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TESTING ON CATHODIC PROTECTION COUPONS FOR THE 100 MV CRITERION

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ABSTRACT

Test results are presented for a buried and cathodically protected structure coupled to a copper ground. When the 100 mV criterion is applied on a structure polarized by foreign uninterruptible current sources, the structure potential decays to its polarized potential instead to its corrosion potential making the use of the 100 mV criterion questionable. Use of coupons eliminates this problem because the coupon potential after interruption always decays to its corrosion potential.

Keywords: cathodic protection, 100 mV criterion, coupons, CP probes, protection criteria, potential monitoring, voltage drop, IR drop, potential decay.

INTRODUCTION

According to the NACE Standard Recommended Practice RPO169-96 [1], one or several of three criteria should be used to determine if the underground or submerged metallic piping systems are cathodically protected.

First criterion - often called an "on" potential measurement - requires that a negative potential of at least 850 mV vs a Cu/CuSO4 electrode (CSE) is achieved with cathodic protection system "on". To interpret this measurement, voltage drops other than those across structure-to-electrolyte boundary must be considered.

Second criterion requires to achieve a negative polarized potential, that is potential across the structure/electrolyte interface, of at least 850 mV vs CSE. This criterion is often called "off" potential measurement because the potential measurement is taken immediately after the cathodic protection current interruption.

The third criterion requires to achieve a minimum of 100 mV of cathodic polarization or potential decay from the "off" potential measurement.

An electrical contact between a pipeline and other metals, such as copper ground and rebar or other sources of uninterruptible current can adversely affect both the pipeline "off" potential measurement and the pipeline decayed potential. This paper provides examples of two alternatives for application of the 100 mV criterion. In the first alternative the measurement is made exclusively on a simulated pipeline and in the second only on a coupon. This paper compares the test results, and shows advantages and limitations of each alternative.

BACKGROUND

The effectiveness of cathodic protection, different techniques to determine and evaluate the voltage drops in soil, limitations and advantages of different test methods have been analyzed by different authors [2-6]. The pipeline "off" potential readings sometimes include errors caused by potential spikes after interruption and long-line currents caused by differences in pipeline potentials at different-size holidays and at different distances from the rectifiers [7-10]. According to the NACE Standard TMO497-97 [11], the accuracy of the "off" potential and 100 mV potential decay criteria, when measured on pipelines, can be adversely affected by currents from directly attached galvanic anodes, contacts with different metals, electrified railroads and transit systems, DC mining equipment, cathodic protection systems on foreign structures, bonds or contacts to other structures, and telluric and long-line currents.

To decrease or eliminate possible errors included in the "off" potential and potential decay measurements and to simplify the measurements, coupons or CP probes with coupons have been installed next to the pipelines simulating a coating defect (holiday). Several authors analyzed the measurements on coupons and discussed their advantages and limitations [12-19].

The application of different criteria on the same pipeline indicated that different criteria required different cathodic protection currents. The differences between the cathodic protection currents to meet the second and third criterion can be substantial, especially in locations where the pipeline corrosion potentials are more positive than -500 mV vs CSE . Stears et al [20] reported that on the Trans Alaska System 93% of the monitored coupons met the 100 mV criterion and only 43% met the negative 850 mV "off" potential criterion. Dearing [21] reported that after a pipeline survey using the 100 mV criterion, it was recommended to lower the rectifier outputs by approximately one-third.

Frequently, it is easier to meet the 100 mV criterion than the negative 850 mV "off" criterion. For this reason, the interest to use the 100 mV criterion has been rapidly increasing. Because application of the 100 mV criterion could polarize the pipelines to lower protection levels than the "off" potential criterion, it is important to consider all possible errors and limitations of both criteria.

TEST DESCRIPTION

A single magnesium anode, a CP probe with 10 sq. cm coupon, and a copper ground rod 30-cm-long with a diameter of 0.95 cm and exposed area of 90 sq. cm were buried in a soil with high content of clay. The CP probe shown in Figure 1 was buried at depth of 90 cm, water was poured over the soil at the coupon and the soil was compacted to ensure a low-resistance contact between the coupon and soil and also to ensure a slow-rate of diffusion of oxygen to the coupon.

Approximately 30 cm of the 1.5-inch-diameter (33.8 cm) PVC tube was filled with a thick slurry of the soil from the test field and compacted in the tube to ensure a low-resistance contact between the soil in the tube and at the coupon. The resistance of the 30-cm-high column of soil was determined from the graph in Figure 2 . The resistance was very low compared to the 10-million-ohm impedance of the instruments. The moisture content in the soil was maintained to some degree by irrigation in 2-day-intervals. The plan view of the test field with its components and reference electrode locations is shown in Figure 3. A test schematic of the components is shown in Figure 4.

All CP probe and copper rod potentials were taken vs CSE provided with an extension rod. The CP probe potentials, and the potential drops across the shunts were measured with a Keithley 197 microvolt-meter and Wavetek 85XT multimeter. The "on" and "off" potential measurements were taken with a uR 1000 Yokogava recorder and Wavetek 85XT multimeter. The shunt at the magnesium anode controlled the amount of the cathodic protection current. The CP probe with a coupon represented in the first alternative a pipeline and in the second a coupon. The coupon has been polarized approximately four weeks before the "off" potential and the potential decay tests started.

FIRST ALTERNATIVE : TEST ON A SIMULATED PIPELINE

This test represents an application of the 100 mV criterion on a simulated pipeline connected to a copper ground. In this alternative the coupon of the CP probe was treated as a coating holiday on a pipeline. It was also assumed that the pipeline was not provided with interruptible test coupons and therefore all potential readings were taken with the reference electrode at grade. To simulate a pipeline, the switch for interruption of the current to measure the "off" potentials was located between the magnesium anode and the coupon coupled with the copper rod (see Figure 4).

It was also assumed that the pipeline simulated by the coupon cannot be disconnected from the copper rod or that it is not known that the contact exists. To eliminate the complexity of different potential levels at different size holidays, the pipeline was simulated by only one CP probe coupon with a 10 sq. cm exposed area. The average soil resistivity in this alternative was 2,900 ohm cm and the corrosion potential on an isolated coupon was -700 mV vs CSE.

The first reading was taken at grade and at the tube of the CP probe, and the second one-meter-away from the tube also at grade for a more remote reading. The magnesium anode current output was measured across a 50-kohm resistor. The currents flowing into or from the coupon and copper rod were measured across 10-ohm resistors (see Figure 4).

The graph in Figure 5 shows the potential decay of a coupon simulating a pipeline in contact with the copper ground. The maximum potential decay from the "off" potential reading after four days was 106 mV, however the coupon was still discharging 56 uA and the "on" potential with the reference electrode one meter remote from the coupon was 6 mV more positive than with the reference electrode at the tube (see Table 1.). The above data shown in Figure 5 and Table 1 indicate that the pipeline coupled with the copper ground met the 100 mV criterion but was still discharging current and was galvanically corroding. It was impossible to determine from the potential decay curve that the pipeline was anodically polarized by the copper ground and that an application of the 100 mV criterion is not valid in this situation.

An example of a large potential decay measured on a simulated pipeline in contact with copper ground is shown in Figure 6. In this test without available coupons for testing, the current supplied by the magnesium anode was increased from 24 to 259 uA by lowering the resistor R1 at the anode (see Figure 4) from 50 kohm to 2.55 kohm. The pipeline simulated by the coupon was receiving 67 uA - indicating full protection. However, the potential decay was 390 mV after four days, a much larger potential decay than the 100 mV required by the criterion. Table 2 shows that the coupon "on" potential with the reference electrode one meter away from the tube was 6 mV more negative than with the reference electrode at the tube indicating that the coupon was receiving current.

SECOND ALTERNATIVE: TEST ON CP PROBE WITH A COUPON

The second alternative for an application of the 100 mV criterion is to install CP probes with coupons in or at the test stations and determine the "off" potentials and potential decays on the coupons instead of directly on the pipeline. In this alternative the coupon "off" potential measurements do not include the soil voltage drop between the grade and the pipeline caused by uninterrupted currents. Also, the coupon-potential-decay curves are not affected by the uninterrupted currents because the coupon potentials decay to their corrosion potentials.

The location of the components in the test field is shown in Figure 3. The pipeline was not modeled for simplicity assuming that the pipeline had near perfect coating. All tests were conducted on the coupon. The test schematic in Figure 7 shows the CP probe with a tube and 10 sq. cm coupon, the magnesium anode, and the copper ground rod. The magnesium anode output was measured across a 50 kohm resistor. This resistor and also the resistors at the CP probe and ground rod were the same as in the test shown in Figures 4 and 5. The switch was located at the CP probe. When the switch was turned "off" it isolated the coupon from the magnesium anode and the copper rod. The average soil resistivity in this test was 4,200 ohm cm and the corrosion potential of an isolated coupon was approximately -640 mV vs CSE.

The reference electrode was placed into the tube to measure the "off" potential. The potential decay after the current interruption to the coupon is shown in Figure 8. The maximum potential decay from the "off" potential reading after eight days was a negative 75 mV. The decay was in a negative direction indicating that the coupon was anodically polarized by the copper rod before the current interruption. It was discharging current and galvanically corroding. The test data in Table 3 show that when the reference electrode was placed at grade at the tube and one meter remote from the tube, the potentials were more positive than with the reference electrode in the tube. This also indicated that the galvanic current was discharging from the coupon. The potential decay in Figure 8 should be compared with the potential decay shown in Figure 5 to appreciate the difference between measurements directly on a pipeline and on coupons.

It is important to notice that the potential decay in Figure 8 did not meet the 100 mV criterion because the potential of the coupon changed in a wrong (negative or cathodic) direction after the current interruption and not in a positive direction as is shown in Figures 5 and 6. Measurement on properly installed CP probes with coupons for the 100 mV criterion application represents the true condition of the pipeline polarized by both the magnesium anode and the copper ground.

If the grounding system or rebar are accessible for testing, a contact with a pipeline should be investigated for instance by measuring and comparing the copper ground or rebar potentials with the potential of the pipeline. The reference electrode must be left at the same location for both measurements.

DISCUSSION

Pipeline contacts with copper ground or rebar are often intermittent and difficult to detect. The contacts are common in power plants, compressor and pump stations, chemical plants, manholes, at electrically operated valves etc. Pipelines can be polarized not only by galvanic currents but also by stray currents from electrified railroads and transit systems, by interference currents from foreign cathodic protection systems and other cathodically protected structures, by telluric currents, currents from welding, and also by long-cell corrosion currents caused by differential aeration.

An example of the effect of differential aeration on validity of the 100 mV criterion is shown in Table 4. The test data were taken from a graph published by Nekoksa [18] for a pipe simulated in a test box with two different soils. One soil (type A) was a mixture of sand, bentonite and gypsum, the other soil (type B) was sand.

The test results shown in Table 4 indicate that the pipeline simulated by small coupons met the 100 mV potential decay criterion. However, in reality 45 mV of the potential decay was compensated for the anodic polarization by the differential aeration current caused by soils with different aeration capabilities and only 55 mV was left for the decay to the corrosion potential.

The above test results show that the 100 mV criterion is not always valid for direct measurements on pipelines if the pipelines are polarized by uninterruptible or unknown currents for the following reason:

- The pipeline "off" potential includes the soil voltage drop caused by current flow between the pipeline and the uninterruptible current source.
- The pipeline potential decays to its polarized potential and not to its corrosion potential.

The above errors in the application of the 100 mV criterion can be corrected by measuring on coupons in addition to the measurements on the pipeline. Measurement on the coupons has the following advantages:

- The "off" potential readings on coupons do not include soil voltage drop from the uninterrupted current sources.
- The coupon potential always decays to its corrosion potential.

- The "off" potential readings on coupons eliminate or minimize the potential spikes, and eliminate effects of transient long-cell currents between different size holidays and pipeline sections polarized to different levels after current interruption.

- Coupons with a tube for the insertion of a reference electrode minimize the soil voltage drops caused by electric gradients around the pipeline, especially when the potential sensing area is very close to the coupon.

- Coupons provide additional information to the measurements on the pipeline. Direction of the current flow between the coupon and the pipeline and the current density on the coupon can be valuable for a proper evaluation of the level of corrosion protection on the pipelines.

- Coupons simplify the "off" potential measurement. There is no need to disconnect the rectifiers or to synchronize the disconnection of rectifiers.

- Coupons can be used in areas with uninterruptible currents for an application of all three criteria.

- Coupons can be used to determine or calculate the soil voltage drops during the "on " potential measurements.

As any test method, the coupons have their limitations. The measurements on the coupons are sensitive to proper installation techniques and polarization history, a coupon simulates only one condition at one location along the pipeline, the corrosion condition of the pipeline could be difficult to determine and properly simulate, the test is not conducted directly on the pipeline but on a simulated pipeline holiday, and the data measured on a pipeline and coupons require some interpretation.

CONCLUSIONS

The above test results for an application of the 100 mV criterion allow to make the following conclusions:

1. In areas with uninterruptible currents (such as in case of directly attached galvanic anodes, contacts with copper ground or rebar, stray currents from electrified railroads and transit systems, interference currents from foreign cathodic protection systems and other cathodically protected structures, telluric currents, currents from welding, mining systems, and also long-cell corrosion currents caused by differential aeration) application of the 100 mV criterion could be invalid because the pipeline "off" potential includes the soil voltage drop caused by uninterruptible currents and the pipeline potential decays to its polarized and not to its corrosion potential.

2. Use of the coupons eliminates or minimizes the errors caused by uninterruptible currents. Coupon potential always decays to its corrosion potential.

3. Because it is not known which criterion for the pipeline corrosion protection will be used in the future, coupons should be installed in or at all test stations at the same time as the pipeline. This will ensure that the coupons would see the same soil condition changes and the same polarization history as the pipeline, and that the installation cost will be minimal or none.

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TABLE 1
SIMULATED PIPELINE POTENTIALS

Reference Electrode Location	"ON" Potential (-mV)	"OFF" Potential (-mV)
At grade, at the tube	610	610
At grade, 1 m remote	604	

Notes: See Figure 5 for potential decay.
Simulated pipeline was discharging galvanic current.

TABLE 2
SIMULATED PIPELINE POTENTIALS

Reference Electrode Location	"ON" Potential (-mV)	"OFF" Potential (-mV)
At grade, at the tube	903	870
At grade, 1 m remote	909	

Notes: See Figure 6 for potential decay.
Simulated pipeline was receiving current before current interruption at Mg anode.

TABLE 3
COUPON POTENTIALS

Reference Electrode Location	"ON" Potential (-mV)	"OFF" Potential (-mV)
In the tube	548	560
At grade, at the tube	540	
At grade, 1 m remote	534	

Notes: See Figure 8 for potential decay.
Coupon was discharging galvanic current before current interruption at the coupon.

TABLE 4
POTENTIALS MEASURED ON A SIMULATED PIPELINE IN A TEST BOX [19]

Corrosion potential measured on an isolated coupon in type A soil	-785 mV
Corrosion potential measured on an isolated coupon in type B soil	-640 mV
Base (native) potential polarized by differential aeration current without cathodic protection in type A soil	-740 mV
Polarized potential by differential aeration and cathodic protection current in soil type A	-840 mV
Potential decay after cathodic protection current interruption in type soil A -840 mV -(-740 mV)	100 mV
True potential decay in soil type A from the potential polarized by cathodic protection and differential aeration currents to the native potential polarized only by differential aeration current . -785 mV -(-840 mV)	55 mV

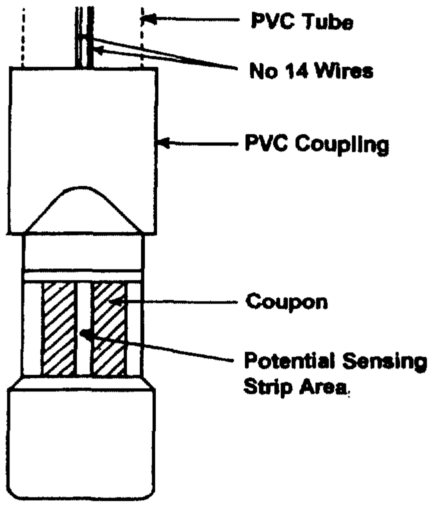

FIGURE 1 :
CP Test Probe with
10 sq. cm Flat Coupon

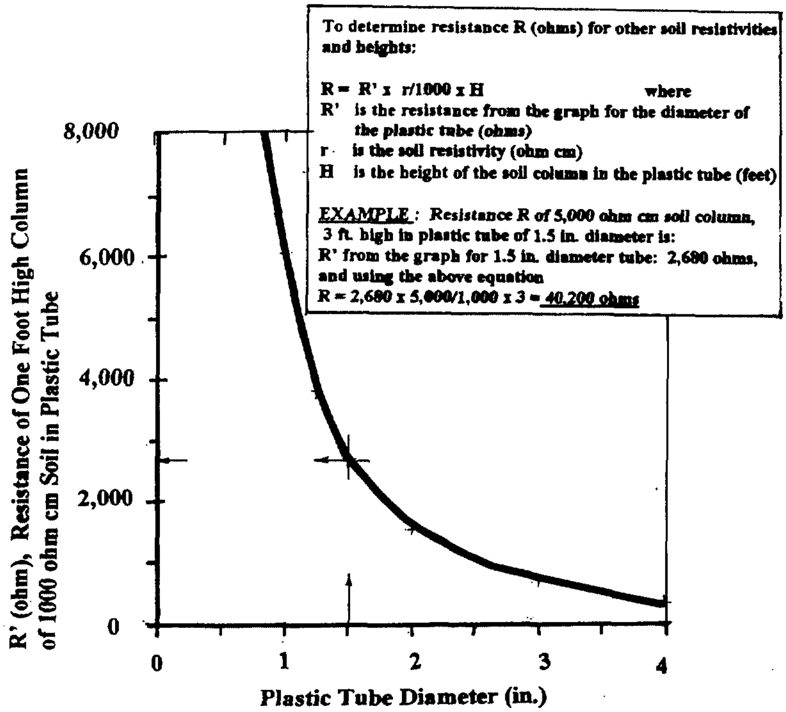

FIGURE 2 :
Soil Resistances in Plastic Tubes of CP Probes

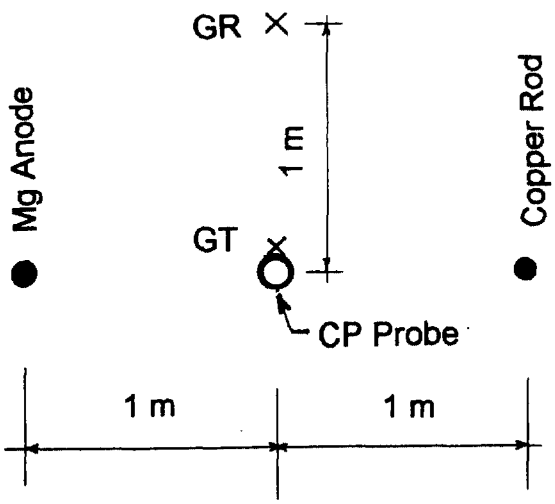

FIGURE 3 :
Plan View of the Test Field.
Reference electrode location:
GT: Grade, at the tube
GR: Grade, remote

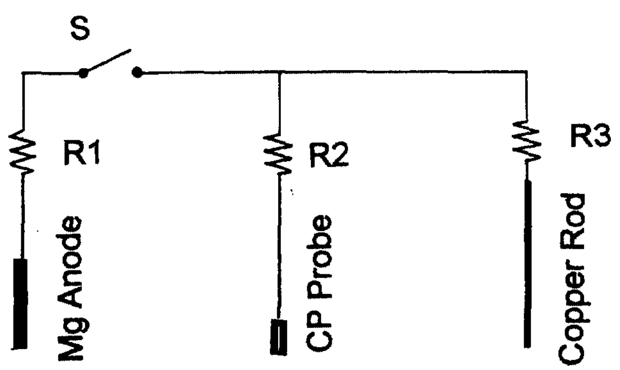

FIGURE 4 :
Test Schematic of a Simulated Pipeline
in Contact with Copper Ground.
R1: 50 kohm, R2: 10 ohm
R3: 10 ohm, S: Switch

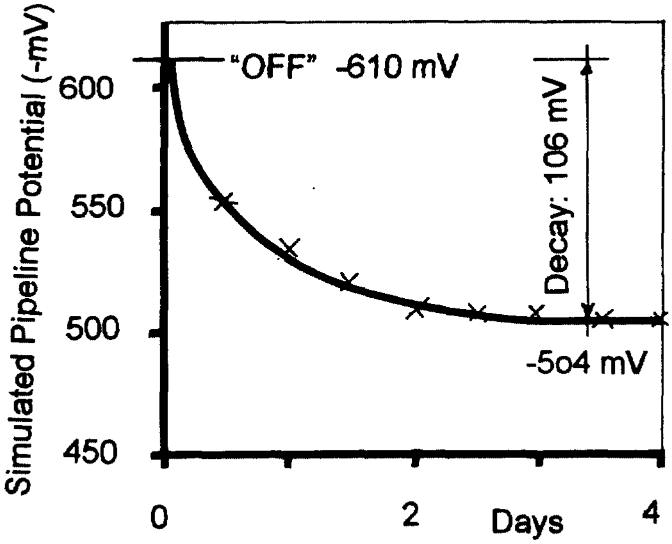

FIGURE 5 :
Potential Decay of a Simulated
Pipeline Coupled to Copper Rod.
Shunt at Mg anode: 50 kohm
Mg discharge: 24 uA
Coupon discharge: 56 uA
Copper rod pick-up: 80 uA
Note: See Fig. 4 for test schematic

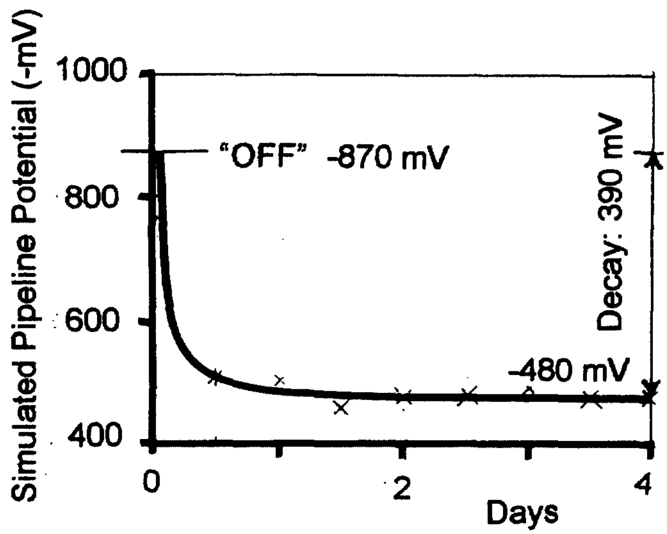

FIGURE 6 :
Potential Decay of a Simulated
Pipeline Coupled to Copper Rod.
Shunt at Mg anode: 2.55 kohm
Mg discharge: 259 uA
Coupon pick-up: 67 uA
Copper rod pick-up: 192 uA
Note: See Fig. 4 for test schematic

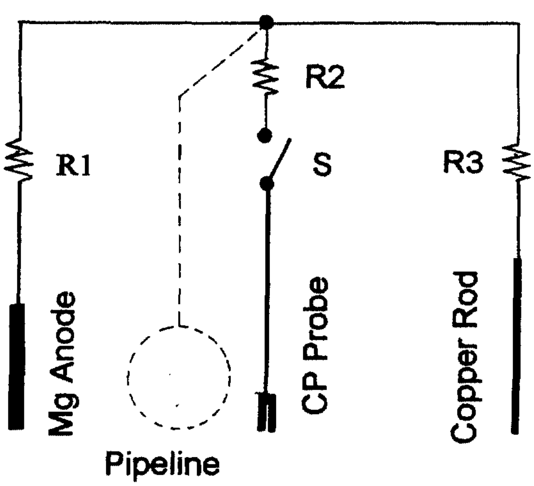

FIGURE 7 :
Test Schematic of a Coupon and
a Pipeline with Near Perfect Coating
in Contact with Copper Ground.
R1: 50 kohm, R2: 10 ohm,
R3: 10 ohm, S: Switch

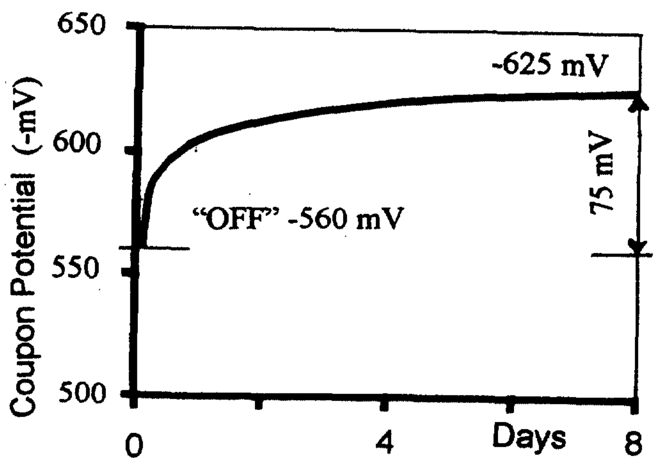

FIGURE 8 :
Potential Decay of a Coupon Coupled
to a Pipeline with Near Perfect Coating
and also to Copper Rod after Current
Interruption.
Shunt at Mg anode: 50 kohm,
Mg anode discharge: 23 uA,
Coupon discharge: 33 uA,
Copper rod pick-up: 56 uA
Note: See Fig. 7 for the test schematic