PETROBRAS

N-2801	REV. A	ENGLISH	DEC / 2005

INSPECTION OF CATHODIC PROTECTION SYSTEMS FOR ON-LAND PIPELINES

Procedure

This Standard replaces and cancels its previous revision.

The CONTEC - Authoring Subcommittee provides guidance on the interpretation of this Standard when questions arise regarding its contents. The Department of PETROBRAS that uses this Standard is responsible for adopting and applying the clauses thereof.

Technical Requirement: a provision established as the most adequate and which shall be used strictly in accordance with this Standard. If a decision is taken not to follow the requirement (“non-conformity” to this Standard) it shall be based on well-founded economic and management reasons, and be approved and registered by the Department of PETROBRAS that uses this Standard. It is characterized by the verb forms “shall,” “it is necessary...,” “is required to...,” “it is required that...,” “is to...,” “has to...,” “only ... is permitted,” and other equivalent expressions having an imperative nature.

Recommended Practice: a provision that may be adopted under the conditions of this Standard, but which admits (and draws attention to) the possibility of there being a more adequate alternative (not written in this Standard) to the particular application. The alternative adopted shall be approved and registered by the Department of PETROBRAS that uses this Standard. It is characterized by the verbal form “should” and equivalent expressions such as “it is recommended that...” and “ought to...” (verbs of a nonmandatory nature). It is indicated by the expression: **[Recommended Practice].**

Copies of the registered “non-conformities” to this Standard that may contribute to the improvement thereof shall be submitted to the CONTEC - Authoring Subcommittee.

Proposed revisions to this Standard shall be submitted to the CONTEC - Authoring Subcommittee, indicating the alphanumeric identification and revision of the Standard, the clause(s) to be revised, the proposed text, and technical/economic justification for revision. The proposals are evaluated during the work for alteration of this Standard.

CONTEC
Comissão de Normalização Técnica

SC - 15
Cathodic Protection

Foreword

PETROBRAS Technical Standards are prepared by Working Groups - WG (consisting of specialists from PETROBRAS and its Subsidiaries), are commented by PETROBRAS Units and PETROBRAS Subsidiaries, are approved by the Authoring Subcommittees - SCs (consisting of specialists from the same specialty, representing the various PETROBRAS Units and PETROBRAS Subsidiaries), and ratified by the Executive Nucleus (consisting of representatives of the PETROBRAS Units and PETROBRAS Subsidiaries). A PETROBRAS Technical Standard is subject to revision at any time by its Authoring Subcommittee and shall be reviewed every 5 years to be revalidated, revised or cancelled. PETROBRAS Technical Standards are prepared in accordance with standard PETROBRAS N-1. For complete information about PETROBRAS Technical Standards see PETROBRAS Technical Standards Catalog.

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FOREWORD

This Standard is the English version (issued in APR/2006) of standard PETROBRAS N-2801 REV. A DEC/2005.

1 SCOPE

1.1 This Standard specifies the minimum conditions required for conducting routine and special inspections in cathodic protection systems used on on-land pipelines, as defined in standard PETROBRAS N-2098.

Note: Subsea pipelines or subsea sections of on-land pipelines are not considered in this Standard and shall be inspected in accordance with standard PETROBRAS N-1487. However, if they are protected by a cathodic protection system installed onshore, the equipment shall be inspected according to this Standard.

1.2 This Standard applies to the inspection of cathodic protection systems of on-land pipelines as of its date of issuance.

1.3 This Standard contains Technical Requirements and Recommended Practices.

2 COMPLEMENTARY DOCUMENTS

The documents listed below are mentioned in the text and contain valid requirements for the present Standard.

PETROBRAS N-1487	- External Inspection - Submarine Pipeline;
PETROBRAS N-1493	- Equipamento de Drenagem para Proteção Catódica;
PETROBRAS N-2098	- Inspeção de Duto Terrestre em Operação;
PETROBRAS N-2608	- Rectifiers for Cathodic Protection;
NACE TM-0497	- Measurement Technique Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping System.

Note: For documents referred in this Standard and for which only the Portuguese version is available, the PETROBRAS department that uses this Standard should be consulted for any information required for the specific application.

3 DEFINITIONS

For the purposes of this Standard the definitions indicated in items 3.1 to 3.24 are adopted.

3.1 SRB

Sulfate-reducing bacteria.

3.2 AC

Electrical alternating current.

3.3 DC

Electrical direct current.

3.4 Dynamic Interference Currents

Electrical direct or alternating currents dispersed in the electrolyte, of telluric origin or from railway or subway traction systems or electric power transmission lines or other cathodic protection systems, which enter particular regions of the pipeline and may cause corrosion at the point on the piping where they leave such structure.

3.5 Telluric Currents

Interference currents circulating in piping resulting from geomagnetic fluctuations of the planet.

3.6 Cathodic Protection Coupon

Device comprised of a permanent copper / copper sulfate ($Cu/CuSO_4$) half cell and a metallic representative sample of the pipeline material with a known exposure area, used to evaluate the efficiency of the cathodic protection applied.

3.7 Remote Monitoring Device - RMD

Device used for remote monitoring of cathodic protection parameters, such as: pipe-to-soil potential, rectifier voltage and current, electrical equipment supply voltage, door opening signal, and drained current.

3.8 Insulation Joint Protection Device - IJPD

Device used for protecting conventional or monobloc type electrical insulation joints against transient voltages induced by lightning or induction from short circuits on electric power transmission lines.

3.9 Electrical Drainage

Equipment with AC power supply comprised of a diode and an electronic switch the function of which is to return the interference current, via anode ground bed or direct connection, to the source of origin.

3.10 Galvanic Drainage

Equipment comprised of a diode the function of which is to return the interference current, via anode ground bed or direct connection, to the source of origin.

3.11 Routine Inspection

Inspection conducted periodically to evaluate the cathodic protection pipe-to-soil potential levels to which the pipelines are subjected, as well as to check on the operating conditions of the basic components of a Cathodic Protection System (CPS) of on-land pipelines.

3.12 Special Inspection

Complementary inspection performed based on pipeline integrity assessment needs, in relation to the external anticorrosive protection system (coating and cathodic protection) of the pipeline, adopting special techniques such as, for example, those presented in item 3.24.

3.13 Conventional Electrical Insulation Joints

Electrical insulating accessory installed on a pair of flanges, between 2 pipeline sections, to provide electrical discontinuity between those sections.

3.14 Monobloc Type Electrical Insulation Joints

Pre-manufactured electrical insulating accessory installed between 2 pipeline sections to provide electrical discontinuity between those sections.

3.15 Test Point - TP

Device intended to measure the electrochemical potential of the pipeline. For the purposes of this Standard, test points are considered to be interconnection boxes between PETROBRAS pipelines and foreign pipelines.

3.16 Protection Potential

Structure-to-electrolyte potential for which the corrosion rate is negligible.

3.17 “ON” Potential

Pipe-to-soil potential measurement when the CPS is operating continuously, that is, potential measured with the ohmic IR drop present in the soil.

3.18 “OFF” Potential

Structure-to-electrolyte potential measured immediately after interrupting application of cathodic protection current from all cathodic protection sources affecting the pipeline potential at the measurement site, that is, the measured ohmic drop free potential.

3.19 Ohmic IR Drop in Soil

Voltage drop in soil, due to the passage of electric current, measured between the reference half-cell and the metallic surface of the pipeline, according to Ohm’s law.

3.20 Continuous Recording of Pipe-to-Soil Potential

Measurement conducted continuously at a particular point for a definite period of time using a recording voltmeter.

3.21 Reference Half-Cell or Electrode

Electrode having a constant open-circuit potential under similar measurement conditions and used for measuring the pipe-to-soil potential.

3.22 Cathodic Protection System - CPS

System comprising a direct current source and anode intended to provide anticorrosive protection current to a buried or submerged metallic structure.

3.23 Cathodic Overprotection

Excessively negative potentials caused by high current densities near a pipeline coating defect.

3.24 Special Inspection Techniques

3.24.1 ACVG (Alternating Current Voltage Gradient) Survey

Quantitative and qualitative coating flaw inspection technique implemented with suitable equipment which precisely locates the coating flaw, from the soil surface, measuring the ohmic drop in the soil from the AC signal injected by a transmitter.

3.24.2 DCVG (Direct Current Voltage Gradient) Survey

Coating flaw inspection technique (qualitative and quantitative) applied to buried pipelines, used on the pipeline right of way. In this technique direct current is injected between the pipeline and the soil and measurements are made of the voltage gradient along the length of pipeline coating to be inspected. The installation of a current switch on the closest rectifier(s) allows assessment of the anodic or cathodic behavior of the test location.

3.24.3 Current Attenuation (CA) Survey

Qualitative coating inspection technique applied to buried pipelines, implemented on the pipeline right of way. In this technique alternating current is injected between the pipeline and the ground, with signal tracing through a sensing coil receiver to measure the force of the magnetic field resulting from the CA signal, locating the pipeline on the right of way and measuring the current along the pipeline. A current attenuation chart is then prepared for a qualitative assessment of the coating.

3.24.4 Close Interval Potential Survey (CIPS)

CPS inspection technique applied on buried pipelines and implemented on the pipeline right of way. This technique involves the determination of the “ON” and “OFF” cathodic protection potentials measured at short intervals of 1 m to 2 m, with synchronized switching of rectifiers or another technique taking into consideration the IR drop in the soil.

4 GENERAL CONDITIONS

4.1 For each Cathodic Protection System (CPS) the basic and detailed design documents as well as background information on operation, inspection, and maintenance shall be available.

Note: If such design documents are not available, documents depicting the current situation of the CPS shall be prepared.

4.2 An execution procedure shall be prepared for the CPS inspection activity, which shall also take into consideration the provisions in items 4.2.1 to 4.2.4.

4.2.1 If there is vandalism on the pipeline right of way.

4.2.2 If the pipelines are subject to pipe-to-soil potential fluctuations due to dynamic interference currents (see ANNEX D), the areas of fluctuations shall be examined and delimited.

4.2.3 In case the pipelines share the right of way with third-party pipelines, the users and monitoring procedures of the respective cathodic protection systems shall be consulted.

4.2.4 If the test point, rectifier or drainage has a permanent $Cu/CuSO_4$ half-cell with a cathodic protection coupon.

4.3 Rectifying equipment, electrical drainage, and galvanic drainage installed in regions with interference currents shall be remotely monitored with acquisition of daily data and fault alarms of at least the following signals:

a) supply voltage (electrical equipment);
b) output voltage (electrical equipment);
c) output current (rectifiers) or drained current (drainage);
d) pipe-to-soil potential;
e) opening of shelter door.

4.4 Instantaneous measurements or the continuous recording of pipe-to-soil potential of routine or special inspections shall be undertaken considering the following:

a) they shall be undertaken after a polarization of at least 2 weeks of energization of the CPS and at least 3 months after the pipeline has been buried;
b) a $Cu/CuSO_4$ reference half-cell shall be used;

Note: A zinc (Zn) electrode may also be used, but the half cell mentioned in paragraph b) shall preferably be adopted.

c) the half-cell shall be connected to the negative terminal of the voltmeter and positioned at ground level and on top of the pipeline;

d) "ON/OFF" pipe-to-soil potential measurements shall be made as follows:
   - all rectifiers that directly or indirectly affect the measurement point shall be turned on and off at the same time, using synchronizing current interrupter switches, acting on the positive or negative terminal of each equipment;
   - the synchronism of the switches shall be checked before the work starts (or is resumed) using, for instance, a paper recorder placed at 2 measurement points;
   - rectifiers shall remain on, without interruptions, throughout the period in which the measurements are not being made;
   - during the work, when there is any indication of abnormality in the CPS, such as, for example, when one or more rectifiers are no longer operating, the cause of the problem shall be identified and its solution shall be implemented so that the quality of the measurements is not adversely affected;

e) as an alternative to paragraph d), the wave form analyzer measurement technique may be used (see item A-1.3.5).

4.5 Routine inspection services shall be recorded on standardized forms and reports prepared according to item 6.4 of this Standard shall be issued. In special inspection services, reports prepared in accordance with item 7.3 of this Standard shall be issued.

4.6 In order to better standardize the systematic procedure adopted for inspection and exercise greater control over protection installations, a digitalized map should be identified and generated showing access to all rectifiers, drainage and test points. **[Recommended Practice]**

4.7 The characteristics of electrical drainage and rectifiers are contemplated in standards PETROBRAS N-1493 and N-2608, respectively.

5 CATHODIC PROTECTION CRITERIA

5.1 Pipelines not Subject to Dynamic Interference Currents

5.1.1 "OFF" polarized pipe-to-soil potential equal to or more negative than the values described in TABLE 1.

TABLE 1 - CATHODIC PROTECTION CRITERIA FOR PIPELINES NOT SUBJECT TO DYNAMIC INTERFERENCE CURRENTS

Electrolyte	Half-Cell	Value
Soil or fresh water without SRB	$Cu/CuSO_4$	- 0.85 Vdc
	Zn	+ 0.25 Vdc
Soil or fresh water with SRB	$Cu/CuSO_4$	- 0.95 Vdc
	Zn	+ 0.15 Vdc

5.1.2 In areas where it is not possible to obtain the criterion set out in item 5.1.1, a difference equal to or greater than 100 mVdc between the “OFF” polarized pipe-to-soil potential and the depolarized or natural value may be adopted as an alternative criterion, with due reservations regarding the following limitations:

a) such criterion shall only be adopted in close interval type surveys;
b) this criterion of 100 mVdc shall not be used in soils with the presence of sulfate-reducing bacteria, pipelines connected to or with dissimilar metal components.

5.1.3 In order to prevent overprotection of the pipeline, the “OFF” polarized pipe-to-soil potential should not be more negative than -1.20 Vdc ($Cu/CuSO_4$). **[Recommended Practice]**

5.1.4 On pipeline sections installed in soils with an electrical resistivity (ρ) greater than 10 000 Ωcm, the following protection criteria (“OFF potentials - $Cu/CuSO_4$) may be considered:

a) 10 000 Ωcm $< \rho \leq$ 100 000 Ωcm: -0.75 Vdc;
b) $>$ 100 000 Ωcm: -0.65 Vdc.

5.1.5 ANNEX A shows how potential measurements shall be made.

5.2 Pipelines Subject to Dynamic Interference Currents

5.2.1 In this case, where the ohmic drop in the soil is hard to assess, the protection criterion should be the “ON” polarized pipe-to-soil potential equal to or more negative than -0.85 Vdc ($Cu/CuSO_4$), evaluated with continuous potential recording. **[Recommended Practice]**

5.2.2 If the rectifier, drainage or test point has a permanent $Cu/CuSO_4$ half cell with a cathodic protection coupon, the “OFF” coupon-to-soil potential shall be in accordance with the criteria set out in item 5.1.

6 ROUTINE INSPECTION

6.1 General

6.1.1 A routine inspection plan shall be implemented and maintained, with a view to establishing routines intended to ensure the operation of the systems within the protection criteria set forth in this Standard, allowing decisions to be made within a reasonable time so as to prevent external corrosion of the pipeline. The purpose of the plan is to:

a) inspect CPS installations;
b) detect points with a deficiency in cathodic protection potential;
c) record nonconformities found;
d) recommend corrective actions.

6.1.2 The periodicity of the routine inspection shall be according to TABLE 2, so to cover the following components of a CPS of on-land pipelines:

a) manual or automatic and air - or oil-cooled rectifiers and their respective power supply branches, energy consumption meter, and shelters;
b) electrical drainage and its respective power supply branches, energy consumption meter, and shelters;
c) galvanic drainage;
d) galvanic or inert anode ground beds;
e) test points;
f) electrical insulation joints and respective protection devices;
g) devices used for remote monitoring of pipe-to-soil potential.

TABLE 2 - FREQUENCY OF ROUTINE INSPECTION

Inspection Item	Frequency				
	Weekly	Fortnightly	Quarterly	Half Yearly	Yearly
1. Pipe-to-Soil Potential					
Pipelines not subject to dynamic interference currents.				X (see item 6.2.1.2)	X (see item 6.2.1.1)
Pipelines subject to dynamic interference currents.				X (see item 6.2.2.2)	X (see item 6.2.2.1)
2. Rectifiers					
Pipelines not subject to dynamic interference currents.		X (see item 6.3.1.1)	X (see item 6.3.1.2)		X (see item 6.3.1.4)
Pipelines subject to dynamic interference currents.	X (see item 6.3.1.3)		X (see item 6.3.1.2)		X (see item 6.3.1.4)
3. Electrical Drainage	X (see item 6.3.2.2)		X (see item 6.3.2.1)		X (see item 6.3.2.3)
4. Galvanic Drainage	X (see item 6.3.3.2)		X (see item 6.3.3.1)		X (see item 6.3.3.3)
5. Inert and Galvanic Anode Ground Beds					X (see item 6.3.4)
6. Test Points					X (see item 6.3.5)
7. Insulating Joints and IJPD			X (see item 6.3.6.1)		X (see item 6.3.6.2)
8. Remote Monitoring Device (RMD)			X (see item 6.3.7)		
9. Electrical Power Supply Branches and Consumption Meter					X (see item 6.3.8)

6.1.3 Rectifiers, electrical drainage, galvanic drainage, insulating joints, IJPD, lightning arresters of electrical power supply branches and RMD should be inspected after rains with a high incidence of lightning in the region. **[Recommended Practice]**

6.1.4 During instantaneous measurements or continuous recording to pipe-to-soil potentials, the following shall be observed:

a) the half cell shall be positioned on the top part of each pipeline on the right of way, maintaining as reference the same position adopted for the previous measurements;
b) "ON/OFF" pipe-to-soil potential measurements shall be made with the "on-off" cycle of rectifiers of not more than 12 seconds "ON" by 3 seconds "OFF";
c) all continuous "ON" potential records shall be made on typical traffic days of the railway/subway system and shall cover the peak traffic hours of railway or subway compositions;
d) when a potential outside the criteria set forth in this Standard is observed, the cause of the anomaly shall be investigated with a view to making the necessary corrections to maintain or adapt the potential to the cathodic protection condition of the pipelines.

6.1.5 During output current measurements of rectifiers or drainage equipment (I_{OUTPUT}), when the shunt of the equipment is used, a calibrated voltmeter shall be utilized and the following rule shall be adopted:

$$I_{OUTPUT} = \frac{\Delta V \times I_N}{V_N}$$

Where:

ΔV = voltage drop measured at the shunt terminals, in mV;
I_N = rated current of shunt, in A;
V_N = rated voltage drop of shunt, in mV.

6.1.6 The operational reliability (D) of each rectifier shall be calculated on a monthly basis, considering the hours of effective operation (read on the hour meter) and the time elapsed between inspections, according to the formula below, incorporating such data into the reports mentioned in item 6.4 of this Standard:

$$D\,(\%) = \frac{\text{hours of operation between inspections (h)}}{\text{time elapsed between inspections (h)}} \times 100$$

Note: An operational availability of at least 95 % is recommended. **[Recommended Practice]**

6.1.7 The results found in the pipe-to-soil potential surveys and in the inspections of the CPS components shall be presented in a report according to item 6.4.

6.1.8 ANNEX C presents a typical scheme recommended for detecting defects in the impressed-current CPS.

6.2 Pipe-to-Soil Potential Surveys

6.2.1 Pipelines Not Subject to Dynamic Interference Currents

6.2.1.1 Yearly Inspection

An “ON/OFF” pipe-to-soil potential survey shall be conducted at each test point (including the casing and on both sides of the electrical insulation joints), rectifier, and block valve, as well as at other points where there is direct or indirect access to the piping metal.

Note: The objective of the measurement of potential made on the casing and on the insulated side of the electrical insulation joints is to assess the electrical insulation with the pipeline.

6.2.1.2 Half-Yearly Inspection

a) a partial survey shall be conducted of the “ON” pipe-to-soil potentials on both sides of the electrical insulation joints and rectifier, comparing them with the last “ON/OFF” potential survey conducted;
b) if a value with a difference greater than 20 % between the respective “ON” potentials is observed at measured locations, an “OFF” potential measurement is also recommended at such location. **[Recommended Practice]**

6.2.2 Pipelines Subject to Dynamic Interference Currents

6.2.2.1 Yearly Inspection

A survey shall be conducted of the intensity and extent of interference by consulting the inspection reports and through continuous “ON” pipe-to-soil potential records. The continuous “ON” potential recording shall be carried out at each test point, rectifier, electrical drainage equipment, galvanic drainage, and block valve, observing item 6.1.4 paragraph c) and in accordance with the criteria in TABLE 3.

TABLE 3 - CRITERIA FOR ANNUAL RECORDS

Recording Time	Pipe-to-Soil Potential Variation (See Note 1)
For 1 hour	From 50 mV to 400 mV
For 4 hours	Over 400 mV
For 24 hours	With potential peaks of -0.85 V (see Note 7)

Notes:
1) The potential variation shall be measured in relation to the prevailing value, i.e. the value of higher incidence obtained in the same continuous record.
2) “ON” pipe-to-soil potential records for at least 24 hours shall be made at least once during the operational lifetime of the pipeline, at each test point, rectifier, electrical drainage equipment, galvanic drainage, and block valve.

3) In electrical and galvanic drainage, continuous records shall also be made of the drained current and of the pipe (+)/rail (-) potential.
4) At test points with a cathodic protection coupon, the “ON/OFF” coupon-to-soil potential as well as the intensity and direction of the electrical current between the coupon and the pipeline shall be surveyed.
5) The cathodic protection professional may increase the recording time and/or reduce the time period between inspections in case significant variations occur in the survey.
6) Pipelines with potential variations less than 50 mV may be treated as not subject to interference currents, item 6.2.1.
7) At locations where potential peaks of -0.85 V occur, selected according to the continuous “ON” potential records, the pipe-to-soil potential shall be continuously recorded for a period of 24 hours.

6.2.2.2 Half-Yearly Inspection

At points where potential peaks of -0.85 V occur, selected according to continuous “ON” potential records obtained in the last yearly inspection, the pipe-to-soil potential shall be recorded continuously for a period of 24 hours.

6.3 Cathodic Protection System Components

6.3.1 Rectifiers

6.3.1.1 For rectifiers without remote monitoring of pipelines not subject to dynamic interference currents, the following items shall be annotated/inspected/measured on a fortnightly basis:

a) date and time of inspection;
b) rectifier location and identification;
c) characteristics: type (manual or automatic), cooling (air or oil), manufacturer, month/year of manufacture, power supply (voltage, frequency, and number of phases) and rated current and voltage;
d) general state of repair (painting, internal and external cleaning, corrosion, and grounding of the equipment frame);
e) operation of voltmeters and ammeter (comparison with digital multimeter);
f) status of circuit breakers, fuses, and transient suppressors, replacing such items where necessary;
g) input voltage;
h) output voltage and current;
i) resistance of circuit external to rectifier, calculated as the ratio between the output voltage and current of the equipment;
j) pipe-to-soil potential with the rectifier on and off;
k) hour meter reading;
l) coarse and fine tap settings.

6.3.1.2 For rectifiers, with remote monitoring, of pipelines subject or not subject to dynamic interference currents, the annotations/inspections/measurements mentioned in item 6.3.1.1 shall be undertaken on a quartertly basis.

6.3.1.3 For rectifiers, without remote monitoring, of pipelines subject to dynamic interference currents, the annotations/inspections/measurements mentioned in item 6.3.1.1 shall be undertaken on a weekly basis.

6.3.1.4 For all rectifiers, the items listed in item 6.3.1.1 as well as those indicated below shall be inspected on an yearly basis:

a) conditions of wiring and inner components, replacing such items where necessary;
b) conditions of rectifier attachment to steel pole (and its strict verticality), clamps, nuts, and bolts;
c) operation of doors, greasing hinge pins, if necessary;
d) physical conditions of electrical contacts (including the grounding terminal of the equipment frame), re-tightening bolts and connections, cleaning and lubricating items where necessary;
e) in oil-cooled rectifiers, collect oil samples for dielectric strength analysis (minimum voltage of 1.5 kV, 60 Hz, for at least 1 minute), check if the moisture content and contaminants are as specified by the cooling oil manufacturer; if any of them fails, change all the oil;
f) permanent $Cu/CuSO_4$ half cells:
   - measure the “ON” potential of the pipeline with the permanent half-cell and a portable half cell, comparing the values;
   - measure, with a portable half cell, the “ON” potential of the pipeline at monitored locations, with a view to comparing it with the signal received remotely;
g) measurement of the AC potential difference between the neutral of the utility company and the grounding system of the equipment, which shall be equal to or less than 6 Vac; if this does not occur, the grounding resistance of the equipment and/or utility company shall be reduced;
h) access conditions (roads, bridges, fences, gates etc.);
i) terrain conditions (signs of erosion, silting etc.) in the shelter installation region, including the right of way;
j) physical conditions of grounding braids of movable parts of the shelter;
k) physical conditions of the external sidewalk, footings, and concrete reinforcements;
l) conditions of galvanization and/or painting of metallic structure and occasional corrosion spots;
m) conditions of concrete or masonry walls and ceiling and painting;
n) operation of shelter door and, if necessary, greasing of hinge pins;
o) physical conditions and attachment of tiles, including anchoring devices;
p) leveling of floor inside shelter, thickness and conditions of crushed stone or cement;
q) electrical ground pit, including cover and rod connections;
r) measurement of the electrical grounding resistance of the equipment, which shall be less than 10 Ω;
s) physical and cleanliness conditions of pull box, including metal cover and entry and exit of electrical conduits and cables, caulking with sealing compound, where necessary;
t) general corrosion conditions of equipment, conduits, attachment pole, and interconnection box;
u) general conditions of shelter.

6.3.2 Electrical Drainage

6.3.2.1 The following items shall be annotated/inspected/measured on a fortnightly basis:

a) date and time of inspection;
b) location and identification of drainage;
c) characteristics: type, manufacturer, month/year of manufacture, power supply (voltage, frequency and number of phases) and rated current;
d) general state of repair (painting, internal and external cleaning, corrosion, and grounding of equipment frame);
e) conditions of voltmeters and ammeter;
f) conditions of circuit breakers, fuses, and transient suppressors, replacing such items where necessary;
g) general conditions of shelter;
h) input voltage;
i) drained current;
j) pipe-to-soil and pipe (+)-to-rail (-) potential;
k) diode conditions;
l) hour meter reading.

6.3.2.2 For electrical drainage the remote monitoring of which is not in service, the following annotations/inspections/measurements mentioned in item 6.3.2.1 shall be undertaken on a weekly basis.

6.3.2.3 The inspection of the items listed in item 6.3.2.1 and those shown below shall be repeated every year:

a) diode characteristics and conditions;
b) conditions of wiring and inner components, replacing such items where necessary;
c) conditions of equipment attachment to steel pole (and its strict verticality), clamps, nuts, and bolts;
d) operation of doors, greasing hinge pins, if necessary;
e) physical conditions of electrical contacts (including grounding terminal of equipment frame), re-tightening bolts and connections, cleaning and lubricating such items where necessary;
f) permanent $Cu/CuSO_4$ half cells [see item 6.3.1.4 paragraph f) of this Standard];
g) measurement of AC potential difference between the neutral of the utility company and the grounding system of the equipment, which shall be equal to or less than 6 Vac; if this does not occur, the grounding resistance of the equipment and/or utility company shall be reduced;
h) access conditions (roads, bridges, fences, gates etc.);
i) terrain conditions (signs of erosion, silting etc.) in the region where the shelter is installed, including the right of way;
j) physical conditions of grounding braid of movable parts of the shelter;
k) physical conditions of external sidewalk, footings, and concrete reinforcements;
l) conditions of concrete or masonry walls and ceiling and painting;
m) operation of the shelter’s door and, if necessary, greasing of hinge pins;
n) physical status and conditions of tile attachment, including fastening devices;
o) leveling of floor inside shelter, thickness and conditions of crushed stone or cement;
p) electrical ground pit, including the cover and rod connections;

q) measurement of the electrical grounding resistance of the equipment, which shall be less than 10 Ω;
r) physical and cleanliness conditions of pull box, including the metal cover and entry and exit of electrical conduits and cables, caulking with sealing compound, where necessary;
s) general corrosion conditions of equipment, conduits, attachment pole, and interconnection box;
t) general condition of shelter.

6.3.3 Galvanic Drainage

6.3.3.1 The items listed below shall be annotated/inspected/measured on a quarterly basis:

a) date and time of inspection;
b) location and identification of drainage;
c) diode characteristics and conditions;
d) conditions of interconnection box (pipeline/anodes);
e) drained current;
f) pipe-to-soil and pipe-to-rail potential.

6.3.3.2 For galvanic drainage whose remote monitoring is not in operation, the annotations/inspections/measurements mentioned in item 6.3.3.1 shall be undertaken on a weekly basis.

6.3.3.3 The inspection of the items listed in item 6.3.3.1 and the ones below shall be repeated on an yearly basis:

a) check if all anodes are electrically active, according to ANNEX B, when applicable;
b) permanent $Cu/CuSO_4$ half cells [see item 6.3.1.4 paragraph f) of this Standard];
c) access conditions.

6.3.4 Galvanic and Inert Anode Ground Beds

The following items shall be annotated/inspected/measured on an annual basis:

a) date and time of inspection;
b) rectifier location and identification;
c) physical and attachment conditions of concrete markers and identification plate of the anode ground bed strip;
d) terrain conditions (signs of corrosion, landslides, silting, exposed cables etc.) on the ground bed installation land strip, from the pipelines to the last anode;
e) existence of buildings and plantations not allowed on the anode ground bed strip;
f) the anode ground bed should be inspected through the procedure shown in ANNEX B or using a high frequency transmitter/ receiver set (current attenuation equipment); **[Recommended Practice]**
g) analysis of the variation in resistance of the inert anode ground bed based on the results indicated in item 6.3.1.1 paragraph i), for future maintenance of the anode ground bed.

6.3.5 Test Points

The following points shall be annotated/inspected/measured on an yearly basis:

a) date and time of inspection;
b) location and identification of test point;
c) type:
   - simple, on casing or on insulating joint;
   - aboveground or buried;
   - in aluminum box, concrete pole etc.;
d) access conditions, preparing or updating the access map;
e) physical conditions, strict verticality and attachment of pole, conduit etc.;
f) painting and identification conditions;
g) physical conditions of box, “Celeron” plate, measurement terminals and electrical cables and, if necessary, identify cables, repair, replace, clean and lubricate;
h) “ON” pipe-to-soil potential measurement (including both sides of the insulating joints and casings) and “OFF” pipe-to-soil potential measurement (when applicable), with a view to checking if there are any short circuits, broken wires, damages to the installation or oxidation of terminal blocks and bolts;
i) verification of operation of permanent $Cu/CuSO_4$ half cell with cathodic protection coupon, when applicable;
j) general conditions of cleanliness.

6.3.6 Electrical Insulation Joints and IJPD

6.3.6.1 The items listed below shall be annotated/inspected/measured on a quarterly basis:

a) date and time of inspection;
b) place and type of joint (conventional or monobloc);
c) operation of zinc anodes, when applicable, measuring their potentials in relation to the soil;
d) conditions of transient suppressor, replacing it, if necessary;
e) “ON” pipe-to-soil potential measurements on both sides, with the zinc anodes disconnected, when applicable.

6.3.6.2 The inspection of the items listed in item 6.3.6.1 and the ones given below shall be repeated every year:

a) physical appearance (dents, undercuts, burns, cracks, and lack of material in regions filled with insulating material);
b) painting conditions;
c) efficiency verification tests (see Chapter A-2 of ANNEX A). **[Recommended Practice]**

6.3.7 RMD

The items listed below shall be annotated/inspected/measured on a quarterly basis:

a) date and time of inspection;
b) location and identification of RMD;
c) measurement, with a portable half cell, of the potentials at monitored points, with a view to comparing them with the signal received remotely;

d) verification of the conditions of the half cell, transducer, and electrical cables, replacing such items where necessary;
e) pipe-to-soil potential or output voltage and current, input voltage (rectifier) and drained current, with a view to comparing them with the signal received remotely.

6.3.8 Power Supply Branches and Consumption Meter

The following items should be annotated/inspected/measured every year: **[Recommended Practice]**

a) date and time of inspection;
b) location and identification of electrical equipment;
c) physical conditions of electrical grounding;
d) physical conditions of energy meter and respective connections;
e) energy meter input and output voltage measurement.

6.4 Procedures for Preparation of Reports/Forms

6.4.1 Quarterly, half-yearly, and yearly inspection reports shall be issued according to the type of inspection performed, observing the following:

a) the results shall be recorded on specific forms and consolidated in the reports;
b) all abnormal conditions of relevance to proper performance of the CPS shall be immediately recorded and reported to the department responsible for solving the problem.

6.4.2 The reports shall contain at least the information described in items 6.4.2.1 to 6.4.2.10.

6.4.2.1 Introduction.

6.4.2.2 Objective of report.

6.4.2.3 Scope of services (inspection items).

6.4.2.4 Pipeline data, such as identification, beginning of operation, nominal diameter, operating temperature, coating type, and length.

6.4.2.5 The results obtained in the pipe-to-soil potential surveys and in the inspections of system components, observing the following, in the case of potential surveys:

a) in the case of pipelines not subject to dynamic interference currents, the report shall contain at least a table with the values obtained and a chart with “ON/OFF” potential values, associated with the kilometer of the right of way, bearing in mind that the output voltage and current shall be informed on the line of each rectifier;

b) in the case of pipelines subject to dynamic interference currents, the report shall present all records made and shall contain at least a table with the maximum, minimum, and prevailing values, identified by the location and respective kilometer of the right of way; the following shall be observed:
   - on the line of each rectifier: inform the output voltage and current and if it is operating in the manual or automatic mode;
   - on the line of each drainage: the maximum, minimum, and prevailing values of the respective drained current and pipe (+) / rail (-) potential.

6.4.2.6 Index of operational availability (D) of each rectifier.

6.4.2.7 Annotation of detected problems that might jeopardize the performance of the system.

6.4.2.8 Conclusions regarding the operation of the cathodic protection components and/or potentials.

6.4.2.9 Recommendations for solving problems encountered.

6.4.2.10 Reference documents.

6.4.3 The forms and reports shall be filed in an organized manner in order to allow the preparation of a history of the CPS and perfect traceability of information.

6.5 Minimum Structure for Carrying Out Routine Inspections

6.5.1 Personnel Qualification

The individuals technically in charge of CPS inspections shall be qualified, bear a certificate from a course on on-land pipeline cathodic protection, promoted by PETROBRAS or a recognized entity, and preferably have training in electrotechnics.

6.5.2 Minimum Recommended Instruments and Accessories

a) 2 digital multimeters, with records for maximum, minimum, and prevailing values, with an internal resistance not less than 10 MΩ/V;
b) 2 potential recorders, with an internal resistance not less than 10 MΩ/V and scales ranging from 2 Volts to 20 Volts, in the case of pipelines subject to dynamic interference currents;
c) 2 $Cu/CuSO_4$ half cells;
d) 1 clamp-on ammeter for alternating and direct current, with a scale, also in milliamperes.

6.5.3 Calibration

6.5.3.1 Measuring instruments shall be calibrated in an accredited laboratory with a maximum periodicity of 2 years.

6.5.3.2 Portable half cells shall be calibrated every year in accredited laboratories or according to the procedure of standard NACE TM-0497.

Note: The standard half cell used in the procedure of standard NACE TM-0497 shall be calibrated in an accredited laboratory, with a maximum periodicity of 2 years, or, alternatively, be replaced by a new one.

7 SPECIAL INSPECTION

7.1 General

7.1.1 A special inspection plan shall be implemented with a view to conducting a detailed survey of the CPS conditions (including the coating), recording nonconformities, and recommending corrective actions.

7.1.2 The special inspection plan (see item 7.2) shall be applied along the entire pipeline or on a specific section using one or more of the special inspection techniques described below:

a) close interval potential survey (CIPS): “ON/OFF” potential profile survey;

Note: The technique described in paragraph a) is not recommended for pipelines subject to dynamic interference currents.

b) DCVG;
c) CA;
d) ACVG.

7.1.3 The special inspection shall take into account the history of external corrosion of the pipeline, the cathodic protection potential level, the presence of interference current, type of coating, history of damage caused by third parties, and environmental effects on the pipeline.

7.1.4 The “ON/OFF” close interval potential inspection shall be performed as follows:

a) the survey shall be conducted so that the spacing between the positioning of a measured point and the next point is not more than 1.5 m, bearing in mind that, on electrical insulation joints, measurements shall be made on the protected and insulated sides;

b) the ohmic drop that occurs on the metal wall of the pipeline, due to the current passing through the pipe, shall be considered at all test points, so as to allow correction of the "ON/OFF" potentials.

7.2 Special Inspection Plan

7.2.1 At least one of the conditions described in TABLE 4 shall be implemented in case it occurs.

TABLE 4 - SPECIAL INSPECTION PLAN (SEE CHAPTER 3)

<table>
<tr><th rowspan="2">Conditions</th><th rowspan="2">Period
(See Note 1)</th><th colspan="3">Action (See Note 2)</th></tr>
<tr><th>Without Interference</th><th colspan="2">With Interference</th></tr>
<tr><td>a) when instrumented pig inspection results show the development of the external corrosive process, as compared to the previous pig inspection, with a thickness loss greater than 50 %, or with an increase in the number of corrosion spots greater than 50 %;</td><td>2 years</td><td>PP + CA/ ACVG or DCVG</td><td colspan="2">CA/ ACVG or DCVG</td></tr>
<tr><td>b) when instrumented pig inspection results show the development of the external corrosive process, as compared to the previous pig inspection, with a thickness loss between 50 % and 20 %, or with an increase in the number of corrosion spots between 50 % and 20 %;</td><td>5 years to 10 years</td><td rowspan="2">PP + CA/ ACVG or DCVG</td><td colspan="2" rowspan="2">CC/ ACVG or DCVG</td></tr>
<tr><td>c) presence of pipe-to-soil potentials outside the protection criteria set forth in Chapter 5 of this Standard;</td><td>2 years</td></tr>
<tr><td>d) heated pipeline, with polyurethane foam thermal insulation and with a history of flaws; or polyethylene tape coating with a history of disbonding;</td><td>5 years</td><td colspan="3">CA/ ACVG or DCVG</td></tr>
<tr><td>e) history of damage caused to pipeline coating by machines, without corrective actions adopted;</td><td>2 years</td><td colspan="2">PP + AC/ ACVG or DCVG</td><td>AC/ ACVG or DCVG</td></tr>
<tr><td>f) history of movement of soil with deformation of pipeline and without corrective actions taken.</td><td>30 days</td><td colspan="3">See ANNEX E</td></tr>
</table>

Notes:
1) Maximum time period for carrying out the special inspection.
2) See item 3.24 (special inspection techniques) for the descriptions of acronyms.
3) The instrumented pig inspection report to be used in TABLE 4 shall be validated by correlation in the field.

7.2.2 For pipelines that do not fall into the categories in TABLE 4, the special inspection plan should be applied every 10 years. **[Recommended Practice]**

7.3 Procedures for Preparation of Reports

Upon completion of the work, a report shall be prepared per pipeline, containing the results obtained in the work, presenting at least the topics mentioned in items 7.3.1 to 7.3.10.

7.3.1 Introduction.

7.3.2 Objective of report.

7.3.3 Scope of services.

7.3.4 Piping data, such as, for instance, beginning of operation, nominal diameter, pipeline wall thickness, coating type and thickness, length, geographic aspects of areas crossed (urban, rural and environmental protection areas, rivers, lakes, and roads) etc.

7.3.5 Detailed description of inspection techniques, methods, and procedures used.

7.3.6 Criteria adopted based on standards and/or specialized technical literature.

7.3.7 Results obtained.

7.3.8 Conclusions regarding the conditions of the anticorrosive system (cathodic protection and coating).

7.3.9 Recommendations for solving problems found.

7.3.10 References to documents and drawings of the contracting and contracted parties and bibliography used.

7.4 Rehabilitation Plan

7.4.1 A plan for rehabilitating the anticorrosive protection system shall be prepared to implement the corrective actions recommended by the special inspection plan. This plan shall contain:

a) reinforcement of CPS;
b) repair or replacement of coating;
c) repair or replacement of pipeline sections, when complemented with the structural analysis of the pipeline.

7.4.2 Corrective actions shall be implemented as soon as possible and their effectiveness shall be periodically assessed, within the periodic inspection plan.

8 CORRECTIVE ACTIONS

8.1 The CPS shall be adapted when a protection deficiency occurs. This adaptation includes the readjustment or reinforcement of the system locally, with the installation of anode ground beds (continuous or otherwise), or in an ample manner with the installation of new rectifier and anode ground bed sets.

8.2 Interfering currents shall be controlled by studying the entire region affected, consulting maps with pipeline grids and interfering sources, installing rectifying and electrical drainage equipment suitably located at the points of return of those currents. Rectifying and electrical drainage equipment shall be immediately repaired. Repair of flaws on coating in regions where the interference current enters and leaves the equipment may reduce such interference.

8.3 The coating shall be repaired when it falls into at least one of the following situations:

a) has flaws located on sections with cathodic protection deficiency and confirmed after a visual inspection in the ditch;
b) flaws are classified as severe according to the report on inspection of coating by special techniques;
c) flaws are detected on the thermal insulation of heated pipes.

8.4 The manner in which the coating is repaired shall take into account the existing coating, the operating temperature of the pipeline, the soil type, and surface preparation.

8.5 If stress corrosion is detected, the pipeline defect shall be analyzed, complemented by specific techniques, for determining whether the pipeline section shall be replaced or repaired.

8.6 A maintenance program shall be adopted to ensure that the CPS and coating remain effective during the lifetime of the pipeline. Preventive and corrective actions shall be taken where routine and special inspections indicate that the protection is in accordance with specified criteria.

/ANNEX A

ANNEX A - CATHODIC PROTECTION MEASUREMENTS

A-1 POTENTIAL MEASUREMENT

A-1.1 General

A-1.1.1 The effectiveness of the cathodic protection shall be assessed through pipeline potential measurements on the pipeline-to-soil interface in relation to the reference electrode.

A-1.1.2 The technique may be selected based on the local site conditions, considering the type and quality of the coating, the soil resistivity and the presence of interference currents, telluric currents etc.

Notes:
1) Where current is flowing through the soil and in the pipeline, there will be an ohmic drop (IR drop) in the soil and coating. Thus, the potential measured with the reference electrode at the ground surface will include a contribution from the IR drop. There are complementary techniques which can be used for a more accurate assessment of the effectiveness of the cathodic protection.
2) Where the only currents flowing in the soil are from the pipeline's own CPS, the potentials measured at the soil surface are generally more negative than the potential at the pipeline-to-soil interface.

A-1.2 "ON" Potential Measurement

A-1.2.1 "ON" potential measurements are taken while the CPS is operating continuously. To minimize the IR drop, the reference electrode shall be placed as close as possible to the pipeline.

A-1.2.2 The values obtained contain various unknown IR drops which vary with time and the position of the electrode. The reading might not reflect the potential at the pipeline-to-soil interface.

A-1.3 Instant "OFF" Potential

A-1.3.1 The IR drop caused by the cathodic protection current can be eliminated by using the instant "OFF" potential technique. The values obtained are referred to as instant OFF" potentials. For buried pipelines, the potential measured in relation to the reference electrode shall generally be measured within 1 second after the protection current is switched off. It rapid depolarization occurs, the "OFF" potential shall be determined using a high speed data processor.

A-1.3.2 The instant "OFF" potential can be measured by a quick response instrument. The ratio of the connected and disconnected periods shall be determined for depolarization not to occur.

A-1.3.3 For an effective instant “OFF” potential measurement, all sources of cathodic protection current to the pipeline shall be simultaneously switched off. FIGURE A-1 shows a typical potential profile during an “ON/OFF” potential measurement and how the IR drop components of the potential measured caused by the cathodic protection current flowing in the soil can be removed to provide the most accurate polarized potential.

Note: Other sources of direct current, telluric currents, and interference currents affect the measurement and therefore give results which are not the true polarization potentials.

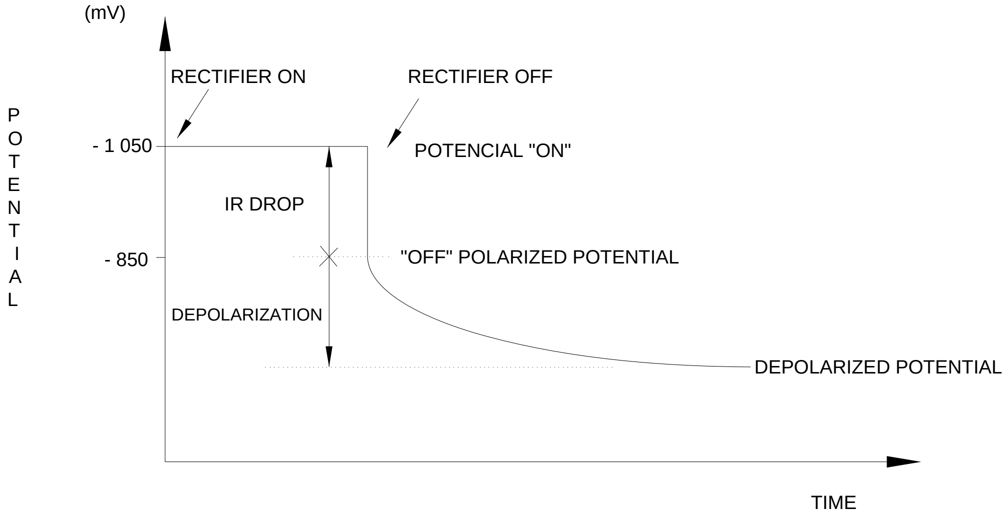

FIGURE A-1 - CATHODIC PROTECTION POLARIZATION DIAGRAM

A-1.3.4 Alternative “OFF” potential measurement techniques may be considered if their accuracy and effectiveness are confirmed.

A-1.3.5 As an option to item 7.1.4, a wave form analyzer may be employed, associated with non-synchronized electronic switches connected to rectifiers, providing the “ON” and “OFF” potentials by means of test point readings.

A-1.4 Cathodic Protection Coupon

A-1.4.1 The IR drop free potential of the pipeline at a specific location can also be assessed by measuring the instant “OFF” potential on test coupons located adjacent to and at same depth as the pipeline. The “OFF” potential measurement can be taken immediately after the test coupon is disconnected from the pipeline and without interrupting the source of protective current.

A-1.4.2 Coupons may be manufactured from materials and coatings similar to those of the pipeline being tested, except for a defined area which is left bare. Coupons are connected to the pipeline through a test point connection, which can be temporarily disconnected.

Notes: 1) It may be acceptable for the metallic coupon to adopt a potential, with respect to the adjacent soil, that is similar to the pipeline potential at a coating defect with the same size. **[Recommended Practice]**

2) Despite there being no current flowing directly to the coupon when it is disconnected from the pipeline, there still is current flowing in the soil surrounding the pipeline and coupon. Thus, with the reference electrode located on the soil surface there can still be a significant contribution from the IR drop in the soil in the coupon potential measurement. The instantaneous “OFF” potential measurement on the coupon is more precise if it is made against a permanent reference electrode buried alongside the test coupon or built in a single assembly (polarization probe). The residual IR drop can be minimized by placing a portable reference electrode in a soil pipe having one of the ends positioned near the coupon and the other end at the surface.

A-2 EFFECTIVENESS OF ELECTRICAL INSULATION JOINTS

A-2.1 General

A-2.1.1 Failures of insulation joints may be due to one of the following factors:

a) defect on the insulation joint itself or on any insulation flange components;
b) external conductive connection between both sides of the insulation joint, such as, for example, pipe supports, other piping, or local grounding system;
c) degradation or lack of internal coating where the pipeline is carrying an electrically-conductive fluid.

A-2.1.2 Measurements that may be made for determining the effectiveness of a monobloc type or conventional insulating joint are described in items A-2.2 through A-2.5. In case of doubts, a combination of 2 or more of the methods described may be used for a higher certainty in the measurements.

A-2.2 Pipe-to-Soil Potential Measurements

Pipe-to-soil potentials shall be measured on both sides of the insulation joint, maintaining a fixed half cell on one of the sides. In case there is a significant difference in potential, the insulation joint/insulation flange is effective. A partially defective insulation joint cannot be easily identified, since the potentials on both sides of the joint may still be different. As a general guide, a potential difference of less than 100 mV may be considered as inconclusive.

A-2.3 Electrical Resistance Measurements

In the case of conventional type electrical insulation joints (flanges) installed, the insulation on each bolt/insulating cartridge shall be checked using an ohmmeter or another equivalent instrument. The acceptable insulation value shall be higher than 2 000 Ω.

Note: In the case of monobloc type electrical insulation joints, it may be difficult to interpret the results of the measurement of the electrical resistance of the insulation joints. This is because the resistance by the external circuit (from the pipeline to earth) or resistivity by the internal circuit (in case the pipeline carries a conductive fluid - electrolyte) are both parallel to the resistance of the insulation joint. The measured equivalent resistance can therefore be a combination of these 3 hypotheses, and a low resistance value possibly found is not always a reliable indication that the joint is defective.

A-2.4 Current Test

When a current test is performed to check the integrity of an insulation joint, it shall be carried out by means of an external DC source, in which a current is applied on one of the side of the insulation joint. If the potential on the other side of the insulation joint does not change, or changes in value in the opposite direction (due to an interference effect), the insulation joint should be considered to be effective.

A-2.5 Audio-Frequency Generator Measurements

Audio-frequency generator measurements shall be conducted by introducing a suitable audio frequency from a frequency generator on one side of the insulation joint, e.g. by a conventional pipe locator and tracing the signal on the opposite side of the insulation joint.

/ANNEX B

ANNEX B - PROCEDURE FOR INSPECTION OF INERT AND GALVANIC ANODE GROUND BEDS

B-1 TESTING OF 2 HALF CELLS

This test is performed using 2 identical copper/copper sulfate half cells from the same manufacturer, in accordance with items B-1.1 through B-1.7 and FIGURE B-1.

B-1.1 Position the first half cell (fixed half cell) at least 50 m away from the anode ground bed.

B-1.2 Position the second half cell (movable half cell) before the first anode and at a distance corresponding to the spacing between anodes.

B-1.3 By displacing the movable half cell along the line joining the anodes, measure the potential between the half cells at intervals corresponding to half the spacing between anodes and over each of the anodes. Measurements shall extend beyond the end of the bed at a distance equal to the spacing between anodes.

B-1.4 Prepare a scale drawing for each surveyed anode ground bed, containing the pipelines, rectifier, anodes, and points where the measurements were made, including the respective values and the polarity adopted.

B-1.5 For each surveyed bed, draw a curve (potential X distance) with the measurements made and check if the peaks observed on that curve coincide with the actual position of the anodes (see FIGURE B-2).

B-1.6 If a potential peak is not observed on a particular anode, this means that it probably is not in operation.

B-1.7 Check the reason for the problem, measuring as well the current drained by the anode (after uncovering its cable), placing the anode back in operation or replacing it. Care shall be taken during the cable unburying operation so as not to damage it.

B-2 RECOMMENDATIONS

B-2.1 In the case of an inert anode ground bed, temporarily connect the rectifier at the highest possible output current (not higher than the rated current), without taking too long to do so, in order to avoid overprotecting the pipeline.

B-2.2 Alternatively, with the aid of a clamp-on ammeter the ground bed may be inspected by measuring the current drained by each anode, comparing with the results of previous inspections.

B-2.3 The results of the measurements made and drawings prepared, service dates, problems detected and solutions adopted shall be included in the report mentioned in item 6.4 of this Standard.

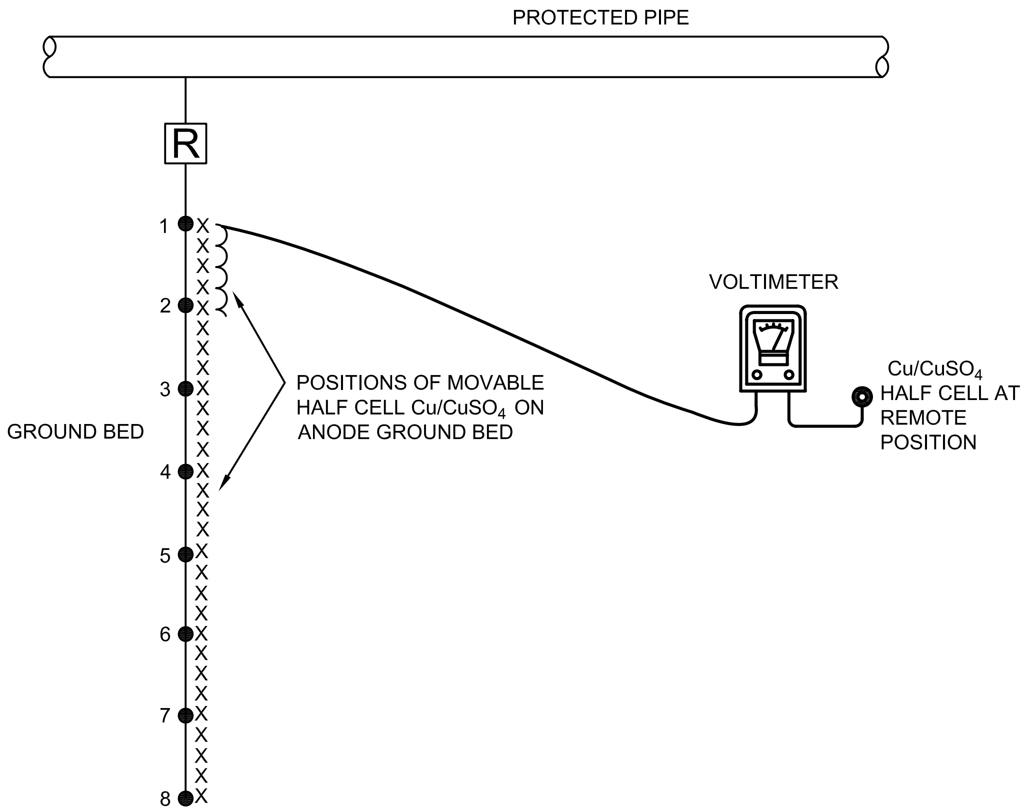

FIGURE B-1 - POTENTIAL MEASUREMENT WITH 2 HALF CELLS ON A GROUND BED

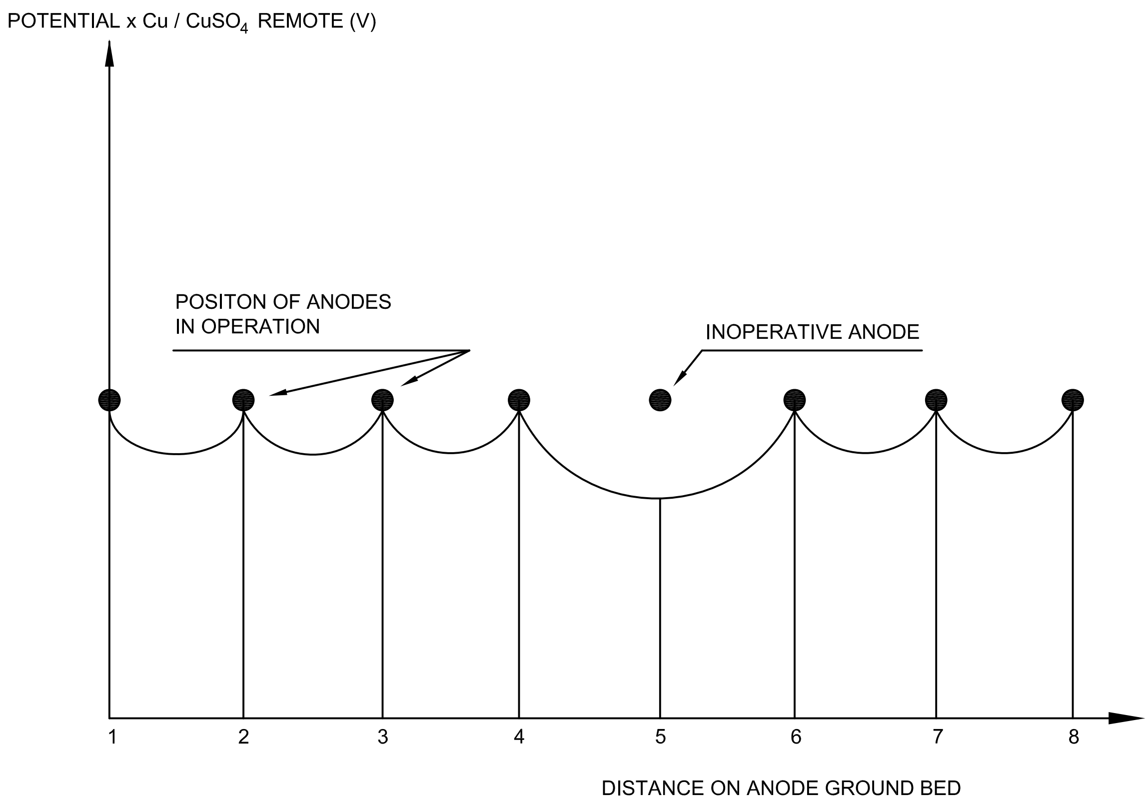

FIGURE B-2 - POTENTIAL VESUS DISTANCE FOR ANODE GROUND BED

/ANNEX C

ANNEX C - SYSTEMATIC PROCEDURE FOR DETECTING FAULTS IN CATHODIC PROTECTION SYSTEMS DURING OPERATION

If abnormal potential and current values are observed in impressed-current cathodic protection systems, a comparison with previous values can indicate the type of fault as shown in TABLE C-1.

TABLE C-1 - TYPE OF FAULTS IN CATHODIC PROTECTION SYSTEMS

Observation	Indication
Pipe-to-soil potential becomes more positive when the CPS is switched on.	1) Indicates inverted connections at the output terminals of the rectifier. It is a very serious fault that could result in severe damage to the pipeline in a relatively short period of time.
Output voltage of rectifier very low and current is zero.	1) AC fuse failure or tripping of circuit breaker; 2) Rectifier power supply failure; 3) Failure in transformer - rectifier.
Output voltage of rectifier is normal and with current low but not zero.	1) Deterioration of anodes or ground bed; 2) Drying out of soil around ground bed; 3) Accumulation of electrolytically produced gas around the anodes (blocking gas); 4) Individual disconnection of anodes in the ground bed.
Output voltage of rectifier is normal and current is zero.	1) Interruption of interconnection cable (main) of anodes or pipeline; 2) Failure of DC fuse or ammeter of rectifier; 3) Complete failure of ground bed.
Output voltage of rectifier is zero and current is zero.	1) Failure of DC fuses.
Output voltage of rectifier is high and current is high.	1) Rectifier with voltage set too high.
Output voltage of rectifier and current is normal, but pipe-to-soil potential is insufficiently negative.	1) Interruption in electrical continuity or increased resistance between point of connection to the pipeline and the test point due to inefficiency of the cable connection; 2) High increase in aeration of the soil at or near the measurement point due to drought or increased local ground drainage;

(CONTINUE)

(CONCLUSION)

TABLE C-1 - TYPE OF FAULTS IN CATHODIC PROTECTION SYSTEMS

Observation	Indication
	3) Failure in insulation device, e.g. short circuiting of insulation joints at the end of the protected pipe; 4) Effect of shielding of cathodic protection or insufficiency of cathodic protection due to the installation of a new pipeline; 5) Failure of CPS on an adjacent section of the pipeline or on a secondary pipeline connected to the main pipeline; 6) Deterioration of, or damage to, the pipeline coating; 7) Addition or extension to the buried pipeline, including contact with other metallic structures; 8) Interaction with the CPS on an adjacent or neighborhood pipeline; 9) Effects of interference current on pipeline.
Output voltage of rectifier is normal and so is the current, but the pipe-to-soil potential is excessively negative.	1) Interruption in electrical continuity of the pipeline at a position further ahead from the measurement point; 2) Another pipeline of the right of way placed out of service or disconnected from the pipeline being protected or has received additional protection via a new CPS; 3) Effects of interference current on the pipelines.
Output voltage of rectifier and current are normal, but pipe-to-soil potentials are fluctuating.	1) Presence of interference earth currents, e.g. interference from DC traction systems or telluric/geomagnetic effects.

/ANNEX D

ANNEX D - ELECTRICAL INTERFERENCE

D-1 GENERAL

Corrosion caused by interference current on buried metallic pipelines differs from other types of corrosion, due to the fact that the current causing the corrosion has a source foreign to the affected pipeline. Usually, the interference current from a foreign source, not electrically connected to the affected pipeline, is drained by this pipeline to the soil. Harmful effects of interference currents occur at locations where the currents are discharged from the affected pipeline to the ground. Electrical interference may be direct current and alternating current.

D-1.1 Types of direct current interference are as follows:

a) constant current sources, such as those from cathodic protection rectifiers;
b) fluctuating current source, such as: direct currents from electrified railway systems and transit systems, coal mine haulage systems and pumps, welding machines and DC transmission lines.

D-1.2 Types of alternating current interference are as follows:

a) temporary interference caused by faults in AC transmission lines (LTs) and railways;
b) interference caused by inductive or conductive coupling between the pipeline and high voltage transmission lines (AC) or electrified railway systems;
c) telluric currents.

D-2 DIRECT CURRENT INTERFERENCE

D-2.1 Measurements

D-2.1.1 For a detailed study, in areas where the presence of interference currents is suspected, one of the following individual or combined measurements may be made:

a) pipeline-to-soil potential with recording and indicating instruments;
b) current density on coupons;
c) current flow in pipeline with recording and indicating instruments;
d) current output variations of suspected source of interference current and correlation with measurements obtained above.

D-2.1.2 The measurements may be carried out for a period of 24 hours or a period which is typical for the suspected interference phenomenon being investigated, so as to correlate the interference levels with time.

D-2.1.3 Interference with other buried pipelines or installations shall be measured after the CPS is energized. Interference measurements shall be conducted as described below:

a) measure the pipe-to-soil potential both on the pipeline under interference and on the interfering pipeline while the relevant sources of cathodic protection current that can interfere are simultaneously interrupted;
b) measure the pipe-to-soil potential at the other pipeline or installation while the CPS is energized.

D-2.1.4 The mean variation of potential at any part of another pipeline or installation being affected by the interference may not cause potentials outside the criteria set out in item 5.3. If due to the effect of the interference the cathodic protection criteria are not met, corrective actions shall be taken to eliminate the interference.

D-2.2 Mitigation of Direct Current Interference Corrosion Problems

D-2.2.1 The most common methods to be considered in solving interference problems on pipelines or other buried structures include:

a) prevention regarding entry or limitation of flow of interfering current through a buried pipeline;
b) a metallic conductor connected to the return (negative) side of the interfering current source;
c) neutralization of the interfering current effect by increasing the cathodic protection level;
d) removal or relocation of the interfering current source.

D-2.2.2 Specific methods to be considered individually or together are given below:

a) design and installation of metallic bonds with a resistor in the bond circuit between the affected pipelines or other structures; the metallic bond electrically conducts interference current from an affected pipeline to another pipeline or to the interfering source;
b) uni-directional control devices, such as: diodes or reverse current switches;
c) coating bare pipeline where interference current enters the pipeline;
d) application of additional cathodic protection current to region of pipeline affected where the interfering current is being discharged;
e) adjustment of the current output from mutually interfered cathodic protection rectifiers;
f) reduction or elimination of the pick-up of interference current by relocation of the ground beds;
g) installation of suitably located insulation joints in the affected pipeline (see Note);
h) improvement in the protective coating on the interfering structure;
i) installation of insulating shields between the pipeline and the interfering structure.

Note: While installing insulation joints will reduce the magnitude of the interference current, the joints may also create other current pick-up and discharge points. To ensure the absence of an interference condition, tests may be performed on the region of the insulation joint.

D-3 ALTERNATING CURRENTS INTERFERENCE

D-3.1 General

The magnitude of permanent or temporary interference from high voltage , in a pipeline, such as: transmission lines and electrified railways, mainly depends on:

a) length of parallel section;
b) distance from the pipeline;
c) AC voltage level of transmission line;
d) AC current level;
e) pipeline coating quality.

Notes: 1) AC interference effects on buried pipelines may require safety measures.
2) Possible effects associated with AC interference include electric shocks, damage to coating, accelerated corrosion, and damage to insulating joint.

D-3.2 Calculation of Alternating Current Induction

D-3.2.1 AC interference may be simulated on a computer considering the data from the affected pipeline, such as coating resistance, diameter, route, location of insulating joints. If the insulation device is installed so that the pipeline is electrically continuous with the ground grid of a plant, the resistance to ground of the grid shall be estimated or the ground grid itself shall be part of the study.

D-3.2.2 The data to be considered for AC traction systems are the interfering high voltage, operating current, layout of high voltage towers and position of the wires, route, including position of transformers, frequency, and characteristics for high voltage transmission lines.

D-3.3 AC Interference Current Measurements

D-3.3.1 To determine the AC corrosion risk, coupons may be installed where the AC current density reaches its maximum level. Coupons may be buried at the same depth as the pipeline and have suitable equipment for current measurements. Additional coupons may be installed to be removed and inspected visually.

D-3.3.2 The current density in a coating defect is the main determining factor in assessing AC corrosion risk. In case of low resistivity soil, high AC current density may occur.

Note: If the AC current density on a 100 mm^2 bare surface (e.g.: external test probe) is higher than 30 A/m^2 there is a higher risk of corrosion. In certain areas, AC corrosion may occur with a AC current density of less than 30 A/m^2 on 100 mm^2 areas of a bare surface. Risk of corrosion is mainly related to the level of AC current density compared to the cathodic protection current density level. If the AC current density is too high, corrosion can be avoided by cathodic protection.

D-3.3.3 In sections where the AC voltage is higher than 10 V or where the voltages along the pipeline show variations to lower values, indicating possible AC discharge, additional measurements shall be performed at the location.

D-3.3.4 No single measurement technique or criterion for the assessment of AC corrosion risk is recognized to assess AC corrosion.

D-3.3.5 The most specific measurements include:

a) pipe-to-soil potential;
b) current density; and
c) current density ratio (AC current density / DC current density).

D-3.4 AC Interference Limits

D-3.4.1 The maximum step and touch voltages shall be limited according to the safety limits specified in the safety standards and maintained at all places where a person could touch the pipeline or a pipeline component.

D-3.4.2 Protection measures against AC corrosion can be achieved through the following measures:

a) by reducing the induced AC voltage;
b) by increasing the cathodic protection level so that the positive part of the AC current can be neglected.

D-3.4.3 To reduce step and touch voltages, the following methods shall be considered:

a) reduce the induced AC voltage by grounding the entire system;
b) install ground grids in areas with workers carrying out activities;
c) install grounding cables running parallel to the pipeline.

D-3.4.4 To reduce the AC voltage, the methods described in items D-3.4.4.1 to D-3.4.4.3 may be considered.

D-3.4.4.1 Install pipeline grounding with uncoupling devices so as to allow AC current to flow and the DC current not to flow. A computer simulation may be required to optimize the number, location, and soil resistance of grounding systems.

D-3.4.4.2 Install grounding with potential control amplifiers to impress a current into the pipeline, compensating or reducing the induced voltage. This method may be applied if the induced voltage cannot be reduced by simple grounding. The location of the compensation amplifiers shall be carefully planned.

D-3.4.4.3 Add grounding systems to provide equalization of potentials at specific areas. These grounding systems can be built using a wide variety of electrodes (galvanized steel, zinc, magnesium etc.). Some grounding systems can have an adverse effect on the efficiency of the cathodic protection. To prevent this effect grounding systems may be connected to the pipeline via appropriate devices, such as spark gaps, DC decouplers etc.).

D-3.4.5 An increase in the DC voltage level to reach a more negative potential can reduce the AC corrosion rate. The pipe-to-soil potentials may not be more negative than the values shown in Chapter 5 of this Standard.

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/ANNEX E

ANNEX E - PROCEDURE FOR INVESTIGATING THE OCCURRENCE OF STRESS CORROSION ON PIPELINES WITH IDENTIFICATION OF SECTIONS OF HIGHER SUSCEPTIBILITY

E-1 For pipelines installed in regions subject to soil movements, which may subject the pipeline to compression and tensile stresses, the criteria given below shall be followed:

a) conduct a geological and geotechnical survey in the region of the right of way, according to systematic and seasonal inspections, to observe any occurrence that might jeopardize the integrity of the pipeline, so as to record and classify the points into risk level;
b) conduct specific inspections at points classified as sensitive, determining the in situ positioning of the pipeline route, including a “plani-altimetric” survey and burial level. These inspections shall identify on pipelines deformation loops and sections subjected to tensile and compression stresses;
c) at points classified as sensitive, where pipeline deformation may occur, inspect the coating to identify points with coating defects.

E-2 For pipelines with polyethylene tape coating, select for investigation the occurrence of CST for all sections in which disbonding occurs on the coating and plastic deformation on the pipeline. Pay special attention to the first 30 km of buried pipelines after the compressor station.

E-3 At points with coating flaws with the presence of electrolyte, measure the pH and the concentration of SRB in the solution retained between the coating and the pipeline and collect the corrosion product for analysis.

E-4 At points where direct pipe-to-soil contact occurs, apply the soil corrosiveness classification technique shown in ANNEX F.

E-5 Remove the coating with water jetting and abrasive blasting in the entire area where disbonding of the coating occurred and perform a non-destructive inspection by magnetic particles.

E-6 When the existence of cracks is detected, consider the replacement of the section under stress.

E-7 Perform soil-to-pipeline interaction analyses to assess the structural safety conditions of the pipeline.

/ANNEX F

ANNEX F - CLASSIFICATION OF SOIL CORROSIVENESS

F-1 INTRODUCTION

F-1.1 The aggressiveness of the soil to metals covers 2 types: specific aggressiveness and relative aggressiveness. The first one is related to the wide variety of physicochemical and biological properties of the soil, whereas the second one depends on outside sources, capable of modifying the corrosion process, such as the presence of leakage currents, macro pile of corrosion etc.

F-1.2 The classification of the soil corrosiveness is applied mainly to small-sized structures (service station tanks and storage tanks) or at the time of assessment of the failure that occurred in a particular equipment, including pipelines, where this corrosiveness may have played an essential role in the failure mode.

F-2 SOIL AGGRESSIVENESS CRITERIA

F-2.1 One of the most complete criteria for assessment of soil aggressiveness is “Trabanelli” where partial aggressiveness indices are assigned to each parameter with a view to defining the overall aggressiveness by the module of the sum total. The modified “Trabanelli” criterion uses the SRB concentration (NMP/g) instead of the redox potential value, and for oxidizing soils this replacement is not recommended. Only one of these indices or both of them together shall be used.

F-2.2 TABLE F-1 presents the partial indices of soil aggressiveness according to the modified “Trabanelli” criterion.

TABLE F-1 - PARTIAL INDICES OF SOIL AGGRESSIVENESS

Soil Parameters	Partial Index	Soil Parameters	Partial Index
Resistivity (ohm.cm)		**Chloride (mg/kg)**	
> 12 000	0	< 100	0
12 000 to 5 000	-1	100 to1 000	-1
5 000 to 2 000	-2	> 1 000	-4
< 2 000	-4		
SRB (NMP/g)		**Sulfide (mg/kg)**	
< 2 x 10	+2	Absent	0
2 x 10 to 103	0	< 0.5	-2
> 103 to 6 x 104	-2	> 0.5	-4
> 6 x 104	-4	-	-

(CONTINUE)

(CONCLUSION)

TABLE F-1 - PARTIAL INDICES OF SOIL AGGRESSIVENESS

Soil Parameters pH	Partial Index	Soil Parameters Sulfate (mg/kg)	Partial Index
> 5	0	< 200	0
< 5	-1	200 to 300	-1
-	-	> 300	-2
Humidity (%)			
< 20	0		
> 20	-1		

F-2.3 In the original “Trabanelli” criterion, the partial indices assigned may be observed between parentheses, in terms of the redox potential range (EPH). For example:

a) > + 400 mV (+2);
b) 400 mV to 200 mV (0);
c) 200 mV to 0 mV (-2);
d) < 0mV (-4).

F-2.4 Once the partial indices are available, the total index of soil aggressiveness shall be calculated. The soil is classified according to TABLE F-2.

TABLE F-2 - SOIL CLASSIFICATION

Soil Classification	Total Aggressiveness Index
Non Aggressive	0
Slightly Aggressive	-1 to -7
Aggressive	-8 to -10
Highly Aggressive	< -10

F-3 SAMPLE COLLECTION PROCEDURE

F-3.1 Samples of the soil surrounding the pipeline shall be collected exactly at the site where the failure occurred. At the determined location, drilling shall be performed with an auger. Samples shall be immediately collected from inside the compacted soil mass in the auger through sterile material:

a) spatulas;
b) 125 mL glass flasks (for microbiological analysis);
c) 500 g plastic bags (for chemical analysis).

F-3.2 In flasks, the soil shall be once again compacted, filling the entire volume to ensure a better anaerobiosis, avoiding contact with the hands and prolonged exposure to air. Flasks shall be identified, plugged, and sealed with [1)]TEFLON® tape.

F-3.3 Flasks sealed this way shall be maintained in an environment that is to be preferably cooled for the shortest time possible until the microbiological analyses are performed.

F-3.4 Plastic bags shall be filled, sealed, and identified. They shall then be kept in a preferably cooled environment for the shortest time possible until the chemical analyses are performed.

[1)] Teflon® it is registered brand of the DuPont for resins, polytetrafluorethylene films, ribbons and staple fibres (PTFE), being an adequate example of a commercially available product. This information is given to facilitate the users in this Standard use and it doesn't mean a recommendation of the product mentioned on the part of PETROBRAS. It is possible to use an equivalent product, since it gives an equal result.

REVISION INDEX

REV. A

Affected Parts	Description of Modification
All	Revised