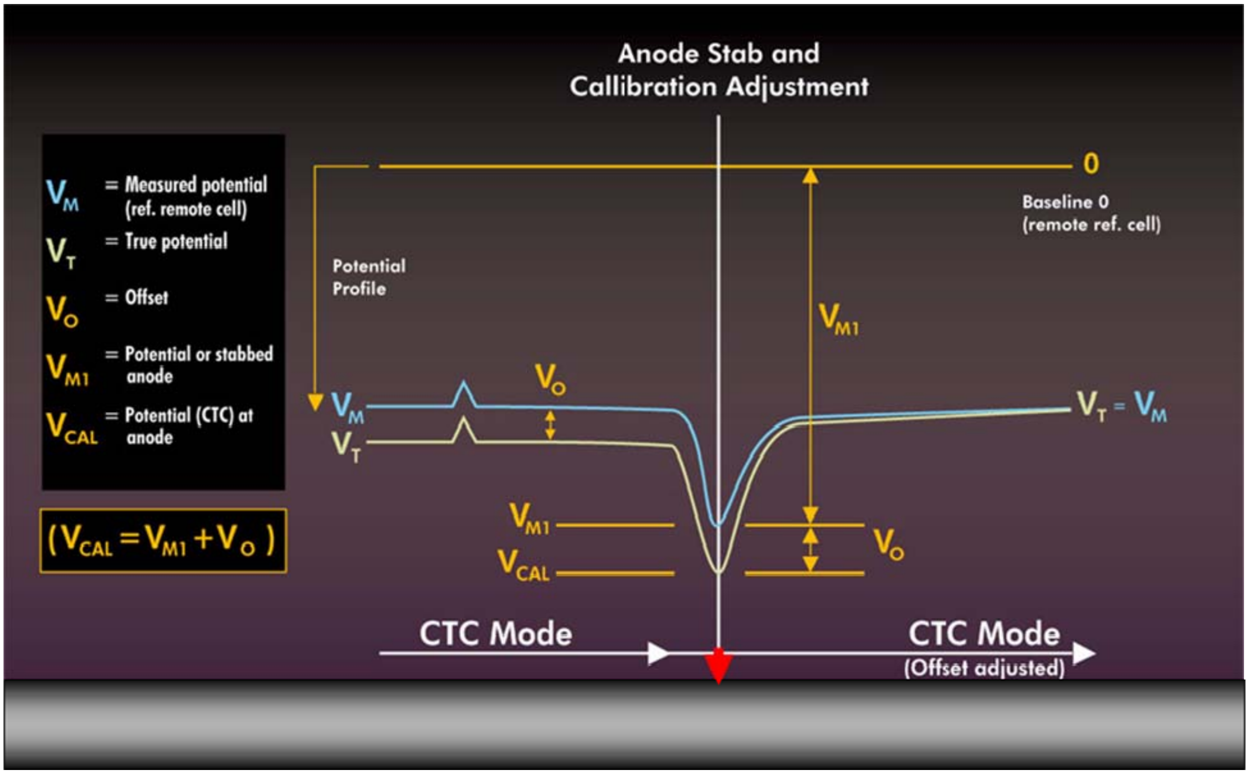
Whilst in contact with the anode or steel surface, the natural potential offsets between the probe & the remote half-cells are zeroed and the value obtained during contact is added, to provide a baseline measurement.

Any change in potential values that occur therefore should only be attributable to the probe half-cell and not the stable remote half-cell; In theory any variations in potential measured are only caused by local potential changes as the probe moves over the surface being inspected.

This, and the following systems described usually require the use of a computerized logging system.



Cell to Cell overview



CTC Offset Calibration Adjustment

Advantages.

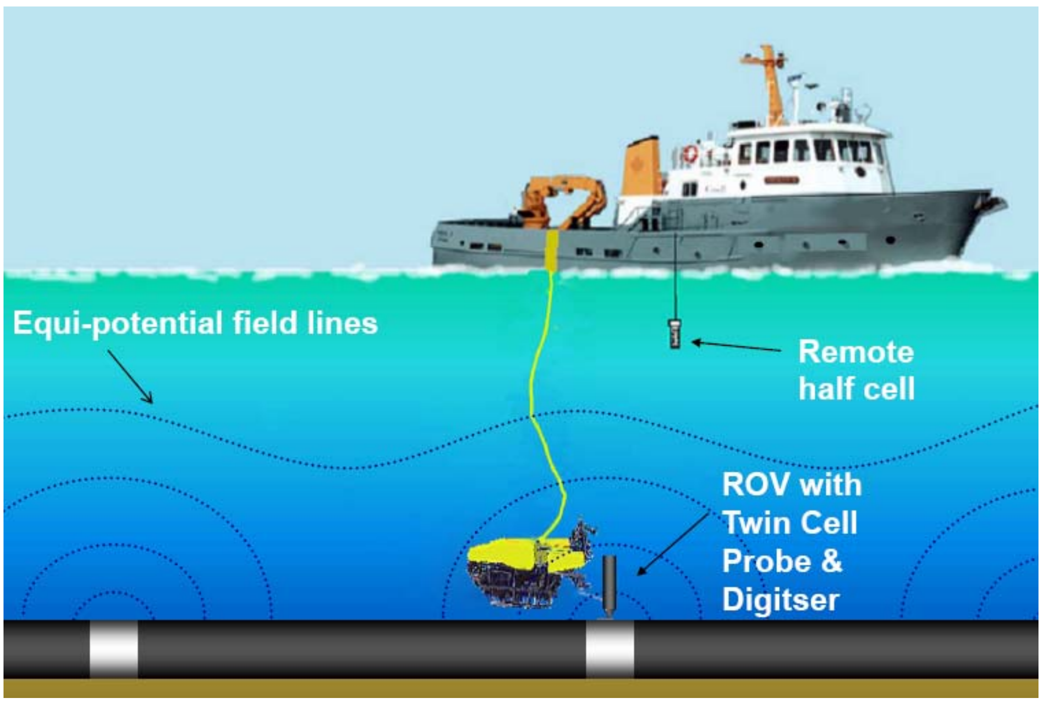
- Using this technique can provide both contact and continuous potential measurements.
- Can be used to provide continuous CP profiles of pipelines and structures.
- Can be used to obtain direct contact CP measurements on steel & anodes.

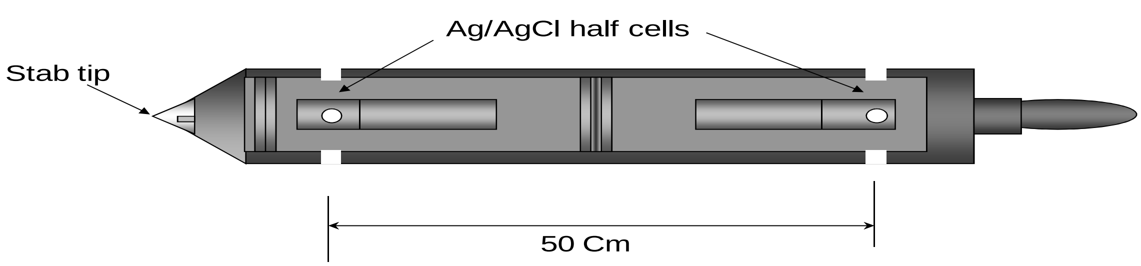
Disadvantages

- Can be difficult to get reading where there is thick marine growth cover.
- Can only provide CP measurements.
- Cannot be used when regular calibration contact cannot be made. i.e. long sections of buried pipeline.
- Cannot be used to provide accurate information on anode current output & remaining life.

2.2.4 Twin Half Cell Contact Probe with Remote (The industry standard for ROV pipeline CP Survey)

As the Remote Half Cell & Contact method, but a significant advantage is gained by incorporating another silver/silver chloride half cell in the probe body. With this additional half cell it is possible to obtain field gradient values allowing anode current density & current output to be calculated. Estimations can now be made regarding the remaining life of anodes. This method can also be used to identify disconnected or inactive anodes.

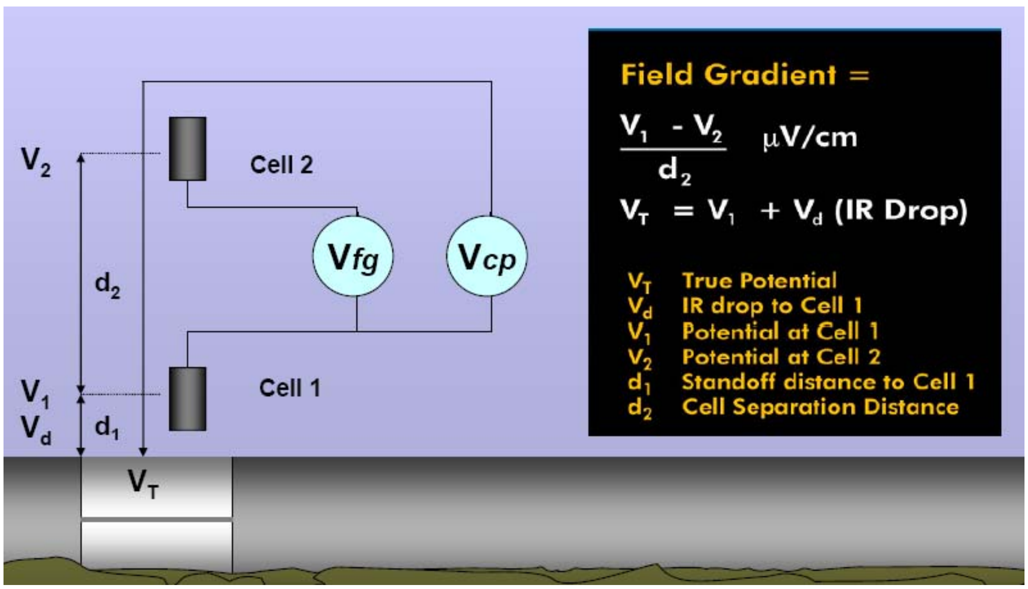




Example of twin half cell contact probe.

The potentials measured from the half cells can either be transferred topside via an analogue voltage signal or digitized subsea and transmitted using a digital encoder.

The advantage of subsea digitization is that possible stray voltages between the conducting wires will not affect the readings.



How field gradient is calculated from the potentials measured in the twin half cell probe

Advantages.

- Using the twin half cell probe can provide both contact and continuous potential measurements.
- Can be used to obtain direct CP contact measurements on steel & anodes.
- Can be used to obtain field gradient values on anodes and steel
- Anode current output and remaining life can be calculated (based on anode information being available)

Disadvantages

- Can be difficult to get contact reading where there is thick marine growth cover.
- Cannot be used when regular calibration contact cannot be made. i.e. long sections of buried pipeline.

2..3 Safety Hazards & Precautions

An on- site Job Hazard Analysis (JHA) should be completed prior to initiating work.
With the work procedures in place on the vessel and/ or supporting installation, all relevant persons responsible for the work, should convene to discuss the potential hazards.
Personnel should be made aware of each other's responsibilities

EXAMPLE CP SURVEY JOB SAFETY ANALYSIS WORKSHEET

Function Area: ROV CP SURVEY		
BASIC JOB STEPS	*POTENTIAL HAZARDS*	*CONTROLS*
1. Mobilisation of Equipment & Personnel	*Slipping, Falling , Tripping, Electric Shock, Back Injury Hazard*	*Personnel to wear appropriate PPE; Hard hat, boots with non slip soles & gloves, Electrical equipment to be connected via ELCB*
2. Attachment/Removal of probe to ROV	*Drowning, Falling , Tripping, Slipping, Other Objects Close by, Electric shock, Falling objects*	*Personnel to wear approved life vests, PPE, Hard Hat boots with non slip soles & gloves.*
3. Survey Logging	*Electric Shock*	*Electrical equipment to be connected via ELCB*
4. Demobilisation of Equipment & personnel	*Slipping, Falling , Tripping, Back Injury Hazard*	*Personnel to wear, hard hat, boots with non slip soles, proper lifting procedures to be adopted.*

3 Survey Preparation

3.1 Work Pack Preparation

The decision to select which type or types of survey to be conducted will be based on both the level of the information required, ranging from a simple spot CP stab survey using a topside voltmeter to a high specification continuous subsea digitized CP data acquisition system. Further, operational & environmental constraints may also have a significant impact on the type & quality of data that can be obtained.

In conjunction with the assigned subsea CP ROV Survey Company, information on the pipelines being surveyed together with the ROV services that will be available on the vessel should be provided.

It is important to note that when developing a CP Survey work pack, a number of external factors not directly related to the CP survey contractor can have a significant effect on their ability to provide the required information.

The following factors should be considered;

Survey Vessel

- Vessel station holding & pipeline tracking capability
- Work space & working environment

Access to platform/structure

- Access to platform/structure (if required)

ROV Capability

- ROV type & ability to hold a probe and have the functionality & sufficient power to make good contact with pipeline anodes and areas of bare metal.
- ROV power, data communications & protocols required for proposed CP inspection type

Navigation

- Navigation system interface to & from CP data acquisition system (if required)

CP Data Acquisition

- CP data type e.g. digital, analogue or visual, data storage requirements.

Video

- Video overlay requirements & protocols

Reporting

- Reporting requirements

Related Pipeline Information Requirements

- Pipeline Identification & Nomenclature
- Pipeline Construction Details (coating, material specifications etc.)
- Pipeline route, with water depth, burial information, crossings etc.
- Extent of pipeline survey
- Condition of pipeline (from previous surveys)
- Year of installation
- Pipeline Anode information
- Previous CP Survey information

To illustrate…

If, for example, a pipeline CP survey is required and part of the deliverable is to provide CP contact & anode current output and estimated remaining life calculations. In order to obtain the information a twin half cell probe would be required. If the supplied ROV was an eyeball type, without a manipulator to hold the probe and insufficient down thrust power to take contact measurements, then it would not be possible for the CP contractor to supply the required deliverable.

Therefore, when considering developing a scope of work for a subsea pipeline CP survey it is recommended that a competent CP survey contractor be brought in at an early stage to provide advice regarding what can be achieved with the proposed project set-up, particularly when proposing detailed CP/FG pipeline surveys.

3.2 Requirements & Review of CP Survey Procedures

Work Execution - Operational Inspection Procedures

For the preparation of a detailed CP inspection procedure, the CP contractor should address the following issues;

- Operational Procedure for the use of the chosen CP data acquisition method(s)

  To also include measurement units (mV, V, µV/cm etc.). Range & sensitivity of the chosen method should be detailed in the procedure)

  For example…

  CP range will be 0 to -2000mV Sensitivity 1mV

  FG range will be -2000 to +2000 µV/cm Sensitivity 1 µV/cm

- Data measurement & type of data provided (e.g. CP, FG, Anode current output & remaining life etc.)
- Interfacing/communications (ROV, Survey & Video) Data telegrams & data transmission formats)
- Salinity & Conductivity of water
- On site Calibrations (Calibration procedures), Standards
- Data Storage procedures including backup
- Equipment maintenance & troubleshooting
- Record keeping (hand written & electronic logs, calibration logs etc.)
- Reporting

3.2.1 Procedures Checklist

1. BASE MOBILISATION PROCEDURE

- Equipment Mobilisation
- Personnel Mobilisation

2. SITE MOBILISATION PROCEDURES

- CP Survey Equipment Set-up (to include Equipment specifications)
- Calibration & Check
- Computer Equipment Set-up
- Interfacing

3. WORK EXECUTION OPERATING PROCEDURES

- CP Equipment Operations
- Data Acquisition & Storage
- QA/QC
- Troubleshooting

4. SITE DEMOBILISATION PROCEDURE

5. BASE DEMOBILISATION PROCEDURE

- Base Demobilisation of Personnel (Job debrief)
- Base Demobilisation of Equipment

6. CP SURVEY REPORTING PROCEDURES

- Data Control
- Logs
- Draft Report.
- Report Approval

3.3 Operational Pre-planning

Prior to commencing the inspection survey the following issues should addressed and confirmed to be in order.

- Safety
- Job Instructions regarding specific contact location/frequency & actions if anomalies found
- Interface test with ROV, Survey & Video Overlay
- Security of probe & connections on ROV
- Data logging & storage test
- Pre-dive CP calibration checks

4 Specific Inspection Requirements (Twin Half Cell Contact Probe with Remote)

Generally the CP survey should comply with a recognised international standard for offshore pipeline survey, for example; ISO 15589-2:2004(E) Annex C (Monitoring of CP systems for offshore pipelines) or equivalent.

4.1 Pre Dive Checks

4.1.1 Pre Dive Calibration Checks

Prior to commencement of the survey all probe & remote half cells should be checked against an accepted reference procedure (for example DNV RP B403) to ensure that they are functioning within the calibration limits.

4.1.2 Pre Dive System Test

Prior to commencement of the survey the system should be tested to ensure that the data received and transmitted is satisfactory and that the acquired data fields are being stored correctly.

4.2 CP Survey

As soon as possible after the commencement of the survey a contact measurement should be taken to reference the system. The contact can either be made on bare steel (eg Flange) or on a pipeline anode.

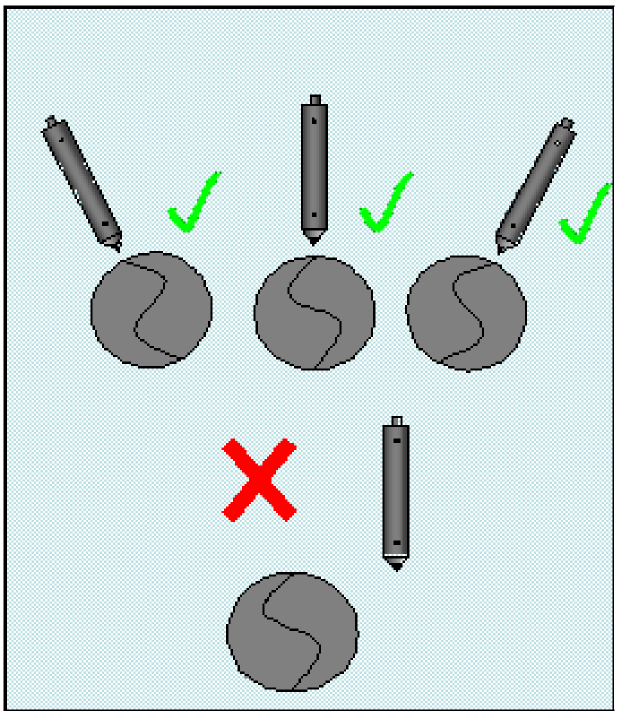
If surveying close to a jacket, the contact frequency on the pipeline should be higher, with contacts taken on the inboard & outboard flanges, areas of bare steel, at the base of the riser and on a representative number of anodes. The actual number of contacts to be taken on the pipeline from the 500m zone to the platform connection should be agreed in advance, but the procedure should have the flexibility to be modified to allow more readings should anomalies be encountered.

The reason for a higher frequency of contacts is that significant potential changes can occur in close proximity to the structure.

Typically, as the distance from the structure increases the anode activity decreases, thereafter contact calibration can be reduced to once every kilometer. If active damage or significant anode activity is observed then the frequency of contacts should be increased.

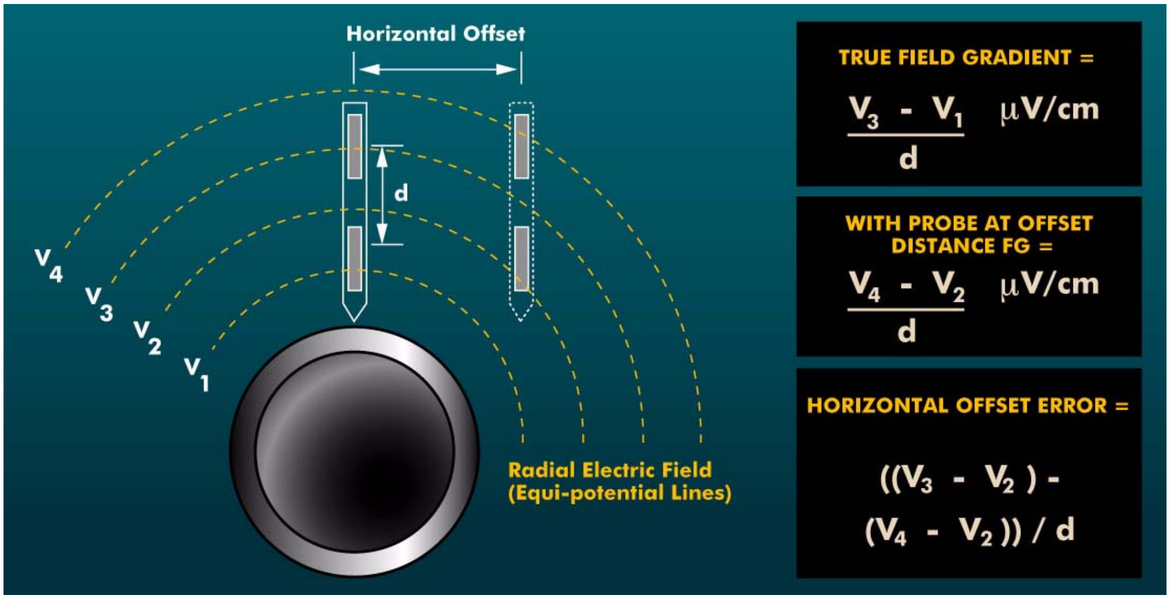
4.3 CP Probe Alignment

During the survey it is important to note that in order to maintain accuracy the probe should be aligned correctly and that the distance between the pipeline surface & the probe is kept to a minimum.



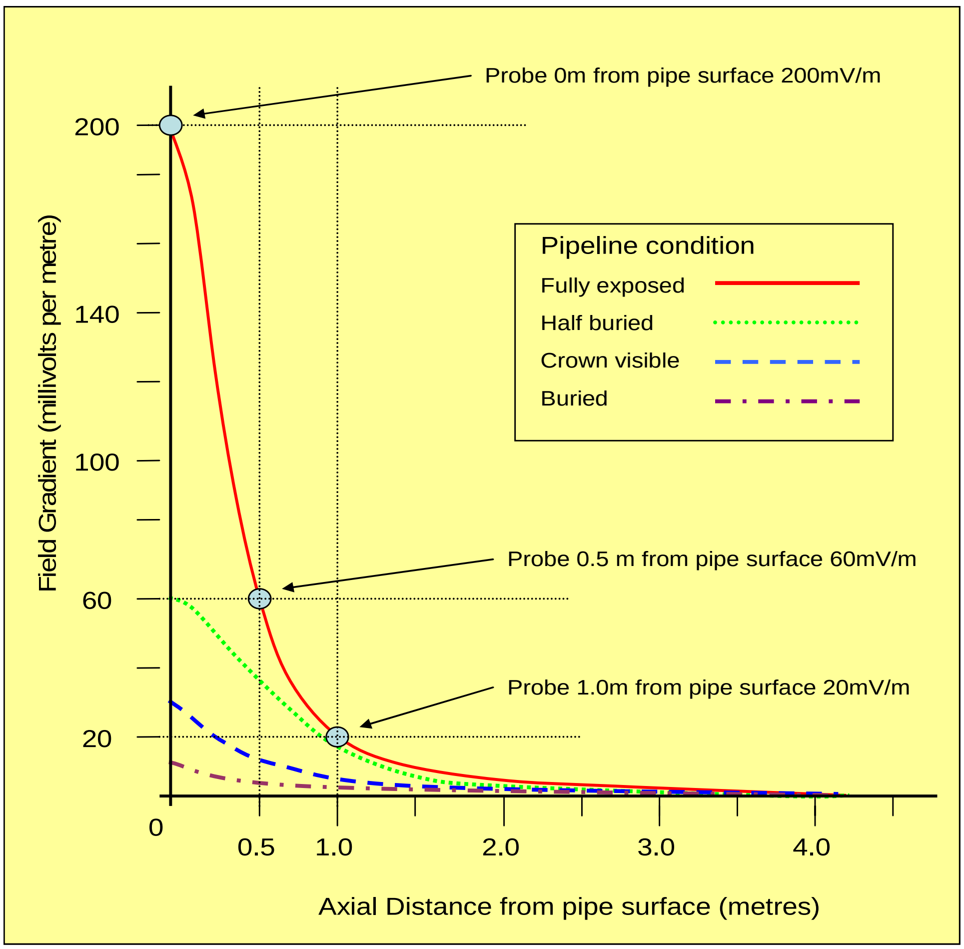
The probe should be aligned radially to the pipeline as shown above.

If the probe is not aligned correctly then horizontal offset errors will be introduced. See illustration below.



Horizontal Offset
d
V4
V3
V2
V1
Radial Electric Field
(Equi-potential Lines)
TRUE FIELD GRADIENT =
V3 - V1 µV/cm
d
WITH PROBE AT OFFSET DISTANCE FG =
V4 - V2 µV/cm
d
HORIZONTAL OFFSET ERROR =
((V3 - V2) -
(V4 - V2)) / d

Probe to pipe distance and burial can have a significant effect on the system's ability to detect cathodic activity. The Twin half Cell contact & remote method relies upon regular contact measurements to maintain accuracy and for the most accurate data acquisition, every effort should be taken to ensure that the pipe to probe distance & probe alignment remains satisfactory. It should also be stated that if a pipeline is buried for long sections and no calibration contacts can be made, the accuracy of the readings can be questionable. This is a limitation of the methodology.



4.4 Anomalies

In addition to physical damage to the pipeline or coating, during a CP survey anodes can be found to be more heavily wasted than expected or conversely not as consumed as would be thought in comparison with other adjacent anodes.

From a purely cathodic protection viewpoint , only potentials recorded outwith the relevant international standards would be considered anomalous. (As described in Table 1 below; extract from; "ISO 15589-2:2004 *Petroleum and natural gas industries -Cathodic protection of pipeline transportation systems -- Part 2: Offshore pipelines"*)

Table 1 — Recommended potential criteria

Material	Minimum negative potential V	Maximum negative potential [a] V
Carbon steel		
Aerobic environment	– 0,80	– 1,10 [b]
Anaerobic environment	– 0,90	– 1,10 [b]
Austenitic stainless steel		
$N_{PRE} \geqslant 40$ [c]	– 0,30 [d]	– 1,10
$N_{PRE} < 40$ [c]	– 0,50 [d]	– 1,10
Duplex stainless steel	– 0,50 [d]	[e]
Martensitic stainless (13 % Cr) steel	– 0,50 [d]	[e]

The potentials given in Table 1 apply to saline mud and normal seawater compositions (salinity 3,2 % to 3,8 %).

The potentials are referenced to an SCE reference electrode, which are equivalent to a silver/silver chloride reference electrode (Ag/AgCl/seawater) in 30 Ω·cm seawater.

[a] These negative limits also ensure negligible impact of CP on pipeline coatings.

[b] Where pipeline systems are fabricated from high strength steel ($\sigma_{SMY} > 550$ MPa), the most negative potential that can be tolerated without causing hydrogen embrittlement shall be ascertained.

[c] N_{PRE} = %Cr + 3,3 %(Mo+0,5W) + 16 %N.

[d] For stainless steels, the minimum negative potentials apply for aerobic and anaerobic conditions.

[e] Depending on strength, specific metallurgical condition and stress level encountered in service, these alloys can be susceptible to hydrogen embrittlement and cracking. If a risk of hydrogen embrittlement exists, then potentials more negative than –0,8 V should be avoided.

There are no set standards with respect to field gradient activity, however when used in conjunction with the CP readings, field gradient can give an indication of high activity, thus identifying anodes with high current output or active bare steel areas on pipelines, or conversely low activity, which in the case of anodes may indicate disconnection or passivity. For further details please refer to Appendix III Interpretation of CP Results .

4.5 Post CP Survey

On completion of the survey, post dive calibrations should be undertaken to ensure that no equipments faults or half cell cells drift has occurred during the survey. A check should also be made to ensure that data integrity has been maintained and data backups made

5 Reporting Requirements

Historic data of periodic inspections and on-line monitoring should be kept such that long-term trends become apparent and can be analysed.

In general terms an inspection survey report shall be provided when the data are processed and interpreted, and depending on the complexity of the survey include the following items:

- Description of the operations performed;
- Technical characteristics and operating parameters of the monitoring equipment used;
- Corrections (if any) applied to the records;
- Plotted graphs of pipe potential along the pipeline;
- Measured field gradients (if required);
- Measured resistivity values (if required);
- Original recordings on paper and on magnetic or optical storage medium;
- Comparison of the recorded data with those recorded at previous surveys

In detail;

Report using Continuous & Contact CP Equipment

- The survey report shall provide a continuous cathodic protection potential level along the entire length of each pipeline, within the survey range. This shall be in illustrated in the form of a chart – CP level (mV) on the 'Y' axis and pipeline length (km) on the 'X' axis.
- A summary table of contacts shall also be provided showing CP level, position in KP and description of the contact e.g "Anode, Flange, Bare Metal Damage etc.. For anode contacts wastage in % shall also be given.

Report using Continuous Contact CP & FG Equipment

- The survey report shall provide a continuous cathodic protection potential level along the entire length of each pipeline, within the survey range. This shall be in illustrated in the form of a chart – CP level (mV) on the 'Y' axis and pipeline length (km) along the 'X' axis.
- The survey report shall provide a continuous FG level along the entire length of each pipeline, within the survey range. This shall be in illustrated in the form of a chart with FG on the 'Y' axis and pipeline length (km) along the 'X' axis
- Contact tables shall also be provided showing CP level, FG level, position in KP and description of the contact e.g "Anode, Flange, Bare Metal Damage etc.. For steel contacts FG level will also be included.

- On the basis that anode information is available the current output & anode remaining life calculations will also be included.

- Estimated anode wastage in % shall also be given.

All survey reports shall include an analysis on the adequacy of the protection to the pipelines, in relation to the cathodic protection system in place. Any anomaly, unusual observation or area of concern should also be analyzed and included in the survey report. Recommendations regarding any remedial action or future survey requirements should also form part of the report.

Optionally, if required ASCII files containing the pipeline CP survey data should be made available for the production of alignment charts or for inclusion into a pipeline corrosion management database. The format of files supplied should have each sample linked to date, time & position.

Before submission to the Client the CP Survey report should be reviewed & approved by the assigned Technical Authority.

6 Glossary of Terms & Definitions Commonly used in CP Survey

active
A state in which a metal tends to corrode; referring to the negative direction of electrode potential (opposite of passive or noble).
active metal
A metal ready to corrode, or being corroded.
active potential
The potential of a corroding material.
anaerobic
In the absence of air or unreacted or free oxygen.
anode
The electrode at which oxidation or corrosion of some component occurs (opposite of cathode). Electrons flow away from the anode in the external circuit.
anode corrosion
The dissolution of a metal acting as an anode.
anodic reaction
Electrode reaction equivalent to a transfer of positive charge from the electronic to the ionic conductor. An anodic reaction is an oxidation process. An example common in corrosion is:
Me -> Me(+n) + n(e-).
calomel electrode
An electrode widely used as a reference electrode of known potential in electrometric measurement of acidity and alkalinity, corrosion studies, voltammetry, and measurement of the potentials of other electrodes.
cathode
The electrode of an electrolytic cell at which reduction is the principal reaction. (Electrons How toward the cathode in the external circuit.). Typical cathodic processes are cation' taking up electrons and being discharged, oxygen being reduced. and the reduction of an element or group of elements from a high Cl a lower valence state.
cathodic polarisation
Polarisation of the cathode; change of the electrode potential in the active (negative) direction due to current flow; a reduction from the initial potential resulting from current flow effects at or near the cathode surface. Potential becomes more active (negative) because of cathodic polarization. See also polarisation.
cathodic protection
(1) Reduction of corrosion rate by shifting the corrosion potential of the electrode toward a less oxidizing potential by applying an external electromotive force. (2) Partial or complete protection of a metal from corrosion by making it a cathode, using either a galvanic or an impressed current.
cathodic reaction
Electrode reaction equivalent to a transfer of negative charge from the electronic to the ionic conductor. A cathodic reaction is a reduction process.
cell
Electrochemical system consisting of an anode and a cathode immersed in an electrolyte. The anode circuit, which permits the flow of electrons from the anode toward the cathode. See also electrochemical cell.
conductivity
The ratio of the electric current density to the electric field in a material. Also called electrical conductivity or specific conductance.

continuity bond
A metallic connection that provides electrical continuity between metal structures.
corrosion
"Corrosion is an irreversible interfacial reaction of a material (metal, ceramic, polymer) with its environment which results in consumption of the material or in dissolution into the material of a component of the environment". As defined by the International Union of Pure and Applied Chemistry (IUPAC)
corrosion effect
A change in any part of the corrosion system caused by corrosion.
corrosion rate
Corrosion effect on a metal per unit of time. The type of corrosion rate used depends on the technical system and on the type of corrosion effect. Thus, corrosion rate may be expressed as an increase in corrosion depth per unit of time (penetration rate, for example, mils/yr.) or the mass of metal turned into corrosion products per unit area of surface per unit of time (weight loss, for example, g/m-/yr). The corrosion effect may vary with time and may not be the same at all points of the corroding surface. Therefore reports of corrosion rates should be accompanied by information on the type, time dependency, and location of the corrosion effect.
current
The net transfer of electric charge per unit time. Also called electric current. Measured in Amps See also current density.
current density
The current flowing to or from a unit area of an electrode surface, generally expressed as milliamps per sq cm, etc).
depolarisation
A decrease in the polarisation of an electrode; the elimination or reduction of polarisation by physical or chemical means; depolarisation results in increased corrosion.
electrolyte
(1) A chemical substance or mixture, usually liquid, containing ions that migrate in an electric field.
(2) A chemical compound or mixture of compounds which when molten or in solution
electric field gradient (FG)
change in electrical potential per unit distance through a conductive medium, arising from the flow of electric current
galvanic
Pertaining to the current resulting from the coupling of dissimilar electrodes in an electrolyte
half cell
An electrode immersed in a suitable electrolyte, designed for measurements of electrode potential. A pure metal in contact with a solution of known concentration of its own ion, at a specific temperature develops a potential which is characteristic and reproducible; when coupled with another half cell, an overall potential develops which is the sum of both half cells.
impressed current
Direct current supplied by a device employing a power source external to the electrode system of a cathodic protection installation.
inert anode
An anode that is insoluble in the electrolyte under the conditions prevailing in the electrolysis.
ion
An atom, or group of atoms, that has gained or lost one or more outer electrons and thus carries an electric charge. Positive ions, or cations, are deficient in outer electrons. Negative ions, or anions, have an excess of outer electrons.
IR drop
voltage, due to any current, developed between two points in the metallic path or in the lateral gradient in an electrolyte such as seawater or seabed, measured between a reference electrode and the metal of the pipe, in accordance with Ohm's Law

passivation.
(1) A reduction of the anodic reaction rate of an electrode involved in corrosion. (2) The process in metal corrosion by which
metals become passive. (3) The changing of a chemically active surface of' a metal to a much less reactive state.
potential
Any of various functions from which intensity or velocity at any point in a field may be calculated. The driving influence of an electrochemical reaction.
protective potential
The threshold value of the corrosion potential that has to be reached to enter a protective potential range. The term used in cathodic protection to refer to the minimum potential required to suppress corrosion.
reference electrode
A non-polarisable electrode with a known and highly reproducible potential used for potentiometric and voltammetric analyses.
See also calomel electrode and silver/silver chloride electrode.
resistance
The opposition that a device or material offers to the flow of direct current, equal to the voltage drop across the element divided by the current through the element. Also called electrical resistance.
riser
(1) That section of pipeline extending from the ocean floor up the platform.
remotely operated vehicle ROV
underwater vehicle operated remotely from a surface vessel or installation
rust
A visible corrosion product consisting of hydrated oxides of iron. Applied only to ferrous alloys.
sacrificial protection
Reduction of corrosion of a metal in an electrolyte by galvanically coupling it to a more anodic metal; a form of cathodic protection.
saturated calomel electrode (SCE)
A reference electrode composed of mercury, mercurous chloride (calomel), and a saturated aqueous chloride solution.
silver/silver chloride reference electrode (Ag/AgCl)
A reference electrode composed of silver, silver chloride, and an aqueous chloride solution.*
**For marine electrodes the aqueous chloride solution is seawater.*
stray current
Current through paths other than the intended circuit.
stray-current corrosion
Corrosion resulting from current through paths other than the intended circuit, e.g., by any extraneous current in the earth.
structure-to-electrolyte potential
The potential difference between the surface of a buried or submerged metallic structure and the electrolyte that is measured with reference to an electrode in contact with the electrolyte.
volt
Basic unit of electrical potential. One volt is the force required to send one ampere of electrical current through a resistance of one ohm

APPENDIX I

Example CP Calibration Log Sheet

3 Calibration Log

Client:	Location:
Job No:	Vessel:

Date:	Time:	Survey Type:

Cells	Readings mV	Comments
Calomel 1 V Calomel 2		
Calomel 1 V Calomel 3		
Calomel 2 V Calomel 3		
Calomel Cell Used to Calibrate		
Calomel Cell to Ag/AgCl 1		
Calomel Cell to Ag/AgCl 2		
Calomel to Remote		
Zinc to Ag/AgCl Cell 1		
Cell 1 to Cell 2		

Survey Engineer	Signed

APPENDIX II

Degradation Mechanisms Affecting CP

The operational life a CP system is dependent on a number of factors namely;

- Design

  Inadequate design of the CP system can lead to premature anode consumption and under protection

- Age

  The pipeline has a finite design life and dependent on the demands placed upon it, it is inevitable that the CP system will eventually become exhausted (applicable for sacrificial systems).

- Damage

  During installation, damage can occur to the pipeline coating or anodes where the coating can be removed exposing bare steel, bonding straps can become detached from the pipeline causing the anodes to be ineffective. Damage can also occur to the pipeline coating after installation e.g. anchor dragging, trawl damage, dropped objects etc. thereby creating an increased demand on the CP system.

- Installation of additional facilities, tie-ins etc.

  During the service life of the pipeline, additional facilities may be installed which can cause increase current demand on the CP, possibly leading to premature failure.

- Changes in environmental conditions

  The surrounding seabed & pipeline environment can change causing damage due to, for example; stability, loss of support (spanning) & upheaval buckling, resulting in pipeline damage.

- Interference

  Interaction between CP systems can occur between the pipeline, other pipelines and structures. e.g at pipeline crossings, failure of electrical isolation at platform tie-in, metallic debris etc. Impressed current CP systems can also cause interference and cause overprotection.

- Passivation/Deactivation

Due to contamination during the manufacturing process some types of sacrificial anodes develop a passive non reactive surface and are unable to supply current to protect the pipeline. Passivation can also occur when mixed sacrificial & impressed current CP systems are electrically connected.

Manifestation of Degradation

The above scenarios are manifested in four forms of degradation that can have a deleterious effect on the effectiveness of a CP system.

- Anode wastage (or inactivity)
- Anode damage
- Coating / Pipeline Damage
- Corrosion

In order to identify the effects of the above factors on a CP system, one or more of the techniques discussed should be able to provide the required level of detail to allow for an assessment to be made. See Table below showing the type of information obtainable from each CP survey type.

		X = Applicable CP Survey Technique			
Required Data Field	***Standard Unit Measured****	***Proximity Half Cell***	***CP Stab Probe***	***Cell to Cell Probe***	***Twin Cell with FG & Remote***
Contact CP	*V or mV*		*X*	*X*	*X*
Proximity Half Cell CP #	*V or mV*	*X*		*X*	*X*
Continuous Proximity CP	*V or mV*	*X*		*X*	*X*
Field Gradient	*µV/cm*				*X*
Anode Current Density	*mA /cm^2*				*X*
Anode Current Output	*A or mA*				*X*
Anode Remaining Life	*Years*				*X*

Note 1# Proximity Half Cell from ROV is mainly used for platform surveys, however short sections of pipeline survey close to a platform can be undertaken, usually less than 100m distant from the base of the structure.

**By convention all CP readings when measured using a Ag/AgCl reference electrode against steel or sacrificial anodes are given in minus V or minus mV for example; -950mV or -0.950 V.*

Field Gradient can give either a positive(+ve) or negative (-ve) value dependent on the field, again by convention a positive field gradient value indicates current flowing into the pipeline surface (e.g. active coating damage) and a negative field gradient indicates current flowing out (e.g. active anode) The larger the field gradient value the greater the activity.

APPENDIX III

Interpretation of CP Survey Results

The effectiveness of CP or other external corrosion control measures can be confirmed by direct measurement of the pipeline potential & activity. However, visual observations of progressive coating deterioration and/or corrosion are also indicators of possible inadequate protection.

Therefore, the potential profile and field gradient readings, together with visual observations obtained during the pipeline survey can provide valuable information on the corrosion protection level and CP system performance.

The potential gives general protection level information while the field gradient gives detail on anode activity and areas with higher current demand such as at damaged areas, field joints, and spool pieces, etc.

Also, from field gradient readings, it is possible to calculate current density, anode current output and the estimated remaining life of the anodes.

Thus, from the close relationship between potential and field gradient measurements obtained, it is possible to compute the level and distribution of potential and current density giving a general representation of the efficiency and effectiveness of the CP system and the integrity of the pipeline coating.

Typical results can be summarised as follows:

A well protected pipeline is expected to have:

- Low electric field strength, and thus, low anode current output
- General potential levels between -900 mV and -1050 mV against Ag/AgCl for zinc anodes, and between -900 mV and -1100 mV for Aluminium alloy anodes.

A poorly or marginally protected pipeline is expected to have:

- High negative field strengths and higher current output at anodes
- Large drops in the potential profiles at the anodes due to high current output.
- High positive field strength readings at local areas of high steel concentration.
- General potential levels more positive than -800 mV.

A pipeline with little or no cathodic protection expected to have:

- Low electric field strength with little or no current output at anode locations
- Flat potential profiles at the anodes due to anodes being 100% consumed
- Low electric field strength readings at local areas of high steel concentration.
- General potential levels approaching that of freely corroding steel (-650mV)